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Electronic Emission and Resonance Forensics

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Executive Summary

Electronic Emission and Resonance Forensics, abbreviated EERF, is a forensic science discipline for the systematic detection, localisation, characterisation, comparison and cataloguing of extremly weak electronic signatures. The word forensic describes the required qualities of the work: controlled access, contemporaneous records, validated instrumentation, traceable calibration, reproducible procedures, impartial interpretation, preserved raw data and conclusions bounded by measurement uncertainty. It does not imply that a crime has occurred, but rather that signal and source identification is being performed.

The inspection is passive-first, non-contact, audibly silent and non-imaging. Its primary mode records naturally present electric-field, magnetic-field and radio-frequency energy without transmitting a deliberate signal, touching a candidate object or reconstructing an optical, thermal, acoustic, radiographic, radar or tomographic image. The output consists of spectra, time series, field-strength values, instrument-state records and alphanumeric coordinates. Analytical plots may display measured quantities, but no physical image or physical access of the object is formed.

The framework addresses several source classes: extremely low-power transmitters; timing and baseband circuitry; residual leakage through apertures, seams, cables and common-mode paths; remote control eavesdropping devices; resonant structures; RF retroreflective or backscatter devices; and devices powered by an incident electromagnetic field. Purely passive measurements cannot reliably exclude a dormant passive device because that device may emit nothing until illuminated. Accordingly, an optional controlled-excitation module is described, but it is subordinate to written legal authority, spectrum compliance, human-exposure assessment, clinical-engineering approval and a minimum-field principle.

The operational target order is now explicit. Tier 1 comprises baseband timing and central clock phenomena, including crystal oscillators, real-time-clock families,

divider-chain products, switching-clock signatures, synchronisation signals, harmonic and subharmonic relationships, and incidental leakage from timing circuits. Tier 2 comprises free-radiated or conducted electronic emissions that may be intentional or unintended, including short bursts, frequency-hopping activity, cable-mode radiation, near-field electric and magnetic components, and radio-frequency signals whose pulse interval or modulation is traceable to a Tier 1 timing source. Tier 3 comprises responses that require ambient or deliberately controlled illumination, including passive and semi-passive backscatter, retro-reflectors, resonant scattering, SAW-resonator or SAW-filter behaviour, nonlinear-junction responses, load modulation, harmonic conversion and remotely powered reradiation.

Candidate illumination regions such as 1.1 GHz to 2.1 GHz, approximately 4.0 GHz and approximately 4.85 GHz are treated solely as investigatory bands. They are not universal activation frequencies. A response near 300 MHz, or within another SAW-associated band, at a harmonic or subharmonic, or at a frequency selected by an internal resonator remains a hypothesis until it survives direct-breakthrough, intermodulation, receiver-overload, local-oscillator, cable-coupling, polarisation, geometry, sham-illumination and independent-receiver controls. Pulse-position modulation is analysed as pulse displacement relative to a defined time reference, not merely as the presence of pulses.

No illuminated response is promoted to device association merely because it appears while the transmitter is energised. The response must disappear or materially diminish under valid field-off conditions, recur when the controlled conditions are restored, remain spatially localisable, survive negative and frequency-offset controls, and be confirmed by an independent receiving architecture with a separately disciplined reference clock. The report preserves the distinction between an observed signal, a candidate device-correlated signal, an illumination-correlated response, a reproducible frequency-translated response, a spatially localised response and a confirmed device-associated response.

The nominal watch-crystal frequency is 32.768 kHz. This frequency is 2^15 Hz and is widely used for real-time clocks and low-power timing. In legacy NTSC composite-video equipment, the nominal chrominance subcarrier is 3.579545 MHz and the horizontal line frequency is approximately 15.734 kHz. These frequencies are candidate indicators, not unique identifiers. Modern digital cameras frequently use different reference, pixel, interface and spread-spectrum clocks, so absence of the legacy frequencies cannot exclude a camera, and presence cannot establish one.

The field campaign begins with a regional inventory at 5 miles and proceeds inward through 2.5 miles, 1 mile, 0.5 mile and 0.25 mile before it reaches the 300-foot site-transition ring. The 5-mile, 2.5-mile and 1-mile annuli each use sixteen planned stations, expanded to twenty-four for high-risk work. The 0.5-mile annulus ordinarily uses twelve stations, with eight as the lowest defensible number where access makes twelve impracticable. The 0.25-mile annulus should also use twelve stations and shall not be represented as complete with fewer than eight.

The same candidate bands, receiver states, probe heights, common time base and coordinate discipline then follow the team through 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet and 3 feet. Fine convergence proceeds in stationary 3-inch increments inside the area being inspected. At every stage, distance is measured to the sensing centre of the probe, actual coordinates replace nominal map positions, fixed sentinels correct for time variation, and the reverse path retraces selected stations to expose drift, state changes and carriage artefacts.

The protocol is performed slowly, deliberately and with the gravity accorded to a technically significant scene. It is not compressed into a few hours merely to satisfy a commercial timetable. Each station has a pre-numbered paper record prepared and completed while the measurement is being made. Equipment is introduced, placed, tuned, moved and withdrawn one controlled item at a time, because hurried movement can alter cable geometry, shielding, common-mode current, reflection, magnetic reluctance, human-body coupling and the behaviour of an intermittent source. The usual project is a multi-week campaign. Four-to-five-day field segments may be separated by one or two weeks during which authorised passive sentinels preserve technical continuity while the visible field team is absent. Complex projects, particularly those involving very rare bursts, diplomatic facilities, or multiple buildings, may mature into months-long studies.

The instrument family includes calibrated air-core and ferrite-rod magnetic probes, smaller-aperture localisation probes, gradiometers, balanced electric-field sensors and calibrated higher-frequency antennas. Ferrite-rod channels may use very long, sectioned copper windings whose inductance, resistance, self-capacitance, self-resonance, Q and transfer factor are measured in the final housing. A stable fixed capacitor bank provides coarse resonance and a sapphire-dielectric piston capacitor provides fine calibration. Any magnetic concentrator is electrically and magnetically characterised, insulated from the primary winding and designed to avoid a continuous conductive shorted turn. Ferrite, amorphous alloy, nanocrystalline alloy and laminated metallic structures are treated as different material classes, each requiring frequency-specific loss, saturation, permeability, noise and artefact validation.

Every dedicated tuned rod or magnetic-alloy bar now incorporates a switchable high-reverse-voltage-rated varactor fine-trim branch in addition to the measured fixed capacitor bank, tuning loops and sapphire piston capacitor. The varactor is a passive voltage-variable capacitor. It does not create active power gain. Its forensic purpose is to preserve and assert the assembled resonance, phase and calibrated transfer factor against temperature, winding, cable and core drift, thereby exploiting resonant voltage magnification without mislabeling it as amplifier gain. Each orthogonal rod receives an independently characterised branch, while the X-axis channel is designated the vector-reference channel for resonance stabilisation. A quiet calibration pilot may be used only during lock acquisition or an interleaved blank. The pilot is removed and the varactor bias is held during evidential acquisition.

When an authorised retroreflector, backscatter or remotely powered examination is conducted, the illumination-monitor receiver now supplies a source-presence trigger to the response analyser, real-time spectrum analyser, oscilloscope and I/Q recorder. The acquisition includes pre-trigger memory and a calibrated trigger-delay programme. Delay is iterated from negative pre-trigger through near-zero, microsecond, millisecond and, where energy storage or wake-up is plausible, second-scale windows until the complete response is captured or the validated search interval is exhausted. A fixed-span real-time or vector capture is preferred for short or intermittent responses. A conventional triggered sweep is retained only when its sweep time, resolution bandwidth and probability of intercept are adequate. Source presence alone never establishes a response.

All evidential electromagnetic measurements are now assigned to a simultaneous multichannel architecture. The minimum admissible vector record uses three separate channels for one X-Y-Z probe triad, all locked to a common frequency reference, sample clock, trigger and epoch. The normative field deployment uses three surveyed pods, each carrying X, Y and Z probes, for nine simultaneous RF pathways. A common-chassis analyser provides at least twelve phase-locked and frequency-locked channels, ordinarily assigning channels 1 through 9 to the probes, channel 10 to illumination or source presence, channel 11 to a terminated or calibration path, and channel 12 to a guard, independent tracking or secondary reference function.

The analyser frequency abscissa controls a channel-specific varactor tuning variable, so every tuned probe is at verified resonance when the waveform is sampled. A switched single-channel analyser may assist reconnaissance, but it cannot establish simultaneity, vector orientation, propagation delay, phase relationship or the onset of a short retroreflective response.

This adds a dedicated magnetic-alloy permeability engineering programme for the low-frequency and medium-frequency receiving probes. It distinguishes intrinsic, initial, maximum, amplitude, incremental, reversible, effective and complex permeability, then relates the real and loss components of permeability to signal transfer, magnetic noise, Q, bandwidth, temperature, mechanical stress, DC bias, remanence, saturation and core geometry. Sixteen alloy families are used as candidate rod, tape-wound, laminated, powder, return-path or flux-concentrator materials. They include 80% nickel-iron-molybdenum, 48% nickel-iron, iron-cobalt-vanadium, grain-oriented and high-silicon electrical steels, moly-permalloy powder, high-flux nickel-iron powder, iron-silicon-aluminum powder, silicon-iron powder, five amorphous ribbon grades and iron-based nanocrystalline ribbon. Published manufacturer values are used only as screening data.

The governing acceptance evidence remains the measured complex impedance, transfer factor, noise, angular response, bias tolerance and stability of the completed probe in its final housing. The revision also makes an important frequency boundary explicit. Metallic magnetic cores may be advantageous for baseband, 15.734 kHz, 32.768 kHz and selected sub-megahertz work, while a 3.579545 MHz channel usually requires lower-permeability powder, nickel-zinc ferrite or an air-core reference. The 1.3 GHz to 1.9 GHz, 4.0 GHz and 4.6 GHz illumination antennas are not treated as magnetic-alloy-core antennas. At those microwave frequencies, the prescribed radiators and reflectors are conventional air, dielectric, waveguide or printed structures whose gain, pattern, matching and safety have been separately validated.

Medical questions remain institutionally separate. EERF may establish whether an electromagnetic field or electronic signature was measured and may quantify it within a validated range. It cannot diagnose a disease or attribute a symptom to that field. Any causal hypothesis requires a separate clinical or human-subject research protocol, independent medical assessment, informed consent, appropriate ethics review and controls against expectation and confirmation bias. The World Health Organization states that symptoms attributed to electromagnetic hypersensitivity can be real and disabling, while also reporting that there is no established scientific basis linking those symptoms to electromagnetic-field exposure.

This version adds a fourth operational workstream within the passive-first hierarchy. The workstream searches for narrow, stable or intermittently keyed carriers associated with surface-acoustic-wave resonators, SAW filters embedded in active circuits, ultra-low-power narrowband-FM transmitters, microphone front ends, audio conversion modules and voice-frequency currents flowing through concealed conductors. Its contextual phase begins with the five regional annuli and then preserves the established 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and 3-foot sequence before stationary three-inch convergence. The outer stations identify ordinary transmitter populations and temporal confounders; the close rings provide the spatial gradients required for localisation.

The SAW method distinguishes a resonator from a filter and both from a passive SAW sensor. A resonator may stabilise an active oscillator and therefore produce a narrow carrier, while a filter may merely select or suppress frequencies in an otherwise active transmitter or receiver. A passive sensor or retroreflective device may be silent until interrogated. Consequently, the protocol uses three concurrent searches: a narrow exact-channel bank with tolerance and drift margins, a continuous broad-spectrum survey that prevents the frequency register from becoming a blindfold, and a time-domain burst recorder for voice-operated, pulsed or very-low-duty-cycle activity. Controlled interrogation remains a separately authorised procedure.

The microphone method does not presume that a miniature acoustic transducer radiates a useful radio signal. It instead tests for the electric and magnetic consequences of bias current, preamplifier current, analogue audio current, pulse-density-modulation clocks, serial data, switching regulators and unbalanced return paths in nearby wiring. A flat 30 Hz to 14 kHz magnetic channel is retained for discovery. C-message weighting and 3 kHz-flat weighting are applied only as analytical views after acquisition, because C-message is a telephone-noise weighting characteristic rather than an antenna resonance. No speech content is listened to, decoded or reported. The evidential product is a field-strength, spectrum, timing and spatial-correlation record.

This release further treats the authorised premises as a controlled spatial measurement scene. Access is isolated and logged, permanent hard points establish a room coordinate frame, furniture and fixtures are located by measured baselines and redundant triangulation, and non-damaging marker triangles identify electromagnetic observations on floors, walls and surfaces. The room is then tessellated into three-dimensional cubes, each cube is processed under a fixed probe sequence, and every movement, state change and physical response is entered into a continuously updated physics ledger. The alloy programme is expanded into a lot-qualification register covering every metallic bar and ring material specified in the framework, with physical properties, weak-field permeability, saturation, loss mechanisms, stress sensitivity, construction form and band-dependent suitability recorded separately.

This version also establishes a comprehensive modulation-analysis discipline. It begins with carrier-like continuous wave and progresses through OOK, AM, DSB, SSB, ISB, VSB, NFM, WFM, FSK, PSK, QAM, OFDM, spread spectrum, NTSC, ATSC, Project 25, pulse-amplitude, pulse-width, pulse-position, pulse-frequency, PCM, pulse-density and hybrid waveforms. It then treats nested subcarriers, noise-like hosts, NFM-on-NFM structures and weak backscatter or frequency-translated responses as forensic recognition problems. Every illustrated waveform is synthetic and non-operational. The governing purpose is to identify non-content observables, discriminate artefacts and localise a reproducible electromagnetic source, not to provide a method for concealing or constructing a transmitter.

This further adds a global communications and interface-forensics chapter. It encompasses IEEE 802.11 Wi-Fi families, Bluetooth Classic and Low Energy, internationally significant cellular systems from pre-cellular and 1G through 5G-Advanced, 6G study status, short-range and low-power networks, RFID/NFC, optical and broadcast bearers, USB, FireWire, Thunderbolt, HDMI, DisplayPort, Ethernet, PCI Express, storage, sensor, audio, industrial, automotive, avionics and historical telecommunications interfaces. It also establishes a long-dwell protocol for sleeping electronics and a separately authorised wideband nonlinear-junction module. The chapter remains modulation-neutral, payload-minimising and bounded by measurement uncertainty. It also adds a frequency-sorted clock and timing register that preserves the supplied point frequencies and broad search ranges, calculates harmonics H2 through H11, and makes harmonic-family tracing a required part of passive localisation and sleep-state examination.

This release additionally establishes nominal 400 Hz alternating current as a priority power-domain family for military and aviation environments. Within many fixed-frequency aircraft and defence systems, 400 Hz is a primary AC source, although modern platforms may also employ DC, 50/60 Hz or variable-frequency AC. The module adds the first 100 consecutive harmonics through 40 kHz, selected higher-order landmarks through 1 MHz, three-phase and rectifier-family interpretation, resonant-probe tuning guidance, and ring-by-ring localisation controls. A 400 Hz comb is treated as an infrastructure or load signature rather than a unique device fingerprint, and every attribution requires source-state correlation, spatial convergence, independent receiving controls and stated uncertainty [121]-[123].

Every commission for which time, authority, access, safety and instrument capability are sufficient now includes a separately identified sub-20 Hz workstream extending nominally from 0.001 Hz to 20 Hz. The workstream is deliberately described as multi-physics rather than as a single radio-frequency search. It measures, with separate calibrated channels, airborne pressure, structure-borne acceleration or velocity, quasi-static electric field, quasi-static magnetic field, environmental state and instrument health. These quantities may occupy the same frequency interval while obeying different propagation laws, coupling mechanisms, units, sensor physics and exposure standards. The report shall therefore state the physical domain before it states the frequency.

The workstream inventories natural and anthropogenic sources that can otherwise imitate an electronic anomaly. Relevant examples include microbaroms, wind and severe weather, volcanic and seismic activity, building sway, lifts, fans, pumps, diesel engines, transport, pressure-control systems, power-conversion envelopes, slow industrial-control signals, the Earth's magnetic variations and specialised communications or platform systems. Biological electrical and biomagnetic rhythms are treated as close-coupled physiological measurements, not as ordinary room-scale transmitters. A shared frequency with an EEG, ECG or EOG band is never reported as proof of entrainment, resonance, exposure or causation.

The framework records symptom reports respectfully and contemporaneously, but it does not convert a symptom narrative into a field attribution. Very high infrasound or mechanical-vibration exposures can produce acute effects such as aural discomfort, body vibration, motion sickness or degraded visual and manual performance under particular exposure conditions. Current authoritative reviews establish that ordinary environmental infrasound selectively produces dread, awe, spiritual ecstasy, seizures, salivary-gland effects or the other specific responses sometimes alleged. Reports associated with diplomatic locations and anomalous health incidents remain clinically important, yet current United States Government assessments do not establish a common foreign-actor mechanism, and NIH studies did not identify significant MRI-detectable brain injury or most biological differences in the examined cohort. EERF therefore measures physical quantities, compares them with applicable standards and leaves medical diagnosis and causal inference to appropriately governed clinical investigation [149], [152], [156], [157].

This version further adds a clock-crystal and resonator workstream extending from slow divided outputs through 122.88 MHz reference systems and their first ten higher harmonics. The workstream includes 32.768 kHz RTC and sleep clocks, 1.8432 MHz serial-communications references, common 2 MHz through 48 MHz embedded clocks, 19.2 MHz mobile-platform references, selected 23.104 MHz GPS receiver implementations, 27.12 MHz RFID-related references, 100 MHz logic and networking clocks, and 122.88 MHz coherent-radio and data-converter clock trees. These values are search hypotheses, never unique device identifiers. The protocol uses common-timebase multichannel measurements to establish whether a candidate fundamental, harmonic, divider product or PLL spur behaves as one spatially coherent family, including during standby, sleep and intermittent wake states.

Chapter Glossary

Terms used in Chapter 1: Executive Summary.

C

CURRENT — The movement of electrons past a reference point. The passage of electrons through a conductor.

E

ELECTROMAGNETIC FIELD — The combination of an electric (E) field and a magnetic (H) field.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

L

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

P

PRIMARY WINDING — The winding of a transformer connected to the electrical source.

R

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

Position of the Advanced Technical and Expert-Practitioner Protocols

This adopts the analytical density, terminological precision and explanatory discipline expected in senior engineering, forensic operations, electromagnetic compatibility, metrology and technical counsel. It remains a proposed professional framework rather than a consensus standard or a universally validated method. Its authority is intended to arise from declared assumptions, traceable measurement, explicit controls, reproducible records, documented uncertainty and conclusions that do not extend beyond the data.

This uses a consistent epistemic hierarchy. Established physical principles are identified as such. Published standards and manufacturer data are treated as external authorities with defined scope and revision status. EERF procedures are identified as proposed practice. Engineering inferences are expressed as hypotheses that must survive rival-source analysis and instrument controls. Validation requirements are separated from completed validation, while observations, interpretations and final classifications remain distinguishable throughout the record.

The intended reader is assumed to possess, or to work under the supervision of persons who possess, substantial professional familiarity with electromagnetic fields, analogue and digital electronics, spectrum analysis, statistical measurement, forensic documentation and safety governance. Definitions are nevertheless retained where a term has materially different meanings across those disciplines, because technical maturity is demonstrated by semantic control, not by unexplained vocabulary. The paper is exact, conditional, quantitative where the data permit, and explicit about limitations.

Chapter Glossary

Terms used in Chapter 2: Position of the Advanced Technical and Expert-Practitioner Edition.

B

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

S

SPECTRUM ANALYSIS — The display of electromagnetic energy arranged according to wavelength or frequency.

T

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

Foundational Principles

Principle	Operational meaning
1. Hypothesis neutrality	The examiner tests alternative explanations and does not treat a reported sensation, suspected location or presumed device type as proof.
2. Passive-first operation	No intentional field is transmitted until the passive examination is complete and a separately authorised active protocol is justified.
3. Metrological traceability	Frequency, amplitude, bandwidth, spatial position, time and uncertainty are traceable to documented references and calibration chains.
4. Controlled scene	Access, personnel, equipment, environmental changes and source-state changes are logged in the manner used for a controlled forensic scene.
5. Non-contact preservation	No candidate object is handled, opened, moved, shielded, disconnected or altered during the non-contact phase.
6. Audibly silent and non-imaging	No acoustic excitation, loudspeaker alert, microphone recording or physical-image reconstruction is used.
7. Reproducibility	A reportable signal must survive repeat passes, blank controls, instrument checks and, where practicable, independent instrumentation.
8. Privacy by design	The method measures energy and timing. It does not demodulate or interpret communications content unless separately authorised and necessary.
9. Clinical and safety primacy	Patient care, life-safety systems and medical-device performance take precedence over the inspection.
10. Proportionate conclusions	The conclusion states only what the measurements support, with explicit limitations and no leap from frequency to device identity or health effect.
11. Target hierarchy	Tier 1 timing and clock phenomena are examined first, Tier 2 radiated phenomena second, and Tier 3 illuminated responses only after passive closure and separate authority.

Principle	Operational meaning
12. Illumination correlation is not causation	Coincidence with transmitter-on time is insufficient. Classification requires negative controls, spatial localisation, artefact exclusion, independent confirmation and stated uncertainty.
13. Modulation-neutral acquisition	Raw waveform, I/Q, spectrum, zero-span and timing data are acquired before a modulation label is accepted. A demodulator output or receiver mode indication is never treated as proof of the underlying waveform.
14. Standards-family and dormant-state coverage	The examiner maintains a current Standards Coverage Register, searches complete validated bandwidths and physical domains, observes low-duty sleep cycles for adequate time, and does not treat a connector, frequency or protocol label as proof of device identity.
16. Simultaneous multichannel acquisition	Every evidential electromagnetic measurement uses at least three simultaneously sampled and synchronized channels. The normative vector deployment uses three spatial pods with X, Y and Z probe axes, producing nine independent RF pathways. A single switched input may support reconnaissance only and cannot support phase, vector, simultaneity or transient-correlation claims.
17. Resonance-qualified sampling	A datum from a tuned rod or loop is admitted only when the analyser-controlled frequency command, the channel-specific varactor bias, the fixed and piston capacitance state, the resonance-lock flag, the common timebase and the complete channel state are recorded. A measurement made while the probe is slewing, unlocked, overloaded or being recalibrated is marked invalid.

Regional Sampling, Volumetric, Campaign-Tempo and Sub-20 Hz Multiphysics Expansion

This section establishes the five-mile-to-three-inch geometry, the defined angular-sampling density and the extended-campaign doctrine, while adding a separate 0.001 Hz to 20 Hz multi-physics workstream. The 5-mile, 2.5-mile and 1-mile annuli each use sixteen planned measurement stations in an ordinary commission and twenty-four in a high-risk commission. The 0.5-mile annulus ordinarily uses twelve stations and never fewer than eight for a complete-ring claim. The 0.25-mile annulus prefers twelve stations and likewise requires at least eight. At every scale, the examiner must distinguish airborne pressure, structure-borne motion, quasi-static electric field, quasi-static magnetic field, ordinary electronic timing, environmental control processes and biological measurement artefacts, because equal numerical frequency does not establish equal source, pathway or biological interaction.

The temporal architecture is equally deliberate. The complete commission is not designed as an hours-long sweep or a single hurried visit. A technically credible programme ordinarily extends across several weeks, using field deployments of approximately four to five days, intervening periods of authorised passive sentinel monitoring and off-site analysis, and later return visits that repeat reference stations before the team advances. Where the suspected phenomenon is rare, state-dependent or responsive to human presence, the campaign may extend for many months or even years. Every measurement, movement, configuration change and interpretive decision is recorded contemporaneously on paper and linked to the time-stamped digital record.

The volume also formalises a twenty-seven-cell neighbourhood. At each selected scale, an area of interest occupies the central cell of a 3 by 3 by 3 assembly, surrounded by six face-sharing, twelve edge-sharing and eight corner-sharing comparison cells. Measurements are paired across opposite walls, opposite faces, accessible floors below and ceilings or stories above. Radial observations are additionally organised as bounded spherical or ellipsoidal shells centred upon the candidate region, while the text warns that near-field coupling, conductive services, shielding apertures, anisotropic materials and multipath prevent an examiner from assuming a truly spherical field. The principle of controlling the high ground is translated into a safety-governed requirement to obtain the highest authorised and practicable measurement elevation, never a licence to climb, fly or enter a restricted area without formal authority and safe access.

A further analytical expansion addresses multilayer composite modulation. Synthetic defensive examples include a band-limited noise-diode source impressed upon a CW, AM or NFM host; a pulse-position-signalling sequence conveyed as a subcarrier; NFM upon NFM; and two or three nested subcarrier levels. The object is not to teach concealment. It is to prevent a receiver operator from dismissing a low-power, intermittent or illumination-correlated response merely because its energy resembles noise, ordinary telemetry or a familiar communications waveform. The prescribed analysis therefore preserves raw complex samples, common-timebase reference channels, envelope, phase, instantaneous-frequency, cyclostationary and cross-channel coherence products, together with sham, offset-frequency, terminated-input and direct-breakthrough controls.

Crystal, Resonator, Oscillator-Module and Harmonic-Family Expansion

We next examine frequency-ordered treatment of low-cost quartz crystals, tuning-fork crystals, ceramic resonators, complete oscillator modules, temperature-compensated oscillators, programmable clock sources, divided timing outputs and periodic state-machine cadences. The new chapter preserves every frequency supplied by the commissioning party, corrects the mathematical descriptions of 32.768 kHz and 1.8432 MHz, and distinguishes a physical resonator frequency from a buffered clock output, a PLL reference, a divided output, a wake cadence, a modulation envelope and a catalogue filter token.

For every non-zero discrete candidate the chapter calculates H2 through H11, namely the first ten harmonics after the fundamental. It repeatedly emphasizes that the most readily traced member of a clock family is often not the fundamental. Higher-frequency energy may couple more efficiently into short conductors, cable shields, enclosure apertures and probe structures, and it may fall within a quieter receiver band. That practical advantage does not permit automatic attribution. A proposed harmonic family must share drift, state changes, burst cadence and spatial convergence within declared uncertainty, while surviving receiver-spur, alias, overload and environmental controls.

The supplied distributor quantities are retained as a dated procurement snapshot rather than a scientific prevalence estimate. Inventory counts change continuously, duplicate category views may refer to overlapping product populations, and zero stock does not establish that a frequency is technologically absent. The evidentially relevant facts are the measured frequency, waveform, timing, coupling path, state dependence and spatial behaviour observed during the authorised examination.

Chapter Glossary

Terms used in Chapter 3: Foundational Principles.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COUPLING PATH — The physical route by which energy transfers from a source to a victim, structure, conductor, sensor, or observer.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

M

MAGNETIC FIELD — (1) The region in which the magnetic forces created by a permanent magnet or by a current-carrying conductor or coil can be detected. (2) The field that is produced when current flows through a conductor or antenna.

METROLOGICAL TRACEABILITY — The property of a measurement result by which it can be related to a reference through a documented, unbroken chain of calibrations, each contributing to measurement uncertainty.

MICROPHONE — An energy converter that changes sound energy into electrical energy.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

1. Purpose, Status and Intended Use

This framework establishes a system for examining premises, rooms, vehicles, equipment zones and other authorised locations for weak electronic phenomena. Its intended use is method development, controlled environmental inspection, research, quality-assured technical consultation and the generation of records capable of independent review. It adapts the scene-to-report logic of the ISO 21043 forensic process while drawing metrological controls from ISO/IEC 17020, ISO/IEC 17025, CISPR measurement practice and the Guide to the Expression of Uncertainty in Measurement [1-11].

Before a laboratory or inspection body presents EERF findings as reliable for a consequential decision, it shall validate the relevant frequency bands, sensors, receiver chains, search geometries, algorithms, decision thresholds and reporting claims. Validation must reflect the intended environment, including dense electronic clutter, shielding, low-duty-cycle signals, spread-spectrum clocks, source orientation, multipath and operator-carried artefacts.

The method may be commissioned where the question is whether a measurable electronic signature exists, whether it is localised to a defined region, or whether it is consistent with a known source class. It may also support an exposure survey when the instrumentation is calibrated for field strength and the applicable human-exposure standard is identified. It shall not be used to diagnose disease, to promise discovery of a concealed device, to intercept communications without authority, or to infer identity, intent, ownership, illegality or causation from a frequency alone.

Chapter Glossary

Terms used in Chapter 4: Purpose, Status and Intended Use.

B

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

T

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

2. Proposed Discipline and Terminology

Electronic Emission and Resonance Forensics is defined as the application of validated forensic, electromagnetic and metrological methods to the recognition, recording, acquisition, analysis, interpretation and reporting of weak electronic emissions and field-dependent responses, while preserving the inspected environment and the integrity of the resulting data. The discipline encompasses direct radiation, quasi-static coupling, conducted or common-mode leakage detectable without device contact, resonant scattering, modulated backscatter, non-linear junction responses and remotely powered operation.

Term	**Proposed definition**
Candidate signal	A measured feature selected for additional examination. Selection is not a conclusion that a device exists.
Electronic signature	A reproducible set of spectral, temporal, spatial, polarisation, phase or modulation attributes associated with an electronic process or source class.
Timing signature	A fundamental, harmonic, subharmonic, mixing product or periodic envelope associated with an oscillator, divider, frame, line, refresh, switching or scheduling process.
RF retroreflective or backscatter device	A passive or semi-passive structure that returns, modulates or redirects incident electromagnetic energy. This use of retroreflector is electromagnetic, not optical.
Remotely powered device	A device that obtains operating energy from an incident electromagnetic field, inductive link, capacitive link or other external coupling mechanism.
Non-contact	No physical contact with, movement of, opening of, connection to or alteration of the candidate object. Probes may be positioned nearby at a measured standoff.
Non-imaging	No reconstruction of the physical appearance or internal structure of an object. Coordinate tables, spectra and time-series plots remain permissible analytical records.

Term	Proposed definition
Audibly silent	No deliberate audible emission, acoustic excitation, loudspeaker alarm or microphone capture. Fanless or remotely located equipment is preferred.
Source association	A reasoned statement that measurements are consistent with a source class or specific reference source, with uncertainty and alternative explanations stated.
Negative finding	No reportable signal was observed above the validated capability of the method under the conditions examined. It is not proof that no device exists.
High-reverse-voltage varactor	A reverse-biased voltage-variable capacitor diode selected with substantial breakdown-voltage headroom. In EERF it is a passive fine-trim element, not an active gain device.
Lock-acquire-hold	A tuning discipline in which a calibration reference is used to acquire the required varactor bias, the reference is removed, and the quiet bias is held unchanged during the evidential record.
Illumination-presence trigger	A trigger derived from measured presence of the authorised illumination waveform rather than from the command to transmit.
Response-latency iteration	A predeclared coarse-to-fine sequence of pre-trigger and positive trigger delays used to capture delayed backscatter, SAW, charging, start-up or encoded responses.
Coherent multichannel acquisition	Simultaneous sampling of two or more RF paths whose sample clocks, local-oscillator references, trigger epoch and timestamps are derived from one characterised time and frequency reference, with measured channel skew and group delay.
Frequency-slaved tuning	A controlled process in which the analyser frequency command is converted through a channel-specific calibration law into a quiet varactor bias so the resonant probe follows the commanded analysis frequency. It does not mean that one common bias voltage is applied blindly to every probe.
Probe pod	A surveyed external head carrying three nominally orthogonal sensing axes, X, Y and Z, together with the minimum quiet front-end components needed to preserve signal integrity. Pod electronics remain part of the controlled analyser system and are not independent free-running instruments.

Term	Proposed definition
Nine-probe vector array	Three spatially separated probe pods, each carrying X, Y and Z axes, for a total of nine simultaneously sampled electromagnetic pathways.
Site master timebase	The common frequency, sample-clock, trigger and time-of-day reference distributed to every analyser chassis, downconverter, digitiser, state logger and illumination monitor used in one comparison series.
Tracking receiver	A narrowband high-selectivity receiver, implemented physically or digitally, that follows a selected analyser input and centre frequency while using a narrower validated noise bandwidth or coherent integration interval than the discovery display.
Resonance-qualified sample	A sample block acquired after the relevant probe has reached and verified its declared resonant state, the calibration pilot has been removed, bias is in hold, the common clock is locked and channel health flags are valid.

Chapter Glossary

Terms used in Chapter 5: Proposed Discipline and Terminology.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

E

ELECTROMAGNETIC FIELD — The combination of an electric (E) field and a magnetic (H) field.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

M

MICROPHONE — An energy converter that changes sound energy into electrical energy.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

O

OSCILLATOR — An oscillator is a nonrotating device that produces alternating current. The frequency is determined by the characteristics of the device.

R

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

3. Scope, Boundaries and Exclusions

Included	Excluded unless separately authorised and validated
Passive electric-field, magnetic-field and RF emission surveys.	Physical search, opening, dismantling, destructive testing or removal of property.
Non-contact localisation by amplitude gradients, loop nulls, phase comparison and controlled probe geometry.	Optical, thermal, X-ray, ultrasound, radar, terahertz or tomographic imaging.
Characterisation of timing fundamentals, harmonics, sidebands, modulation envelopes and intermittent activity.	Decoding, listening to, reconstructing or interpreting communications content.
Observation of ambient-carrier reflections or backscatter.	Deliberate active interrogation without written spectrum, safety, clinical and legal approval.
Optional low-field linear, backscatter or non-linear-junction response testing under a separate active plan.	Any claim that a signal is harmful, intentional, illegal or attributable to a person merely because it is detected.
Field-strength measurement where the entire system is calibrated and uncertainty is known.	Clinical diagnosis, treatment advice or medical-causation opinion.
Forensically controlled recording, hashing, review and reporting.	Use of unvalidated black-box classification as the sole basis for a conclusion.
Passive physical-layer, timing, port, cable, sleep-state and standards-family examination across wireless, wired, optical and conducted domains.	Payload decoding, credential collection, active association, pairing, enumeration, injection, impersonation or protocol exploitation without separate authority.

NON-NEGOTIABLE LIMIT
EERF cannot convert a reported physical symptom into proof of electromagnetic exposure, nor convert a narrowband line into proof of a concealed transmitter. The instrument reading, the source inference and the medical question are three separate propositions.

Chapter Glossary

Terms used in Chapter 6: Scope, Boundaries and Exclusions.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

L

LOOP — A curved conductor that connects the ends of a coaxial cable or other transmission line and projects into a waveguide or resonant cavity for the purpose of injecting or extracting energy.

M

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RADAR — Radio detection and ranging: the use of transmitted electromagnetic energy and received echoes or scattered signals to detect, locate, characterize, or track objects and phenomena.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

4. Scientific and Metrological Foundation

4.0A Frequency is not a physical domain

A frequency value is a temporal descriptor, not a source classification. A 10 Hz line in a spectrum may represent an acoustic pressure wave in air, a floor acceleration, a magnetic-flux-density variation, an electric-field variation, a motor-speed component, a digital control envelope, a beat product, an instrument-drift term or a biological signal acquired by electrodes. Those phenomena cannot be merged merely because their Fourier components occupy the same horizontal coordinate. The instrument, calibration, unit, transfer function, propagation model and evidential vocabulary must remain domain-specific.

The interval from 0.001 Hz to 20 Hz is especially vulnerable to conceptual error. At the low end, a single cycle lasts 1,000 seconds. At 20 Hz, an electromagnetic wavelength in free space is approximately 15,000 kilometres, so an ordinary room or campus is electrically minute and the relevant electromagnetic coupling is usually quasi-static rather than a propagating plane wave. By contrast, a 17 Hz acoustic wave in air has a wavelength of roughly 20 metres and can be strongly altered by room geometry, ducts, apertures, structural transmission and standing-wave behaviour. The same nominal frequency therefore presents radically different measurement physics.

4.1 Emission pathways

Electronic energy may leave a circuit through intended radiation, unintended electric-field coupling, unintended magnetic-field coupling, common-mode current on conductors, leakage through apertures and seams, cable shields, power rails, ground paths, switching transients or harmonic generation. A buffered output or metal enclosure may reduce one path while leaving another. A clock fundamental can be weaker than its harmonics, and a nominally continuous oscillator can be gated, duty-cycled or altered by power-management states. The examination therefore searches families of related features rather than a single exact line.

Field-theory elaboration. An advanced technical account of Emission pathways distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. Spatial nulls, phase reversals, vector orientation, and response to controlled geometric changes are often more informative than a single amplitude maximum, particularly in reflective rooms and near extended conductors. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

4.2 Near-field and far-field behaviour

At 32.768 kHz the free-space wavelength is approximately 9.15 kilometres. The 300-foot ring is only 91.44 metres from the premises and remains deeply electrically small relative to that wavelength, so indoor and near-building measurements commonly depend upon quasi-static magnetic and electric coupling, conductive paths, source dimensions and nearby structures rather than a clean plane-wave bearing. At 3.579545 MHz the wavelength is approximately 83.75 metres, or 274.78 feet. The 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and 3-foot stages are approximately 1.092, 0.546, 0.364, 0.182, 0.109, 0.0546, 0.0437 and 0.0109 wavelength respectively.

This deliberate progression crosses several coupling and propagation scales and can expose reflections, cable radiation, shield leakage, structural reradiation and reactive coupling. No single inverse-distance law is imposed across all rings. The team records the actual lateral pattern, height dependence, orientation, phase and inward or outward reproducibility.

Electromagnetic interpretation. An advanced technical account of Near-field and far-field behaviour distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

4.3 Instrument response and selectivity

A broad discovery scan should precede narrow filtering. Excessively selective filtering at the outset can miss drift, spread-spectrum clocking, burst activity, sidebands and intermittent operation. Once a stable candidate is identified, narrow resolution bandwidth, coherent averaging, lock-in detection or high-Q analogue filtering may increase signal-to-noise ratio. Every filter shall have a documented centre frequency, bandwidth, shape factor, group delay, settling time and overload behaviour. Raw wideband data shall be retained whenever practicable so that later filtering does not replace the original observation.

Advanced technical elaboration. A technically mature treatment of Instrument response and selectivity begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

4.4 Measurement uncertainty

A field reading is incomplete without its uncertainty and the conditions that define it. Relevant components include sensor factor, cable loss, preamplifier gain, receiver amplitude accuracy, frequency-reference error, probe orientation, standoff, spatial repeatability, temperature, bandwidth, detector response, environmental variability, interpolation and operator positioning. The laboratory shall maintain band-specific uncertainty budgets and report expanded uncertainty with the coverage factor and confidence convention stated. The JCGM Guide provides the general framework [9].

Traceability and uncertainty analysis. At expert-practitioner level, Measurement uncertainty begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. Where a result depends upon subtraction, ratios, phase differences, or spatial gradients, covariance between channels and stations is considered rather than assuming every input quantity is independent. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

4.5 Source models, coupling paths and field components

The method shall begin with several competing source models, including a compact magnetic loop, a compact electric dipole, an extended conductor, a shield aperture, a common-mode cable, a passive resonator and a remote radiating source. The governing physical or metrological basis is Maxwellian coupling in which electric and magnetic components, conductive current paths and structural materials can contribute differently at the same nominal frequency. The examiner shall treat this basis as a testable model rather than an assumption. No single inverse-distance law is imposed throughout a building because the field can pass through reactive, induction, radiating and guided-current regimes. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced physical analysis. An advanced technical account of Source models, coupling paths and field components distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The section is technically complete only when the relevant field regime and the limits of the adopted approximation are stated [129-131].

The required configuration is as follows. At least one magnetic sensor and one electric-field sensor are used when the candidate band and access permit, with orthogonal orientation and fixed standoff. The primary observables are component amplitude, phase where coherent, polarisation or axis, null direction, spatial gradient, harmonic relationships and time stability. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are a remote reference, sensor rotation, changed standoff, an independent sensor geometry and a reverse path. The principal artefacts and confounders are conducted currents, steel concentration, capacitive loading by personnel, receiver intermodulation, several simultaneous sources and multipath. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a source model may guide the next measurement only when it predicts observations better than its alternatives. The principal limitation is the accessible field maximum can lie on a conductor or shield seam rather than at the originating circuit. The record shall contain the models considered, predictions, discriminating measurements, residual inconsistencies and the model retained for navigation. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

4.6 Electrically small geometry at 15.734 kHz and 32.768 kHz

Low-frequency localisation shall recognise that the entire 300-foot approach is electrically small relative to the free-space wavelength at the principal timing bands. The governing physical or metrological basis is quasi-static magnetic and electric coupling, for which source geometry and nearby conductors matter more than a simple plane-wave bearing. The examiner shall treat this basis as a testable model rather than an assumption. The wavelength comparison is a scale indicator, not a hard boundary and not proof that every indoor source behaves as an ideal dipole. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Clock and timing interpretation. A technically mature analysis of electrically small geometry at 15.734 kHz and 32.768 kHz distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

The required configuration is as follows. Long ferrite rods, air-core loops, electric-field plates and multi-axis measurements are used before higher-frequency far-field assumptions are applied. The primary observables are vector component changes, loop or rod nulls, response versus standoff, response across a wall or service path, and frequency-family coherence. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are fixed-height repeats, opposite-direction rotation, lateral points at the same radius and a source-absent control position. The principal artefacts and confounders are mains harmonics, switching converters, magnetic steel, moving ferromagnetic objects and electrostatic pickup into a nominal magnetic channel. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is low-frequency advancement requires a reproducible gradient or directional structure, not merely a narrow spectral line. The principal limitation is distance cannot be inferred uniquely from one amplitude without a validated source model. The record shall contain wavelength calculations, probe axis, effective aperture, field component, spatial pattern and uncertainty. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

4.7 Transition and multipath behaviour near 3.579545 MHz

The 3.579545 MHz channel shall account for the fact that 300 feet is slightly greater than one free-space wavelength while the inner rings are progressively smaller fractions of a wavelength. The governing physical or metrological basis is radiating-field propagation, reflection, diffraction, cable radiation and near-field coupling that can coexist around a premises. The examiner shall treat this basis as a testable model rather than an assumption. An exterior amplitude maximum is not automatically closer to the source because standing waves and antenna pattern can create displaced peaks. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Oscillator-family analysis. For transition and multipath behaviour near 3.579545 MHz, the most detectable member of a timing family may be a harmonic or coupled sideband rather than the fundamental, particularly when the fundamental lies in a high-noise region of the spectrum or is poorly coupled to the available probe. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

The required configuration is as follows. A calibrated loop or other suitable antenna is measured at changed heights, polarisations and azimuths, with preselection against strong broadcast and communications signals. The primary observables are frequency stability, phase relative to a reference, polarisation, bearing, height dependence, multipath fading and inward versus lateral change. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are antenna substitution, height change, independent receiver, preselector change and repeat measurements after the environment is temporally stable. The principal artefacts and confounders are receiver images, local oscillator products, digital clocks, nearby transmitters, reflected external signals and cable pickup. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a premises-associated interpretation requires converging evidence from exterior and interior geometry. The principal limitation is a single bearing can be unreliable in reflective urban or institutional settings. The record shall contain antenna factor, orientation, height, site constraints, external bearings, phase or amplitude pattern and tested alternatives. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

4.8 Resonance, Quality Factor and Temporal Settling

Resonant probes shall be treated as dynamic measurement systems whose selectivity and voltage gain are accompanied by finite bandwidth and ring-down. The governing physical or metrological basis is energy exchange between inductance and capacitance with loss in copper, core, dielectric, shield and amplifier loading. The examiner shall treat this basis as a testable model rather than an assumption. A high measured Q does not by itself establish superior field sensitivity, because the source may drift or the probe may become microphonic and slow to settle. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Metrological interpretation. The mature treatment of resonance, quality factor and temporal settling distinguishes calibration, verification, adjustment, characterisation, and validation. These activities are related, but they are not interchangeable and they do not support the same evidential claim. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

The required configuration is as follows. Centre frequency, 3 dB bandwidth, loaded Q, transfer factor, group delay or ring-down and temperature dependence are measured with the final housing. The primary observables are peak response, phase crossing, skirt response, transient decay, noise spectral density and response to a known field. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are broadband companion channel, movement-to-dwell delay, retuning blank and repeat resonance check after transport. The principal artefacts and confounders are mechanical ringing, tuning-tool capacitance, temperature shift, amplifier loading, a cracked core and a closed conductive shield turn. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is high-Q data are used for confirmation only when the candidate remained within the validated passband throughout the comparison. The principal limitation is amplitude changes can represent detuning rather than spatial change. The record shall contain tuning date, capacitor setting, fixed capacitance, measured L, R, f0, Q, bandwidth, temperature and settling interval. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

4.9 Measurement uncertainty for frequency, amplitude and position

Every material result shall distinguish uncertainty in frequency, field or relative amplitude, and source-region position. The governing physical or metrological basis is propagation of reference, calibration, repeatability, orientation, coordinate, standoff, aperture, model and environmental contributions. The examiner shall treat this basis as a testable model rather than an assumption. Grid spacing is not spatial accuracy, and a precise frequency does not imply a precise source location.

The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Traceability and uncertainty analysis. An advanced metrological approach to measurement uncertainty for frequency, amplitude and position treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

The required configuration is as follows. Uncertainty models are prepared during validation and updated with case-specific contributions such as inaccessible geometry or temperature excursion. The primary observables are calibration residuals, repeat variance, coordinate checks, reference-clock error, probe-aperture coverage and blind-localisation performance. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are duplicate points, reference-source checks, coordinate verification, independent processing and reviewer recalculation. The principal artefacts and confounders are unrecognised covariance, rounding, use of nominal rather than actual coordinates, and mixing calibrated and uncalibrated channels. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a reported interval shall be no narrower than the validated resolution and expanded uncertainty support. The principal limitation is uncertainty can be anisotropic, particularly behind walls or inaccessible surfaces. The record shall contain the measurement equation, standard contributions, distributions, sensitivity coefficients, coverage factor and final interval. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 7: Scientific and Metrological Foundation.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BEARING — An angular direction from a defined reference meridian or axis to a source, target, or line of sight.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

S

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

W

WAVELENGTH — The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

Mathematical Foundations for Electronic Emission and Resonance Forensics

1. Forward Electromagnetic Observation Model

The measurement should be expressed as a forward operator rather than as an intuitive statement that a source "produces a signal." Let the unknown state θ contain current distribution, oscillator state, material parameters, geometry, coupling path, and temporal activity. Let g describe probe position, orientation, loading, and receiver configuration. The recorded complex data satisfy $y = H(\theta,g)+n+\delta$, where n is stochastic measurement noise and δ is model discrepancy. This representation forces the examiner to distinguish source physics from the instrument and from errors in the assumed environment. It also makes clear that a frequency line is not a source identity; it is one component of an observation generated by a many-to-one operator.

Application discipline for forward electromagnetic observation model: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

2. Inverse Localisation and Regularisation

Localisation is an inverse problem. The estimate $\hat{\theta} = \arg\min_\theta ||W[y-H(\theta,g)]||^2 + \lambda^2R(\theta)$ balances agreement with measured data against a regularisation term that encodes smoothness, sparsity, bounded support, or another defensible prior. Regularisation is not a cosmetic numerical device. It selects among otherwise non-unique solutions, and the selected feature may therefore reflect the prior as strongly as the data. The report should identify the regulariser, parameter-selection method, sensitivity to λ, and spatial features that remain stable under reasonable alternatives.

Application discipline for inverse localisation and regularisation: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

3. Identifiability and Experimental Design

A parameter is identifiable only when distinct values produce measurably distinct observations under the available geometry and noise. Closely spaced sources, symmetric layouts, correlated harmonic families, and poorly conditioned probe arrays can make localisation or classification structurally ambiguous. The Fisher information matrix $J^T R^{-1} J$ provides a local measure of parameter sensitivity; near-singularity indicates directions in parameter space that the experiment cannot resolve. The correct response is not to report more digits but to change the experiment - probe orientation, baseline, frequency, controlled illumination, or independent modality - to increase discriminating information.

Application discipline for identifiability and experimental design: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

4. Resonator Dynamics and Pole-Zero Structure.

A resonant response should be represented by poles, zeros, damping, and coupling rather than by frequency alone. For a lightly damped mode, $H(s)=K\omega_0^2/(s^2+2\zeta\omega_0 s+\omega_0^2)$, with quality factor $Q\approx1/(2\zeta)$ only under the assumptions of a second-order linear mode. Loaded Q, unloaded Q, external coupling, and measurement loading are different quantities. Mode splitting, anti-resonances, and asymmetric line shapes can indicate coupled resonators or interference between direct and resonant paths. Ring-down data provide an independent temporal estimate of damping and should be reconciled with frequency-domain fitting.

5. Nonlinear Mixing and Harmonic-Family Attribution.

Harmonics and intermodulation products are generated by nonlinear transfer characteristics. If $v\_out = a_1 v + a_2 v^2 + a_3 v^3 + \ldots$, multiple input tones generate sum and difference products whose amplitudes depend on coefficients, drive level, bias, and filtering. A family of evenly related lines is therefore compatible with several mechanisms: a clocked source, a switched converter, receiver intermodulation, a nonlinear junction, or a deliberately modulated device. Power-scaling tests, front-end attenuation, alternate receivers, spatial gradients, and source-off controls are required before the family can support attribution.

6. Likelihood-Ratio Detection and ROC Analysis

Detection should be framed as a comparison between hypotheses H_0 and H_1. The likelihood ratio $\Lambda(y)=p(y|H_1)/p(y|H_0)$ is compared with a threshold determined by prior odds and decision losses. Receiver-operating-characteristic curves describe the trade between probability of detection and false alarm as the threshold varies. A fixed threshold reported without the background distribution, observation duration, and number of searched cells is uninterpretable. Multiple-frequency, multiple-position, and multiple-time searches require control of the trials factor because the maximum of many noise samples can appear significant.

Application discipline for likelihood-ratio detection and roc analysis: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

7. CFAR and Nonstationary Backgrounds

Constant-false-alarm-rate methods estimate a local background and adapt the threshold, but their assumptions can fail in dense, nonstationary, or spatially structured environments. Cell-averaging CFAR is biased by interfering targets; greatest-of and smallest-of variants trade robustness against sensitivity; ordered-statistic methods depend on the rank parameter and reference-window design. In TSCM or TEMPEST work, the “background” may include legitimate intermittent emitters, receiver spurs, and moving personnel. The algorithm and guard/reference geometry must be retained so that a later reviewer can reproduce the detection decision.

Application discipline for cfar and nonstationary backgrounds: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

8. Matched Filtering and Coherent Integration

For a known waveform in additive Gaussian noise, the matched filter maximises output signal-to-noise ratio. Its benefit depends on waveform fidelity, timing uncertainty, phase stability, and noise colour. Coherent integration accumulates complex samples and can improve amplitude sensitivity proportional to N when phase is stable; noncoherent integration offers a smaller gain but tolerates phase variation. Claims of processing gain must state effective independent samples, window loss, duty cycle, frequency drift, and the extent to which the template was selected after inspecting the data.

Application discipline for matched filtering and coherent integration: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

9. Covariance-Based Measurement Uncertainty

For a result $z=f(x)$, first-order propagation gives $\Sigma_z \approx J_f \Sigma_x J_f^T + \Sigma_{model}$. The covariance matrix must include correlated calibration terms, shared clocks, probe-position errors, cable movement, gain drift, phase offsets, interpolation, environmental changes, and model discrepancy. Treating correlated contributions as independent can materially understate uncertainty. Nonlinear or bounded problems should be checked by Monte Carlo propagation, with distributions and correlations justified from calibration data or repeated measurements rather than chosen for convenience.

Application discipline for covariance-based measurement uncertainty: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

10. Bayesian Fusion of Heterogeneous Evidence

RF amplitude, phase, spatial gradient, thermal observation, physical inspection, network evidence, and controlled-illumination response are not automatically independent. A Bayesian network can represent their common causes and preserve the distinction between evidence about source existence, location, mechanism, and intent. Posterior summaries should be accompanied by prior sensitivity and posterior-predictive checks. A result that is highly sensitive to an unverified prior or that predicts observations unlike the measured record should not be presented as robust merely because the optimisation converged.

Application discipline for bayesian fusion of heterogeneous evidence: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

11. Residual Diagnostics and Model Discrepancy

A fitted model is credible only if its residuals behave as expected. Residuals should be inspected across frequency, time, position, probe orientation, and measurement session for structure, heteroscedasticity, autocorrelation, and unexplained harmonics. A small aggregate error can conceal systematic misfit that matters for localisation. Competing models should be compared by predictive performance, information criteria, or held-out measurements, while recognising that statistical preference does not repair a physically implausible model.

Application discipline for residual diagnostics and model discrepancy: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

12. Blind Controls and Cross-Modal Validation.

Validation should include source-off measurements, sham movements, dummy paths, blind probe repositioning, receiver substitution, controlled injected references, and independent physical modalities. The purpose is not ceremonial confirmation but active search for mechanisms that could mimic the preferred explanation. A cross-modal result is valuable only when the modalities have sufficiently independent error structures. Two software displays driven by the same front end are not independent confirmation.

13. Post-Graduate Research Programme

The specialist reader should be able to design and execute a complete inverse electromagnetic examination. The programme should include a forward model, identifiability analysis, measurement geometry, calibration plan, uncertainty covariance, detection threshold, regularisation strategy, residual tests, blind controls, and an expert-report template that separates observation, model-dependent inference, and unresolved alternatives. At least one dataset should contain two partially coherent sources, one receiver-generated spur, and a deliberately changed environmental boundary so that a superficially persuasive but incorrect solution is available to the unwary analyst.

Application discipline for post-graduate research programme: the examiner shall state the data domain, reference plane, calibration state, parameterisation, numerical or analytical approximation, and the evidence needed to falsify the preferred account. Results are to be reported with parameter covariance or bounded sensitivity, not as isolated best-fit values. Where the model is non-unique, the report shall identify the equivalence class of solutions and the additional experiment with the greatest expected discrimination.

A resonant response should be represented by poles, zeros, damping, and coupling rather than by frequency alone. For a lightly damped mode, $H(s)=K\omega_0^2/(s^2+2\zeta\omega_0 s+\omega_0^2)$, with quality factor $Q\approx 1/(2\zeta)$ only under the assumptions of a second-order linear mode. Loaded Q, unloaded Q, external coupling, and measurement loading are different quantities. Mode splitting, anti-resonances, and asymmetric line shapes can indicate coupled resonators or interference between direct and resonant paths. Ring-down data provide an independent temporal estimate of damping and should be reconciled with frequency-domain fitting.

Validation should include source-off measurements, sham movements, dummy paths, blind probe repositioning, receiver substitution, controlled injected references, and independent physical modalities. The purpose is not ceremonial confirmation but active search for mechanisms that could mimic the preferred explanation. A cross-modal result is valuable only when the modalities have sufficiently independent error structures. Two software displays driven by the same front end are not independent confirmation.

Chapter Glossary

Terms used in Chapter 8: Graduate Mathematical Foundations for Electronic Emission and Resonance Forensics.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

N

NONLINEAR JUNCTION — An electrical contact or material interface whose current-voltage relationship is nonlinear and can therefore generate harmonics, intermodulation products, rectification, or load-modulated responses.

R

REFERENCE PLANE — The physical or mathematical location at which a signal, impedance, power, field, or calibration quantity is defined.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

S

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

5. Medical, Ethical, Legal and Privacy Guardrails

Where an inspection arises from unexplained signs or symptoms, the commission shall be divided into two independent streams. The technical stream determines what fields or signatures can be measured. The clinical stream evaluates symptoms through ordinary medical practice and, if research is contemplated, through a properly governed protocol. Technical examiners should be blinded, so far as practicable, to the claimed source location and moment-to-moment symptom reports. This reduces the risk that expectations alter grid density, instrument settings or interpretive emphasis.

The WHO position on electromagnetic hypersensitivity is relevant to language and duty of care. It recognises that reported symptoms can be real and disabling, while stating that there are no clear diagnostic criteria and no established scientific basis linking those symptoms to electromagnetic-field exposure [22]. The appropriate EERF response is neither dismissal nor confirmation. It is disciplined measurement, transparent uncertainty, alternative-hypothesis testing and referral of medical questions to qualified clinicians.

Written authority shall identify the premises, dates, permitted areas, permitted state changes, data classes, privacy limitations, active-transmission permissions and report recipients. Local law governs entry, privacy, communications interception, radio transmission, workplace safety, medical-device safety and data protection. In the United Kingdom, an active plan may require consideration of Ofcom requirements; in the United States, FCC rules may apply. Neither reference substitutes for jurisdiction-specific legal advice.

Data minimisation is a design requirement. The preferred record is calibrated energy, spectrum and timing data, not communications content. Audio demodulation, video reconstruction, network payload capture and device interrogation are outside the default method. If a receiver inevitably captures raw in-phase and quadrature data containing incidental communications, access shall be restricted, retention justified, encryption applied and unnecessary content destroyed under an approved schedule.

Chapter Glossary

Terms used in Chapter 9: Medical, Ethical, Legal and Privacy Guardrails.

B

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DEMODULATION — The removal of intelligence from a transmission medium.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

T

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

6. Examination Questions and Decision Propositions

Question	Permissible proposition	Impermissible leap
Q1. Presence	Was a reproducible signal observed above the validated capability of the method?	A concealed device must be present.
Q2. Character	What are its frequency, bandwidth, stability, duty cycle, harmonics, sidebands and field components?	The exact circuit is known from one spectral line.
Q3. Location	Where is the measured field strongest, and what bounding region is supported by repeatable gradients?	The physical object has been imaged or uniquely located.
Q4. Association	Is the signature consistent with a known oscillator, source class or reference specimen?	Consistency proves identity, ownership, intent or purpose.
Q5. Exposure	What calibrated field strength was measured, with uncertainty, at defined coordinates and times?	A measured field caused a symptom.
Q6. Absence	Was no reportable signal found under the examined states and validated sensitivity?	No passive, intermittent, shielded or dormant device exists.
Q7. Medical effect	Outside EERF. Refer to independent clinical or research governance.	Technical examiner diagnoses or attributes illness.

Chapter Glossary

Terms used in Chapter 10: Examination Questions and Decision Propositions.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DUTY CYCLE — In a transmitter, ratio of time on to time off.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

O

OSCILLATOR — An oscillator is a nonrotating device that produces alternating current. The frequency is determined by the characteristics of the device.

T

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

7. Signal Taxonomy and Candidate Timing Signatures

The watch list is an investigative aid, not a catalogue of unique fingerprints. Common consumer, industrial, medical and building systems can produce the same frequencies. Each candidate shall be assessed as a family comprising the nominal line, frequency tolerance, harmonics, subharmonics, mixing products, modulation envelope, spatial behaviour and source-state correlation.

Candidate family	**Potential relevance**	**Common confounders and limitations**
50 or 60 Hz and harmonics	Mains coupling, transformer fields, rectifier ripple and ground currents.	Nearly ubiquitous. Strong fields can mask weak low-frequency signatures and create receiver intermodulation.
32.768 kHz and harmonics	Real-time clocks, low-power timers, wake-up schedulers and watch-crystal oscillators. Ultra-low-power implementations may dissipate well below 1 microwatt [24].	Not unique. Frequency shifts with load capacitance, temperature and ageing. Fundamental may be weaker than harmonics or may stop in some power states.
15.625 kHz or about 15.734 kHz	Legacy 625-line or 525-line horizontal timing and related scan circuitry.	Also resembles switching-supply and display noise. Modern digital cameras and displays may not use these frequencies.
3.579545 MHz	Nominal NTSC chrominance subcarrier or derived timing in legacy composite-video equipment [26].	Presence does not establish a camera. It can arise from legacy video gear, test equipment, crystals and harmonics of unrelated systems.

Candidate family	Potential relevance	Common confounders and limitations
4.43361875 MHz	Nominal PAL chrominance subcarrier in legacy composite-video equipment.	Same non-uniqueness and modern-equipment limitations as NTSC.
125 kHz and 134.2 kHz	Low-frequency RFID, access-control, animal-identification and inductive links.	Readers, door systems and chargers can dominate. Passive tags may be silent without excitation.
13.56 MHz	HF RFID, NFC, inductive power and industrial or medical systems.	Ambient transmitters may be intermittent. A passive response requires an incident field.
24, 25, 26, 27, 38.4, 40 or 48 MHz families	Common reference clocks, USB-related clocks, radio and camera system clocks.	These are broad candidate families, not camera identifiers. Spread-spectrum and multiplication can move or broaden energy.
433.92, 868 and 902-928 MHz regions	Short-range devices, sensors, controls, RFID and telemetry, depending on jurisdiction.	Dense legitimate use. Regulatory bands and exact allocations differ by country.
2.4 and 5 GHz regions	Wi-Fi, Bluetooth, proprietary telemetry and remotely powered or backscatter research systems.	Extremely crowded. Signal presence alone rarely supports local source attribution.
Switching combs from tens of kHz to several MHz	DC-DC converters, charge pumps, PWM, LED drivers and power-management circuits.	Fundamental and harmonics vary with load and mode. They can mimic timing circuits and create broad contamination.

Candidate family	Potential relevance	Common confounders and limitations
Approximately 300 MHz response region	Possible reradiation, internal resonator output, pulse-position-modulated return, difference-frequency product or other translated response during an authorised illumination test.	Not unique and readily confused with external services, receiver images, intermodulation or the absolute difference between illumination sources. It requires field-off, offset-frequency and independent-receiver controls.
1.1 GHz to 2.2 GHz candidate illumination region	Possible directional excitation region for a predeclared remotely powered, retro-reflector, resonant or frequency-translating hypothesis.	Candidate range only. Regulatory authority, field limits, antenna calibration, medical-device compatibility and response-path isolation are required before use.
Approximately 3.5 GHz and 5.3 GHz candidate illumination regions	Possible higher-frequency excitation regions for structures whose receiving aperture, retro-reflector, SAW response or nonlinear behaviour is not evident passively.	Candidate frequencies only. Multipath, direct breakthrough, harmonics, mixer products and material-specific resonance can dominate. No universal activation claim is permitted.
1.8432 MHz and related multiples	UART, modem and serial baud-generator families.	Common in many unrelated instruments. Confirm integer-divider relationships and spatial association.
11.2896/12.288 MHz audio families and multiples	Audio codecs, I2S/TDM, PDM microphones and always-on audio processing.	44.1 kHz and 48 kHz sample families overlap many general-purpose clocks.
13/19.2/26/38.4/52 MHz	Mobile-radio reference, TCXO and synthesiser families.	Implementation and power state vary. A serving-cell signal does not prove a local handset.

Candidate family	Potential relevance	Common confounders and limitations
25/50/100/125/156.25 MHz	Ethernet, PCIe and serial transceiver reference families.	Spread-spectrum clocking, gating and harmonics can broaden or remove the apparent line.
27/74.25/148.5/297/594 MHz	Digital video pixel and link-timing families.	Video timing is not specific to a camera. Displays, converters and test equipment share these values.
48/60/120/240/480 MHz and 8 kHz envelope	USB controller, PHY and microframe relationships.	Traffic and suspend state alter leakage. USB Type-C/PD can remain active while data lanes are quiet.

TECHNICAL CORRECTION
Use 32.768 kHz as the nominal watch-crystal value. For legacy NTSC composite video, use 3.579545 MHz for the colour subcarrier and approximately 15.734 kHz for the horizontal line rate. These are precise candidate frequencies, not unique device fingerprints.

The following hierarchy governs candidate selection and prevents a strong radio-frequency carrier from displacing the more probative search for the clock or baseband process that may organise it. A candidate may occupy more than one tier, but its evidential status is recorded separately in each tier.

Tier	Primary object of examination	Illustrative observables	Required caution
Tier 1. Baseband timing and central clock	Oscillators, crystal-derived timing, real-time clocks, divider chains, synchronisation, switching clocks and bus timing.	Frequency stability, harmonics, subharmonics, divider ratios, phase coherence, burst cadence, sidebands and leakage gradients.	A common frequency is not a unique device identifier. Shielding may alter the dominant leakage path or suppress the fundamental while leaving harmonics.
Tier 2. Radiated and conducted emissions	Intentional or unintended RF radiation, near-field electric or magnetic energy, cable-mode emission, conducted escape, low-duty-cycle bursts and hopping activity.	Carrier frequency, occupied bandwidth, pulse interval, modulation family, bearing, polarisation, cable or service-path continuation and relation to Tier 1 timing.	External transmitters, common-mode conductors, receiver products and multipath can create convincing but non-local source patterns.
Tier 3. Controlled-illumination response	Passive, semi-passive, remotely powered, resonant, backscatter, retroreflective, SAW-associated, nonlinear-junction and load-modulated structures.	Same-frequency scattering, sidebands, harmonic or subharmonic return, frequency translation, PPM displacement, activation threshold, latency and field-dependent spatial response.	Active work requires separate authority and risk control. A transmitter-correlated feature is not device-associated until direct leakage and instrumental artefacts are excluded.

7.1 Timing-family relationship analysis

Candidate components shall be organised into timing families only when measured relationships support the grouping. The governing physical or metrological basis is fundamentals, harmonics, subharmonics, divider products, sidebands, burst repetition and correlated drift arising from one oscillator or timing chain. The examiner shall treat this basis as a testable model rather than an assumption. Nominal numerical proximity is insufficient because unrelated building systems can occupy the same spectral region. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Time-domain elaboration. The advanced technical treatment of Timing-family relationship analysis regards a clock as a family of related observables rather than a single nominal line. The fundamental, harmonics, subharmonics, divider products, modulation sidebands, burst cadence, drift, and state-dependent amplitude belong to one timing hypothesis. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. The report avoids claiming a specific oscillator merely from frequency coincidence, especially where common industry clocks or power harmonics are abundant [24-26, 81-123].

The required configuration is as follows. The analysis uses frequency estimates with uncertainty, time-aligned amplitude histories and common-source state comparisons. The primary observables are integer frequency ratios, residual error, harmonic phase where available, common start and stop events, sideband spacing and correlated thermal drift. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are independent frequency reference, changed receiver sample rate, alternate resolution bandwidth and source-absent intervals. The principal artefacts and confounders are FFT-bin coincidence, spectral leakage, aliasing, receiver spurs, mains-related combs and independent oscillators with close nominal values. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a family is reported when relationships persist across repeats and spatial measurements within uncertainty. The principal limitation is shielding and waveform shape can suppress expected family members, so absence of one harmonic is not automatically disproof. The record shall contain each component, ratio calculation, residual, uncertainty, time correlation and alternative grouping considered. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes. Where a candidate appears in section 16A.21.1, the default comparison set comprises the fundamental and the ten following harmonic orders, H2 through H11, subject to the receiver coverage, probe validation and artefact controls stated there.

7.2 32.768 kHz and nearby low-power timing candidates

The watch-crystal family shall be examined over a window that includes drift, pulling and nearby non-nominal lines such as 32.766 kHz. The governing physical or metrological basis is a 2^15 Hz quartz oscillator, divider chain or related low-power timing circuit that can couple through magnetic, electric or common-mode paths. The examiner shall treat this basis as a testable model rather than an assumption. 32.768 kHz is common and non-unique, while a device can gate its output, stop the external crystal or use an internal RC clock. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Clock and timing interpretation. For 32.768 kHz and nearby low-power timing candidates, the most detectable member of a timing family may be a harmonic or coupled sideband rather than the fundamental, particularly when the fundamental lies in a high-noise region or is poorly coupled to the available probe. Periodic bursts are analysed in both frequency and time because a stable pulse interval can reveal a clock domain even when the carrier frequency changes or the spectral line is intermittent. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The required configuration is as follows. A broad discovery channel precedes a tuned ferrite-rod confirmation channel, with harmonics and divider products included in the acquisition plan. The primary observables are measured centre frequency, drift, linewidth, duty cycle, harmonics, wake envelopes, field component and spatial gradient. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are known watch and clock inventory, independent probe, receiver blank, gain-step test and time-separated revisit. The principal artefacts and confounders are switch-mode power supplies, building controls, receiver clocks, test equipment and ordinary real-time clocks. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the line may be described as consistent with a low-power timing source only after non-unique alternatives are tested. The principal limitation is absence cannot exclude a dormant, shielded, gated or differently clocked device. The record shall contain nominal and observed frequency separately, offset in hertz and ppm, temperature, tuning centre, harmonics and tested known sources. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

The examiner shall not stop after checking 32.768 kHz. Exact and tolerance-expanded searches shall also include the supplied sub-hertz and hertz-rate outputs, the 16 kHz through 32.768 kHz low-frequency family, the 1.8432 MHz serial-clock family, the 8 MHz through 48 MHz embedded-system family, and the 100 MHz and 122.88 MHz high-rate reference families. Each candidate is tested as a possible crystal frequency, ceramic-resonator frequency, buffered clock, PLL reference, divided output, wake cadence, modulation envelope or catalogue token, according to the physics of the measured channel.

7.3 Legacy analogue-video timing candidates

The 15.734 kHz and 3.579545 MHz bands shall be treated as legacy timing hypotheses rather than as unique camera signatures. The governing physical or metrological basis is horizontal scanning and chrominance subcarrier relationships in historical 525-line analogue composite-video systems. The examiner shall treat this basis as a testable model rather than an assumption. Modern digital cameras may use unrelated clocks, and many non-camera devices can contain the same or nearby frequencies. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Oscillator-family analysis. The advanced technical treatment of Legacy analogue-video timing candidates regards a clock as a family of related observables rather than a single nominal line. The fundamental, harmonics, subharmonics, divider products, modulation sidebands, burst cadence, drift, and state-dependent amplitude belong to one timing hypothesis. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The required configuration is as follows. Both nominal components, harmonics, mathematical relationship and common temporal or spatial behaviour are measured. The primary observables are frequency ratio, simultaneous activation, correlated amplitude, harmonic structure, component polarisation and source-region overlap. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are known display and test-equipment inventory, changed antenna height, independent magnetic and higher-frequency channels, and external-bearing survey. The principal artefacts and confounders are switching converters near 15.7 kHz, crystal test sources, legacy displays, receiver images and external radio-frequency fields. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a camera-related source class is not reported unless multiple independent features and contextual evidence support that proposition. The principal limitation is even a complete legacy timing family may identify a video-related circuit without identifying its function or physical form. The record shall contain measured components, relationship calculations, spatial correspondence, known-source tests and the neutral source-class wording used. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

7.4 Switched-power and digital-clock confounders

Power converters, lighting controls and digital systems shall be treated as primary alternative explanations in every relevant band. The governing physical or metrological basis is periodic switching, pulse-width modulation, burst mode, spread spectrum and clock harmonics that create lines and combs. The examiner shall treat this basis as a testable model rather than an assumption. A stable line can come from an ordinary power function, while a variable line can still arise from a legitimate timing circuit. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Clock and timing interpretation. A technically mature analysis of Switched-power and digital-clock confounders distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Periodic bursts are analysed in both frequency and time because a stable pulse interval can reveal a clock domain even when the carrier frequency changes or the spectral line is intermittent. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The required configuration is as follows. The inventory records location, operating state, duty cycle and lawful state-change options for building and portable equipment. The primary observables are load-dependent frequency, comb spacing, start-up transient, harmonic envelope, mains synchronism and spatial association with known infrastructure. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are one-at-a-time state change, restoration, preselector change, gain-step test and comparison before and after a service entry. The principal artefacts and confounders are compound breaker changes, ground-path alteration, receiver overload and coincident time variation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a known-source attribution requires reproducible follow-the-state behaviour or equivalent independent evidence. The principal limitation is essential medical, safety or building systems may not be switched and therefore remain unresolved confounders. The record shall contain state-change authority, exact time, expected and observed effect, restoration and remaining uncertainty. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

7.5 Passive resonators, retroreflectors and remotely powered devices

The framework shall distinguish spontaneous emission from passive resonance, ambient backscatter and deliberately powered response. The governing physical or metrological basis is an incident field can be reflected, modulated, loaded or harvested by a passive or semi-passive structure without an independent free-running transmitter. The examiner shall treat this basis as a testable model rather than an assumption. A purely passive survey cannot exclude an object that emits nothing in the available ambient field. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Retroreflective-response analysis. For passive resonators, retroreflectors and remotely powered devices, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

The required configuration is as follows. Passive observations are completed and sealed before any controlled excitation plan is introduced. The primary observables are carrier-correlated sidebands, impedance or phase perturbation, reproducible response to authorised field changes and spatial localisation of the response. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are sham resonators, empty-scene trials, transmitter leakage checks, field monitor, alternate excitation frequency and independent receiver. The principal artefacts and confounders are receiver desensitisation, direct coupling, intermodulation, ordinary metal resonance and field-induced response in known electronics. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a remotely powered or backscatter classification requires a response that follows the controlled incident field under predeclared criteria. The principal limitation is the response does not reveal communications content, intended use or medical significance. The record shall contain passive closure time, excitation authority, incident field, exposure controls, response metrics, sham results and stop conditions. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 11: Signal Taxonomy and Candidate Timing Signatures.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CARRIER FREQUENCY — The frequency of an unmodulated transmitter output.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MAGNETIC FIELD — (1) The region in which the magnetic forces created by a permanent magnet or by a current-carrying conductor or coil can be detected. (2) The field that is produced when current flows through a conductor or antenna.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

T

TEST EQUIPMENT — A general term applied to devices used to test electrical and electronic circuits.

8. Governance, Roles and Competence

The inspection team shall be functionally separated so that no individual controls the commission, operates every instrument, interprets every anomaly and approves the final report. The degree of separation may be proportionate to the case, but independent technical review is mandatory for a consequential conclusion. ISO/IEC 17020:2026 emphasises competence, impartiality and consistent operation for inspection bodies, and ISO/IEC 17025 supplies the corresponding laboratory competence model [6-7].

Role	Minimum responsibility
Commissioning authority	Defines the authorised question, premises, scope, privacy limits, recipients and decision use.
Inspection manager	Controls the area, personnel, sequence, deviations, safety co-ordination and contemporaneous log.
Lead electronics examiner	Selects sensors and settings, executes the survey and records technical observations without exceeding the authorised scope.
Metrology and quality lead	Approves calibration status, check sources, uncertainty budgets, blanks, validation applicability and nonconformity handling.
Data custodian	Maintains identifiers, timestamps, hashes, access controls, backups, transfer logs and retention.
Clinical safety liaison	Protects patient care, reviews active-field plans, confirms medical-device constraints and holds stop-work authority.
Legal or privacy adviser	Reviews entry authority, data acquisition, spectrum use, communications privacy and report dissemination.
Independent reviewer	Re-examines the method, raw data, artefact exclusions, calculations, uncertainty and wording before issue.

8.1 Competence domains

- Electromagnetic field theory, near-field probing, antennas, resonators, transmission lines, shielding, grounding and EMC measurement.

Metrological interpretation. A advanced metrological approach to Competence domains treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

- Low-noise analogue design, preamplifier noise and linearity, filter theory, sampling, spectral estimation, lock-in detection and receiver overload recognition.
- Forensic scene control, contemporaneous documentation, cognitive-bias management, preservation, review and proportionate reporting.
- Metrology, calibration, measurement uncertainty, method validation, detection theory, false-alarm analysis and proficiency testing.
- Medical-device EMC, electrical safety, spectrum regulation, privacy, consent and human-subject research boundaries where relevant.

Chapter Glossary

Terms used in Chapter 12: Governance, Roles and Competence.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

E

ELECTROMAGNETIC FIELD — The combination of an electric (E) field and a magnetic (H) field.

EMC — Electromagnetic compatibility: the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to other systems.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

9. Controlled Electronic Inspection Area and Zoning

The inspected location shall be treated as a Controlled Electronic Inspection Area, abbreviated CEIA. The boundary is established before specialised instruments enter. Access is limited to recorded personnel carrying pre-characterised equipment. Paper credentials and manual logs are preferred to wireless badges. Necessary life-safety and clinical systems remain operational unless an authorised responsible engineer directs a safe state change.

Zone	**Nominal geometry**	**Purpose and principal controls**
Regional Zone R-5	Nominal 5-mile annulus, 8.04672 km or 26,400 feet.	Establish the broad-area spectral, temporal and directional inventory from lawful, safe stations. Identify high-power broadcast, cellular, fixed-link, aviation, satellite, industrial and transport sources; record terrain, altitude and occupied azimuths.
Regional Zone R-2.5	Nominal 2.5-mile annulus, 4.02336 km or 13,200 feet.	Repeat matched bands and reference channels nearer the site. Test whether strong lines, bursts and noise-like features remain regional, become site-bearing, or change through terrain and urban clutter.

Zone	Nominal geometry	Purpose and principal controls
Regional Zone R-1	Nominal 1-mile annulus, 1.609344 km or 5,280 feet.	Resolve local cellular, land-mobile, building-control, utility, transport and fixed-link populations. Add longer dwell for intermittent activity and retain simultaneous remote sentinels.
Regional Zone R-0.5	Nominal 0.5-mile annulus, 804.672 m or 2,640 feet.	Characterise neighbourhood infrastructure, adjacent premises, parking, roofline, utility and service-path contributions before the inspected premises dominates the geometry.
Regional Zone R-0.25	Nominal 0.25-mile annulus, 402.336 m or 1,320 feet.	Create the immediate site-adjacent comparison. Test access roads, fences, buried and overhead services, nearby plant, roofs and neighbouring electronics while preserving lawful standoff.

Zone	Nominal geometry	Purpose and principal controls
Zone 0. 300-foot site-transition ring	300-foot radius, or greatest documented lawful distance.	Convert the regional inventory into a controlled premises-referenced baseline. Repeat matched azimuths and heights, deploy the fixed reference channel, and test whether any candidate can be separated from the regional and neighbourhood population.
Zone 1. Outer-transition ring	150-foot radius.	Repeat the 300-foot configuration at matched azimuths, heights, axes and dwell. Determine whether a candidate begins a reproducible premises-centred trend or merely follows external bearing, time or mobile equipment.
Zone 2. Outer-comparison ring	100-foot radius.	Repeat matched 150-foot stations while the 300-foot reference remains active. Test recurrence, spatial change, vector behaviour, coherence and alternative exterior sources.
Zone 3. Intermediate comparison ring	50-foot radius.	Resolve broad lateral gradient, bearing stability, propagation-regime changes and immediate external infrastructure while maintaining low-gain discovery coverage.

Zone	**Nominal geometry**	**Purpose and principal controls**
Zone 4. Service-path discrimination ring	30-foot radius.	Use matched radial stations and short parallel or perpendicular transects to distinguish premises convergence from fences, pipes, earthing conductors, cables, buried services and other extended paths. Introduce smaller probes only through overlap controls.
Zone 5. Pre-boundary comparison ring	15-foot radius or measured wall-referenced standoff.	Acquire a stable wall-normal, wall-tangential and vertical comparison before threshold activity, door movement or personnel entry. Reserve matched stations and settings for the 12-foot ring.
Zone 6. Near-premises envelope	12-foot radius or accessible perimeter offset.	Measure walls, windows, roofline, floor boundaries, services and threshold regions without contact or state change, using the 15-foot record as the immediate comparator.
Zone 7. Threshold control	Immediate exterior and entry plane.	Acquire stationary before-entry and after-entry records. Introduce one examiner and one characterised instrument assembly at a time.

Zone	Nominal geometry	Purpose and principal controls
Zone 8. Interior coarse geometry	3-foot cells, rings or validated equivalent.	Search the full authorised volume at repeated heights and orthogonal axes. Preserve a fixed reference channel and regular blanks.
Zone 9. Fine convergence	3-inch decrements or 3-inch raster spacing from the 3-foot boundary inward.	Use progressively smaller-aperture ferrite rods, shielded loops, gradiometers and electric-field probes with transfer-factor overlap and no target contact.
Zone 10. Confirmatory hold	Smallest supported three-dimensional region.	Conduct long dwell, independent receiver and probe confirmation, null-angle mapping, height or standoff perturbation, dummy-probe controls and uncertainty evaluation.
Zone 11. Reverse path and closure	Retrace the 3-inch, 3-foot, threshold, 12-foot, 15-foot, 30-foot, 50-foot, 100-foot, 150-foot, 300-foot, 0.25-mile, 0.5-mile, 1-mile, 2.5-mile and 5-mile reference points where operationally proportionate.	Test drift, intermittent state, operator carriage and temporal confounding; hash and reconcile all records before leaving.

Distances are operational defaults, not physical laws. The preferred regional sequence is a 5-mile inventory annulus, a 2.5-mile annulus, a 1-mile annulus, a 0.5-mile annulus and a 0.25-mile site-adjacent annulus. The controlled exterior sequence then uses a 300-foot remote-reference ring, a 150-foot outer-transition ring, a 100-foot outer-comparison ring, a 50-foot intermediate ring and a 30-foot service-path discrimination ring. The near-premises sequence uses a 15-foot pre-boundary comparison, a 12-foot envelope, a threshold dwell, a 3-foot interior geometry and exact 3-inch decrements or cells. If a prescribed annulus cannot be occupied lawfully or safely, the examiner records the greatest accessible radius, the missing azimuthal sector and the resulting limitation rather than pretending that the nominal geometry was achieved.

9.1 Nested 5-mile, 2.5-mile, 1-mile, 0.5-mile, 0.25-mile, 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and 3-foot geometry

The controlled inspection area shall use nested stations that assign a distinct evidential purpose to each radius. The 5-mile through 0.25-mile annuli establish the regional transmitter and noise inventory before the team enters the premises-associated field. The 300-foot ring becomes the formal transition from regional reconnaissance to controlled site comparison. The 150-foot, 100-foot, 50-foot and 30-foot rings test persistence, bearing, infrastructure coupling and premises-centred convergence. The 15-foot and 12-foot stages preserve a stable pre-threshold and building-envelope record. The 3-foot and 3-inch stages then perform volumetric localisation. No outer annulus is evidence that a source belongs to the inspected premises, and no amplitude trend is interpreted without common-timebase reference channels, actual coordinates, antenna transfer factors, environmental logs and competing-source tests.

Advanced practitioner analysis. For expert practice, the complete five-mile-to-three-inch geometry is an interaction among propagation, instrument dynamic range, antenna physics, land access, topography, building fabric, service routes, time variation and inference. The outer annuli are deliberately broad because a high-power or intermittent emitter several miles away may dominate a receiver at one azimuth, disappear behind terrain or structure at another, and produce receiver intermodulation only after the team approaches metallic infrastructure.

Conversely, a genuine low-level site-associated signal may be invisible at the regional stations and first appear at 300 feet or closer. The method therefore asks a sequence of bounded questions rather than expecting a monotonic rise.

The required configuration is as follows. A fixed premises datum, measured probe-centre coordinates, principal azimuths and at least two heights are established where access permits. Matched station families are planned at 300, 150, 100, 50 and 30 feet. The 15-foot and 12-foot families are additionally referenced to accessible wall faces, openings and service penetrations, while the 3-foot geometry is referenced to the declared candidate sector or interior grid. The primary observables are candidate amplitude, background, directional pattern, time stability and change relative to the immediately preceding ring, with the fixed 300-foot reference retained where practicable. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series and requires an overlap measurement.

The minimum controls are matching reverse-path points, a stationary reference, actual-distance recording, terminated-input and dummy-probe observations, gain-linearity checks and at least one lateral control at each material exterior stage. The 150-foot stage must test whether the first inward change follows the premises or merely time and mobile equipment. The 30-foot stage must test whether a candidate follows a service route or extended conductor. The 15-foot stage must test whether a near-boundary change remains stable before doors, personnel or threshold systems alter the scene. The principal artefacts and confounders are partial access, traffic, utility systems, changing weather, external transmitters, nearby metal, probe detuning and time drift. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation.

The advancement or reporting rule is that movement to each inner ring occurs only after the preceding ring has supplied a documented reason for the next geometry. A candidate need not increase monotonically, because nulls, conductive paths, shielding and multipath can reverse an amplitude trend. It must, however, survive the applicable blanks and demonstrate a reproducible frequency, time, vector, phase, gradient or source-state relation that the next ring can test. A full 150-foot, 30-foot or 15-foot ring may be replaced by controlled arcs or transects when access is restricted, but the substitute geometry, omitted sectors and resulting loss of discrimination are recorded before classification.

The record shall contain nominal and actual radii, accessible sectors, coordinate uncertainty, heights, orientations, dwell, reference treatment and deviations. The conclusion remains a bounded measurement proposition, not proof of a concealed object, unlawful conduct or medical causation.

9.2 Personnel and equipment contamination control

Every person and item entering an inner zone shall be treated as a potential electromagnetic source, scatterer or capacitive load. The governing physical or metrological basis is personal electronics, medical devices, batteries, cables, ferromagnetic objects and the human body can alter sensitive measurements. The examiner shall treat this basis as a testable model rather than an assumption. Necessary medical devices are not removed merely to create a quieter scene. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced practitioner analysis. At expert-practitioner level, Personnel and equipment contamination control is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The required configuration is as follows. An equipment manifest, personal-device declaration, stand-off marks and a minimum moving sensor assembly are used. The primary observables are self-emission spectra, carriage effects, changes when personnel move, and electric-field changes with body position. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are characterisation at 300 feet, personnel substitution, remote triggering and fixed operator location. The principal artefacts and confounders are smartwatches, phones, hearing devices, key fobs, magnetic fasteners, fibre converters and digital displays. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is equipment advances only after its combined configuration has a satisfactory blank and self-emission profile. The principal limitation is some essential devices can remain unresolved contributors and must be disclosed. The record shall contain item identifier, state, owner, location, characterisation file and any restriction imposed. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

9.3 Access, scene integrity and silent movement

The area shall be controlled with forensic-scene discipline even though no crime and no physical evidence collection are presumed. The governing physical or metrological basis is repeatable access and movement preserve the electromagnetic state and the validity of spatial comparisons. The examiner shall treat this basis as a testable model rather than an assumption. The protocol does not authorise searching, opening or seizing property. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Three-dimensional search analysis. At expert-practitioner level, Access, scene integrity and silent movement is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

The required configuration is as follows. One entry point, a personnel log, passive coordinate markers, cable routes and emergency egress are established. The primary observables are time of entry, equipment state, door and lighting changes, footfall or cable movement during dwell, and environmental disturbances.

Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are remote acquisition, stationary dwell, one assembly moved at a time and contemporaneous deviation logging. The principal artefacts and confounders are door contacts, automatic lighting, lift cycles, HVAC changes, acoustic alarms and movement-induced microphonics. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a disturbed acquisition is marked and repeated after the validated settling interval. The principal limitation is clinical care and life safety override scene quieting. The record shall contain access events, movement sequence, disturbances, repeats and restoration of the ordinary state. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

9.4 Partial rings, inaccessible sectors and adaptive geometry

When complete circles cannot be measured, the method shall preserve comparability through declared substitute geometry. The governing physical or metrological basis is arcs, chords, radial transects and orthogonal perimeters can still test spatial propositions when their limitations are explicit. The examiner shall treat this basis as a testable model rather than an assumption. Unmeasured space cannot be represented as negative evidence. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Spatial-measurement interpretation. The mature treatment of Partial rings, inaccessible sectors and adaptive geometry replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

The required configuration is as follows. Substitute points are selected before candidate interpretation where practicable and referenced to the same datum. The primary observables are lateral symmetry, inward trend, bearing consistency and difference between accessible sectors. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are repeat of boundary points, stationary reference and comparison with an external low-response point. The principal artefacts and confounders are one-sided approach bias, external sources aligned with the transect and interpolation across walls or private property. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the search can advance when the available geometry still distinguishes a material hypothesis, otherwise the limitation governs the conclusion. The principal limitation is source direction can remain ambiguous when only one side of a premises is accessible. The record shall contain reason for missing sectors, substitute geometry, unexamined volume and reduced inference. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 13: Controlled Electronic Inspection Area and Zoning.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BEARING — An angular direction from a defined reference meridian or axis to a source, target, or line of sight.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

10. Instrumentation and Receiver Architecture

10.1 Functional chain

SENSOR -> INPUT PROTECTION -> PRESELECTION -> LOW-NOISE GAIN -> CALIBRATED RECEIVER -> FIBRE LINK -> REMOTE RECORDER

The following integration extends 10. Instrumentation and Receiver Architecture with measurement-system metrology for spectrum and emission surveys. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Measurement-System Metrology for Spectrum and Emission Surveys

The measurement problem for Ambient and site qualification begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records ambient spectra by antenna orientation and position, temporal occupancy, field gradients, known transmitter schedules, and shielded-room residuals. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A defensible procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are intermittent external signals, building resonances, common utility conductors, moving vehicles, and time-varying industrial noise.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result should be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to ambient and site qualification within measurement-system metrology for spectrum and emission surveys, with the local volume retaining ownership of the final inference.

Validation of Traceability and measurement records requires a control structure proportionate to the consequence of the claim. The minimum credible suite includes machine-readable configuration capture, immutable raw data, signed calibration files, peer review, and a reproducible calculation workbook. These controls test different parts of the inference: some verify the instrument, some challenge the proposed mechanism, and some test whether the observation recurs under changed geometry, state, or examiner. Validation must be prospective wherever possible, with acceptance criteria defined before the result is known. Negative and null results belong in the evidence package because they delimit the conditions under which the effect appears. When the source is a historical report, commercial datasheet, or public-release standard, validation also includes checking edition, page image, units, and current applicability.

A conclusion that survives independent methods and adversarial controls is stronger than one supported by repeated measurements from the same chain, because repeated use of one chain can reproduce the same hidden bias. In this placement, that control is applied specifically to traceability and measurement records within measurement-system metrology for spectrum and emission surveys, with the local volume retaining ownership of the final inference.

This integrated treatment returns the discussion to Instrumentation and Receiver Architecture with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

The chain shall be modular so that sensitivity can be increased without concealing overload or intermodulation. The first amplifier is not automatically used. Strong ambient broadcast, mains or digital signals can drive a low-noise amplifier into compression and manufacture false spectral lines. Each gain state requires a documented noise figure, input-referred noise, 1 dB compression point, third-order intercept, passband flatness and bypass path. A preselector or band-pass filter should precede high gain where the environment is strong.

Band or function	**Preferred sensors and methods**	**Essential controls**
DC to 100 kHz	Tri-axial induction coils, shielded loops, flux-density sensors where bandwidth permits, and high-impedance electric-field plates or probes.	Low-noise battery supply, cable-motion control, 50/60 Hz dynamic range, orientation record and IEC 61786-informed calibration where exposure quantities are reported [15-16].
9 kHz to 30 MHz	Shielded magnetic loops, active electric-field probes, tuned loops, high-dynamic-range EMI receiver and coherent or lock-in analysis.	Receiver conforming, where applicable, to CISPR 16-1-1 characteristics; antenna factor and site effects documented [10, 12-13].
30 MHz to 1 GHz	Biconical, log-periodic, dipole, loop and calibrated near-field probes.	Preselection against broadcast and mobile signals, polarisation control and multipath testing.
1 to 18 GHz	Log-periodic or horn antennas, calibrated broadband probes and miniature near-field E or H probes.	Cable loss, connector repeatability, antenna pattern, body shadowing and receiver phase noise.
Above 18 GHz, optional	Waveguide or horn assemblies and band-specific receiver modules.	Use only after demonstrated need and separate validation. Small movement and material absorption can dominate.

Band or function	Preferred sensors and methods	Essential controls
Timing and synchronisation	Low-phase-noise OCXO or rubidium reference outside the CEIA, distributed over fibre or a characterised low-emission link.	Reference accuracy, holdover, timestamp traceability and self-emission survey.
Data acquisition	Raw I/Q when lawful and necessary, spectrum traces, zero-span time series, detector outputs, event triggers and environmental channels.	Sampling theorem, anti-alias filtering, clock coherence, file format, hash, metadata and privacy controls.
Position and orientation	Non-conductive tripod, engraved or low-emission distance scale, mechanical angle index and alphanumeric grid markers.	No wireless positioning beacon. Record probe centre, axis, height, standoff and uncertainty.
Approximately 250 MHz to 350 MHz response survey	Calibrated VHF/UHF antenna, shielded near-field loop where appropriate, high-linearity preselector and synchronised pulse recorder.	Strong rejection of the authorised illumination band, two-receiver confirmation, external-service inventory, intermodulation prediction and frequency-offset control.
.9 GHz to 2.3 GHz controlled illumination	Authority-limited signal source, calibrated directional antenna, directional coupler, field monitor and independent response receiver.	Minimum-field progression, harmonic filter, human-exposure and medical-device review, direct-breakthrough test, sham cycle and separately disciplined receive clock.
Approximately 3.2 GHz and 5.7 GHz controlled illumination	Characterised microwave source and antenna appropriate to the specific authorised band and geometry, with calibrated power monitoring.	Near-field boundary calculation, cable and connector leakage survey, polarisation and angle controls, source-off repeat, frequency-offset repeat and post-test passive survey.

10.2 Discovery and confirmation channels

At least three separate, simultaneously sampled and synchronised RF channels are mandatory for an evidential vector measurement. A single channel can record a one-axis observation. Two channels can support a differential comparison, but they cannot resolve a complete three-component field. The minimum admissible arrangement is therefore one X-Y-Z triad whose sample clocks, local-oscillator references, triggers and timestamps share one timebase. The normative arrangement is three spatial pods, each containing X, Y and Z probes, for nine concurrent pathways. Discovery and confirmation are implemented as parallel analysis functions within each pathway, while a terminated, dummy or guard channel remains available to expose receiver-generated spurs, cable microphonics and digital contamination. Sequential RF switching is permitted for preliminary reconnaissance only and is not represented as simultaneous acquisition.

Synchronous measurement elaboration. In discovery and confirmation channels, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot [7-16].

10.3 Specialised Low-Frequency Timing Channel

For 32.768 kHz work, the preferred architecture is a shielded or balanced magnetic search coil with known transfer impedance, followed by a low-current-noise preamplifier, a band-limiting preselector, an anti-alias filter and a coherent digital detector referenced to a stable clock. The analysis should search the nominal frequency with a tolerance window, its harmonics, possible 1 Hz division products, periodic wake envelopes and frequency pulling. The probe shall be rotated through three orthogonal axes because a small loop can produce a sharp null even when the source is nearby.

Multichannel receiver analysis. In specialised low-frequency timing channel, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. The calibration record includes clock distribution, trigger topology, channel skew, aperture jitter, local-oscillator phase noise, amplitude flatness, group delay, mutual coupling, cross-channel leakage, and the stability of correction coefficients. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot [7-16].

10.4 Broadband Air-Core Magnetic Loops

Air-core loops shall provide a comparatively simple magnetic discovery and confirmation path without ferrite hysteresis or permeability variation. The governing physical or metrological basis is Faraday induction proportional to loop turns, effective area, frequency and incident magnetic flux. The examiner shall treat this basis as a testable model rather than an assumption. An air-core loop can have lower sensitivity than a resonant ferrite rod and can still pick up electric fields through capacitance. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Sensor and front-end elaboration. At advanced-practitioner level, Broadband air-core magnetic loops are specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

The required configuration is as follows. Several loop sizes, balanced winding, electrostatic shield with a deliberate gap, non-conductive support and a low-noise differential input are provided. The primary observables are induced voltage, angular null, frequency response, cable common mode and comparison between loop sizes. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are loop reversal, shield-ground change under validation, dummy loop, terminated input and known-field calibration. The principal artefacts and confounders are closed shield turns, cable pickup, preamplifier input current noise, nearby metal and mechanical motion. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule as the loop confirms an environmental magnetic component when its response follows calibrated orientation and spatial behaviour. The principal limitation is effective aperture can average over a region larger than the final localisation interval. The record shall contain turns, dimensions, shield gap, transfer factor, axis, cable and calibration uncertainty. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.5 Long ferrite-rod antenna for low-frequency discovery

A long ferrite-rod probe shall improve directional low-frequency sensitivity while remaining mechanically and electrically characterised. The governing physical or metrological basis is high-permeability material concentrates magnetic flux through a multi-turn copper winding, increasing induced voltage relative to physical area. The examiner shall treat this basis as a testable model rather than an assumption. Apparent rod permeability depends on geometry, and more turns can reduce self-resonant frequency and increase noise. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Sensor and front-end elaboration. The technically mature interpretation of Long ferrite-rod antenna for low-frequency discovery treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

The required configuration is as follows. A slender MnZn candidate rod, sectioned fine-wire or litz winding, insulating former, split electrostatic shield and quiet preamplifier are assembled as one configuration. The primary observables are inductance, resistance, self-resonance, Q, transfer factor, axial pattern, null depth, temperature drift and microphonics. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

Every dedicated tuned version of the long rod shall contain a serialised, switchable high-reverse-voltage-rated varactor branch. The branch is electrically parallel, series or divider-coupled to the fixed bank and sapphire piston according to the measured tank impedance. It is a fine-control element only. The fixed bank supplies coarse capacitance, the piston establishes the mechanically stable calibration centre, and the varactor corrects the small residual required to maintain that centre. A 30 V or 60 V (potentially up to 360 volts) class device may be selected when its capacitance range, quality factor, leakage, package parasitics and temperature behaviour are suitable, but the operational reverse bias remains the minimum quiet value required and stays well below the rated breakdown. The high rating provides headroom and linearity. It is not authority to place hazardous voltage on the probe [124-126].

The X-axis rod is the reference channel for resonance stabilisation and transfer-factor comparison. A calibration winding or shielded substitution source measures the phase and amplitude error from the declared set point. The controller acquires lock, stores the required bias and then enters hold. No digital correction, switching converter, pulse-width-modulated bias source or search-signal-following feedback operates during the evidential record. If the bias must change beyond the predeclared tolerance, the current comparison series closes, a new configuration suffix is issued and the affected ring or cube points are repeated. Y-axis and Z-axis rods are separately calibrated and are not numerically forced to imitate the X-axis response.

The minimum controls are alternate-core rod, air-core loop, impact check, reversed rotation and known-field transfer test. The principal artefacts and confounders are core cracks, stress, conductive end caps, winding motion, parasitic capacitance and magnetic fasteners. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

Varactor-specific controls include hard bypass, fixed-capacitance substitution, two bias points that bracket the operating point, zero-bias leakage review, anti-series-pair comparison where used, bias-line termination, calibration-pilot-off confirmation, temperature excursion, and a two-tone or strong-field intermodulation challenge. A candidate that changes with varactor bias but not with probe position is treated first as a tuning-network or receiver artefact.

The advancement or reporting rule is the rod is released for casework only within the validated frequency, field and temperature range. The principal limitation is large physical aperture can produce excellent detection but broad localisation. The record shall contain core material and lot, dimensions, turns by section, wire, L, R, self-resonance, Q and calibration. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

The phrase ferrite-rod probe does not prevent the use of a qualified magnetic-alloy element as a segmented return path, open flux concentrator, differential core or alternate receiving core. Appendix F.3 defines the controlling permeability terminology, the frequency-dependent loss analysis, the demagnetising correction, the conductive skin-depth limits and the comparative qualification of sixteen alloy families. A material substitution is never a minor maintenance action. It creates a new probe configuration because the alloy chemistry, anneal, ribbon or lamination thickness, powder permeability grade, gap, mechanical clamping and magnetic conditioning can alter sensitivity, phase, self-noise, saturation, null depth and bandwidth.

10.6 Short ferrite rods and miniature near-field loops

Small-aperture probes shall be used during the 3-foot and 3-inch stages to improve spatial resolution after a candidate has been confirmed. The governing physical or metrological basis is reduced sensing volume and stronger response to local gradients at the cost of lower induced signal. The examiner shall treat this basis as a testable model rather than an assumption. Smaller physical size does not guarantee better location if noise or cross-axis response dominates. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Sensor and front-end elaboration. For short ferrite rods, small close field probes, and miniature near-field loops, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

The required configuration is as follows. Short rods, shielded loops and orthogonal pairs are calibrated with the intended preamplifier and non-contact spacer. The primary observables are local gradient, null angle, differential response, response versus standoff and agreement with the larger probe. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are overlap points with the long rod, fixed reference channel, probe substitution and axis reversal. The principal artefacts and confounders are hand proximity, surface capacitance, cable motion, metal edges and loss of sensitivity causing noise maxima. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is aperture reduction is accepted when both probes track the same candidate family through an overlap set. The principal limitation is the smaller probe may fail to detect an intermittent or deeply shielded source that the larger probe detects. The record shall contain aperture, transfer factor, overlap coordinates, response ratio and resolution floor. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.7 Sectioned copper winding and litz-wire selection

The high-turn, sectioned copper winding shall be engineered to maximise validated signal-to-noise ratio rather than turn count alone. The governing physical or metrological basis is turns increase induced voltage and inductance while resistance, proximity effect, distributed capacitance and mechanical susceptibility also increase. The examiner shall treat this basis as a testable model rather than an assumption. A randomly wound high-turn coil can self-resonate near the target and become a poorly understood distributed network. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Probe-engineering analysis. The technically mature interpretation of sectioned copper winding and litz-wire selection treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure.

The required configuration is as follows. Turns are divided into reproducible sections with controlled pitch, insulation, winding sense, inter-section spacing and low-capacitance interconnections. The primary observables are DC resistance, complex impedance, self-resonant modes, Q, thermal coefficient, noise and field transfer factor. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are comparison of winding prototypes, four-wire resistance, impedance at several drive levels and mechanical disturbance tests in the laboratory. The principal artefacts and confounders are strand breakage, uneven tension, dielectric absorption, triboelectric cable effects and capacitive coupling between sections. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the chosen winding is the design that meets sensitivity, bandwidth, settling and reproducibility criteria together. The principal limitation is manufacturing variation can be substantial in very high-turn hand-wound assemblies. The record shall contain wire specification, total length, turns, sections, winding process, resistance, impedance sweep and acceptance values. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.8 Fixed capacitor bank and sapphire piston fine tuning

Resonance shall be established by a measured fixed capacitance network and finely adjusted by a variable sapphire-dielectric piston capacitor. The governing physical or metrological basis is the LC resonance f0 = 1 divided by 2 pi square-root of L times C, with total capacitance including all parasitic contributions. The examiner shall treat this basis as a testable model rather than an assumption. A sapphire trimmer commonly offers a limited picofarad range and is not assumed to provide the entire capacitance required at low frequency. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Resonant receiving-system perspective. The technically mature interpretation of Fixed capacitor bank and sapphire piston fine tuning treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

The required configuration is as follows. Low-loss fixed capacitors place the network near target, while a mechanically locked non-magnetic piston supplies fine adjustment after final assembly. The primary observables are centre frequency, bandwidth, Q, phase crossing, tuning sensitivity, backlash and temperature shift. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

10.8.1 Hybrid sapphire-piston and high-reverse-voltage varactor tuning

The released tuned-rod architecture contains three capacitance functions. A low-loss fixed bank provides the bulk value. The sapphire piston provides mechanically traceable fine calibration. A high-reverse-voltage-rated varactor branch supplies electronic trim over a deliberately restricted range. The varactor branch shall normally account for only the residual adjustment needed after the fixed bank and piston are set. This design states the total tank capacitance, the varactor contribution at minimum, nominal and maximum bias, and the resulting centre-frequency span.

Probe-engineering analysis. The technically mature interpretation of hybrid sapphire-piston and high-reverse-voltage varactor tuning treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

A matched anti-series pair is preferred when the induced tank voltage, calibration pilot or nearby strong field could drive one junction through a materially different portion of its capacitance-voltage curve. The bias feed uses a battery-derived or otherwise low-noise analogue source, a high-isolation feedthrough, a validated low-pass network and a physical layout that prevents the control lead from becoming a second antenna. A switching regulator, digital potentiometer, serial bus or continuously clocked digital-to-analogue converter is not placed in the probe head unless its emissions and intermodulation products have been shown to remain below the declared detection threshold.

X-axis stabilisation is a metrological reference function. Before a station series begins, the X-axis rod is placed in the calibration fixture or exposed to the internal calibration winding, the phase or amplitude error is minimised, and the bias value is stored. The calibration stimulus is then removed, the bias is held, and a blank is acquired. The same held bias remains in force through the matched spatial comparison. The term resonant transfer optimisation means maintaining the peak calibrated transfer factor of the passive resonator. It does not mean that the varactor generates energy or replaces the ultra-low-noise preamplifier.

Release records include diode manufacturer and part number, lot, rated reverse voltage, capacitance-voltage data, leakage, quality factor or series resistance, package capacitance, pair matching, bias range, bias-source noise, tuning range, centre frequency, loaded Q, settling, temperature coefficient, X-axis lock error, hold drift, bypass result and intermodulation result. Manufacturer data are screening inputs. The final probe is qualified as an assembled system.

Table 10-A. Hybrid tuning and X-axis stabilisation controls

Function	Hardware or state	Mandatory control	Required record
Coarse resonance	Measured low-loss fixed capacitor bank	Independent capacitance measurement and temperature check	Selected values, tolerance, dielectric, temperature coefficient
Mechanical fine calibration	Locked sapphire piston capacitor	Approach from both directions; backlash and tool-removal blank	Mechanical index, measured capacitance, lock condition
Electronic fine trim	High-reverse-voltage varactor or matched anti-series pair	Hard bypass and fixed-capacitance substitution	Part, lot, C-V curve, leakage, bias, tuning span
X-axis reference lock	Calibration winding or shielded substitution field	Pilot-off blank and independent frequency measurement	Set point, phase error, transfer factor, lock time
Evidence hold	Quiet held bias, no active correction	Bias monitor and no-clock confirmation	Held voltage, drift, temperature, start and stop time
Artefact rejection	Two-tone, strong-field and bias-line tests	Alternate bias, terminated bias lead and independent receiver	Intermodulation map, spurs, overload and disposition

The minimum controls are approach from both tuning directions, tool-removed verification, closed-housing verification, reference-source check and post-transport check. The principal artefacts and confounders are tool capacitance, body capacitance, lock-induced stress, minimum trimmer capacitance and amplifier input capacitance. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a tuning state is released only when its complete transfer function and blank are recorded. The principal limitation is retuning changes sensitivity and therefore breaks direct amplitude comparability with prior series. The record shall contain measured L, fixed capacitances, trimmer model and setting, total estimated C, f0, Q, temperature and calibration file. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.9 Flux concentrator ring and gapped magnetic return path

A concentrator ring or yoke may be incorporated only when its magnetic function and electrical isolation are explicit and validated. The governing physical or metrological basis is a high-permeability path can redirect or concentrate flux, support rear rejection or create a differential magnetic circuit. The examiner shall treat this basis as a testable model rather than an assumption. A continuous conductive alloy ring can behave as a shorted turn, add eddy-current loss and suppress the desired field. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Resonant receiving-system perspective. At advanced-practitioner level, flux concentrator ring and gapped magnetic return path is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The required configuration is as follows. The preferred element is split, gapped, laminated, tape-wound with insulation, or ferrite, and is mechanically separated from the primary winding. The primary observables are change in transfer factor, pattern, null angle, Q, phase, saturation behaviour, hysteresis and cross-axis response. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are probe tests with and without the concentrator, reversed gap orientation, electric and magnetic fixtures, and multi-level field excitation. The principal artefacts and confounders are closed conductive paths, mounting stress, magnetic remanence, coupling to steel structures and unmodelled secondary resonance. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the concentrator is retained only if it improves a validated performance quantity without unacceptable distortion or loss. The principal limitation is a laboratory gain can become a field-site bias near ferromagnetic building material. The record shall contain material, geometry, gap, insulation, placement, magnetic and electrical continuity, and comparative calibration. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.10 Electrostatic shielding of magnetic probes

Electrostatic shielding shall reduce capacitive pickup while preserving the magnetic aperture and avoiding a closed turn. The governing physical or metrological basis is a grounded conductive screen intercepts electric displacement current, while a deliberate longitudinal or circumferential gap prevents circulating current. The examiner shall treat this basis as a testable model rather than an assumption. An unbroken foil, braid or housing ring can damp resonance and rotate the magnetic pattern. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Probe-engineering analysis. At expert-practitioner level, Electrostatic shielding of magnetic probes is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The required configuration is as follows. The shield has a documented gap, overlap, single grounding point, spacing from the winding and connection to the analogue reference. The primary observables are electric-field rejection, magnetic transfer factor, shield current, Q, noise, null depth and cable dependence. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are electric-field fixture, magnetic-field fixture, continuity and impedance tests, alternate ground point during validation and cable-connected calibration. The principal artefacts and confounders are screws bridging the gap, conductive adhesive, cable braid bypass, floating charge and ground-loop current. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the shield is accepted only if electric response falls without material loss of magnetic performance. The principal limitation is shield effectiveness depends on complete assembly and nearby structures. The record shall contain material, gap dimensions, grounding, measured rejection and magnetic response before and after shielding. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.11 Ultra-low-noise preamplifier and input matching

The first gain stage shall preserve the weak probe signal without manufacturing candidate-band components or overloading on ordinary fields. The governing physical or metrological basis is combined amplifier voltage noise, current noise through source impedance, winding noise, dielectric loss and environmental interference. The examiner shall treat this basis as a testable model rather than an assumption. The amplifier with the lowest advertised voltage noise may perform poorly with a high-impedance resonant source. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Resonant receiving-system perspective. At advanced-practitioner level, Ultra-low-noise preamplifier and input matching is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The required configuration is as follows. A battery-powered analogue front end with appropriate voltage, transimpedance or differential topology, linear regulation and minimal digital circuitry is used. The primary observables are input-referred noise, gain, phase, impedance loading, dynamic range, overload recovery, intermodulation and temperature drift. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are terminated input, resistor and actual-probe noise tests, gain step, bypass, two-tone test and strong out-of-band exposure. The principal artefacts and confounders are chopper ripple, switching regulators, protection-diode mixing, relay fields, microcontroller clocks and low-battery oscillation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the front end is fit only when it remains linear and quieter than the expected environmental floor in the validated band. The principal limitation is laboratory noise performance can be overwhelmed by cable and site interference. The record shall contain schematic revision, device lot, gain states, input network, noise curves, linearity and self-emission library. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.12 Analogue preselection and high-selectivity filtering

Narrow filters shall improve selectivity only after adequate analogue preselection protects the receiver from strong out-of-band energy. The governing physical or metrological basis is band-limiting reduces equivalent noise bandwidth and prevents large signals from reaching non-linear stages or aliasing into the analysis band. The examiner shall treat this basis as a testable model rather than an assumption. A digital filter with an extremely narrow transition band cannot undo analogue overload or intermodulation created before sampling. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Probe-engineering analysis. For analogue preselection and high-selectivity filtering, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

The required configuration is as follows. Switchable low-pass, high-pass and band-pass networks are paired with known gain and phase response, followed by coherent digital filtering when needed. The primary observables are passband, stopband, insertion loss, phase, ringing, equivalent noise bandwidth, overload margin and candidate response. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are filter bypass, alternate preselector, injected tone sweep, gain-step test and different sample rate. The principal artefacts and confounders are filter ringing, component microphonics, relay coupling, aliased parent signals and software window leakage. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a component is confirmed only when it remains at the same physical frequency under valid filter and sampling changes. The principal limitation is very narrow filtering can conceal modulation, drift and neighbouring family components. The record shall contain filter identity, measured response, bandwidth, settling, detector and raw wideband companion data. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.13 Coherent reference clocks and frequency metrology

Frequency and phase claims shall be supported by a characterised reference clock independent of the candidate source. The governing physical or metrological basis is sample timing error maps directly into frequency error and can create apparent drift or harmonic residuals. The examiner shall treat this basis as a testable model rather than an assumption. A disciplined reference can itself radiate candidate-like lines and must be physically and electrically isolated. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Synchronous measurement elaboration. The advanced technical treatment of Coherent reference clocks and frequency metrology regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

The required configuration is as follows. A calibrated reference remains at the remote station, distributes timing by characterised fibre or records a simultaneous reference channel. The primary observables are clock offset, stability, phase noise, synchronisation state, time uncertainty and candidate frequency residual. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are reference comparison before and after deployment, independent oscillator check, terminated-input clock spur survey and changed digitiser. The principal artefacts and confounders are reference leakage, GPS receiver electronics, fibre-converter clocks, shared-clock correlation and timestamp discontinuity. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is frequency relationships are reported only to precision supported by reference and estimator uncertainty. The principal limitation is phase localisation can fail if channels are not synchronised or if the source is intermittent. The record shall contain reference type, calibration, distribution, stability, clock-spur map and time-alignment method. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.13A Coherent common-chassis analyser, nine-probe vector array and frequency-slaved tuning

The preferred EERF receiver is not a conventional single-input swept spectrum analyser followed by an RF switch. It is a simultaneous-sampling search receiver and spectrum-analysis system in which multiple front ends, downconverters or digitiser channels operate from one metrological state. The architecture is required because a weak source may change during a switch interval, a burst may exist for only a few seconds, a retroreflective response may begin after an uncertain latency, and a coherent field cannot be reconstructed from measurements made at different times. A switched instrument remains useful for low-risk reconnaissance, but its results are labelled sequential and cannot be used to claim phase, vector direction, common onset or propagation delay.

Sensor and front-end elaboration. The technically mature interpretation of Coherent common-chassis analyser, nine-probe vector array and frequency-slaved tuning treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The common chassis may be PXI Express, AXIe, VXI, a manufacturer-integrated real-time receiver, or an equivalent modular platform. Expansion cards may be original equipment, manufacturer-supported, or independently qualified aftermarket modules. Every card is treated as part of one instrument configuration. The chassis backplane distributes the master reference, sample clock, trigger, deterministic control messages and event identifiers. Unsupported modifications that compromise electrical safety, electromagnetic compatibility, calibration integrity or firmware control are prohibited. Within EERF that statement is a configuration claim, not a universal performance claim, and it requires retained calibration, channel-coherence and field-trial records before it is described as validated for the declared field use in a report.

10.13A.1 Mandatory channel hierarchy

Three channels are the minimum. They form one physical X-Y-Z triad and establish the lowest-order vector record. Nine channels are the normal field baseline. They form three pods, identified A, B and C, at surveyed coordinates, with X, Y and Z sensing axes in each pod. Twelve channels are the preferred chassis minimum because the nine probe paths leave three channels for source reference, artefact control and independent confirmation. Additional channels may record a second band, a second illumination monitor, a conducted current probe, a field-strength standard, or a second receive architecture.

Coherent-array interpretation. The advanced technical treatment of Mandatory channel hierarchy regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. The calibration record includes clock distribution, trigger topology, channel skew, aperture jitter, local-oscillator phase noise, amplitude flatness, group delay, mutual coupling, cross-channel leakage, and the stability of correction coefficients. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone .

The channel count refers to simultaneously sampled RF pathways, not merely to connectors on a front panel. Every active path must have an independent analogue input and an independently addressable digital record. Multiplexing nine probes through one or two analogue chains does not satisfy the requirement. Digital channelisation of a sufficiently wide and simultaneously sampled input may satisfy the requirement only when the nine probes remain physically independent, each input is acquired at the same time, and the channeliser group delay, dynamic range and interchannel isolation have been validated.

Channel allocation	**Normal assignment**	**Required evidential function**
1-3	Pod A, X, Y and Z	Local three-axis vector at surveyed pod A.
4-6	Pod B, X, Y and Z	Second spatial vector for gradient, direction and coherence comparison.
7-9	Pod C, X, Y and Z	Third spatial vector for localisation, extended-source testing and closure.
10	Illumination or interrogation reference	Measured source presence, waveform, level, trigger epoch and direct-leakage reference.
11	Terminated, dummy or calibration path	Receiver spur, bias-line, cable, calibration-pilot and common-chassis artefact control.
12	Guard, narrowband tracking or independent reference	High-selectivity confirmation, secondary LO plan, conducted-path monitor or safety channel.
13 and above	Optional expansion	Parallel bands, additional pods, redundant receiver architecture or environmental controls.

Table 10-C. Preferred 12-channel allocation for the three-pod nine-probe field array.

10.13A.2 Pod geometry, axes and reference centres

Each pod is a mechanically rigid and electrically quiet assembly whose nominally orthogonal axes are established by metrology rather than by visual inspection. The X, Y and Z axes are defined in the room coordinate frame, and the pod position is recorded to the electromagnetic sensing centre of each head. Large low-frequency bars may not intersect at one physical point. In that case the pod has a surveyed virtual centre, and the offset vector from that centre to each probe aperture is included in the localisation model. Pod spacing is selected for the expected field region, wavelength, source extent, room geometry and probe aperture. It is not chosen solely for visual symmetry.

Advanced technical elaboration. For expert practice, Pod geometry, axes and reference centres is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions.

The three pods permit two distinct comparisons. Within each pod, the X-Y-Z triad measures orientation and null structure. Between pods, matched axes measure spatial gradient, coherence, phase where validated, and whether the field follows a point-like source, an extended conductor or a broad environmental background. Mutual coupling between heads and pods is measured with all possible combinations of active, bypassed, terminated and disconnected states. A pod that materially perturbs another pod is moved, reconfigured or entered into a coupling-correction model whose residual uncertainty is demonstrated.

10.13A.3 Shared frequency reference, sample clock, trigger and epoch

All channels share one site master timebase. The minimum distributed state is a frequency reference, an ADC or digitiser sample clock or a deterministic clock relationship, a common trigger, and a time-of-day or run epoch. A 10 MHz reference and 1 PPS epoch are common engineering choices, but the protocol does not require those particular values. What is required is traceable frequency, measured phase noise, known lock status, characterised distribution delay and a retained record of every unlock, relock or holdover interval.

Multichannel receiver analysis. The purpose of shared frequency reference, sample clock, trigger and epoch is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition. A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot.

For phase-bearing measurements, interchannel timing skew is converted into phase uncertainty. If the maximum permitted phase error is phi_max degrees at frequency f_max hertz, the corresponding skew limit is |delta t| <= phi_max / (360 f_max). At 700 MHz, a 10 degree phase budget corresponds to approximately 39.7 ps. At 30 MHz, the same budget corresponds to approximately 926 ps. These values illustrate why phase claims require calibrated common-clock hardware and cannot be inferred from independent USB instruments merely because their computer timestamps appear similar.

Each channel receives an amplitude, phase and group-delay calibration across its authorised band. The correction is represented as a complex transfer function

$H_i(f)$, together with uncertainty and the date, temperature, gain state, cable and preselector configuration. A correction derived for one gain state or cable is not silently reused for another. If several common-chassis analysers are needed for incompatible band physics, they are all disciplined to the site master and cross-calibrated with a shared test signal and event trigger before their data are fused.

10.13A.4 Frequency-abscissa-to-varactor Slave Control

The horizontal frequency coordinate of the analyser is the command source for resonant tuning. It shall not be confused with the physical X-oriented antenna in a pod. At frequency command f_k, the controller evaluates an individually calibrated bias law $V_i = F_i(f_k, T_i, \text{configuration}_i)$ for every tuned channel i. The total resonating capacitance is $C_{total,i} = C_{fixed,i} + C_{piston,i} + C_{var,i}(V_i) + C_{stray,i}$, and the nominal resonance is $f_{0,i} = 1 / [2 \pi \sqrt{L_i C_{total,i}}]$. Here L_i is the measured winding inductance, $C_{var,i}$ is the varactor capacitance at the applied reverse bias, and $C_{stray,i}$ includes measured fixture, shield, cable and device capacitance.

Sensor and front-end elaboration. The technically mature interpretation of frequency-abscissa-to-varactor slave control treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

One common bias voltage is not applied blindly to nine probes. Component tolerance, magnetic permeability, winding capacitance, cable loading, temperature and pod construction make the required voltage channel-specific. The analyser distributes the same frequency command, while each channel controller produces its own validated quiet bias. The physical X-axis probe may serve as the lock-reference channel for a pod, but the Y and Z probes retain independent bias laws and independent lock flags. The system records both meanings of X explicitly as frequency abscissa and spatial axis. It bares mention that the X-Axis tuning voltage is used to feed the varactor, through appropriate amplification, so that as the X-Axis is measured the antenna is more or less tuned via the X-Axis tuning voltage. It is not a function of actual “tuning” the antenna, but rather the changes in voltage tethers the antenna to the receiver or analyzer. The analyzer slightly lags the X-Axis tuning voltage so that the antenna varactor is a slave to the analyzer and not the inverse.

Switching logic, tuning-voltage generation, control DACs, state logging and digital signal handling remain within the primary analyser chassis or a shielded chassis extension whose timing and power are derived from it. The first low-noise transistor or transformer may remain at the probe head when cable capacitance, triboelectric noise or source impedance makes a remote first stage necessary. Such a front end is still part of the mother system. It contains no free-running digital clock, switch-mode converter or unlogged automatic gain process, and its power and state are controlled from the chassis.

10.13A.5 Resonance-qualified Measurement Transaction

Every frequency point or fixed-span capture follows a state transaction. The analyser issues the frequency command. The channel controllers set their biases. The tanks settle. A shielded calibration winding, directional bridge or internal reflectometric check verifies the resonance and transfer state. The calibration stimulus is then removed or blanked. Bias enters hold. All RF channels acquire simultaneously. Finally, channel health, lock, overload, clipping, clock, temperature and state hashes are written with the waveform. The waveform is not admitted merely because the analyser display showed a peak.

Advanced physical analysis. In Resonance-qualified measurement transaction, the observable is not a free-standing property of the suspected circuit. It is the solution of a boundary-value problem involving source geometry, wavelength, material properties, apertures, conductors, nearby structures, and the receiving probe. At electrically small dimensions, terms proportional to 1/r cubed and 1/r squared may dominate over the radiating 1/r term, so amplitude-distance behaviour cannot be interpreted through free-space path loss alone. The section is technically complete only when the relevant field regime and the limits of the adopted approximation are stated.

State	Required action	Validity rule
1. Command	Broadcast common frequency, span, bandwidth, gain and event identifier.	No evidential samples.
2. Tune	Apply channel-specific varactor biases and any authorised switch state.	No evidential samples while bias is moving.
3. Settle	Wait validated electrical, magnetic, thermal and filter settling intervals.	Timer and channel health must pass.
4. Verify	Use a quiet pilot, bridge or substitution check to verify resonance and transfer.	Pilot response within validated tolerance.
5. Blank and hold	Remove pilot, freeze bias, disable unnecessary control traffic.	Bias and lock remain stable.
6. Acquire	Sample all active channels from the same trigger and sample epoch.	No overload, clipping, unlock or missing channel.
7. Close	Record checksums, state, calibration identifiers and any invalidation event.	Only resonance-qualified blocks enter comparison.

Table 10-D. Resonance-qualified simultaneous measurement transaction.

10.13A.6 Per-input high-selectivity tracking receiver

Every spectrum-analysis input is accompanied by a high-sensitivity tracking-receiver function. It may be a physically separate narrowband receiver, a second digital downconverter, or a validated software channel derived from the same simultaneous ADC stream. The tracking receiver follows the selected centre frequency, uses a narrower IF or digital noise bandwidth, and may apply coherent integration or matched filtering to a predeclared signal family. Its purpose is to increase selectivity and reduce integrated noise. It does not create signal energy and is not described as improving intrinsic antenna gain.

Coherent-array interpretation. In per-input high-selectivity tracking receiver, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. The calibration record includes clock distribution, trigger topology, channel skew, aperture jitter, local-oscillator phase noise, amplitude flatness, group delay, mutual coupling, cross-channel leakage, and the stability of correction coefficients. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix.

Where one analogue signal is split between a wideband analyser and a narrowband tracking receiver, splitter loss, impedance interaction, added noise and isolation are measured. A dual-output low-noise stage may be used only if its linearity, reverse isolation and common-mode behaviour are validated. Where both displays are formed digitally from one ADC record, the raw record remains authoritative and the two processing paths retain their filter coefficients, decimation, detector, window and latency metadata.

The wideband search receiver provides continuous real-time sampling, occupancy and event detection within its validated instantaneous bandwidth. The spectrum analyser controls selected bands, resonance state and metrological settings. When a line or burst is selected, the tracking receiver narrows around it without interrupting the nine-channel record. This pairing is especially important when the fundamental is masked but a harmonic is traceable, when a weak narrowband FM carrier sits near a strong service, or when an illumination-correlated response exists only briefly.

10.13A.7 Band-physics segmentation from 20 Hz through 700 MHz

The nine-channel geometry is repeated across probe families rather than forcing one antenna to cover incompatible physics. Below approximately 30 MHz, the magnetic material, winding, resonating capacitance, electrostatic shield, preamplifier noise model and physical aperture determine the usable band. Five or more low-frequency systems may therefore be required. Above approximately 30 MHz, broadband loops, dipoles, biconicals, log-periodic structures and active near-field probes are generally easier to match over useful spans, but the three-pod X-Y-Z geometry remains valuable for orientation, gradient and transient correlation.

Field-theory elaboration. A advanced technical account of Band-physics segmentation from 20 Hz through 700 MHz distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The section is technically complete only when the relevant field regime and the limits of the adopted approximation are stated [129-131].

Nominal band	Preferred head physics	Array and receiver treatment
20 Hz to 300 Hz	Long laminated, amorphous, nanocrystalline or high-permeability bar probes; very high turn count; low-current-noise input.	Dedicated three-pod X-Y-Z set. Long settling, mains and 400 Hz controls, low-frequency tracking receiver.
300 Hz to 3 kHz	Voice and power-frequency magnetic bars, differential bars and current probes.	Dedicated or shared low-frequency chassis with per-channel resonance and microphonic controls.
3 kHz to 14 kHz	Voice-frequency bars, balanced loops and cable-current probes.	Flat discovery plus tuned confirmation. Content-minimising metrics only.
14 kHz to 100 kHz	MnZn ferrite, nanocrystalline or laminated probes selected by measured complex permeability.	Timing families including 15.734 kHz and 32.768 kHz, harmonic tracking and narrow coherent detection.
100 kHz to 1 MHz	Shorter ferrite rods, powder or nanocrystalline candidates, shielded loops and gradiometers.	Band-specific preselection, reduced turns, self-resonance margin and calibrated varactor law.
1 MHz to 30 MHz	NiZn ferrite where validated, air-core loops, active H-field and E-field probes.	Separate head family where magnetic loss or winding capacitance limits lower-band rods.
30 MHz to 700 MHz	Broadband loop, dipole, biconical, log-periodic, monopole and calibrated near-field probes.	Three pods with X-Y-Z orientations or equivalent orthogonal field sensors, simultaneous real-time I/Q and tracking receivers.
Above 700 MHz	Band-specific horns, log-periodics, panels, loops or waveguide probes.	Separate coherent modules as required. The same trigger, timebase and array principles continue.

Table 10-E. Band-physics segmentation for multichannel pod deployment.

10.13A.8 Multiple coherent chassis across incompatible bands

The method discourages one independent spectrum analyser per antenna because independent local oscillators, sample clocks, trigger delays and user settings frustrate coherent interpretation. It does permit several band-specific common-chassis systems when low-frequency magnetic physics, RF front-end range, dynamic range or instantaneous bandwidth cannot be combined credibly in one chassis. A demanding survey may therefore employ eight to twelve analysers, but each analyser is itself multichannel, and all analysers are disciplined to the same site master reference and event identifier.

Synchronous measurement elaboration. In multiple coherent chassis across incompatible bands, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone.

Cross-chassis fusion is permitted only after a shared calibration event measures timestamp offset, sample-clock relationship, amplitude scale and group delay. If phase coherence cannot be established across chassis, the data may still be compared in frequency, amplitude, occupancy and event time within the measured uncertainty. The report states which quantities are coherent within a chassis and which are merely time-correlated across chassis.

10.13A.9 Intermittent, burst and very-low-duty-cycle capture

Burst devices and illuminated retroreflectors cannot be assessed reliably merely by a slow sequential sweep alone. Each common-chassis system therefore maintains a fixed-span or channelised real-time record over the highest-priority bands, with circular pre-trigger memory, post-trigger storage, persistence and a validated probability of intercept. The event detector may use level, frequency mask, matched correlation, cyclostationary statistic, pulse interval or an illumination-reference trigger. The trigger decision and the full raw data block are both retained.

Signal-analysis interpretation. The expert treatment of intermittent, burst and very-low-duty-cycle capture begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity.

A source active for only a few seconds each day requires an authorised long-dwell monitoring plan rather than an optimistic short sweep. The plan records duty window, instrument uptime, storage gaps, threshold changes, software restarts and environmental transitions. All 162 probe channels must remain simultaneous during a captured event so the transient can be localised from its actual field, not from a reconstructed sequence assembled after the event has vanished.

10.13A.10 Retroreflector and illumination-trigger integration

In the preferred 12-channel allocation, channel 10 records the actual illumination or interrogation field and establishes time zero. Channels 1 through 9 record the three-pod response array. Channel 11 remains terminated, connected to a dummy head or driven by a controlled calibration path. Channel 12 records a guard band, an independent receiver plan or a second source monitor. The common trigger starts every channel, while the acquisition system iterates the response delay through the validated coarse-to-fine schedule described in Section 10.18.1.

Controlled-illumination interpretation. The expert treatment of Retroreflector and illumination-trigger integration begins with the passive baseline and the recognition that an applied field changes the scene. The illumination source, coupling path, suspected response path, and receiver are therefore treated as one controlled experiment. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

When the response frequency is unknown, the system does not sweep one broad span and assume that a short return will remain present. It uses parallel instantaneous bands, a channelised real-time receiver, or repeated identical authorised illumination trials in predeclared frequency segments. Delay, frequency segment, polarisation, illumination level and pod geometry are varied according to a controlled design. A response is not promoted unless it survives direct-leakage, terminated-input, sham, frequency-offset, overload and independent-receiver controls.

10.13A.11 Controlled-space filter and penetration-path correlation

Within a Sensitive Compartmented Information Facility, SCIF, or another controlled space, the defensive protocol may test whether a candidate signal is coherently present on protected and unprotected sides of an authorised low-pass filter, feedthrough, cable shield, power path or service penetration. This is a detection and characterisation activity. It does not describe a method for constructing a bypass device. Simultaneous channels are placed at lawful accessible points on the interior path, exterior path and nearby controls, with current probes, magnetic probes, electric-field probes or conducted receivers selected for the actual service.

Probe-engineering analysis. The technically mature interpretation of Controlled-space filter and penetration-path correlation treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure.

A filter-bypass hypothesis requires common timing or modulation, compatible drift, measured transfer delay or phase where valid, reproducible source-state dependence and spatial concentration at a penetration or conductor. An ordinary infrastructure signal, filter leakage within specification, cable common mode, ground loop or receiver cross-talk remains an alternative explanation until excluded. Any measurement on classified or controlled infrastructure is governed by the facility authority, information-security rules and a separate handling plan.

10.13A.12 Array calibration, matrix correction and invalidation

The nine-probe array is calibrated as a coupled system. If $v(f)$ is the nine-element vector of measured complex voltages, $h(f)$ is the desired field-component vector and $C(f)$ is the measured coupling and transfer matrix, the linearised model is $v(f) = C(f)\,h(f) + n(f)$. Matrix inversion or regularised estimation may be used only where C is stable, well-conditioned and validated. Otherwise the raw channel outputs and pairwise comparisons are reported without claiming a corrected field vector.

Traceability and uncertainty analysis. A advanced metrological approach to Array calibration, matrix correction and invalidation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified.

Acceptance testing covers gain and phase matching, channel skew, crosstalk, reverse isolation, common-mode response, mutual coupling, varactor-generated harmonics and intermodulation, bias feedthrough, group-delay stability, clock spurs, chassis self-emission, overload recovery and trigger fan-out. A record is invalidated by any unlogged channel switch, gain change, tuning movement, clock unlock, missing sample block, ADC clipping, tracking-filter retune, calibration pilot leakage or unexplained state divergence among nominally matched channels.

10.13A.13 Required record and reporting language

Each acquisition block states chassis identifier, card and channel serials, firmware and software versions, site master reference, pod coordinates, physical axis, probe configuration, band module, cable, preselector, gain, sample rate, instantaneous bandwidth, RBW or analysis bandwidth, tracking-receiver bandwidth, frequency command, varactor bias, piston setting, lock result, settling time, calibration identifier, trigger source, trigger delay, pre-trigger interval, clock status, channel skew correction, overload state and file hash. The raw nine-channel block is preserved before vector combination or spatial interpolation.

Evidential reasoning elaboration. A mature forensic approach to Required record and reporting language separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

The report distinguishes observed simultaneity from inferred simultaneity. It may state that a feature was recorded concurrently on specified channels within a measured timing uncertainty. It may state that the feature had compatible phase or coherence only when the relevant calibration supports that statement. It shall not describe a source as localised merely because one channel was largest, nor describe a chassis as validated for the declared field use without the retained evidence required by the intended-use validation programme.

10.14 Gradiometers and differential magnetic arrays

Every gradiometer or differential magnetic array used for evidential interpretation shall be implemented within the coherent multichannel architecture of Section 10.13A. The minimum gradiometer uses two simultaneous channels plus a third orthogonal or control channel. The normal three-pod deployment keeps all nine X-Y-Z paths active, permitting spatial differences to be computed after acquisition rather than by analogue switching. Analogue subtraction remains permissible when its common-mode rejection, phase balance, overload behaviour and residual output are measured, but the unsubtracted component channels are retained whenever practicable.

Sensor and front-end elaboration. For Gradiometers and differential magnetic arrays, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations.

Differential probes shall reject broad common fields and reveal local gradients when their matching and geometry are validated. The governing physical or metrological basis is subtraction of two spatially separated magnetic measurements with known baseline and orientation. The examiner shall treat this basis as a testable model rather than an assumption. A building field is rarely uniform, and mismatch can leave residuals larger than the desired local signal. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

The required configuration is as follows. Matched sensors, symmetric preamplifiers, calibrated complex gain and a rigid non-magnetic baseline are used. The primary observables are single-ended channels, differential output, common-mode rejection, phase mismatch, gradient and baseline dependence. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

Where the differential array uses tuned rods, each rod has an independent varactor branch and bypass state. The X-axis element is the resonance-reference channel, not a mathematical substitute for the other axes. Complex matching coefficients are established after all three axes have reached their held bias. Continuous servo action during a spatial pass is prohibited because it can transform a changing environmental signal into a changing tuning command and obscure the actual gradient.

The minimum controls are uniform-field test, channel interchange, physical reversal, zero-baseline electronic test and local dipole scan. The principal artefacts and confounders are amplitude mismatch, phase error, unequal electric-field pickup, structural non-uniformity and shared electronics. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a differential maximum supports localisation only when single-ended data and reversal controls agree. The principal limitation is the result is a gradient over the baseline, not field at a mathematical point. The record shall contain sensor serials, baseline, matching coefficients, CMRR, orientation and both raw channels. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.15 Electric-field probes and guarded high-impedance sensors

Electric-field probes shall characterise capacitive and common-mode coupling that magnetic sensors may not reveal. The governing physical or metrological basis is displacement current and potential difference coupled to a plate, monopole or guarded electrode. The examiner shall treat this basis as a testable model rather than an assumption. The human body, nearby walls and cable geometry become part of the capacitance and can change the result. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Sensor and front-end elaboration. The technically mature interpretation of Electric-field probes and guarded high-impedance sensors treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure.

The required configuration is as follows. A balanced or guarded sensor, high-input-impedance low-noise amplifier, fixed non-conductive support and remote readout are used. The primary observables are field-related voltage, orientation, response to personnel distance, wall standoff, cable common mode and correlation with magnetic channels. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are dummy electrode, personnel-position test, shielded cable check, sensor rotation and known electric-field fixture. The principal artefacts and confounders are triboelectric cable charge, leakage, humidity, static charge, body capacitance and amplifier bias-current noise. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is an electric component is reported separately and is not converted to a magnetic or plane-wave quantity without a validated model. The principal limitation is absolute field calibration in a cluttered near field can carry substantial site dependence. The record shall contain electrode dimensions, guard, input impedance, cable, personnel geometry, transfer factor and environmental conditions. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.16 Higher-frequency antennas and near-field probes

The megahertz and radio-frequency channels shall use antennas appropriate to the field regime and spatial task. The governing physical or metrological basis is electric and magnetic coupling, radiation, reflection and local near-field interaction with conductors and apertures. The examiner shall treat this basis as a testable model rather than an assumption. A small near-field probe is not automatically a calibrated far-field antenna, and a large calibrated antenna can have poor local resolution. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

The following integration extends 10.16 Higher-frequency antennas and near-field probes with custom sensors, resonant probes, and calibration-range engineering. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Custom Sensors, Resonant Probes, and Calibration-Range Engineering

Uncertainty analysis for In-situ verification and drift control must include both numerical error and model uncertainty. Numerical uncertainty arises from calibration, resolution, repeatability, positioning, timing, and noise; model uncertainty arises when the wrong source, path, boundary condition, or causal mechanism has been assumed. Relevant failure mechanisms include transport damage, connector contamination, battery sag, firmware change, temperature, and unrecorded replacement parts. A mature report distinguishes random variation, systematic bias, and epistemic uncertainty, then shows which term dominates the conclusion. Sensitivity analysis should test whether a plausible change in an uncertain input reverses the decision or merely changes its margin. When the evidence supports several explanations, the report should retain competing hypotheses and state what additional observation would discriminate among them.

This is preferable to burying uncertainty in a generic caveat, because decision makers need to know whether confidence is limited by instrument performance, missing access, incomplete source material, or a fundamentally nonunique inverse problem. In this placement, that control is applied specifically to in-situ verification and drift control within custom sensors, resonant probes, and calibration-range engineering, with the local volume retaining ownership of the final inference.

This integrated treatment returns the discussion to 10.16 Higher-frequency antennas and near-field probes with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

Sensor and front-end elaboration. At advanced-practitioner level, Higher-frequency antennas and near-field probes is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The required configuration is as follows. Shielded loops, monopoles, dipoles, biconical or log-periodic antennas and miniature probes are assigned to discovery, confirmation or localisation roles. The primary observables are antenna output, polarisation, bearing, height response, phase, near-field gradient and preselector dependence. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are antenna substitution, polarisation change, height change, external reference and independent receiver. The principal artefacts and confounders are multipath, cable radiation, common mode, receiver images, local oscillator leakage and antenna-body interaction. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is source-region inference uses overlapping evidence from appropriate large and small apertures. The principal limitation is site-specific field distortion can dominate nominal antenna pattern. The record shall contain antenna factor or relative role, dimensions, orientation, height, cable, calibration and site limitations. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.17 Fibre links, remote recording and audibly silent operation

Noisy digital electronics shall be separated from the sensing aperture while preserving lossless, time-stamped data acquisition. The governing physical or metrological basis is optical isolation interrupts conductive common-mode paths and allows the recorder to remain at the remote station. The examiner shall treat this basis as a testable model rather than an assumption. Optical converters contain oscillators and switching regulators and can contaminate the probe if placed too close. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Forensic interpretation. For Fibre links, remote recording and audibly silent operation, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions.

The required configuration is as follows. The minimum analogue front end remains local, while conversion to fibre occurs at a validated distance or in a characterised enclosure. The primary observables are self-emission versus distance, data integrity, latency, timing stability, battery state and noise with the link active or inactive. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are link-off blank, alternate fibre converter, remote termination, battery-state sweep and independent recorder. The principal artefacts and confounders are converter clocks, memory writes, fan noise, status LEDs, ground paths through auxiliary cables and packet cadence. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the link configuration is fixed for a comparison series and included in the self-emission library. The principal limitation is remote placement does not remove radiated or magnetic coupling unless distance and shielding are validated. The record shall contain converter serials, distance, enclosure, power, data protocol, clock behaviour and blank files. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

10.18 Controlled illumination transmitter and response-monitor architecture

A controlled-illumination system shall be treated as two metrologically separate instruments. The transmit chain creates a known incident field. The receive chain measures a possible response while remaining sufficiently isolated from the transmit chain to avoid mistaking direct leakage, receiver compression or internally generated mixing for an environmental phenomenon. Physical separation, shielding, polarisation discrimination, filtering, time gating and independent reference channels are engineering controls, not substitutes for negative tests.

Retroreflective-response analysis. For Controlled illumination transmitter and response-monitor architecture, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied.

The transmit chain shall include a frequency-agile but authority-limited source, waveform generator, level control, interlock, calibrated directional coupler, forward and reflected power monitoring, appropriate harmonic filtering, a characterised feed line and a directional antenna whose gain, pattern, polarisation and near-field boundary are documented. Candidate frequencies in the .9 GHz to 2.3 GHz, 3.8 GHz and 6.2 GHz regions may be programmed only when they fall within the written authorisation and the applicable national allocation. The source shall begin at the lowest technically useful field, with step size, maximum field, duty cycle and dwell fixed before observation of the result.

The receive chain shall use a response antenna or probe selected for the hypothesised return band, including a calibrated 300 MHz-region antenna where that response is being tested. Preselection must reject the illumination frequency and its expected harmonics before low-noise gain. Where the hypothesised response is frequency translated, the front end shall demonstrate adequate isolation at the transmit frequency and linearity under the worst authorised field. A reference receiver monitors the actual transmitted waveform, while a second independent receiver records the response band with a distinct local-oscillator plan and a separately disciplined clock.

The minimum instrument set consists of a transmitter monitor, a field or power-density monitor at a representative accessible point, a receive-chain overload indicator, a terminated receive input, a dummy antenna or non-responsive load, an independent response receiver, an emergency stop and a written state machine that records source-off, sham, source-on, frequency-offset, polarisation-change, position-change and post-test passive states. Every source transition is timestamped into the same timebase as the response data.

10.18.1 Illumination-presence trigger and source-synchronised response acquisition

The transmitter monitor or a dedicated illumination-monitor receiver shall generate a hardware or time-stamped software trigger when the authorised illumination waveform is actually present at the monitored path. Trigger formation may use calibrated envelope level, correlation to the commanded waveform, an RF-burst detector or a qualified frequency-mask condition. Threshold, hysteresis, debounce, holdoff and false-trigger rate are established with the source terminated and with representative ambient signals. The command to transmit is not used as the sole timing reference because synthesiser settling, amplifier turn-on, relays, couplers and feed paths introduce variable latency.

Retroreflective-response analysis. A advanced technical analysis of Illumination-presence trigger and source-synchronised response acquisition separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. Pre-trigger memory and a coarse-to-fine delay search are used because rectification, energy storage, logic wake-up, resonator settling, pulse encoding, and decay can introduce latency from microseconds to seconds. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied.

The source-presence trigger fans out to the response spectrum analyser, real-time spectrum analyser, vector I/Q recorder, oscilloscope and state logger through a characterised distribution path. A common reference clock and, where used, pulse-per-second epoch establish time alignment. Each recorder retains a pre-trigger interval that shows the response band before illumination begins. For transient returns, a fixed-span real-time or vector acquisition is preferred. A swept analyser may be triggered, but a sweep across a broad span is not represented as gap-free capture unless its validated probability of intercept and sweep timing support that claim.

Trigger delay is iterated rather than guessed. The first pass covers the complete source transition with negative pre-trigger and zero delay. Subsequent passes use a predeclared coarse-to-fine series spanning the plausible propagation, SAW delay, rectifier charging, oscillator start-up, logic wake and pulse-encoding intervals. Once a response is observed, the delay is bracketed on both sides and refined until onset, peak, duration and recovery are captured within the timing uncertainty. If no response is found, the report states the tested delay interval and capture-window limits rather than asserting that no delayed response exists.

Every delay step is repeated under source-off, sham, frequency-offset, position-change and independent-receiver controls. A response must recur with compatible latency and frequency relation while remaining absent from terminated-input and direct-leakage controls. The trigger system is itself challenged for cable coupling, ground loops, digital clock emission, analyzer arming transients and trigger-out feedthrough.

For the preferred 12-channel chassis, 192-channel system, the illumination monitor occupies channel 10 and distributes the source-presence event to channels 1 through 9, the terminated or calibration channel 11 and the guard or independent reference channel 12. The response record therefore contains the actual illumination waveform, three complete X-Y-Z spatial vectors, a receiver-artefact control and an independent comparison within one sample epoch. Delay iteration changes the acquisition gate or post-trigger window, not the relative timing among channels. Any channel that arms late, loses reference lock or misses the event invalidates the corresponding vector comparison.

Table 10-B. Source-triggered acquisition variables

Variable	Required treatment	Reason for control
Source-presence detector	Record detector type, threshold, hysteresis, holdoff and measured latency	Separates actual RF presence from the command state
Pre-trigger memory	Retain a declared interval before source onset	Shows baseline and any response preceding the nominal trigger
Trigger delay	Iterate through a predeclared coarse-to-fine schedule	Captures delayed charging, wake, SAW or encoding responses
Acquisition mode	Prefer fixed-span real-time, vector I/Q or zero-span for short events	Avoids missing a response during a broad swept scan
Capture window	Long enough for onset, steady state and recovery	Prevents partial-event classification
Reference timing	Common clock, characterised distribution and timestamp uncertainty	Supports response-latency and PPM measurements
Negative controls	Terminated input, sham, source-off, frequency offset and independent receiver	Rejects direct leakage and instrument-generated responses
Stop gate	Hardware source-off and verified field-off before movement	Protects safety, compatibility and scene integrity

CONTROLLED ILLUMINATION PATH: waveform source -> level control and interlock -> harmonic filter -> directional coupler -> calibrated feed line -> directional antenna -> candidate region
RESPONSE PATH: candidate region -> response antenna or probe -> transmit-band rejection -> low-noise preamplifier -> calibrated receiver or digitiser -> immutable raw data
REFERENCE AND SAFETY PATHS: coupler monitor + field monitor + overload monitor + separately disciplined clocks + emergency stop + synchronised state log

10.19 Sub-20 Hz Multiphysics sensor channels and common-timebase integration

The 0.001 Hz to 20 Hz workstream shall not rely upon a conventional AC-coupled spectrum analyser input whose transformer, coupling capacitor or firmware high-pass filter suppresses the phenomenon under examination. The primary acquisition chain uses DC-coupled or explicitly characterised very-low-frequency front ends, low-drift differential amplifiers, precision voltage references, 24-bit or better analogue-to-digital conversion where practicable, anti-alias filtering, deterministic time stamping and common-clock sampling. The spectrum analyser or search-receiver display may remain the analyst's principal interface, but the underlying evidence is the calibrated time-series record from a domain-appropriate transducer.

At least three spatially separated multiphysics pods are used where geometry permits. Each pod may contain orthogonal magnetic channels, orthogonal electric-field channels, orthogonal structure-borne motion channels and a pressure channel or differential microbarometer. An exterior reference station records pressure, wind, temperature, magnetic field, seismic motion and master time. The channels share one disciplined time base so that phase, delay and coherence can be compared, but each physical domain retains its own calibration chain and uncertainty budget.

The preprocessing head may allocate part of the existing twelve-card architecture to the sub-20 Hz suite. Each card shall preserve channel identity, sensor serial number, orientation, gain, offset, temperature, anti-alias corner, calibration date, time-base status and overload history. FPGA processing may decimate, calculate power spectral density, estimate cross-spectral coherence and issue candidate-event flags. It shall never discard the raw or losslessly compressed source record merely because an automated detector did not declare an event.

Chapter Glossary

Terms used in Chapter 14: Instrumentation and Receiver Architecture.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CAPACITANCE — The property of an electrical circuit that opposes changes in voltage.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

D

DYNAMIC RANGE — The span between the smallest and largest input levels that a system can process while meeting specified performance criteria.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

IMPEDANCE — The complex ratio of voltage to current at a stated frequency and reference plane, including both resistive and reactive components.

INDUCED VOLTAGE — See INDUCED ELECTROMOTIVE FORCE.

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

S

SUSCEPTIBILITY — The degree to which equipment or a system is adversely affected by electromagnetic, electrical, acoustic, optical, mechanical, or environmental exposure.

11. Instrument Quieting and Self-Emission Control

The inspection system can easily become the strongest electronic source in the room. Every person, battery pack, cable, preamplifier, optical transceiver, recorder, display and accessory shall therefore have a self-emission profile. The profile is measured before deployment, after any firmware or hardware change, and at the start of the commission. A quiet device in one band may be noisy in another, and a battery-powered instrument can still contain a switching converter or display clock.

The common-chassis system is profiled as a whole and by channel. Expansion cards, backplane clocks, trigger fan-out, DAC updates, varactor-bias filters, pod power feeds, tracking receivers and digital channelisers can produce coherent artefacts that look more persuasive than random noise. The self-emission library therefore includes all-channel idle, one-channel active, nine-channel active, tuning sweep, hold, calibration pilot, trigger, pre-trigger memory write, storage transfer and illumination-monitor states. A line that appears identically in the terminated channel and all probe channels is presumed instrument-related until disproved.

Control	Required practice
Personal electronics	No phones, smartwatches, wireless earbuds, active badges, hearing accessories or personal radios inside the CEIA unless clinically necessary, authorised and characterised.
Power	Prefer battery operation with characterised low-noise regulation. Keep chargers, inverters and switch-mode supplies outside the remote reference zone.
Data links	Prefer fibre. Place optical-electrical converters outside the fine-search area or inside a characterised shielded enclosure.
Displays and processors	Use fanless systems, disable wireless interfaces, dim or switch off displays during dwell, and locate high-speed processors remotely.
Cables	Fix cable geometry, use ferrites or common-mode chokes only if validated, avoid movement during dwell and record every connection.

Control	Required practice
Receiver checks	Acquire terminated-input, dummy-probe, amplifier-bypass and gain-step traces. A genuine environmental signal should behave consistently with the sensor path.
Personnel entry	Introduce one person or item at a time. Acquire a before-and-after trace so that new lines can be attributed or rejected.
Reference library	Maintain spectra for all team equipment in each operating state, including sleep, display refresh, data transfer and storage writes.

11.1 Instrument self-emission library

Every deployed instrument shall have a state-resolved library of its own conducted and radiated emissions. The governing physical or metrological basis is clocks, regulators, displays, storage, communications and control cycles can create narrow lines and bursts within the search bands. The examiner shall treat this basis as a testable model rather than an assumption. A manufacturer specification does not replace measurement of the exact configured unit. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Electromagnetic interpretation. An advanced technical account of Instrument self-emission library distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. At electrically small dimensions, terms proportional to 1/r cubed and 1/r squared may dominate over the radiating 1/r term, so amplitude-distance behaviour cannot be interpreted through free-space path loss alone. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model.

The required configuration is as follows. Terminated-input, dummy-probe and independent radiated measurements are acquired for start-up, idle, acquisition, write, gain change and low-battery states. The primary observables are frequency, amplitude, duty cycle, state correlation, temperature and distance dependence. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are second unit, power-state change, display-off state and independent receiver. The principal artefacts and confounders are unrecorded firmware tasks, battery protection, fibre conversion, charging and periodic housekeeping. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a known internal line can be excluded only when the environmental candidate is demonstrably different in frequency, state or spatial behaviour. The principal limitation is self-emissions can change after repair or software update. The record shall contain hardware, firmware, configuration, states, raw files and date of last verification. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

11.2 Cable motion, triboelectricity and magnetic contamination

Cables and mechanical supports shall be controlled as active parts of the sensitive measurement chain. The governing physical or metrological basis is dielectric motion, piezoelectric effects, changing loop area, connector movement and ferromagnetic hardware can generate or modulate signals. The examiner shall treat this basis as a testable model rather than an assumption. An electrically shielded cable can still be microphonic or magnetically active. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced practitioner analysis. At expert-practitioner level, Cable motion, triboelectricity and magnetic contamination is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions.

The required configuration is as follows. Low-microphonic cable, fixed strain relief, non-magnetic hardware and a settled stationary geometry are used. The primary observables are transients after movement, noise versus cable bend, response to connector pressure and change with cable orientation. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are laboratory movement test, field dummy cable, fixed reference and repeated dwell after extended settling. The principal artefacts and confounders are footfall, air movement, tripod vibration, magnetic screws and cable braid current. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is an acquisition disturbed by movement is rejected or repeated, not filtered into apparent evidence. The principal limitation is very high-Q and high-impedance probes can remain sensitive after visible motion stops. The record shall contain cable type, routing, clamps, settling time, disturbance events and repeats. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

11.3 Ordered environmental quieting

Known environmental sources shall be changed one at a time only after the ordinary-state survey is complete. The governing physical or metrological basis is controlled state comparison can attribute a candidate without destroying the baseline state or changing several coupling paths at once. The examiner shall treat this basis as a testable model rather than an assumption. Opening a breaker or disconnecting a multi-device circuit is a compound intervention. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced practitioner analysis. A technically mature treatment of Ordered environmental quieting begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty.

The required configuration is as follows. A preapproved quieting order identifies safe devices, responsible persons, expected effects and restoration checks. The primary observables are candidate response before, during and after the state change, plus changes elsewhere in the spectrum. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are restoration repeat, unchanged reference channel, independent known-source monitor and no-change sham interval. The principal artefacts and confounders are coincident source intermittency, ground reconfiguration, network traffic change and automatic backup activation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is attribution requires reproducible follow-the-state behaviour under restored conditions. The principal limitation is essential medical, security, refrigeration and life-safety systems may remain operating. The record shall contain authority, device, time, person, expected result, observed result, restoration and remaining confounders. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

11.4 Personnel stand-off and body-coupling control

Personnel shall remain at validated positions during dwell to avoid becoming an uncontrolled antenna, shield or capacitive element. The governing physical or metrological basis is the human body alters electric-field capacitance, scatters higher-frequency fields and carries personal magnetic or electronic sources. The examiner shall treat this basis as a testable model rather than an assumption. Necessary clinical support and safety presence can take precedence over ideal stand-off. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Field-theory elaboration. The advanced treatment of Personnel stand-off and body-coupling control begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

The required configuration is as follows. Remote triggering, passive markers, non-conductive supports and a declared operator position are used. The primary observables are candidate change with personnel distance, orientation and substitution, particularly in electric-field channels. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are empty-position repeat, alternate examiner, remote probe and personal-device characterisation. The principal artefacts and confounders are phones, watches, medical wearables, magnetic clothing, movement and body heat. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a personnel-dependent component is not localised to the premises until the coupling is understood. The principal limitation is some necessary devices can prevent complete elimination of personnel contribution. The record shall contain persons present, positions, necessary devices, deviations and effect on interpretation. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 15: Instrument Quieting and Self-Emission Control.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COUPLING PATH — The physical route by which energy transfers from a source to a victim, structure, conductor, sensor, or observer.

D

DISPLACEMENT CURRENT — The current that appears to flow through a capacitor.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

12. Pre-Deployment Planning and Authorisation

12.1 Define the precise technical question in neutral terms. Example: Determine whether a reproducible narrowband or periodic electronic signature can be measured and localised within the authorised area under the stated operating conditions.

12.2 Obtain written property, privacy, safety and spectrum authority. Record whether active transmission, state changes, access to service panels, power interruption or patient-area entry is permitted.

12.3 Prepare an inventory of known emitters and operationally necessary systems. Include building automation, security, access control, Wi-Fi, medical devices, chargers, lighting, solar inverters, lifts, HVAC, alarms and neighbouring transmitters.

12.4 Select frequency bands and minimum dwell from the case question and validation envelope. Do not begin with a single favoured frequency. Reserve bandwidth for unexpected features and harmonics.

12.5 Confirm calibration, check-source results, receiver firmware, software version, time reference, storage capacity, battery state, data schema and instrument emission profiles.

12.6 Predeclare candidate-selection rules, artefact tests, localisation criteria and reporting categories. The criteria may vary by band, but they shall not be invented after seeing a desired result.

12.7 Establish safety and stop-work authority. In a healthcare environment, obtain written clinical-engineering review before any intentional field is generated. IEC 60601-1-2 and FDA EMC guidance are relevant to medical-device risk management [18, 21].

12.8 Prepare blank forms, unique identifiers, tamper-evident data media, cryptographic-hash tools, deviation forms, a nonconformity process and an independent-review plan.

12.9 Site geometry and ring-feasibility plan

The team shall prepare the nested-ring coordinate plan before deployment and before learning any client-suspected micro-location where practicable. The governing physical or metrological basis is predeclared geometry reduces expectation bias and ensures that inaccessible sectors are recognised before an anomaly attracts attention. The examiner shall treat this basis as a testable model rather than an assumption. The plan cannot authorise access to neighbouring property or controlled clinical zones. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Scene-geometry elaboration. At expert-practitioner level, Site geometry and ring-feasibility plan is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

The required configuration is as follows. The drawing or coordinate table identifies the datum; the 300-foot, 150-foot, 100-foot, 50-foot and 30-foot exterior stations; the 15-foot and 12-foot wall-referenced stations; the threshold, 3-foot and 3-inch geometries; hazards; service entries; and approved substitute points. The primary observables are actual access, line of sight, elevation, structural materials and anticipated external sources. The plan identifies which 150-foot stations match the 300-foot azimuths, which 30-foot transects cross service routes, and which 15-foot stations will be repeated at 12 feet. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series.

The minimum controls are independent review of the plan, coordinate verification and separation of suspected-location information from field staff where possible. The principal artefacts and confounders are late geometry changes, one-sided sampling, inaccurate distance estimates and use of wireless survey equipment. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the field manager approves the geometry and deviations before acquisition begins. The principal limitation is some sites require adaptive arcs or additional intermediate points. The record shall contain datum, stations, access authority, hazards, unexamined areas and approved substitutions. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

12.10 Probe deployment matrix

Sensors shall be assigned to stages and bands before the search so that probe choice does not follow the desired result. The governing physical or metrological basis is that larger, more sensitive apertures support discovery, while medium apertures, differential probes and smaller rods support service-path and fine localisation. The 300-foot, 150-foot and 100-foot stages ordinarily begin with the same large-aperture reference family. The 50-foot stage preserves that family while planning the 30-foot service-path tests. At 30 feet, medium-aperture rods, compact loops or gradiometers may be introduced only through overlap measurements. The 15-foot and 12-foot stages use matched wall-referenced settings, and the 3-foot and 3-inch stages use the smallest validated aperture. The examiner shall treat this basis as a testable model rather than an assumption. One probe cannot be assumed optimal from 300 feet through 3 inches.

Resonant receiving-system perspective. The technically mature interpretation of Probe deployment matrix treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

The required configuration is as follows. The matrix identifies probe serial, band, gain, filter, height, axis, dwell, expected sensitivity, aperture and overlap stage. The primary observables are probe-specific noise, candidate response, overload margin and overlap agreement. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are predeployment calibration, spare-probe characterisation and independent receiver assignment. The principal artefacts and confounders are selective substitution, unrecorded retuning, incomparable gain and probe-specific lines. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is deviation from the matrix requires a recorded technical reason and a bridging overlap set. The principal limitation is unexpected site interference may require an additional characterised configuration. The record shall contain the original matrix, approved changes, overlap data and configuration identifiers. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

12.11 Frequency plan and acquisition bandwidths

The examination shall combine wide discovery spans with candidate-specific high-resolution acquisitions. The governing physical or metrological basis is wide coverage identifies parent signals and confounders, while narrow bandwidth improves signal-to-noise ratio and frequency estimation. The examiner shall treat this basis as a testable model rather than an assumption. A search limited to three named frequencies can miss modern electronics and misclassify ordinary sources. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Oscillator-family analysis. The advanced technical treatment of Frequency plan and acquisition bandwidths regards a clock as a family of related observables rather than a single nominal line. The fundamental, harmonics, subharmonics, divider products, modulation sidebands, burst cadence, drift, and state-dependent amplitude belong to one timing hypothesis. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The required configuration is as follows. Band plans include low-frequency magnetic and electric channels, 9 kHz to 30 MHz coverage, higher-frequency sweeps as authorised, and time records. The primary observables are noise floor, strong out-of-band sources, candidate families, duty cycle and drift. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are alternate sample rates, resolution bandwidths, preselectors and independent clocks. The principal artefacts and confounders are aliasing, spectral leakage, peak-hold bias, insufficient dwell and dynamic-range collapse. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is candidate-specific narrowing occurs only after wideband context and blanks are preserved. The principal limitation is finite dwell cannot exclude rare intermittent activity. The record shall contain spans, sample rates, filters, windows, detectors, dwell and rationale. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

12.12 Non-contact, silent and non-imaging plan

The written method shall define how the team preserves non-contact, audibly silent and non-imaging conditions throughout the search. The governing physical or metrological basis is fixed standoff and numerical coordinate acquisition prevent physical disturbance and avoid constructing a visual representation of a hidden object. The examiner shall treat this basis as a testable model rather than an assumption. The protocol may use an existing lawful floor plan as a coordinate reference but does not create radar, thermal, optical or tomographic images. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

System-level interpretation. At expert-practitioner level, Non-contact, silent and non-imaging plan is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The required configuration is as follows. Non-conductive spacers, tripods, passive markers, remote triggers and numerical displays are specified. The primary observables are standoff, coordinate, axis, spectra, time series, field components and line or polar plots. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are standoff verification, no-contact witness, acoustic check of equipment and review of analytical outputs. The principal artefacts and confounders are probe touching a wall, audible alarms, operator steering by headphones and image-like interpolated heat maps. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the method stops at the nearest safe validated standoff or inaccessible boundary. The principal limitation is depth behind a surface may remain unresolved. The record shall contain minimum clearances, equipment noise state, outputs produced and any separately authorised imaging method. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

12.13 Medical and clinical coordination plan

Where the commission concerns medical mysteries or occurs near patients, technical measurement shall remain institutionally separate from diagnosis and treatment. The governing physical or metrological basis is electromagnetic measurement can establish a physical field quantity but cannot by itself establish biological causation. The examiner shall treat this basis as a testable model rather than an assumption. No symptom provocation, exposure experiment or medical-device manipulation occurs under the passive inspection authority. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Legal, clinical, and ethical elaboration. The mature treatment of Medical and clinical coordination plan recognises that technical capability does not itself create legal authority, clinical justification, or acceptable risk. Clinical or medical questions remain institutionally separate from electromagnetic measurement; a field observation does not establish diagnosis, injury, exposure significance, or causation. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The required configuration is as follows. Clinical engineering, medical leadership, ethics or legal authority and the technical team define roles and stop-work conditions. The primary observables are technical field data, medical-device status and safety events, kept in separate records unless authorised linkage is necessary. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are independent clinical assessment, exposure review for any active phase and patient-first emergency authority. The principal artefacts and confounders are expectation bias, coincident symptoms, inappropriate causal language and interference with essential equipment. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the EERF report ends at measured phenomena and explicitly disclaims medical causation. The principal limitation is a clinically meaningful hypothesis requires a separate properly governed research or medical process. The record shall contain approvals, roles, restrictions, stop rules and separation of technical and clinical conclusions. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

12.14 Controlled-illumination authorisation and hazard plan

The active plan is a distinct controlled document. It identifies the legal basis for transmission, the responsible spectrum authority, the authorised frequencies and bandwidths, maximum conducted and radiated levels, waveform, duty cycle, antenna, location, exclusion volume, dwell, monitoring points and stop conditions. It also states the technical proposition being tested and why passive evidence is insufficient. A general desire to find a hidden object is not an adequate test proposition.

Legal, clinical, and ethical elaboration. At expert-practitioner level, Controlled-illumination authorisation and hazard plan is an engineering control boundary rather than a ceremonial disclaimer. Authority, privacy, spectrum use, exposure, medical-device compatibility, occupational safety, data handling, and property access must be resolved before the corresponding action occurs. Clinical or medical questions remain institutionally separate from electromagnetic measurement; a field observation does not establish diagnosis, injury, exposure significance, or causation. The examination stops when a required control is absent or when the measured conditions exceed the authorised envelope [17-23, 29-30].

The plan shall address electromagnetic compatibility with ordinary and safety-critical equipment, medical-device and implanted-device susceptibility, occupational and public exposure, ignition and battery-heating risk, unintended activation, data alteration, communication disruption and evidential contamination. Where a clinical environment is involved, clinical engineering retains authority to prohibit or terminate the test. Where persons cannot be excluded, the plan uses conservative field assessment, real-time monitoring and a lower operational limit than the applicable exposure ceiling when uncertainty or device susceptibility warrants it.

The planned response frequencies are listed separately from the illumination frequencies. The receive architecture, preselectors, attenuation, expected direct-leakage level and maximum permissible receiver input are calculated before deployment. Candidate response mechanisms include same-frequency backscatter, sidebands around the incident carrier, harmonic or subharmonic responses, difference-frequency or other intermodulation products, and internally timed reradiation such as a possible PPM signal near 300 MHz. Each mechanism receives a distinct control sequence.

Approval is signed by the commissioning authority, technical lead, safety officer, spectrum or communications authority where applicable, clinical engineering where applicable, and the independent reviewer. Any unplanned frequency, power, antenna, waveform or geometry change suspends the test until the plan is amended and reapproved.

Gate	Minimum documentary evidence	Decision
Passive closure	Completed passive ring and grid series, final blanks, hashes, unresolved limitations and technical review.	Proceed only if the active proposition cannot be answered passively.

Gate	Minimum documentary evidence	Decision
Legal and spectrum authority	Written frequency, bandwidth, level, modulation, location and duration permission.	No transmission without explicit scope.
Safety and clinical review	Exposure assessment, equipment susceptibility review, exclusion plan, emergency stop and responsible persons.	Stop if any material risk remains uncontrolled.
Receiver protection and artefact plan	Predicted direct leakage, preselector rejection, overload margin, intermodulation map and independent receiver design.	Do not energise until the receive chain is demonstrably linear.
Predeclared decision rule	Response metric, repeatability requirement, field-off behaviour, negative controls, spatial criterion and uncertainty.	No post hoc threshold selection.

Chapter Glossary

Terms used in Chapter 16: Pre-Deployment Planning and Authorisation.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DUTY CYCLE — In a transmitter, ratio of time on to time off.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

S

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

SUSCEPTIBILITY — The degree to which equipment or a system is adversely affected by electromagnetic, electrical, acoustic, optical, mechanical, or environmental exposure.

V

VERIFICATION — The confirmation, through examination or objective evidence, that specified requirements have been fulfilled.

12A. Regional Spectrum Inventory from Five Miles to the 300-Foot Transition

The regional inventory is a defensive measurement stage conducted before close approach. It is designed to prevent a nearby transmitter, a distant high-power emitter, a scheduled burst, a utility carrier, an aircraft or transport system, a cellular sector, a fixed microwave link, or a receiver-generated mixing product from being misclassified as premises-associated. It does not authorise interception of content, entry upon land, interference with communications, transmitter enumeration by unauthorised association, or collection of information unrelated to the commissioned technical question. The examiner records energy, timing, bandwidth, direction, field strength and lawful public metadata only to the extent required for source discrimination.

A ring is an evidential annulus, not a demand to drive or walk a mathematically perfect circle. Stations are selected from authorised roads, public positions, client-controlled property, neighbouring facilities under written permission, or internal points where a very large campus extends across the nominal radius. Each station receives a unique coordinate, height, azimuth, antenna polarisation, receiver configuration, time-base status, dwell and environmental record. Missing sectors, access barriers, terrain shadowing and altitude differences are preserved as uncertainty and coverage limitations.

12A.1 Regional annulus sequence and purpose. The five outer annuli are processed from outside inward under a pre-approved station-density plan. At 5 miles, sixteen stations establish the broad emitter census and receiver-noise portrait, or twenty-four stations where the risk classification requires fifteen-degree angular sampling. The 2.5-mile and 1-mile annuli repeat the same sixteen-station architecture, again increased to twenty-four in high-risk work. The 0.5-mile annulus ordinarily uses twelve stations, although an access-constrained plan may proceed with eight if the missing sectors and interpretive limitations are expressly approved.

The 0.25-mile annulus should use twelve stations and shall not use fewer than eight. The 300-foot ring then becomes the first premises-referenced controlled comparison. Each inward movement requires review of the fixed reference channels and the contemporaneous paper record, not merely a stronger trace on the mobile receiver.

12A.2 Contemporaneous sentinels and temporal closure

At least one stationary sentinel remains at an outer authorised location while the mobile array advances. For time-varying environments, two sentinels on materially different bearings are preferred. All channels share a disciplined reference or are related by a measured clock offset. A candidate that appears at the inner array but also rises at the sentinel is provisionally classified as temporal or regional until geometry shows otherwise. A candidate that increases only on a service corridor is provisionally classified as conducted or infrastructure-coupled. A candidate that changes coherently across all X, Y and Z components at multiple inward radii may justify a closer premises-centred test, but not attribution.

Every regional station is documented contemporaneously in a bound or pre-numbered paper log. The station identifier, planned and actual bearing, coordinates, height, start and stop time, personnel, probe geometry, receiver state, calibration reference, environmental condition, equipment movement, anomaly and decision are written while the activity occurs. Instrument metadata and later analyst notes supplement the paper record but do not replace it. A reconstructed note prepared after departure is identified as retrospective and cannot be silently presented as contemporaneous field documentation.

12A.3 Altitude, terrain and slant range. Horizontal map radius and electromagnetic path length are not identical. A station on a hill, upper storey, parking structure or roof may have a markedly different slant range and line of sight than a station at grade. The record therefore includes elevation above the declared site datum and, when useful, the slant range R = sqrt(rho^2 + delta-z^2), where rho is horizontal separation and delta-z is vertical separation. The method does not use elevation to claim free-space propagation in a cluttered environment. It uses elevation to make the geometry explicit and to prevent a high-ground station from being compared as though it were coplanar.

12A.4 Regional stop conditions. Work stops or moves when the station is unsafe, obstructs traffic, violates property or spectrum rules, compromises privacy, creates an aviation or clinical risk, attracts uncontrolled public interaction, or cannot maintain instrument security. No measurement objective justifies an unsafe roof, ladder, mast, vehicle position, roadside shoulder, subterranean space, drone flight or restricted-area entry. The preferred high ground is the highest lawful, structurally suitable and safely accessible position, not the greatest conceivable altitude.

12A.5 Regional sub-audio, infrasonic and quasi-static environmental baseline

The outer annuli provide the only practical opportunity to determine whether a slow or infrasonic feature is regional rather than premises-centred. A persistent pressure oscillation that is coherent at the 5-mile and 2.5-mile stations may arise from weather, microbaroms, distant industrial activity or another regional source. A magnetic variation coherent across several miles may be geomagnetic, power-system related or instrumental. A floor-acceleration line that appears only on one structure may be local machinery. These distinctions cannot be made from a single receiver inside the target room.

The mobile team records a minimum screening dwell appropriate to the frequency under examination, while one or more fixed sentinels provide the long records required below approximately 0.01 Hz. A station occupied for ten minutes cannot establish behaviour at 0.001 Hz, because it has not observed even one complete cycle. The report must therefore state the lowest frequency supported by the actual observation duration and must not describe nominal instrument bandwidth as demonstrated campaign coverage.

Elevated positions are used only where lawful, structurally suitable and safe. Height can improve separation from ground-borne vibration, provide a different acoustic path and reduce obstruction, but it can also increase wind noise, building sway and electric-field exposure. The highest safe and authorised point is a comparison station, not an automatic optimum.

The five outer annuli are processed from outside inward under a pre-approved station-density plan. At 5 miles, sixteen stations establish the broad emitter census and receiver-noise portrait, or twenty-four stations where the risk classification requires fifteen-degree angular sampling. The 2. 5-mile and 1-mile annuli repeat the same sixteen-station architecture, again increased to twenty-four in high-risk work. The 0. 5-mile annulus ordinarily uses twelve stations, although an access-constrained plan may proceed with eight if the missing sectors and interpretive limitations are expressly approved. The 0. 25-mile annulus should use twelve stations and shall not use fewer than eight. The 300-foot ring then becomes the first premises-referenced controlled comparison. Each inward movement requires review of the fixed reference channels and the contemporaneous paper record, not merely a stronger trace on the mobile receiver.

Horizontal map radius and electromagnetic path length are not identical. A station on a hill, upper storey, parking structure or roof may have a markedly different slant range and line of sight than a station at grade. The record therefore includes elevation above the declared site datum and, when useful, the slant range R = sqrt(rho^2 + delta-z^2), where rho is horizontal separation and delta-z is vertical separation. The method does not use elevation to claim free-space propagation in a cluttered environment. It uses elevation to make the geometry explicit and to prevent a high-ground station from being compared as though it were coplanar.

Chapter Glossary

Terms used in Chapter 17: A. Regional Spectrum Inventory from Five Miles to the 300-Foot Transition.

A

ANOMALY — An observation that differs from a defined baseline or expected model; an anomaly is not, by itself, a hostile finding.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

E

ENVIRONMENTAL BASELINE — A time-, place-, configuration-, and instrument-specific model of ordinary signals, noise, occupancy, and infrastructure behaviour.

L

LINE OF SIGHT — Straight line from a radar antenna to a target.

P

PROPAGATION — Waves traveling through a medium.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

S

SLANT RANGE — See RANGE.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

13. Field Procedure: Five-Mile Regional Inventory, Thirteen-Radius Nested Survey and 3-Inch Convergence

The operative search sequence is 5 miles, 2.5 miles, 1 mile, 0.5 mile, 0.25 mile, 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet, 3 feet, followed by stationary 3-inch decrements and a three-dimensional 3-inch lattice. The 5-mile, 2.5-mile and 1-mile annuli each use sixteen planned locations, or twenty-four locations in a high-risk commission. The 0.5-mile annulus ordinarily uses twelve and shall use no fewer than eight. The 0.25-mile annulus should use twelve and shall also use no fewer than eight. The regional annuli inventory the surrounding transmitter and noise environment. The 300-foot ring begins the controlled premises comparison. Substituted stations, skipped sectors, noncontemporaneous comparisons and incomplete ring counts are recorded as limitations rather than concealed by nominal compliance.

The procedure is deliberately slow, quiet, geometry-controlled and contemporaneously documented. Speed is subordinate to comparability, scene preservation and the avoidance of experimental perturbation. The complete campaign is not intended to be performed in a few hours or a single day. It commonly unfolds over weeks, with four-to-five-day field segments separated by analysis and passive-monitoring intervals, and it may extend over months when the relevant emissions are rare or state-dependent. Each equipment item is introduced, placed and moved at a measured pace. Its position is recorded before acquisition and again after movement. Every inward series has a corresponding withdrawal or closure series. The purpose of unobtrusive movement is not to authorise deception, trespass or evasion of lawful oversight. It is to avoid changing the behaviour of an intermittent source or a human operator, and to preserve the electromagnetic boundary conditions of a scene that may involve suspected technical interference.

Stage	Action	Control purpose
1. Authority and safety brief	Confirm scope, exclusions, legal authority, privacy limits, clinical restrictions, stop-work authority, emergency route and critical equipment.	Signed and time-stamped opening record.
2. Establish the 5-mile regional inventory	Occupy sixteen lawful, safe and approximately equiangular stations around the nominal annulus. Increase to twenty-four stations for a high-risk commission. Record coordinates, altitude, actual azimuth, antenna set, receiver state, paper-log page and long-dwell spectral occupancy. Deploy at least one stationary sentinel.	Defines broad-area emitters and receiver behaviour before the inspected site can dominate operator attention.
3. Advance to the 2.5-mile annulus	Repeat the sixteen-station geometry, or the twenty-four-station high-risk geometry, with matched bands, directions and time windows. Compare bearings, burst recurrence, field-strength changes and sentinel coherence.	Separates persistent regional services from features beginning to exhibit site-bearing or terrain-dependent behaviour.

Stage	Action	Control purpose
4. Advance to the 1-mile annulus	Resolve local cellular, land-mobile, fixed-link, utility, transport, consumer and intermittent activity at sixteen stations, or twenty-four stations in a high-risk commission, using common-timebase capture and contemporaneous paper records.	Builds the local emitter census and identifies schedules that could confound a shorter inspection.
5. Advance to the 0.5-mile annulus	Acquire twelve neighbourhood and adjacent-premises stations. If access makes twelve impracticable, use no fewer than eight and identify every unmeasured sector. Include service corridors and feasible high-ground observations.	Tests whether a candidate belongs to the wider neighbourhood, an extended conductor, or the site vicinity.
6. Advance to the 0.25-mile annulus	Create the immediate site-adjacent record from twelve stations where practicable and never fewer than eight. Preserve outer sentinels, record vertical tiers, and complete the paper station ledger before advancing to 300 feet.	Establishes the final regional comparison before the 300-foot controlled transition.

Stage	Action	Control purpose
7. Establish the 300-foot site-transition ring	Place remote recorder, disciplined reference clock and broad sensor set at measured 300-foot stations, or document the greatest available radius and missing sectors.	Converts the regional inventory into the first controlled premises-referenced baseline and prevents the team from beginning inside an already selected anomaly.
8. Receiver and probe blanks	Acquire terminated-input, dummy-probe, amplifier-bypass, gain-step and preselector traces at the remote reference.	Identifies internal spurs, phase-noise skirts, overload, aliases and probe-independent lines.
9. Personnel and equipment characterisation	Introduce each person, battery, cable, probe, recorder and accessory individually to the reference channel, then remove it.	No item advances until its emissions are catalogued or controlled.
10. Complete the 300-foot azimuth set	Measure four or more cardinal or site-defined stations with fixed sensing-centre height and axis; acquire lateral controls outside the apparent bearing.	Distinguishes premises-centred structure from remote directionality and local clutter.
11. Advance to the 150-foot ring	Repeat the 300-foot configuration at matched azimuths, heights, axes, gain, bandwidth and dwell while the fixed remote channel records.	Creates the first controlled inward comparison and tests external bearing, time variation and mobile-system effects.
12. Advance to the 100-foot ring	Repeat matched 150-foot stations with the 300-foot reference retained; add orientation repeats only after the core set is complete.	Tests recurrence and spatial behaviour across three exterior scales.

Stage	Action	Control purpose
13. Advance to the 50-foot ring	Repeat matched stations, map immediate infrastructure and preserve discovery bandwidth.	Identifies broad gradients and designs the 30-foot service-path tests.
14. Advance to the 30-foot ring	Acquire matched radial stations and short parallel or perpendicular transects across suspected cables, pipes, fences, earth conductors and buried services. Introduce smaller probes only through overlap.	Separates premises convergence from extended conductive or service-path coupling.
15. Establish the 15-foot pre-boundary ring	Acquire wall-normal, wall-tangential and vertical measurements with doors closed and ordinary systems unchanged; reserve matched points for 12 feet.	Creates a stable pre-threshold state and identifies entry-sensitive or service-penetration candidates.
16. Establish the 12-foot envelope	Survey the accessible perimeter, services, floor, ceiling and entry plane at stations matched to the 15-foot set without touching the premises or changing its state.	Separates wall, cable, aperture and interior-source hypotheses.
17. Threshold dwell	Hold all sensors stationary outside the entry for the validated dwell. Record door, HVAC, lift, traffic, lighting and critical-system state.	Creates the immediate before-entry comparison.

Stage	Action	Control purpose
18. Controlled entry	One examiner and one pre-cleared sensor assembly enter. No further item enters until the candidate and blank traces are reviewed.	Prevents unexplained lines from entering with the team.
19. Unaltered-state survey	Measure the authorised volume in its ordinary state before switching or moving equipment.	Preserves natural context and constrains hypothesis-driven quieting.
20. Three-foot coarse grid	Traverse complete 3-foot cells, rings or equivalent transects at declared heights and axes with serpentine motion and stationary dwell.	Creates uniform volumetric coverage and candidate gradients.
21. Candidate gate	Apply predeclared recurrence, independence, linearity, frequency, gradient and blank criteria before reducing spacing.	Prevents a visually attractive but unconfirmed trace from controlling the search.
22. Probe-aperture transition	Substitute a smaller ferrite rod, shielded loop, gradiometer or electric-field probe only after an overlap station is acquired with both probes.	Separates transfer-factor change from true spatial increase.
23. Three-inch convergence ladder	Reduce radial standoff or raster spacing in exact 3-inch steps, recording every point, axis, height, dwell, null and reference trace. Re-centre only after a complete block.	Produces the smallest supported bounding region without contact or imaging.

Stage	Action	Control purpose
24. Vertical and opposite-face tests	Repeat selected 3-inch stations at changed height, opposite wall or accessible rear surface, and reversed orientation.	Constrains depth and discriminates a local source from an extended conductor or shield seam.
25. Independent confirmation	Repeat the candidate with a second sensor architecture, receiver path, operator or time window plus terminated and dummy controls.	Required before classification as a confirmed and localised electronic signal.
26. Optional controlled excitation	Only after passive completion and separate legal, spectrum, exposure, clinical and safety approvals. Apply the minimum planned field and monitor independently.	Permits limited resonance or backscatter testing without commands, payload access or image formation.
27. Reverse path and data closure	Withdraw through the 3-inch points, 3-foot grid, threshold, 12-foot, 15-foot, 30-foot, 50-foot, 100-foot, 150-foot, 300-foot and selected regional sentinel stations; hash files, reconcile clocks and document environmental changes.	Tests drift and time variation while completing chain of custody.

13.1 Default acquisition set at each point

- Broad discovery sweep at validated low gain with overload indicator recorded.

Advanced practitioner analysis. At expert-practitioner level, Default acquisition set at each point is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty .

- Selected timing-band traces, including 32.768 kHz and its validated search window, with narrow and wide views.
- Zero-span or time-domain recording sufficient to observe duty cycle, burst timing and intermittent operation.
- Three orthogonal magnetic-probe orientations and, where relevant, electric-field orientation.
- Probe height, standoff, axis, coordinates, timestamp, environmental state, gain, RBW, VBW, detector, dwell and reference-clock status.
- A short blank or dummy-probe trace at the start and end of each grid row or other validated interval.

• A minimum of three simultaneously sampled X-Y-Z channels for every evidential field measurement. The normal deployment uses three pods and nine simultaneous probe channels.

• Common timebase, frequency-reference, trigger, channel-skew, group-delay and lock status for the complete multichannel block.

• Per-channel resonance state, varactor bias, piston setting, settling interval and tracking-receiver bandwidth, with all tuned channels in hold during acquisition.

• Where a 12-channel or 192-channel chassis is used, channels 10 through 12 are assigned to illumination or source reference, terminated or calibration control, and guard or independent confirmation before the station begins.

At every exterior ring, threshold station, interior grid point and three-inch localisation point, the examiner maintains three parallel records. The Tier 1 record captures baseband timing and clock-family evidence. The Tier 2 record captures free-radiated or conducted RF evidence. The Tier 3 record remains marked not performed during passive work and, if separately authorised later, captures illumination and response states without overwriting the passive series. This separation permits an independent reviewer to determine whether the apparent source gradient preceded or followed deliberate excitation.

Record group	Required fields at every ring or grid stage
Tier 1 timing record	Candidate fundamental, timing-family hypothesis, harmonics, subharmonics, divider products, frequency and uncertainty, phase or coherence where available, burst interval, jitter, probe type, axis, height, bandwidth, dwell and reference-clock status.
Tier 2 radiated record	Carrier or centre frequency, occupied bandwidth, modulation or burst description, field component, calibrated amplitude and uncertainty, antenna or probe, polarisation, azimuth, elevation, bearing, cable or service-path association, detector and repeatability.
Tier 3 illumination record	Illumination frequency, waveform, conducted power, antenna gain, estimated or measured field, azimuth, elevation, polarisation, source state, suspected response frequency, PPM or other modulation metric, latency, controls, independent receiver and confidence class.
Common controls	Coordinate and uncertainty, environmental and premises state, personnel state, instrument configuration, blank or dummy file, gain and preselector state, raw-file identifier and hash, deviations, stop events and examiner note.

13.2 Stage A, 300-foot remote-reference ring

Purpose and geometry. The 300-foot ring is the site-transition stage. It does not replace the five regional annuli and no longer carries the burden of constructing the regional emitter census by itself. Eight or more principal azimuths are preferred, with complete actual coordinates and at least two heights when lawful access and safety permit. The ring tests whether features preserved through the regional campaign begin to exhibit premises-referenced behaviour. The stated distance is measured to the electrical or magnetic sensing centre of the probe. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations, identifies the omitted solid angle and retains the nearest valid regional sentinel for temporal correction.

Spatial-measurement interpretation. At expert-practitioner level, Stage A, 300-foot remote-reference ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location.

Instrumentation. The remote recorder and reference clock remain outside the probe aperture. Broadband magnetic and electric sensors, the long low-frequency rod and appropriate higher-frequency antennas are characterised at each station. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Acquire terminated-input and dummy-probe records first, then environmental records at each azimuth without changing gain or tuning. Repeat a subset after the full ring to quantify time drift, and leave a stationary reference at a low-interference point when feasible. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Instrument states, personnel positions and external events are logged, and the strongest bearing is repeated with a second sensor. The team specifically tests regional transmitters, road vehicles, utility lines, weather, neighbouring buildings and the search equipment itself. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Advance when the system is stable, blanks are satisfactory and the next ring will test a defined candidate or establish a lower-distance background. The output is a remote spectral and directional baseline, not a promise that an ultra-low-power internal source was detectable. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.3 Stage B, 150-foot outer-transition ring

Purpose and geometry. The 150-foot ring is the first controlled transition away from the 300-foot remote-reference environment. Stations are matched to the principal 300-foot azimuths, probe-centre heights and sensing axes wherever access permits. At least one lateral control is placed outside any apparent radial bearing. The stated distance is measured to the electrical or magnetic centre of the probe. Where a complete ring is impossible, documented arcs, chords and radial stations are used without interpolating across unexamined sectors.

Scene-geometry elaboration. At expert-practitioner level, Stage B, 150-foot outer-transition ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

I**nstrumentation**. T**h**e large air-core loop, long ferrite rod, electric-field probe, applicable higher-frequency antenna, preamplifier, receiver and clock configuration used at 300 feet are repeated before any smaller or differently tuned sensor is introduced. The fixed capacitor bank and sapphire piston setting remain locked. The fixed 300-foot reference channel continues to record where practicable. Settling time is observed after movement, and no audible or target-seeking indication is presented to the positioning operator.

Search action. Complete the matched 150-foot station set before adding candidate-centred points. Acquire broad discovery, candidate-band, time-domain and blank records at identical gain, bandwidth, orientation and dwell. Record roads, vehicles, overhead conductors, fences, neighbouring premises and mobile transmitters that can dominate this radius. Repeat the strongest, weakest and one lateral-control station after the ring to estimate time variation.

Controls. Compare the mobile channel with the stationary 300-foot channel, terminated input, dummy probe and gain-step trace. A candidate that follows the team, cable route, receiver state or common temporal change is not treated as a premises-centred gradient. A candidate need not rise monotonically, but it must show a reproducible frequency, vector, phase, coherence or spatial relation exceeding combined repeatability and reference-channel variation.

Gate and output. Advance to 100 feet only when the system remains stable and the 100-foot geometry will test a stated alternative, such as a premises-centred trend, persistent external bearing or negative coverage. The output is the first matched inward comparison, with actual coordinates, uncertainty, external-source observations and reasons for advancement or hold. A negative 150-foot result does not exclude an ultra-low-power or intermittent source.

13.4 Stage C, 100-foot comparison ring

Purpose and geometry. The 100-foot ring tests whether candidate behaviour persists or changes after the 150-foot outer-transition stage. Stations correspond as closely as possible to the 150-foot azimuths, while the stationary 300-foot reference supplies wider environmental context. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve matched comparisons. Missing azimuths are treated as unexamined sectors and are not filled by interpolation.

Spatial-measurement interpretation. At expert-practitioner level, Stage C, 100-foot comparison ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. The same probe configuration and broad acquisition are used first, followed by candidate-band confirmation without field retuning. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Repeat one matched 150-foot station and verify the 300-foot reference before moving inward, then acquire the complete 100-foot ring and repeat its strongest and weakest stations. Use identical dwell, orientation and probe configuration, with extra points only after the comparison set is complete. Candidate selection is deferred until the planned station block is complete, except where an immediate safety or overload condition requires intervention. All weak, negative and contradictory observations remain in the case record.

Controls. The stationary 300-foot reference, one repeated 150-foot point, a gain-step test and a dummy-probe check are reviewed before candidate promotion. The team specifically tests time variation, operator carriage, cable motion, intermediate outdoor equipment and external sources aligned with one radial path. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate appearing on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Advance to 50 feet only when recurrence, linearity and a meaningful spatial question are documented. The output states whether the candidate increased, decreased, remained unchanged or behaved inconsistently relative to the matched 150-foot station, with the 300-foot record retained as remote context. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.5 Stage D, 50-foot site-discrimination ring

Purpose and geometry. The 50-foot ring examines immediate external infrastructure and prepares the service-path questions that will be tested at 30 feet. Principal azimuths are matched to the 100-foot ring and supplemented near service entrances, overhead conductors, plant, neighbouring structures and strong remote bearings. The stated distance is measured to the electrical or magnetic centre of the probe. Documented arcs, chords or radial stations are used where a complete ring is impossible, with missing azimuths retained as unexamined sectors.

Three-dimensional search analysis. The mature treatment of Stage D, 50-foot site-discrimination ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

Instrumentation. Magnetic and electric probes are paired, and higher-frequency antennas are measured at changed heights in separate controlled series. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Acquire regular ring points before targeted service-path points, then perform angular null scans at selected low-frequency maxima. Mark the fences, pipes, cables, drains, earthing conductors and other paths that will receive paired radial and transverse measurements at 30 feet. Use lateral points around isolated maxima and maintain the same candidate-band settings through the complete block. Candidate selection is deferred until the planned station set is complete.

Controls. Compare both sides of accessible service routes, repeat after a known external event and use an independent receiver for material candidates. The team specifically tests buried services, utility plant, vehicles, metal fences, reflections and extended conductors. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Advance to 30 feet when the data support a defined service-path or premises-convergence question and do not reduce the candidate to an instrument or clearly external explanation. The output identifies bearings, external infrastructure, contradictory points and the radial or transverse station pairs required at 30 feet. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed.

13.6 Stage E, 30-foot service-path discrimination ring

Purpose and geometry. The 30-foot ring bridges broad exterior mapping and near-boundary examination. Stations remain matched to the 50-foot ring, but selected sectors also receive short transects parallel and perpendicular to fences, pipes, buried services, protective-earth conductors, cable routes, drains and structural members. Actual distance to both the premises datum and the nearest boundary surface is recorded because irregular buildings can make a nominal radius misleading.

Scene-geometry elaboration. The mature treatment of Stage E, 30-foot service-path discrimination ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. The outgoing large-aperture loop or rod is measured first. A medium-aperture ferrite rod, compact loop, gradiometer or service-path probe may then be introduced through a documented overlap station. Lower gain and broad discovery bandwidth are used before high-Q confirmation. Resonant frequency, Q, input headroom and probe noise are checked before and after the ring because nearby metal can detune the ferrite assembly or concentrate flux.

Search action. Complete matched radial stations before denser candidate-sector measurements. Acquire paired points on both sides of an accessible service route and at lateral offsets sufficient to determine whether the field follows an extended path or converges on the premises. Preserve identical probe centre, axis, height and dwell within each series. No one-dimensional inverse-square law is imposed.

Controls. Repeat selected points with the probe rotated, the concentrator removed where the configuration permits, a dummy probe connected and the cable route held constant. Compare along-path and cross-path gradients, check for vehicle or utility-state changes, and repeat a 50-foot overlap point after the 30-foot ring. A strong line following a service conductor is reported as a path association, not as proof of an internal miniature device.

Gate and output. Advance to 15 feet when the data support a candidate sector, a controlled near-boundary comparison or a comprehensive negative exterior mapping. The output states whether the candidate is premises-centred, external-bearing, extended-path-associated or unresolved, with uncertainty and omitted sectors. The 30-foot stage is not silently collapsed into the 50-foot or 15-foot stages.

13.7 Stage F, 15-foot pre-boundary comparison ring

Purpose and geometry. The 15-foot ring establishes a stable pre-boundary comparison before the 12-foot building-envelope examination and threshold operations. Stations are referenced to accessible wall faces, doors, windows, floor or roof boundaries and service penetrations. The probe axes are defined as boundary normal, boundary tangent and vertical. The actual probe-centre standoff is recorded at every point.

Spatial-measurement interpretation. At expert-practitioner level, Stage F, 15-foot pre-boundary comparison ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. The same primary probe configuration and receiver settings intended for the 12-foot ring are used first. Medium-aperture rods or loops may supplement the large probe only after overlap. An electric-field channel is acquired with a fixed support and personnel-position convention. A fixed near-boundary reference can be established at a low-gradient 15-foot station after its emissions and mechanical influence are characterised.

Search action. Acquire the complete planned 15-foot set while doors remain closed and the premises remains in its ordinary authorised state. Measure principal approach sectors and lateral offsets around service penetrations or wall maxima. No person enters the premises and no unknown object is touched. Candidate sectors are selected only after the complete ring or authorised partial geometry is finished.

Controls. Repeat the 300-foot reference and at least one 30-foot control where practicable. Verify receiver headroom, fixed capacitor and sapphire-piston settings, mechanical settling, dummy-probe response and personnel stand-off. Test whether an apparent maximum follows wall reinforcement, service penetration, door hardware or nearby known electronics. Geometry or safety restrictions are recorded rather than relabelled as completed 15-foot and 12-foot measurements.

Gate and output. Advance to 12 feet only when the pre-boundary state is stable, safety and clinical conditions remain satisfied, and the 12-foot stations will test a stated boundary-coupling question. The output is a matched 15-foot station set, wall-relative vector record, candidate-sector map and explicit basis for threshold approach. The 15-foot ring does not authorise entry.

13.8 Stage G, 12-foot building-envelope ring

Purpose and geometry. The 12-foot ring resolves sectors of the building envelope, apertures and service penetrations after the 15-foot pre-boundary comparison is complete. Points follow walls, corners, doors, windows and penetrations at nominal 12-foot standoff or the nearest comparable authorised distance. Stations are matched to the 15-foot wall-normal, wall-tangential and vertical coordinate convention. The stated distance is measured to the electrical or magnetic centre of the probe. Missing sectors remain explicit and are not filled by interpolation.

Spatial-measurement interpretation. For Stage G, 12-foot building-envelope ring, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Instrumentation. The long ferrite rod, air-core loop, electric-field probe, gradiometer where useful and higher-frequency probe are applied in declared order. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Measure regular boundary points first, then repeat maxima at orthogonal orientations and heights without touching the structure. Record actual wall standoff and compare each material 12-foot station with its 15-foot counterpart. Scan laterally across a maximum to determine whether it is compact, ridge-like, aperture-associated or service-path-associated. Candidate selection is deferred until the planned station block is complete.

Controls. Use the outside stationary reference, repeat the matched 15-foot station, reverse direction along the envelope and compare magnetic with electric response. The team specifically tests steelwork, wiring, door contacts, lighting, service cables, reflections and body capacitance. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. Independent confirmation remains necessary for material candidates.

Gate and output. Entry occurs only after a threshold plan, safety check and interior geometry are ready. The output is a ranked set of envelope sectors and alternative coupling paths, not an object location. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.9 Stage H, threshold dwell and controlled entry

Purpose and geometry. The threshold stage separates effects of entry, door state, personnel position and automatic building responses from genuine interior gradients. Matched points are established immediately outside and inside the threshold, with a fixed reference remaining outside. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve the intended comparison as far as lawful access allows. Missing azimuths are treated as unexamined sectors and are not filled by interpolation in the final conclusion.

Advanced practitioner analysis. At expert-practitioner level, Stage H, threshold dwell and controlled entry is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Instrumentation. A compact quiet assembly enters first while the recorder and unnecessary electronics remain remote. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Record closed-door, open-door, unoccupied-inside and occupied-inside states only where safe and authorised, restoring each condition. Dwell long enough to include known automatic-lighting or access-control delays, and note every change. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Repeat door and entry states, use a no-entry sham interval and compare the stationary reference. The team specifically tests door sensors, lighting, HVAC, body capacitance, shielding change and source activation caused by ordinary occupancy. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. The interior survey begins when threshold effects are understood or explicitly retained as limitations. The output distinguishes a premises-state transition from a location-dependent field where possible. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.10 Stage I, interior three-foot coarse grid

Purpose and geometry. The interior grid searches the complete authorised volume without beginning beside a suspected object. Nominal three-foot cells are sampled on a serpentine path at validated heights and axes, with inaccessible cells recorded. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve the intended comparison as far as lawful access allows. Missing azimuths are treated as unexamined sectors and are not filled by interpolation in the final conclusion.

Three-dimensional search analysis. At expert-practitioner level, Stage I, interior three-foot coarse grid is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. Broad magnetic, tuned low-frequency, electric-field and higher-frequency channels are assigned by the deployment matrix. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Complete each row or block before candidate ranking, and keep the probe stationary on a non-conductive support during dwell. Repeat neighbouring cells around any candidate in reverse order and add vertical points when source elevation is uncertain. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Use reference normalisation where valid, probe rotation, local blanks and a second sensor at the candidate and a low-response point. The team specifically tests time variation, wiring ridges, ceiling or floor sources, furniture metal, moving people and probe-aperture averaging. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Declare a provisional local origin only after a stable neighbouring gradient survives controls. The output is a bounded candidate region large enough to contain the supported field source or coupling path. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.11 Stage J, three-foot candidate-containment ring

Purpose and geometry. The three-foot ring converts a coarse grid anomaly into a controlled local spatial model. Twelve positions at 30-degree intervals are preferred around the provisional centre, or an equivalent orthogonal perimeter in constrained space. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve the intended comparison as far as lawful access allows. Missing azimuths are treated as unexamined sectors and are not filled by interpolation in the final conclusion.

Scene-geometry elaboration. At expert-practitioner level, Stage J, three-foot candidate-containment ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. The outgoing larger probe is measured first, followed by a smaller loop or rod, gradiometer and electric-field comparison. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Acquire the complete ring before re-centring and measure three axes or a validated subset at consistent height and standoff. Include overlap points, a low-response point and a reverse ring before entering fine convergence. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Probe substitution, channel independence, null reversal and time-separated repeats are mandatory for a material candidate. The team specifically tests standing waves, conductive ridges, multiple sources, broad aperture and a visually favoured centre. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Proceed when two observables support a smaller region and the incoming probe tracks the same signal family. The output is a revised local origin, source-model choice and uncertainty for the fine-search geometry. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.12 Stage K, three-inch radial decrement

Purpose and geometry. The radial decrement narrows the region without touching the premises or constructing an image. Radii are 36, 33, 30, 27, 24, 21, 18, 15, 12, 9, 6 and 3 inches, measured to the probe centre. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve the intended comparison as far as lawful access allows. Missing azimuths are treated as unexamined sectors and are not filled by interpolation in the final conclusion.

Advanced technical elaboration. A technically mature treatment of Stage K, three-inch radial decrement begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Instrumentation. Small-aperture rods, shielded loops, gradiometers and electric-field probes are used with a simultaneous broader reference where high Q is employed. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Complete every point on one radius before calculating a new centre, and lock the probe configuration throughout that ring. At least two axes or observables are used, with a stationary dwell and measured mechanical settling interval at each step. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Reverse selected radii, repeat the provisional maximum and low point, and confirm with a second probe and receiver. The team specifically tests detuning, probe ringing, cable motion, aperture effects, surface capacitance and multiple maxima. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Continue only while the next radius is predicted to distinguish competing locations or source models. The output is an increasingly bounded coordinate interval with preserved uncertainty and re-centring history. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.13 Stage L, three-inch Cartesian and vertical lattice

Purpose and geometry. The final lattice addresses walls, surfaces and three-dimensional regions that cannot be represented by complete circles. Points are spaced at nominal three-inch intervals along accessible x, y and z directions, with standoff fixed for each plane. The stated distance is measured to the electrical or magnetic centre of the probe, not to the operator, tripod foot or recorder. Where a complete ring is impossible, the team uses documented arcs, chords or radial stations that preserve the intended comparison as far as lawful access allows. Missing azimuths are treated as unexamined sectors and are not filled by interpolation in the final conclusion.

Advanced technical elaboration. For expert practice, Stage L, three-inch Cartesian and vertical lattice is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Instrumentation. The smallest validated probe, differential channel and independent confirmation path are used. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Traverse through and beyond the maximum on both sides where access permits, rather than approaching from one direction only. Record every actual coordinate, aperture, orientation, height, standoff and inaccessible point. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Use axis reversal, probe substitution, reference channel and reverse traversal of the local line or plane. The team specifically tests one-sided depth ambiguity, wall reinforcement, cable routes, edge concentration and coordinate error. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. Stop when the validated resolution floor is reached, further movement risks contact, or remaining ambiguity cannot be reduced non-invasively. The output is an anisotropic three-dimensional bounding region, not the outline or image of a device. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.14 Stage M, reverse-path withdrawal and closure

Purpose and geometry. The withdrawal stage tests whether the inward spatial pattern survives time, instrument and environmental change. Selected three-inch points, the three-foot ring, grid controls, threshold, 12-foot, 15-foot, 30-foot, 50-foot, 100-foot, 150-foot and 300-foot stations are repeated in reverse order. The stated distance is measured to the electrical or magnetic centre of the probe. Where complete repetition is impossible, the validated shortened reverse set and its limitations are recorded.

Spatial-measurement interpretation. At expert-practitioner level, Stage M, reverse-path withdrawal and closure is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Instrumentation. The same configurations remain fixed, with final blanks and reference checks acquired before shutdown. The default acquisition includes a broad discovery record, a candidate-band record, a time-domain or spectrogram record where intermittency matters, and a stationary blank or reference channel. Probe orientation and height are repeated in a declared order. The sensor is stationary during dwell, and the operator remains at the validated personnel stand-off. A high-Q resonant probe is allowed to settle after movement before acquisition begins.

Search action. Repeat material points, reconcile changes with the stationary reference and document all premises-state differences. Use the predeclared shortened reverse set only when full repetition is impracticable and its coverage is validated. Candidate selection is deferred until the planned station set or block is complete, except where an immediate safety or overload condition requires intervention. This rule limits expectation-driven steering toward an attractive trace. All points, including weak, negative and contradictory observations, remain in the case record.

Controls. Post-series termination, dummy probe, reference-source check, battery and temperature record, and raw-file hash closure are required. The team specifically tests source intermittency, instrument drift, temperature, building cycles, battery change and altered occupancy. A candidate that follows time, personnel carriage, cable position, sample rate, gain state or the instrument blank does not satisfy the spatial proposition. A candidate that appears on only one architecture remains unresolved until an independent path confirms compatible frequency and location behaviour.

Gate and output. The case proceeds to interpretation only after integrity, calibration and control completeness are reviewed. The output states reproducibility, unresolved temporal effects and the final defensible source-associated region. The stage does not guarantee detection at the stated distance and does not establish absence when nothing is observed. Its function is to add controlled spatial evidence. The examiner records the reason for advancement, repetition, lateral expansion, re-centring or termination before equipment is moved.

13.15 Stage N, sub-20 Hz Multiphysics continuation through every ring

The sub-20 Hz workstream begins at the regional annuli and remains active through the 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot, 3-foot and three-inch stages. At each point, the examiner records pressure, motion, electric field, magnetic field, weather, building state, instrument state and time-base health. Where a domain is not measured, the omission and its consequence are entered contemporaneously. No station is described as a complete sub-20 Hz station merely because one low-frequency magnetic probe was present.

The close rings use matched opposite-surface measurements. Walls are measured on both sides where access permits; floors are paired with the room below or the accessible structural underside; ceilings are paired with the plenum, loft, roof space or room above. The examiner compares amplitude, phase, delay, vector orientation and coherence. A structure-borne signal that strengthens on the floor and remains weak in pressure is treated differently from an airborne pressure field that is coherent across the room, or a quasi-static magnetic gradient that follows a conductor.

At the three-inch convergence stage, the centre cell is still a hypothesis region rather than a presumed source. Slow fields can be spatially broad, and a narrow amplitude maximum may be produced by a sensor, cable, ferromagnetic object, pressure leak or structural mode. Reverse-path closure, sensor substitution, polarity reversal, dummy channels, motion controls and an exterior reference are mandatory before a local source is inferred.

Chapter Glossary

Terms used in Chapter 18.

A

ANOMALY — An observation that differs from a defined baseline or expected model; an anomaly is not, by itself, a hostile finding.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BEARING — An angular direction from a defined reference meridian or axis to a source, target, or line of sight.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

L

LOOP — A curved conductor that connects the ends of a coaxial cable or other transmission line and projects into a waveguide or resonant cavity for the purpose of injecting or extracting energy.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

14. Interior Grid Search and Fine Localisation

The interior method is expanded by Chapter 32 into a scale-dependent 3 by 3 by 3 neighbourhood. The candidate cell occupies the centre of twenty-seven cells, and each measurement is paired with face, edge and corner comparisons, opposite surfaces, and feasible vertical observations from the storey below or above. The geometry is repeated at coarse, intermediate and fine scales rather than assuming that a single floor plan contains the relevant field.

14.1 Grid design

The grid uses alphanumeric and Cartesian coordinates rather than object photographs. The authorised interior is first divided into 3-foot cells or a validated equivalent, with declared x, y and z origins, sensing-centre height and probe axis. Around a confirmed candidate, the grid contracts through overlapping stations to 3-inch increments. A radial sequence from 36 inches to 3 inches contains twelve nominal standoffs, but the centre may be re-estimated after each completed ring or raster block. Actual distances are recorded rather than rounded to the nominal label. Every reduction retains at least one overlap measurement with the preceding probe aperture so that an apparent increase caused by changing sensor transfer factor is not mistaken for spatial convergence.

Three-dimensional search analysis. For Grid design, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

14.2 Search motion

The default path is serpentine, sometimes called boustrophedon, so that every cell is visited without repeated long transits. The probe moves slowly and stops before acquisition. Motion-induced voltages, triboelectric cable noise, hand-capacitance changes and microphonic components must settle. The examiner does not sweep a probe rapidly in search of an audible response because the method has no acoustic alert and because motion can manufacture the very transient being sought.

Three-dimensional search analysis. The mature treatment of Search motion replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

14.3 Dwell and intermittency

Dwell time is band- and hypothesis-dependent. A coarse dwell may be seconds, whereas a low-duty-cycle or highly stable oscillator may require minutes of coherent observation. The validation study shall establish the probability of detection as a function of dwell, duty cycle and signal level. If a signal appears only once, the examiner extends observation and records it as a transient until recurrence or an independent correlating event is established.

14.4 Fine localisation outputs

The output is a three-dimensional bounding region expressed through coordinates, probe aperture, standoff and expanded uncertainty, not an image of an object. The final region is supported by the 3-foot geometry, the 3-inch decrement or raster sequence, orthogonal axes, loop or rod nulls, differential or gradiometric response, height changes, reverse-path repeats and independent instrumentation. Example: a confirmed 32.7679 kHz magnetic component may be reported as strongest within x = 2.31-2.46 metres, y = 1.08-1.23 metres and z = 0.61-0.76 metre, after aperture and coordinate uncertainty are included. This supports a source or coupled-conductor region. It does not identify the article within that volume and does not establish a medical effect.

Spatial-measurement interpretation. At expert-practitioner level, Fine localisation outputs is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

14.5 Amplitude gradients, null planes and phase fusion

Fine localisation shall combine complementary observables rather than treating amplitude as a complete source locator. The governing physical or metrological basis is amplitude indicates relative coupling, a directional null defines a bearing plane, a gradiometer indicates local gradient, and coherent phase can distinguish orientation or common source. The examiner shall treat this basis as a testable model rather than an assumption. Each observable can be distorted by multiple sources, cross-axis pickup or structural materials. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Synchronous measurement elaboration. The purpose of Amplitude gradients, null planes and phase fusion is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

The required configuration is as follows. Measurements are taken from at least two coordinates and orientations with a fixed reference where phase is used. The primary observables are gradient vector, null angle, null depth, phase difference, differential channel and uncertainty. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are rotation in both directions, channel interchange, repeated bearings and alternate probe geometry. The principal artefacts and confounders are mechanical backlash, cable torque, phase drift, filled nulls and model mismatch. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the bounding region is narrowed only where independent observables overlap within uncertainty. The principal limitation is inconsistent observables require a larger region or an unresolved classification. The record shall contain raw components, bearings, gradients, phase reference, intersection method and propagated spatial uncertainty. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

14.6 Adaptive re-centring without expectation bias

Re-centring shall follow a predeclared algorithm applied after a complete ring or raster block. The governing physical or metrological basis is robust centroid, intersecting null planes or validated source-model fitting can move the local origin toward the supported region. The examiner shall treat this basis as a testable model rather than an assumption. Re-centring after every visually strong point converts random maxima into a biased search path. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Scene-geometry elaboration. The mature treatment of Adaptive re-centring without expectation bias replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

The required configuration is as follows. The algorithm, weights, outlier rule, coordinate precision and minimum data set are fixed in the plan. The primary observables are station values, uncertainties, residuals, model fit and centre stability under resampling. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are blind analyst where practicable, independent recalculation and sensitivity analysis with suspect points removed. The principal artefacts and confounders are single-point domination, overfitting, rounded coordinates and use of post hoc thresholds. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the new centre is a navigation coordinate only and is accepted when stable within the validated rule. The principal limitation is several sources or extended conductors may make a single centre inappropriate. The record shall contain input points, algorithm version, centre, uncertainty, residuals and reason for selecting the next geometry. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

14.7 Multiple maxima and extended-source models

Multiple peaks shall trigger competing-source and coupling-path analysis rather than selection of the peak nearest the suspected object. The governing physical or metrological basis is several devices, one source coupled to several conductors, standing waves, structural concentration and sensor side lobes can create multiple maxima. The examiner shall treat this basis as a testable model rather than an assumption. The largest accessible value can be displaced from the originating electronics. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Field-theory elaboration. In Multiple maxima and extended-source models, the observable is not a free-standing property of the suspected circuit. It is the solution of a boundary-value problem involving source geometry, wavelength, material properties, apertures, conductors, nearby structures, and the receiving probe. At electrically small dimensions, terms proportional to 1/r cubed and 1/r squared may dominate over the radiating 1/r term, so amplitude-distance behaviour cannot be interpreted through free-space path loss alone. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

The required configuration is as follows. Maxima are repeated in time-balanced order and scanned transversely and longitudinally with magnetic and electric probes. The primary observables are phase coherence, harmonic family, ridge orientation, vertical continuation and response along conductors. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are stationary reference, alternate aperture, reverse traversal and known-source state comparison. The principal artefacts and confounders are time drift masquerading as location, normalisation error, probe pattern lobes and one-sided access. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is separate regions or an extended path are reported when the data do not support one compact source. The principal limitation is physical origin can remain outside the accessible volume. The record shall contain all maxima, model comparisons, rejected compact-source assumptions and final region geometry. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

14.8 Non-imaging data fusion and spatial reporting

Data from several probes shall be fused as numerical propositions rather than rendered as a physical image of a hidden object. The governing physical or metrological basis is overlap of coordinate intervals, frequency families, field components and uncertainty supports a source-associated region. The examiner shall treat this basis as a testable model rather than an assumption. Interpolated colour maps can imply resolution and physical shape not present in the measurements. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise. Thermal making with be used at this point merely to provide an indexed, thermal photography mural as a backdrop for more specialised imagery.

Spatial-measurement interpretation. The mature treatment of Non-imaging data fusion and spatial reporting replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

The required configuration is as follows. Coordinate tables, line plots, spectra, time series and polar null plots are the default outputs. The primary observables are measured values at actual stations, uncertainty intervals and probe-specific response. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are review of interpolation, no unmeasured pixel values, colour-independent labels and comparison with raw data. The principal artefacts and confounders are smoothing, contour closure, selective scale, hidden negative points and apparent object outlines. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the report states x, y and z intervals and their evidential basis. The principal limitation is a bounded field region is not a physical depiction or unique device identification. The record shall contain plot generation method, included data, excluded points, uncertainty and explicit non-imaging limitation. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation.

Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

14.9 Crime-scene-derived scene discipline

Interior localisation shall apply a scene-processing overlay adapted from methodical crime-scene practice without treating the premises as a criminal scene. Before detailed electronic work begins, the inspection manager establishes a single controlled route, an entry and exit log, a protected staging area, a room datum, fixed hard points and a prohibition on unrecorded movement. The original room state is preserved by dimensional drawing and coordinate records rather than by creating an image of a suspected device. Appendix N governs the detailed access, drawing, marker and cube-processing controls.

Spatial-measurement interpretation. For crime-scene-derived scene discipline, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object.

14.10 Hard points, room drawing and triangulated placement

At least three stable, non-collinear hard points shall be designated where geometry permits. Distances among those points are measured as closure checks, and the x, y and z coordinate frame is stated before furniture, doors, services, instruments or candidate regions are entered. Furniture placement is recorded from multiple corners or fiducials, with redundant distances from the hard points and a calculated orientation angle. A rough measurement drawing is sealed as the unaltered baseline. Later corrections are made on a dated revision, never by silently changing the original record.

Spatial-measurement interpretation. At expert-practitioner level, Hard points, room drawing and triangulated placement is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

14.11 Three-dimensional cube processing and marker discipline

The room shall be modelled as a series of addressable volumes rather than only as a floor grid. A coarse three-foot cube lattice is used for initial interior comparison, followed by twelve-inch and three-inch subcubes when a candidate warrants refinement. Floors, walls, ceilings and furniture surfaces receive linked surface-cell identifiers. Black-and-white triangular markers may be placed adjacent to an observation point on a floor, wall or surface, but never on a suspected item. Each marker carries a unique identifier, coordinate, height, probe orientation, timestamp and candidate classification.

Three-dimensional search analysis. For Three-dimensional cube processing and marker discipline, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object.

14.12 Movement, action and continuously updated physics ledger

Every movement of a person, probe, cable, door, blind, furniture item, building service or authorised source state shall be logged before the next measurement is accepted. The log records the actor, reason, starting and ending coordinates, time, affected cubes and the mandatory remeasurement set. For each cube the examiner maintains a physics behaviour vector containing frequency, amplitude, noise floor, phase or coherence where available, polarisation, null angle, gradient, dwell, sensor configuration, environmental state and uncertainty. A cube is closed only after its primary pass, orthogonal pass, negative controls and reverse-path check reconcile.

Three-dimensional search analysis. At expert-practitioner level, Movement, action and continuously updated physics ledger is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference.

Chapter Glossary

Terms used in Chapter 19: Interior Grid Search and Fine Localisation.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

15. Candidate Signal Confirmation and Artefact Rejection

A candidate becomes reportable only after the examiner has tested whether it could have been generated by the receiver, amplifier, cable, recorder, reference clock, body-worn item, known building system or an external source. No single test is sufficient. Confirmation is cumulative and should include both positive reproducibility and negative controls.

Test	Expected result for a genuine environmental signal	Artefact indication
Repeat pass	Feature recurs within stated frequency and amplitude variability.	Absent without an explained source-state change.
Independent instrument	Second receiver or sensor detects a compatible feature.	Appears only on one architecture or software path.
Terminated input or dummy probe	Feature disappears or changes consistently with loss of environmental coupling.	Feature remains unchanged with the sensor removed.
Gain-step linearity	Indicated level changes consistently and remains below compression.	Unexpected products appear, disappear or move with gain.
Preselector change	Signal follows the relevant passband and lawful amplitude response.	Line persists outside the passband, indicating internal digital contamination.
Probe rotation	Amplitude or null changes consistently with field orientation.	No sensor-dependent behaviour, or change follows cable movement only.
Spatial repeatability	A similar gradient or maximum recurs on approach and withdrawal.	Maximum follows the operator, recorder or cable rather than the location.
Time reference comparison	Frequency is stable relative to an independent reference or its drift is physically plausible.	Line is exactly tied to the receiver sample clock or display refresh.

Test	Expected result for a genuine environmental signal	Artefact indication
Known-source state test	Feature responds reproducibly to one authorised state change, if the source is known.	Multiple uncontrolled changes prevent interpretation.
External bearing or ring	Spatial pattern is compatible with an internal or external source model.	Strongest value remains on the same external bearing at every indoor point.

DECISION THRESHOLD
No universal 3 dB, 6 dB or other threshold is imposed by this draft. The organisation shall validate candidate-selection and confirmation thresholds for each band, receiver, dwell and environment, then declare them before case interpretation.

15.1 Mandatory candidate confirmation sequence

A candidate shall pass a fixed confirmation sequence before being classified as an environmental electronic signal. The governing physical or metrological basis is independent challenges separate environmental coupling from receiver, probe, cable and software artefacts. The examiner shall treat this basis as a testable model rather than an assumption. Repeated appearance on one unchanged system is not independent confirmation. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

The required configuration is as follows. The sequence includes repeat pass, reverse path, terminated input, dummy probe, gain step, amplifier bypass, preselector change, second sensor, second receiver and revisit. The primary observables are frequency, amplitude, spatial difference and expected response under each control. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are the sequence itself, applied at the maximum, a lower-response point and a remote-control point. The principal artefacts and confounders are receiver spur, cable pickup, front-end mixing, software bin, local clock and source intermittency. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is classification rises only as independent controls support the environmental hypothesis. The principal limitation is some intermittent signals cannot be fully confirmed in the available examination window. The record shall contain expected and observed result for every test, including findings that weaken the preferred explanation. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

15.2 Receiver non-linearity and intermodulation rejection

The receiver chain shall be challenged for non-linear generation of candidate-band components. The governing physical or metrological basis is strong signals mix in semiconductor junctions, protection devices, amplifiers, mixers and analogue-to-digital converters. The examiner shall treat this basis as a testable model rather than an assumption. An unlit overload indicator does not prove linear operation. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Signal-analysis interpretation. For Receiver non-linearity and intermodulation rejection, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

The required configuration is as follows. Gain, attenuation and preselection are changed through calibrated states while the environmental geometry remains fixed. The primary observables are input-referred amplitude scaling, appearance or disappearance of candidate and parent signals, and intermodulation relationships. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are two-tone laboratory test, field gain step, amplifier bypass, alternate receiver and added preselection. The principal artefacts and confounders are compression, clipping, diode mixing, local oscillator products and automatic gain control. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a genuine environmental line should remain at the same physical frequency and scale consistently within uncertainty. The principal limitation is several strong unknown signals can create complex products difficult to reconstruct. The record shall contain gain states, parent signals, scaling calculations, overload indicators and conclusion. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

15.3 Aliasing, sample-rate and digital-processing controls

Digital acquisition shall be tested for aliases and processing artefacts before a narrow line is accepted. The governing physical or metrological basis is energy above Nyquist or from clock-related processes can fold into the displayed spectrum, while windows and block length affect leakage. The examiner shall treat this basis as a testable model rather than an assumption. A high-resolution display does not prove that the physical analogue input contained the indicated frequency. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced technical elaboration. For expert practice, Aliasing, sample-rate and digital-processing controls is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The required configuration is as follows. The candidate is reacquired at a different validated sample rate and analogue band limit, with raw time data preserved. The primary observables are physical frequency stability, movement predicted by alias equations, window dependence and block-synchronous features. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are alternate digitiser, sample rate, anti-alias filter, software implementation and synthetic-data verification. The principal artefacts and confounders are decimation errors, clock spur, FFT leakage, numerical overflow and display interpolation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a candidate must remain at the same physical frequency under valid acquisition changes. The principal limitation is an intermittent source can complicate comparisons unless simultaneously monitored. The record shall contain sample rate, filter, window, FFT length, software version, raw files and alias calculations. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

15.4 Probe resonance, microphonics and electric-field leakage

The sensor assembly shall be tested for motion-induced and mixed-component artefacts. The governing physical or metrological basis is mechanical motion modulates inductance and capacitance, while electric fields couple through winding and cable capacitance. The examiner shall treat this basis as a testable model rather than an assumption. A resonant narrow line can be the probe ringing after movement rather than a continuing environmental source. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Probe-engineering analysis. At advanced-practitioner level, Probe resonance, microphonics and electric-field leakage is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

The required configuration is as follows. Settling delay, time-domain recording, electrostatic shield verification and magnetic-versus-electric comparison are used. The primary observables are onset relative to movement, decay constant, orientation, shield dependence and recurrence while stationary. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are laboratory mechanical stimulus, dummy mechanical assembly, fixed field reference and alternate probe. The principal artefacts and confounders are cable triboelectricity, loose winding, shield charge, concentrator eddy currents and surface capacitance. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is only stationary recurrent energy surviving the mixed-component controls supports the environmental signal proposition. The principal limitation is very weak fields may be measurable only with a probe that also has increased mechanical sensitivity. The record shall contain settling time, movement events, time traces, shield state, comparison probes and disposition. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

15.5 External-source and building-path rejection

The analysis shall distinguish a premises-associated source from an external emitter or current carried into the premises. The governing physical or metrological basis is external fields can enter through radiation, wiring, pipes, grounds and structural conductors. The examiner shall treat this basis as a testable model rather than an assumption. An interior maximum can occur where an external field couples most strongly, not where it originates. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced technical elaboration. For expert practice, External-source and building-path rejection is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The required configuration is as follows. Outer-ring bearings, service-path scans, stationary reference and adjacent-space measurements are compared. The primary observables are bearing, phase, field component, gradient across the boundary, continuation along conductors and response to known external events. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are both sides of service entry, changed antenna height, transverse scan and independent public-source information where lawful. The principal artefacts and confounders are multipath, conducted common mode, steel concentration, neighbouring premises and shared utilities. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is premises association requires evidence inconsistent with a solely external or extended-path explanation. The principal limitation is origin can remain outside the authorised search volume. The record shall contain external hypotheses, measurements, access limits and residual alternatives. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

15.6 Pulse-position and modulation-family discrimination

Pulse-position modulation, abbreviated PPM, represents information or timing by displacing a pulse from a defined reference position within a frame or symbol interval. The measured quantity is therefore time displacement, not merely pulse amplitude or pulse presence. The examiner shall define the frame reference, pulse-detection rule, sampling rate, timing reference, estimator and uncertainty before assigning a PPM description. **A train of irregular pulses, a receiver squelch event or a burst whose amplitude crosses a threshold at varying times is not automatically PPM.**

Advanced spectral-temporal analysis. A advanced technical analysis of Pulse-position and modulation-family discrimination preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

PPM shall be distinguished from pulse-amplitude modulation, in which pulse magnitude changes; pulse-width modulation, in which duration changes; pulse-repetition-frequency modulation, in which the interval between frames changes; on-off keying, in which pulses are present or absent; ordinary amplitude modulation, in which a carrier envelope varies; and load modulation, in which a device changes its impedance and therefore the reflected or coupled carrier. A response may combine these mechanisms. The report states which observable supports each description and which alternatives remain.

The minimum controls are a fixed reference-clock check, changed detection threshold, raw waveform review, independent pulse detector, transmitter waveform comparison, source-off record, frequency-offset record and synthetic-data validation of the timing estimator. Timing displacement must remain materially unchanged when the amplitude threshold is varied within the validated range. Otherwise amplitude noise may be masquerading as position modulation.

This expands this discrimination into a complete modulation taxonomy and forensic waveform-analysis protocol. This governs all later use of the terms CW, OOK, AM, sideband, FM, pulse, digital television, Project 25, subcarrier, composite modulation and nested modulation.

15.7 Illumination artefact and direct-breakthrough rejection

An illumination-correlated response shall first be treated as a property of the complete transmit-receive system. Direct antenna coupling, connector leakage, transmitter harmonics, phase noise, receiver compression, desensitisation, local-oscillator radiation, digital clock spurs, cable common mode and nonlinear mixing can all produce repeatable features that appear only when the source is energised. The test therefore attempts to falsify the environmental-response hypothesis before promoting it.

Retroreflective-response analysis. For Illumination artefact and direct-breakthrough rejection, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

A genuine frequency-translated environmental response should remain at its physical response frequency when the receiver intermediate-frequency architecture or sample rate is changed, should display a spatial gradient associated with the candidate region rather than the receiving cable, and should follow the predeclared relation to the illumination source during small authorised frequency offsets. Conversely, an instrument image often moves according to the receiver local oscillator or disappears when preselection is strengthened. A difference-frequency product near 300 MHz, for example, can be created by two strong illumination or ambient frequencies separated by 300 MHz and must be predicted before field interpretation.

A source-presence-triggered display is deliberately correlated with illumination and therefore cannot, by itself, prove an environmental response. The same trigger can expose transmitter leakage, filter settling, receiver gain recovery, digital arming transients and trigger-line coupling. The analyst shall inspect pre-trigger data, compare multiple trigger delays, repeat with a terminated response input, alter the receiver intermediate-frequency plan and verify that the observed latency belongs to the spatially localised response rather than to the instrument chain.

Challenge	Environmental-response expectation	Artefact indication
Source-off	Response falls to background or to a predeclared residual level after stated settling time.	Response persists unchanged or follows receiver state rather than field state.
Frequency offset	Translated response follows the physically hypothesised relation, within uncertainty.	Feature remains fixed to an internal receiver spur or moves according to local-oscillator arithmetic.
Polarisation change	Response changes in a spatially and electromagnetically plausible manner.	Change follows cable orientation or transmitter leakage path only.
Receiver substitution	Same physical frequency and timing are observed by an independent architecture.	Feature is absent or appears at a different physical frequency.
Preselector and attenuation	Response scales without evidence of compression and survives adequate transmit-band rejection.	Feature collapses when front-end linearity is restored or moves with gain state.
Position change	Response exhibits a repeatable gradient or null around the candidate region.	Maximum remains at the receiver, feed line, coupler or transmitter enclosure.

Chapter Glossary

Terms used in Chapter 20: Candidate Signal Confirmation and Artefact Rejection.

A

ALIASING — The indistinguishable mapping of different continuous-time frequencies to the same sampled representation when the sampling process is insufficiently constrained.

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

AUTOMATIC GAIN CONTROL — A circuit used to vary radar receiver gain for best reception of signals that have widely varying amplitudes.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

15A. Comprehensive Modulation Taxonomy, Composite Subcarriers, and Forensic Waveform Analysis

15A.1 Purpose, scope and defensive-use boundary

This chapter establishes a modulation-neutral method for recognising, measuring and reporting weak electromagnetic waveforms encountered during Electronic Emission and Resonance Forensics. It begins with a pure continuous carrier and advances through conventional analogue and digital families, television and public-safety systems, pulse methods, multicarrier systems, spread spectrum, nested subcarriers and illuminated retroreflective responses. The progression is deliberate. A faint line that looks like continuous wave at a wide resolution bandwidth can reveal OOK, phase steps, pulse-position structure or a low-rate subcarrier when the record is examined in zero span, I/Q, instantaneous-frequency, waterfall or cyclic-frequency domains. Conversely, a broad noise-like plateau can be an ordinary digital service, an overloaded receiver, a switching converter or a structured spread-spectrum signal. Classification follows evidence, not appearance.

System-level interpretation. For expert practice, Purpose, scope and defensive-use boundary is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

No finite text can enumerate every proprietary or experimental waveform. The taxonomy therefore covers the principal physical families and supplies a general procedure for unlisted signals. Historical frequency and modulation examples in the user-supplied frequency register and Threat Index remain provenance-controlled search intelligence, not universal fingerprints [53-56]. This chapter does not authorise interception, content recovery or active transmission. It is written for defensive inspection, metrological research and lawful source localisation. Composite-modulation examples are synthetic and intentionally omit deployable circuit values, coding sequences, concealment parameters and implementation details. Their purpose is to show what an examiner may observe and how an apparently complicated waveform can be separated into testable components.

TERMINOLOGY AND SAFETY NOTICE
The word cloaking is replaced in this framework by composite modulation, spectral embedding or nested subcarrier. Those terms describe an observed signal structure. They do not imply invisibility, legality, intent or a construction method. A pure CW signal cannot literally contain a subcarrier. Once amplitude, phase, frequency, load or reflection coefficient is varied by a subcarrier, the emission is a modulated carrier that may retain a visually dominant carrier line.

15A.2 Signal model and controlled vocabulary

A general real passband signal may be written as $s(t) = A(t) \cos[2 \pi f_c t + \phi(t)]$, where $A(t)$ is the instantaneous amplitude in volts or field-strength units, f_c is the nominal carrier frequency in hertz, $\phi(t)$ is the time-varying phase in radians and t is time in seconds. Amplitude modulation acts primarily through $A(t)$. Phase modulation acts through $\phi(t)$. Frequency modulation is observed through the instantaneous frequency $f_i(t) = f_c + [1/(2 \pi)] \, d\phi(t)/dt$. Pulse methods impose controlled changes upon amplitude, width, position, interval, count, polarity, phase or frequency. Digital modulations select among discrete states, often after pulse shaping. A subcarrier is a periodic waveform above baseband that is itself modulated and then used to vary a higher-frequency carrier, optical source, load impedance or reflection coefficient.

Advanced technical elaboration. At expert-practitioner level, Signal model and controlled vocabulary is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The abbreviation PDM can be ambiguous. It can mean pulse-duration modulation or pulse-density modulation. This chapter writes the full term whenever ambiguity is possible. The expression PPS is also ambiguous. In this framework, pulse-position signalling, abbreviated PPS only within a defined record, means a pulse-position-coded sequence or subcarrier. A one-pulse-per-second timing reference is written 1 PPS. NTSC, ATSC and P25 are systems containing several coding, framing and modulation elements. They are not interchangeable with a single generic modulation label. NFM and WFM are descriptive categories whose practical boundary depends on deviation, message bandwidth, modulation index, channel plan and receiver design. The report therefore states measured deviation and occupied bandwidth rather than relying on the adjective narrow or wide.

15A.3 Measurement domains and acquisition architecture

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Probe or antenna	Preselector and overload monitor	Low-noise gain or passive bypass	Synchronous I/Q acquisition	Oscilloscope, FFT and waterfall	Feature extraction, controls and evidential classification

The examiner shall preserve at least five observational domains whenever the signal-to-noise ratio and storage capacity permit. The first is raw time-domain voltage or calibrated field quantity. The second is complex I/Q, from which envelope, phase and instantaneous frequency can be derived. The third is the ordinary spectrum, including narrowband, wideband, zero-span and max-hold views. The fourth is the time-frequency record, ordinarily a waterfall or persistence display. The fifth is a periodic-statistics record, including autocorrelation, pulse-interval histograms and, for noise-like signals, cyclic autocorrelation or spectral correlation. A modulation classification that exists in only one processed display is provisional.

Oscillator-family analysis. A technically mature analysis of Measurement domains and acquisition architecture distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The acquisition chain is protected against overload before gain is applied. A preselector or tracking filter limits strong out-of-band energy. A coupler or parallel monitor records the illumination waveform when active testing is separately authorised. The reference clock is disciplined and its uncertainty is carried into carrier, symbol, pulse-position and subcarrier estimates. Sampling rate is selected for the observable. A narrow carrier can be estimated with a small analysis bandwidth, but a short pulse requires enough analogue and digital bandwidth to preserve its rise time and a sufficiently high sample rate to support the declared timing uncertainty. Raw files are retained before envelope detection, discrimination, decimation, filtering or thresholding.

Modulation recognition is performed on simultaneous channels, not on a single probe moved through several orientations after the event. At least one X-Y-Z triad is retained for every evidential waveform, and the normal three-pod array records nine concurrent paths. This permits the examiner to determine whether an OOK edge, pulse-position displacement, FM excursion, hop, SAW-delayed return or nested subcarrier appeared at the same instant and with a spatially coherent pattern. The analyser frequency command also drives the per-channel resonance controller, so a tuned waveform is accepted only when every channel included in the comparison was verified at resonance and in bias hold. The associated narrowband tracking receiver follows each selected input without interrupting the raw I/Q record.

15A.4 Master modulation taxonomy

Family	Included methods	Principal non-content observables
Continuous and amplitude	CW; interrupted CW; OOK; binary and multilevel ASK; AM DSB full-carrier; DSB suppressed-carrier; SSB USB; SSB LSB; ISB; VSB; amplitude companding; load modulation	Carrier line, envelope, symmetric or asymmetric sidebands, pulse combs, carrier suppression

Family	Included methods	Principal non-content observables
Angle modulation	PM; NFM; WFM; direct FM; reactance FM; subcarrier FM; FSK; CPFSK; MSK; GMSK; MFSK	Constant envelope, instantaneous phase or frequency, Bessel sidebands, discrete deviation states
Phase and quadrature digital	BPSK; QPSK; OQPSK; pi/4-DQPSK; DQPSK; 8PSK; 16/64/256/1024/4096-QAM; APSK	Constellation state, symbol clock, cyclostationary structure, occupied-bandwidth edge
Multicarrier and spread spectrum	OFDM; COFDM; OFDMA; DSSS; FHSS; hybrid spread spectrum; chirp spread spectrum; time hopping	Flat-topped or comb-like spectra, pilots, guards, hop dwell, spreading-code cyclic features
Pulse analogue	PAM; pulse-duration or pulse-width modulation; PPM; pulse-frequency or repetition-frequency modulation; pulse-interval modulation; pulse-number modulation; pulse-polarity modulation	Pulse height, width, position, interval, count or polarity varies while other quantities remain controlled
Pulse digital	PCM; DPCM; delta modulation; adaptive delta modulation; Manchester or bi-phase; sigma-delta pulse-density modulation; return-to-zero and non-return-to-zero line coding	Clock combs, transition density, framing, quantisation and coding structure
Pulsed RF and sensing	Interrupted carrier; gated burst; VOX; confidence beacon; phase-coded pulse; chirped pulse; pulse compression; impulse radio and UWB	Rise and fall time, pulse width, PRI, duty cycle, bandwidth inversely related to edge and pulse duration
Television and public-safety systems		System-specific pilots, synchronisation, framing, symbol rates and emission envelopes. These are systems, not single generic modulations

Family	Included methods	Principal non-content observables
Composite, nested and reflective	AM-on-FM; FM-on-AM; NFM-on-NFM; subcarrier multiplex; noise-like host plus cyclic subcarrier; same-frequency backscatter; translated reradiation; nonlinear harmonic response	Multiple demodulation layers, spectral clusters, cyclic frequencies, illumination correlation and spatial response gradients

The table is a classification map, not a decision by itself. Many physical signals occupy more than one row. OOK is both an amplitude-keyed signal and a pulsed RF signal. GMSK is both filtered FSK and continuous-phase modulation. ATSC 3.0 is OFDM whose individual subcarriers may carry QPSK or high-order constellations. A retroreflector device can present same-frequency load modulation while a rectifying or active circuit simultaneously produces harmonics or a translated carrier. The examiner records the hierarchy explicitly, for example: outer carrier, NFM; subcarrier, NFM; low-rate timing, pulse-position signaling. Unknown remains a valid classification when evidence does not support a narrower statement.

Waveform and modulation elaboration. For Master modulation taxonomy, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

15A.5 Continuous wave, carrier leakage and oscillator lines

Continuous wave, CW, is the limiting case in which amplitude, frequency and phase are substantially constant over the observation interval. A laboratory oscillator line, local-oscillator leak, pilot, clock harmonic or weak resonator response may appear as CW. Real sources possess phase noise, amplitude noise, drift, mains-related sidebands and finite turn-on behaviour. A very weak modulation can be hidden beneath the displayed resolution bandwidth, leaving a carrier-like line that is not truly unmodulated. The examiner therefore repeats the observation with progressively narrower resolution bandwidth, zero span, coherent I/Q and long-term frequency tracking. A carrier line that moves with receiver tuning, disappears under preselection or changes with input attenuation may be an instrument product rather than an environmental source.

Waveform and modulation elaboration. The expert treatment of Continuous wave, carrier leakage and oscillator lines begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

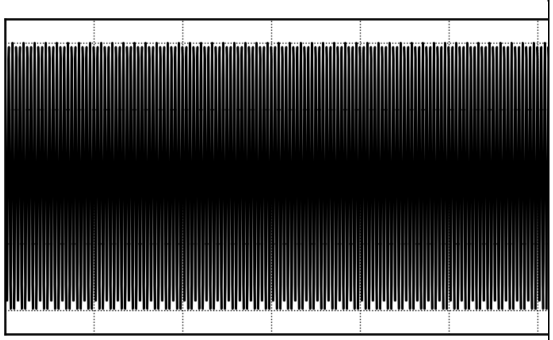
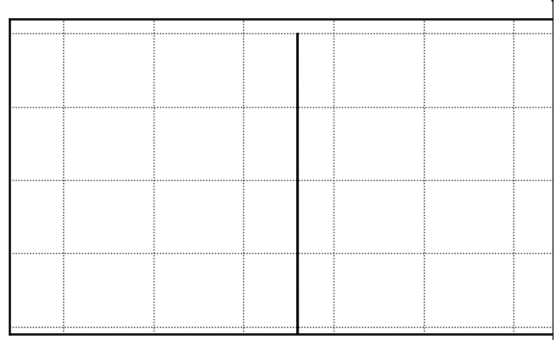
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-1. Synthetic continuous-wave carrier. *The left panel shows a constant-amplitude carrier. The right panel shows a dominant narrow line. The illustration is not a device fingerprint.*

15A.6 Interrupted CW, OOK and amplitude-shift keying

On-off keying, OOK, multiplies a carrier by a binary state. It may encode data, gate a beacon, conserve energy, implement voice operation or arise unintentionally when a circuit crosses its operating threshold. Interrupted CW is an older descriptive term for carrier bursts. Multilevel amplitude-shift keying, ASK, permits more than two amplitudes. The time record shows distinct envelope states, while the spectrum contains a carrier component, modulation sidebands and, for periodic gating, a comb spaced by the repetition frequency. Finite rise and fall times determine high-frequency spectral extent. A spectrum analyser with long sweep time can miss short OOK events, so max hold, persistence, zero span and time-stamped I/Q are required.

OOK shall be distinguished from receiver squelch, automatic gain control, impulsive interference and intermittent cable contact. A changed detector threshold is especially important because a continuous weak carrier may appear to switch on and off when noise moves it across the display threshold. The classification is strengthened when the envelope states persist in raw I/Q, the carrier phase remains coherent through gaps where technically expected, and the same repetition or code timing appears on an independent receiver.

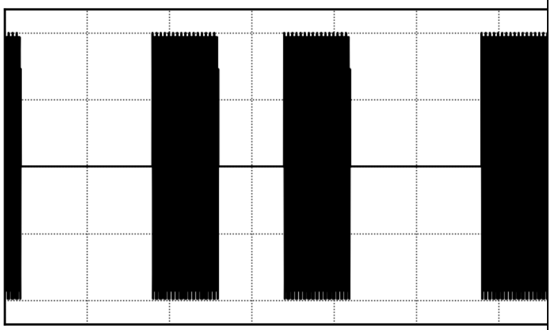
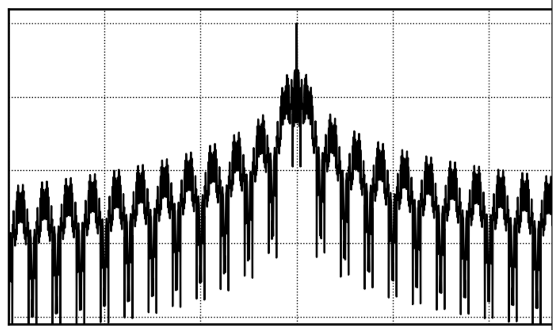
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-2. Synthetic on-off-keyed carrier. *The time-domain envelope switches between carrier present and absent. The spectral display shows broadening and periodic structure caused by gating.*

15A.7 Conventional AM, DSB full-carrier and DSB suppressed-carrier

Conventional amplitude modulation, often called double-sideband full-carrier AM, varies carrier amplitude in proportion to a message. For a single sinusoidal message, the ordinary spectrum contains the carrier and two sidebands at equal offsets. The modulation index is estimated from envelope extrema only after the receiver is known to be linear. Overmodulation creates envelope reversals and additional spectral components. Double-sideband suppressed-carrier, DSB-SC, removes or greatly reduces the carrier term, leaving two coherent sidebands. A weak residual carrier may be intentional, leakage or imbalance. In near-field work, changing probe orientation can change apparent carrier-to-sideband ratio because separate circuit nodes couple differently.

Waveform and modulation elaboration. A advanced technical analysis of Conventional AM, DSB full-carrier and DSB suppressed-carrier preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation.

Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

AM-like envelopes also arise from load modulation, rotating polarisation, multipath fading, moving personnel, preamplifier compression and supply ripple. A diode envelope detector is therefore only one view. Complex I/Q establishes whether sidebands possess the phase relation expected from amplitude modulation.

Gain-step and preselector controls test linearity. A candidate is not described as voice or intelligence merely because its envelope lies within the voice band. The non-content report gives carrier, sideband offsets, envelope depth, duty cycle, coherence and spatial behaviour.

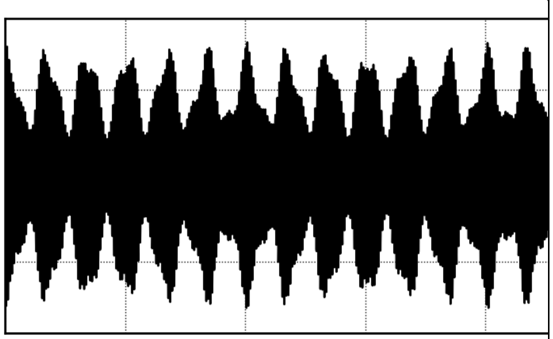
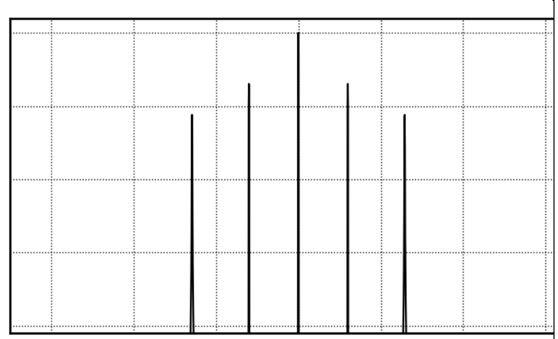
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-3. Synthetic double-sideband full-carrier AM. *The carrier envelope follows a low-frequency message. The spectrum shows a carrier and paired sidebands.*

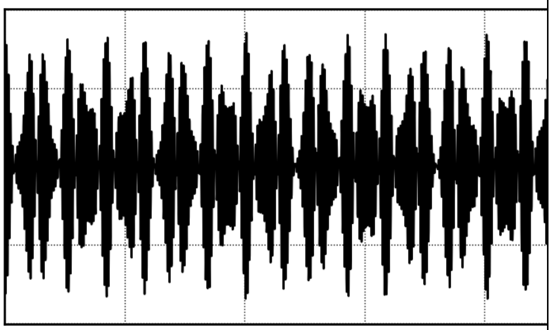
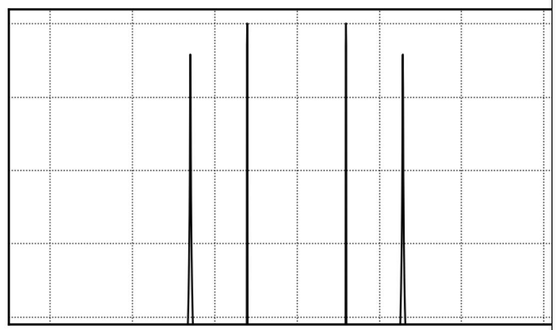
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-4. Synthetic double-sideband suppressed-carrier signal. *The time waveform crosses through envelope reversals. The ordinary carrier line is reduced while paired sidebands remain.*

15A.8 USB, LSB and single-sideband variants

Single-sideband modulation transmits one sideband and ordinarily suppresses the other. Upper sideband, USB, preserves components above the nominal carrier. Lower sideband, LSB, preserves components below it. The carrier may be suppressed, reduced or retained. The essential forensic cue is spectral asymmetry with a coherent analytic-signal relationship, not merely a lopsided trace. Receiver image rejection, filter skirt, preselector asymmetry and an adjacent unrelated signal can imitate one-sided energy. The examiner therefore reverses or changes the intermediate-frequency architecture, records complex I/Q and tests the signal with an independent receiver whose image plan differs.

Communications-family analysis. At expert-practitioner level, USB, LSB and single-sideband variants is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. External ports and internal buses can produce fundamentals, harmonics, common-mode currents, connector radiation, spread-spectrum skirts, burst cadences, and low-frequency power-state signatures even when payload communication is absent. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

At very low signal levels, a residual carrier can provide a useful frequency reference. A suppressed-carrier SSB waveform may look noise-like in the time domain and may have no obvious envelope. Synchronous detection with the wrong carrier phase can produce misleading amplitude or apparent polarity. The report states whether the carrier was measured, estimated or reconstructed. It also states the occupied sideband, lower and upper frequency limits, and whether the opposite sideband was absent above a validated rejection level.

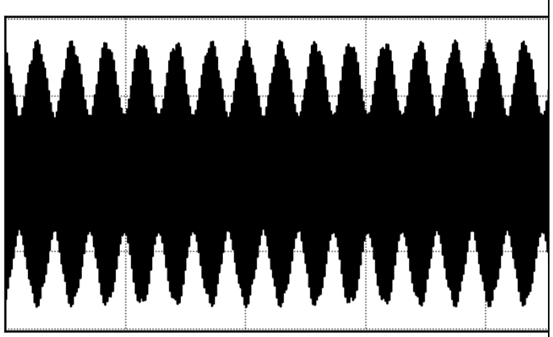
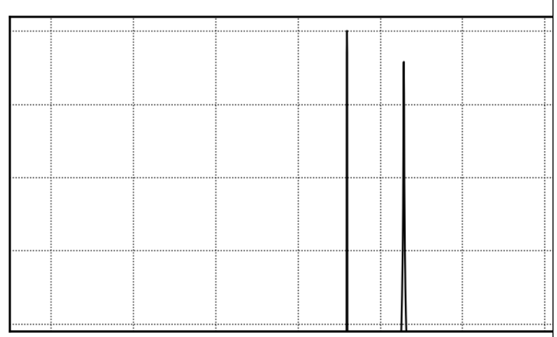
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-5. Synthetic upper-sideband signal. *The spectral energy lies principally above the nominal carrier region.*

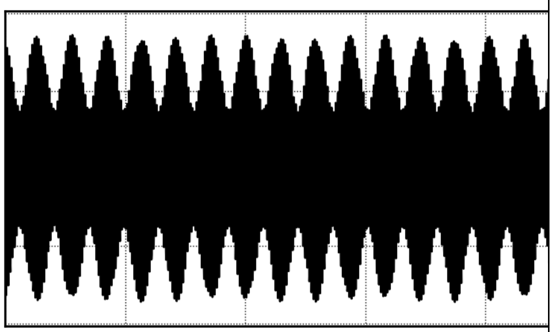
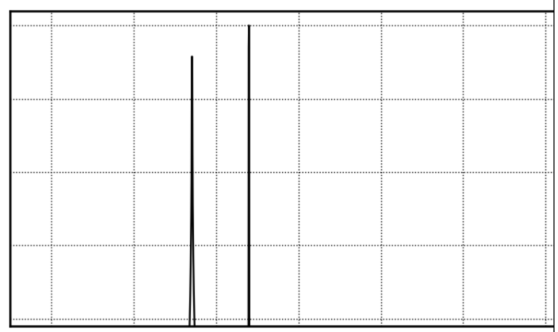
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-6. Synthetic lower-sideband signal. *The spectral energy lies principally below the nominal carrier region.*

15A.9 Independent sideband and vestigial sideband

Independent sideband, ISB, assigns different information or channel groups to the upper and lower sidebands. The two sides need not share bandwidth, level or content. A single envelope detector mixes them and may obscure the independence, so the examiner separates sidebands in complex baseband and tests each for distinct timing, modulation and cyclic features. Vestigial-sideband modulation, VSB, transmits one sideband substantially and retains only a vestige of the other. VSB is historically important in analogue television and structurally important in ATSC 1.0 8-VSB. A sloping or asymmetrical receiver filter can mimic VSB. Confirmation therefore uses calibrated passband characterisation and a frequency-reversed or alternate receiver path.

Advanced spectral-temporal analysis. For Independent sideband and vestigial sideband, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

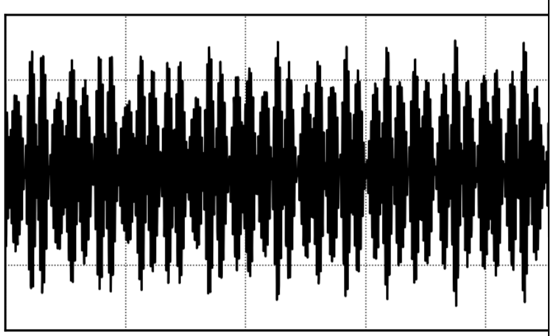
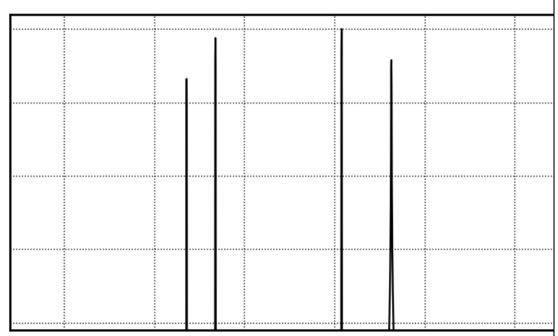
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-7. Synthetic independent-sideband signal. *Different synthetic messages occupy the two sidebands. The waveform is illustrative and carries no intelligible content.*

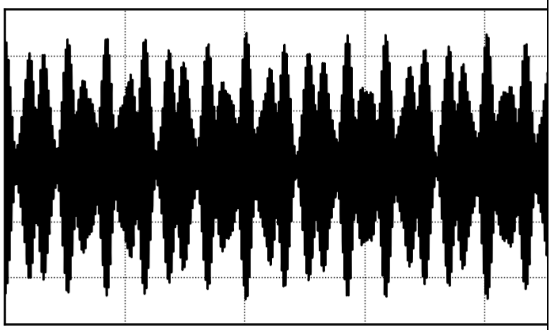
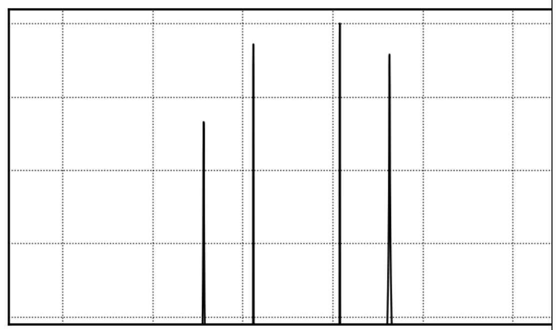
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-8. Synthetic vestigial-sideband signal. *One sideband is transmitted substantially while only a residual portion of the opposite side remains.*

15A.10 Phase modulation and instantaneous-frequency analysis

Phase modulation, PM, varies instantaneous phase in proportion to a message. Frequency modulation varies the time derivative of phase. The two are mathematically related, so a short observation or unsuitable demodulator can confuse them. PM of a step produces an abrupt phase transition and an impulse-like instantaneous-frequency event. FM of a constant message produces a sustained frequency offset. The examiner unwraps phase only after carrier removal, I/Q imbalance correction and adequate signal-to-noise ratio. Cycle slips are recorded rather than silently repaired.

Coherent-array interpretation. The advanced technical treatment of Phase modulation and instantaneous-frequency analysis regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot [7-16].

Phase steps also arise from multipath cancellation, switched antennas, PLL reacquisition and digital sampling discontinuities. A PM classification requires repeatable phase behaviour referenced to a stable carrier or pilot. When the signal is a backscatter response, the propagation path contributes phase. Small movement of antenna, cable or personnel can therefore produce phase excursions far larger than the device modulation. Stationary geometry and a simultaneous reference channel are essential.

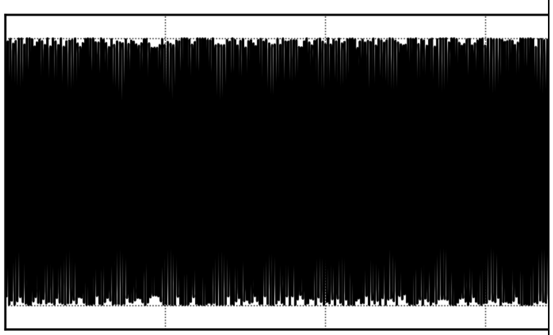
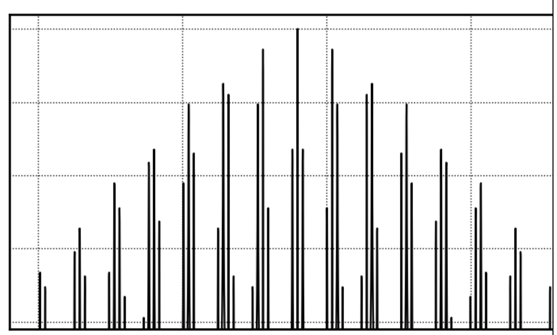
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-9. Synthetic phase-modulated carrier. *The carrier maintains approximately constant amplitude while its phase and instantaneous frequency vary.*

15A.11 Narrowband and wideband frequency modulation

Frequency modulation, FM, varies instantaneous frequency. For a sinusoidal message, the modulation index beta is the ratio of peak deviation Delta f to message frequency f_m. Low beta produces a carrier with a small number of significant sidebands and is commonly described as NFM. Large beta produces many Bessel-distributed sidebands and is commonly described as WFM. The adjectives are not sufficient for evidence. The examiner estimates deviation, highest significant modulation frequency, occupied bandwidth, carrier drift and discriminator output. Carson's approximation, B approximately 2(Delta f + f_m), is a planning estimate rather than a universal mask [72-73].

Advanced spectral-temporal analysis. For Narrowband and wideband frequency modulation, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

Weak FM may look like phase noise around a carrier. Free-running oscillators can drift across a narrow receiver filter and create false amplitude modulation. Conversely, an amplitude-limited receiver can hide genuine AM while preserving FM. The required acquisition therefore includes both amplitude and instantaneous-frequency records, a wider discovery bandwidth, a narrow estimation bandwidth and an independent reference-clock check. In low-power microphone searches, an 8 kHz to 14 kHz observed channel may be consistent with low-deviation FM, but the relationship must be measured rather than assumed.

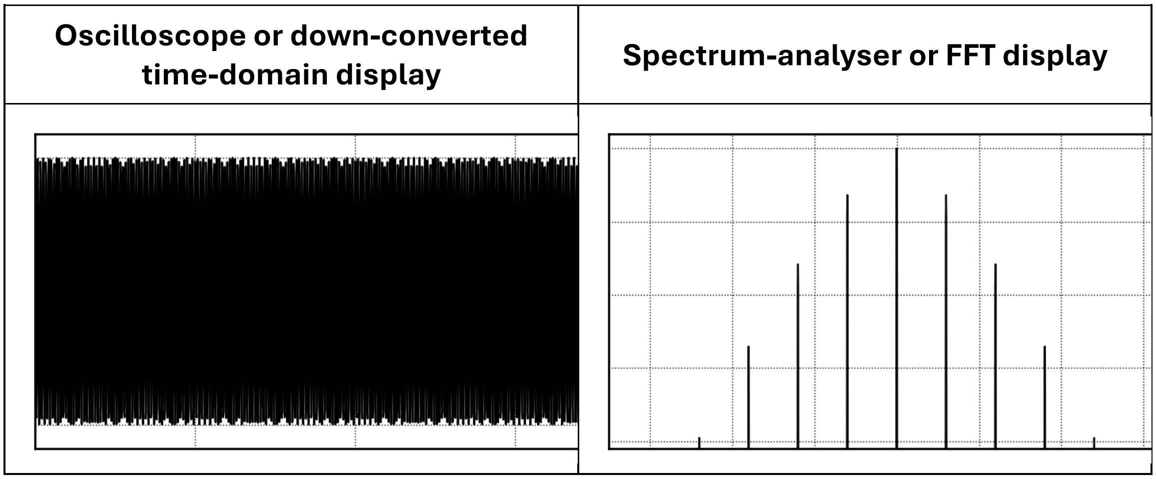


Figure 15A-10. Synthetic narrowband FM. *A small modulation index produces limited sideband spread around the carrier.*

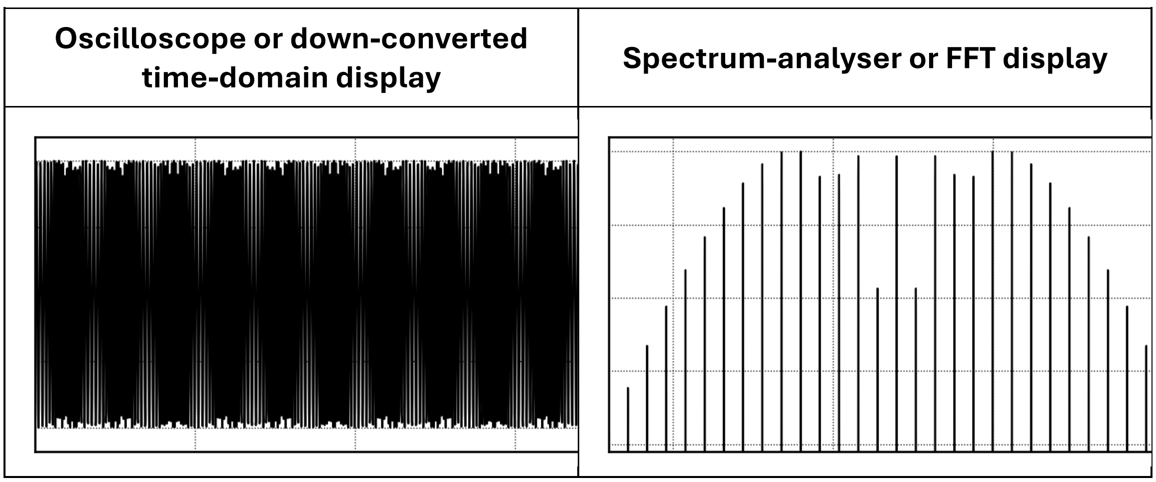


Figure 15A-11. Synthetic wideband FM. *A larger modulation index produces numerous significant sidebands and a wider occupied region.*

15A.12 FSK, CPFSK, MSK and GMSK

Frequency-shift keying, FSK, selects among discrete instantaneous-frequency states. Binary FSK uses two states. MFSK uses more. Discontinuous FSK can contain phase jumps at symbol boundaries. Continuous-phase FSK, CPFSK, integrates the frequency states so phase remains continuous. Minimum-shift keying, MSK, is a continuous-phase form with a particular modulation index. Gaussian minimum-shift keying, GMSK, filters the data before phase integration, reducing sidelobes at the cost of controlled intersymbol memory. A conventional spectrum analyser may show two or more lobes, a compact continuous-phase spectrum or only a broadened carrier depending on rate, deviation and resolution bandwidth.

Waveform and modulation elaboration. For FSK, CPFSK, MSK and GMSK, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

The examiner estimates symbol rate from autocorrelation, transition spacing or cyclic frequency, then measures frequency states from instantaneous frequency. A receiver discriminator with excessive smoothing can merge states and make four-level FSK look analogue. An overly narrow preselector can convert FSK into amplitude changes. The report therefore identifies the analysis filter and confirms the state pattern in raw I/Q. The NTIA necessary-bandwidth guidance treats digital FM separately and notes the influence of filtering and the number of signalling states [73].

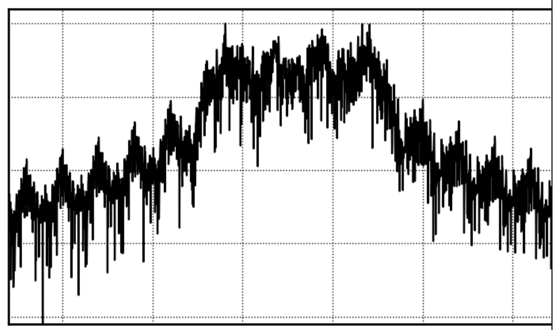
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-12. Synthetic four-level FSK. *The time-domain carrier changes instantaneous frequency among four states. The spectrum broadens into state-related components.*

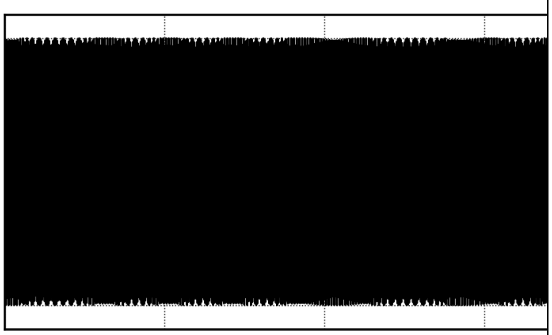
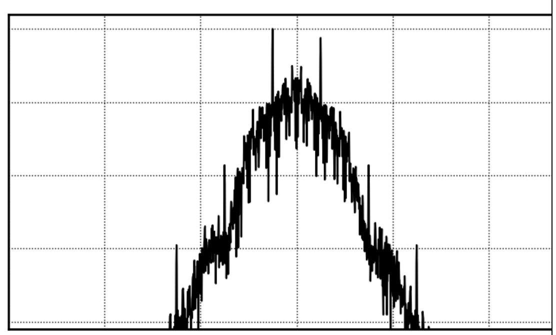
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-13. Synthetic Gaussian-filtered continuous-phase FSK. *The smooth phase trajectory reduces abrupt spectral sidelobes compared with unfiltered switching.*

15A.13 PSK, differential PSK, QAM and APSK

Phase-shift keying, PSK, selects discrete carrier phases. BPSK uses two states. QPSK uses four. OQPSK offsets I and Q transitions to reduce envelope excursions.

DQPSK encodes changes between states rather than absolute phase. Pi/4-DQPSK alternates constellations to limit large phase transitions. Higher-order PSK increases state density. Quadrature amplitude modulation, QAM, varies both I and Q amplitudes, producing a rectangular or shaped constellation. APSK arranges states on amplitude rings. The ordinary time waveform may resemble noise, while the spectrum mainly reflects symbol rate and pulse shaping. Classification therefore depends on complex I/Q, differential phase, constellation density and cyclic structure.

Signal-analysis interpretation. A advanced technical analysis of PSK, differential PSK, QAM and APSK preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

A distorted or low-SNR QAM signal can collapse into an apparent ring or noise cloud. Multipath rotates and disperses the constellation. Receiver AGC can alter amplitude distributions. Before classification, the examiner corrects known I/Q imbalance, checks carrier-frequency offset and records whether equalisation was applied. An equalised constellation is a derived display, not raw evidence. The source file and processing parameters remain available for review. The approximate occupied bandwidth of root-raised-cosine ASK, PSK and QAM depends on symbol rate and roll-off [73].

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display

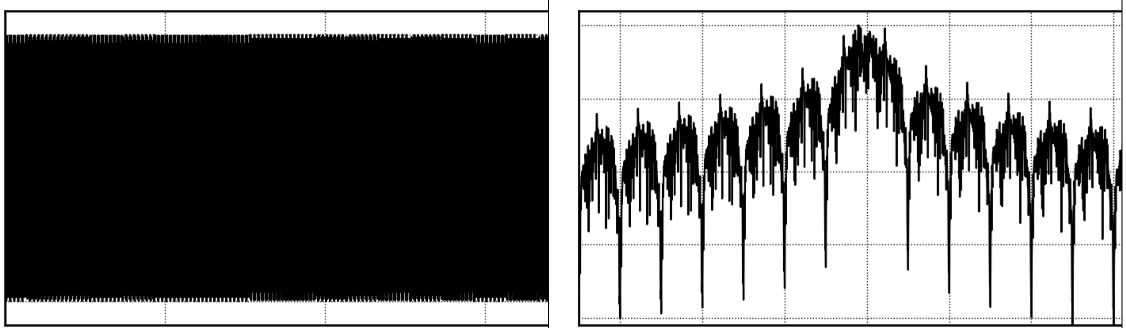


Figure 15A-14. Synthetic QPSK signal. *Phase states change at symbol boundaries. The ordinary spectrum does not by itself reveal the constellation.*

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display

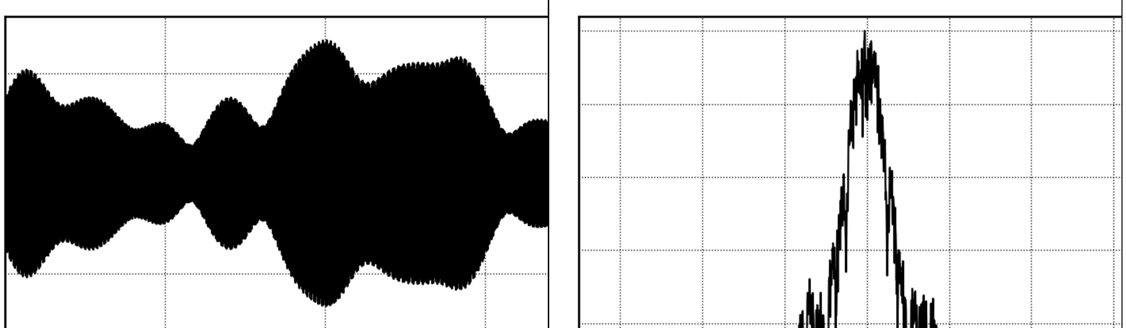


Figure 15A-15. Synthetic 16-QAM signal. *Amplitude and phase both vary. The spectrum reflects pulse shaping and symbol rate rather than the number of constellation points alone.*

15A.14 OFDM and multicarrier waveforms

Orthogonal frequency-division multiplexing, OFDM, divides data among many closely spaced orthogonal subcarriers. Each subcarrier may use PSK or QAM. A cyclic prefix can create a strong autocorrelation feature. Pilots, null subcarriers, guards, preambles and time-varying resource allocation produce structure within an otherwise flat-topped spectrum. High peak-to-average ratio and clipping can create spectral regrowth. A weak OFDM signal may resemble raised noise. The examiner therefore tests for stable band edges, subcarrier spacing, cyclic prefix, pilot periodicity and repeated preamble structure rather than relying on spectral shape alone.

Advanced spectral-temporal analysis. For OFDM and multicarrier waveforms, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform.

Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

Multiple unrelated narrow signals can also create a comb, while impulsive noise passed through a channel filter can mimic an OFDM plateau. The candidate must remain coherent in time-frequency analysis and should present the same subcarrier spacing or cyclic features at multiple stations.

The NTIA guidance describes OFDM and related multicarrier systems in terms of active subcarriers and spacing [73]. ATSC 3.0 is a particular standards-based OFDM system and is treated separately below.

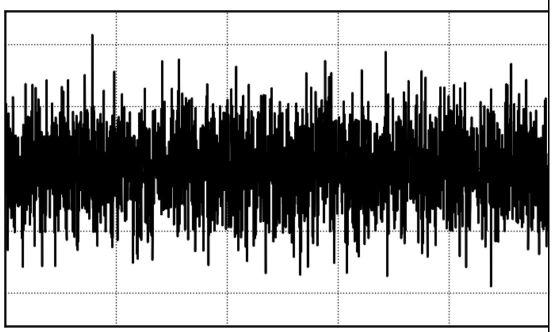
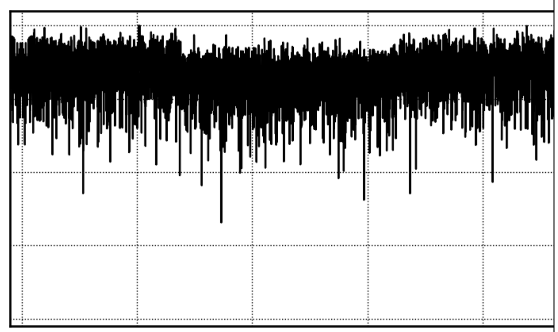
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-16. Synthetic OFDM signal. *The time waveform is noise-like with high peak-to-average ratio. The spectral display forms a broad multicarrier plateau.*

15A.15 Direct-sequence, frequency-hopping and noise-like spread spectrum

Direct-sequence spread spectrum, DSSS, multiplies a lower-rate data sequence by a higher-rate spreading sequence. The signal bandwidth follows chip rate more strongly than user data rate. Frequency-hopping spread spectrum, FHSS, moves a narrow instantaneous emission among frequencies according to a hop sequence. Hybrid systems combine direct sequence and hopping. Chirp spread spectrum maps information to swept-frequency chirps. These methods are intentionally wider than the underlying information bandwidth, but they are not invisible. They create chip clocks, hop dwell, repeated preambles, cyclic statistics, spectral edges, autocorrelation peaks or time-frequency trajectories.

A spectrum sweep can miss FHSS if dwell is short, and a narrow receiver can mistake each hop for an unrelated burst. A wide I/Q recorder or multiple synchronised receivers is preferred. DSSS may appear as noise but can exhibit non-Gaussian amplitude, stable bandwidth, code-period autocorrelation and spectral correlation.

The examiner does not attempt code recovery unless separately authorised and necessary. Non-content features are sufficient for source detection and localisation. The NTIA guidance treats DSSS and FHSS as spread-spectrum families and distinguishes instantaneous from total hopping bandwidth [73].

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display

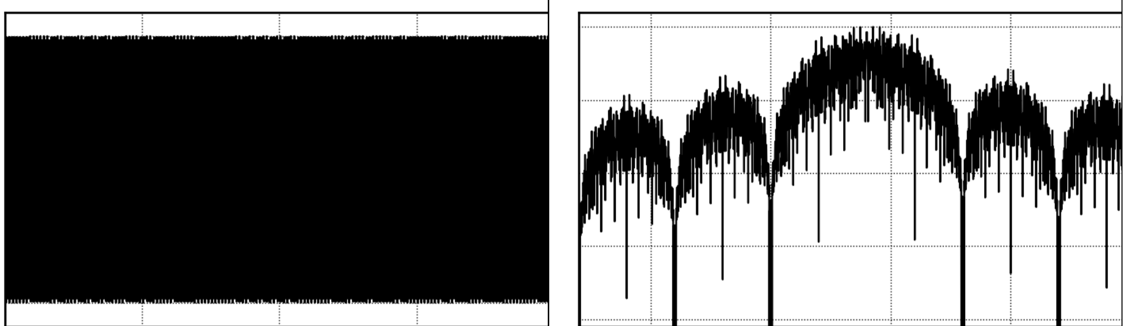


Figure 15A-17. Synthetic direct-sequence spread-spectrum signal. *The carrier is spread by a higher-rate binary sequence, creating a wider noise-like spectrum with hidden periodic structure.*

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display

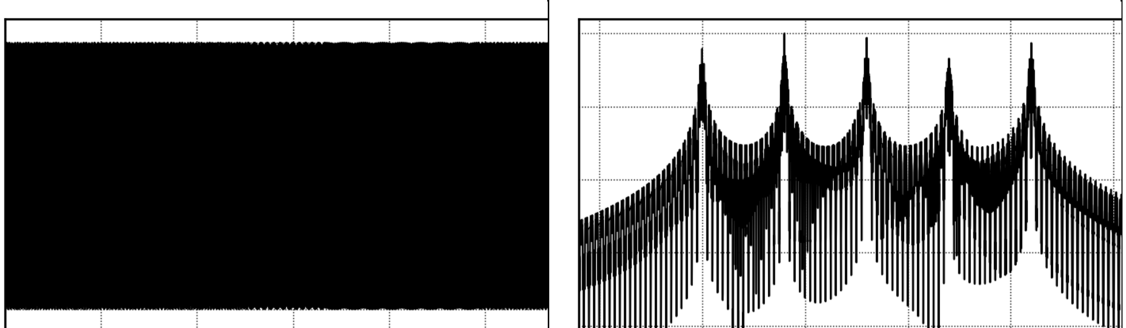


Figure 15A-18. Synthetic frequency-hopping signal. *The instantaneous carrier occupies one hop at a time. A persistent spectrum accumulates energy across the hop set.*

15A.16 NTSC composite timing and vestigial-sideband signatures

NTSC is a legacy analogue television system rather than a single modulation. Its composite video waveform contains horizontal synchronising pulses, blanking, colour burst, luminance and chrominance. In historical System M operation, the colour subcarrier is approximately 3.579545 MHz, horizontal scanning is approximately 15.734264 kHz and field rate is approximately 59.94 Hz.

The transmitted radio-frequency visual signal uses vestigial-sideband amplitude modulation, with an aural FM carrier 4.5 MHz above the visual carrier in the historical 6 MHz channel arrangement [26,79].

Modern premises may still contain cameras, converters, test generators or legacy circuitry that leak these timing families without radiating a complete broadcast waveform.

Advanced spectral-temporal analysis. The expert treatment of NTSC composite timing with or without vestigial-sideband signatures begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables.

Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail.

The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

The forensic question is therefore hierarchical. A 15.734 kHz line may be horizontal timing, a switching harmonic or an unrelated oscillator. A 3.579545 MHz line may be colour-reference leakage, a crystal harmonic or an RF source. A complete NTSC-like hypothesis requires coherent relationships among line timing, colour burst, frame or field periodicity and, where present, VSB spectral structure. The examiner shall not reconstruct an image. Only timing, spectral and spatial attributes are retained. The synthetic plate below shows the form of one composite line and a stylised RF envelope. It is not a standards-compliance waveform.

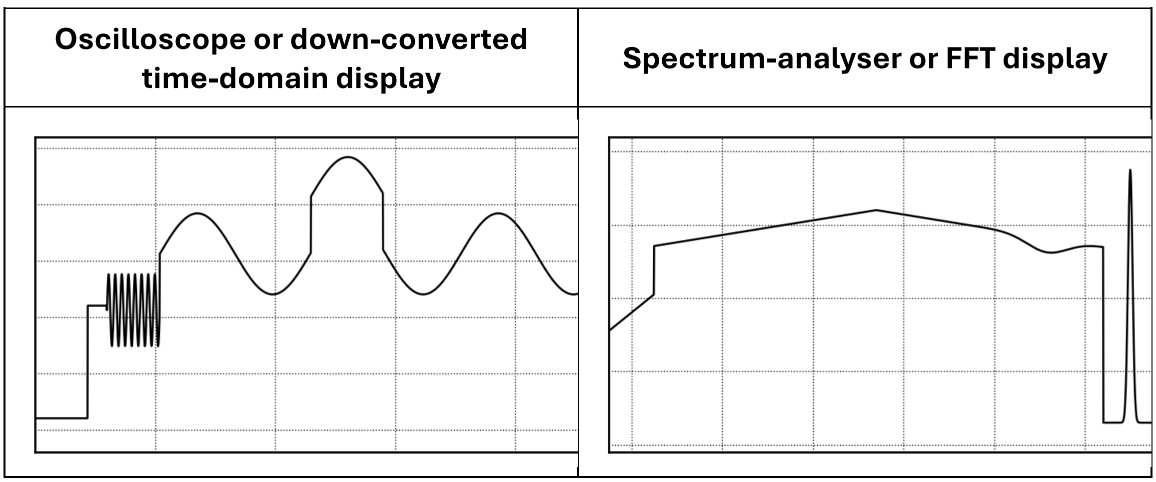


Figure 15A-19. Synthetic NTSC-like composite line and stylised VSB channel. *The time display includes sync, blanking, colour-burst-like oscillation and active-video levels. The spectrum shows a visual-carrier region, vestigial lower sideband, chroma region and separate aural carrier.*

15A.17 ATSC 1.0 8-VSB

ATSC 1.0 terrestrial digital television uses 8-level vestigial-sideband modulation. The ATSC A/53 transmission standard describes an approximately 10.76 Msymbol/s composite data signal, a small pilot, 832-symbol data segments, four-symbol segment synchronisation and data-field synchronisation [74]. At ordinary spectrum-analyser resolution, a received 8-VSB channel appears as a broadly filled 6 MHz emission with a characteristic pilot near one edge and shaped band limits. In the time domain it resembles multilevel noise with embedded synchronisation. A narrow leakage from a receiver, converter or modulator may expose symbol-clock, field-sync or pilot-related features without reproducing the whole channel.

Advanced spectral-temporal analysis. For ATSC 1.0 8-VSB, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

An 8-VSB classification requires more than a flat spectrum. The examiner searches for pilot position, segment repetition, field synchronisation, symbol rate and VSB asymmetry. Adjacent digital services, OFDM, broadband noise and receiver overload can imitate the gross envelope. The synthetic waveform below demonstrates an 8-level, pilot-offset, pulse-shaped signal only. It is not an ATSC test vector and shall not be used for compliance testing.

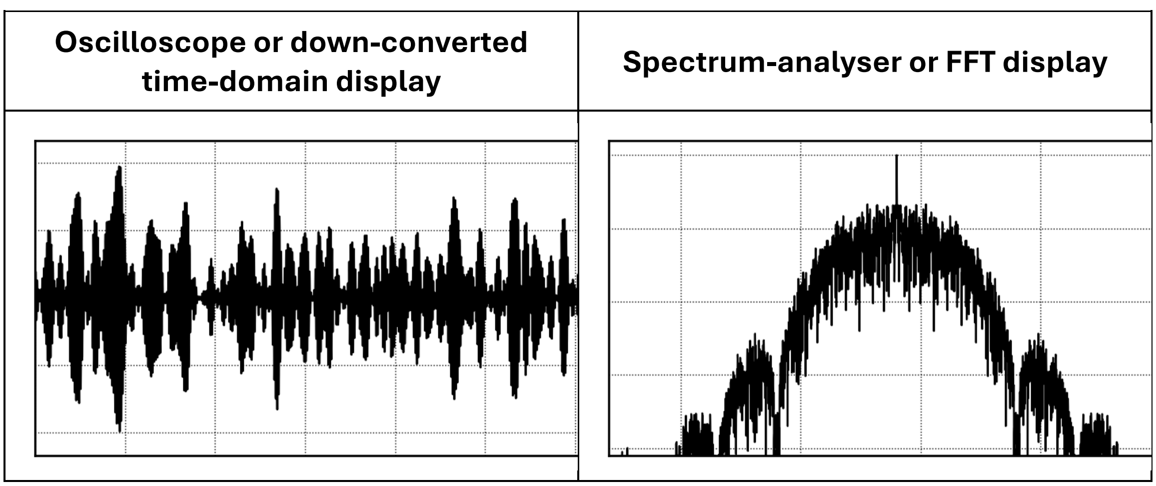


Figure 15A-20. Synthetic 8-VSB-like waveform. *The time display is multilevel and noise-like. The spectrum has a vestigial-sideband-like occupied region and a carrier-offset component.*

15A.18 ATSC 3.0 physical-layer signatures

ATSC 3.0 uses a flexible OFDM physical layer with a bootstrap, preambles, physical-layer pipes, LDPC and BCH coding, selectable FFT and guard parameters, and constellations ranging from QPSK through high-order non-uniform QAM in current recommended practice [75-76]. The bootstrap is a universal discovery structure and was the subject of a 2026 clarification amendment [75]. Because configurations vary, there is no single ATSC 3.0 spectrum beyond the authorised channel envelope. The forensic task is to identify a standards-consistent collection of bootstrap, preamble, OFDM, pilot, cyclic-prefix and frame features, not merely to label any broad OFDM signal as ATSC.

Waveform and modulation elaboration. The expert treatment of ATSC 3.0 physical-layer signatures begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

A low-level emission from television equipment may be an internal clock, local oscillator, memory bus, tuner leak or partial IF rather than an over-the-air ATSC signal. The examiner compares centre frequency, bandwidth, repetition, reference-clock family and spatial gradient. Content decoding is unnecessary for source-class association. The synthetic plate shows a preamble-like burst followed by an OFDM body and is not a standards-conformance waveform.

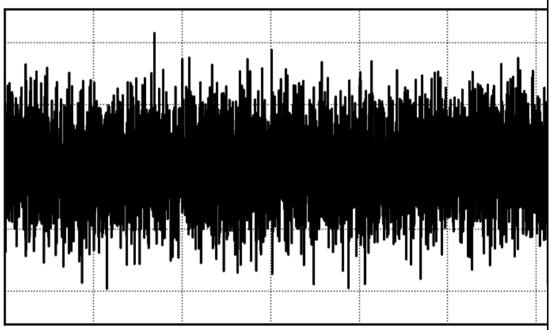
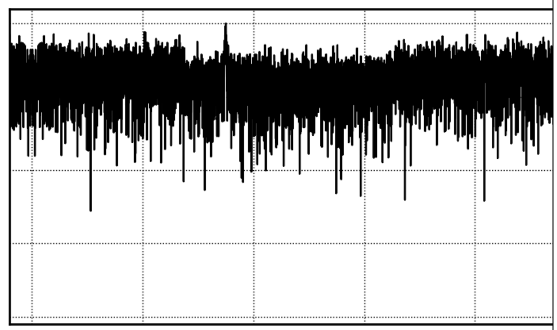
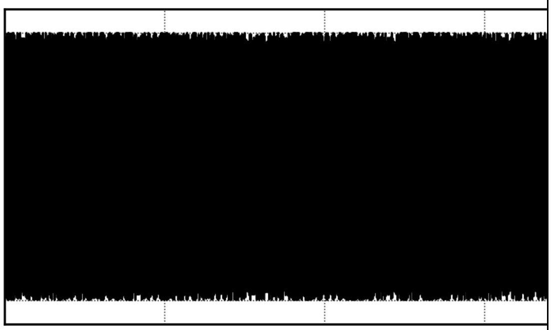
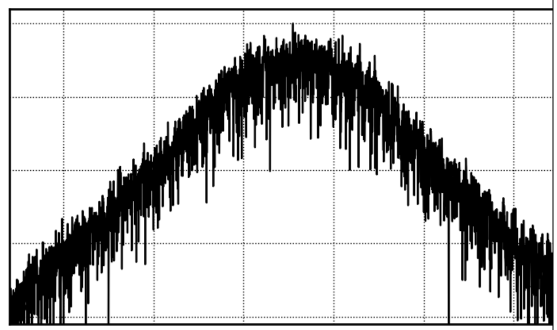
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-21. Synthetic ATSC 3.0-like bootstrap and OFDM body. *The early structured burst differs from the following noise-like multicarrier interval. The spectral display is broadly occupied.*

Forensic recognition uses instantaneous-frequency histograms for C4FM, differential phase and I/Q analysis for CQPSK-like forms, burst timing, repeated synchronisation and channel-spacing context. Simulcast multipath can distort the time waveform and create apparent amplitude modulation. A strong nearby P25 transmitter can also overload a receiver and generate intermodulation in unrelated bands. The plate below is a synthetic C4FM-like waveform using the conventional four deviation states for illustration. It is not a conformance signal and contains no decodable voice or data.

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

15A.20 APCO Project 25 Phase 2

P25 Phase 2 uses two-slot TDMA and harmonised waveforms. The NTIA guidance identifies H-DQPSK for the downlink and H-CPM for the uplink, with a 12 kbps gross example in each direction [73]. H-DQPSK is a differentially encoded quadrature phase waveform shaped for the channel. H-CPM is continuous-phase modulation. A captured Phase 2 channel can therefore exhibit slot periodicity, burst ramps, synchronisation, differential-phase structure, continuous-phase state transitions and direction-dependent waveform characteristics.

Coherent-array interpretation. The purpose of APCO Project 25 Phase 2 is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

A short isolated burst is not enough to identify P25 Phase 2. The examiner measures slot timing, symbol rate, occupied bandwidth, phase continuity, cyclic features and repeated frame structure. DMR, TETRA, NXDN, digital telemetry and proprietary TDMA can occupy superficially similar bandwidths. The synthetic plate combines generic differential-phase and continuous-phase characteristics for recognition training only. It is not a P25 test vector.

Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display

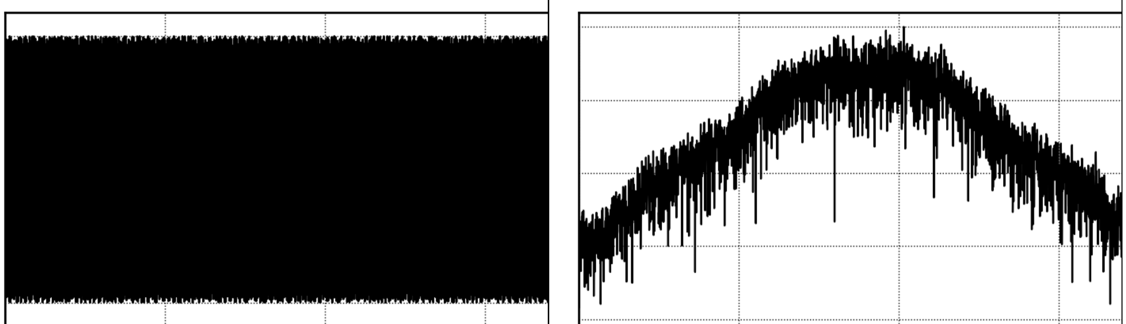


Figure 15A-23. Synthetic P25 Phase 2 H-DQPSK/H-CPM-family illustration. *The waveform retains a controlled envelope while differential phase changes create the occupied spectrum.*

15A.21 Pulse-modulation framework

Pulse modulation is classified by the pulse attribute that changes while the frame reference and other attributes are controlled. Pulse-amplitude modulation varies height. Pulse-width or pulse-duration modulation varies duration. Pulse-position modulation varies displacement within a frame. Pulse-frequency or pulse-repetition-frequency modulation varies repetition rate. Pulse-interval modulation varies the interval between selected edges. Pulse-number modulation varies count. Pulse-polarity modulation changes sign. PCM quantises a source and represents the code digitally. Pulse-density modulation varies the proportion of one state over an interval. Hybrid systems vary several attributes at once. The examiner shall not assign a name merely because pulses are present.

Advanced spectral-temporal analysis. For Pulse-modulation framework, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

The minimum pulse descriptor contains amplitude, baseline, polarity, 10-to-90 per cent rise time, 90-to-10 per cent fall time, width at declared reference points, position relative to a declared frame, pulse repetition interval, duty cycle, jitter, missing-pulse rate, carrier phase where applicable and uncertainty. Threshold choice is recorded. A second detector, changed threshold and raw waveform review are mandatory for a PPM conclusion. Receiver blanking, AGC, squelch and digital packetisation can manufacture apparent pulses that do not exist at the antenna port.

15A.22 Pulse-amplitude modulation

In PAM, pulse timing and nominal width remain fixed while amplitude takes analogue or discrete values. Sample-and-hold systems, multiplexers, telemetry and intermediate stages can leak PAM-like waveforms. Channel filtering rounds pulse edges and intersymbol interference alters apparent amplitude. A saturated receiver clips the levels and may convert multilevel PAM into binary pulses. The examiner therefore records unclipped raw voltage, input attenuation, baseline, level histogram and pulse timing. PAM of an RF carrier is an amplitude-keyed system and may produce carrier-centred sidebands and a repetition comb.

Advanced spectral-temporal analysis. For Pulse-amplitude modulation, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

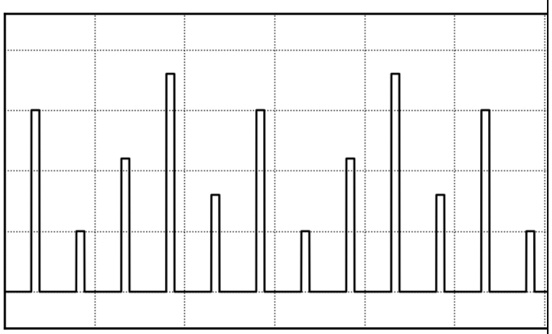
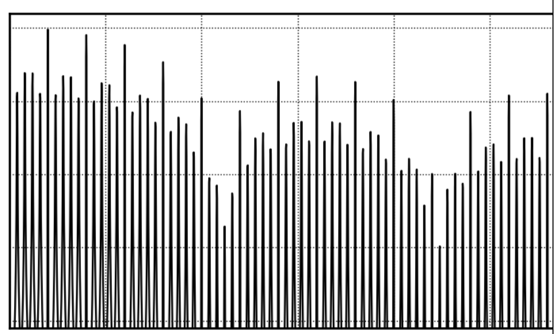
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-24. Synthetic pulse-amplitude modulation. *Pulse height changes while nominal pulse position and width remain fixed.*

15A.23 Pulse-width or pulse-duration modulation

Pulse-width modulation, PWM, and pulse-duration modulation vary the interval between selected leading and trailing edge reference points. Switching power converters, dimmers, motor controls, class-D amplifiers and optical links commonly use this principle, making it a major confounder. Width variation changes average value and the locations of spectral nulls. Edge speed controls high-frequency extension. A comparator threshold can make amplitude noise look like width modulation, so width shall be measured at several validated fractional-amplitude levels and on an independent channel.

Signal-analysis interpretation. The expert treatment of Pulse-width or pulse-duration modulation begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

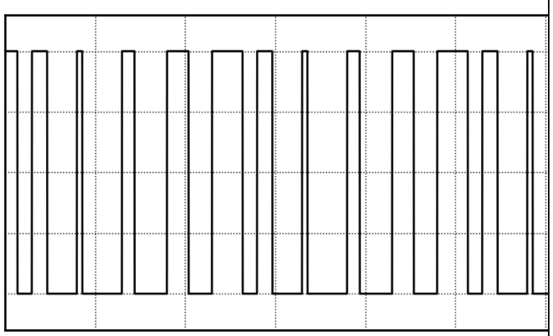
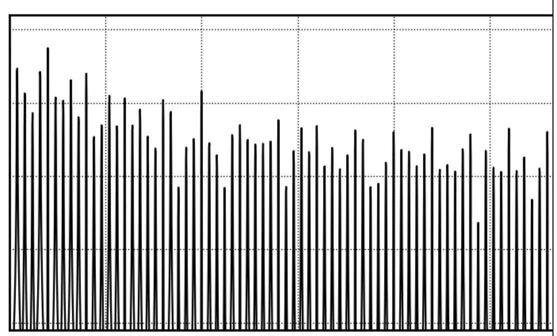
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-25. Synthetic pulse-width modulation. *Pulse duration changes while the nominal frame start remains fixed.*

15A.24 Pulse-position modulation and pulse-position signalling

Pulse-position modulation, PPM, encodes a state by moving a pulse within a defined frame or symbol interval. The reference may be an external clock, a separate sync pulse, a preceding edge or a recovered frame estimate. Without a stable reference, irregular timing is not PPM. A weak retroreflective response may return a pulse in one of several positions, or a periodic load change may create position-coded sidebands around an illumination carrier. The examiner estimates pulse position from raw samples or a defined interpolation method and carries clock, trigger, threshold and signal-to-noise uncertainty into the result.

Waveform and modulation elaboration. A advanced technical analysis of Pulse-position modulation and pulse-position signalling preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

In this document, the phrase CW with a PPS subcarrier is interpreted as a carrier-dominant signal whose amplitude, phase, frequency or reflection coefficient is weakly modulated by a pulse-position-signalling sequence. It is not pure CW. The most robust detection features may be the frame repetition, pulse-position histogram, cyclic frequency and illumination correlation rather than the weak pulse amplitude itself. A changed threshold, source-off control and independent timing estimator are mandatory.

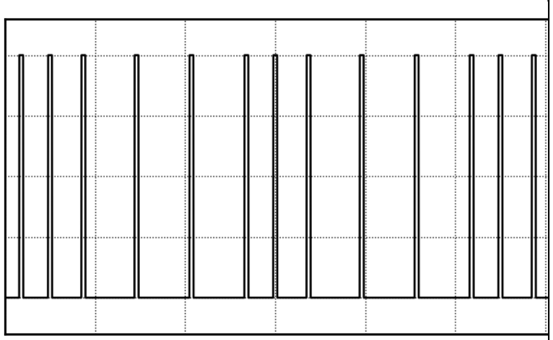
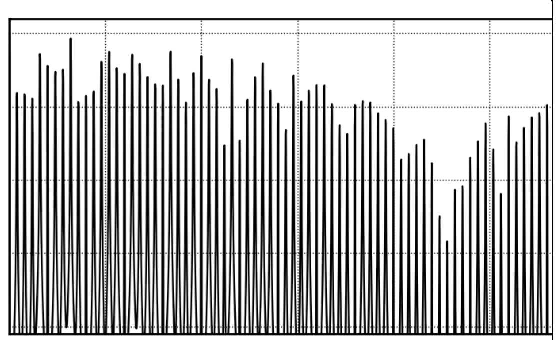
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-26. Synthetic pulse-position modulation. *Pulse displacement changes within each frame while pulse height and nominal width remain controlled.*

15A.25 Pulse-frequency, repetition-frequency and interval modulation

Pulse-frequency modulation, pulse-repetition-frequency modulation and pulse-interval modulation vary the spacing of pulses or frames. The distinctions depend on whether the controlled variable is instantaneous repetition frequency, interval between selected events or a coded pattern of intervals. Beacons, switching converters, sensor interfaces and packet systems can all create variable interval sequences. The ordinary spectrum may show a broadened comb or several repetition lines. A time-interval histogram and Allan-type stability analysis are often more informative than average frequency.

Waveform and modulation elaboration. For Pulse-frequency, repetition-frequency and interval modulation, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

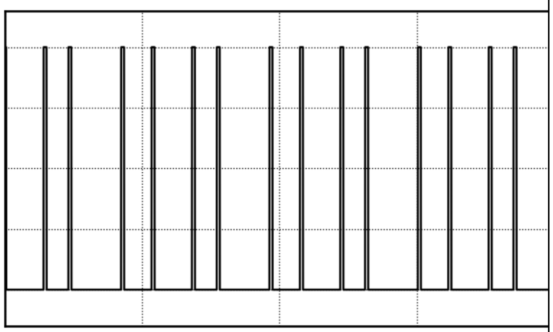
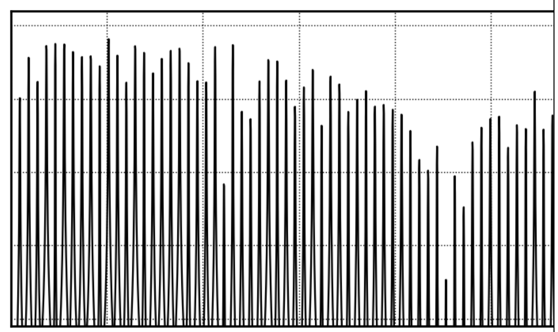
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-27. Synthetic pulse-frequency or interval modulation. *Pulse interval changes from event to event, producing a broadened or multi-line repetition spectrum.*

15A.26 PCM, delta modulation and pulse-density modulation

Pulse-code modulation, PCM, samples and quantises a source, then transmits a binary or multilevel code. The RF modulation carrying PCM may be FSK, PSK, QAM, PM or another family. Delta modulation encodes the direction of change. Adaptive delta modulation varies step size. Sigma-delta conversion produces a high-rate one-bit sequence whose local density represents a lower-frequency signal. Digital microphones frequently emit pulse-density streams and associated clocks. A raw binary line can radiate a comb at bit clock and framing rates even when no intentional RF transmitter exists.

Waveform and modulation elaboration. For PCM, delta modulation and pulse-density modulation, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

The forensic method does not decode private content. It estimates clock, transition density, framing, spectral zeros, sideband families and spatial coupling. Pulse-density modulation is distinguished from pulse-duration modulation by spelling the term and examining whether individual pulse width is fixed. A cable carrying PDM may produce magnetic leakage whose audio-related sidebands lie around a clock in the hundreds of kilohertz or megahertz. The voice-frequency bar probe separately tests current-associated magnetic fields below 14 kHz without reconstructing speech.

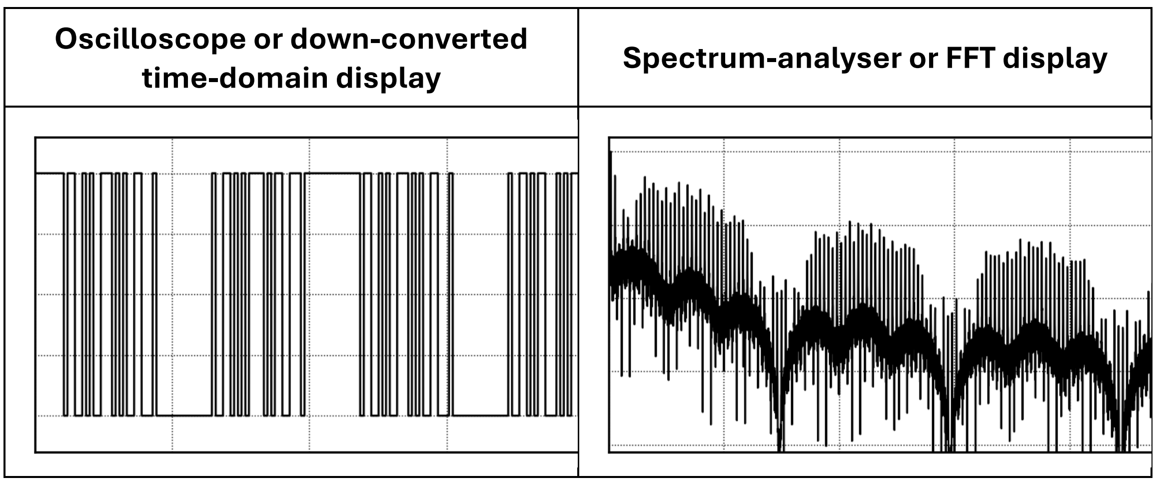


Figure 15A-28. Synthetic pulse-code-modulated serial line. *Quantised sample words form a binary line with clock-related spectral structure.*

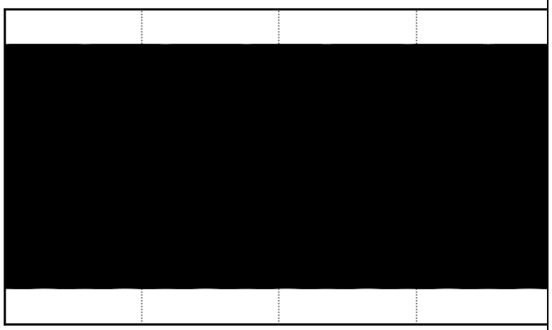
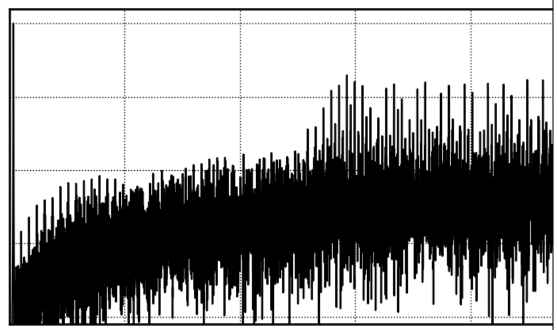
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-29. Synthetic sigma-delta pulse-density stream. *Individual pulses have fixed levels while local one-density follows a lower-frequency waveform.*

15A.27 Burst, VOX, duty-cycled and confidence-beacon emissions

Low-power devices often conserve energy by transmitting only during activity, in short scheduled bursts or as sparse confidence beacons. Voice operation, VOX, can produce irregular bursts whose onset follows acoustic level and whose release includes a hold time. A periodic confidence beacon can be brief enough to disappear between slow spectrum sweeps. Duty-cycle correction is therefore essential when comparing average and peak power. At 300 feet, long dwell, max hold and event-triggered I/Q capture are more important than rapid visual scanning.

Advanced spectral-temporal analysis. For Burst, VOX, duty-cycled and confidence-beacon emissions, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

A burst seen only after the team enters may be caused by body coupling, movement, a wireless device carried by personnel or a building system reacting to presence. Access control and the electronics register are therefore part of signal analysis. The candidate is rechecked on withdrawal and with a stationary reference receiver. The report distinguishes continuous absence from absence during the finite observation window.

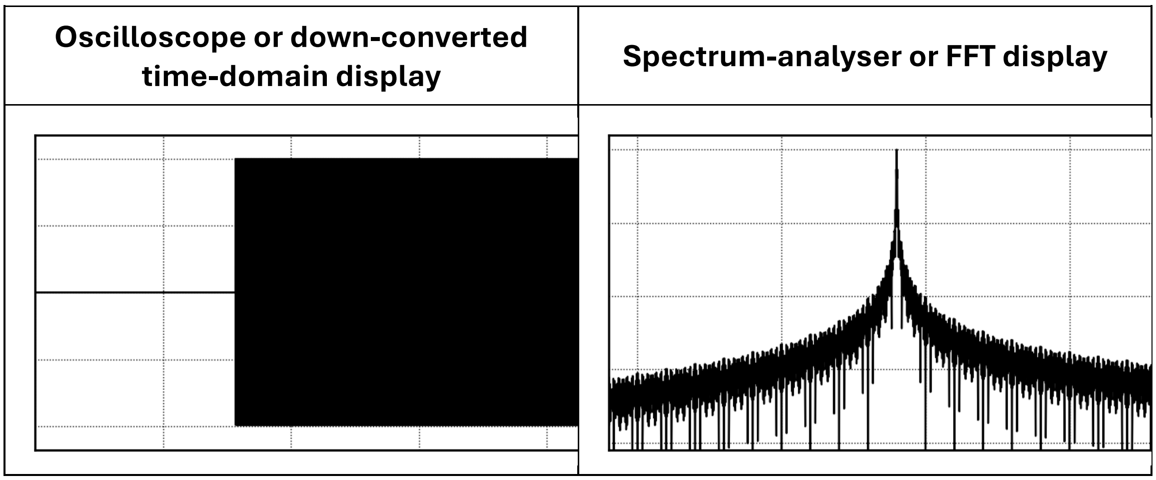


Figure 15A-30. Synthetic duty-cycled carrier bursts. *Carrier energy appears in separated intervals. The accumulated spectrum alone does not reveal duty cycle.*

15A.28 UWB impulses, phase-coded pulses and pulse compression

Impulse radio and ultrawideband systems use very short pulses or pulse-like waveforms whose bandwidth is a substantial fraction of centre frequency. Phase-coded pulse trains divide a pulse into chips with controlled phase. Frequency-modulated pulses or chirps sweep frequency during the pulse and may be compressed by matched filtering. Rise time, pulse duration, chip interval and sweep span determine spectral extent. A conventional narrowband receiver can detect only a fragment or produce a click-like artefact. Wideband calibrated acquisition and careful antenna impulse response are required.

Multichannel receiver analysis. The advanced technical treatment of UWB impulses, phase-coded pulses and pulse compression regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

Electrostatic discharge, relay contacts, brush motors, switching edges and instrument digital activity are major confounders. A genuine structured pulse system should show repeatable PRI, coding or chirp behaviour and a spatially consistent source region. The antenna and preamplifier must be characterised in the time domain because ringing can create false pulse trains.

The NTIA guidance treats unmodulated, phase-coded and frequency-modulated pulses separately and notes that practical bandwidth depends on pulse duration and rise time [73].

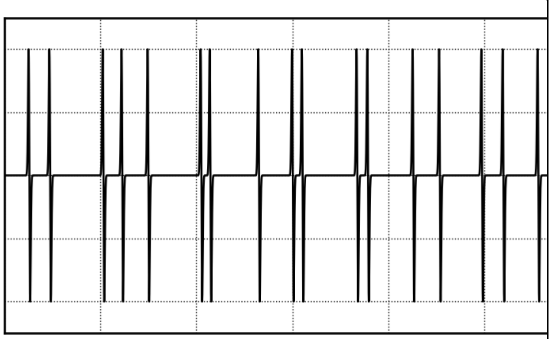
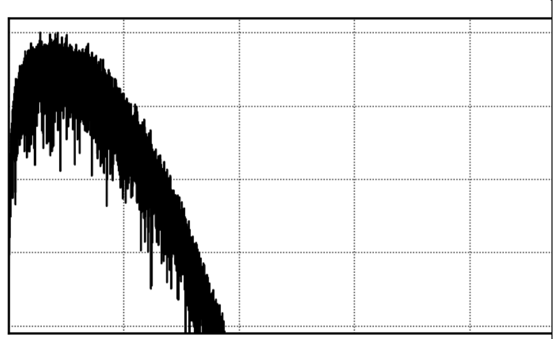
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-31. Synthetic differentiated-Gaussian impulse train. *Short bipolar impulses produce a very broad spectrum. The synthetic signal is not an operational UWB waveform.*

15A.29 Composite and nested modulation model

A composite signal contains more than one modulation process or information-bearing component. In a nested signal, one modulated waveform becomes the baseband or subcarrier for another. A useful **analytical** form is s(t) = A_c[1 + m_a u(t)] cos{2 pi f_c t + k_p v(t) + 2 pi k_f integral w(t) dt}. Here u(t) can be an amplitude subcarrier, v(t) a phase subcarrier and w(t) a frequency-control waveform. Each of u, v and w may itself be modulated. A retroreflector extends the model by making the reflection coefficient Gamma(t) time-varying, so the received field contains Gamma(t) multiplied by the incident field and the propagation response.

Waveform and modulation elaboration. The expert treatment of Composite and nested modulation model begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail.

Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

Composite structure is not proof of deliberate concealment. Broadcast stereo, television, telemetry, remote controls, RFID, wireless sensors and ordinary digital radios routinely combine carriers, pilots, subcarriers, framing and coding.

The forensic task is to enumerate layers and test each against alternative sources. The examiner begins with the strongest invariant, which may be carrier frequency, occupied bandwidth, pulse repetition, cyclic frequency, subcarrier spacing, source-on correlation or spatial gradient. Demodulation proceeds one layer at a time, with raw data preserved and each filter, discriminator and threshold recorded.

15A.30 Carrier-dominant waveform with pulse-position subcarrier

A carrier-dominant composite can look like CW at wide resolution because most power remains in the carrier. Weak pulse-position signalling may vary the envelope, phase, frequency or load only briefly. In the spectrum, the result can be a strong line surrounded by a low-level comb or clustered sidebands.

In zero span, brief events appear at frame-related positions. In cyclic analysis, the frame rate and position pattern can remain visible below the ordinary spectrum noise floor. The examiner therefore combines close-in high-dynamic-range spectrum, carrier-nulled I/Q, zero-span persistence and pulse-time analysis.

Waveform and modulation elaboration. A advanced technical analysis of Carrier-dominant waveform with pulse-position subcarrier preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation.

Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

The carrier may be an ambient illumination source rather than a locally generated transmitter. If the candidate is backscatter, the sidebands should vary with illumination polarisation, angle and field level, while direct leakage follows the transmitter-receiver path. The source-off and sham sequence is decisive. A response that persists when the illumination port is terminated is not an illumination-dependent retroreflective response.

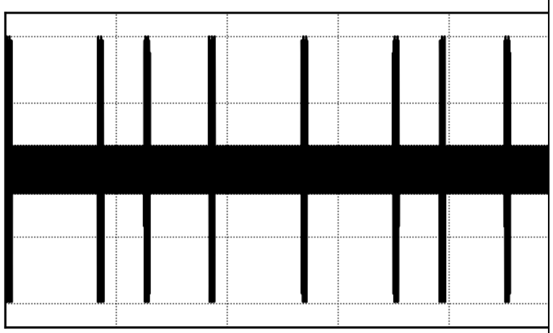
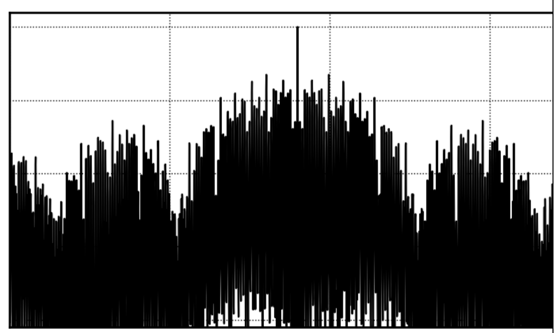
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-32. Synthetic carrier-dominant waveform with pulse-position signalling. *The strong carrier masks weak time-localised envelope events in an ordinary view, while the close-in spectrum contains pulse-related structure.*

15A.31 Noise-like AM or FM host with pulse-position subcarrier

A noise-like host can be amplitude-modulated or frequency-modulated by a low-rate pulse-position sequence. The average spectrum may show only a raised noise floor or a broad plateau. The hidden structure appears as periodic variance, repeated time-frequency texture, spectral correlation or a pulse-position histogram after envelope or discriminator processing.

Ordinary noise from a preamplifier, switching converter or digital system can also be cyclostationary, so periodicity alone is not sufficient. The feature must be spatially localised, reproducible and absent in terminated-input and dummy-probe controls.

Waveform and modulation elaboration. The expert treatment of Noise-like AM or FM host with pulse-position subcarrier begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables.

Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

The examiner first estimates the host bandwidth and tests Gaussianity, stationarity and receiver linearity. The second stage searches for cyclic frequencies without presuming a code. The third stage aligns records to the candidate frame and examines whether pulse positions repeat beyond chance. A fourth stage compares illumination on, off, sham and frequency-offset states. The synthetic example uses amplitude modulation of a noise-like host. Equivalent logic applies when the host drives instantaneous frequency.

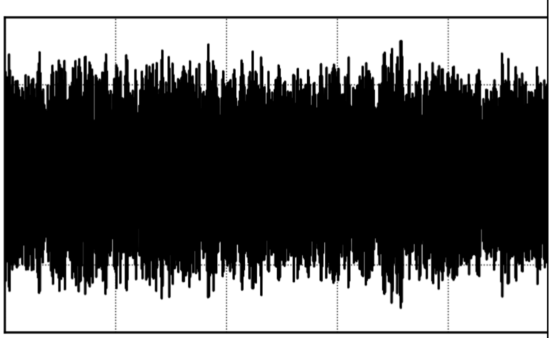
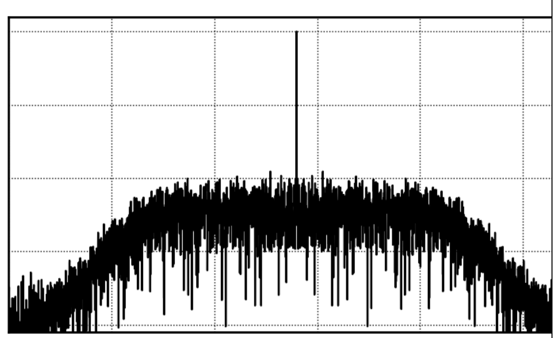
Oscilloscope or down-converted time-domain display	**Spectrum-analyser or FFT display**
	

Figure 15A-33. Synthetic noise-like AM host with weak pulse-position structure. *The ordinary spectrum is broadly noise-like, while the time-domain variance contains repeated pulse-position events.*

15A.32 NFM carrier carrying an NFM subcarrier

In NFM-on-NFM, a lower-frequency subcarrier is frequency-modulated by a message or timing sequence, then that subcarrier frequency-modulates the outer RF carrier. The outer signal may retain a constant envelope. A first FM discriminator recovers the modulated subcarrier.

A second discriminator, applied only after the subcarrier is isolated and the first-stage response is calibrated, recovers its instantaneous frequency. Direct spectrum analysis can reveal clusters around the outer carrier at the subcarrier offset, with fine structure determined by the inner modulation.

Advanced spectral-temporal analysis. The expert treatment of NFM carrier carrying an NFM subcarrier begins with the complex analytic signal rather than a visual resemblance on a single spectrum display.

Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

The same spectral pattern can arise from power-supply sidebands, PLL reference spurs, vibration, multipath or two independent sources. The examiner therefore checks whether the subcarrier and inner modulation remain phase or time coherent, whether they share the same spatial gradient, and whether both disappear under source-off control.

This layered process is a recognition method. It is not a recipe for producing a covert waveform.

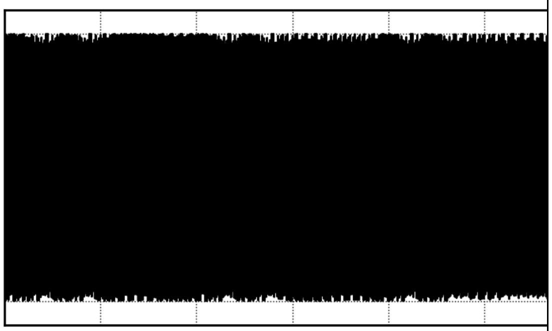
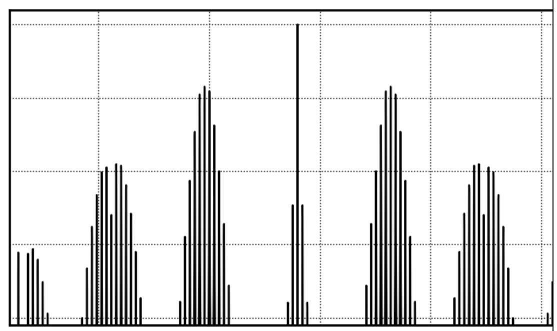
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-34. Synthetic NFM-on-NFM composite. *The outer carrier has approximately constant amplitude. The spectrum contains clustered sidebands reflecting both subcarrier and inner modulation.*

15A.33 Cross-family and same-family nesting

This extends the treatment to two- and three-level composite chains, including band-limited noise from a noise diode used as a host or masking component, CW or NFM outer carriers, pulse-position-signalling subcarriers, and NFM subcarriers conveyed by NFM hosts. These are analysed solely as defensive recognition problems. The framework does not prescribe concealment parameters, transmitter construction, unauthorised interception or operational evasion.

Composite systems can place AM on an FM carrier, FM on an AM subcarrier, PSK on an OFDM subcarrier, pulse-position signalling on a noise-like host, or one NFM layer inside another. Cross-family nesting often leaves several distinct invariants. AM contributes envelope correlation. FM contributes instantaneous-frequency variation. Pulse structure contributes a repetition comb.

Digital framing contributes cyclic frequencies. Same-family nesting can be harder for a single demodulator because the first discriminator output still resembles a modulated carrier, yet it is often easier for a forensic search because the spectrum contains multiple stable spacings and the two-stage demodulation is testable.

The analysis ledger records an ordered hierarchy rather than a single label. An example entry is: outer carrier 433.920 MHz, NFM-like; first subcarrier 4.2 kHz, NFM-like; low-rate sequence 125 Hz, pulse-position-like; source state illumination-correlated; classification provisional. Each layer receives its own uncertainty and control result. If one layer is not supported, it is removed without changing the raw record.

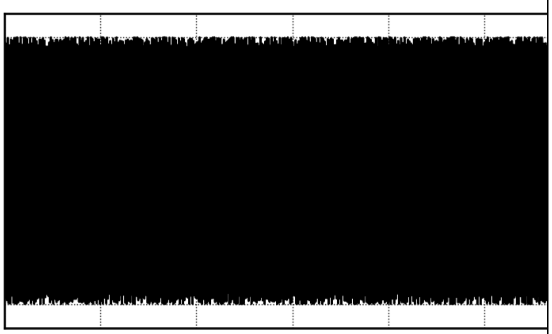
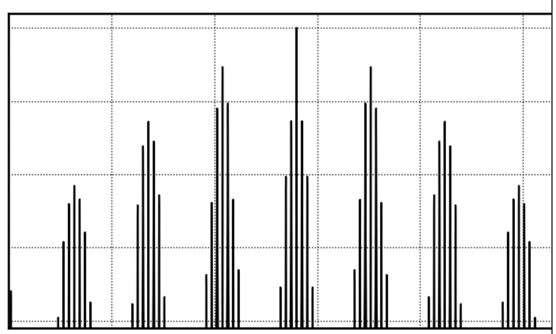
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-35. Synthetic FM carrier with AM subcarrier. *The spectrum shows outer-FM spreading with additional structure produced by the amplitude-modulated subcarrier.*

15A.34 Retroreflective, backscatter and frequency-translated composite responses

A passive or semi-passive structure can vary its reflection coefficient so that an incident carrier is returned with sidebands. A rectifying or energy-storing circuit can activate an oscillator or encoder and reradiate at the same frequency, a harmonic, a subharmonic or a translated frequency. A SAW reflective delay line can return delayed coded echoes. A nonlinear junction can create sums, differences and harmonics without any intentional encoding. These mechanisms must be separated. Same-frequency backscatter is examined close to the illumination carrier with high isolation. Frequency-translated responses are examined in a protected receive band. Harmonic responses are predicted from the illumination spectrum before the field test begins.

Retroreflective-response analysis. The expert treatment of Retroreflective, backscatter and frequency-translated composite responses begins with the passive baseline and the recognition that an applied field changes the scene. The illumination source, coupling path, suspected response path, and receiver are therefore treated as one controlled experiment. Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation.

The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

The response path can be simultaneously complicated and conspicuous. It is complicated because direct leakage, phase noise and intermodulation can be much stronger than the response. It is conspicuous because a genuine response may supply several linked observables: illumination-on timing, a fixed translation relation, pulse-position structure, polarisation dependence, angle dependence, coherent delay and a steep local spatial gradient. The evidential value lies in that conjunction, not in any one line. The synthetic plate shows a strong illumination component and a much weaker gated translated response.

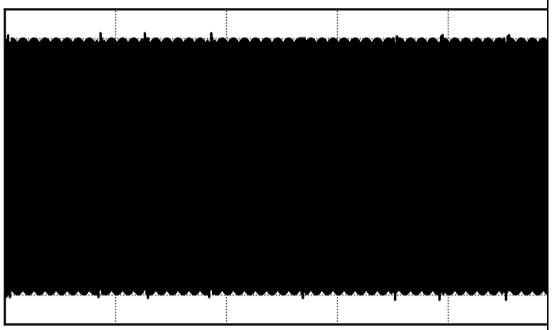
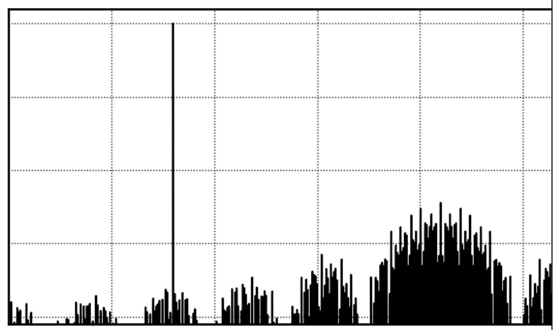
Oscilloscope or down-converted time-domain display	Spectrum-analyser or FFT display
	

Figure 15A-36. Synthetic illumination carrier and weak pulse-position-coded translated response. *The strong source and weak response occupy different frequencies. Direct leakage and receiver intermodulation must be excluded before interpretation.*

15A.34.1 Source-referenced trigger, pre-trigger memory and response-latency iteration

Retroreflective and remotely powered responses can be missed when the response analyser begins too early, too late or on the wrong frequency segment. The illumination-monitor channel therefore establishes time zero from measured source presence. The response recorder preserves data before time zero, across the source rise and through the declared post-trigger window. Where available, the preferred record is continuous gap-free I/Q over the response band. A triggered conventional sweep is an adjunct for stable or repetitive responses, not the sole record for a single short event.

The delay programme covers more than free-space propagation. Electromagnetic propagation across a room is effectively immediate at the time scales of ordinary swept instruments, but couplers, detectors, filters, relays, source settling and analyser arming can contribute measurable delay. A passive SAW delay structure may return a short deterministic echo, while a remotely powered circuit may require rectifier charging, voltage-threshold crossing, oscillator build-up, logic start-up and encoder framing. The tested interval shall therefore be set from the response hypothesis and instrument characterisation rather than from distance alone.

A practical coarse schedule uses negative pre-trigger, zero delay, then approximately logarithmic positive delays. Illustrative delay points are 10 microseconds, 30 microseconds, 100 microseconds, 300 microseconds, 1 millisecond, 3 milliseconds, 10 milliseconds, 30 milliseconds, 100 milliseconds, 300 milliseconds, 1 second, 3 seconds and 10 seconds.

These values are not mandatory frequencies or device characteristics. They are a search scaffold. The capture window at each point overlaps the neighbouring interval so that a response cannot fall invisibly between windows.

When a candidate appears, the examiner brackets its onset with an earlier and later delay, halves or otherwise refines the interval, and repeats until the latency estimate is limited by the calibrated timing uncertainty or the response jitter.

The response must remain at the same physical frequency, retain its translation or modulation relation, and converge spatially. Delay refinement stops if the response is not reproducible, if the receive chain is overloaded, if the source monitor is unstable, or if a safety or compatibility gate opens.

The final response-latency record includes source-detection latency, trigger-distribution latency, analyser trigger uncertainty, pre-trigger length, requested and measured delay, response onset, response peak, duration, recovery, jitter, missed-event rate, source-off result, sham result, independent-receiver result and expanded timing uncertainty.

A response observed at one attractive delay without the controls remains illumination-correlated only.

Table 15A-17A. Delay-iteration and real-time capture sequence

Stage	Delay and capture action	Release criterion
Instrument characterisation	Loop back source monitor and trigger paths; measure fixed latency and jitter	Latency budget and uncertainty approved
Baseline and pre-trigger	Acquire source-off and source-on records with negative pre-trigger and zero delay	Baseline, source rise and direct leakage visible
Coarse delay search	Use overlapping windows from microseconds through the justified maximum interval	No unobserved gap between windows
Response bracketing	Place one delay before and one after the apparent onset	Candidate recurs at compatible frequency and geometry
Fine delay refinement	Reduce the bracket until limited by response jitter or calibrated timing uncertainty	Onset, peak, duration and recovery quantified
Controlled confirmation	Randomise live, sham, source-off, frequency-offset and receiver-control trials	Latency and response survive negative controls

15A.35 Why composite low-power signals can be difficult and easy to find

Composite low-power signals are difficult when the examiner uses a single receiver mode, a fast sweep, an unsuitable bandwidth or a fixed list of frequencies. Energy may be divided among carrier, sidebands, pulses and hops. A pulse can be absent during the sweep. A noise-like host can sit below ambient digital emissions. A retroreflective response can be masked by illumination leakage. A high-turn magnetic probe can be self-resonant below the target or mechanically microphonic. Any one of these conditions can hide the signal from a superficial search.

Oscillator-family analysis. The advanced technical treatment of Why composite low-power signals can be difficult and easy to find regards a clock as a family of related observables rather than a single nominal line. The fundamental, harmonics, subharmonics, divider products, modulation sidebands, burst cadence, drift, and state-dependent amplitude belong to one timing hypothesis. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

The same signal becomes easier when independent structure is exploited. A stable clock gives harmonic and divider relationships. A periodic burst gives a comb. PPM gives a frame and position histogram. NFM-on-NFM gives two discriminator stages. OFDM gives subcarrier spacing and cyclic prefix.

Backscatter gives source-on correlation, polarisation and spatial gradients. A long controlled ring sequence provides distance behaviour.

A cube lattice provides local gradients. The correct strategy is therefore not merely more gain. It is the accumulation of orthogonal evidence under controlled geometry.

15A.36 Forensic unmixing and recognition workflow

Stage	Required action
1. Preserve	Acquire raw calibrated waveform and I/Q, reference clock state, receiver state, probe geometry and environmental log.
2. Protect	Demonstrate linearity with attenuation, preselection, dummy load and alternate receiver.
3. Describe	Measure carrier or centre frequency, occupied bandwidth, envelope, phase, instantaneous frequency, pulse descriptors and duty cycle without assigning content.
4. Search periodicity	Autocorrelation, PRI histogram, spectral comb, cyclic frequency, symbol or chip clock and repeated preamble.
5. Separate layers	Carrier removal, envelope detection, FM or PM discrimination, subcarrier filtering, second-stage analysis and residual inspection.
6. Test geometry	Probe rotation, polarisation, azimuth, elevation, standoff, cube gradient and reverse path.
7. Test source state	Passive baseline, illumination off, on, sham, frequency offset, polarisation change and field-level step.
8. Confirm independently	Second receiver, different IF plan, alternate sensor geometry, independently disciplined clock and separate analyst.
9. Classify cautiously	Observed signal through confirmed device-associated response, with alternatives and uncertainty.

Carrier removal shall be reversible. A notch or cancellation process can create sidebands or distort pulse timing. The original carrier-present record is retained. Envelope and discriminator outputs are derived from complex I/Q where practical, because analogue detector transfer functions can be difficult to reproduce.

When a subcarrier is isolated, the filter passband, group delay, transient response and edge effects are documented. A residual signal is inspected after each removal stage. Unexplained residuals prevent an overconfident single-label conclusion.

System-level interpretation. A technically mature treatment of Forensic unmixing and recognition workflow begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

15A.37 Cyclostationary and spectral-correlation analysis

A cyclostationary signal has statistics that vary periodically. Mean, variance, autocorrelation or spectral correlation can repeat at a frame, symbol, chip, pulse or subcarrier rate. This makes cyclostationary analysis useful for detecting structured signals whose ordinary spectrum resembles noise. The cyclic autocorrelation at cyclic frequency alpha examines correlation between signal components separated by alpha.

Spectral-correlation displays can reveal pilots, symbol clocks, pulse repetition and nested subcarriers. They are especially useful for low-duty-cycle or noise-like composite responses.

Scene-geometry elaboration. The mature treatment of Cyclostationary and spectral-correlation analysis replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded.

Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Cyclostationarity is not unique to communications. Switching supplies, rotating machinery, sampled data systems, mains-synchronised loads and digital instruments are cyclostationary. The result must survive terminated-input, dummy-probe, alternate-location and instrument-power controls.

Statistical significance is established with noise-only records and multiple-comparison control. The synthetic plate below has periodic variance. Its average spectrum is broadly noise-like, yet its time structure repeats.

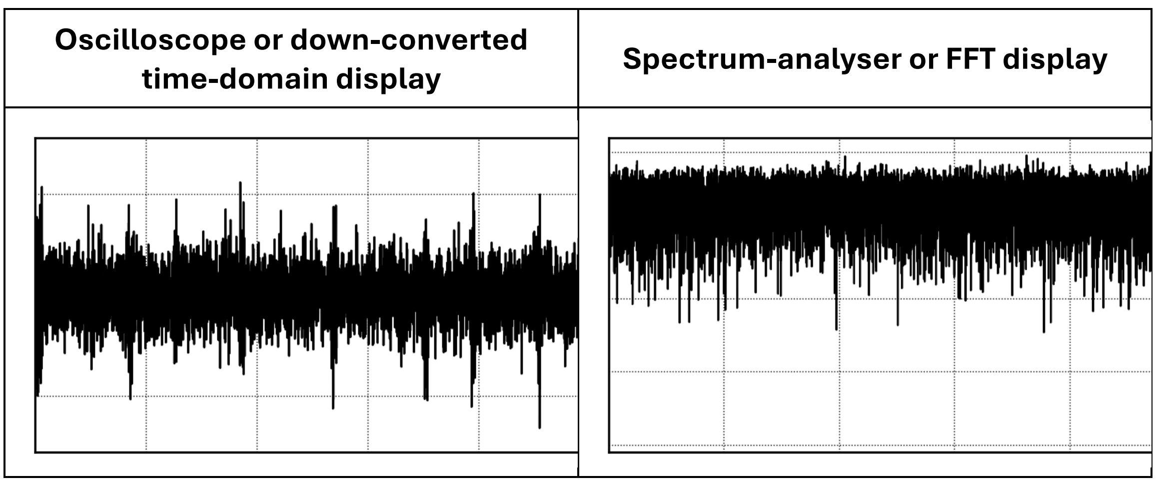


Figure 15A-37. Synthetic cyclostationary noise-like process. *Periodic variance creates structure that may be weak in an ordinary spectrum but visible in cyclic analysis.*

15A.38 Oscilloscope and time-domain acquisition discipline

The oscilloscope view may be direct RF, down-converted IF, complex-baseband component, envelope, discriminator output or pulse detector output. The record states which. Direct RF requires sufficient analogue bandwidth and probe loading control. Down-conversion requires a recorded local oscillator and image plan.

Envelope views suppress phase information. Discriminator views suppress amplitude information. A screenshot alone is insufficient. Raw samples, sample rate, vertical scale, input impedance, coupling, bandwidth limit, trigger source, pretrigger fraction, averaging, interpolation and probe calibration are retained.

Advanced practitioner analysis. A technically mature treatment of Oscilloscope and time-domain acquisition discipline begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate.

The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Pulse work uses enough bandwidth to preserve the declared edge and enough sample rate to support timing uncertainty. Carrier and phase work uses a stable timebase and coherent trigger where available.

Persistence can reveal rare states, but it can also merge unrelated events. Averaging can erase non-coherent bursts. Automatic measurements are verified against raw cursors or an independent algorithm. The oscilloscope is placed outside the sensitive region or linked by fibre where its display, processor and switch-mode supply would contaminate the scene.

15A.39 Spectrum-analyser, SDR and waterfall discipline

The spectrum analyser is configured in at least three modes. Discovery mode uses a span broad enough to reveal neighbouring emissions, conservative preamplifier use, peak or sample detection as appropriate, persistence and a sweep time compatible with the resolution bandwidth.

Characterisation mode narrows span and resolution bandwidth to measure carrier, sidebands, occupied bandwidth and phase noise without sweeping across a drifting signal. Event mode uses zero span, real-time spectrum or triggered I/Q to capture bursts. Video bandwidth, detector, trace mode, attenuation, preselection, reference level and preamplifier state are recorded.

An SDR can capture wide I/Q but may contain internal spurs, DC offset, I/Q imbalance, aliasing and USB or network noise. Sample-rate changes, centre-frequency changes and independent receiver confirmation are mandatory.

Waterfall colour is not evidential amplitude unless calibrated. In this black-and-white paper, intensity is described numerically. A candidate is not promoted because it looks visually unusual. It is promoted because measured features are reproducible, spatially consistent and survive artefact controls.

15A.40 Modulation-recognition decision matrix

Waveform and modulation elaboration. For Modulation-recognition decision matrix, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform.

Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail.

The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

Observed pattern	Candidate families	Required discriminator and control
Narrow carrier line	CW, weak AM, unmodulated oscillator leakage, pilot	Zero-span amplitude, close-in phase noise, long coherent dwell, source rotation and gain-step control
Symmetric sidebands	AM, DSB-SC, PM or low-index FM	Envelope test, carrier suppression measurement, quadrature demodulation, sideband phase comparison
One-sided or unequal sidebands	USB, LSB, ISB, VSB, filter asymmetry	Complex I/Q analysis, analytic-signal reconstruction, changed receiver filter and image-rejection control
Constant envelope with broadened spectrum	FM, FSK, PSK, CPM, spread spectrum	Instantaneous frequency and phase, discriminator output, constellation or differential phase, cyclostationarity
Pulse comb	OOK, burst, PPM, PWM, confidence beacon, periodic load modulation	Zero-span, persistence, pulse descriptor word, PRI histogram, timing reference and threshold-variation test
Noise-like plateau	DSSS, OFDM, digital television, deliberately noise-like composite	Spectral kurtosis, cyclic autocorrelation, pilot search, autocorrelation peaks, time gating and reference-channel subtraction
Illumination-correlated weak response	Backscatter, nonlinear junction, remotely powered or translated response	Source-off and sham tests, frequency-offset relation, polarisation, spatial gradient, independent receiver and direct-leakage exclusion

15A.41 Integration with the nested rings and three-dimensional cube protocol

Ring or lattice	Purpose	Modulation-analysis discipline
300 ft	Remote electromagnetic reference	Long dwell, broad spans, priority-channel list, timing-family lines, persistent waterfall, receiver self-emission library. No active illumination.
150 ft	First transition test	Repeat exact settings. Test whether carrier, pulse comb, cyclic feature or modulation envelope changes beyond uncertainty.
100 ft	Corroboration and bearing	Add orthogonal antenna axes, zero-span on persistent candidates, initial modulation-family classification without content recovery.
50 ft	Site discrimination	Separate premises-associated gradients from external fields, service conductors and receiver overload. Begin matched narrowband and cyclostationary views.
30 ft	Service-path discrimination	Map cable, pipe, earth and structural paths. Compare magnetic, electric and radiated channels and pulse timing.
15 ft	Pre-boundary comparison	Freeze receiver state. Establish a reproducible pre-entry record for carrier, subcarrier, PRI, duty cycle and cyclic frequencies.
12 ft	Envelope and threshold	Measure wall-normal gradients and polarisation. Complete passive baseline before any controlled entry or illumination decision.
3 ft	Candidate containment	Use small loops, gradiometers, directional probes and independent receiver architecture. Extract modulation only as needed for classification.
3 in lattice	Fine convergence	Stationary probe centre, fixed orientation, coherent dwell, threshold sweeps, pulse-time uncertainty, reverse-path confirmation and coordinate-only reporting.

At every ring, the same candidate identifier is retained even when the best description changes. A line first recorded as CW may later become OOK, NFM or a composite signal. The original label is not overwritten. The ledger records the observation sequence and the evidence that justified each refinement. When probe type, alloy, winding, capacitor setting, preamplifier, antenna, receiver or filter changes, a new measurement series is opened. This prevents a sensitivity improvement caused by retuning from being mistaken for a spatial increase.

Spatial-measurement interpretation. The mature treatment of Integration with the nested rings and three-dimensional cube protocol replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded.

Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object.

15A.42 Artefact rejection for composite and pulse signals

Composite modulation is particularly vulnerable to false interpretation because a nonlinear receiver can manufacture nested products. Two strong ambient carriers can mix to produce a difference frequency. A switched attenuator can gate a local-oscillator spur. An FM discriminator can convert amplitude noise to apparent frequency noise. A narrow filter can ring after an impulse and create a pulse train. AGC can produce envelope steps. Digital decimation can alias a high-frequency clock into a low-frequency subcarrier. The artefact plan therefore predicts harmonics, sums, differences, images, aliases and filter transients before interpretation.

Advanced spectral-temporal analysis. For Artefact rejection for composite and pulse signals, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement.

The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

Minimum controls are input termination, dummy probe, preamplifier bypass, attenuation step, alternate preselector, centre-frequency shift, sample-rate shift, second receiver with a different IF, cable movement control, source-off, sham source, frequency-offset source and spatial displacement. A genuine environmental subcarrier remains at its physical frequency under receiver changes. An alias or image moves according to the changed sampling or local-oscillator plan. A real pulse-position displacement remains materially stable when the detection threshold is varied within the validated region.

15A.43 Evidential classification and reporting

The modulation label is subordinate to the evidential classification. An observed signal can be described as carrier-like, NFM-like, pulse-position-like or OFDM-like without asserting source identity. A candidate device-correlated signal requires spatial and temporal association. An illumination-correlated response requires source-state controls. A reproducible frequency-translated response requires a stable relation to the illumination frequency and artefact exclusion. A spatially localised response requires a bounded gradient under fixed geometry. A confirmed device-associated response additionally requires independent confirmation and an uncertainty statement under the framework's governing criteria.

Forensic interpretation. The advanced technical treatment of Evidential classification and reporting distinguishes recognition, recording, acquisition, analysis, interpretation, and reporting as separate stages. A conclusion is not allowed to migrate backwards and reshape the raw record. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

The report gives both positive and negative findings. Example: A carrier-dominant emission at the stated frequency displayed a 125 Hz cyclic feature and pulse-position clusters after carrier removal. The feature increased within the specified cube, survived threshold and receiver changes, and was absent in source-off and dummy-path controls. The measurements support a spatially localised, illumination-correlated composite response. They do not establish device identity, content, ownership, intent, medical effect or illegality. This language is preferable to asserting that a hidden or cloaked transmitter was found.

15A.44 Worked analytical examples

Advanced practitioner analysis. A technically mature treatment of Worked analytical examples begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

15A-E1. AM sideband prediction

Let f_c be the carrier frequency, f_m the single modulation frequency and m_a the amplitude-modulation index. For conventional DSB full-carrier AM, spectral components occur at f_c and f_c plus or minus f_m. With f_c = 150.000 MHz and f_m = 3.000 kHz, the expected first-order sidebands are 149.997 MHz and 150.003 MHz. A measured pair does not prove AM because mixer products and periodic loading can create the same spacing. The envelope, carrier phase relation and gain-step behaviour must also agree.

Waveform and modulation elaboration. A advanced technical analysis of AM sideband prediction preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement.

The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

15A-E2. Carson Estimate for NFM

Let Delta f be peak frequency deviation and f_m the highest significant modulation frequency. Carson's approximation is B approximately 2(Delta f + f_m). With Delta and is approximately 12 kHz. This supports an 8 kHz to 14 kHz analysis family, but it is neither a regulatory mask nor proof of audio content.

Waveform and modulation elaboration. A advanced technical analysis of Carson estimate for NFM preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content.

15A-E3. Carson Estimate for WFM

With Delta and, B is approximately 2(75 + 15). A spectrum with this width may still be digital, composite or overloaded. The examiner therefore checks instantaneous frequency, pilot or subcarrier structure, and receiver linearity.

Waveform and modulation elaboration. A advanced technical analysis of Carson estimate for WFM preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity.

15A-E4. Pulse-width spectral scale

For an ideal rectangular pulse of duration tau, the first spectral null occurs at approximately 1/tau. If is near 50 kHz. Rise and fall time broaden the practical spectrum further. A 20 microsecond pulse cannot be evaluated reliably with a 1 kHz receiver channel even if the pulse repetition rate is low.

Signal-analysis interpretation. The expert treatment of Pulse-width spectral scale begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables.

The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy.

15A-E5. Pulse-position sampling

Let Delta t be the measured displacement, f_s the sample rate and n the equivalent sample displacement. Then n = Delta t times f_s. With Delta t = 80 microseconds and f_s = 2 MS/s, n = 160 samples. If the combined standard timing uncertainty is 6 samples, the standard uncertainty in time is 3 microseconds. The report states the threshold and interpolation method because amplitude noise can move a threshold crossing.

Multichannel receiver analysis. In Pulse-position sampling, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

15A-E6. OOK pulse-comb spacing

A periodic OOK burst repeated every T_r seconds produces spectral components separated by 1/T_r. If T_r = 10 ms, the line spacing is 100 Hz. This is a powerful detection invariant because the carrier may drift while the repetition comb remains stable. The examiner tests whether the 100 Hz structure persists after source-off, dummy-load and receiver-path controls.

Waveform and modulation elaboration. A advanced technical analysis of OOK pulse-comb spacing preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

15A-E7. NFM-on-NFM sideband family

Let a subcarrier at f_s be frequency-modulated by a baseband component f_m, and let that subcarrier then frequency-modulate an outer carrier f_c. A first inspection looks for clusters near f_c plus or minus f_s, with secondary spacings near f_m. For f_s = 4.2 kHz and f_m = 250 Hz, candidate clusters occur about 4.2 kHz from the outer carrier and may contain 250 Hz fine structure. The exact amplitudes depend on both modulation indices and cannot be inferred from spacing alone.

Advanced spectral-temporal analysis. The expert treatment of NFM-on-NFM sideband family begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement.

The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

15A-E8. OFDM occupied span

For N_a active orthogonal subcarriers separated by Delta f, a first-order occupied span is B approximately N_a Delta f, excluding implementation-dependent guards and windowing. If N_a = 1024 and Delta f = 1 kHz, B is approximately 1.024 MHz. An apparently flat plateau of that width should be tested for cyclic prefix, pilot periodicity and stable edge shape before an OFDM classification is assigned.

Advanced spectral-temporal analysis. A advanced technical analysis of OFDM occupied span preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation.

Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

15A-E9. Coherent repetition gain

For N identical, phase-aligned repetitions in independent noise, the ideal coherent power signal-to-noise improvement is 10 log10(N) relative to one record when phase is maintained and the records are combined coherently. For N = 100, the ideal processing advantage is 20 dB. Clock error, phase drift, motion and nonstationarity reduce this figure, so the measured gain and residual mismatch are reported.

Synchronous measurement elaboration. In Coherent repetition gain, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. The calibration record includes clock distribution, trigger topology, channel skew, aperture jitter, local-oscillator phase noise, amplitude flatness, group delay, mutual coupling, cross-channel leakage, and the stability of correction coefficients.

Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

15A-E10. Sapphire trim at 32.768 kHz

For resonance, C = 1 divided by [(2 pi f)^2 L]. With f = 32.768 kHz and L = 1 H, C is approximately 23.59 nF. A 1 pF change is only about 0.0042 per cent of that capacitance and shifts frequency by roughly half that fraction, about 0.0021 per cent or 0.69 Hz. A sapphire piston trimmer is therefore a fine correction element, not the main tuning capacitor, at this frequency. A switched low-loss fixed bank supplies the bulk capacitance.

Time-domain elaboration. The advanced technical treatment of Sapphire trim at 32.768 kHz regards a clock as a family of related observables rather than a single nominal line. The fundamental, harmonics, subharmonics, divider products, modulation sidebands, burst cadence, drift, and state-dependent amplitude belong to one timing hypothesis. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

15A-E11. Direct-leakage rejection ratio

Let P_L be measured direct illumination leakage at the receiver input and P_R the candidate response. The required rejection margin is M = P_L - P_R in decibels. If leakage is -35 dBm and the response is -105 dBm, M = 70 dB. Preselection, physical isolation and cancellation must provide adequate linearity margin before the weak response is interpreted. A receiver that is compressed by the -35 dBm path cannot validate the -105 dBm feature.

Advanced technical elaboration. For expert practice, Direct-leakage rejection ratio is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression.

The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

15A-E12. Cyclic-frequency interpretation

If a noise-like waveform contains a periodic variance or pulse-position structure with period T_0, its principal cyclic frequency is $\alpha = 1/T_0$. With $T_0 = 8$ ms, $\alpha = 125$ Hz. A conventional average spectrum may resemble noise, while spectral-correlation analysis can show energy coupled between frequencies separated by 125 Hz and its harmonics. The same feature must survive reference-channel subtraction and timing-jitter analysis.

Evidential reasoning elaboration.

The advanced technical treatment of Cyclic-frequency interpretation distinguishes recognition, recording, acquisition, analysis, interpretation, and reporting as separate stages. A conclusion is not allowed to migrate backwards and reshape the raw record. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

15A.45 Modulation-analysis field record

Field	Entry
Case, room, cube and station identifiers	
Carrier or centre frequency and uncertainty	
Acquisition bandwidth, sample rate and reference clock	
Time-domain display type and trigger rule	
Spectrum, zero-span, waterfall and persistence settings	
Carrier, envelope, phase and instantaneous-frequency observations	
Pulse amplitude, width, position, interval, duty cycle and jitter	
Subcarrier frequency, modulation family and hierarchy	
Symbol, chip, hop, frame or cyclic-frequency estimates	
Illumination state, reference waveform and direct-leakage level	
Threshold-change, gain-step, sample-rate and filter controls	
Independent receiver and alternate antenna result	
Spatial gradient, polarisation and reverse-path result	
Candidate classification and alternatives retained	
Raw file identifiers, hashes and reviewer signature	

The record is completed even when the final classification is unknown. Unknown is preferable to a forced label. Raw data and calibration evidence remain primary. Figures in this chapter are synthetic teaching plates. They are not fingerprints and shall not be used to claim that a field waveform originates from a particular device or manufacturer.

APCO Project 25, P25, is a public-safety land-mobile-radio standards suite. Phase 1 common-air-interface waveforms include compatible four-level frequency modulation, C4FM, and coherent quadrature phase-shift-keying or linear-simulcast forms at fixed infrastructure.

NTIA necessary-bandwidth guidance gives a 9. 6 kbps C4FM example with four frequency states and discusses P25 C4FM/CQPSK families [73, 78]. A P25 signal therefore presents framing, symbol-rate, deviation-state and synchronisation features in addition to its occupied bandwidth. It must not be inferred from an 8 kHz to 10 kHz emission alone.

Figure 15A-22. Synthetic P25 Phase 1 C4FM-like waveform. The instantaneous frequency occupies four levels while the envelope remains approximately constant.

Let Delta f be peak frequency deviation and f_m the highest significant modulation frequency. Carson's approximation is B approximately 2(Delta f + f_m). With Delta $f=3kHz$ and $fm=3kHz$, B is approximately 12 kHz. This supports an 8 kHz to 14 kHz analysis family, but it is neither a regulatory mask nor proof of audio content.

For an ideal rectangular pulse of duration tau, the first spectral null occurs at approximately 1/tau. If $\tau=20$microseconds, thefirstnull is near 50 kHz. Rise and fall time broaden the practical spectrum further. A 20 microsecond pulse cannot be evaluated reliably with a 1 kHz receiver channel even if the pulse repetition rate is low.

Chapter Glossary

Terms used in Chapter 21.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

AMPLITUDE MODULATION — Any method of varying the amplitude of an electromagnetic carrier frequency in accordance with the intelligence to be transmitted.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

D

DUTY CYCLE — In a transmitter, ratio of time on to time off.

DYNAMIC RANGE — The span between the smallest and largest input levels that a system can process while meeting specified performance criteria.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

L

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

M

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

MODULATION INDEX — The ratio of frequency deviation to the frequency of the modulating signal.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

R

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

S

SDR — Software-defined radio: a programmable radio architecture in which tuning, filtering, demodulation, analysis, or related functions are implemented digitally.

16. Target-Signal Hierarchy, Passive Detection, and Controlled Illumination Response Analysis

16.1 Purpose and governing sequence

This section governs the relationship between naturally present timing leakage, free-radiated emissions and responses that appear only when a suitable incident field is present. It is deliberately ordered from least intrusive to most intrusive. Tier 1 and Tier 2 work is passive. Tier 3 work is an authorised secondary procedure.

The examiner completes, seals and reviews the passive record before any deliberate illumination equipment enters the controlled electronic inspection area.

The sequence protects both scientific validity and scene integrity. If an active source is introduced too early, its leakage, harmonics, intermodulation products and induced currents can contaminate the very baseline needed to decide whether a candidate was naturally active. Passive closure therefore includes final terminated-input files, dummy-probe records, instrument self-emission checks, reference-clock status, ring and grid maps, raw-file hashes and a list of unresolved passive limitations.

A negative passive examination does not exclude a dormant passive or semi-passive structure. It establishes only that no reportable emission or ambient-carrier response was observed above the validated method capability during the stated bands, states and times. The decision to proceed to illumination depends upon a specific testable hypothesis, legal and safety authority, and a receive system shown to remain linear in the proposed field.

16.2 Formal three-tier target hierarchy

Tier 1 has evidential priority because a low-frequency baseband or central clock may persist when a radio transmitter is duty-cycled, disabled, shielded or frequency agile. The examiner searches for oscillator fundamentals, crystal-derived timing, divider products, harmonics, subharmonics, switching-clock combs, synchronisation frequencies, recurrent burst intervals and phase-stable relationships.

The 32.768 kHz family, approximately 15.734 kHz legacy horizontal timing, 3.579545 MHz legacy colour reference and other clock families are examples, not exclusive signatures.

Evidential reasoning elaboration. A mature forensic approach to formal three-tier target hierarchy separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence.

Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion.

Tier 2 addresses energy that leaves the circuit or its attached conductors as an electric, magnetic or radio-frequency field. The signal may be intentional, unintended, conducted into services and reradiated, or present only during brief state changes.

Tier 2 interpretation therefore combines frequency with time, field component, antenna or probe orientation, bearing, spatial gradient, cable or service-path continuation, duty cycle and relation to a Tier 1 clock.

Tier 3 addresses devices or structures whose measurable response depends upon incident energy. The class includes passive and semi-passive tags, resonant scatterers, retroreflective or load-modulated circuits, SAW-resonator or SAW-filter structures, harmonic or nonlinear-junction responders, and remotely powered circuits that rectify, store and subsequently reradiate energy.

Tier 3 terminology describes the observed response mechanism. It does not identify ownership, intent, legality or medical significance.

Tier	Search object	Permitted passive conclusion	Additional requirement for progression
1	Baseband timing and central clock phenomena	A reproducible timing-family signal was observed and spatially characterised.	Survive blank, receiver, frequency-reference and source-path controls.
2	Radiated or conducted electronic emissions	A reproducible electromagnetic emission was observed and related, or not related, to a timing family.	Survive external-source, service-path, multipath and instrument-linearity controls.
3	Illumination-dependent response	An authorised incident field produced a reproducible response under stated conditions.	Survive source-off, sham, offset, geometry, direct-leakage, independent-receiver and uncertainty controls.

16.3 Tier 1 baseband and central clock search

Tier 1 acquisition begins with wide enough bandwidth to capture drift, sidebands, gated operation and nearby switching products, followed by coherent or narrowband confirmation. The examiner does not tune a high-Q ferrite probe to a single expected frequency and then treat the resulting response as discovery. A broadband companion channel remains active so that probe resonance, movement and environmental transients can be distinguished from a true spectral family.

Clock and timing interpretation. A technically mature analysis of Tier 1 baseband and central clock search distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock.

A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence.

For each candidate, the record identifies the nominal frequency, measured frequency, uncertainty, reference-clock source, harmonic and subharmonic relationships, pulse or burst cadence, jitter, phase stability where available, field component and spatial behaviour. A central clock may be more readily detected through a harmonic, a divider output or a common-mode conductor than through its fundamental. The search therefore follows mathematically related features across the ring sequence rather than demanding the same dominant line at every distance.

The Tier 1 conclusion remains limited to a timing source or timing-associated coupling path within the stated region. A 32.768 kHz component, for example, is consistent with a wide class of ordinary real-time-clock circuits. Even a stable family of harmonics does not identify a particular device without discriminating source-specific evidence.

16.4 Tier 2 radiated and conducted signal search

Tier 2 broadens the examination to intentional and unintended radio-frequency energy, near-field electric and magnetic components, cable-mode radiation, periodic bursts, low-duty-cycle transmissions and frequency-hopping activity. The receiving architecture must preserve dynamic range because ordinary local transmitters can be many orders of magnitude stronger than the candidate. Preselection and gain steps are recorded at every change.

A Tier 2 signal is evaluated for relation to Tier 1. The carrier may be unrelated to the clock, phase locked to it, burst at an interval derived from it, or contain sidebands spaced by a timing frequency. These relationships are hypotheses tested against frequency uncertainty and time synchronisation. Arithmetic coincidence alone is weak evidence when a dense spectrum provides many possible ratios.

The outer rings remain important at radio frequencies. A signal that maintains an external bearing, follows a road or utility route, or strengthens at the receiving cable rather than the premises may be an external source or common-mode artefact. Interior localisation begins only after the examiner has challenged these alternatives.

16.5 Candidate illumination bands and qualification

The candidate regions from .9 GHz to 2.3 GHz, around 4.0 GHz and around 5.6 GHz are engineering hypotheses. They may be selected because prior device-response data, a measured resonance, lawful technical intelligence, a calibrated bench test or a controlled spectral reconnaissance indicates that incident energy in the region could couple to the questioned structure. They shall never be described as universal frequencies for concealed, passive or remotely powered devices.

Controlled-illumination interpretation. A advanced technical analysis of Candidate illumination bands and qualification separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission.

Pre-trigger memory and a coarse-to-fine delay search are used because rectification, energy storage, logic wake-up, resonator settling, pulse encoding, and decay can introduce latency from microseconds to seconds. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied.

Band qualification begins with jurisdiction and site authority. The plan identifies permitted emissions, occupied bandwidth, out-of-band limits, antenna location, duty cycle and maximum field. It then characterises the entire transmit chain, including synthesiser spurs, phase noise, harmonics, feed-line leakage and antenna pattern. A receive-chain compatibility test establishes that the response receiver remains below compression and desensitisation thresholds while the source operates at the maximum authorised level.

A stepped-frequency test uses discrete predeclared frequencies, stable dwell and source-off intervals. A swept-frequency test is used only when the sweep rate, resolution, detector response and device charging time are compatible with the hypothesis.

A rapid sweep can pass through a narrow resonance without delivering sufficient energy, while a slow sweep can blur temporal causality if environmental states change. The chosen method and its limitation are reported.

CANDIDATE-BAND LIMIT
The listed illumination and response frequencies are examples to be tested, not characteristics to be presumed. No negative or positive conclusion may be extended beyond the authorised and validated bands.

16.6 Incident-energy reception, rectification and storage model

A remotely powered circuit may receive energy through an antenna, loop, resonant trace, cable, aperture or distributed structure. The available power depends upon incident field, polarisation match, effective aperture, impedance match, orientation, multipath and losses. A rectifier or nonlinear junction may convert part of the alternating energy into direct current. A storage capacitor or other energy reservoir may then accumulate charge until a threshold is reached, after which a timing, encoding or switching circuit becomes active.

This process can create latency, hysteresis and burst behaviour. The response may begin only after several illumination intervals, continue briefly after the source is removed, or change repetition rate as stored voltage varies. Such behaviour is recorded as an engineering observation, not assumed to prove a particular circuit. Heating, ordinary power-management systems and receiver automatic-gain control can produce superficially similar delays.

The test therefore records incident field or forward power, source-on duration, source-off duration, response onset, response cessation, repeated thresholds and post-illumination passive behaviour. A single onset event is insufficient. At least one descending-level series and one time-separated repeat are required where safety and authority permit, because a true energy threshold should demonstrate reproducible, bounded behaviour rather than an arbitrary one-time coincidence.

16.7 Reradiation, backscatter and frequency translation

Same-frequency backscatter occurs when the questioned structure changes the amplitude or phase of the incident carrier and thereby alters the returned field. Load modulation can create sidebands around the carrier. Harmonic response occurs when nonlinear elements generate integer multiples. Subharmonic or regenerative behaviour may appear when an internal oscillator or divider participates. Frequency translation can also place energy at a response frequency determined by an internal resonator, mixer relation or timing circuit rather than at the illumination frequency.

Controlled-illumination interpretation. For Reradiation, backscatter and frequency translation, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern.

Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied.

A possible response near 300 MHz is therefore evaluated under several competing models. It may be an internally selected reradiated carrier, a SAW-associated response, a PPM transmission, an ordinary external service, a receiver image, a harmonic or subharmonic, or an intermodulation product such as the absolute difference between two strong signals.

The examiner computes plausible products before field interpretation and uses source-frequency offsets to determine whether the response follows the predicted physical relation.

The report distinguishes same-frequency scattering, carrier sidebands, harmonic generation, frequency translation and independent internally timed transmission. These mechanisms have different expectations for phase coherence, frequency offset, latency, polarisation and spatial pattern. A single spectrum plot cannot establish the mechanism.

DIRECT LEAKAGE: illumination source -> receiving system. No environmental conversion is required.
SAME-FREQUENCY BACKSCATTER: illumination carrier -> questioned structure -> reflected carrier with amplitude or phase change.
LOAD MODULATION: illumination carrier -> questioned structure -> sidebands spaced by the internal modulation rate.
FREQUENCY TRANSLATION: illumination carrier -> energy conversion or mixing -> response at another frequency, for example a candidate region near 300 MHz.
INTERNALLY TIMED RERADIATION: harvested energy -> local timing or encoding -> independent burst or PPM waveform whose timing is measured against a defined reference.

16.8 SAW-resonator and SAW-filter hypotheses

A surface acoustic wave, or SAW, resonator or filter can provide a narrow frequency-selective response, stable delay or coded reflection in an appropriate device architecture. The presence of a response within a frequency range commonly associated with SAW components does not prove that a SAW device is present. Ordinary radio services, filters in nearby equipment and receiver front-end responses occupy many of the same regions.

Resonant receiving-system perspective. For SAW-resonator and SAW-filter hypotheses, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response.

Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range.

The SAW hypothesis is supported by a reproducible frequency-selective response, a bandwidth and group-delay behaviour compatible with the measured structure, a spatial maximum associated with the candidate region, and independent confirmation after receiver and illumination paths are altered. Where a coded or delayed response is alleged, the code or delay must be measured from raw time-domain data with stated timing uncertainty and compared with negative controls.

A calibrated frequency sweep may characterise a resonance, but the sweep shall not be converted into a spatial image. The permitted output is a table or plot of response magnitude, phase or delay against frequency and coordinate. Any inference about component construction remains a source-class hypothesis unless independently verified.

16.9 Pulse-position modulation definition and measurement

In PPM, the information-bearing quantity is the time position of a pulse relative to a frame reference or nominal slot. The examiner defines the frame period T_frame, the reference time t_ref, the observed pulse time t_p and the displacement delta_t = t_p - t_ref. A sequence may use discrete slots, continuously variable displacement or a coded pattern. The analysis must state which model is being tested.

Signal-analysis interpretation. The expert treatment of Pulse-position modulation definition and measurement begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

Pulse detection uses raw, unsmoothed data preserved at a sampling rate adequate for the claimed timing resolution. The detector may use a matched filter, threshold crossing or model fit, but its bias and variance are validated with synthetic and laboratory signals. The examiner repeats the measurement under reasonable threshold changes and reports timing jitter, missed pulses, false detections and the uncertainty of each displacement estimate.

PPM differs from pulse-amplitude modulation, pulse-width modulation, pulse-repetition-frequency modulation, on-off keying, load modulation and ordinary amplitude modulation. A pulse whose apparent position changes because its amplitude crosses a fixed threshold later is an amplitude-to-time artefact unless a validated estimator removes that bias. A receiver automatic-gain event or squelch opening can create the same illusion.

Modulation family	Primary changing quantity	Principal EERF discriminator
PPM	Pulse position within a defined frame or slot.	Measure time displacement relative to a stable reference and test threshold invariance.
PAM	Pulse amplitude.	Pulse time remains fixed while magnitude changes.
PWM	Pulse duration or width.	Leading, trailing or both edges move to change duration.
PRF modulation	Interval between pulses or frames.	Repetition period changes rather than position within a fixed frame.
On-off keying	Presence or absence of carrier or pulse.	Symbol is represented by energy presence, not displacement.
Load modulation	Impedance presented to the incident field.	Sidebands or carrier perturbation follow a load-switching rate.
Receiver artefact	Internal gain, threshold, mixing or timing state.	Feature changes with receiver architecture, gain, threshold or local oscillator.

16.10 Passive baseline with source disconnected and terminated

Before active equipment enters the controlled area, the passive series is closed. When the active apparatus is staged, the illumination source output remains disconnected and terminated in a characterised load. The receiver then records the intended response bands with the complete transmit equipment present but electrically unable to radiate. This identifies source-enclosure emissions, digital-control spurs, reference-clock leakage and cable-borne contamination.

Advanced technical elaboration. For expert practice, Passive baseline with source disconnected and terminated is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression.

The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The termination is rated for the maximum possible source level and its return loss is documented. A source-off state selected only in software is insufficient because internal synthesisers, clocks or amplifiers may continue to emit.

Physical termination and, where practicable, power removal provide distinct controls. The record names which state was used.

The passive baseline is repeated at the candidate coordinate, at an empty control coordinate and at the receiver or cable path. If a proposed 300 MHz response already appears when the illumination output is physically terminated, it is not classified as an illumination-dependent environmental response.

16.11 Receiver-only and dummy-path controls

The receive chain is challenged with a terminated input, a dummy probe, a non-responsive antenna substitute where practicable, and an independent receiver. The terminated input tests internal receiver and cable electronics. The dummy probe tests mechanical and electric-field pickup without the intended aperture. The independent receiver tests whether the feature depends upon a particular mixer, intermediate frequency, sample clock or software path.

Advanced technical elaboration. For expert practice, Receiver-only and dummy-path controls is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The control sequence is performed with the transmitter absent or terminated, then repeated at selected authorised source levels. If a feature grows with transmitter level while the receive input is terminated, the coupling occurs inside the receiving system or through its power, clock or control path. Such a feature is an artefact until the path is identified and corrected.

Gain steps, preselector substitution and additional attenuation are used to establish linearity. A true external response should scale in a manner compatible with the calibrated chain. A product that changes disproportionately, appears only above a front-end level or vanishes after modest preselection is consistent with overload or intermodulation.

16.12 Minimum-field illumination and progression

The first active state uses the minimum technically useful source level defined by validation, not the maximum permitted level. The source increases in predeclared increments while forward power, reflected power and a representative field quantity are recorded. The examiner does not raise the level merely because no response is immediately visible. Each dwell includes sufficient time for receiver settling and, where the energy-harvesting hypothesis requires it, sufficient charging time.

Active-test metrology. A advanced technical analysis of Minimum-field illumination and progression separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission.

The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

The progression has stop limits for human exposure, medical-device behaviour, communications effects, receiver overload, unexpected heating, battery distress, abnormal odour, life-safety alarm, field-monitor discrepancy and any unplanned signal. The emergency stop removes RF power by a hardware path. Resumption always requires review of the stop event and, where appropriate, renewed authority.

A response threshold is estimated from repeated ascending and descending sequences rather than a single crossing. Hysteresis, latency and post-source persistence are reported.

Calculated activation distance or power is not presented as guaranteed performance because coupling, orientation, impedance, material, shielding and multipath can alter available power profoundly.

16.13 Directional geometry, azimuth, elevation and polarisation

Directional illumination is applied from a documented coordinate with known antenna phase centre, height, azimuth, elevation and polarisation. The candidate region is not assumed to lie on the antenna boresight merely because that geometry produces the largest response. Reflections, cable coupling and structural conductors can shift the field maximum. A field or power-density survey therefore accompanies the response measurement.

Advanced practitioner analysis. For expert practice, Directional geometry, azimuth, elevation and polarisation is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression.

The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

At least two materially different azimuths and, where access permits, two elevations or heights are used. Orthogonal or otherwise justified polarisations test coupling orientation. The receive antenna is also rotated or substituted so that transmit-polarisation effects can be separated from receive-path leakage. The sequence is predeclared to reduce selection of only the geometry that produces a favourable result.

Spatial localisation uses response gradients, nulls, phase or timing differences and repeatable coordinate changes. It does not form a radar or tomographic image. The final output is a bounded coordinate region with uncertainty and a table of the illumination and receive geometries that produced or failed to produce the response.

16.14 Stepped-frequency and swept-frequency excitation

A stepped test records a complete source-off, source-on and source-off cycle at each authorised frequency. The step size is small enough to resolve the hypothesised resonance and large enough to avoid unnecessary exposure and data volume. The order may be randomised or interleaved with control frequencies so that drift is not mistaken for a frequency-selective response.

A sweep test is permitted only when the source output, antenna factor, field monitor, receiver detector and device-response time are characterised across the sweep. The sweep waveform is recorded directly. The response is time aligned to the instantaneous source frequency, including synthesiser settling and group delay. If the response may require energy accumulation, discrete dwell steps are preferred because a continuous sweep may under-energise a narrow resonance.

Frequency-offset controls deliberately move the source by a small authorised amount. A translated response should move according to the proposed relation. A fixed environmental transmitter may not move. A receiver image may move according to the local-oscillator plan. The observed behaviour is compared with each model before classification.

16.15 Time-correlated transmitted and received waveform recording

The transmitted waveform, forward-power monitor, source-state control and received response are recorded against a common or cross-calibrated timebase. The clock relationship and uncertainty are measured before and after the series. Merely noting that the transmitter was on during a response is inadequate for PPM, latency or coherent-sideband analysis.

Signal-analysis interpretation. A advanced technical analysis of Time-correlated transmitted and received waveform recording preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

The source-state record includes commanded and measured transition times. Amplifier turn-on delay, synthesiser settling, relay operation and detector latency are characterised. The receive record includes sample rate, anti-alias filtering, trigger method, dropped-sample status and time-stamp uncertainty. The raw record is immutable. Any resampling, alignment or filtering is performed on a derivative with versioned code and parameters.

Time correlation supports, but does not by itself establish, a physical response. A periodic source can coincide with a periodic environmental signal by chance, and both may be locked to a common mains or reference clock. Spatial localisation and independent architecture remain necessary.

16.16 Illumination-on, off, sham and perturbation controls

The minimum state sequence includes source physically terminated, source connected but disabled, sham illumination, valid illumination, source-off recovery, frequency-offset illumination, polarisation change and position change. A sham state reproduces operator movement, relay sounds if any, software commands, timing and recording without delivering the test field. The method remains audibly silent to the inspected environment, but internal relays and equipment motion are still logged because they can produce electromagnetic transients.

Controlled-illumination interpretation. An advanced technical analysis of Illumination-on, off, sham and perturbation controls separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

The order is varied or blinded where practicable. The analyst who selects candidate intervals should not know every source state during initial review. This reduces expectation bias and permits an estimate of false association. The state code is revealed only after the candidate-selection rules are applied.

A response is expected to disappear or materially diminish under valid field-off conditions and to recur when the controlled conditions are restored. The allowed residual, latency and persistence are predeclared from the device model and validation. A response that remains unchanged through all source states is not illumination-correlated, although it may still be a Tier 1 or Tier 2 candidate.

16.17 Direct breakthrough, harmonics, images and intermodulation

Direct breakthrough is measured by replacing the environmental response antenna with a calibrated load or screened reference path and by mapping the source field at the receive equipment, cables and connectors. The receive preselector must reject the illumination frequency before high gain. The residual source component is quantified so that sidebands and translated products can be interpreted against a known leakage floor.

Advanced spectral-temporal analysis. For Direct breakthrough, harmonics, images and intermodulation, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content.

Transmitter harmonics and spurs are measured at the coupler and with an independent spectrum measurement. Receiver images are predicted from the local-oscillator and intermediate-frequency plan. Intermodulation products m f1 plus or minus n f2 are calculated for strong ambient and test frequencies within the front-end passband. A 300 MHz feature, for example, can equal the difference between 1.6 GHz and 1.3 GHz. That arithmetic relation is a warning requiring level, offset and independent-receiver tests, not proof of a translated device response.

Overload and desensitisation are tested by attenuation and preselection while monitoring the noise floor and known reference tone or reference signal. A receiver whose noise floor rises, reference tone falls or output ceases to scale linearly is not producing valid weak-signal evidence during that state. Affected acquisitions are quarantined and repeated after the chain is corrected.

Mechanism	**Frequency behaviour**	**Spatial behaviour**	**Decisive control**
Direct leakage	At illumination frequency or transmitter spur.	Strongest near transmitter, feed line, receiver cable or enclosure.	Terminated receive input and transmit-path relocation.
Same-frequency backscatter	At illumination carrier with amplitude or phase perturbation.	Gradient or null associated with candidate region after leakage normalisation.	Reference-channel subtraction and geometry change.
Harmonic response	At integer multiple of illumination frequency.	Localised only if environmental nonlinear element is local.	Transmitter harmonic measurement and level-slope test.
Intermodulation	At m f1 plus or minus n f2.	Often follows receiver or cable path and strong-signal environment.	Preselection, attenuation, source offset and independent mixer plan.

Mechanism	Frequency behaviour	Spatial behaviour	Decisive control
Frequency-translated reradiation	At a distinct response following a predeclared relation or internal resonance.	Repeatable candidate-region gradient.	Source offset, source-off recurrence test and independent receiver.
Internally generated transmission	May remain fixed while illumination controls activation or timing.	Localised response with onset and persistence behaviour.	Energy-threshold series, field-off persistence and timing correlation.

16.18 Independent confirmation architecture

Independent confirmation uses a second receiving chain whose vulnerabilities are materially different. Merely splitting the same antenna into two identical receivers is useful redundancy but not full independence. Preferred differences include antenna geometry, preselector design, front-end gain distribution, intermediate frequency, digitiser, sample clock, analysis software and physical cable route.

Both receivers are disciplined or cross-checked against separate traceable references. A candidate must appear at the same physical frequency and compatible time, not merely the same displayed bin. The independent chain repeats at least one source-off, one valid source-on, one frequency-offset and one position-change state. Where PPM is alleged, the pulse displacement is re-estimated with an independent algorithm.

Disagreement is not averaged away. The examiner determines whether sensitivity, bandwidth, overload, antenna pattern or timing uncertainty explains the difference. If not, the highest classification is withheld.

16.19 Integration with the 300-foot to three-inch search geometry

Passive Tier 1 and Tier 2 records are acquired through the complete sequence of 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet, threshold control, 3-

foot interior geometry, stationary three-inch decrements and the final three-dimensional three-inch lattice.

The same coordinate datum, probe centre, axis notation and reference clock are used throughout. A candidate is not advanced solely because its amplitude rises inward. Direction, time, field component and external-path alternatives must remain compatible.

Controlled illumination does not automatically repeat every outer ring. The active plan selects only the minimum locations needed to test field dependence and spatial association. A remote transmit location may be outside the 300-foot ring if authorised and technically justified, while response measurements may follow the established ring and grid coordinates. Every active coordinate is linked to its passive counterpart.

At each selected ring or grid point, the record separates illumination parameters from response parameters. It includes source frequency and waveform, measured or estimated field, azimuth, elevation, polarisation, response frequency, modulation, field strength and uncertainty, receive configuration, dwell, reference-clock status, controls, repeatability and confidence class. The reverse path is repeated after active work to identify drift, latching or persistent state change.

16.20 Non-contact, non-imaging and privacy limits

The inspection catalogues electromagnetic characteristics and spatial coordinates without touching, opening, moving, photographing, imaging, mechanically disturbing or damaging the suspected device or surrounding structure. Directional illumination and spatial response measurement do not authorise radar imaging, synthetic-aperture reconstruction, tomography, optical capture, thermal imaging or content interception. Analytical plots may show signal magnitude, frequency, time and coordinate, but they shall not render an object image.

Governance and safety analysis. For Non-contact, non-imaging and privacy limits, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. The risk assessment addresses implanted and life-supporting devices, electromagnetic compatibility, spectrum licensing, heating, battery stress, fire, unintended activation, data alteration, interference with communications, and evidential contamination. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The method seeks energy and timing, not communication content. Demodulation is limited to the minimum features necessary to distinguish modulation families, such as pulse times, widths, amplitudes or sideband spacing. Identity, payload, memory, authentication exchange or private content is not read unless a separate lawful authority and validated method expressly permit it.

The non-contact rule also protects evidential integrity. A suspected source is not shielded, disconnected or manipulated to prove the hypothesis during this phase. Any later physical examination is a separately documented procedure with its own authority, contamination controls and chain of custody.

16.21 Safety, exposure and stop-work controls

Electromagnetic illumination is not presumed harmless. The risk assessment considers spectrum legality, public and occupational exposure, implanted devices, medical electrical equipment, life-safety systems, communication systems, ignition, battery heating, electrostatic discharge, unintended activation, data alteration and evidential contamination. Applicable limits are verified for the jurisdiction and frequency. Measurement uncertainty and field non-uniformity are included.

Governance and safety analysis. For Safety, exposure and stop-work controls, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. A limitation imposed by law, safety, privacy, or clinical necessity is reported openly and is never relabelled as a completed measurement [1-9, 17-23].

No active test is performed near a patient, implanted device or safety-critical medical equipment without clinical-engineering approval and an exclusion or monitoring plan. A conservative operational limit may be set below the regulatory exposure limit because electromagnetic compatibility and medical-device immunity are different questions. Any alarm, reset, unexpected reading, patient distress or communication disruption causes immediate hardware shutdown and preservation of the event record.

Post-test checks include source power verification, field-off confirmation, equipment status, temperature or battery condition where observable without contact, and a passive repeat. A changed environmental state is treated as a potential consequence of the test and reported.

16.22 Evidential classification and reporting rule

The evidential ladder is cumulative. An observed signal is a measured feature above the applicable selection criterion. A candidate device-correlated signal has reproducible temporal or spatial behaviour consistent with the authorised search proposition but has not yet survived the illumination or localisation requirements. An illumination-correlated response follows the controlled source states under negative controls. A reproducible frequency-translated response additionally demonstrates a stable relation between illumination and a distinct response frequency while surviving receiver-product tests. A spatially localised response is bounded by repeatable coordinate behaviour. A confirmed device-associated response requires all prior elements, independent confirmation and a stated uncertainty.

Reporting and custody perspective. For Evidential classification and reporting rule, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions [1-9].

No class is awarded merely because a signal appears during illumination. The minimum confirmation set is spatial localisation, reproducibility, field-off and sham controls, frequency-offset or equivalent mechanism test, receiver-artifact exclusion, illumination-path controls, independent instrumentation and uncertainty. If a material control cannot be performed, the class is capped at the highest level supported without that control and the omission is prominent.

Even the highest class states association with a bounded response region under the tested conditions. It does not by itself identify the construction, owner, purpose, legality, content or medical effect of a device. The report uses the exact class name and the observations supporting it.

Outcome or class	Required evidence	Permitted statement
0. No reportable signal	No feature survives the validated selection and confirmation criteria in the examined states.	No reportable signal was observed above the stated capability. Dormant, out-of-band, shielded or intermittent sources are not excluded.

Outcome or class	Required evidence	Permitted statement
1. Observed signal	A measured feature is recorded with instrument state, coordinate and uncertainty.	An electronic signal was observed under the stated conditions. Source association is not established.
2. Candidate device-correlated signal	The feature is reproducible and displays timing, spatial or source-class behaviour consistent with the proposition.	The signal is a candidate for device correlation, subject to remaining alternatives and controls.
3. Illumination-correlated response	The feature follows authorised source states and survives field-off, sham and basic receiver controls.	A reproducible response correlated with the stated illumination was measured. Mechanism and device association are not yet established.
4. Reproducible frequency-translated response	A distinct response frequency follows the predeclared relation and survives offset, intermodulation, image and independent-receiver tests.	A reproducible frequency-translated response was measured under the stated conditions.
5. Spatially localised response	The confirmed response exhibits a repeatable gradient, null or coordinate bound with uncertainty.	The response is localised to the stated three-dimensional region under the tested conditions.
6. Confirmed device-associated response	All prior requirements plus independent architecture, negative controls, illumination-path controls and complete uncertainty statement.	The data support association of the measured response with an electronic device or structure within the stated region and conditions. Identity and purpose remain unestablished unless independently proven.

16.23 Required case record

The case record contains the passive closure certificate, active authorisation, spectrum and safety approvals, transmitter and antenna calibration, field calculations and measurements, source-state log, forward and reflected power, response receiver states, raw and derivative files, timing-reference records, coordinate and geometry data, control outcomes, stop events, uncertainty budgets and reviewer decisions. Every file receives a unique identifier and cryptographic hash.

Forensic interpretation. The advanced technical treatment of Required case record distinguishes recognition, recording, acquisition, analysis, interpretation, and reporting as separate stages. A conclusion is not allowed to migrate backwards and reshape the raw record. Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

For each active acquisition, the data dictionary records the illumination frequency and waveform, source level, antenna gain, estimated or measured field, azimuth, elevation, polarisation, response frequency, modulation family, pulse timing, latency, duty cycle, receiver bandwidth, detector, dwell, reference clocks, environmental state, controls and confidence class. Missing fields require a reason.

The released report includes enough information for a competent independent examiner to reconstruct the mechanism tests and determine why an observed feature was or was not promoted. It does not publish unnecessary private communication content or operational details beyond the authorised technical purpose.

16.24 Ultra-low-power SAW, narrowband and microphone-related target families

A supplementary target family is established for lawful, non-contact searches involving SAW-stabilised oscillators, SAW-filtered transmitters, low-power microphone links, conducted audio paths and magnetic leakage from miniature microphone circuitry. These targets remain subordinate to the existing hierarchy.

Baseband and central timing signals remain Tier 1, radiated RF remains Tier 2, and passive or remotely energised SAW responses remain Tier 3. The supplementary protocol does not alter the requirement to search the entire authorised spectrum and does not treat any listed frequency as inherently suspicious.

Audio-frequency magnetic interpretation. The advanced treatment of Ultra-low-power SAW, narrowband and microphone-related target families does not presume that a miniature microphone radiates a useful radio signal. It tests the magnetic and electric consequences of bias current, preamplifier current, analogue audio, pulse-density clocks, serial data, regulator activity, and cable imbalance.

C-message or other weighting is applied only as a derived analytical view after a flat and unaltered acquisition has been preserved, because a weighting curve is not a physical antenna resonance. The report describes field strength, coherence, bandwidth, spatial path, and state correlation without listening to, transcribing, or reconstructing private speech [18-23].

For planning, 5 mW is represented as approximately +7 dBm and 5 microwatts as approximately -23 dBm. The latter value is included as a demanding engineering design target, not as an assertion that such power is typical of any source class.

A signal-power claim shall not be inferred from received level alone because antenna efficiency, mismatch, shielding, building loss, polarisation, cable coupling, duty cycle and receiver bandwidth can change the result by many tens of decibels.

The method therefore records field strength or calibrated received power with stated geometry and uncertainty instead of back-calculating an unqualified transmitter output.

The narrowband-FM search uses 6 kHz, 8 kHz, 10 kHz, 12.5 kHz, 14 kHz and 16 kHz analysis channels, together with narrower carrier-estimation bandwidths. Carson-type bandwidth estimates are used only to form hypotheses. For example, a 3 kHz peak deviation and a 3 kHz highest modulating frequency yield an approximate occupied bandwidth of 12 kHz, while a 5 kHz deviation with the same audio limit yields approximately 16 kHz. Accordingly, an observed 8 kHz to 14 kHz signal cannot automatically be described as plus or minus 5 kHz NFM.

Appendices J to M contain the ring-by-ring procedure, the harvested frequency register, the voice-frequency magnetic bar-probe specification, worked sensitivity calculations, validation studies and field records. The register includes frequencies supplied with the case materials and frequencies found in current component catalogues.

Every entry carries provenance and a search-window rule so that historical material, current manufacturer data, regulatory bands and case-specific intelligence are not silently conflated.

Chapter Glossary

Terms used in Chapter 22: Target-Signal Hierarchy, Passive Detection, and Controlled Illumination Response Analysis.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

D

DUTY CYCLE — In a transmitter, ratio of time on to time off.

DYNAMIC RANGE — The span between the smallest and largest input levels that a system can process while meeting specified performance criteria.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

L

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

M

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

16A. Global Digital and Analogue Communications Standards, Interface Timing, Sleep-State Emissions, and Wideband Nonlinear-Junction Detection

16A.1 Purpose and completeness doctrine

This chapter expands EERF from a finite target-frequency method into a standards-aware, waveform-neutral and implementation-aware search discipline. It covers modern and historical wireless systems, cellular systems across all internationally significant generations, wired external ports, internal digital buses, analogue and digital audio/video paths, telecommunications, powerline communications, industrial control, automotive networks, optical links, sleep-state timing domains and authorised nonlinear-junction examination.

The objective is not to decode private content. The objective is to recognise energy, timing, bandwidth, modulation family, state transitions and spatial association sufficiently well to direct a non-contact forensic localisation.

The following integration extends Global Digital and Analogue Communications Standards, Interface Timing, Sleep-State Emissions, and Wideband Nonlinear-Junction Detection with SHF PSK modem performance, phase noise, and interoperability.

It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

SHF PSK Modem Performance, Phase Noise, and Interoperability

Modem profile discipline must be introduced as a mechanism, not as a catalogue entry. standardized modem profiles define symbol rates, modulation families, coding, acquisition behavior, interfaces, and permissible implementation options needed for interoperable SHF links.

The controlling model identifies the system boundary, the energy or information that crosses it, and the state variables that determine the response. A postgraduate treatment should name the approximations that make the model tractable, explain when those approximations fail, and separate the latent physical state from the quantity displayed by an instrument. Accordingly, the analysis centers on carrier frequency, symbol clock, coding mode, roll-off, framing, acquisition thresholds, and control-interface state.

Uncertainty analysis for Modem profile discipline must include both numerical error and model uncertainty. Numerical uncertainty arises from calibration, resolution, repeatability, positioning, timing, and noise; model uncertainty arises when the wrong source, path, boundary condition, or causal mechanism has been assumed. Relevant failure mechanisms include profile drift, undocumented vendor extensions, mismatched coding, stale presets, and partial compatibility that fails under stress.

A mature report distinguishes random variation, systematic bias, and epistemic uncertainty, then shows which term dominates the conclusion. Sensitivity analysis should test whether a plausible change in an uncertain input reverses the decision or merely changes its margin. When the evidence supports several explanations, the report should retain competing hypotheses and state what additional observation would discriminate among them.

This is preferable to burying uncertainty in a generic caveat, because decision makers need to know whether confidence is limited by instrument performance, missing access, incomplete source material, or a fundamentally nonunique inverse problem. In this placement, that control is applied specifically to modem profile discipline within shf psk modem performance, phase noise, and interoperability, with the local volume retaining ownership of the final inference.

The measurement problem for Error vector magnitude begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records

RMS EVM, peak EVM, amplitude imbalance, quadrature error, residual frequency offset, and error distribution by symbol.

Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A rigorous procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are noise, compression, phase noise, IQ skew, channel distortion, timing error, and inappropriate reference normalization.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result should be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to error vector magnitude within SHF PSK modem performance, phase noise, and interoperability, with the local volume retaining ownership of the final inference.

For expert practice, Adjacent-channel and nonlinear stress should culminate in a traceable decision record. The record identifies the question, lawful authority, inspected configuration, method, raw evidence, correction model, uncertainty, alternative explanations, and disposition. It should make visible the transition from observation to interpretation and from interpretation to operational action. interference analysis should distinguish channel occupancy from receiver-created degradation and should preserve the complete RF level plan.

The instructions and protocols surrounding the procedure should also define a stop condition: evidence may be insufficient because of access limits, instrument saturation, uncontrolled ambient conditions, missing source records, or an unresolved model conflict. Declaring such a limitation is an expert act, not a failure.

The measurement problem for IF interfaces and control provenance begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records IF center frequency, impedance, level, group delay, reference clocks, control words, status flags, and configuration transitions. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A defensible procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds.

It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are incorrect reference plane, unterminated ports, ground loops, software-state ambiguity, and undocumented automatic control.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to if interfaces and control provenance within SHF PSK modem performance, phase noise, and interoperability, with the local volume retaining ownership of the final inference.

For expert practice, IF interfaces and control provenance should culminate in a traceable decision record. The record identifies the question, lawful authority, inspected configuration, method, raw evidence, correction model, uncertainty, alternative explanations, and disposition. It should make visible the transition from observation to interpretation and from interpretation to operational action. an examiner can use correlated control and IF evidence to reconstruct modem state, but only when interface timing and configuration provenance are preserved. The prose surrounding the procedure should also define a stop condition: evidence may be insufficient because of access limits, instrument saturation, uncontrolled ambient conditions, missing source records, or an unresolved model conflict. Declaring such a limitation is an expert act, not a failure.

The following integration extends 16A. Global Digital and Analogue Communications Standards, Interface Timing, Sleep-State Emissions, and Wideband Nonlinear-Junction Detection with tactical digital messaging and layered MIL-STD-188-220 analysis. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Tactical Digital Messaging and Layered MIL-STD-188-220 Analysis

COMSEC boundaries must be introduced as a mechanism, not as a catalogue entry. communications security can encrypt content while leaving traffic shape, timing, synchronization, network management, and failure states observable. The controlling model identifies the system boundary, the energy or information that crosses it, and the state variables that determine the response. A postgraduate treatment should name the approximations that make the model tractable, explain when those approximations fail, and separate the latent physical state from the quantity displayed by an instrument. Accordingly, the analysis centers on cipher synchronization, fill status indicators, encrypted frame lengths, key-change intervals, retransmission patterns, and link alarms.

This integrated treatment returns the discussion to 16A. Global Digital and Analogue Communications Standards, Interface Timing, Sleep-State Emissions, and Wideband Nonlinear-Junction Detection with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

System-level interpretation. At expert-practitioner level, Purpose and completeness doctrine is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support.

The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

No static paper can literally contain every national channel plan, private profile, superseded revision, optional feature, proprietary extension and future amendment. In this framework, comprehensive coverage means that the examiner maintains a controlled standards register, checks the current edition and regional implementation before each case, searches the complete validated instrument bandwidth rather than only named channels, and records any unresolved phenomenon without forcing it into a familiar category. Standards are hypothesis generators. Measured physics remains the evidence.

RELEASE-DATE STANDARD STATUS
The standards cut-off for this release is 13 July 2026. IEEE 802.11-2024 is the current roll-up WLAN standard, with later amendments including IEEE 802.11be-2024, IEEE 802.11bf-2025 and IEEE 802.11bk-2025. Bluetooth Core Specification 6.3 was released on 6 May 2026. 3GPP Release 19 was completed in December 2025, while Release 20 continues 5G-Advanced work and early 6G studies. IMT-2030 is an ITU framework, not a final universal 6G air interface. USB4 Specification v2.0, USB Type-C Release 2.5 and USB Power Delivery Revision 3.2 Version 1.2 are the current USB-IF baseline documents identified for this release. All edition statements must be rechecked before field use.

16A.2 Evidential rule: identify from physics upward

A protocol name sits several inferential layers above the measured field. The examiner first establishes a repeatable electric, magnetic, conducted, optical or reradiated phenomenon. The examiner then characterises carrier structure, bandwidth, line code, symbol or pulse timing, clock relationships, burst cadence, duplex behaviour and power-state dependence.

Only after those observations survive controls may the examiner compare them with a standards family. A frequency match alone is weak evidence because the same oscillator, intermediate frequency, sample clock or serial rate can occur in unrelated equipment.

Advanced physical analysis. The advanced treatment of Evidential rule: identify from physics upward begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. Spatial nulls, phase reversals, vector orientation, and response to controlled geometric changes are often more informative than a single amplitude maximum, particularly in reflective rooms and near extended conductors.

The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

The report separates measured facts from engineering hypotheses. Measured facts include frequency, uncertainty, field strength, probe, orientation, coordinate, time, bandwidth, periodicity and response to controlled state changes.

A standards hypothesis states the protocols consistent with those facts and the observations that would disconfirm each. Device identity requires additional spatial, documentary or physical evidence. Purpose, ownership, legality and medical effect are outside the scope of a spectral match.

16A.3 Standards currency, jurisdiction and configuration control

Before deployment, the technical lead freezes a case-specific Standards Coverage Register. The register records publication date, amendment status, jurisdiction, service assumptions, allocated bands, channel raster, permitted power, modulation and sleep features. It states whether each source is current, superseded, withdrawn, historical, proprietary, experimental or proposed. The case file preserves the exact revision used so another examiner can reproduce the interpretation after standards change.

Standards and interface interpretation. At expert-practitioner level, Standards currency, jurisdiction and configuration control is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

Table 16A-1. Standards-source and currency-control register

Domain	Primary standards sources	Case-specific fields
Wi-Fi / WLAN	IEEE 802.11 base standard, published amendments, IEEE 802 working-group status and applicable national band rules	PHY family, channel width, centre-frequency set, guard interval, power-save mechanism, regional limits and amendment status

Domain	Primary standards sources	Case-specific fields
Cellular and mobile	3GPP, 3GPP2 historical specifications, ITU-R IMT recommendations, ETSI, TIA, ARIB and national administrations	RAT, release, band, duplex arrangement, channel bandwidth, numerology, paging cycle, power-saving mode and deployment region
Bluetooth	Bluetooth SIG adopted core, profile and qualification specifications	BR/EDR or LE PHY, channel plan, advertising or connection procedure, audio or mesh feature and power-control state
Short-range / IoT	IEEE, ETSI, ISO/IEC, CSA, Connectivity Standards Alliance, LoRa Alliance, Wi-SUN Alliance and regional SRD rules	Bearer, modulation, channel plan, duty cycle, beaconing, mesh or star behaviour and sleep method
Ports and cables	USB-IF, HDMI Forum, VESA, IEEE, PCI-SIG, MIPI Alliance, JEDEC, INCITS and vendor-neutral electrical specifications	Generation, line code, lane rate, reference clock, low-power state, sideband channel, active-cable electronics and alternate mode
Industrial / vehicle / avionics	IEC, ISO, SAE, ARINC, RTCA, ODVA, PI, FieldComm Group, KNX Association and ASHRAE	Physical medium, line code, bit rate, schedule, redundant path, power state and installation topology
Historical systems	ITU-T, ETSI, TIA, national archives and manufacturer documentation	Former channel plans, modem or telephony signalling, analogue carriers, line rates and coexistence artefacts

16A.4 Universal physical-signal model

Every candidate is decomposed into six observable layers: energy source; oscillator and timing tree; baseband or line-code process; physical interface; propagation or conducted path; and environmental or instrument coupling.

A single device may expose more than one layer. A sleeping handset may have no ordinary uplink yet retain an RTC, PMIC switcher, SIM clock, sensor-hub bus, charger controller and periodic paging receiver. A connected display may radiate from its pixel clock, high-speed lanes, DDC, CEC, cable shield and power converter simultaneously.

System-level interpretation. For expert practice, Universal physical-signal model is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table 16A-2. Layered observation and inference model

Layer	Examples	Permissible inference	Control
Energy and state	Battery, mains, harvested energy, soft off, suspend, active	Documented state and state-correlated change	Independent power/state record and stabilisation dwell
Clock tree	Crystal, MEMS oscillator, PLL, divider, spread-spectrum clock	Candidate timing family and coherence	Reference-clock verification, harmonics and alternative sources
Baseband / line code	OFDM, GFSK, PAM, Manchester, NRZI, pulse timing	Modulation or interface family	I/Q, time-domain and bandwidth controls
Physical interface	Antenna, twisted pair, optical emitter, PCB bus, coax	Candidate bearer and geometry	Probe diversity, polarisation and cable controls

Layer	Examples	Permissible inference	Control
Propagation path	Free space, near field, common mode, structural service	Spatial or path association	Reference station, reverse path and control cubes
Instrument / environment	LO leakage, aliasing, PIM, broadcast, neighbouring device	Possible confounder only	Terminated input, dummy probe and independent receiver

16A.5 Device-state taxonomy and the false binary of on versus off

The protocol distinguishes active, connected-idle, network-idle, suspend, connected standby, deep sleep, hibernate, soft off, mechanical off and energy-harvesting states. The label displayed by an operating system is not accepted without measurement.

A system described as asleep can retain an RTC, PMIC sequencer, embedded controller, DRAM self-refresh, battery gauge, charger, USB Power Delivery controller, Ethernet PHY, wake-on-wireless receiver, sensor hub, always-on audio DSP or cellular paging receiver. Conversely, aggressive clock gating may remove an expected line while the device remains active.

Advanced practitioner analysis. For expert practice, Device-state taxonomy and the false binary of on versus off is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table 16A-3. Dormant and low-power states with likely surviving observables

State	Domains likely to survive	Candidate observables	Examination rule
Mechanical off / source removed	No designed active domain	External illumination, stored charge, passive resonance or energy harvesting only	Confirm actual source removal. Absence of signal does not prove absence of a device.
Soft off	Embedded controller, PMIC, charger and wake domains	32 kHz family, regulator switching, USB PD and Ethernet link	Compare mains and battery configurations only under authority.
Suspend / connected standby	DRAM refresh, PMIC, sensor hub and selected radios	RTC, memory refresh, Wi-Fi/Bluetooth/cellular events and always-on audio	Long time records and exact intervention logs are mandatory.
Hibernate / deep sleep	RTC, power button, charger, fuel gauge and optional wake PHY	Low-duty I2C/SMBus, 32 kHz, PMIC and link pulses	Use narrowband integration and magnetic probes.
Wi-Fi power save	DTIM, TWT, WUR and association maintenance	Beacon listening, trigger exchanges and 802.11ba wake signals	Do not stimulate association in the passive protocol.
Bluetooth sleep	Advertising, periodic advertising or connection events	Short 2.4 GHz bursts separated by long intervals	Observe all primary advertising channels with sufficient dwell.

State	**Domains likely to survive**	**Candidate observables**	**Examination rule**
Cellular DRX / eDRX / PSM	Paging, tracking update, SIM/eSIM and timing domains	Receive windows, rare access bursts and duty-cycled TCXO	Observation must exceed plausible network cycles.
Thread / Zigbee sleepy endpoint	Low-power timer and parent polling	Sparse 802.15.4 frames and 32.7 kHz wake oscillator	Observe parent and child locations separately.
LoRaWAN Class A/B/C	Different sleep/listen regimes	Rare chirps, beacon cadence or near-continuous receive electronics	Long monitoring and event records.
USB suspend	Pull resistors, hub, Type-C and PD remain	Resume, CC BMC traffic, hub state and charger switching	Monitor data lanes, CC pins and local controller separately.
Ethernet EEE / WoL	PHY remains linked or wake-capable	LPI refresh, link pulses, wake receiver and 25/125 MHz clocks	Use time-domain cable-current capture.
PCIe L1 substates	Auxiliary power and wake logic	CLKREQ, PME, reference-clock gating and link-management events	Test common-clock and independent-clock hypotheses.
SATA slumber / DevSleep	PHY and device enter staged low power	Out-of-band wake, controller clocks and background storage activity	Correlate with authorised system state records.
Panel self refresh	Panel timing controller and local framebuffer	Main link quiet while AUX/control and panel clocks persist	A quiet cable is not a fully inactive display.
Always-on voice processing	Low-power DSP, PDM microphone and SRAM	PDM clock, decimation, wake-word engine and periodic maintenance	Do not reconstruct or listen to speech.

16A.6 Integration with the nested search geometry

The communications and interface search uses the established geometry without creating a separate sweep that would destroy comparability. The same frequency references, time source, antenna heights, receiver architecture, station-count plan and environmental log follow the team from the 5-mile regional annulus to the final three-inch lattice. Broad wireless infrastructure is characterised at the outer annuli. Conducted paths, local clocks, ports and sleeping domains receive progressively greater emphasis as the team approaches the premises.

Advanced technical elaboration. For expert practice, Integration with the nested search geometry is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table 16A-4. Standards-aware function of each search ring

Station	Function	Communications and interface task
300 ft	Remote reference	Full-band occupancy, public infrastructure, persistent clock families, environmental baseline and no intentional illumination.
150 ft	Outer transition	Repeat matched azimuths and instrument settings. Test whether candidates follow time, public infrastructure or premises bearing.

Station	Function	Communications and interface task
100 ft	Outer comparison	Long dwell on sparse radio families, paging and sleep events. Retain the 300-foot reference channel.
50 ft	Near-premises discrimination	Polarisation, antenna height, structural coupling, exterior-face comparison and overload control.
30 ft	Service-path ring	Power, telecom, coax, pipes, fences, earth conductors, vehicle and utility coupling.
15 ft	Pre-boundary control	Stable wall-referenced record before entry or door movement alters the scene.
12 ft	Envelope / threshold	Near-field probes, cable and aperture mapping, strict equipment log and threshold intervention records.
3 ft	Localisation ring	Port, cable, furniture, wall and cube-specific measurements in orthogonal orientations.
3-inch decrements	Stationary convergence	Record exact x/y/z, probe phase centre, angle, field, phase, null and uncertainty without sweeping motion.
Three-dimensional lattice	Final bounded volume	Repeat maxima/minima, reverse path, control cubes, independent receiver and movement-event remeasurement.

16A.7 Wi-Fi and IEEE 802.11 family

The Wi-Fi examination does not begin by searching only 2.4 GHz and 5 GHz. It includes regional 6 GHz allocations, sub-1 GHz 802.11ah, television-white-space 802.11af, vehicular 802.11p/802.11bd, millimetre-wave 802.11ad/ay, optical 802.11bb and wake-up-radio 802.11ba. MAC amendments that change roaming, randomised addresses, security, sensing or positioning may alter packet timing without creating a new RF PHY. The examiner records the PHY separately from the higher-layer service.

Digital-system elaboration. At expert-practitioner level, Wi-Fi and IEEE 802.11 family is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. The examiner records the edition and jurisdictional status of any cited standard, while treating manufacturer configuration, regional band plan, optional features, and power-saving modes as variables that require case-specific verification. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

Access points often remain conspicuous, while a client in power save may transmit only association maintenance, scans, trigger responses or target-wake-time traffic. Randomised addresses prevent reliable identity inference. Multi-link operation can place related bursts in more than one band.

Beamformed 60 GHz and 75 GHz equipment may be invisible to an omnidirectional lower-frequency antenna. An optical implementation requires a photodetector and shall not be sought exclusively with an RF receiver.

Table 16A-5. Internationally significant IEEE 802.11 PHY and operational families

Family	Band	PHY / modulation	Forensic observables
802.11 legacy FHSS	2.4 GHz	2GFSK/4GFSK hopping, 1 or 2 Mb/s	Hop cadence and one-MHz channel occupancy; principally historical.
802.11 legacy DSSS / 802.11b	2.4 GHz	DBPSK, DQPSK, Barker, CCK	Eleven-MHz chip family, 22 MHz-class envelope, beacon cadence and long/short preambles.

Family	Band	PHY / modulation	Forensic observables
802.11a / g	5 GHz / 2.4 GHz	64-point OFDM, 20 MHz	312.5 kHz subcarrier spacing and 4 microsecond ordinary symbol cadence.
802.11n, HT	2.4 and 5 GHz	MIMO-OFDM, 20/40 MHz	Aggregation, multiple spatial streams, 20/40 MHz coexistence and short guard interval.
802.11ac, VHT	5 GHz	MIMO-OFDM, 20 to 160 MHz	Beamforming, 80+80 MHz operation, wider bursts and 256-QAM-capable PHY.
802.11ax, HE	2.4, 5 and regional 6 GHz	OFDMA, MU-MIMO, up to 1024-QAM	78.125 kHz subcarrier spacing, resource units, trigger uplink, BSS colouring and target wake time.
802.11be, EHT	2.4, 5 and regional 6 GHz	OFDMA, multi-link, up to 4096-QAM	Up to 320 MHz, puncturing, multi-link operation and highly aggregated bursts.
802.11ad / ay	Above 45 GHz, commonly 60 GHz	DMG / EDMG single-carrier and OFDM	Directional beam training, short high-rate bursts and millimetre-wave front-end clocks.
802.11ah	Sub-1 GHz regional bands	Narrower-band OFDM	Long-range low-power beacons, restricted-access windows and sparse sensor traffic.
802.11af	Television white-space bands	OFDM adapted to regional TV channels	Geolocation-controlled operation and jurisdiction-specific channels.
802.11p / bd	5.9 GHz ITS and variants	OCB OFDM / next-generation V2X	Roadside and vehicle bursts, high Doppler and safety-message cadence.
802.11ba	Wake-up-radio companion	OOK and multicarrier OOK	Low-duty wake signals may remain while the principal WLAN transceiver sleeps.

Family	Band	PHY / modulation	Forensic observables
802.11bb	Visible and infrared optical bands	Optical wireless PHY	Modulated optical flux and LED-driver timing require non-imaging photodetectors.
802.11bf / bk	Uses supported WLAN PHY resources	Sensing and 320 MHz positioning procedures	Channel sounding, ranging and precise timing exchanges may occur without ordinary user traffic.

16A.8 Bluetooth Classic, Bluetooth Low Energy, Mesh and audio

Bluetooth Classic and Bluetooth Low Energy share the 2.4 GHz ISM band but use different channel plans and access behaviour. A wideband detector can merge them with Wi-Fi, microwave leakage and proprietary devices. The protocol therefore uses channelised I/Q capture or a receiver capable of distinguishing one-MHz classic hopping from two-MHz LE channels, then compares event timing, packet duration and occupied bandwidth without decoding private payloads.

Standards and interface interpretation. For Bluetooth Classic, Bluetooth Low Energy, Mesh and audio, the standards register provides candidate timing and spectral relationships, not a finite list of frequencies at which all compliant products must radiate. The examiner records the edition and jurisdictional status of any cited standard, while treating manufacturer configuration, regional band plan, optional features, and power-saving modes as variables that require case-specific verification. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

A device can be discoverable, advertising, connected, periodically advertising, relaying mesh traffic, carrying isochronous audio or nearly silent between long intervals. Bluetooth Core 6.3 is the adopted core edition at the release date, but a product may implement only selected features. The report names measured PHY and observable procedures, not a complete capability set inferred from a version label.

Table 16A-6. Bluetooth physical layers and operational signatures

Family	Channel plan	Modulation	Forensic observables
BR basic rate	2.4 GHz, 79 one-MHz channels	GFSK, 1 Mb/s	1,600 hops/s family, inquiry, page and connection events.
EDR	Classic channel plan	pi/4-DQPSK at 2 Mb/s; 8DPSK at 3 Mb/s	GFSK access header followed by a phase-modulated payload region.
LE 1M	2.4 GHz, 40 two-MHz channels	GFSK, 1 Mb/s	Advertising on primary channels 37, 38 and 39, then sparse connection events.
LE 2M	Same LE channels	GFSK, 2 Mb/s	Shorter packets and wider occupied spectrum.
LE Coded	Same LE channels	GFSK with or	Longer coded packets and low information rate for extended range.
Extended / periodic advertising	2.4 GHz	Selected LE PHY	Primary advertisements direct the receiver to secondary channels; periodic trains expose sleepers.
LE Audio / isochronous	2.4 GHz	LE PHY with CIS or BIS timing	Regular isochronous event timing, broadcast audio and controller-to-codec clock relationships.

Family	Channel plan	Modulation	Forensic observables
Mesh	LE advertising bearers	Managed flooding	Relay retransmission, friendship polling and low-power-node event schedules.
Direction finding	LE packets	Constant tone extension	Angle measurement tone intervals distinguish ranging activity from ordinary data.
Channel sounding	Bluetooth Core 6.x feature family	Phase-based ranging and round-trip timing	Coherent tone and timing exchanges may be visible during otherwise sparse application traffic.

16A.9 International cellular systems across all generations

The cellular examination is radio-access-technology neutral and generation neutral. It begins with analogue mobile radio and first-generation cellular systems, proceeds through GSM, cdmaOne, D-AMPS, PDC, PHS and iDEN, then covers UMTS, cdma2000, TD-SCDMA, WiMAX, LTE, cellular IoT, 5G NR and 5G-Advanced.

Country-specific systems no longer commercially active remain in the historical register because stored equipment, test systems and repurposed components can persist.

Communications-family analysis. The mature treatment of International cellular systems across all generations distinguishes normative air-interface or cable specifications from implementation leakage, board-level clocks, power-management activity, spread-spectrum clocking, and enclosure coupling.

Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

A static frequency list is inadequate. Cellular bands, supplementary downlink, carrier aggregation, dynamic spectrum sharing, unlicensed operation, private networks, satellite extensions and regional refarming change. The examiner imports current 3GPP band tables and national allocations into the case register, but still searches continuously. A signal is not classified as cellular merely because it lies in a mobile band, and a device is not excluded because it lies outside a familiar national handset band.

Table 16A-7. Cellular and mobile-radio formats from 0G through 5G-Advanced, with 6G status

System	Context	Access / modulation	Forensic observables
Pre-cellular MTS / IMTS	0G, regional VHF/UHF	Analogue FM, supervisory tones, selective calling	Long carriers, control tones, channelised duplex pairs and relatively high-power base transmitters.
AMPS	1G, principally 800 MHz Americas	Analogue FM voice and FSK control	30 kHz channels, control-channel activity and supervisory audio tones.
TACS / ETACS / JTACS	1G regional 800/900 MHz	AMPS-derived analogue FM and FSK	Different duplex plans and channel rasters from AMPS.
NMT-450 / NMT-900	1G Nordic and international	Analogue FM and FFSK	Persistent control channels and regional duplex pairs.

System	Context	Access / modulation	Forensic observables
C-Netz / Radiocom 2000 / RTMS / NTT analogue	Historical regional 1G	Analogue FM with national control signalling	Retain in the historical register for stored, specialist and repurposed equipment.
GSM	2G, 450/480/750/850/900/1800/1900 families	FDMA/TDMA with GMSK	200 kHz carriers, eight time slots, 4.615 ms frames, multiframes and 13/26 MHz clock families.
GPRS / EDGE / EGPRS	2.5G / 2.75G GSM evolution	GMSK and 8PSK, later higher-order modes	Bursty multislot packet activity within GSM timing.
IS-54 / IS-136 D-AMPS	2G Americas	TDMA with pi/4-DQPSK	30 kHz channels, time slots and digital control channels.
IS-95 cdmaOne	2G / 2.5G	Direct-sequence CDMA	1.2288 Mcchip/s reference family and noise-like 1.25 MHz carriers.
PDC	2G Japan	TDMA with pi/4-DQPSK	Narrow channelised bursts and Japanese frequency plans.

System	Context	Access / modulation	Forensic observables
PHS / PAS	Microcell cordless-cellular	TDMA/TDD with pi/4-DQPSK	1.9 GHz-class 5 ms half-frames, base beacons and low-power handsets.
iDEN	Specialised mobile radio	TDMA digital voice/data	Dispatch signalling and 25 kHz block structures.
UMTS UTRA FDD / WCDMA	3G international paired bands	Direct-sequence CDMA, QPSK; HSPA adds QAM	3.84 Mcchip/s family, 5 MHz carriers, slots and scrambling-code structure.
UTRA TDD / TD-SCDMA	3G unpaired and Chinese deployments	TD-CDMA and synchronous CDMA	TDD frame periodicity, 1.28 or 3.84 Mcchip/s families and regional bands.
cdma2000 1x / EV-DO	3GPP2, 1.25 MHz carriers	Direct-sequence CDMA with scheduled packet evolution	1.2288 Mcchip/s family, pilot/sync/paging and time-scheduled data bursts.
Mobile WiMAX, 802.16e	IMT-2000 regional deployments	Scalable OFDMA	Frame-synchronous TDD/FDD and multiple channel bandwidths.

System	Context	Access / modulation	Forensic observables
LTE E-UTRA FDD / TDD	4G, Release 8 onward	Downlink OFDMA, uplink SC-FDMA	15 kHz subcarriers, 10 ms frames, 1 ms subframes, reference signals and carrier aggregation.
LTE-Advanced / Pro	4G evolution	Carrier aggregation, MIMO, higher-order QAM	Multiple component carriers, coordinated timing and cross-carrier scheduling.
LTE-M	Cellular IoT	LTE-derived narrow operation and repetitions	eDRX, power-saving mode and periodic network acquisition can dominate detectability.
NB-IoT	Cellular IoT, approximately 180 kHz	Narrow OFDMA downlink and tone-based uplink	Long sleep intervals, repetitions and infrequent random-access bursts.
5G NR FR1	Sub-7.125 GHz allocations by region	CP-OFDM downlink/uplink and optional DFT-s-OFDM uplink	15/30/60 kHz and other authorised numerologies, bandwidth parts, TDD patterns and beam management.

System	Context	Access / modulation	Forensic observables
5G NR FR2	Millimetre-wave allocations	Beamformed OFDM	Directional synchronisation bursts, beam sweeps and high-frequency front-end clocks.
5G-Advanced, Release 18/19	Current 5G evolution	NR enhancements, RedCap/eRedCap, NTN, positioning and sensing-related features	Reduced-capability devices, satellite timing, sparse paging and multi-band operation.
NR-U / private NR	Unlicensed or local licensed deployments	NR waveform with regional channel-access rules	Cellular frame timing combined with contention or enterprise-local coverage.
6G / IMT-2030	Pre-standard research and study status	No final universal air interface as of the release date	Record as experimental or proposed. Do not assign a final 6G standard from an unexplained waveform.

16A.10 Cellular timing, paging and sleep-state protocol

For each cellular candidate, the examiner records downlink and uplink relationship, FDD or TDD behaviour, channel bandwidth, subcarrier spacing or chip rate, synchronisation structure, serving-cell timing, burst duty factor and local spatial gradient. The serving base station is an environmental reference, not evidence of a local device. A handset candidate requires a localised uplink, local timing leakage, state correlation or another independent association.

Digital-system elaboration. For Cellular timing, paging and sleep-state protocol, the standards register provides candidate timing and spectral relationships, not a finite list of frequencies at which all compliant products must radiate. External ports and internal buses can produce fundamentals, harmonics, common-mode currents, connector radiation, spread-spectrum skirts, burst cadences, and low-frequency power-state signatures even when payload communication is absent. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

Sleeping endpoints require long observation. DRX, eDRX and power-saving mode can create intervals lasting seconds, minutes or longer. Records shall include continuous waterfall, event-triggered I/Q, reference-channel capture and clock-family monitoring. The observation window must exceed the longest credible cycle by a validated margin. A quiet short sweep is not a negative cellular result.

16A.11 Low-power wireless, IoT, professional radio and paging

Higher-layer names must not be confused with physical layers. Matter commonly uses Ethernet, Wi-Fi or Thread and may use Bluetooth LE for commissioning. Thread and Zigbee ordinarily use IEEE 802.15.4 radios. WirelessHART and ISA100.11a use managed industrial overlays on related PHYs. The report first identifies the bearer, then documents higher-layer evidence only where authorised metadata or device records exist.

Clock and timing interpretation. A technically mature analysis of Low-power wireless, IoT, professional radio and paging distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

Table 16A-8. Low-power, mesh, paging and professional-mobile families

Family	Band / context	Modulation / access	Forensic observables
IEEE 802.15.4 O-QPSK	2.4 GHz and regional sub-GHz	DSSS O-QPSK, BPSK or regional PHY	Zigbee, Thread, 6LoWPAN, WirelessHART, ISA100.11a and many proprietary sensor systems.
IEEE 802.15.4g / Wi-SUN	Regional sub-GHz utility bands	FSK, OFDM or O-QPSK SUN PHYs	Long-lived mesh infrastructure, periodic metering and field-area-network traffic.
IEEE 802.15.4a / z UWB	Regional UWB bands	Impulse radio and secure ranging enhancements	Nanosecond pulses, broad spectrum, time-of-flight exchanges and low average power.
Z-Wave	Regional sub-GHz bands	FSK/GFSK and later long-range modes	Home-automation mesh traffic, wake-up intervals and region-specific channels.
EnOcean	Regional sub-GHz and 2.4 GHz variants	ASK/FSK and energy-harvesting telegrams	Very short low-duty transmissions triggered by harvested mechanical or solar energy.
LoRa / LoRaWAN	Regional unlicensed bands	Chirp spread spectrum and FSK options	Long chirps, spreading-factor-dependent duration and Class A/B/C sleep/listen behaviour.

Family	Band / context	Modulation / access	Forensic observables
Sigfox	Regional sub-GHz	Ultra-narrowband DBPSK uplink and GFSK downlink	Very narrow, sparse messages and strict regional duty limits.
mioty	Regional sub-GHz	Telegram splitting over many sub-packets	Dispersed low-power fragments can resemble unrelated narrow pulses unless time-associated.
DASH7	433/868/915 MHz regions	GFSK and burst-oriented low-power protocol	Asynchronous low-latency bursts and long sleep periods.
Wireless M-Bus / Wize	169/433/868 MHz and regional plans	FSK/GFSK or long-range metering modes	Meter telegrams, periodicity, long idle periods and building-wide distribution.
DECT / DECT ULE / DECT-2020 NR	Regional 1.8/1.9 GHz and assigned bands	TDMA/TDD GFSK and later OFDM-based NR	Base beacons, 10 ms classic frames, low-energy sensor traffic and IMT-2020-oriented DECT NR.
POCSAG / FLEX / ERMES paging	VHF/UHF regional paging bands	FSK and synchronous codeword frames	Persistent high-power infrastructure and periodic batch structures; receivers may have local clocks but no uplink.
TETRA	Regional professional-mobile bands	pi/4-DQPSK TDMA/TDD or FDD	Four-slot frames, control channels, direct mode and trunked-system timing.
DMR / dPMR / NXDN	VHF/UHF professional radio	4FSK with two-slot TDMA or narrow FDMA	12.5/6.25 kHz channel families, colour codes, repeaters and low-duty handheld bursts.

Family	Band / context	Modulation / access	Forensic observables
APCO Project 25	VHF/UHF/700/800 MHz public safety		Control channels, trunking, 12.5 kHz channels and two-slot Phase 2 traffic.
MPT 1327 and analogue trunking	Historical VHF/UHF systems	FSK control plus analogue FM traffic	Control-channel cadence and assigned traffic channels.

16A.12 RFID, NFC, wireless power, backscatter and SAW families

Passive and semi-passive systems may be silent until illuminated. The passive survey therefore records ambient carriers, local resonances and rectifier-like harmonic products before any authorised active test. Controlled illumination remains a secondary module subject to spectrum, exposure, clinical, evidence-preservation and equipment-safety authority. A response correlated with illumination is not automatically a device identification.

Retroreflective-response analysis. A advanced technical analysis of RFID, NFC, wireless power, backscatter and SAW families separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission.

Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. A nonlinear or harmonic response remains a junction or material observation unless additional evidence supports an electronic device interpretation [17-23].

Table 16A-9. RFID, NFC, wireless-power and passive-response families

Family	Band	Physical method	Forensic observables
LF RFID	Approximately 125/134.2 kHz	Inductive coupling, ASK/FSK/PSK variants	Reader field, tag load modulation and strong local magnetic near field.
HF RFID / NFC	13.56 MHz	ISO/IEC 14443, 15693, 18092 and NFC Forum modes	Reader carrier, 106/212/424/848 kbit/s families, load-modulated sidebands and polling cadence.
UHF RFID	Regional 860 to 960 MHz	EPC Gen2 / ISO/IEC 18000-63 backscatter	Reader CW, PIE downlink, tag backscatter and inventory-slot timing.
Microwave RFID / active tags	2.45 GHz, 5.8 GHz and other authorised bands	Backscatter or active FSK/PSK	Directional interrogation, sparse replies and regional allocation differences.
Qi wireless power	Low-frequency inductive power transfer	ASK/FSK control superimposed on power transfer	Strong magnetic field, ping/negotiation cadence and power-stage switching.
AirFuel and resonant WPT	Resonant or RF power-transfer bands	Load modulation and control links	Resonant field, rectifier products, control telemetry and possible dormant-device activation.
SAW passive sensor / tag	Component-specific VHF/UHF/microwave resonances	Reflective delay line or resonant backscatter	Interrogation-correlated echoes, frequency shift, coded delays and no continuous local carrier.

16A.13 Broadcast, satellite, navigation, radar, optical and acoustic bearers

Broadcast and navigation carriers are often external infrastructure, yet they matter because they can produce receiver overload, passive intermodulation, cable common mode and unintentional illumination. The examiner maps them at 300 and 150 feet, preserves a remote reference channel and does not promote a local candidate unless the inward spatial behaviour differs materially from the external field.

Table 16A-10. Broadcast, navigation, radar and optical families

Family	Region / band	Modulation	Forensic significance
AM / long-wave / medium-wave / short-wave	LF through HF	AM, SSB, DRM and regional systems	Strong external carriers can illuminate nonlinear junctions and create conducted common-mode energy.
FM broadcast / RDS	Regional VHF band	WFM stereo multiplex with pilot and subcarriers	19 kHz pilot, 38 kHz stereo subcarrier and 57 kHz RDS family.
Analogue television	Regional VHF/UHF and cable channels	VSB picture with FM or AM sound; NTSC/PAL/SECAM	15.734 or 15.625 kHz line timing, colour references and channel-specific carriers.
ATSC 1.0	6 MHz terrestrial channels	8-VSB	Pilot, segment sync, field sync and 10.76 Msymbol/s family.

Family	Region / band	Modulation	Forensic significance
ATSC 3.0	Regional terrestrial channels	OFDM with configurable numerology	Bootstrap, physical-layer pipes, LDPC and time-frequency interleaving.
DVB-T/T2 / ISDB-T / DTMB	International terrestrial digital TV	COFDM, BST-OFDM or TDS-OFDM families	Country-specific channel bandwidth, pilot patterns and frame cadence.
DAB / DAB+ / DRM	VHF Band III, L-band or HF/MF	COFDM / OFDM digital radio	Mode-dependent symbol timing, ensemble frames and external illumination potential.
Satellite reception and transmission	L/S/C/X/Ku/Ka and other allocations	QPSK, 8PSK, APSK, OFDM and proprietary waveforms	LNB local oscillators, reference clocks, IF cables, burst terminals and highly directional paths.
GNSS	L-band and augmentation bands	DSSS BPSK/BOC families	External signals are weak, but receiver TCXO, synthesiser, sampling and correlator clocks may leak locally.
Radar / altimeter / automotive radar	HF through millimetre-wave	Pulsed, FMCW, phase-coded and chirped waveforms	Strong periodic bursts, sweep ramps and local chirp-generator clocks.
Infrared / optical communications	Visible and infrared	OOK, PPM, OFDM and protocol-specific pulse trains	Use non-imaging photodiodes, optical attenuators and timing analysis rather than cameras.

16A.14 External ports and cable-borne interfaces

External ports are examined as electrical systems, not merely as connector shapes. The examiner records connector, cable, shield termination, cable route, ferrites, adapters, active cables, docks, retimers, alternate modes and power state. The same USB-C receptacle can carry USB 2.0, USB 3.2, USB4, DisplayPort, Thunderbolt, analogue audio or only power. A connector label is not a physical-layer finding.

Digital-system elaboration. For External ports and cable-borne interfaces, the standards register provides candidate timing and spectral relationships, not a finite list of frequencies at which all compliant products must radiate.

External ports and internal buses can produce fundamentals, harmonics, common-mode currents, connector radiation, spread-spectrum skirts, burst cadences, and low-frequency power-state signatures even when payload communication is absent. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

Table 16A-11. External high-speed port families

Interface	Electrical rate / medium	Coding / timing	Forensic observables
USB 1.0/1.1 low/full speed	1.5 / 12 Mb/s D+ and D-	NRZI, bit stuffing, 1 ms frames	6/48 MHz families, SOF cadence, suspend keep-alive and remote wake.
USB 2.0 high speed	480 Mb/s differential	NRZI, 125 microsecond microframes	8 kHz microframe envelope, 60/480 MHz relations, chirp attach, HSIC and eUSB2 variants.

Interface	Electrical rate / medium	Coding / timing	Forensic observables
USB 3.0/3.1/3.2 Gen 1	5 Gb/s SuperSpeed	8b/10b, LFPS low-power signalling	Five-GHz-class lane energy, spread-spectrum clock and periodic LFPS.
USB 3.1/3.2 Gen 2 / 2x2	10 / 20 Gb/s	128b/132b, one or two lanes	Ten-GHz-class lane families, lane bonding, retimer clocks and LFPS.
USB4 v1 / v2	20/40/80 Gb/s and defined asymmetric modes	Packet tunnelling over high-speed lanes	Router, retimer, Type-C orientation, PD and tunneled DisplayPort/PCIe signatures.
USB Type-C CC / PD	Low-speed CC1/CC2	Biphase mark coded Power Delivery	Attach, role and power-contract traffic can persist while data lanes sleep.
IEEE 1394a FireWire	100/200/400 Mb/s	Data-strobe encoding	Bus reset, arbitration, cycle-start timing and cable common-mode leakage.
IEEE 1394b FireWire	800 Mb/s and higher defined rates	8b/10b beta mode	Higher-rate serial energy and bilingual PHY behaviour.
Thunderbolt 1/2	Mini DisplayPort connector	PCIe and DisplayPort tunnelling	Router clocks, active cables and combined display/storage signatures.
Thunderbolt 3/4/5	USB-C connector	High-speed tunnelling	PD and cable-marker traffic, routers, asymmetric modes and wake management.
HDMI 1.x / 2.0	Three TMDS data lanes plus clock	Transition-minimised 10-bit symbols	Pixel-clock families, TMDS rates, DDC, CEC and hot-plug detect.

Interface	Electrical rate / medium	Coding / timing	Forensic observables
HDMI 2.1 / 2.2	FRL fixed-rate lanes	FRL block coding and link training	Lane-rate families, training patterns, eARC and standby CEC/DDC activity.
DVI-D / DVI-I	TMDS and optional analogue	TMDS or RGBHV	Forwarded clock, DDC and pixel-rate harmonics.
DisplayPort 1.x / 2.1b	Main link plus AUX	8b/10b or 128b/132b UHBR	Embedded clock, link training, AUX management, MST and panel self-refresh.
VGA / RGBHV	Analogue RGB plus sync	Analogue video and horizontal/vertical timing	Pixel clock, 15 kHz-class legacy sync and cable common-mode current.
SDI families	Coaxial serial digital video	Scrambled NRZI and embedded timing	270 Mb/s through multi-gigabit families, cable radiation and reference sync.

16A.15 USB-specific active, suspended and power-only search discipline

USB is searched in three domains. First, D+ and D- or SuperSpeed lane energy is sought at the connector and cable without electrical contact. Second, Type-C configuration-channel and USB Power Delivery traffic is sought because it can remain active while the high-speed path is suspended. Third, internal hub, retimer, charger and controller clocks are sought in the device body. A quiet data cable does not exclude an active PD controller or a self-powered peripheral.

Communications-family analysis. At expert-practitioner level, USB-specific active, suspended and power-only search discipline is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. The report names a standards family only at the level supported by the physical observables and states when multiple implementations remain plausible [81-120].

The examiner records frame and microframe envelopes, LFPS, attach chirps, spread-spectrum shoulders, lane count, cable orientation and state transitions. USB enumeration, descriptor requests, device-class interrogation and packet injection are outside the passive protocol. Any authorised active enumeration is a separate digital-forensic action with evidence-preservation controls.

16A.16 HDMI, DisplayPort, DVI, Thunderbolt and video-port discipline

A video interface can be localised through a forwarded clock, embedded-clock lanes, link training, auxiliary channels, EDID/DDC transactions, hot-plug detect, CEC, eARC, display-panel refresh and power-management timing. HDMI TMDS and HDMI FRL are different physical layers. DisplayPort 8b/10b and UHBR 128b/132b links are likewise different. Thunderbolt tunnels other protocols and can introduce active-cable and retimer emissions distinct from host or display.

Digital-system elaboration. At expert-practitioner level, HDMI, DisplayPort, DVI, Thunderbolt and video-port discipline is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

The protocol records whether a display is active, blanked, asleep, self-refreshing, disconnected or powered through another source. It maps the host, cable, adapter, dock and display separately. The presence of a 148.5 MHz family can be consistent with video timing but does not establish whether the source is a camera, graphics system, test generator, converter or unrelated oscillator.

16A.17 Ethernet, coax, twisted-pair broadband and powerline communications

Cable systems are examined with non-contact current probes, electric-field probes, magnetic loops and remote reference channels. Differential data can produce little external field when balance is excellent, while shield currents, common-mode conversion, poor termination, adapters and connected power supplies can dominate the observable signature. The examiner therefore measures the cable, each end, shields, protective earth and nearby services.

Digital-system elaboration. At expert-practitioner level, Ethernet, coax, twisted-pair broadband and powerline communications is approached through standards families without assuming that a detected emission identifies a particular protocol implementation. The same clock, line code, packet cadence, or power-state interval may occur in unrelated systems. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

Table 16A-12. Ethernet, broadband and powerline families

Interface	Medium / rate	Coding / access	Forensic observables
10BASE-T	10 Mb/s twisted pair	Manchester coding	Normal link pulses near 16 ms intervals, 20 MHz-class edge energy and cable-current leakage.
100BASE-TX	100 Mb/s	4B/5B, MLT-3	25/125 MHz clock relationships, continuous idle and common-mode cable emissions.
1000BASE-T	1 Gb/s four-pair	PAM-5 with echo cancellation	125 MBd family, four-pair symmetry and power-sensitive PHY clocks.
2.5G/5GBASE-T	2.5 / 5 Gb/s	PAM-16 derived multilevel signalling	1000BASE-T-derived clock families with wider occupied cable spectrum.
10GBASE-T	10 Gb/s	PAM-16 with LDPC	Approximately 800 MBd-class multilevel energy and strong cable-balance dependence.
Optical / direct-attach Ethernet	1 Gb/s through 800 Gb/s and developing higher rates	8b/10b, 64b/66b, PAM4 and lane aggregation	156.25 MHz and derived reference families, module management and gearbox clocks.
Energy Efficient Ethernet	IEEE 802.3az and successors	Low-power idle refresh	Sparse refresh bursts, wake transitions and retained PHY management.
Power over Ethernet	IEEE 802.3af/at/bt	DC power plus Ethernet data	PSE classification, maintain-power signatures, converter switching and cable-current asymmetry.

Interface	Medium / rate	Coding / access	Forensic observables
DOCSIS / cable modem	Coaxial broadband	QAM, OFDM/OFDMA by generation	Downstream carriers, upstream bursts, tuner and cable-modem reference clocks.
MoCA	In-home coax	OFDM over regional coax bands	Bursty network activity and strong conducted path on coax shields.
xDSL	Copper telephone pair	DMT or legacy CAP/QAM	Tone combs, superframe cadence, line-driver fields and modem crystal families.
G.hn / HomePlug / IEEE 1901	Mains, coax or telephone wiring	OFDM with notches and adaptive carriers	Conducted broadband energy, zero-crossing relationships and line-coupler resonance.
X10 / CEBus / legacy PLC	Mains wiring	120 kHz bursts or spread-spectrum carrier current	Zero-crossing-synchronised burst patterns and strong circuit-specific propagation.

16A.18 Internal buses, storage, camera, display and audio interfaces

Internal digital interfaces are commonly more detectable through near-field magnetic or electric probes than through far-field antennas.

Their strongest lines may be reference clocks, harmonics, spread-spectrum shoulders, frame cadences, power-converter sidebands or cable common mode rather than the serial data rate itself.

The examiner shall not assume that a gigabit lane produces a single spectral line at the bit rate.

Communications-family analysis. The mature treatment of Internal buses, storage, camera, display and audio interfaces distinguishes normative air-interface or cable specifications from implementation leakage, board-level clocks, power-management activity, spread-spectrum clocking, and enclosure coupling.

The examiner records the edition and jurisdictional status of any cited standard, while treating manufacturer configuration, regional band plan, optional features, and power-saving modes as variables that require case-specific verification.

The report names a standards family only at the level supported by the physical observables and states when multiple implementations remain plausible [81-120].

Table 16A-13. Internal digital-bus, storage, camera, display and audio families

Interface	Rate / medium	Coding / timing	Forensic observables
PCI / PCI-X	33/66/100/133 MHz parallel	Synchronous parallel bus	Clock fundamentals, harmonics and broad simultaneous-switching signatures.
PCI Express Gen 1 through Gen 7	2.5 to 128 GT/s by generation	8b/10b then 128b/130b and later PAM4-based Gen 7	100 MHz reference family, spread-spectrum clock, link training, L0s/L1/L1 substates and retimers.
SATA	1.5/3/6 Gb/s	8b/10b serial with OOB signalling	COMRESET/COMINIT, partial/slumber/DevSleep transitions and storage-controller clocks.
SAS	Multi-gigabit serial storage	8b/10b or 64b/66b by generation	Expander clocks, wide ports, out-of-band management and cable emissions.
NVMe	PCIe transport	PCIe electrical PHY	Identify PCIe first. NVMe is a protocol over the PCIe bearer, not a separate radiated PHY.

Interface	Rate / medium	Coding / timing	Forensic observables
SCSI / parallel ATA / floppy	Historical parallel storage buses	Single-ended or differential parallel handshakes	5/8/10/16/33 MHz and device-specific clocks, strobes and cable radiation.
SD / SDIO / eMMC	Removable and embedded storage	Clocked command/data bus	400 kHz initialisation, 25/50/100/200 MHz-class operation and background access bursts.
UFS	Embedded serial storage	MIPI M-PHY with UniPro	Gear-dependent serial lanes, reference clock and hibern8 low-power transitions.
I2C / SMBus / PMBus	Two-wire open-drain control	100 kHz through multi-megahertz modes	Pull-up-dependent edges, periodic sensors, battery gauges, PMIC and sleep-state management.
I3C	Two-wire successor bus	Push-pull and open-drain phases	Dynamic-address traffic, in-band interrupts and higher-rate bursts.
SPI / QSPI / OSPI	Clocked chip-select buses	Single, dual, quad or octal serial data	SCLK families, flash reads, boot bursts and memory-mapped continuous activity.
UART	Asynchronous serial	Start/stop framing	1.8432 MHz and related baud-generator families; sparse console, modem and debug bursts.
JTAG / SWD / cJTAG	Debug and test ports	Clocked serial test access	TCK/SWCLK, reset and low-duty boundary-scan activity. Passive detection does not authorise interrogation.
MIPI CSI-2 / DSI	Camera and display links	D-PHY or C-PHY lanes	Lane-rate energy, escape mode, clock lane where used, sensor master clock and frame cadence.
eDP / LVDS / FPD-Link	Internal display and camera links	Differential serial or source-synchronous lanes	Pixel or link-rate families, panel timing controller, AUX/control and panel self-refresh.

Interface	Rate / medium	Coding / timing	Forensic observables
I2S / TDM / PCM audio	Digital audio buses	Bit clock plus word select and data	44.1/48 kHz sample families, 2.8224/3.072/6.144/12.288 MHz clocks and codec master clocks.
PDM microphone	One-bit oversampled audio	Clock and density-modulated data	768 kHz to several MHz clock, always-on voice processing and load-correlated cable magnetic field.
SoundWire / SLIMbus	Mobile audio/control bus	Clocked multi-drop serial	Low-power audio links, frame timing and wake-up events.

16A.19 Historical serial, parallel, telephony and carrier systems

Modern premises can still contain legacy buses, alarm panels, modems, lift controls, industrial gateways, telephone extensions and archival equipment. Their low rates can couple efficiently into long wiring and may remain visible when modern high-speed links are idle. Historical systems are therefore retained as controlled search families rather than dismissed as obsolete.

Signal-analysis interpretation. For Historical serial, parallel, telephony and carrier systems, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform.

Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

Table 16A-14. Historical serial, parallel and telecommunications families

Interface	Medium / context	Coding / timing	Forensic observables
RS-232 / V.24	Single-ended serial, point-to-point	UART framing with mark/space voltages	Baud clocks, charge-pump switching and cable fields from 50 baud through high-rate proprietary use.
RS-422 / RS-485	Differential multi-drop	UART or protocol-specific framing	Long cable current, termination reflections and Modbus/industrial schedules.
PS/2	Keyboard / mouse	Bidirectional clock and data near 10 to 16.7 kHz	Clock pulses and host inhibit behaviour may persist in standby.
Centronics / IEEE 1284	Parallel printer port	Strobe/acknowledge handshakes	Parallel edge energy, printer status polling and legacy peripheral clocks.
GPIB / IEEE 488	Parallel instrumentation bus	Three-wire handshake with eight data lines	Controller polling, talk/listen transitions and instrument clock leakage.
MIDI DIN / USB-MIDI	31.25 kbaud current loop or USB class	UART framing or USB packets	2 MHz-class divider relationships, sparse event bursts and optocoupler current.
POTS	Analogue voice pair	Baseband audio, ringing, supervisory DC	20/25 Hz ringing, dial pulses, DTMF, 300 Hz to 3.4 kHz voice-band current and hybrid imbalance.
ISDN BRI / PRI	2B+D and 30B+D/23B+D digital telephony	2B1Q or AMI/HDB3 and framed digital channels	80/160 kbaud U-interface, 192 kbit/s S/T and 1.544/2.048 Mbit/s line timing.

Interface	Medium / context	Coding / timing	Forensic observables
V-series modems	PSTN data	FSK, PSK, QAM, trellis and echo-cancelled duplex	Originate/answer tones, symbol clocks and line-driven audio-band spectra.
T1 / E1 / J1	Digital carrier	AMI/B8ZS or HDB3	1.544/2.048 Mb/s framing, 8 kHz frame cadence and strong cable clock families.
SONET / SDH	Optical transport	Scrambled synchronous framing	8 kHz frame family, 155.52 MHz multiples and optical module clocks.

16A.20 Industrial, building, automotive, avionics and military buses

Deterministic control networks often produce exceptionally repeatable timing. That repeatability can aid localisation, but it can also create strong distributed fields along the entire plant.

The examiner distinguishes a compact source from an extended network by along-path and transverse gradients, endpoint comparison, schedule correlation, independent current measurements and control cells on the same service.

Table 16A-15. Industrial, building, automotive, avionics and military families

Bus / family	Medium	Coding / access	Forensic observables
CAN / CAN FD / CAN XL	Automotive and industrial differential bus	Dominant/recessive NRZ with bit stuffing and higher-rate phases	Nominal/arbitration rates, data-phase clocks, periodic ECUs and wake patterns.

Bus / family	Medium	Coding / access	Forensic observables
LIN	Single-wire automotive bus	UART-like frames	Master schedule, sync byte and 19.2 kbit/s-class traffic.
FlexRay	Automotive deterministic bus	Dual-channel time-triggered differential signalling	Static/dynamic segments, cycle counters and 10 Mb/s timing.
MOST	Automotive multimedia	Optical or electrical synchronous ring	44.1/48 kHz-linked audio timing and network frames.
SENT / PSI5	Automotive sensors	Pulse-width coded / current-modulated serial	Microsecond pulse intervals, frame pauses and sensor-power coupling.
Automotive Ethernet	100BASE-T1 through multi-gigabit T1	PAM and single-pair Ethernet	Master/slave PHY clocks, link training, wake-up and cable common mode.
Modbus RTU / ASCII / TCP	Industrial serial or Ethernet	UART framing or Ethernet	Polling cycles, silent intervals and gateway clocks.
PROFIBUS / PROFINET	Fieldbus / industrial Ethernet	RS-485 FDL or Ethernet real time	Token rotation, cyclic I/O and deterministic frame timing.
EtherCAT	Industrial Ethernet processing-on-the-fly	100BASE-TX physical layer	Highly regular cyclic frames and distributed-clock synchronisation.
EtherNet/IP / CIP	Industrial Ethernet	Ethernet with cyclic and explicit messaging	Requested packet intervals and switch/PLC clock families.
HART	4 to 20 mA analogue loop	Bell 202 1,200/2,200 Hz FSK	Audio-band loop magnetic field and scheduled digital bursts.

Bus / family	**Medium**	**Coding / access**	**Forensic observables**
FOUNDATION Fieldbus	31.25 kbit/s powered fieldbus	Manchester-coded current modulation	Bus power, link active scheduler timing and long cable fields.
BACnet MS/TP / IP	Building automation	RS-485 token passing or Ethernet/IP	Token rotation, periodic object polling and controller crystal families.
KNX TP / RF / IP	Building control	Twisted-pair baseband, regional RF or IP	Telegram bursts, bus-power coupling and distributed actuator responses.
DALI	Lighting control bus	Manchester-coded two-wire signalling	1,200 bit/s commands, LED-driver switching and address polling.
MIL-STD-1553	Avionics dual-redundant bus	Manchester II at 1 Mb/s	Command/response timing, transformer coupling and 1 MHz family.
ARINC 429	Avionics unidirectional bus	Bipolar return-to-zero at 12.5 or 100 kb/s	Fixed word rates, repeated labels and shielded-twisted-pair leakage.
AFDX / ARINC 664	Deterministic avionics Ethernet	Switched Ethernet with virtual links	Bandwidth-allocation-gap timing and redundant network clocks.
SpaceWire	Spacecraft serial link	Data-strobe encoding	Link idle, time codes and 10 to hundreds of Mb/s energy.

16A.21 Standard timing-component and baseband search register

The timing register is not a list of magic frequencies. It is a set of starting hypotheses for coherent narrowband, harmonic-family and sideband analysis.

Each candidate is checked over a tolerance window that accounts for component tolerance, ageing, temperature, load, pulling, spread-spectrum modulation and measurement uncertainty. The entire validated bandwidth remains subject to continuous search.

Time-domain elaboration. A technically mature analysis of Standard timing-component and baseband search register distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock.

Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

Table 16A-16. Common clock and timing families for active and sleeping devices

Frequency family	Typical source classes	Forensic use and caution
400 Hz nominal; platform-specific tolerance and variable-frequency alternatives	Aircraft and military AC generation, ground-power units, motor-generator sets, static inverters, avionics converters and powered loads	Priority power-domain family. Search the fundamental, phase-related fields, 400 Hz-spaced harmonics, converter-characteristic orders and modulation sidebands. Not a unique device signature.
32.768 kHz	RTC, wake timer, PMIC, always-on controller	Fundamental, harmonics, divider products and periodic wake envelope; not universal.
15.625 / 15.734 kHz	Legacy video horizontal timing	Line-rate fundamental, harmonics and scan/load sidebands.

Frequency family	Typical source classes	Forensic use and caution
3.579545 / 4.43361875 MHz	NTSC / PAL colour reference families	Crystal line, harmonics and video-related modulation; not proof of a camera.
1.8432 / 3.6864 / 7.3728 / 14.7456 MHz	UART and modem baud generators	Exact divider relationships to common serial rates.
11.2896 / 22.5792 / 45.1584 MHz	44.1 kHz audio sample family	256x/512x master clocks and codec sidebands.
12.288 / 24.576 / 49.152 MHz	48 kHz audio sample family	Audio master clocks, I2S/PDM relations and codec activity.
13 / 19.2 / 26 / 38.4 / 52 MHz	Mobile radio reference families	TCXO, PLL comparison, divided clocks and duty-cycled radio wake behaviour.
10 / 16.368 / 16.3676 / 24.5535 MHz	GNSS and precision receiver references	TCXO/OCXO, synthesiser comparison and sampling families; implementation dependent.
25 / 50 / 125 / 156.25 MHz	Ethernet and serial transceiver references	PHY clocks, multiples, spread-spectrum shoulders and low-power-idle refresh.
27 / 74.25 / 148.5 / 297 / 594 MHz	Digital video pixel and link timing	Forwarded clock, lane-rate harmonics and display refresh sidebands.
48 / 60 / 120 / 240 / 480 MHz	USB controller and PHY relations	Full/high-speed references, frame/microframe envelopes and gated controller clocks.
100 MHz	PCI Express and many digital platforms	Common reference or independent spread-spectrum references, plus harmonics.
455 kHz / 10.7 / 21.4 / 45 MHz	Historical IF filters and resonators	Local oscillator, IF leakage and nearby ceramic/crystal families.
User-specific FPGA / MCU clocks	Digital logic and mixed-signal systems	Any validated frequency. Search continuously and derive harmonics/subharmonics rather than relying on a list.

16A.21.1 Expanded clock and timing candidate-frequency and harmonic register

This register is a controlled search index, not a list of unique device fingerprints. The entries are retained in the units supplied. In particular, 17.734475 Hz is treated literally as Hertz and must not be silently substituted with a Megahertz value. The 0 Hz entry represents direct current, static bias, offset or a steady state and therefore has no harmonic series. The three broad ranges are not single oscillators. They are search-band descriptors, sorted by their lower frequency boundary, and their harmonic columns show mathematically scaled bands rather than predicted discrete spectral lines. The 400 Hz entry is a power-system family and receives extended treatment in section 16A.21.2.

Clock and timing interpretation. A technically mature analysis of Expanded clock and timing candidate-frequency and harmonic register distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Periodic bursts are analysed in both frequency and time because a stable pulse interval can reveal a clock domain even when the carrier frequency changes or the spectral line is intermittent. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

For a point-frequency candidate, the fundamental is designated H1 and the ten harmonic orders after the fundamental are H2 through H11. Let f_0 be the nominal fundamental frequency in hertz and let n be the integer harmonic order. The predicted harmonic is $f_n = n f_0$ for $n = 2, 3, \ldots, 11$. For a broad search range extending from f_L to f_H, the corresponding harmonic search band is $[n f_L, n f_H]$. Each actual acquisition window shall be widened for component tolerance, ageing, temperature, load pulling, spread spectrum clocking, measurement-reference uncertainty, receiver error and observed drift.

Very often, the most traceable member of a timing family is not the fundamental but one or more harmonics. A nominally low-frequency crystal, RC oscillator, divider output or clock buffer may drive sharp-edged digital transitions whose Fourier components extend well above the base frequency. Printed conductors, component leads, shield seams, apertures, cables and common-mode paths may couple more efficiently at a selected harmonic, while the receiving antenna, ferrite assembly, preamplifier, preselector or local electromagnetic environment may provide a lower noise floor at that higher frequency. Package, enclosure and wiring resonances can also make harmonic amplitude non-monotonic.

Consequently, a reproducible harmonic may be the easiest signal with which to establish a spatial gradient and reveal the source region, even when the fundamental remains below the practical noise floor.

The examiner shall not identify a common source from integer arithmetic alone. A proposed harmonic family must also exhibit compatible frequency error, drift, start-stop behaviour, burst cadence, sideband spacing, orientation response and spatial movement.

The preferred localisation sequence is to discover the strongest reproducible family member, trace it through the established 300-foot to three-inch search geometry, and then confirm as many additional family members as the validated instrumentation permits. Receiver sample rate, local-oscillator plan, resolution bandwidth, preselection, gain and probe type shall be changed in controlled series to exclude aliases, analyser spurs, overload, intermodulation and instrument-clock leakage.

The table extends to 1.1 GHz because H11 of a 100 MHz fundamental is 1.1 GHz. No single probe is suitable across that span. Low-frequency magnetic bars and loops are used only within their validated transfer range; higher-frequency loops, electric-field probes, biconical or log-periodic antennas, and appropriate microwave structures are substituted as frequency increases.

The result record shall identify which harmonic drove the localisation, which other members were confirmed or absent, the uncertainty applied to every search window, and the ordinary electronic sources considered as alternatives.

Table 16A-16A. Frequency-sorted clock and timing candidate register with the first ten harmonic orders after the fundamental, H2 through H11.

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
0 Hz	DC	H2: not applicable H3: not applicable H4: not applicable H5: not applicable H6: not applicable	H7: not applicable H8: not applicable H9: not applicable H10: not applicable H11: not applicable
1 Hz	Point	H2: 2 Hz H3: 3 Hz H4: 4 Hz H5: 5 Hz H6: 6 Hz	H7: 7 Hz H8: 8 Hz H9: 9 Hz H10: 10 Hz H11: 11 Hz
1.024 Hz	Point	H2: 2.048 Hz H3: 3.072 Hz H4: 4.096 Hz H5: 5.12 Hz H6: 6.144 Hz	H7: 7.168 Hz H8: 8.192 Hz H9: 9.216 Hz H10: 10.24 Hz H11: 11.264 Hz
17.734475 Hz	Point	H2: 35.46895 Hz H3: 53.203425 Hz H4: 70.9379 Hz H5: 88.672375 Hz H6: 106.40685 Hz	H7: 124.141325 Hz H8: 141.8758 Hz H9: 159.610275 Hz H10: 177.34475 Hz H11: 195.079225 Hz
32 Hz	Point	H2: 64 Hz H3: 96 Hz H4: 128 Hz H5: 160 Hz H6: 192 Hz	H7: 224 Hz H8: 256 Hz H9: 288 Hz H10: 320 Hz H11: 352 Hz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
256 Hz	Point	H2: 512 Hz H3: 768 Hz H4: 1.024 kHz H5: 1.28 kHz H6: 1.536 kHz	H7: 1.792 kHz H8: 2.048 kHz H9: 2.304 kHz H10: 2.56 kHz H11: 2.816 kHz
400 Hz	Point	H2: 800 Hz H3: 1.2 kHz H4: 1.6 kHz H5: 2 kHz H6: 2.4 kHz	H7: 2.8 kHz H8: 3.2 kHz H9: 3.6 kHz H10: 4 kHz H11: 4.4 kHz
488 Hz to 2 MHz	Range	H2: 976 Hz to 4 MHz H3: 1.464 kHz to 6 MHz H4: 1.952 kHz to 8 MHz H5: 2.44 kHz to 10 MHz H6: 2.928 kHz to 12 MHz	H7: 3.416 kHz to 14 MHz H8: 3.904 kHz to 16 MHz H9: 4.392 kHz to 18 MHz H10: 4.88 kHz to 20 MHz H11: 5.368 kHz to 22 MHz
512 Hz	Point	H2: 1.024 kHz H3: 1.536 kHz H4: 2.048 kHz H5: 2.56 kHz H6: 3.072 kHz	H7: 3.584 kHz H8: 4.096 kHz H9: 4.608 kHz H10: 5.12 kHz H11: 5.632 kHz
1 kHz to 20 MHz	Range	H2: 2 kHz to 40 MHz H3: 3 kHz to 60 MHz H4: 4 kHz to 80 MHz H5: 5 kHz to 100 MHz H6: 6 kHz to 120 MHz	H7: 7 kHz to 140 MHz H8: 8 kHz to 160 MHz H9: 9 kHz to 180 MHz H10: 10 kHz to 200 MHz H11: 11 kHz to 220 MHz
1 kHz to 33 MHz	Range	H2: 2 kHz to 66 MHz H3: 3 kHz to 99 MHz H4: 4 kHz to 132 MHz H5: 5 kHz to 165 MHz H6: 6 kHz to 198 MHz	H7: 7 kHz to 231 MHz H8: 8 kHz to 264 MHz H9: 9 kHz to 297 MHz H10: 10 kHz to 330 MHz H11: 11 kHz to 363 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
1.024 kHz	Point	H2: 2.048 kHz H3: 3.072 kHz H4: 4.096 kHz H5: 5.12 kHz H6: 6.144 kHz	H7: 7.168 kHz H8: 8.192 kHz H9: 9.216 kHz H10: 10.24 kHz H11: 11.264 kHz
2 kHz	Point	H2: 4 kHz H3: 6 kHz H4: 8 kHz H5: 10 kHz H6: 12 kHz	H7: 14 kHz H8: 16 kHz H9: 18 kHz H10: 20 kHz H11: 22 kHz
3 kHz	Point	H2: 6 kHz H3: 9 kHz H4: 12 kHz H5: 15 kHz H6: 18 kHz	H7: 21 kHz H8: 24 kHz H9: 27 kHz H10: 30 kHz H11: 33 kHz
3.2 kHz	Point	H2: 6.4 kHz H3: 9.6 kHz H4: 12.8 kHz H5: 16 kHz H6: 19.2 kHz	H7: 22.4 kHz H8: 25.6 kHz H9: 28.8 kHz H10: 32 kHz H11: 35.2 kHz
3.5 kHz	Point	H2: 7 kHz H3: 10.5 kHz H4: 14 kHz H5: 17.5 kHz H6: 21 kHz	H7: 24.5 kHz H8: 28 kHz H9: 31.5 kHz H10: 35 kHz H11: 38.5 kHz
3.52 kHz	Point	H2: 7.04 kHz H3: 10.56 kHz H4: 14.08 kHz H5: 17.6 kHz H6: 21.12 kHz	H7: 24.64 kHz H8: 28.16 kHz H9: 31.68 kHz H10: 35.2 kHz H11: 38.72 kHz
3.898 kHz	Point	H2: 7.796 kHz H3: 11.694 kHz H4: 15.592 kHz H5: 19.49 kHz H6: 23.388 kHz	H7: 27.286 kHz H8: 31.184 kHz H9: 35.082 kHz H10: 38.98 kHz H11: 42.878 kHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
4 kHz	Point	H2: 8 kHz H3: 12 kHz H4: 16 kHz H5: 20 kHz H6: 24 kHz	H7: 28 kHz H8: 32 kHz H9: 36 kHz H10: 40 kHz H11: 44 kHz
4.096 kHz	Point	H2: 8.192 kHz H3: 12.288 kHz H4: 16.384 kHz H5: 20.48 kHz H6: 24.576 kHz	H7: 28.672 kHz H8: 32.768 kHz H9: 36.864 kHz H10: 40.96 kHz H11: 45.056 kHz
4.28 kHz	Point	H2: 8.56 kHz H3: 12.84 kHz H4: 17.12 kHz H5: 21.4 kHz H6: 25.68 kHz	H7: 29.96 kHz H8: 34.24 kHz H9: 38.52 kHz H10: 42.8 kHz H11: 47.08 kHz
4.5 kHz	Point	H2: 9 kHz H3: 13.5 kHz H4: 18 kHz H5: 22.5 kHz H6: 27 kHz	H7: 31.5 kHz H8: 36 kHz H9: 40.5 kHz H10: 45 kHz H11: 49.5 kHz
4.608 kHz	Point	H2: 9.216 kHz H3: 13.824 kHz H4: 18.432 kHz H5: 23.04 kHz H6: 27.648 kHz	H7: 32.256 kHz H8: 36.864 kHz H9: 41.472 kHz H10: 46.08 kHz H11: 50.688 kHz
4.9152 kHz	Point	H2: 9.8304 kHz H3: 14.7456 kHz H4: 19.6608 kHz H5: 24.576 kHz H6: 29.4912 kHz	H7: 34.4064 kHz H8: 39.3216 kHz H9: 44.2368 kHz H10: 49.152 kHz H11: 54.0672 kHz
5 kHz	Point	H2: 10 kHz H3: 15 kHz H4: 20 kHz H5: 25 kHz H6: 30 kHz	H7: 35 kHz H8: 40 kHz H9: 45 kHz H10: 50 kHz H11: 55 kHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
6 kHz	Point	H2: 12 kHz H3: 18 kHz H4: 24 kHz H5: 30 kHz H6: 36 kHz	H7: 42 kHz H8: 48 kHz H9: 54 kHz H10: 60 kHz H11: 66 kHz
8 kHz	Point	H2: 16 kHz H3: 24 kHz H4: 32 kHz H5: 40 kHz H6: 48 kHz	H7: 56 kHz H8: 64 kHz H9: 72 kHz H10: 80 kHz H11: 88 kHz
9 kHz	Point	H2: 18 kHz H3: 27 kHz H4: 36 kHz H5: 45 kHz H6: 54 kHz	H7: 63 kHz H8: 72 kHz H9: 81 kHz H10: 90 kHz H11: 99 kHz
10 kHz	Point	H2: 20 kHz H3: 30 kHz H4: 40 kHz H5: 50 kHz H6: 60 kHz	H7: 70 kHz H8: 80 kHz H9: 90 kHz H10: 100 kHz H11: 110 kHz
10.7 kHz	Point	H2: 21.4 kHz H3: 32.1 kHz H4: 42.8 kHz H5: 53.5 kHz H6: 64.2 kHz	H7: 74.9 kHz H8: 85.6 kHz H9: 96.3 kHz H10: 107 kHz H11: 117.7 kHz
12 kHz	Point	H2: 24 kHz H3: 36 kHz H4: 48 kHz H5: 60 kHz H6: 72 kHz	H7: 84 kHz H8: 96 kHz H9: 108 kHz H10: 120 kHz H11: 132 kHz
13 kHz	Point	H2: 26 kHz H3: 39 kHz H4: 52 kHz H5: 65 kHz H6: 78 kHz	H7: 91 kHz H8: 104 kHz H9: 117 kHz H10: 130 kHz H11: 143 kHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
15 kHz	Point	H2: 30 kHz H3: 45 kHz H4: 60 kHz H5: 75 kHz H6: 90 kHz	H7: 105 kHz H8: 120 kHz H9: 135 kHz H10: 150 kHz H11: 165 kHz
16 kHz	Point	H2: 32 kHz H3: 48 kHz H4: 64 kHz H5: 80 kHz H6: 96 kHz	H7: 112 kHz H8: 128 kHz H9: 144 kHz H10: 160 kHz H11: 176 kHz
16.384 kHz	Point	H2: 32.768 kHz H3: 49.152 kHz H4: 65.536 kHz H5: 81.92 kHz H6: 98.304 kHz	H7: 114.688 kHz H8: 131.072 kHz H9: 147.456 kHz H10: 163.84 kHz H11: 180.224 kHz
18 kHz	Point	H2: 36 kHz H3: 54 kHz H4: 72 kHz H5: 90 kHz H6: 108 kHz	H7: 126 kHz H8: 144 kHz H9: 162 kHz H10: 180 kHz H11: 198 kHz
20 kHz	Point	H2: 40 kHz H3: 60 kHz H4: 80 kHz H5: 100 kHz H6: 120 kHz	H7: 140 kHz H8: 160 kHz H9: 180 kHz H10: 200 kHz H11: 220 kHz
24 kHz	Point	H2: 48 kHz H3: 72 kHz H4: 96 kHz H5: 120 kHz H6: 144 kHz	H7: 168 kHz H8: 192 kHz H9: 216 kHz H10: 240 kHz H11: 264 kHz
25 kHz	Point	H2: 50 kHz H3: 75 kHz H4: 100 kHz H5: 125 kHz H6: 150 kHz	H7: 175 kHz H8: 200 kHz H9: 225 kHz H10: 250 kHz H11: 275 kHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
30 kHz	Point	H2: 60 kHz H3: 90 kHz H4: 120 kHz H5: 150 kHz H6: 180 kHz	H7: 210 kHz H8: 240 kHz H9: 270 kHz H10: 300 kHz H11: 330 kHz
32 kHz	Point	H2: 64 kHz H3: 96 kHz H4: 128 kHz H5: 160 kHz H6: 192 kHz	H7: 224 kHz H8: 256 kHz H9: 288 kHz H10: 320 kHz H11: 352 kHz
32.768 kHz	Point	H2: 65.536 kHz H3: 98.304 kHz H4: 131.072 kHz H5: 163.84 kHz H6: 196.608 kHz	H7: 229.376 kHz H8: 262.144 kHz H9: 294.912 kHz H10: 327.68 kHz H11: 360.448 kHz
33 kHz	Point	H2: 66 kHz H3: 99 kHz H4: 132 kHz H5: 165 kHz H6: 198 kHz	H7: 231 kHz H8: 264 kHz H9: 297 kHz H10: 330 kHz H11: 363 kHz
35 kHz	Point	H2: 70 kHz H3: 105 kHz H4: 140 kHz H5: 175 kHz H6: 210 kHz	H7: 245 kHz H8: 280 kHz H9: 315 kHz H10: 350 kHz H11: 385 kHz
36 kHz	Point	H2: 72 kHz H3: 108 kHz H4: 144 kHz H5: 180 kHz H6: 216 kHz	H7: 252 kHz H8: 288 kHz H9: 324 kHz H10: 360 kHz H11: 396 kHz
37.4 kHz	Point	H2: 74.8 kHz H3: 112.2 kHz H4: 149.6 kHz H5: 187 kHz H6: 224.4 kHz	H7: 261.8 kHz H8: 299.2 kHz H9: 336.6 kHz H10: 374 kHz H11: 411.4 kHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
38.4 kHz	Point	H2: 76.8 kHz H3: 115.2 kHz H4: 153.6 kHz H5: 192 kHz H6: 230.4 kHz	H7: 268.8 kHz H8: 307.2 kHz H9: 345.6 kHz H10: 384 kHz H11: 422.4 kHz
40 kHz	Point	H2: 80 kHz H3: 120 kHz H4: 160 kHz H5: 200 kHz H6: 240 kHz	H7: 280 kHz H8: 320 kHz H9: 360 kHz H10: 400 kHz H11: 440 kHz
44 kHz	Point	H2: 88 kHz H3: 132 kHz H4: 176 kHz H5: 220 kHz H6: 264 kHz	H7: 308 kHz H8: 352 kHz H9: 396 kHz H10: 440 kHz H11: 484 kHz
44.1 kHz	Point	H2: 88.2 kHz H3: 132.3 kHz H4: 176.4 kHz H5: 220.5 kHz H6: 264.6 kHz	H7: 308.7 kHz H8: 352.8 kHz H9: 396.9 kHz H10: 441 kHz H11: 485.1 kHz
45 kHz	Point	H2: 90 kHz H3: 135 kHz H4: 180 kHz H5: 225 kHz H6: 270 kHz	H7: 315 kHz H8: 360 kHz H9: 405 kHz H10: 450 kHz H11: 495 kHz
48 kHz	Point	H2: 96 kHz H3: 144 kHz H4: 192 kHz H5: 240 kHz H6: 288 kHz	H7: 336 kHz H8: 384 kHz H9: 432 kHz H10: 480 kHz H11: 528 kHz
50 kHz	Point	H2: 100 kHz H3: 150 kHz H4: 200 kHz H5: 250 kHz H6: 300 kHz	H7: 350 kHz H8: 400 kHz H9: 450 kHz H10: 500 kHz H11: 550 kHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
60 kHz	Point	H2: 120 kHz H3: 180 kHz H4: 240 kHz H5: 300 kHz H6: 360 kHz	H7: 420 kHz H8: 480 kHz H9: 540 kHz H10: 600 kHz H11: 660 kHz
75 kHz	Point	H2: 150 kHz H3: 225 kHz H4: 300 kHz H5: 375 kHz H6: 450 kHz	H7: 525 kHz H8: 600 kHz H9: 675 kHz H10: 750 kHz H11: 825 kHz
80 kHz	Point	H2: 160 kHz H3: 240 kHz H4: 320 kHz H5: 400 kHz H6: 480 kHz	H7: 560 kHz H8: 640 kHz H9: 720 kHz H10: 800 kHz H11: 880 kHz
100 kHz	Point	H2: 200 kHz H3: 300 kHz H4: 400 kHz H5: 500 kHz H6: 600 kHz	H7: 700 kHz H8: 800 kHz H9: 900 kHz H10: 1 MHz H11: 1.1 MHz
120 kHz	Point	H2: 240 kHz H3: 360 kHz H4: 480 kHz H5: 600 kHz H6: 720 kHz	H7: 840 kHz H8: 960 kHz H9: 1.08 MHz H10: 1.2 MHz H11: 1.32 MHz
125 kHz	Point	H2: 250 kHz H3: 375 kHz H4: 500 kHz H5: 625 kHz H6: 750 kHz	H7: 875 kHz H8: 1 MHz H9: 1.125 MHz H10: 1.25 MHz H11: 1.375 MHz
150 kHz	Point	H2: 300 kHz H3: 450 kHz H4: 600 kHz H5: 750 kHz H6: 900 kHz	H7: 1.05 MHz H8: 1.2 MHz H9: 1.35 MHz H10: 1.5 MHz H11: 1.65 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
160 kHz	Point	H2: 320 kHz H3: 480 kHz H4: 640 kHz H5: 800 kHz H6: 960 kHz	H7: 1.12 MHz H8: 1.28 MHz H9: 1.44 MHz H10: 1.6 MHz H11: 1.76 MHz
200 kHz	Point	H2: 400 kHz H3: 600 kHz H4: 800 kHz H5: 1 MHz H6: 1.2 MHz	H7: 1.4 MHz H8: 1.6 MHz H9: 1.8 MHz H10: 2 MHz H11: 2.2 MHz
250 kHz	Point	H2: 500 kHz H3: 750 kHz H4: 1 MHz H5: 1.25 MHz H6: 1.5 MHz	H7: 1.75 MHz H8: 2 MHz H9: 2.25 MHz H10: 2.5 MHz H11: 2.75 MHz
300 kHz	Point	H2: 600 kHz H3: 900 kHz H4: 1.2 MHz H5: 1.5 MHz H6: 1.8 MHz	H7: 2.1 MHz H8: 2.4 MHz H9: 2.7 MHz H10: 3 MHz H11: 3.3 MHz
307.2 kHz	Point	H2: 614.4 kHz H3: 921.6 kHz H4: 1.2288 MHz H5: 1.536 MHz H6: 1.8432 MHz	H7: 2.1504 MHz H8: 2.4576 MHz H9: 2.7648 MHz H10: 3.072 MHz H11: 3.3792 MHz
320 kHz	Point	H2: 640 kHz H3: 960 kHz H4: 1.28 MHz H5: 1.6 MHz H6: 1.92 MHz	H7: 2.24 MHz H8: 2.56 MHz H9: 2.88 MHz H10: 3.2 MHz H11: 3.52 MHz
327.68 kHz	Point	H2: 655.36 kHz H3: 983.04 kHz H4: 1.31072 MHz H5: 1.6384 MHz H6: 1.96608 MHz	H7: 2.29376 MHz H8: 2.62144 MHz H9: 2.94912 MHz H10: 3.2768 MHz H11: 3.60448 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
400 kHz	Point	H2: 800 kHz H3: 1.2 MHz H4: 1.6 MHz H5: 2 MHz H6: 2.4 MHz	H7: 2.8 MHz H8: 3.2 MHz H9: 3.6 MHz H10: 4 MHz H11: 4.4 MHz
455 kHz	Point	H2: 910 kHz H3: 1.365 MHz H4: 1.82 MHz H5: 2.275 MHz H6: 2.73 MHz	H7: 3.185 MHz H8: 3.64 MHz H9: 4.095 MHz H10: 4.55 MHz H11: 5.005 MHz
480 kHz	Point	H2: 960 kHz H3: 1.44 MHz H4: 1.92 MHz H5: 2.4 MHz H6: 2.88 MHz	H7: 3.36 MHz H8: 3.84 MHz H9: 4.32 MHz H10: 4.8 MHz H11: 5.28 MHz
500 kHz	Point	H2: 1 MHz H3: 1.5 MHz H4: 2 MHz H5: 2.5 MHz H6: 3 MHz	H7: 3.5 MHz H8: 4 MHz H9: 4.5 MHz H10: 5 MHz H11: 5.5 MHz
600 kHz	Point	H2: 1.2 MHz H3: 1.8 MHz H4: 2.4 MHz H5: 3 MHz H6: 3.6 MHz	H7: 4.2 MHz H8: 4.8 MHz H9: 5.4 MHz H10: 6 MHz H11: 6.6 MHz
800 kHz	Point	H2: 1.6 MHz H3: 2.4 MHz H4: 3.2 MHz H5: 4 MHz H6: 4.8 MHz	H7: 5.6 MHz H8: 6.4 MHz H9: 7.2 MHz H10: 8 MHz H11: 8.8 MHz
1 MHz	Point	H2: 2 MHz H3: 3 MHz H4: 4 MHz H5: 5 MHz H6: 6 MHz	H7: 7 MHz H8: 8 MHz H9: 9 MHz H10: 10 MHz H11: 11 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
1.008 MHz	Point	H2: 2.016 MHz H3: 3.024 MHz H4: 4.032 MHz H5: 5.04 MHz H6: 6.048 MHz	H7: 7.056 MHz H8: 8.064 MHz H9: 9.072 MHz H10: 10.08 MHz H11: 11.088 MHz
1.024 MHz	Point	H2: 2.048 MHz H3: 3.072 MHz H4: 4.096 MHz H5: 5.12 MHz H6: 6.144 MHz	H7: 7.168 MHz H8: 8.192 MHz H9: 9.216 MHz H10: 10.24 MHz H11: 11.264 MHz
1.2 MHz	Point	H2: 2.4 MHz H3: 3.6 MHz H4: 4.8 MHz H5: 6 MHz H6: 7.2 MHz	H7: 8.4 MHz H8: 9.6 MHz H9: 10.8 MHz H10: 12 MHz H11: 13.2 MHz
1.2288 MHz	Point	H2: 2.4576 MHz H3: 3.6864 MHz H4: 4.9152 MHz H5: 6.144 MHz H6: 7.3728 MHz	H7: 8.6016 MHz H8: 9.8304 MHz H9: 11.0592 MHz H10: 12.288 MHz H11: 13.5168 MHz
1.5 MHz	Point	H2: 3 MHz H3: 4.5 MHz H4: 6 MHz H5: 7.5 MHz H6: 9 MHz	H7: 10.5 MHz H8: 12 MHz H9: 13.5 MHz H10: 15 MHz H11: 16.5 MHz
1.6 MHz	Point	H2: 3.2 MHz H3: 4.8 MHz H4: 6.4 MHz H5: 8 MHz H6: 9.6 MHz	H7: 11.2 MHz H8: 12.8 MHz H9: 14.4 MHz H10: 16 MHz H11: 17.6 MHz
1.8 MHz	Point	H2: 3.6 MHz H3: 5.4 MHz H4: 7.2 MHz H5: 9 MHz H6: 10.8 MHz	H7: 12.6 MHz H8: 14.4 MHz H9: 16.2 MHz H10: 18 MHz H11: 19.8 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
2 MHz	Point	H2: 4 MHz H3: 6 MHz H4: 8 MHz H5: 10 MHz H6: 12 MHz	H7: 14 MHz H8: 16 MHz H9: 18 MHz H10: 20 MHz H11: 22 MHz
2.048 MHz	Point	H2: 4.096 MHz H3: 6.144 MHz H4: 8.192 MHz H5: 10.24 MHz H6: 12.288 MHz	H7: 14.336 MHz H8: 16.384 MHz H9: 18.432 MHz H10: 20.48 MHz H11: 22.528 MHz
2.097152 MHz	Point	H2: 4.194304 MHz H3: 6.291456 MHz H4: 8.388608 MHz H5: 10.48576 MHz H6: 12.582912 MHz	H7: 14.680064 MHz H8: 16.777216 MHz H9: 18.874368 MHz H10: 20.97152 MHz H11: 23.068672 MHz
2.4 MHz	Point	H2: 4.8 MHz H3: 7.2 MHz H4: 9.6 MHz H5: 12 MHz H6: 14.4 MHz	H7: 16.8 MHz H8: 19.2 MHz H9: 21.6 MHz H10: 24 MHz H11: 26.4 MHz
2.4576 MHz	Point	H2: 4.9152 MHz H3: 7.3728 MHz H4: 9.8304 MHz H5: 12.288 MHz H6: 14.7456 MHz	H7: 17.2032 MHz H8: 19.6608 MHz H9: 22.1184 MHz H10: 24.576 MHz H11: 27.0336 MHz
2.5 MHz	Point	H2: 5 MHz H3: 7.5 MHz H4: 10 MHz H5: 12.5 MHz H6: 15 MHz	H7: 17.5 MHz H8: 20 MHz H9: 22.5 MHz H10: 25 MHz H11: 27.5 MHz
3 MHz	Point	H2: 6 MHz H3: 9 MHz H4: 12 MHz H5: 15 MHz H6: 18 MHz	H7: 21 MHz H8: 24 MHz H9: 27 MHz H10: 30 MHz H11: 33 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
3.072 MHz	Point	H2: 6.144 MHz H3: 9.216 MHz H4: 12.288 MHz H5: 15.36 MHz H6: 18.432 MHz	H7: 21.504 MHz H8: 24.576 MHz H9: 27.648 MHz H10: 30.72 MHz H11: 33.792 MHz
3.2 MHz	Point	H2: 6.4 MHz H3: 9.6 MHz H4: 12.8 MHz H5: 16 MHz H6: 19.2 MHz	H7: 22.4 MHz H8: 25.6 MHz H9: 28.8 MHz H10: 32 MHz H11: 35.2 MHz
3.2768 MHz	Point	H2: 6.5536 MHz H3: 9.8304 MHz H4: 13.1072 MHz H5: 16.384 MHz H6: 19.6608 MHz	H7: 22.9376 MHz H8: 26.2144 MHz H9: 29.4912 MHz H10: 32.768 MHz H11: 36.0448 MHz
3.579545 MHz	Point	H2: 7.15909 MHz H3: 10.738635 MHz H4: 14.31818 MHz H5: 17.897725 MHz H6: 21.47727 MHz	H7: 25.056815 MHz H8: 28.63636 MHz H9: 32.215905 MHz H10: 35.79545 MHz H11: 39.374995 MHz
3.6864 MHz	Point	H2: 7.3728 MHz H3: 11.0592 MHz H4: 14.7456 MHz H5: 18.432 MHz H6: 22.1184 MHz	H7: 25.8048 MHz H8: 29.4912 MHz H9: 33.1776 MHz H10: 36.864 MHz H11: 40.5504 MHz
4 MHz	Point	H2: 8 MHz H3: 12 MHz H4: 16 MHz H5: 20 MHz H6: 24 MHz	H7: 28 MHz H8: 32 MHz H9: 36 MHz H10: 40 MHz H11: 44 MHz
4.032 MHz	Point	H2: 8.064 MHz H3: 12.096 MHz H4: 16.128 MHz H5: 20.16 MHz H6: 24.192 MHz	H7: 28.224 MHz H8: 32.256 MHz H9: 36.288 MHz H10: 40.32 MHz H11: 44.352 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
4.096 MHz	Point	H2: 8.192 MHz H3: 12.288 MHz H4: 16.384 MHz H5: 20.48 MHz H6: 24.576 MHz	H7: 28.672 MHz H8: 32.768 MHz H9: 36.864 MHz H10: 40.96 MHz H11: 45.056 MHz
4.194304 MHz	Point	H2: 8.388608 MHz H3: 12.582912 MHz H4: 16.777216 MHz H5: 20.97152 MHz H6: 25.165824 MHz	H7: 29.360128 MHz H8: 33.554432 MHz H9: 37.748736 MHz H10: 41.94304 MHz H11: 46.137344 MHz
4.433619 MHz	Point	H2: 8.867238 MHz H3: 13.300857 MHz H4: 17.734476 MHz H5: 22.168095 MHz H6: 26.601714 MHz	H7: 31.035333 MHz H8: 35.468952 MHz H9: 39.902571 MHz H10: 44.33619 MHz H11: 48.769809 MHz
4.5 MHz	Point	H2: 9 MHz H3: 13.5 MHz H4: 18 MHz H5: 22.5 MHz H6: 27 MHz	H7: 31.5 MHz H8: 36 MHz H9: 40.5 MHz H10: 45 MHz H11: 49.5 MHz
4.8 MHz	Point	H2: 9.6 MHz H3: 14.4 MHz H4: 19.2 MHz H5: 24 MHz H6: 28.8 MHz	H7: 33.6 MHz H8: 38.4 MHz H9: 43.2 MHz H10: 48 MHz H11: 52.8 MHz
5 MHz	Point	H2: 10 MHz H3: 15 MHz H4: 20 MHz H5: 25 MHz H6: 30 MHz	H7: 35 MHz H8: 40 MHz H9: 45 MHz H10: 50 MHz H11: 55 MHz
5.0688 MHz	Point	H2: 10.1376 MHz H3: 15.2064 MHz H4: 20.2752 MHz H5: 25.344 MHz H6: 30.4128 MHz	H7: 35.4816 MHz H8: 40.5504 MHz H9: 45.6192 MHz H10: 50.688 MHz H11: 55.7568 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
5.12 MHz	Point	H2: 10.24 MHz H3: 15.36 MHz H4: 20.48 MHz H5: 25.6 MHz H6: 30.72 MHz	H7: 35.84 MHz H8: 40.96 MHz H9: 46.08 MHz H10: 51.2 MHz H11: 56.32 MHz
6 MHz	Point	H2: 12 MHz H3: 18 MHz H4: 24 MHz H5: 30 MHz H6: 36 MHz	H7: 42 MHz H8: 48 MHz H9: 54 MHz H10: 60 MHz H11: 66 MHz
6.144 MHz	Point	H2: 12.288 MHz H3: 18.432 MHz H4: 24.576 MHz H5: 30.72 MHz H6: 36.864 MHz	H7: 43.008 MHz H8: 49.152 MHz H9: 55.296 MHz H10: 61.44 MHz H11: 67.584 MHz
6.25 MHz	Point	H2: 12.5 MHz H3: 18.75 MHz H4: 25 MHz H5: 31.25 MHz H6: 37.5 MHz	H7: 43.75 MHz H8: 50 MHz H9: 56.25 MHz H10: 62.5 MHz H11: 68.75 MHz
6.4 MHz	Point	H2: 12.8 MHz H3: 19.2 MHz H4: 25.6 MHz H5: 32 MHz H6: 38.4 MHz	H7: 44.8 MHz H8: 51.2 MHz H9: 57.6 MHz H10: 64 MHz H11: 70.4 MHz
6.5 MHz	Point	H2: 13 MHz H3: 19.5 MHz H4: 26 MHz H5: 32.5 MHz H6: 39 MHz	H7: 45.5 MHz H8: 52 MHz H9: 58.5 MHz H10: 65 MHz H11: 71.5 MHz
7 MHz	Point	H2: 14 MHz H3: 21 MHz H4: 28 MHz H5: 35 MHz H6: 42 MHz	H7: 49 MHz H8: 56 MHz H9: 63 MHz H10: 70 MHz H11: 77 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
7.3728 MHz	Point	H2: 14.7456 MHz H3: 22.1184 MHz H4: 29.4912 MHz H5: 36.864 MHz H6: 44.2368 MHz	H7: 51.6096 MHz H8: 58.9824 MHz H9: 66.3552 MHz H10: 73.728 MHz H11: 81.1008 MHz
8 MHz	Point	H2: 16 MHz H3: 24 MHz H4: 32 MHz H5: 40 MHz H6: 48 MHz	H7: 56 MHz H8: 64 MHz H9: 72 MHz H10: 80 MHz H11: 88 MHz
8.192 MHz	Point	H2: 16.384 MHz H3: 24.576 MHz H4: 32.768 MHz H5: 40.96 MHz H6: 49.152 MHz	H7: 57.344 MHz H8: 65.536 MHz H9: 73.728 MHz H10: 81.92 MHz H11: 90.112 MHz
8.388608 MHz	Point	H2: 16.777216 MHz H3: 25.165824 MHz H4: 33.554432 MHz H5: 41.94304 MHz H6: 50.331648 MHz	H7: 58.720256 MHz H8: 67.108864 MHz H9: 75.497472 MHz H10: 83.88608 MHz H11: 92.274688 MHz
8.4672 MHz	Point	H2: 16.9344 MHz H3: 25.4016 MHz H4: 33.8688 MHz H5: 42.336 MHz H6: 50.8032 MHz	H7: 59.2704 MHz H8: 67.7376 MHz H9: 76.2048 MHz H10: 84.672 MHz H11: 93.1392 MHz
9 MHz	Point	H2: 18 MHz H3: 27 MHz H4: 36 MHz H5: 45 MHz H6: 54 MHz	H7: 63 MHz H8: 72 MHz H9: 81 MHz H10: 90 MHz H11: 99 MHz
9.6 MHz	Point	H2: 19.2 MHz H3: 28.8 MHz H4: 38.4 MHz H5: 48 MHz H6: 57.6 MHz	H7: 67.2 MHz H8: 76.8 MHz H9: 86.4 MHz H10: 96 MHz H11: 105.6 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
10 MHz	Point	H2: 20 MHz H3: 30 MHz H4: 40 MHz H5: 50 MHz H6: 60 MHz	H7: 70 MHz H8: 80 MHz H9: 90 MHz H10: 100 MHz H11: 110 MHz
10.24 MHz	Point	H2: 20.48 MHz H3: 30.72 MHz H4: 40.96 MHz H5: 51.2 MHz H6: 61.44 MHz	H7: 71.68 MHz H8: 81.92 MHz H9: 92.16 MHz H10: 102.4 MHz H11: 112.64 MHz
11 MHz	Point	H2: 22 MHz H3: 33 MHz H4: 44 MHz H5: 55 MHz H6: 66 MHz	H7: 77 MHz H8: 88 MHz H9: 99 MHz H10: 110 MHz H11: 121 MHz
11.0592 MHz	Point	H2: 22.1184 MHz H3: 33.1776 MHz H4: 44.2368 MHz H5: 55.296 MHz H6: 66.3552 MHz	H7: 77.4144 MHz H8: 88.4736 MHz H9: 99.5328 MHz H10: 110.592 MHz H11: 121.6512 MHz
12 MHz	Point	H2: 24 MHz H3: 36 MHz H4: 48 MHz H5: 60 MHz H6: 72 MHz	H7: 84 MHz H8: 96 MHz H9: 108 MHz H10: 120 MHz H11: 132 MHz
12.288 MHz	Point	H2: 24.576 MHz H3: 36.864 MHz H4: 49.152 MHz H5: 61.44 MHz H6: 73.728 MHz	H7: 86.016 MHz H8: 98.304 MHz H9: 110.592 MHz H10: 122.88 MHz H11: 135.168 MHz
12.5 MHz	Point	H2: 25 MHz H3: 37.5 MHz H4: 50 MHz H5: 62.5 MHz H6: 75 MHz	H7: 87.5 MHz H8: 100 MHz H9: 112.5 MHz H10: 125 MHz H11: 137.5 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
13 MHz	Point	H2: 26 MHz H3: 39 MHz H4: 52 MHz H5: 65 MHz H6: 78 MHz	H7: 91 MHz H8: 104 MHz H9: 117 MHz H10: 130 MHz H11: 143 MHz
13.56 MHz	Point	H2: 27.12 MHz H3: 40.68 MHz H4: 54.24 MHz H5: 67.8 MHz H6: 81.36 MHz	H7: 94.92 MHz H8: 108.48 MHz H9: 122.04 MHz H10: 135.6 MHz H11: 149.16 MHz
14 MHz	Point	H2: 28 MHz H3: 42 MHz H4: 56 MHz H5: 70 MHz H6: 84 MHz	H7: 98 MHz H8: 112 MHz H9: 126 MHz H10: 140 MHz H11: 154 MHz
14.31818 MHz	Point	H2: 28.63636 MHz H3: 42.95454 MHz H4: 57.27272 MHz H5: 71.5909 MHz H6: 85.90908 MHz	H7: 100.22726 MHz H8: 114.54544 MHz H9: 128.86362 MHz H10: 143.1818 MHz H11: 157.49998 MHz
15 MHz	Point	H2: 30 MHz H3: 45 MHz H4: 60 MHz H5: 75 MHz H6: 90 MHz	H7: 105 MHz H8: 120 MHz H9: 135 MHz H10: 150 MHz H11: 165 MHz
16 MHz	Point	H2: 32 MHz H3: 48 MHz H4: 64 MHz H5: 80 MHz H6: 96 MHz	H7: 112 MHz H8: 128 MHz H9: 144 MHz H10: 160 MHz H11: 176 MHz
16.384 MHz	Point	H2: 32.768 MHz H3: 49.152 MHz H4: 65.536 MHz H5: 81.92 MHz H6: 98.304 MHz	H7: 114.688 MHz H8: 131.072 MHz H9: 147.456 MHz H10: 163.84 MHz H11: 180.224 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
16.8 MHz	Point	H2: 33.6 MHz H3: 50.4 MHz H4: 67.2 MHz H5: 84 MHz H6: 100.8 MHz	H7: 117.6 MHz H8: 134.4 MHz H9: 151.2 MHz H10: 168 MHz H11: 184.8 MHz
16.9344 MHz	Point	H2: 33.8688 MHz H3: 50.8032 MHz H4: 67.7376 MHz H5: 84.672 MHz H6: 101.6064 MHz	H7: 118.5408 MHz H8: 135.4752 MHz H9: 152.4096 MHz H10: 169.344 MHz H11: 186.2784 MHz
18 MHz	Point	H2: 36 MHz H3: 54 MHz H4: 72 MHz H5: 90 MHz H6: 108 MHz	H7: 126 MHz H8: 144 MHz H9: 162 MHz H10: 180 MHz H11: 198 MHz
19.2 MHz	Point	H2: 38.4 MHz H3: 57.6 MHz H4: 76.8 MHz H5: 96 MHz H6: 115.2 MHz	H7: 134.4 MHz H8: 153.6 MHz H9: 172.8 MHz H10: 192 MHz H11: 211.2 MHz
20 MHz	Point	H2: 40 MHz H3: 60 MHz H4: 80 MHz H5: 100 MHz H6: 120 MHz	H7: 140 MHz H8: 160 MHz H9: 180 MHz H10: 200 MHz H11: 220 MHz
20.48 MHz	Point	H2: 40.96 MHz H3: 61.44 MHz H4: 81.92 MHz H5: 102.4 MHz H6: 122.88 MHz	H7: 143.36 MHz H8: 163.84 MHz H9: 184.32 MHz H10: 204.8 MHz H11: 225.28 MHz
22 MHz	Point	H2: 44 MHz H3: 66 MHz H4: 88 MHz H5: 110 MHz H6: 132 MHz	H7: 154 MHz H8: 176 MHz H9: 198 MHz H10: 220 MHz H11: 242 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
22.1184 MHz	Point	H2: 44.2368 MHz H3: 66.3552 MHz H4: 88.4736 MHz H5: 110.592 MHz H6: 132.7104 MHz	H7: 154.8288 MHz H8: 176.9472 MHz H9: 199.0656 MHz H10: 221.184 MHz H11: 243.3024 MHz
24 MHz	Point	H2: 48 MHz H3: 72 MHz H4: 96 MHz H5: 120 MHz H6: 144 MHz	H7: 168 MHz H8: 192 MHz H9: 216 MHz H10: 240 MHz H11: 264 MHz
24.576 MHz	Point	H2: 49.152 MHz H3: 73.728 MHz H4: 98.304 MHz H5: 122.88 MHz H6: 147.456 MHz	H7: 172.032 MHz H8: 196.608 MHz H9: 221.184 MHz H10: 245.76 MHz H11: 270.336 MHz
25 MHz	Point	H2: 50 MHz H3: 75 MHz H4: 100 MHz H5: 125 MHz H6: 150 MHz	H7: 175 MHz H8: 200 MHz H9: 225 MHz H10: 250 MHz H11: 275 MHz
26 MHz	Point	H2: 52 MHz H3: 78 MHz H4: 104 MHz H5: 130 MHz H6: 156 MHz	H7: 182 MHz H8: 208 MHz H9: 234 MHz H10: 260 MHz H11: 286 MHz
27 MHz	Point	H2: 54 MHz H3: 81 MHz H4: 108 MHz H5: 135 MHz H6: 162 MHz	H7: 189 MHz H8: 216 MHz H9: 243 MHz H10: 270 MHz H11: 297 MHz
28 MHz	Point	H2: 56 MHz H3: 84 MHz H4: 112 MHz H5: 140 MHz H6: 168 MHz	H7: 196 MHz H8: 224 MHz H9: 252 MHz H10: 280 MHz H11: 308 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
30 MHz	Point	H2: 60 MHz H3: 90 MHz H4: 120 MHz H5: 150 MHz H6: 180 MHz	H7: 210 MHz H8: 240 MHz H9: 270 MHz H10: 300 MHz H11: 330 MHz
32 MHz	Point	H2: 64 MHz H3: 96 MHz H4: 128 MHz H5: 160 MHz H6: 192 MHz	H7: 224 MHz H8: 256 MHz H9: 288 MHz H10: 320 MHz H11: 352 MHz
33 MHz	Point	H2: 66 MHz H3: 99 MHz H4: 132 MHz H5: 165 MHz H6: 198 MHz	H7: 231 MHz H8: 264 MHz H9: 297 MHz H10: 330 MHz H11: 363 MHz
33.333 MHz	Point	H2: 66.666 MHz H3: 99.999 MHz H4: 133.332 MHz H5: 166.665 MHz H6: 199.998 MHz	H7: 233.331 MHz H8: 266.664 MHz H9: 299.997 MHz H10: 333.33 MHz H11: 366.663 MHz
36 MHz	Point	H2: 72 MHz H3: 108 MHz H4: 144 MHz H5: 180 MHz H6: 216 MHz	H7: 252 MHz H8: 288 MHz H9: 324 MHz H10: 360 MHz H11: 396 MHz
37.4 MHz	Point	H2: 74.8 MHz H3: 112.2 MHz H4: 149.6 MHz H5: 187 MHz H6: 224.4 MHz	H7: 261.8 MHz H8: 299.2 MHz H9: 336.6 MHz H10: 374 MHz H11: 411.4 MHz
38.4 MHz	Point	H2: 76.8 MHz H3: 115.2 MHz H4: 153.6 MHz H5: 192 MHz H6: 230.4 MHz	H7: 268.8 MHz H8: 307.2 MHz H9: 345.6 MHz H10: 384 MHz H11: 422.4 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
40 MHz	Point	H2: 80 MHz H3: 120 MHz H4: 160 MHz H5: 200 MHz H6: 240 MHz	H7: 280 MHz H8: 320 MHz H9: 360 MHz H10: 400 MHz H11: 440 MHz
44 MHz	Point	H2: 88 MHz H3: 132 MHz H4: 176 MHz H5: 220 MHz H6: 264 MHz	H7: 308 MHz H8: 352 MHz H9: 396 MHz H10: 440 MHz H11: 484 MHz
44.736 MHz	Point	H2: 89.472 MHz H3: 134.208 MHz H4: 178.944 MHz H5: 223.68 MHz H6: 268.416 MHz	H7: 313.152 MHz H8: 357.888 MHz H9: 402.624 MHz H10: 447.36 MHz H11: 492.096 MHz
45 MHz	Point	H2: 90 MHz H3: 135 MHz H4: 180 MHz H5: 225 MHz H6: 270 MHz	H7: 315 MHz H8: 360 MHz H9: 405 MHz H10: 450 MHz H11: 495 MHz
48 MHz	Point	H2: 96 MHz H3: 144 MHz H4: 192 MHz H5: 240 MHz H6: 288 MHz	H7: 336 MHz H8: 384 MHz H9: 432 MHz H10: 480 MHz H11: 528 MHz
49.152 MHz	Point	H2: 98.304 MHz H3: 147.456 MHz H4: 196.608 MHz H5: 245.76 MHz H6: 294.912 MHz	H7: 344.064 MHz H8: 393.216 MHz H9: 442.368 MHz H10: 491.52 MHz H11: 540.672 MHz
50 MHz	Point	H2: 100 MHz H3: 150 MHz H4: 200 MHz H5: 250 MHz H6: 300 MHz	H7: 350 MHz H8: 400 MHz H9: 450 MHz H10: 500 MHz H11: 550 MHz

Nominal fundamental or range	**Entry class**	**H2 through H6**	**H7 through H11**
52 MHz	Point	H2: 104 MHz H3: 156 MHz H4: 208 MHz H5: 260 MHz H6: 312 MHz	H7: 364 MHz H8: 416 MHz H9: 468 MHz H10: 520 MHz H11: 572 MHz
54 MHz	Point	H2: 108 MHz H3: 162 MHz H4: 216 MHz H5: 270 MHz H6: 324 MHz	H7: 378 MHz H8: 432 MHz H9: 486 MHz H10: 540 MHz H11: 594 MHz
60 MHz	Point	H2: 120 MHz H3: 180 MHz H4: 240 MHz H5: 300 MHz H6: 360 MHz	H7: 420 MHz H8: 480 MHz H9: 540 MHz H10: 600 MHz H11: 660 MHz
64 MHz	Point	H2: 128 MHz H3: 192 MHz H4: 256 MHz H5: 320 MHz H6: 384 MHz	H7: 448 MHz H8: 512 MHz H9: 576 MHz H10: 640 MHz H11: 704 MHz
66 MHz	Point	H2: 132 MHz H3: 198 MHz H4: 264 MHz H5: 330 MHz H6: 396 MHz	H7: 462 MHz H8: 528 MHz H9: 594 MHz H10: 660 MHz H11: 726 MHz
70 MHz	Point	H2: 140 MHz H3: 210 MHz H4: 280 MHz H5: 350 MHz H6: 420 MHz	H7: 490 MHz H8: 560 MHz H9: 630 MHz H10: 700 MHz H11: 770 MHz
72 MHz	Point	H2: 144 MHz H3: 216 MHz H4: 288 MHz H5: 360 MHz H6: 432 MHz	H7: 504 MHz H8: 576 MHz H9: 648 MHz H10: 720 MHz H11: 792 MHz

Nominal fundamental or range	Entry class	H2 through H6	H7 through H11
75 MHz	Point	H2: 150 MHz H3: 225 MHz H4: 300 MHz H5: 375 MHz H6: 450 MHz	H7: 525 MHz H8: 600 MHz H9: 675 MHz H10: 750 MHz H11: 825 MHz
80 MHz	Point	H2: 160 MHz H3: 240 MHz H4: 320 MHz H5: 400 MHz H6: 480 MHz	H7: 560 MHz H8: 640 MHz H9: 720 MHz H10: 800 MHz H11: 880 MHz
81 MHz	Point	H2: 162 MHz H3: 243 MHz H4: 324 MHz H5: 405 MHz H6: 486 MHz	H7: 567 MHz H8: 648 MHz H9: 729 MHz H10: 810 MHz H11: 891 MHz
90 MHz	Point	H2: 180 MHz H3: 270 MHz H4: 360 MHz H5: 450 MHz H6: 540 MHz	H7: 630 MHz H8: 720 MHz H9: 810 MHz H10: 900 MHz H11: 990 MHz
96 MHz	Point	H2: 192 MHz H3: 288 MHz H4: 384 MHz H5: 480 MHz H6: 576 MHz	H7: 672 MHz H8: 768 MHz H9: 864 MHz H10: 960 MHz H11: 1.056 GHz
100 MHz	Point	H2: 200 MHz H3: 300 MHz H4: 400 MHz H5: 500 MHz H6: 600 MHz	H7: 700 MHz H8: 800 MHz H9: 900 MHz H10: 1 GHz H11: 1.1 GHz

Range rows can generate broad overlapping harmonic bands. They shall be used as scheduling and coverage checks, not as proof that a harmonic exists throughout the full band. Search software should merge overlapping windows for efficient acquisition while retaining the provenance of each contributing entry. A line observed inside an overlap is assigned only after its measured timing and spatial behaviour support one candidate family more strongly than competing explanations.

Harmonic absence is not dispositive. Sinusoidal drive, balanced layout, differential routing, filtering, shielding and low-edge-rate buffers may suppress particular orders. Conversely, a strong integer-related line can arise from an unrelated oscillator or from mains, converter, display, communications or instrument clocks. The evidential conclusion must therefore remain a bounded statement about a measured signal family, its reproducibility and its localised field behaviour.

16A.21.2 400 Hz military and aviation power-source family and extended harmonic protocol

Nominal 400 Hz alternating current shall be treated as a priority power-domain signature in military and aviation examinations. MIL-STD-704 is the active United States Department of Defense interface standard for aircraft electric power characteristics, and the companion MIL-HDBK-704 series expressly includes single-phase and three-phase 115 V, 400 Hz utilisation equipment. FAA guidance also recognises 400 Hz aircraft electrical outlets.

Within many fixed-frequency aircraft and defence systems, 400 Hz is therefore a primary AC source. It is not universal. Other platforms may use 28 VDC, higher-voltage DC, 50/60 Hz AC or variable-frequency AC, and the actual aircraft, vehicle, ground-support or facility documentation governs [121]-[123].

Clock and timing interpretation. For 400 Hz military and aviation power-source family and extended harmonic protocol, the most detectable member of a timing family may be a harmonic or coupled sideband rather than the fundamental, particularly when the fundamental lies in a high-noise region or is poorly coupled to the available probe. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error.

The report avoids claiming a specific oscillator merely from frequency coincidence, especially where common industry clocks or power harmonics are abundant [24-26, 81-123].

The forensic value of 400 Hz lies in the complete power family rather than the nominal line alone. One 400 Hz cycle lasts 2.5 milliseconds. For integer harmonic order n, the predicted line is $f_n = n \times 400$ Hz. A generator, inverter, transformer, rectifier, motor, cable bundle, connector, shield termination, chassis seam, return conductor and nonlinear load can each alter the observed family. Balanced three-phase geometry may reduce the fundamental at a particular probe position, while load current, magnetic saturation, rectification or common-mode conversion makes one or more harmonics easier to detect and trace. The examiner shall therefore compare amplitude, phase, vector orientation, drift, sideband spacing, intermittency and spatial gradient across several family members.

The first 100 consecutive orders are tabulated below. They extend from H1 at 400 Hz through H100 at 40 kHz and provide a dense but manageable discovery comb across the audio and lower ultrasonic region. The table does not assert that all orders will exist, nor that a line on a 400 Hz grid arose from 400 Hz power. At higher order the number of accidental numerical coincidences grows rapidly. For example, H82 is 32.8 kHz and is not the 32.768 kHz watch-crystal frequency; H39 is 15.6 kHz and is not the approximately 15.734 kHz NTSC horizontal family. A claimed relationship must survive the same drift, phase, timing, state-change and spatial tests as any other harmonic family.

Table 16A-16B. First 100 consecutive harmonics of a nominal 400 Hz power fundamental

Order	**Frequency**	**Order**	**Frequency**	**Order**	**Frequency**
H1	400 Hz	H35	14 kHz	H68	27.2 kHz
H2	800 Hz	H36	14.4 kHz	H69	27.6 kHz
H3	1.2 kHz	H37	14.8 kHz	H70	28 kHz
H4	1.6 kHz	H38	15.2 kHz	H71	28.4 kHz
H5	2 kHz	H39	15.6 kHz	H72	28.8 kHz
H6	2.4 kHz	H40	16 kHz	H73	29.2 kHz
H7	2.8 kHz	H41	16.4 kHz	H74	29.6 kHz
H8	3.2 kHz	H42	16.8 kHz	H75	30 kHz
H9	3.6 kHz	H43	17.2 kHz	H76	30.4 kHz
H10	4 kHz	H44	17.6 kHz	H77	30.8 kHz

Order	Frequency	Order	Frequency	Order	Frequency
H11	4.4 kHz	H45	18 kHz	H78	31.2 kHz
H12	4.8 kHz	H46	18.4 kHz	H79	31.6 kHz
H13	5.2 kHz	H47	18.8 kHz	H80	32 kHz
H14	5.6 kHz	H48	19.2 kHz	H81	32.4 kHz
H15	6 kHz	H49	19.6 kHz	H82	32.8 kHz
H16	6.4 kHz	H50	20 kHz	H83	33.2 kHz
H17	6.8 kHz	H51	20.4 kHz	H84	33.6 kHz
H18	7.2 kHz	H52	20.8 kHz	H85	34 kHz
H19	7.6 kHz	H53	21.2 kHz	H86	34.4 kHz
H20	8 kHz	H54	21.6 kHz	H87	34.8 kHz
H21	8.4 kHz	H55	22 kHz	H88	35.2 kHz
H22	8.8 kHz	H56	22.4 kHz	H89	35.6 kHz
H23	9.2 kHz	H57	22.8 kHz	H90	36 kHz
H24	9.6 kHz	H58	23.2 kHz	H91	36.4 kHz
H25	10 kHz	H59	23.6 kHz	H92	36.8 kHz
H26	10.4 kHz	H60	24 kHz	H93	37.2 kHz
H27	10.8 kHz	H61	24.4 kHz	H94	37.6 kHz
H28	11.2 kHz	H62	24.8 kHz	H95	38 kHz
H29	11.6 kHz	H63	25.2 kHz	H96	38.4 kHz
H30	12 kHz	H64	25.6 kHz	H97	38.8 kHz
H31	12.4 kHz	H65	26 kHz	H98	39.2 kHz
H32	12.8 kHz	H66	26.4 kHz	H99	39.6 kHz
H33	13.2 kHz	H67	26.8 kHz	H100	40 kHz
H34	13.6 kHz				

Selected higher-order checkpoints are useful for broad-band correlation after a low-order family has already been established. They shall not be searched or reported as independent proof. Above H100, the examiner records the nearest predicted order, the measured offset in hertz and parts per million, the common frequency drift, and the probability of an unrelated line within the measurement window. The H819 and H820 entries deliberately bracket 327.68 kHz, and H1137 and H1138 bracket 455 kHz, illustrating why high-order arithmetic can mislead unless frequency error and behaviour are assessed.

Table 16A-16C. Selected higher-order 400 Hz harmonic landmarks through 1 MHz.

Order	**Frequency**	**Selected landmark or comparison**
H125	50 kHz	50 kHz checkpoint
H150	60 kHz	60 kHz checkpoint
H160	64 kHz	64 kHz binary-related checkpoint
H192	76.8 kHz	76.8 kHz checkpoint
H200	80 kHz	80 kHz checkpoint
H250	100 kHz	100 kHz checkpoint
H300	120 kHz	120 kHz checkpoint
H320	128 kHz	128 kHz binary-related checkpoint
H375	150 kHz	150 kHz checkpoint
H400	160 kHz	160 kHz checkpoint
H480	192 kHz	192 kHz sample-rate-related checkpoint
H500	200 kHz	200 kHz checkpoint
H625	250 kHz	250 kHz checkpoint
H750	300 kHz	300 kHz checkpoint
H768	307.2 kHz	307.2 kHz clock-family checkpoint
H800	320 kHz	320 kHz checkpoint
H819	327.6 kHz	327.6 kHz, lower bracket near 327.68 kHz
H820	328 kHz	328.0 kHz, upper bracket near 327.68 kHz
H1000	400 kHz	400 kHz checkpoint
H1137	454.8 kHz	454.8 kHz, lower bracket near 455 kHz
H1138	455.2 kHz	455.2 kHz, upper bracket near 455 kHz

Order	Frequency	Selected landmark or comparison
H1200	480 kHz	480 kHz checkpoint
H1250	500 kHz	500 kHz checkpoint
H1500	600 kHz	600 kHz checkpoint
H2000	800 kHz	800 kHz checkpoint
H2500	1 MHz	1 MHz checkpoint

Harmonic shape provides engineering hypotheses, not automatic source identification. In an idealised six-pulse converter, characteristic current harmonics occur at h = 6k +/- 1, while an idealised twelve-pulse converter produces a prominent h = 12k +/- 1 family. Triplen components at h = 3k can be important in phase-to-neutral systems and neutral conductors; even-order components can indicate asymmetry, half-wave behaviour, DC bias, clipping or magnetic saturation. Actual aircraft and military power systems include generator regulation, commutation overlap, phase imbalance, filters, transformer connections, PWM conversion, switched loads and protection circuits, so non-characteristic harmonics and interharmonics are expected. The pattern table is a disciplined hypothesis generator only.

Table 16A-16D. Diagnostic patterns within a nominal 400 Hz power family.

Observed pattern	**Orders or relationship**	**Candidate physical cause**	**Required control and caution**
Fundamental	$\mathrm{H}_1 = 400\mathrm{Hz}(1)$	Generator, inverter, motor-generator set, ground-power unit or conducted load current.	Measure frequency stability, phase, amplitude, field vector, and correlation with authorised power-state changes.
Even-order family	H2, H4, H6,...	Waveform asymmetry, half-wave behaviour, DC bias, clipping, magnetic saturation or unequal positive and negative conduction.	Exclude receiver distortion and probe-core saturation by gain-step, dummy-probe and calibrated-source tests.
Triplen family	H3, H6, H9,...	Zero-sequence or phase-to-neutral current, unbalanced nonlinear loads, neutral-current accumulation, transformer connection effects.	Interpret only with known phase topology. A balanced three-wire system can suppress some triplen components in line current.

Observed pattern	**Orders or relationship**	**Candidate physical cause**	**Required control and caution**
Six-pulse rectifier family	$h = 6k +/ -1 : \mathrm{H}_5, \mathrm{H}_7, \mathrm{H}_{11}, \mathrm{H}_{13}, \mathrm{H}_{17}, \mathrm{H}_{19}, \ldots (2)$	Characteristic current harmonics of an idealised six-pulse converter.	Real converters, filtering, commutation overlap, imbalance and control strategy alter amplitudes and create non-characteristic components.
Twelve-pulse rectifier family	$h = 12k +/ -1 : \mathrm{H}_{11}, \mathrm{H}_{13}, \mathrm{H}_{23}, \mathrm{H}_{25}, \mathrm{H}_{35}, \mathrm{H}_{37}, \ldots (3)$	Characteristic family of an idealised twelve-pulse converter with phase-shifted bridges.	Do not infer converter pulse number from two lines alone. Confirm a wider order pattern and platform documentation.
Sideband family	n x 400 Hz +/- fm	Load cycling, shaft-speed variation, control-loop modulation, PWM envelopes, mechanical vibration or periodic switching.	Confirm symmetric spacing and common modulation rate across several harmonics.

Observed pattern	**Orders or relationship**	**Candidate physical cause**	**Required control and caution**
Interharmonics	Non-integer multiples of 400 Hz	Variable-frequency generation, asynchronous loads, switching converters, beat products or unrelated sources.	Do not force an integer-harmonic model. Estimate the actual fundamental and test alternative families.
Three-phase relationship	Nominally 120 degrees between phases	Phase-related source or distributed load path.	Non-contact field phase is geometry dependent. A measured field is not automatically equal to conductor voltage phase.
Single isolated line	One spectral component only	Could be a power-family member, an unrelated oscillator, acoustic pickup or an instrument artefact.	No family classification without repeatability, spatial gradient, negative controls and uncertainty.

A resonant 400 Hz magnetic bar cannot ordinarily be tuned by a sapphire piston capacitor alone. Commercial piston trimmers generally supply a comparatively small picofarad-range adjustment, whereas a 400 Hz resonance commonly requires nanofarads or microfarads unless the completed probe inductance is exceptionally large.

The correct architecture is a measured high-permeability bar or laminated core, a winding whose resistance and distributed capacitance have been characterised, a stable low-loss fixed capacitor bank for coarse resonance, and a sapphire piston element used only for fine trim.

The completed probe, concentrator, cable, shield and preamplifier input thus must be measured as one system. The resonance equation is C = 1 / (4 pi^2 f^2 L), where C is capacitance in farads, f is 400 Hz, and L is measured inductance in henries.

Table 16A-16E. Illustrative 400 Hz resonant-probe capacitance requirements.

Measured inductance L	Capacitance for 400 Hz resonance	Engineering implication
0.10 H	1.58 microfarads	High capacitance. Use a low-loss fixed capacitor bank; a piston trimmer can only provide a very small fine correction.
1 H	158 nanofarads	Practical only with a stable fixed bank and careful control of winding resistance, core loss and environmental pickup.
10 H	15.8 nanofarads	Compatible with a fixed nanofarad bank. The sapphire piston remains a fine-trim element, not the principal tuning capacitance.
100 H	1.58 nanofarads	Extremely high inductance increases winding resistance, distributed capacitance, stress sensitivity and self-resonance risk.

The 400 Hz family is integrated into the established 300-foot inward search sequence. The acquisition channel shall remain passive unless a separately authorised procedure applies. At every ring, the examiner records the measured fundamental frequency, uncertainty, phase or cross-spectral relationship where available, H2 through at least H25 amplitudes, total harmonic distortion, dominant

higher orders, sidebands, probe axis, probe alloy and winding, gain, bandwidth, reference-clock status, environmental state and control results. A full H1 through H100 vector is acquired at selected stations and whenever the family becomes spatially localised. Dwell, FFT resolution and averaging are validated against the lowest expected duty cycle and the required frequency uncertainty rather than fixed by an untested universal number.

Table 16A-16F. Passive search and localisation sequence for the 400 Hz military and aviation power family.

Search stage	**400 Hz family action**	**Mandatory controls**
300 ft and 150 ft	Establish the environmental 400 Hz baseline and the first matched transition comparison. Record the entire 30 Hz to at least 40 kHz magnetic and electric spectrum, with a wider validated channel where available.	Fixed antenna/probe geometry, reference-clock record, 50/60 Hz comparison, dummy-probe channel, and identification of nearby aircraft, ground-power, rail, industrial or laboratory sources.
100 ft, 50 ft and 30 ft	Test whether the fundamental or harmonic vector converges towards the premises, a service route, a cable run, a transformer, a vehicle, or a ground-power path.	Repeat three orthogonal probe axes, preserve gain and bandwidth, and record phase or cross-spectral coherence where the instrumentation supports it.
15 ft, 12 ft and 3 ft	Separate structural coupling from a local load. Map panels, conduits, cable bundles, earthing conductors, power converters, floor penetrations and equipment boundaries without contact.	Use smaller magnetic loops or bars, electric-field probes, differential/gradiometric channels, and independent receiving chains. Prevent probe-core saturation.

Search stage	400 Hz family action	Mandatory controls
Three-inch decrement and cube lattice	Record the local gradient, vector orientation, null, phase, harmonic ratios, sidebands, intermittency and response to authorised state changes.	Every movement of equipment, cable or furniture is an experimental intervention requiring before-and-after measurements and remeasurement of affected cubes.
Classification gate	Promote a 400 Hz family only when multiple orders or phase/timing relationships move coherently and the spatial maximum is reproducible.	A lawful aircraft or military power source, ground-power unit, inverter, VFD or test supply is a likely alternative explanation. Report the measured source class, not an allegation.

Receiver and probe controls are mandatory because 400 Hz lies within the acoustic, vibration and power-interference environment. The team shall use terminated-input and dummy-probe channels, gain-step tests, a mechanically isolated control probe, battery-powered receiving equipment where practicable, independent instruments, and a deliberate check for microphone, cable-motion, preamplifier-microphonic and analogue-to-digital artefacts. Where a three-phase source is suspected, phase relationships are recorded from safe, authorised non-contact measurements or from approved power-monitoring points. The team shall not expose conductors or connect to aircraft power without qualified authority.

A 400 Hz observation is classified as a power-domain family only when the measured frequency, harmonic or sideband relationships, source state and spatial field pattern are mutually consistent. It is classified as device-associated only after the source is bounded to a specific item or conductor path and alternative infrastructure explanations have been tested. The report shall state whether the dominant trace was the fundamental or a harmonic. This is particularly important because, in practical installations, harmonic leakage can be the clearest and most spatially traceable route to the active equipment even when the 400 Hz fundamental is attenuated by balance, shielding or cancellation.

16A.22 Modulation-neutral acquisition for unknown or proprietary standards

A standards-complete method cannot rely upon protocol decoders. The discovery pass uses power spectral density, peak hold, persistence, occupancy, time-domain triggering, cyclostationary features, instantaneous frequency, envelope statistics, autocorrelation, cross-correlation with reference stations and spatial gradients. The receiver stores raw I/Q or equivalent traceable observables at a rate and bit depth appropriate to the band. Analysis products never replace the original record.

Standards and interface interpretation. For Modulation-neutral acquisition for unknown or proprietary standards, the standards register provides candidate timing and spectral relationships, not a finite list of frequencies at which all compliant products must radiate. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. This approach expands technical coverage without encouraging unauthorised association, pairing, payload decoding, credential use, packet injection, or service disruption [81-120].

Unknown signals are described by measured properties: centre frequency, occupied bandwidth, pulse duration, repetition pattern, subcarrier structure, amplitude distribution, phase continuity, hopping span, time-frequency occupancy, polarisation, field component, cable association and state dependence. A candidate remains unknown rather than being forced into the nearest named standard.

Table 16A-17. Modulation-neutral acquisition views

View	Primary question	Examples of useful result	Principal trap
Long-span spectrum	Where does energy depart from baseline?	Persistent carriers, wide envelopes, clock combs	Narrow RBW can miss short bursts; wide RBW can bury weak lines
Waterfall / persistence	When and how often does it occur?	Sleep events, hopping, paging, periodic maintenance	Display persistence is not calibrated probability
Triggered I/Q	What is the waveform structure?	Preamble, line code, phase continuity, pulse position	Trigger bias can exclude unanticipated events
Time-domain current	Does a cable or power path carry the phenomenon?	Link pulses, frame envelopes, control bursts	Probe loading and common-mode pickup
Cyclostationary analysis	Is there hidden periodic structure below noise?	Symbol, frame or hop recurrence	Estimator artefact and multiple-comparison false positives
Spatial gradient	Where is it strongest or weakest?	Bounded source, cable ridge, external field	Multipath, probe loading and human-body perturbation

16A.23 Wideband nonlinear-junction detection: physical basis and limits

A nonlinear-junction detector is an authorised active instrument that illuminates a region at a fundamental frequency and receives harmonic responses generated by nonlinear junctions.

Semiconductor junctions, oxidised metal contacts, dissimilar-metal interfaces, corroded fasteners, ferrites, protection devices and receiver front ends can all respond. An NLJD can therefore establish a repeatable junction-like phenomenon, but it cannot by itself prove the presence, identity, function, ownership, state or purpose of an electronic device.

Retroreflective-response analysis. A advanced technical analysis of Wideband nonlinear-junction detection: physical basis and limits separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission.

The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

The often-used comparison between second and third harmonics is a heuristic, not a universal discriminator. Junction geometry, bias, corrosion, orientation, frequency, source power, saturation, receiver dynamic range and passive intermodulation alter the ratio.

The evidential method uses passive baselines, source-harmonic controls, multiple source levels, geometric localisation, sham targets, frequency diversity and independent confirmation.

Table 16A-18. Wideband NLJD examination sequence

Stage	Required action
1. Authority and safety gate	Document legal authority, spectrum permission, exposure limits, medical/implant review, evidence-preservation assessment and site approval.

Stage	Required action
2. Passive baseline	Record the fundamental and harmonic bands with the NLJD source disconnected and physically terminated.
3. Instrument self-test	Use certified semiconductor and corrosion/PIM targets, dummy loads, source-harmonic measurements and receiver-image tests outside the scene.
4. Minimum source level	Begin at the lowest validated field. Increase only under a written progression rule and stop limits.
5. Frequency diversity	Where equipment permits, compare more than one authorised fundamental to distinguish junction behaviour from resonant clutter.
6. Geometry and polarisation	Measure multiple azimuths, elevations, stand-offs and polarisations. Record the antenna phase centre.
7. Harmonic channels	Record f0 leakage, 2f0 and 3f0 simultaneously or time-synchronously with uncertainty and noise.
8. Power-response curve	Acquire at least three valid source levels. Reproducible nonlinear slope is more informative than a single harmonic tone.
9. PIM and corrosion controls	Test fasteners, screens, dissimilar metals, rust, cables and building joints. Metal-to-metal nonlinearity can imitate electronics.
10. Spatial confirmation	Require a bounded three-dimensional gradient and reproducible maximum or null.
11. Independent confirmation	Use a second receiver architecture, a second NLJD, or materially different fundamental where available.
12. Restrained classification	Report junction-like, candidate electronic, spatially localised or device-associated only at the validated evidential level.

16A.24 NLJD risk, evidence-preservation and medical controls

NLJD examination occurs after passive work unless an emergency authority expressly changes the sequence. Medical devices, implanted electronics, explosives, battery systems, aircraft, vehicles, industrial controls and evidence-bearing digital devices require a documented risk review. Illumination can wake, alter, log, heat, upset or damage equipment. Stop-work limits are established before entry and source operation is time-stamped in every receiver channel.

Authorisation-control perspective. At expert-practitioner level, NLJD risk, evidence-preservation and medical controls is an engineering control boundary rather than a ceremonial disclaimer. Authority, privacy, spectrum use, exposure, medical-device compatibility, occupational safety, data handling, and property access must be resolved before the corresponding action occurs.

The risk assessment addresses implanted and life-supporting devices, electromagnetic compatibility, spectrum licensing, heating, battery stress, fire, unintended activation, data alteration, interference with communications, and evidential contamination. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The source frequency and field shall comply with the actual jurisdiction and site rules. The team records field strength or EIRP, antenna, duty cycle, dwell, distance, polarisation and uncertainty. The source is physically terminated during sham and passive controls. A signal that persists when the source is removed, or that tracks receiver gain rather than incident field, is not treated as an illumination response.

16A.25 Instrument and probe coverage matrix

Probe-engineering analysis. The technically mature interpretation of Instrument and probe coverage matrix treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Domain	Principal sensors	Target families and controls
30 Hz to 300 Hz	Long high-permeability bar, fluxgate comparator, differential coil, current clamp	Mains, low-rate bus current, microphone wiring, mechanical and geomagnetic controls
300 Hz to 14 kHz	Voice-frequency alloy bar, gradiometer, shielded low-noise preamplifier	POTS/audio wiring, HART, codec and microphone-current signatures
14 kHz to 100 kHz	MnZn ferrite rod, nanocrystalline bar/ring, air-core loop	Video sync, 32.768 kHz, LF RFID, switching regulators and ultrasonic control
100 kHz to 1 MHz	Qualified ferrite rod, air-core loop, capacitive probe, conducted coupler	PLC, ceramic resonators, low-rate clocks and bus harmonics
1 MHz to 30 MHz	Small loop, electric-field probe, current clamp, HF receiver	Crystals, modems, DSL/PLC, video colour references and digital buses
30 MHz to 300 MHz	Biconical, log-periodic, shielded loop and electric probe	VHF radio, clock harmonics, legacy wireless and cable radiation
300 MHz to 1 GHz	Log-periodic, Yagi, compact loop and independent receiver	SAW oscillators, UHF telemetry, 802.15.4, RFID and cellular low bands
1 GHz to 7.125 GHz	Log-periodic, double-ridged horn, patch array and low-noise downconverter	Wi-Fi, Bluetooth, cellular FR1, GNSS leakage, ports and microwave video
7.125 GHz to 26.5 GHz	Calibrated horn, waveguide preselection and low-loss feed	High harmonics, point-to-point, satellite and some FR2 allocations
26.5 GHz to 95 GHz and above	Band-specific horns, extenders and millimetre-wave receivers	802.11ad/ay, 5G FR2, radar and proprietary links

Domain	Principal sensors	Target families and controls
Optical / infrared	Photodiode, optical power meter, spectrometer and camera-free detector	IrDA, LiFi, remote control and modulated illumination without imaging
Nonlinear junction	Calibrated NLJD with f0, 2f0 and 3f0 receivers	Dormant junctions and PIM candidates under active-test authority

16A.26 Receiver architecture and clock integrity

At least one stationary reference channel remains outside the immediate search path. Mobile receivers use independent low-noise front ends, preselection, calibrated attenuation and reference clocks traceable to the case timebase.

Local oscillators, sample clocks, displays, data links, network adapters, switch-mode supplies and operator electronics are inventoried because they can produce the very families being sought.

Multichannel receiver analysis. The advanced technical treatment of Receiver architecture and clock integrity regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay.

A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot. A modern instrument chassis is usually capable of multiple 12 channel cards [7-16].

For high-dynamic-range environments, the team performs gain-step, attenuation-step, preselector, antenna-disconnect, terminated-input and independent-architecture controls. A candidate that changes frequency with sample rate, disappears under a different intermediate-frequency plan, or grows disproportionately with front-end gain is treated as an instrument artefact until disproved.

16A.27 Cube-by-cube standards-behaviour record

Each room cube records frequency and uncertainty, occupied bandwidth, modulation-neutral descriptors, probe, orientation, coordinate, reference-clock status, state of every cable and port, device power state, environmental change, reference-channel behaviour, reverse-path result and classification. A cube is not described merely as positive or negative. It contains the complete measurement state needed to reproduce the observation.

Standards and interface interpretation. The mature treatment of Cube-by-cube standards-behaviour record distinguishes normative air-interface or cable specifications from implementation leakage, board-level clocks, power-management activity, spread-spectrum clocking, and enclosure coupling. External ports and internal buses can produce fundamentals, harmonics, common-mode currents, connector radiation, spread-spectrum skirts, burst cadences, and low-frequency power-state signatures even when payload communication is absent. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

Table 16A-20. Minimum cube record for communications and interface phenomena

Field	Required entry
Spatial identity	Room, cube x/y/z, surface cell if applicable, hard-point datum, coordinate uncertainty and probe phase centre

Field	Required entry
Signal identity	Frequency, uncertainty, bandwidth, time, periodicity, modulation-neutral descriptors and file hash
Instrument state	Receiver, front end, preselector, gain, attenuation, RBW/VBW or sample rate, detector and clock reference
Probe geometry	Probe/antenna type, axis, polarisation, azimuth, elevation, standoff, cable route and operator position
Interface state	Port/cable type, connector state, power role, alternate mode, link state, display state and network state
Power state	Active, idle, suspend, deep sleep, soft off, mechanical off or unknown, with intervention time
Controls	Terminated input, dummy probe, reference station, gain step, reverse path, independent receiver and external-source comparison
Interpretation	Measured fact, candidate standards family, disconfirming observations, uncertainty and evidential class

16A.28 Advancement gates and stop conditions

Advanced practitioner analysis. At expert-practitioner level, Advancement gates and stop conditions is treated as a defined measurement proposition rather than a descriptive heading.

The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table 16A-28. Advancement gates for standards and interface examinations

Decision point	Advance only when	Stop, hold or return when
Outer ring to inner ring	Reference stable, candidate recurrent and spatial question stated	Time variation, operator carriage or external infrastructure explains the change
Broadband to narrowband	Centre and drift envelope measured without overload	Narrow filter produces ringing, false line or loss of intermittent events
Far field to near field	Probe overlap confirms same candidate family	New probe responds to a different line or is loaded by nearby metal
Passive to controlled state change	Passive record sealed and intervention authorised	State change would alter evidence or safety cannot be controlled
Passive to NLJD	Legal, spectrum, exposure, medical and evidence gates signed	Implant, explosive, battery, aircraft, medical or unknown risk remains unresolved
Candidate to device-associated	Spatial localisation, repeatability, controls and independent evidence converge	Only frequency or illumination correlation exists

16A.29 Evidential classifications for digital and analogue communications

The existing EERF evidential ladder remains controlling. For this chapter, the examiner may add the descriptors measured timing line; measured cable-mode emission; measured wireless PHY candidate; standards-consistent burst family;

state-correlated interface response; spatially localised interface candidate; nonlinear-junction-like response; and confirmed device-associated response. Each descriptor states what was measured and what remains unknown.

Standards and interface interpretation. The mature treatment of Evidential classifications for digital and analogue communications distinguishes normative air-interface or cable specifications from implementation leakage, board-level clocks, power-management activity, spread-spectrum clocking, and enclosure coupling. The examiner records the edition and jurisdictional status of any cited standard, while treating manufacturer configuration, regional band plan, optional features, and power-saving modes as variables that require case-specific verification.

The report names a standards family only at the level supported by the physical observables and states when multiple implementations remain plausible [81-120].

The phrase all communications methods searched is prohibited unless the report identifies validated frequency and optical ranges, conducted paths, ports, Standards Coverage Register revision, dwell, probability-of-intercept limitations, inaccessible areas and active-test exclusions.

A defensible conclusion is bounded. It may state that no qualifying phenomenon was detected under documented conditions. It may not claim that no electronic device exists.

16A.30 Privacy, content, legal and clinical boundaries

The chapter is designed for field recognition and localisation, not interception. Payloads, conversations, images, credentials, identifiers and encrypted content are not collected beyond what is strictly necessary and lawfully authorised to classify the physical layer. MAC addresses, subscriber identifiers, device names and network names are personal or operational data and are minimised. Randomised addresses and encrypted management frames also make identity inference unreliable.

Legal, clinical, and ethical elaboration. At expert-practitioner level, Privacy, content, legal and clinical boundaries is an engineering control boundary rather than a ceremonial disclaimer. Authority, privacy, spectrum use, exposure, medical-device compatibility, occupational safety, data handling, and property access must be resolved before the corresponding action occurs. Clinical or medical questions remain institutionally separate from electromagnetic measurement; a field observation does not establish diagnosis, injury, exposure significance, or causation. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

Active association, pairing, authentication, enumeration, packet injection, rogue access-point operation, cellular impersonation, SIM interrogation, USB enumeration, HDMI or DisplayPort querying and protocol fuzzing are outside the passive protocol. They require separate legal and technical authority, change control and evidence-preservation assessment. Nothing in this chapter establishes medical causation. Clinical interpretation remains independent of the electromagnetic survey.

16A.31 Worked timing, spectral and uncertainty examples

Metrological interpretation. At expert-practitioner level, Worked timing, spectral and uncertainty examples begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

Example 16A-1. Wi-Fi legacy OFDM timing. Let B = 20 MHz be channel bandwidth and N = 64 be transform length. The nominal subcarrier spacing is Delta f = B/N = 20,000,000/64 = 312,500 Hz. The useful symbol time is T_u = 1/Delta f = 3.2 microseconds. Adding the ordinary 0.8 microsecond guard interval gives 4.0 microseconds. A 20 MHz envelope alone is not sufficient. The subcarrier spacing, packet timing and spatial gradient must agree.

Example 16A-2. Wi-Fi high-efficiency timing. For a 20 MHz 802.11ax waveform with, Delta. The useful symbol time is 12.8 microseconds. Depending on the guard interval, the total symbol time is longer. A receiver resolution bandwidth wider than 78.125 kHz may show the envelope but cannot resolve individual subcarriers.

Example 16A-3. Bluetooth classic hopping interval. Bluetooth basic-rate time slots are 625 microseconds. The reciprocal is 1/625. A hopping family near this rate supports a Bluetooth hypothesis only when one-MHz classic channels, packet duration and access behaviour are also present.

Example 16A-4. GSM frame-envelope family. A GSM TDMA frame is approximately 4.615 ms. The reciprocal is approximately 216.7 Hz. A line or envelope near 216.7 Hz can arise from other periodic systems, so the examiner also requires 200 kHz carrier structure, slot timing, multiframe recurrence and a spatial association.

Example 16A-5. 5G NR numerology. NR subcarrier spacing is Delta. For, Delta the nominal slot duration is 1/2^mu with normal cyclic prefix. Four slots therefore occur in one millisecond. Bandwidth-part gating and discontinuous reception can make the endpoint far less visible than the serving cell.

Example 16A-6. USB 2.0 microframe cadence. High-speed USB divides a 1 ms frame into eight microframes. A 8 kHz scheduling envelope may appear around controller, cable or power-converter emissions, but it is neither necessary nor sufficient for a USB finding.

Example 16A-7. UART baud generator. Let. A conventional 16-times oversampling UART generating 9,600 bit/s uses divisor is a useful search key rather than a unique identifier.

Example 16A-8. HDMI TMDS lane rate. For a legacy pixel clock, the nominal TMDS serial rate per data lane is 10. The examiner may observe the forwarded clock, lane-rate spectral energy, common-mode cable current, DDC or CEC. Deep colour, chroma subsampling and FRL alter the relation.

Example 16A-9. PCIe spread-spectrum reference. A nominal 100 MHz PCIe reference with 0.5 percent downspread extends from 99.5 MHz to 100.0 MHz. Its fifth harmonic spans approximately 497.5 MHz to 500.0 MHz before jitter and filtering. Independent-clock architectures and L1 substates can gate or remove the line.

Example 16A-10. Coherent integration gain. For, ideal amplitude signal-to-noise improvement is 10. Real improvement is lower when timing jitter, drift, phase noise, movement and non-stationary background reduce coherence. The method shall validate the actual gain with a traceable source.

Example 16A-11. Duty-cycle observation. Suppose a sleeping cellular endpoint is observable for 160 ms in an eDRX cycle of 20.48 s. The duty factor is 0.160/20.48 = 0.0078125, or 0.78125 percent. A ten-second sweep can contain no event. The observation interval must cover several plausible cycles plus timing margin.

Example 16A-12. NLJD harmonic channels. For an authorised fundamental, and. The source own harmonics must first be measured into a certified load. A tone at either harmonic is not probative until direct leakage, images, external transmitters and passive intermodulation are excluded.

Example 16A-13. Near-field wavelength context. At, wavelength, where. Lambda is approximately 22.11 m. The conventional reactive near-field boundary for a small antenna is on the order of lambda/(2 pi), approximately 3.52 m. Actual coupling depends on loop geometry, shielding and conductive structures.

Example 16A-14. Three-inch gradient. A coherent line rises from -111 dB to -105 dB over one three-inch step. The measured gradient is 6 dB/3. The examiner repeats the path in reverse and in orthogonal probe orientations, then reports coordinate and amplitude uncertainty.

Example 16A-15. Combined frequency uncertainty. If receiver calibration contributes 0.5 Hz standard uncertainty, reference-clock transfer contributes 0.3 Hz and estimator repeatability contributes 0.8 Hz, the uncorrelated combined standard uncertainty is. With coverage factor is approximately 2.0 Hz.

Bluetooth basic-rate time slots are 625 microseconds. The reciprocal is 1/625 microseconds=1, 600slotspersecond. A hopping family near this rate supports a Bluetooth hypothesis only when one-MHz classic channels, packet duration and access behaviour are also present.

A GSM TDMA frame is approximately 4. 615 ms. The reciprocal is approximately 216. 7 Hz. A line or envelope near 216. 7 Hz can arise from other periodic systems, so the examiner also requires 200 kHz carrier structure, slot timing, multiframe recurrence and a spatial association.

For a legacy pixel clock fp=148. 5MHz, the nominal TMDS serial rate per data lane is 10 fp=1. 485Gb/s. The examiner may observe the forwarded clock, lane-rate spectral energy, common-mode cable current, DDC or CEC. Deep colour, chroma subsampling and FRL alter the relation.

A nominal 100 MHz PCIe reference with 0. 5 percent downspread extends from 99. 5 MHz to 100. 0 MHz. Its fifth harmonic spans approximately 497. 5 MHz to 500. 0

MHz before jitter and filtering. Independent-clock architectures and L1 substates can gate or remove the line.

Suppose a sleeping cellular endpoint is observable for 160 ms in an eDRX cycle of 20. 48 s. The duty factor is 0. 160/20. 48 = 0. 0078125, or 0. 78125 percent. A ten-second sweep can contain no event. The observation interval must cover several plausible cycles plus timing margin.

A coherent line rises from -111 dB to -105 dB over one three-inch step. The measured gradient is 6 dB/3 in=2dBperinchalongthatvector.

The examiner repeats the path in reverse and in orthogonal probe orientations, then reports coordinate and amplitude uncertainty.

If receiver calibration contributes 0. 5 Hz standard uncertainty, reference-clock transfer contributes 0. 3 Hz and estimator repeatability contributes 0. 8 Hz, the uncorrelated combined standard uncertainty is 0. 52+0. 32+0. 82=0. 99Hz. With coverage factor k=2, expandeduncertainty is approximately 2. 0 Hz.

16A.32 Required records and forms

Table 16A-22. Additional controlled records

Forensic interpretation. A mature forensic approach to Required records and forms separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Contemporaneous written notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel.

The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions [1-9].

Record	Mandatory fields
16A-F1 Standards Currency Record	Case date; jurisdiction; register revision; official sources; cut-off dates; examiner; reviewer; exceptions
16A-F2 Wireless PHY Observation	Band; centre; bandwidth; timing; modulation-neutral features; antenna; bearing; infrastructure comparison; classification
16A-F3 Dormant-State Record	Declared and measured state; cables; mains/battery; start time; stabilisation; surviving clocks; event intervals; controls
16A-F4 Port and Cable Record	Connector; cable; shield; route; link state; power role; alternate mode; clock family; common-mode field; endpoints
16A-F5 Cellular RAT Record	Generation/RAT candidate; duplex; band; numerology; frame evidence; base-station reference; local gradient; privacy limits
16A-F6 Unknown Waveform Record	Raw I/Q identifier; frequency; bandwidth; pulse/hop features; spatial result; alternative hypotheses; disconfirming tests
16A-F7 NLJD Response Record	Fundamental; source calibration; 2f0; 3f0; noise; geometry; power-response points; PIM controls; cube; confirmation
16A-F8 Standards Exception Record	Uncovered band or interface; reason; substitute method; risk; commissioning-authority decision; report limitation

16A.33 Validation, proficiency and maintenance programme

The laboratory validates representative devices for each major waveform and interface family across active, idle, sleep and off states. Validation includes shielded and unshielded devices, battery and mains power, different cable lengths, retimers, active cables, spread-spectrum clocks, frequency hopping, low-duty traffic, beamforming and encrypted payloads. The result is a probability-of-detection model, not a promise that every implementation will be found at every distance.

Traceability and uncertainty analysis. At expert-practitioner level, Validation, proficiency and maintenance programme begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

False-positive trials include broadcast infrastructure, building Wi-Fi, cellular base stations, laptops, test equipment, chargers, switching supplies, LED lighting, corroded metal, industrial networks, medical devices, vehicles and neighbouring premises. A method is released for casework only after blind trials, repeatability, reproducibility, uncertainty, competence and independent review requirements are met. The Standards Coverage Register is reviewed at least quarterly and before every case.

16A.34 Chapter conclusion

The revised EERF protocol searches modern and historical communications through one common physical method. It begins 300 feet away, maps ambient infrastructure, progresses through controlled rings, isolates cable and interface paths, observes sleepers for adequate time, resolves three-dimensional gradients and uses active nonlinear-junction illumination only under a separate authority gate. Standards guide the search, but they never replace measurement, controls, uncertainty or restrained reporting.

Advanced technical elaboration. At expert-practitioner level, this chapter conclusion is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Chapter Glossary

Terms used in Chapter 23.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

F

FUNDAMENTAL FREQUENCY — The basic frequency or first harmonic frequency.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

N

NLJD — Nonlinear junction detector: an instrument that illuminates a search area with radio-frequency energy and observes harmonic or intermodulation responses associated with nonlinear junctions.

O

OSCILLATOR — An oscillator is a nonrotating device that produces alternating current. The frequency is determined by the characteristics of the device.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

R

RADAR — Radio detection and ranging: the use of transmitted electromagnetic energy and received echoes or scattered signals to detect, locate, characterize, or track objects and phenomena.

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

17. Localisation Without Physical Imaging

17.1 Low-frequency localisation

At very low frequencies, geometric direction finding based upon far-field assumptions is usually inappropriate indoors. Localisation instead uses magnetic-loop nulls, orthogonal-axis ratios, amplitude gradients, differential probes, controlled standoff and repeated measurements from several sides and heights. The examiner should expect conductive structures, wiring, ferromagnetic materials and return currents to distort the field. A sharp local maximum may identify a current path rather than the originating circuit.

Spatial-measurement interpretation. The mature treatment of Low-frequency localisation replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

17.2 Higher-frequency localisation

At VHF, UHF and microwave frequencies, directional antennas and phase comparison may provide bearings, but reflections can create false maxima and nulls. Bearings shall be repeated with changed antenna position, polarisation and height. Where the signal bandwidth and clock coherence support time-difference methods, the validation shall show performance in representative indoor multipath. No algorithm may claim centimetre accuracy merely because it prints a precise coordinate.

Scene-geometry elaboration. The mature treatment of Higher-frequency localisation replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

17.3 Final localisation statement

The report shall state the supported spatial resolution and uncertainty. Suitable forms include a coordinate interval, cell cluster, distance range from a reference plane or bounded volume. Unsuitable wording includes located the device inside the wall unless the physical object is independently identified by an authorised method. The EERF conclusion remains an association between measured field behaviour and a region.

Three-dimensional search analysis. The mature treatment of Final localisation statement replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

17.4 Coordinate-only localisation products

The final product shall locate measured phenomena by coordinates, orientation, standoff and uncertainty without depicting a hidden object. The governing physical or metrological basis is numerical spatial sampling defines a bounded region through measured gradients and directional information. The examiner shall treat this basis as a testable model rather than an assumption. The region is not the object outline and can include a conductor or coupling path. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Sensor and front-end elaboration. For Coordinate-only localisation products, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

The required configuration is as follows. A declared datum, x, y, z coordinates, probe-centre convention and uncertainty are used throughout. The primary observables are station values, nulls, gradients, phase and component overlap. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are coordinate check, reverse traversal, aperture correction and independent review. The principal artefacts and confounders are using tripod rather than probe coordinates, rounding, inaccessible depth and misleading interpolation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the smallest reported region shall still contain the validated coverage uncertainty. The principal limitation is depth behind a one-sided surface can remain broad. The record shall contain bounds by axis, datum, coverage, unmeasured space and model. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

17.5 Language when the physical device remains unknown

Reports shall use neutral terms such as source-associated region, field maximum region or bounded candidate volume until independent identification occurs. The governing physical or metrological basis is electromagnetic association is weaker than physical identification and can be displaced by coupling paths. The examiner shall treat this basis as a testable model rather than an assumption. Co-location with a known object does not prove that the object generated the signal. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Oscillator-family analysis. A technically mature analysis of Language when the physical device remains unknown distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. The report avoids claiming a specific oscillator merely from frequency coincidence, especially where common industry clocks or power harmonics are abundant [24-26, 81-123].

The required configuration is as follows. Known-device state tests are separated from passive localisation and documented as association tests. The primary observables are follow-the-state response, spatial overlap, frequency family and independent sensor confirmation. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are restoration, adjacent-object comparison and source-absent state. The principal artefacts and confounders are crowded equipment racks, shared wiring, shielding seams and client expectation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is source-class or device association is stated only at the level supported by independent evidence. The principal limitation is the physical object may remain inaccessible or unidentified. The record shall contain exact wording, tested association, alternatives and limits. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

17.6 Resolution floor and termination criteria

The search shall stop when further nominal movement would exceed validated spatial capability or risk disturbance. The governing physical or metrological basis is probe aperture, coordinate error, standoff and field distortion set a practical resolution independent of grid spacing. The examiner shall treat this basis as a testable model rather than an assumption. A three-inch step does not guarantee three-inch accuracy. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced practitioner analysis. For expert practice, Resolution floor and termination criteria is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The required configuration is as follows. Resolution is established in blind trials for each final probe and source class. The primary observables are coverage interval, repeat variation, aperture response and model residual. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are known-source checks, reverse local scan and uncertainty recalculation. The principal artefacts and confounders are false precision, overfitting and one-point maxima. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is terminate at the smallest defensible region, safe standoff or inaccessible boundary. The principal limitation is one or more axes can remain unresolved. The record shall contain stop reason, final bounds, resolution floor and residual hypotheses. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 24: Localisation Without Physical Imaging.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

D

DIRECTION FINDING — The estimation of the direction of arrival of a signal from measured amplitude, phase, time, polarization, pattern, or spatial-correlation differences.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

I

INDUCED VOLTAGE — See INDUCED ELECTROMOTIVE FORCE.

S

SUSCEPTIBILITY — The degree to which equipment or a system is adversely affected by electromagnetic, electrical, acoustic, optical, mechanical, or environmental exposure.

18. Data Integrity, Chain of Custody and Privacy

Although the inspection may be civil, medical or research-oriented, the data shall be managed with forensic discipline. Every file receives a unique identifier, source instrument, operator, start and stop time, coordinate, settings, software version and relationship to the master case identifier. Raw files are preserved read-only. Processing creates derivative files linked to the raw parent, with the script, version, parameters and analyst recorded.

Data control	**Minimum requirement**
Time	UTC timestamp plus local time zone, reference source, synchronisation status and estimated time uncertainty.
Identity	Case ID, acquisition ID, instrument serial number, sensor serial number, operator and coordinate.
Settings	Frequency span, centre frequency, sample rate, RBW, VBW, detector, attenuation, preamplifier, preselector, dwell and trigger.
Integrity	SHA-256 or approved successor hash at acquisition closure, transfer and archive verification.
Raw and derivative separation	Raw data remain unchanged. Every filtered, averaged, resampled or graphed output has a documented lineage.
Access	Role-based access, encrypted storage and logged export. Clinical and technical data are segregated unless a lawful protocol joins them.
Incidental content	Minimise capture, restrict access, avoid demodulation and apply approved review and deletion procedures.
Retention	Follow contract, law, accreditation and research obligations. A destruction hold applies when findings are disputed or under review.
Review	Independent reviewer can reproduce material calculations and trace each reported result to raw data and calibration records.

18.1 Algorithm and software control

Digital filters, peak finders, event detectors, classifiers and localisation routines are part of the measurement method. Source code or a controlled executable shall be versioned. Test vectors shall verify numerical correctness. Training data, if machine learning is used, shall be representative and separated from validation data. A human-readable explanation and independent technical review remain necessary. An opaque label such as hidden transmitter detected is not an acceptable analytical result.

System-level interpretation. A technically mature treatment of Algorithm and software control begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

18.2 Raw waveform preservation and immutable acquisition

Raw time-domain or receiver-native data shall be retained so that spectra and candidate decisions can be independently reproduced. The governing physical or metrological basis is derived displays can conceal windowing, averaging, clipping, decimation and software choices. The examiner shall treat this basis as a testable model rather than an assumption. A screenshot is not a substitute for raw data and metadata. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Waveform and modulation elaboration. For raw waveform preservation and immutable acquisition, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

The required configuration is as follows. Files are written to controlled media, assigned unique identifiers and hashed at acquisition closure. The primary observables are file size, format, sample count, timestamps, dropped samples, overload flags and hash. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are copy verification, independent parser, known test file and read-only archive. The principal artefacts and confounders are silent format conversion, metadata loss, clock discontinuity and software overwrite. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is a material conclusion is not released when its raw source data cannot be verified. The principal limitation is proprietary formats can restrict independent review unless export and validation are planned. The record shall contain file manifest, hashes, software, storage, copies and chain of custody. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

18.3 Coordinate, instrument-state and premises-state synchronization

Every acquisition shall link measured data to its actual spatial and operational state. The governing physical or metrological basis is location and time comparisons fail when coordinates, probe settings or premises changes are misaligned. The examiner shall treat this basis as a testable model rather than an assumption. Nominal stage labels do not replace actual coordinates and timestamps. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Synchronous measurement elaboration. In Coordinate, instrument-state and premises-state synchronisation, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

The required configuration is as follows. A common UTC time base, acquisition IDs, station IDs and state-change events are synchronised. The primary observables are start and stop time, coordinate, axis, gain, tuning, filter, temperature, persons present and known equipment state. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are log reconciliation, timestamp check, duplicate station labels and reviewer spot checks. The principal artefacts and confounders are clock drift, manual transcription, reused filenames and delayed state-change logging. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is unreconciled data are excluded from precise spatial inference or explicitly qualified. The principal limitation is historical building-state information can be incomplete. The record shall contain linked identifiers, time uncertainty, corrections and unresolved discrepancies. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

18.4 Software, algorithm and version control

Analysis software shall be validated and version-controlled for the calculations used in material conclusions. The governing physical or metrological basis is FFT, filtering, frequency estimation, normalisation, re-centring and uncertainty algorithms can change results. The examiner shall treat this basis as a testable model rather than an assumption. A visually plausible plot does not establish numerical correctness. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

The required configuration is as follows. Source code or controlled executable, parameter files, test vectors and environment are archived. The primary observables are numerical output, tolerance, processing log and reproducibility on independent systems. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are synthetic signals, known files, independent implementation and regression tests. The principal artefacts and confounders are version drift, hidden defaults, floating-point error, time-zone conversion and spreadsheet formula mistakes. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is only validated versions and recorded parameters are used for released results. The principal limitation is proprietary systems may limit transparency and must be compensated by validation evidence. The record shall contain version, hash, parameters, test results and analyst. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 25: Data Integrity, Chain of Custody and Privacy.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

CHAIN OF CUSTODY — The documented history of possession, handling, transfer, storage, examination, and disposition of an item of evidence.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HASH — A fixed-length value produced by a deterministic function and used to detect whether digital content has changed.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

VERIFICATION — The confirmation, through examination or objective evidence, that specified requirements have been fulfilled.

19. Interpretation, Classification and Reporting Language

Interpretation follows the separation between observation, inference and opinion used in modern forensic practice. The observation is what the instrument recorded. The inference connects the observation to a physical explanation. The opinion states how strongly the data support a proposition, considering alternatives and method limitations. ISO 21043 Parts 3, 4 and 5 provide the current general architecture for analysis, interpretation and reporting [3-5].

Class	Meaning	Permitted report statement
0. No reportable signal	No feature survived the validated selection and confirmation criteria in the examined bands and states.	No reportable signal was observed above the stated method capability. This does not establish absence of a dormant, intermittent, shielded or out-of-band source.
1. Observed signal	A measured feature is recorded with coordinate, instrument state and uncertainty, but source association is not established.	An electronic signal was observed under the stated conditions. Its source and significance remain unresolved.
2. Candidate device-correlated signal	The feature is reproducible and displays timing, spatial or source-class behaviour consistent with the authorised proposition.	The signal is a candidate for device correlation, subject to the stated alternatives and outstanding controls.
3. Illumination-correlated response	The feature follows authorised illumination states and survives source-off, sham and basic receiver controls.	A reproducible response correlated with the stated illumination was measured. Correlation does not yet establish the response mechanism or device association.

Class	Meaning	Permitted report statement
4. Reproducible frequency-translated response	A distinct response frequency follows the predeclared relation and survives offset-frequency, intermodulation, receiver-image and independent-receiver controls.	A reproducible frequency-translated response was measured under the stated conditions and uncertainties.
5. Spatially localised response	The confirmed response exhibits a repeatable gradient, null, bearing or three-dimensional coordinate bound.	The response was localised to the stated region and uncertainty under the tested conditions.
6. Confirmed device-associated response	All prior requirements plus independent receiving architecture, spatial localisation, negative controls, illumination-path controls and a complete uncertainty statement.	The data support association of the measured response with an electronic device or structure within the stated region and tested conditions. Identity, purpose, ownership, legality and medical effect are not established by this class alone.

19.1 Mandatory limitations paragraph

Advanced technical elaboration. For expert practice, Mandatory limitations paragraph is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

MODEL LIMITATION
The examination measured electromagnetic phenomena only. It did not form a physical image, touch or open a candidate object, determine ownership or intent, establish illegality, diagnose a medical condition or determine whether any measured field caused a symptom. Frequencies described as consistent with a circuit class are not unique identifiers.

19.2 Example of defensible wording

A narrowband magnetic-field component centred at 32,767.9 Hz was observed on two passes, with a stated expanded frequency uncertainty of 1.2 Hz and a reproducible maximum within grid cells F4-H6. The feature was absent on the terminated-input and dummy-probe controls and was independently observed with a second receiver. The frequency and stability are consistent with a nominal 32.768 kHz timing oscillator. They are not specific to a particular device, and no opinion is offered on medical effect.

Advanced technical elaboration. For expert practice, Example of defensible wording is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

19.3 Proposition hierarchy and calibrated language

Interpretation shall progress from observation to confirmation, localisation and source association without skipping levels. The governing physical or metrological basis is each stronger proposition requires additional independent evidence and narrower alternatives. The examiner shall treat this basis as a testable model rather than an assumption. A detected line is not a device, and a localised field is not a medical cause. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

The required configuration is as follows. The classification scale and permitted wording are applied consistently. The primary observables are controls passed, spatial evidence, source-state association and uncertainty. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are technical review, alternative-hypothesis checklist and comparison with model wording. The principal artefacts and confounders are dramatic labels, nominal-frequency naming, client expectation and omission of negative evidence. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is the report uses the least strong statement that fully reflects the evidence. The principal limitation is some findings remain unresolved despite extensive measurement. The record shall contain classification, rationale, limitations and rejected stronger wording. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

19.4 Negative findings and capability statements

A negative result shall describe what was not observed under defined conditions, rather than assert universal absence. The governing physical or metrological basis is detection depends on source state, coupling, frequency, shielding, dwell, field strength and method sensitivity. The examiner shall treat this basis as a testable model rather than an assumption. Dormant passive structures and intermittent devices can produce no observable signal during the examination. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Advanced practitioner analysis. A technically mature treatment of Negative findings and capability statements begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The required configuration is as follows. The report lists bands, states, locations, detection limits and unexamined conditions. The primary observables are noise floor, blanks, coverage, dwell and validated detection performance. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are positive control or transfer check, data-completeness review and method-capability citation. The principal artefacts and confounders are equating no candidate with no device and omitting inaccessible volumes. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is negative wording remains bounded to the examined states and method capability. The principal limitation is absence of evidence is not evidence of universal absence. The record shall contain coverage, sensitivity, exclusions and exact negative statement. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

19.5 Medical boundary and causation disclaimer

The report shall separate measured electromagnetic phenomena from any assertion about symptoms, diagnosis or injury. The governing physical or metrological basis is physical measurement and clinical causation require different study designs, evidence and professional competence. The examiner shall treat this basis as a testable model rather than an assumption. Temporal or spatial coincidence does not establish biological mechanism or causation. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Legal, clinical, and ethical elaboration. The mature treatment of Medical boundary and causation disclaimer recognises that technical capability does not itself create legal authority, clinical justification, or acceptable risk. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. A limitation imposed by law, safety, privacy, or clinical necessity is reported openly and is never relabelled as a completed measurement [1-9, 17-23].

The required configuration is as follows. Technical findings are issued independently from clinical records unless authorised integration is required. The primary observables are field quantities and technical uncertainty only. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are medical review, ethics governance for research and avoidance of symptom-led field steering. The principal artefacts and confounders are confirmation bias, nocebo effects, selective timing and causal overstatement. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is EERF conclusions end with the measured field and source-associated region. The principal limitation is clinical meaning remains outside the technical report. The record shall contain scope, disclaimer and any separate clinical process.

The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 26: Interpretation, Classification and Reporting Language.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COUPLING PATH — The physical route by which energy transfers from a source to a victim, structure, conductor, sensor, or observer.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

20. Validation, Quality Assurance and Research Programme

The credibility of EERF will depend less upon the novelty of its sensors than upon rigorous validation. NISTIR 8589, published in December 2025, identifies guiding principles for the collection and use of validation data in forensic science and expressly builds upon ISO/IEC 17025 [8]. The EERF programme should adopt that evidence-based approach, publish performance data where lawful and distinguish developmental sensitivity from validated casework capability.

20.1 Validation stages

Measurement-science elaboration. The mature treatment of Validation stages distinguishes calibration, verification, adjustment, characterisation, and validation. These activities are related, but they are not interchangeable and they do not support the same evidential claim. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

Stage	Test environment	Required evidence
I. Component characterisation	Bench, screened enclosure and calibrated sources.	Sensor transfer function, noise, linearity, dynamic range, filter response, phase noise, self-emissions and temperature behaviour.
II. Controlled-source detection	Anechoic, semi-anechoic or shielded setting with known low-power sources.	Probability of detection versus level, distance, orientation, shielding, duty cycle, bandwidth and dwell.

Stage	Test environment	Required evidence
III. Blind mixed-source trials	Known sources, sham objects and confounders placed by an independent controller.	False-alarm rate, missed-detection rate, source-class discrimination and operator bias assessment.
IV. Representative buildings	Homes, offices, hospitals and industrial spaces with normal electronic clutter.	Robustness to multipath, mains noise, HVAC cycles, neighbouring sources, movement and realistic access limitations.
V. Inter-operator and inter-laboratory	Different teams, instruments and locations.	Repeatability, reproducibility, agreement, proficiency-testing design and transferability of thresholds.
VI. Operational pilot	Restricted real commissions with independent review and conservative reporting.	Nonconformities, decision utility, privacy performance, safety events, client comprehension and revision needs.

20.2 Performance measures

- Probability of detection as a function of calibrated field, source orientation, dwell and environmental clutter.

Reporting and custody perspective. A mature forensic approach to performance measures separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

- False-alarm rate per band, grid cell, hour and inspection, with confidence intervals.

- Minimum detectable field or received power under specified sensor, bandwidth and dwell conditions.
- Localisation error distribution and coverage probability for the reported bounding region.
- Frequency, amplitude, phase and timing accuracy, plus expanded measurement uncertainty.
- Repeatability within operator, reproducibility between operators, and inter-instrument agreement.
- Robustness to overload, intermodulation, aliasing, spread-spectrum clocks, intermittent transmissions and cable motion.
- Specificity of source-class associations and performance against confounder libraries.

20.3 Novel research agenda

The new discipline should sponsor research into ultra-low-noise magnetic and electric-field transducers, self-calibrating tri-axial probes, optically isolated preamplifiers, cryogenic or chopper-stabilised front ends where justified, high-selectivity analogue and digital filters, coherent sensor pairs, ambient-backscatter detection, low-phase-noise reference distribution, sensor self-emission cancellation and benchmark datasets containing true sources and realistic confounders. Novel sensitivity is useful only when accompanied by linearity, uncertainty, artefact rejection and independent replication.

Advanced technical elaboration. At expert-practitioner level, Novel research agenda is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

20.4 Validation of the nested-ring geometry

The 300-foot to three-inch sequence, including the 150-foot, 30-foot and 15-foot rings, shall be evaluated in blind trials with internal, external, extended and absent sources. The governing physical or metrological basis is that controlled placement permits measurement of detection, source discrimination, localisation coverage and false-region rate at each advancement gate. Trials shall include complete and partial rings, sources coupled to services, intermittent sources and empty scenes. Ablation trials shall omit one ring at a time so the contribution of the 150-foot, 30-foot and 15-foot stages can be quantified rather than presumed. Success with one strong laboratory source does not validate ordinary premises.

Metrological interpretation. At expert-practitioner level, Validation of the nested-ring geometry begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

The required configuration is as follows. Trials vary source level, frequency, orientation, duty cycle, shielding, building type and access limitation. The primary observables are probability of detection, false alarm, correct external classification, bounding-volume coverage, size and time. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are sham trials, no-source trials, independent placement and concealed prevalence. The principal artefacts and confounders are examiner cueing, fixed source positions, development-test leakage and selective reporting. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is claims are limited to conditions where predeclared performance is demonstrated. The principal limitation is rare real environments can fall outside validation. The record shall contain protocol, placements, raw data, outcomes, intervals and failures. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

20.5 Probe and resonant-network validation

Each released probe configuration shall undergo electrical, magnetic, mechanical and environmental validation. The governing physical or metrological basis is the complete assembly, not an isolated component, determines sensitivity, pattern, noise and stability. The examiner shall treat this basis as a testable model rather than an assumption. A recalculated resonance or manufacturer core value is not a calibration. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Measurement-science elaboration. An advanced metrological approach to probe and resonant-network validation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

The required configuration is as follows. Impedance, transfer factor, Q, pattern, noise, overload, temperature, vibration and repeat assembly are tested. The primary observables are performance distributions and configuration-to-configuration variation. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are known field, independent instrument, alternate operator and blind tuning repeat. The principal artefacts and confounders are prototype selection bias, unrecorded adjustment, fixture coupling and damaged core. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is acceptance intervals and permitted role are defined from the measured distribution. The principal limitation is component substitution can require revalidation. The record shall contain design revision, methods, results, uncertainty and release decision. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

20.6 Detection limit and false-alarm performance

Sensitivity shall be expressed through detection probability and false-alarm performance in representative interference. The governing physical or metrological basis is statistical overlap of source-present and source-absent measurements determines reliable decision thresholds. The examiner shall treat this basis as a testable model rather than an assumption. Thermal noise alone rarely represents the environmental floor in occupied premises. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise. Typically, each channel of the analyzer will have a DANL of -170 dBm or better, usually significantly better.

Reporting and custody perspective. A mature forensic approach to Detection limit and false-alarm performance separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

The required configuration is as follows. Randomised source levels, blanks, confounders, duty cycles and frequency offsets are tested. The primary observables are receiver operating characteristic, detection probability, false-alarm probability and uncertainty. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are sequestered test set, predeclared threshold and independent analysis. The principal artefacts and confounders are optimistic threshold selection, repeated-use overfitting and omission of difficult sites. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is case statements cite the validated operating point and relevant environment. The principal limitation is performance changes with dwell, bandwidth and source state. The record shall contain distributions, threshold, confidence intervals and applicability. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

20.7 Proficiency, adversarial review and ongoing monitoring

Examiner and system performance shall be monitored with blind, negative and adversarial cases. The governing physical or metrological basis is challenging ordinary confounders and instrument artefacts tests both sensitivity and restraint. The examiner shall treat this basis as a testable model rather than an assumption. A correct answer reached through undocumented procedure is not complete competence. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Traceability and uncertainty analysis. At expert-practitioner level, Proficiency, adversarial review and ongoing monitoring begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

The required configuration is as follows. Tests include no source, several sources, external source, ordinary device at suspected location and receiver artefact. The primary observables are classification, localisation coverage, procedural compliance, uncertainty and report wording. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are independent scoring, concealed ground truth and trend review. The principal artefacts and confounders are cueing, familiar test reuse, forgiving scoring and publication bias. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is nonconformities require corrective action and demonstrated effectiveness. The principal limitation is proficiency cannot reproduce every site complexity. The record shall contain test design, response, score, review, corrective action and follow-up. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

20.8 Controlled-illumination, PPM and translated-response validation

Validation shall use blind and double-blind trials containing genuine passive sources, remotely powered devices, ordinary electronic confounders, empty locations, deliberate receiver artefacts and external transmitters. The test set shall include response-present and response-absent trials across orientation, shielding, distance, multipath, duty cycle, illumination level and candidate frequency. Examiners shall not know the source state during candidate selection.

Traceability and uncertainty analysis. A advanced metrological approach to Controlled-illumination, PPM and translated-response validation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Where a result depends upon subtraction, ratios, phase differences, or spatial gradients, covariance between channels and stations is considered rather than assuming every input quantity is independent. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

Performance measures include probability of detection, false-alarm probability, localisation error, response-frequency error, PPM displacement error, jitter uncertainty, activation-threshold repeatability, direct-leakage rejection, intermodulation false-positive rate, receiver-overload incidence and classification agreement. The validated scope states the bands, field range, antennas, receivers, geometry and device-response classes actually tested.

The PPM estimator is validated with synthetic waveforms and traceable hardware timing signals spanning pulse amplitude, width, rise time, signal-to-noise ratio, sampling phase, missing pulses and competing modulation. The illumination path is challenged with known harmonics, spurs and two-tone intermodulation. The independent receiver must correctly reject receiver-specific images and reproduce genuine response frequencies within the combined uncertainty.

No activation distance or probability is extrapolated beyond the validated field and geometry. Results are monitored through ongoing quality-control sources, blind proficiency trials and trend charts for false alarms, timing bias and field calibration. A material change to source, amplifier, antenna, preselector, clock, firmware or analysis code triggers impact assessment and, where necessary, revalidation.

Chapter Glossary

Terms used in Chapter 27: Validation, Quality Assurance and Research Programme.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

DETECTION LIMIT — The smallest quantity or signal that can be distinguished from background with a stated probability of detection and false-alarm performance.

DUTY CYCLE — In a transmitter, ratio of time on to time off.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

S

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

21. Safety, Medical Environments and Stop-Work Rules

Passive reception ordinarily presents little electromagnetic risk, but the inspection as a whole still introduces trip hazards, conductive structures, batteries, cables, tools and the possibility of interference from active modules. In healthcare settings, medical-device basic safety and essential performance under electromagnetic disturbance are governed by a mature EMC framework, including IEC 60601-1-2 and FDA guidance [18, 21]. An EERF active plan must sit beneath, not outside, that framework.

Immediate stop-work condition	Required response
Patient distress or clinical request	Cease activity, remove non-essential equipment and yield control to clinical staff.
Medical-device alarm, reset, unexpected reading or degraded performance	Stop any active field immediately, document time and state, notify clinical engineering and do not resume without written clearance.
Field or power exceeds authorised limit	Shut down transmitter, preserve logs, verify field meter and initiate nonconformity review.
Loss of calibration check, time reference or instrument linearity	Suspend affected measurements and determine the validity of data acquired since the last acceptable check.
Uncontrolled emitter or person enters the CEIA	Mark the time, pause comparison series, characterise the change and repeat affected points.
Overload or intermodulation indication	Reduce gain, add validated preselection, repeat blanks and invalidate affected traces unless demonstrated otherwise.
Battery damage, heat, odour or leakage	Isolate equipment under electrical and fire-safety procedures. Do not continue with the affected unit.
Privacy or authority boundary exceeded	Stop acquisition, secure data and obtain legal or supervisory direction.

Immediate stop-work condition	Required response
Custody or identifier discrepancy	Quarantine affected files or media and resolve before analysis.

21.1 Human exposure assessment

When EERF reports exposure quantities or intentionally generates fields, the applicable frequency-specific human-exposure guidance and national law shall be identified. IEC 61786-1 and 61786-2 address low-frequency field instrumentation and procedures from 1 Hz to 100 kHz, while IEC/IEEE 63184:2025 addresses wireless-power-transfer exposure assessment from 3 kHz to 30 MHz [15-17]. These standards do not, by themselves, authorise a clinical exposure or establish a causal medical conclusion.

System-level interpretation. At expert-practitioner level, Human exposure assessment is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

21.2 Passive-probe mechanical and electrical safety

Passive operation shall still control long rods, tripods, cables, batteries, stored resonant energy and fragile ferrite. The governing physical or metrological basis is physical equipment can create impact, trip, electrical and fragmentation hazards even without intentional transmission. The examiner shall treat this basis as a testable model rather than an assumption. Non-magnetic does not mean safe in MRI or other strong-field environments. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Legal, clinical, and ethical elaboration. For passive-probe mechanical and electrical safety, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. A limitation imposed by law, safety, privacy, or clinical necessity is reported openly and is never relabelled as a completed measurement [1-9, 17-23].

The required configuration is as follows. Ferrite containment, cable routing, battery protection, non-conductive supports and emergency egress are inspected. The primary observables are damage, temperature, battery state, cable condition and proximity to live conductors. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are pre-use inspection, post-transport check, equipment count and clinical-zone approval. The principal artefacts and confounders are cracked rods, shorted batteries, blocked routes and magnetic hardware. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is unsafe equipment is removed before acquisition. The principal limitation is some clinical zones prohibit the apparatus entirely. The record shall contain inspection, defects, restrictions and corrective action. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

21.3 Active-field safety hierarchy

Any active field shall follow avoidance, ambient-carrier use, minimum-field testing and immediate stop authority. The governing physical or metrological basis is intentional fields can cause exposure, medical-device interference, heating or communications disruption. The examiner shall treat this basis as a testable model rather than an assumption. Measurement standards do not themselves authorise exposure or clinical experimentation. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Governance and safety analysis. For Active-field safety hierarchy, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The required configuration is as follows. An independent calibrated field monitor, exposure assessment, transmitter interlock and responsible operator are required. The primary observables are incident field, contact current where relevant, device status, temperature and alarms. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are field-off state, independent monitor, pre-test medical-device review and emergency shutdown. The principal artefacts and confounders are monitor saturation, field non-uniformity, transmitter harmonics and unreviewed implants. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is any alarm, limit exceedance, distress or loss of monitoring causes immediate cessation. The principal limitation is some settings cannot safely support active testing. The record shall contain assessment, limits, monitor data, personnel, events and shutdown. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

21.4 Controlled-illumination safety and compatibility matrix

The safety decision separates human exposure from electromagnetic compatibility. Compliance with an exposure limit does not establish that a medical device, implanted device, alarm, communication link or sensitive instrument will function correctly. The active plan therefore evaluates both field exposure and equipment susceptibility, with clinical and life-safety priorities controlling the decision.

Governance and safety analysis. For Controlled-illumination safety and compatibility matrix, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. The risk assessment addresses implanted and life-supporting devices, electromagnetic compatibility, spectrum licensing, heating, battery stress, fire, unintended activation, data alteration, interference with communications, and evidential contamination. A limitation imposed by law, safety, privacy, or clinical necessity is reported openly and is never relabelled as a completed measurement [1-9, 17-23].

The test area is surveyed for persons, implanted-device declarations handled under appropriate privacy controls, medical electrical equipment, oxygen-rich or flammable environments, batteries, pyrotechnic or explosive hazards, critical communications, access systems and evidence whose electronic state could be changed. Any unresolved material hazard prevents activation.

Hazard domain	Required assessment	Stop condition
Human exposure	Frequency-specific field quantity, averaging time, uncertainty, persons present and applicable limit.	Measured or predicted field exceeds the authorised operational limit or monitoring is lost.
Implanted and medical devices	Clinical-engineering review, separation, immunity information, monitoring and patient-care priority.	Alarm, reset, unexpected value, distress or loss of clinical approval.
Electromagnetic compatibility	Life-safety, communications, access control, computing, sensors and ordinary equipment.	Any disruption or unexplained state change.

Hazard domain	Required assessment	Stop condition
Thermal, battery and fire	Absorbed-energy plausibility, battery condition, temperature indicators, ventilation and fire response.	Unexpected heat, odour, smoke, swelling, leakage or alarm.
Data and evidential integrity	Risk of activation, memory change, clock change, erasure, latching or contamination.	Any unplanned data or device-state alteration.
Spectrum and third parties	Authorised band, emissions mask, antenna direction, boundary field and interference monitoring.	Out-of-band emission, complaint, interference or authority limit exceeded.

Chapter Glossary

Terms used in Chapter 28: Safety, Medical Environments and Stop-Work Rules.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

E

EMC — Electromagnetic compatibility: the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to other systems.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

S

SUSCEPTIBILITY — The degree to which equipment or a system is adversely affected by electromagnetic, electrical, acoustic, optical, mechanical, or environmental exposure.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

22. Implementation Roadmap

Phase	Principal output	Gate to advance
1. Governance and terminology	Approved scope, definitions, ethics position, legal matrix, safety policy and document control.	Multidisciplinary approval and explicit non-medical-causation boundary.
2. Instrument architecture	Band-specific sensor chains, self-emission library, calibration plan, data schema and quieting protocol.	Bench linearity, noise and artefact tests passed.
3. Controlled validation	Blind source and sham trials across levels, shielding, orientations, duty cycles and confounders.	Predeclared performance criteria met with uncertainty.
4. Representative field validation	Building trials, inter-operator studies, localisation performance and privacy review.	Demonstrated reproducibility and acceptable false-alarm rate.
5. Restricted operational pilot	Conservative reports, independent review, nonconformity log and client comprehension assessment.	Quality board authorises defined claims and limitations.
6. Accreditation and external review	Alignment with ISO/IEC 17020 or 17025 as appropriate, proficiency testing and published method performance.	External audit or peer assessment.
7. Consensus development	Professional working group, shared terminology, reference artefacts, open datasets and proposed documentary standard.	Broad stakeholder review and revision.

22.1 Engineering development workstream

The organisation shall develop probes and receiver chains under formal design control before case deployment. The governing physical or metrological basis is requirements, prototypes, verification, validation and configuration management convert a concept into a reproducible instrument. The examiner shall treat this basis as a testable model rather than an assumption. A sensitive prototype is not an evidential method. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Spatial-measurement interpretation. The mature treatment of Engineering development workstream replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

The required configuration is as follows. Design inputs cover bands, noise, aperture, non-contact, silence, safety, calibration and data integrity. The primary observables are test results, design reviews, failure modes and manufacturing variation. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are independent review, controlled drawings, component traceability and change control. The principal artefacts and confounders are prototype selection, undocumented hand adjustment and dependence on one builder. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is field release follows acceptance and validation gates. The principal limitation is research configurations remain clearly labelled and separated from operational claims. The record shall contain requirements, drawings, bills of material, tests, reviews and release. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

22.2 Method accreditation and quality-system workstream

The proposed discipline shall be embedded in a quality system aligned with forensic process, inspection and laboratory competence principles. The governing physical or metrological basis is document control, impartiality, competence, validation, traceability, nonconformity and review create reliable operation. The examiner shall treat this basis as a testable model rather than an assumption. Use of standards language does not imply accreditation before an accreditor grants it. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Metrological interpretation. At expert-practitioner level, Method accreditation and quality-system workstream begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

The required configuration is as follows. Controlled procedures (described herein), roles, training, calibration, proficiency and report review are implemented. The primary observables are audit findings, quality indicators, corrective actions and method performance. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are internal audit, management review, external technical review and proficiency testing. The principal artefacts and confounders are scope creep, outdated documents, conflicts of interest and unsupported marketing claims. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified. In the case of a measurement system which utilizes real-time synchronized measurements over more then 12 channels, each card after the first card shall have the ability to have a test noise sources, terminations, and other test signals routed to every cards and every channel with the shared chassis, as well as a shared discipline time base and phase lock.

The advancement or reporting rule in public claims remain limited to actual validation and accreditation status. The principal limitation is novel methods may require staged research use before formal recognition. The record shall contain scope, approvals, audits, accreditation status and limitations. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

22.3 Clinical, ethical and legal governance workstream

Medical-mystery commissions shall be governed so that technical investigation does not become unapproved exposure research or intrusive surveillance. The governing physical or metrological basis is separate authority, consent, privacy limits and clinical independence protect subjects and evidential neutrality. The examiner shall treat this basis as a testable model rather than an assumption. The method does not infer illness, intercept communications or search property beyond consent and law. The model is retained only while the measured frequency, time, orientation and distance behaviour remain compatible with it. A contrary observation is recorded and used to select the next measurement, rather than being discarded as inconvenient noise.

Authorisation-control perspective. For Clinical, ethical and legal governance workstream, the planned measurement is translated into identifiable hazards, affected persons, protected data classes, equipment interactions, stop conditions, and named decision owners. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The required configuration is as follows. Commission terms identify premises, persons, data recipients, excluded content, active-field limits and stop authority. The primary observables are authorisations, consent, privacy incidents and clinical restrictions. Frequency reference, probe-centre coordinate, axis, height, standoff, gain, bandwidth, dwell, temperature and premises state are fixed or explicitly recorded. Any alteration of sensor, cable, capacitor setting, preamplifier, filter or sample rate begins a separately identified series. This separation prevents an improvement caused by retuning or gain change from being misrepresented as an inward spatial increase.

The minimum controls are legal review, ethics review where applicable, minimisation and independent medical oversight. The principal artefacts and confounders are purpose drift, excessive data collection, symptom-led confirmation and unauthorised active interrogation. At least one control shall challenge the sensor path, one shall challenge the receiver or analysis path, and one shall challenge the environmental-source interpretation. Where a control cannot be performed because of safety, access or clinical necessity, the omission and its likely effect are entered before the result is classified.

The advancement or reporting rule is work stops when authority, consent or safety is unclear. The principal limitation is some questions cannot be answered within a lawful passive non-imaging scope. The record shall contain authority, consent, privacy plan, clinical boundaries and final data disposition. The conclusion is expressed as a bounded measurement proposition, not as proof of a concealed object, unlawful conduct or medical causation. Independent technical review shall be able to reconstruct the decision from raw files, calibration evidence, coordinate records and contemporaneous notes.

Chapter Glossary

Terms used in Chapter 29: Implementation Roadmap.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

23. Conclusion

EERF can be developed into a credible new forensic discipline if it is built upon controlled-scene practice, low-noise electronics, electromagnetic competence, common-timebase multichannel acquisition, rigorous artefact controls, explicit uncertainty and bounded interpretation. This extends that discipline from a five-mile regional inventory through thirteen principal radii and finally into a three-inch volumetric lattice. It also recognises that a room is not a flat plan but a set of coupled three-dimensional cells, that walls and floors require paired observations from both accessible sides, that safe high-ground measurements reduce missing upper-hemisphere information, and that composite modulation may require envelope, phase, instantaneous-frequency and cyclostationary analysis before a weak or intermittent signal can be classified. The resulting method remains passive-first, non-contact, non-imaging, privacy-limited and incapable by itself of establishing medical causation or unlawful purpose.

The decisive scientific discipline is equally important. A 32.768 kHz line, a 3.579545 MHz component or a 15.734 kHz periodicity can guide examination, but none is unique. Shielding, near-field coupling, building wiring, intermittent operation, ambient backscatter and instrument self-emissions can all complicate the inference. The final report must therefore distinguish measured fact, source-class consistency and medical causation. Only the first two belong within EERF, and the second is permitted only to the strength demonstrated by validation.

Chapter Glossary

Terms used in Chapter 30: Conclusion.

B

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

T

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

24. Advanced Electromagnetic Measurement Science

This chapter supplies the conceptual bridge between textbook electromagnetics and field examination. It is written for the practitioner who must determine what a spectrum, time trace, vector field, or spatial gradient means when the source is weak, partially shielded, intermittently active, or coupled through a structure that is not known in advance.

The purpose is not to merely present a novel theory. It is to ensure that every measurement proposition rests upon a declared physical model and a traceable instrument model [9, 129-131].

The treatment is intentionally more rigorous than an equipment manual. It distinguishes source variables from propagation variables, sensor response from receiver response, and physical absence from non-detection. It also recognises that many EERF problems are inverse problems. The examiner observes fields outside an unknown object and seeks a bounded statement about the source, while incomplete geometry, environmental noise, multipath, and instrument limitations prevent a unique reconstruction.

24.1 Maxwellian source taxonomy and field decomposition

Weak electronic signatures arise from charge motion, time-varying electric flux, magnetic flux, switching discontinuities, and structural currents, each of which can couple through a different physical path. The governing quantities include charge density ρ, current density J, electric field E, magnetic field H, magnetic flux density B, electric flux density D, conductivity σ, permittivity ε, permeability μ, angular frequency ω, and position r. Maxwell's equations require continuity among these quantities, but the relative importance of conduction, displacement, induction, and radiation changes with frequency, dimensions, materials, and observation distance. This section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [129-131].

In operational practice, the examiner identifies a primary source model and at least one rival model, then selects electric, magnetic, conducted, and radiative sensors capable of discriminating between them. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A candidate is challenged by orientation changes, distance changes, conductor-path tests, state changes, and independent receiver geometry so that one convenient coupling explanation does not become the only explanation by assumption.

The interpretive boundary is explicit. A measured field supports only the source properties that the model and controls can constrain; it does not reveal concealed construction or purpose by itself. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.2 Quasi-static, induction, radiating near-field, and far-field regimes

Field behaviour changes continuously with electrical size and distance, so geometric distance expressed in feet is not enough to select a propagation model. The governing quantities include wavelength $\lambda = c/f$, wavenumber $k = 2\pi/\lambda$, source dimension D, range r, electrical size kD, and normalised range kr. Reactive and induction terms can fall approximately as 1/r cubed and 1/r squared, while radiating terms fall approximately as 1/r, although conductive structures and boundaries can alter those simple dependencies. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [129-131].

In operational practice, every station is annotated with frequency-scaled geometry and with the field component measured, while free-space path loss is reserved for conditions in which its assumptions are credible. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The examiner does not infer source range from amplitude alone and does not call a 300-foot measurement far field merely because it is outside the building.

The interpretive boundary is explicit. The adopted regime is an approximation whose validity must be reassessed when frequency, source dimension, shielding, or environmental geometry changes. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.3 Coupled source-probe-receiver transfer functions

The indication displayed by an analyser is the convolution of source behaviour, propagation, probe response, analogue conditioning, sampling, and signal processing. The governing quantities include source spectrum $S(f)$, propagation operator $P(f,r)$, probe transfer function $H_p(f,\theta,T)$, receiver transfer function $H_r(f,g)$, processing operator $A(f,t)$, and additive or multiplicative noise $n(t)$. A useful abstract model is $Y(f) = A\{H_r(f) H_p(f) P(f,r) S(f)\} + N(f)$, which clarifies that an observed peak can be created, suppressed, shifted, broadened, or distorted at several stages. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-16, 129-131].

In operational practice, the field record retains raw data and the exact configuration required to reconstruct the applied transfer functions, including tuning, gain, bandwidth, detector, window, and calibration coefficients. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Gain-step tests, channel substitution, terminated-input records, reference sources, and independent probe types are used to locate the stage at which a feature enters the chain.

The interpretive boundary is explicit. The system model supports causal discrimination, but it does not make an underdetermined inverse problem unique without additional spatial or temporal evidence. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.4 Complex impedance, resonance, quality factor, and settling

A tuned receiving probe is governed by complex impedance rather than nominal inductance and capacitance alone. The governing quantities include resistance $R(f)$, inductive reactance $X_L = 2\pi fL$, capacitive reactance $X_C = 1/(2\pi fC)$, impedance $Z = R + j(X_L - X_C)$, resonant frequency $f0$, loaded quality factor Q_L, bandwidth B, and settling time τ. Resonance occurs where net reactance crosses zero, while the useful transfer factor and selectivity depend upon loss, loading, coupling, component tolerances, and distributed parasitics. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [31-36, 124-131].

In operational practice, the analyser-controlled tuning loop approaches resonance, waits through the measured settling interval, verifies resonance through a calibrated observable, removes the pilot where required, and acquires only during the qualified hold state. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The process is repeated after temperature change, probe movement, cable substitution, or gain-state change because each can alter the loaded resonance and the apparent field amplitude.

The interpretive boundary is explicit. A high Q can improve selectivity but may reduce capture probability for drifting or brief signals; the chosen Q is therefore an operational compromise, not an intrinsic measure of quality. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.5 Noise processes and sensitivity limits

Ultra-low-level detection is limited by several noise mechanisms whose spectra, statistics, and dependence on source impedance differ materially. The governing quantities include thermal noise, voltage and current noise densities e_n and i_n, 1/f corner frequency, shot noise, generation-recombination noise, oscillator phase noise, quantisation noise, environmental variance, and equivalent noise bandwidth. Narrowing bandwidth reduces integrated white noise, but it does not remove deterministic interference, flicker noise, phase-noise skirts, microphonics, or overload products created before the filter. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-16, 127-131].

In operational practice, the receiver and probe are characterised together over the intended source impedance, frequency, gain, and temperature range, and sensitivity is reported for a declared probability of detection and false-alarm condition. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Noise-floor improvement is challenged with terminated inputs, dummy probes, known field sources, altered bandwidth, altered dwell, and a second receiver architecture.

The interpretive boundary is explicit. A displayed trace below an arbitrary reference line is not a validated detection limit; sensitivity is a performance statement tied to a method and environment. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.6 Time-frequency resolution and transient observation

Short bursts, slow clocks, drifting oscillators, and nested modulation require a deliberate trade between temporal resolution, frequency resolution, and observation duration. The governing quantities include record duration T, nominal bin spacing $\Delta f \approx 1/T$, sample rate f_s, window function, overlap, resolution bandwidth, dwell, trigger latency, pre-trigger depth, and burst duration τ_b. A narrow spectral bin requires a long observation, while a short observation broadens the spectral representation, window choice further changes leakage and amplitude accuracy. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object.

The following integration extends Time-frequency resolution and transient observation with advanced integrated engineering and evidentiary analysis. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Advanced Integrated Engineering and Evidentiary Analysis

Spectrum-search modes: swept, stepped-FFT, and stare should be treated as a testable mechanism. Its immediate relevance to RF survey and technical-security measurement is that it identifies which quantities are physically meaningful, which are merely instrument outputs, and which require a model before they can support an inference. A spectrum survey trades instantaneous bandwidth, revisit time, resolution, sensitivity, and data volume; swept, stepped-FFT, and fixed-span stare modes reveal different classes of activity. The practitioner should distinguish the system boundary from the surrounding environment, state the excitation and observation conditions, and identify the variables that remain uncontrolled. That discipline prevents the reader from treating revisit interval; RBW; dwell; occupancy; transient capture probability as self-explanatory evidence. Its value lies in making the inferential chain auditable: source, model, measurement, uncertainty, and conclusion remain separable.

Wideband I/Q recording, data-rate engineering, and evidentiary retention should be introduced as a disciplined model whose assumptions remain visible throughout acquisition and interpretation. Its immediate relevance to RF survey and technical-security measurement is that it identifies which quantities are physically meaningful, which are merely instrument outputs, and which require a model before they can support an inference. Continuous wideband capture converts RF uncertainty into storage, timing, and provenance demands; sample format, lossless metadata, trigger policy, and retention determine later analytic options. The practitioner should distinguish the system boundary from the surrounding environment, state the excitation and observation conditions, and identify the variables that remain uncontrolled. That discipline prevents the reader from treating throughput; dropped samples; trigger latency; storage integrity; replay fidelity as self-explanatory evidence.

Spread spectrum, direct sequence, and processing gain is best understood as an interface between physical behavior and evidentiary judgment. Its immediate relevance to RF survey and technical-security measurement is that it identifies which quantities are physically meaningful, which are merely instrument outputs, and which require a model before they can support an inference. Direct-sequence systems spread symbols with a code whose correlation properties support despreading and multiple access; processing gain does not remove near-far and synchronization limits. The practitioner should distinguish the system boundary from the surrounding environment, state the excitation and observation conditions, and identify the variables that remain uncontrolled. That discipline prevents the reader from treating chip rate; code period; correlation peak; despread SNR as self-explanatory evidence. This treatment therefore belongs in the body of the chapter, with a short cross-reference to the deeper mathematical owner volume rather than a repeated generic definition.

Time standards, timestamp semantics, and collection chronology should be introduced as a disciplined model whose assumptions remain visible throughout acquisition and interpretation. Its immediate relevance to RF survey and technical-security measurement is that it identifies which quantities are physically meaningful, which are merely instrument outputs, and which require a model before they can support an inference. A timestamp is an instrument output with scale, epoch, time-zone, latency, and uncertainty; coherent multi-sensor analysis requires explicit treatment of clocks and processing delay.

The practitioner should distinguish the system boundary from the surrounding environment, state the excitation and observation conditions, and identify the variables that remain uncontrolled. That discipline prevents the reader from treating clock offset; drift; latency; time-scale conversion; ordering confidence as self-explanatory evidence. The resulting method should be read as a controlled bridge between theory, instrument state, and the final claim, not as an operational shortcut.

Spectrum occupancy, baseline models, and change detection is a governing technical proposition rather than a detachable fact. Its immediate relevance to RF survey and technical-security measurement is that it identifies which quantities are physically meaningful, which are merely instrument outputs, and which require a model before they can support an inference.

A spectrum baseline is a conditional model indexed by location, antenna, time, bandwidth, threshold, and receiver state; change detection should distinguish new energy from normal variability. The practitioner should distinguish the system boundary from the surrounding environment, state the excitation and observation conditions, and identify the variables that remain uncontrolled. That discipline prevents the reader from treating occupancy; energy history; novelty score; persistence as self-explanatory evidence.

Placed in this form, the material deepens the volume and series without converting it into a duplicated antenna or radar textbook. In this placement, the control is applied to the local measurement and evidentiary question within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

The physical development for Spectrum-search modes: swept, stepped-FFT, and stare should begin with conservation, geometry, and constitutive assumptions before numerical substitution. A compact governing relation is T_revisit approximately N_steps(T_settle+T_acq+T_proc). This expression is not a free-standing recipe: every symbol requires a reference direction, unit system, bandwidth or time convention where applicable, and a statement of whether the quantity is peak, RMS, average, available, accepted, or radiated. In V80, the derivation should explicitly connect the equation to revisit interval; RBW; dwell; occupancy; transient capture probability, then show the limiting cases that recover familiar behavior.

Dimensional analysis and sign-convention checks should precede any logarithmic conversion, because a correct-looking decibel result can conceal an inconsistent linear model. Where the geometry is electrically small, large, layered, dispersive, or near-field, the text should say so rather than silently inherit a free-space far-field approximation.

The physical development for Wideband I/Q recording, data-rate engineering, and evidentiary retention should begin with conservation, geometry, and constitutive assumptions before numerical substitution. A compact governing relation is data_rate=2 N_channels f_s bits_per_sample. This expression is not a free-standing recipe: every symbol requires a reference direction, unit system, bandwidth or time convention where applicable, and a statement of whether the quantity is peak, RMS, average, available, accepted, or radiated. In V80, the derivation should explicitly connect the equation to throughput; dropped samples; trigger latency; storage integrity; replay fidelity, then show the limiting cases that recover familiar behavior.

Dimensional analysis and sign-convention checks should precede any logarithmic conversion, because a correct-looking decibel result can conceal an inconsistent linear model. Where the geometry is electrically small, large, layered, dispersive, or near-field, the text should say so rather than silently inherit a free-space far-field approximation.

The physical development for Spread spectrum, direct sequence, and processing gain should begin with conservation, geometry, and constitutive assumptions before numerical substitution. A compact governing relation is G_p=R_chip/R_data approximately B_spread/B_data. This expression is not a free-standing recipe: every symbol requires a reference direction, unit system, bandwidth or time convention where applicable, and a statement of whether the quantity is peak, RMS, average, available, accepted, or radiated. In V80, the derivation should explicitly connect the equation to chip rate; code period; correlation peak; despread SNR, then show the limiting cases that recover familiar behavior. Dimensional analysis and sign-convention checks should precede any logarithmic conversion, because a correct-looking decibel result can conceal an inconsistent linear model. Where the geometry is electrically small, large, layered, dispersive, or near-field, the text should say so rather than silently inherit a free-space far-field approximation.

The physical development for Time standards, timestamp semantics, and collection chronology should begin with conservation, geometry, and constitutive assumptions before numerical substitution. A compact governing relation is t_event=t_recorded-delta_latency plus/minus u_time. This expression is not a free-standing recipe: every symbol requires a reference direction, unit system, bandwidth or time convention where applicable, and a statement of whether the quantity is peak, RMS, average, available, accepted, or radiated. In V80, the derivation should explicitly connect the equation to clock offset; drift; latency; time-scale conversion; ordering confidence, then show the limiting cases that recover familiar behavior. Dimensional analysis and sign-convention checks should precede any logarithmic conversion, because a correct-looking decibel result can conceal an inconsistent linear model. Where the geometry is electrically small, large, layered, dispersive, or near-field, the text should say so rather than silently inherit a free-space far-field approximation.

The physical development for Spectrum occupancy, baseline models, and change detection should begin with conservation, geometry, and constitutive assumptions before numerical substitution. A compact governing relation is D_t=distance(feature_t,baseline_context); alarm if D_t>eta. This expression is not a free-standing recipe: every symbol requires a reference direction, unit system, bandwidth or time convention where applicable, and a statement of whether the quantity is peak, RMS, average, available, accepted, or radiated. In V80, the derivation should explicitly connect the equation to occupancy; energy history; novelty score; persistence, then show the limiting cases that recover familiar behavior. Dimensional analysis and sign-convention checks should precede any logarithmic conversion, because a correct-looking decibel result can conceal an inconsistent linear model. Where the geometry is electrically small, large, layered, dispersive, or near-field, the text should say so rather than silently inherit a free-space far-field approximation.

A second acquisition path should be favored when the consequence is substantial, particularly where front-end overload, receiver-generated products, or fixture coupling can imitate the phenomenon. Raw complex samples or trace data, instrument screenshots, configuration exports, calibration records, and field notes should remain linked by identifiers and hashes. In this placement, the control is applied to the local measurement and evidentiary question within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

Interpretation should proceed from calibrated data to features, from features to models, and only then from models to claims. In the context of FCC Title 47 Spectrum Governance, Allocation Tables, Licensed-Service Boundaries, and RF Survey Evidence Ledgers for Defensive TSCM, Spectrum-search modes: swept, stepped-FFT, and stare supplies a signals-intelligence collection and characterization layer that can be reused without duplicating the owner treatment.

The processing record should state window functions, averaging, interpolation, thresholding, normalization, coordinate transforms, calibration correction, and any censoring or analyst selection. Estimates derived from revisit interval; RBW; dwell; occupancy; transient capture probability should carry uncertainty or confidence measures that reflect both measurement noise and model sensitivity.

Where a logarithmic, spectral, image, or polar display is used, the underlying numerical values and scale limits should remain available. Cross-volume references should direct the reader to the mathematical derivation, instrumentation doctrine, and evidence-governance treatment rather than restating the same generic paragraph in multiple places. In this placement, the control is applied to the local measurement and evidentiary question within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

The text should resist a display-led workflow in which a visually salient pattern is treated as proof before numerical characterization. In the context of FCC Title 47 Spectrum Governance, Allocation Tables, Licensed-Service Boundaries, and RF Survey Evidence Ledgers for Defensive TSCM, Wideband I/Q recording, data-rate engineering, and evidentiary retention supplies a signals-intelligence collection and characterization layer that can be reused without duplicating the owner treatment.

The processing record should state window functions, averaging, interpolation, thresholding, normalization, coordinate transforms, calibration correction, and any censoring or analyst selection. Estimates derived from throughput; dropped samples; trigger latency; storage integrity; replay fidelity should carry uncertainty or confidence measures that reflect both measurement noise and model sensitivity.

Processing should preserve the distinction between detection, parameter estimation, classification, and attribution. In the context of FCC Title 47 Spectrum Governance, Allocation Tables, Licensed-Service Boundaries, and RF Survey

Evidence Ledgers for Defensive TSCM, spread spectrum, direct sequence, and processing gain supplies a signals-intelligence collection and characterization layer that can be reused without duplicating the owner treatment.

The processing record should state window functions, averaging, interpolation, thresholding, normalization, coordinate transforms, calibration correction, and any censoring or analyst selection.

Estimates derived from chip rate; code period; correlation peak; despread SNR should carry uncertainty or confidence measures that reflect both measurement noise and model sensitivity. Where a logarithmic, spectral, image, or polar display is used, the underlying numerical values and scale limits should remain available.

The analytic sequence should be written as a chain of transformations whose inputs and assumptions can be replayed. In the context of FCC Title 47 Spectrum Governance, Allocation Tables, Licensed-Service Boundaries, and RF Survey Evidence Ledgers for Defensive TSCM, Time standards, timestamp semantics, and collection chronology supplies a signals-intelligence collection and characterization layer that can be reused without duplicating the owner treatment. The processing record should state window functions, averaging, interpolation, thresholding, normalization, coordinate transforms, calibration correction, and any censoring or analyst selection. Estimates derived from clock offset; drift; latency; time-scale conversion; ordering confidence should carry uncertainty or confidence measures that reflect both measurement noise and model sensitivity.

Interpretation should proceed from calibrated data to features, from features to models, and only then from models to claims. In the context of FCC Title 47 Spectrum Governance, Allocation Tables, Licensed-Service Boundaries, and RF Survey Evidence Ledgers for Defensive TSCM, Spectrum occupancy, baseline models, and change detection supplies a signals-intelligence collection and characterization layer that can be reused without duplicating the owner treatment. The processing record should state window functions, averaging, interpolation, thresholding, normalization, coordinate transforms, calibration correction, and any censoring or analyst selection. Estimates derived from occupancy; energy history; novelty score; persistence should carry uncertainty or confidence measures that reflect both measurement noise and model sensitivity.

Uncertainty should be organized by source, coupling path, processing transformation, and decision consequence. For Spectrum-search modes: swept, stepped-FFT, and stare, the known failure mechanisms include gaps between steps; threshold bias; overload from out-of-band signals; hidden detector averaging. In V80, those mechanisms should be converted into explicit counter-hypotheses with predicted changes under frequency, power, polarization, distance, orientation, load, timing, or substitution. The reader should be warned that an apparently stable signature can originate in the receiver, cable, reference clock, digital pipeline, nearby infrastructure, or survey procedure. Correlated errors must not be counted as independent confirmation, and repeated measurements under unchanged conditions do not establish robustness. The correct conclusion is the narrowest one that survives the discriminating tests, with unresolved alternatives retained in the report.

The error analysis must be adversarial in the engineering sense: it should actively seek mechanisms that would reproduce the observation without the preferred explanation. For Wideband I/Q recording, data-rate engineering, and evidentiary retention, the known failure mechanisms include undocumented scaling; packet loss; clock discontinuity; lossy compression; metadata separation. In V80, those mechanisms should be converted into explicit counter-hypotheses with predicted changes under frequency, power, polarization, distance, orientation, load, timing, or substitution. The reader should be warned that an apparently stable signature can originate in the receiver, cable, reference clock, digital pipeline, nearby infrastructure, or survey procedure. Correlated errors must not be counted as independent confirmation, and repeated measurements under unchanged conditions do not establish robustness. The correct conclusion is the narrowest one that survives the discriminating tests, with unresolved alternatives retained in the report.

A strong section does not merely list tolerances; it enumerates alternative physical and instrumental causes and states how each would be discriminated. For spread spectrum, direct sequence, and processing gain, the known failure mechanisms include wrong code phase; near-far interference; multipath replicas; clock mismatch. In V80, those mechanisms should be converted into explicit counter-hypotheses with predicted changes under frequency, power, polarization, distance, orientation, load, timing, or substitution. The reader should be warned that an apparently stable signature can originate in the receiver, cable, reference clock, digital pipeline, nearby infrastructure, or survey procedure. Correlated errors must not be counted as independent confirmation, and repeated measurements under unchanged conditions do not establish robustness. The correct conclusion is the narrowest one that survives the discriminating tests, with unresolved alternatives retained in the report.

A strong section does not merely list tolerances; it enumerates alternative physical and instrumental causes and states how each would be discriminated. For Time standards, timestamp semantics, and collection chronology, the known failure mechanisms include mixing UTC, GPS, TAI, and local time; NTP steps; buffer delay; leap-second error. In V80, those mechanisms should be converted into explicit counter-hypotheses with predicted changes under frequency, power, polarization, distance, orientation, load, timing, or substitution. The reader should be warned that an apparently stable signature can originate in the receiver, cable, reference clock, digital pipeline, nearby infrastructure, or survey procedure. Correlated errors must not be counted as independent confirmation, and repeated measurements under unchanged conditions do not establish robustness. The correct conclusion is the narrowest one that survives the discriminating tests, with unresolved alternatives retained in the report.

A strong section does not merely list tolerances; it enumerates alternative physical and instrumental causes and states how each would be discriminated. For Spectrum occupancy, baseline models, and change detection, the known failure mechanisms include threshold drift; seasonal traffic; antenna changes; intermittent overload; baseline poisoning. In V80, those mechanisms should be converted into explicit counter-hypotheses with predicted changes under frequency, power, polarization, distance, orientation, load, timing, or substitution. The reader should be warned that an apparently stable signature can originate in the receiver, cable, reference clock, digital pipeline, nearby infrastructure, or survey procedure. Correlated errors must not be counted as independent confirmation, and repeated measurements under unchanged conditions do not establish robustness. The correct conclusion is the narrowest one that survives the discriminating tests, with unresolved alternatives retained in the report.

Validation for Spectrum-search modes: swept, stepped-FFT, and stare should be planned before the decisive observation is interpreted. The minimum control is to inject signals with controlled duration and frequency agility, then estimate empirical probability of observation. Acceptance criteria should be numerical where practicable and should include repeatability, independent-instrument agreement, calibration validity, environmental stability, and sensitivity to reasonable processing choices. The report should identify whether the result is a measurement, a model prediction, a simulation-assisted inference, a source-derived historical proposition, or a legal-administrative qualification. Source anchors for this treatment are SIG-5 (32-47); SIG-6 (48-59); SIG-7 (60-79); SIG-74 (7702-7876); they support the engineering synthesis but do not authorize reproduction of commercial figures, tables, or source prose. Because the exact TSCM documents is available, this paragraph is staged for semantic comparison and heading-level adjudication before any successor release is asserted. In this placement, the control is applied to spectrum-search modes: swept within Volume

80, so configuration, authority, and uncertainty remain tied to the local chapter context.

Validation for Wideband I/Q recording, data-rate engineering, and evidentiary retention should be planned before the decisive observation is interpreted. The minimum control is to perform loopback replay, hash files and metadata, monitor drop counters, and verify sample continuity. Acceptance criteria should be numerical where practicable and should include repeatability, independent-instrument agreement, calibration validity, environmental stability, and sensitivity to reasonable processing choices. The report should identify whether the result is a measurement, a model prediction, a simulation-assisted inference, a source-derived historical proposition, or a legal-administrative qualification. Source anchors for this treatment are SIG-5; SIG-7; SIG-82; and FORE-1 they support the engineering synthesis but do not authorize reproduction of commercial figures, tables, or source prose. This paragraph is staged for semantic comparison and heading-level adjudication before any successor release is asserted. In this placement, the control is applied to wideband I/Q recording within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

Validation for Spread spectrum, direct sequence, and processing gain should be planned before the decisive observation is interpreted. The minimum control is to verify acquisition and tracking over code phase, Doppler, interference, and multipath conditions. Acceptance criteria should be numerical where practicable and should include repeatability, independent-instrument agreement, calibration validity, environmental stability, and sensitivity to reasonable processing choices. The report should identify whether the result is a measurement, a model prediction, a simulation-assisted inference, a source-derived historical proposition, or a legal-administrative qualification. Source anchors for this treatment are SIG-72; and SIG-73; they support the engineering synthesis but do not authorize reproduction of commercial figures, tables, or source prose. In this placement, the control is applied to spread spectrum within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

Validation for Time standards, timestamp semantics, and collection chronology should be planned before the decisive observation is interpreted. The minimum control is to compare against traceable time references, log synchronization state, and preserve raw counters with converted time. Acceptance criteria should be numerical where practicable and should include repeatability, independent-instrument agreement, calibration validity, environmental stability, and sensitivity to reasonable processing choices. The report should identify whether the result is a measurement, a model prediction, a simulation-assisted inference, a source-derived historical proposition, or a legal-administrative qualification.

Validation for Spectrum occupancy, baseline models, and change detection should be planned before the decisive observation is interpreted. The minimum control is to maintain control channels, version baselines, and test detection and false-alarm rates with injected events. Acceptance criteria should be numerical where practicable and should include repeatability, independent-instrument agreement, calibration validity, environmental stability, and sensitivity to reasonable processing choices. The report should identify whether the result is a measurement, a model prediction, a simulation-assisted inference, a source-derived historical proposition, or a legal-administrative qualification. In this placement, the control is applied to spectrum occupancy within Volume 80, so configuration, authority, and uncertainty remain tied to the local chapter context.

This integrated treatment returns the discussion to 24.6 Time-frequency resolution and transient observation with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

In operational practice, the field plan assigns separate discovery, confirmation, and transient-capture settings rather than expecting one sweep to reveal every signal class. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The examiner retains time-domain or I/Q data whenever intermittency, PPM, frequency hopping, rapid wake-up, or illumination-correlated response is material.

The interpretive boundary is explicit. Failure to observe a brief event during a slow sequential sweep is not evidence that the event did not occur between sweep visits. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.7 Detection theory, thresholds, and false-alarm control

Expert practice requires a decision rule that separates ordinary background variation from a candidate requiring further examination. The governing quantities include null and alternative hypotheses $H0$ and $H1$, test statistic $T(x)$, threshold η, probability of detection P_D, probability of false alarm P_{FA}, prevalence of transients, and cost of missed or false promotion. A threshold chosen after viewing the decisive data inflates apparent performance and encourages expectation bias, whereas a predeclared rule permits repeatable advancement and honest comparison. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-9].

In operational practice, thresholds are based on validation or a documented provisional study, and candidate promotion requires recurrence, control compliance, spatial behaviour, and receiver linearity rather than amplitude alone. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The team records candidates that fail confirmation so that the false-promotion burden and common confounders remain visible in quality review.

The interpretive boundary is explicit. The method may remain exploratory where performance data are incomplete, but its language must then remain exploratory as well. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

24.8 Measurement uncertainty, covariance, and traceability

Every quantitative EERF result combines instrument, probe, environmental, spatial, temporal, and model contributions. The governing quantities include standard uncertainty u_i, sensitivity coefficient c_i, covariance u_{ij}, combined standard uncertainty u_c, coverage factor k, expanded uncertainty $U = k u_c$, and metrological traceability. For correlated channels or repeated stations, the covariance terms can be material, particularly when a shared clock, calibration source, probe fixture, or environmental drift affects several inputs in the same direction. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-16].

In operational practice, the uncertainty model is prepared before reporting and is revised when the actual measurement sequence reveals an influence quantity not represented in the original budget. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The report distinguishes resolution from uncertainty, repeatability from reproducibility, and calibration status from fitness for the intended source geometry.

The interpretive boundary is explicit. Where model inadequacy dominates and cannot be credibly quantified, the conclusion is expressed qualitatively with the limitation stated rather than disguised by excessive decimal places. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 24-1. Measurement-model hierarchy for advanced EERF interpretation

Level	Question	Required record	Permitted conclusion
Physical source	What charge, current, flux, switching, or scattering process could create the field?	Frequency, phase, geometry, state, materials, rival models	A bounded source mechanism hypothesis
Coupling path	How could the field or current reach the probe?	Distance, orientation, conductor path, apertures, structures, polarisation	A supported coupling-path description
Probe and receiver	How did the instrument transform the field?	Transfer function, calibration, tuning, gain, bandwidth, detector, timing	A traceable instrument indication
Decision statistic	Why was the feature promoted?	Threshold, controls, recurrence, uncertainty, invalidation rules	A candidate classification
Forensic interpretation	What is the strongest conclusion consistent with the complete record?	Raw and derived data, contrary findings, alternative explanations	A qualified technical opinion

Chapter Glossary

Terms used in Chapter 31: Advanced Electromagnetic Measurement Science.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

D

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

DETECTION LIMIT — The smallest quantity or signal that can be distinguished from background with a stated probability of detection and false-alarm performance.

F

FLUX DENSITY — The number of magnetic lines of force passing through a given area.

I

IMPEDANCE — The complex ratio of voltage to current at a stated frequency and reference plane, including both resistive and reactive components.

P

POLARIZATION — The time-varying orientation and trajectory of the electric-field vector at a point in space.

R

RMS — Abbreviation of root mean square.

S

SNR — Signal-to-noise ratio: signal power divided by noise power at a stated reference plane and bandwidth.

25. Resonant Probe, Magnetic-Core, Tuning, and Front-End Engineering

This chapter expands the sensor engineering from component selection to completed-system qualification. Low-frequency sensitivity is rarely determined by a single impressive material figure. The useful result emerges from the interaction of complex permeability, demagnetising geometry, winding resistance and capacitance, tuning law, shielding, preamplifier noise, mechanical construction, and the field geometry being measured.

The completed probe is therefore treated as a calibrated transducer with a version-controlled bill of materials and measured transfer function. Substitution of a core, winding, trimmer, diode, cable, shield, or front-end board is a method change when it can alter sensitivity, phase, bandwidth, noise, linearity, microphonics, or spatial response.

25.1 Magnetic material selection by complex permeability and loss

Magnetic-core selection requires the frequency-dependent real and imaginary permeability of the actual material condition, not only a maximum or initial permeability figure quoted at an unrelated test frequency. The governing quantities include $\mu'(f)$, $\mu''(f)$, magnetic loss tangent $\tan\delta_m = \mu''/\mu'$, saturation flux density B_s, coercivity H_c, remanence B_r, resistivity ρ_e, Curie temperature, magnetostriction, ribbon or particle dimensions, and mechanical stress state. The real component supports flux concentration and inductance, while the imaginary component represents loss that can lower Q, increase noise, and change phase; both vary with frequency, field amplitude, temperature, bias, and processing. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object.

In operational practice, each material lot is screened in representative bar and ring geometry over the intended frequency band, with small-signal impedance, loss, noise, temperature, and stress measurements retained. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Trade names are not treated as interchangeable alloys, and catalogue values are not extended beyond their test conditions without measurement.

The interpretive boundary is explicit. The preferred material is the one that produces the best validated system signal-to-noise ratio and stability, not necessarily the highest intrinsic permeability. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.2 Demagnetising factor and effective permeability of open bars

An open rod or bar experiences a demagnetising field that can reduce its effective permeability by orders of magnitude relative to the intrinsic material value. The governing quantities include intrinsic permeability μ_i, demagnetising factor N_d, effective permeability $\mu_{eff} \approx \mu_i/[1 + N_d(\mu_i - 1)]$, aspect ratio, cross-sectional shape, air gaps, and nearby magnetic return paths. As μ_i becomes very large, geometry can dominate and the incremental benefit of still higher intrinsic permeability diminishes; length, diameter, taper, and concentrator design may therefore matter more than the headline material number. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [31-36, 129-131].

In operational practice, probe prototypes are measured in the intended mechanical enclosure and with the actual concentrator because a bare material coupon does not represent the assembled field path. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Mechanical clamping, adhesive shrinkage, cutting damage, bending, and nearby ferromagnetic hardware are challenged as influence quantities.

The interpretive boundary is explicit. Calculated μ_{eff} is used for design screening, while measured inductance and field transfer function control final qualification. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.3 Winding architecture, litz selection, resistance, and parasitic capacitance

The winding is simultaneously a signal transducer, a resistance, a distributed capacitor, a mechanical structure, and a possible antenna for unwanted electric fields. The governing quantities include turn count N, mean turn length, copper resistivity, wire diameter, strand count, skin depth δ, proximity effect, winding resistance $R_w(f)$, interwinding capacitance C_d, self-resonant frequency, section spacing, and electrostatic balance. Increasing N can raise induced voltage in the simplest model, but it also raises resistance and capacitance, lowers self-resonant frequency, lengthens settling, and can make the winding more microphonic and more susceptible to electric-field pickup. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [31-36, 129-131].

In operational practice, the design uses sectional or basket winding where appropriate, compares solid wire with validated litz constructions, and measures impedance and noise after impregnation, shielding, and cable connection. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The chosen wire and sectioning are justified by the actual band; litz wire advantageous at one frequency can add cost or capacitance without benefit at another.

The interpretive boundary is explicit. No turn-count target is accepted without a completed-probe sensitivity, bandwidth, and stability measurement. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.4 Fixed capacitor banks, sapphire piston trimming, and varactor control

The tuning network combines coarse, mechanically stable capacitance with fine manual and electronic adjustment while preserving low loss, repeatability, and linearity. The governing quantities include fixed capacitance C_f, sapphire-piston capacitance C_s, varactor capacitance $C_v(V_b)$, reverse-bias voltage V_b, series resistance R_s, diode quality factor, tuning sensitivity df/dV, temperature coefficient, bias noise, and stored calibration polynomial. The sapphire trimmer provides a low-loss mechanical reference, while the high-reverse-voltage varactor provides controlled fine X-Axis tracking; neither eliminates the need to measure the complete resonator under the deployed source impedance and field level. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [124-131].

In operational practice, the analyser generates per-channel tuning commands, the controller applies filtered bias, the probe settles, resonance is verified, the pilot is removed or blanked, and the evidential sample is acquired during a held bias state. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Anti-series devices, hard bypass states, fixed-capacitance substitution, two-tone tests, leakage-current monitoring, and temperature logging challenge diode-generated rectification or intermodulation.

The interpretive boundary is explicit. The varactor is described as a tuning element and not as a source of gain; any improvement is quantified as resonant transfer optimisation of the passive network. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.5 Concentrator rings, shields, and avoidance of shorted turns

A flux concentrator can improve coupling only when its magnetic path, gap, conductivity, loss, and relationship to the primary winding are controlled. The governing quantities include ring permeability, gap reluctance, cross-sectional area, magnetic path length, conductivity, lamination or ribbon thickness, segmentation, induced circulating current, shield aperture, and winding-to-ring spacing. An uninterrupted conductive ring or screen can behave as a shorted turn and oppose the field being measured, while an ungapped high-permeability path can saturate, retain magnetisation, or distort the spatial response. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [31-36, 129-131].

In operational practice, split, laminated, powdered, ferrite, amorphous, or nanocrystalline structures are compared with non-magnetic controls and are mapped for gain, phase, null direction, saturation, and hysteresis. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The electrostatic shield is slit and connected at a controlled point so that electric-field rejection does not introduce a closed conductive loop.

The interpretive boundary is explicit. The final concentrator is qualified as part of the probe assembly and is not represented merely by the permeability of its raw material. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.6 Low-noise preamplifier design and source-impedance matching

The best front end minimises total input-referred noise for the complex impedance of the tuned probe while preserving headroom, stability, and immunity to common-mode interference. The governing quantities include voltage-noise density e_n, current-noise density i_n, source impedance Z_s(f), noise resistance, input capacitance, bias current, gain, noise figure, input compression point, output intercept, feedback impedance, and common-mode rejection.

A device with exceptionally low voltage noise can perform poorly with a high-impedance resonator if current noise or input capacitance dominates; conversely, a very high-input-impedance stage may sacrifice voltage noise or overload behaviour. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-16, 129-131].

In operational practice, the front end is measured with the actual probe, a substituted impedance network, a terminated input, and strong out-of-band interferers across every gain and filter state. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

Stability, oscillation, recovery from overload, cable drive, power-supply coupling, and self-emission are evaluated in the final enclosure.

The interpretive boundary is explicit. The reported sensitivity belongs to the probe and preamplifier combination and is not transferred to another source impedance by assumption. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.7 Dynamic range, nonlinearity, and intermodulation control

Ultra-low-level search often occurs in the presence of strong broadcast, cellular, switching, mains, and illumination fields, making linearity as important as small-signal noise. The governing quantities include 1 dB compression, second-order and third-order intercept, spurious-free dynamic range, blocking, desensitisation, reciprocal mixing, local-oscillator leakage, ADC full scale, crest factor, and gain distribution.

A narrow digital display can contain a convincing false line created by analogue overload, mixer products, clock feedthrough, aliasing, or front-end rectification long before the selected analysis bandwidth is applied. This section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [10-14, 127-131].

In operational practice, preselection, attenuation steps, gain redistribution, channel substitution, source-off tests, two-tone challenges, and independent receiver topology are used to test linearity. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A candidate that does not scale plausibly with input attenuation or changes frequency when receiver architecture changes is treated as an instrument product.

The interpretive boundary is explicit. Sensitivity claims are always paired with headroom and false-response performance because a receiver that detects its own products is not sensitive in a forensic sense.

A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

25.8 Probe calibration, orientation maps, and environmental qualification

A calibrated probe requires more than a single amplitude factor at one frequency and orientation. The governing quantities include complex antenna factor or probe factor, phase response, orthogonality, null depth, cross-axis sensitivity, uniform-field volume, field-coil geometry, temperature, humidity, vibration, position repeatability, cable state, and calibration uncertainty.

Vector probes and resonant bars can exhibit frequency-dependent pattern distortion, cross-axis pickup, mechanical microphonics, and enclosure coupling invisible in a one-point calibration. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object [7-16, 31-36].

In operational practice, the qualification programme maps amplitude and phase over frequency, axis, orientation, field strength, temperature, and representative deployment geometries, then defines an acceptance envelope. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

Field checks before and after the search test drift and gross damage, but they do not replace periodic traceable calibration or configuration control.

The interpretive boundary is explicit. Data outside the qualified envelope may remain useful for discovery, but they are not reported as calibrated field measurements. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 25-1. Completed-probe design variables and principal consequences

Design variable	Desired contribution	Adverse consequence if uncontrolled	Qualification evidence
Core material and geometry	Flux concentration and inductance	Loss, saturation, hysteresis, demagnetising limitation, stress sensitivity	Complex impedance, field transfer, temperature and bias tests
Winding turns and sectioning	Induced voltage and desired inductance	Resistance, capacitance, low self-resonance, microphonics	RLC sweep, noise, SRF and vibration tests
Sapphire and fixed capacitance	Stable coarse and manual fine tuning	Insufficient range, dielectric loss, mechanical drift	Tuning range, Q, repeatability and temperature tests

Design variable	**Desired contribution**	**Adverse consequence if uncontrolled**	**Qualification evidence**
Varactor branch	Electronic fine tracking	Rectification, intermodulation, bias noise, temperature drift	Bypass, substitution, two-tone and leakage tests
Concentrator and shield	Magnetic coupling and electric-field rejection	Shorted turn, saturation, phase distortion, spatial-pattern error	Gapped and control comparisons, pattern mapping
Preamplifier	Low input-referred noise and usable gain	Oscillation, overload, current-noise penalty, self-emission	Noise, stability, compression, blocking and self-emission tests

Chapter Glossary

Terms used in Chapter 32: Resonant Probe, Magnetic-Core, Tuning, and Front-End Engineering.

C

CAPACITANCE — The property of an electrical circuit that opposes changes in voltage.

D

DYNAMIC RANGE — The span between the smallest and largest input levels that a system can process while meeting specified performance criteria.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

I

IMPEDANCE — The complex ratio of voltage to current at a stated frequency and reference plane, including both resistive and reactive components.

INDUCED VOLTAGE — See INDUCED ELECTROMOTIVE FORCE.

INDUCTANCE — The property of a circuit that tends to oppose a change in the existing current flow. The symbol for inductance is L.

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

R

RESISTANCE — (1) The opposition a device or material offers to the flow of current. The effect of resistance is to raise the temperature of the material or device carrying the current.

S

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

V

VOLTAGE — (1) The term used to signify electrical pressure. Voltage is a force that causes current to flow through an electrical conductor.

26. Coherent Multichannel Array and Receiver Metrology

A multichannel array becomes a measurement instrument only when its channels share a defensible temporal and spectral frame. Merely placing several receivers beside one another creates parallel observations, but it does not establish that the observations describe the same electromagnetic event. This chapter therefore treats the twelve-channel mother chassis, the three external three-axis pods, the tuning-control paths, and the associated reference channels as a single distributed metrological system. It's essential properties are simultaneity, determinism, traceability, bounded channel inequality, and an auditable record of every state transition occurring between the command to observe and the acceptance of a measurement.

The preferred arrangement is a modular analyser or modular search receiver containing twelve or more phase-coherent acquisition paths within one governed chassis. Aftermarket expansion boards are acceptable only when the assembled instrument has been characterised as a whole, because a common enclosure and a common software interface do not prove a common local oscillator, sample clock, trigger epoch, analogue group delay, or phase response.

The functional requirement is consequently more exacting than a procurement description. Each evidential channel must be referred to the same frequency standard and measurement epoch, and each channel-specific departure from the common response must be measured, corrected where justified, and retained as part of the uncertainty record.

The chapter is directed towards expert practitioners who must reconcile radio-frequency engineering with forensic reproducibility. It explains how synchronisation error becomes a spatial error, how mutual coupling becomes an apparent field vector, how tuning latency can misregister a transient, and how a narrow tracking receiver can increase selectivity while simultaneously concealing a signal that falls outside its passband. It does not prescribe a particular commercial instrument. It specifies the performance, control, verification, and documentation properties that any proposed instrument must demonstrate before its output is relied upon.

26.1 Common frequency reference, sample clock, trigger, and event epoch

Coherent vector measurement begins with a shared definition of frequency and time, because phase, delay, pulse position, and spatial comparison are meaningless when channels do not observe a common epoch. The governing quantities include reference frequency f_{ref}, sample rate f_s, sample interval $T_s = 1/f_s$, local-oscillator phase $\phi_{LO}(t)$, trigger time t_0, trigger uncertainty u_t, channel skew Δt_i, aperture jitter, phase noise $L(f)$, and fractional frequency error $y(t)$. A timing displacement Δt produces a phase displacement $\Delta\phi = 2\pi f \Delta t$, so the same physical skew that appears negligible at audio frequency can become a large angular error at hundreds of megahertz.

Reference distribution, clock fan-out, cable delay, connector repeatability, and software time stamping must therefore be considered jointly rather than as independent conveniences. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The applicable principles are consistent with multichannel array and antenna-measurement practice in references [44], [129], and [130].

In operational practice, the site master is allowed to stabilise; every chassis reports lock status; a common event pulse is injected into all acquisition paths; channel-to-channel delay and phase are measured over the working bands; and lock-loss, relock, or reference substitution creates an explicit data boundary.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A second reference source, independent of the instrument under test, is used periodically to expose a shared but erroneous time base, while pre-acquisition and post-acquisition verification records are retained with the evidence package.

The interpretive boundary is explicit. Common time does not by itself establish source coherence. A phase relationship is attributed to the environment only after instrument coherence, reference integrity, and channel-delay corrections have been demonstrated. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.2 Twelve-channel chassis allocation and deterministic signal paths

A twelve-channel architecture supports nine spatially separated sensing paths together with three controls, but only when every path has a declared analogue, digital, and software topology. The governing quantities include channel identity c_i, probe identity p_i, analogue gain $G_i(f)$, noise figure $NF_i(f)$, input compression point $P1dB_i$, third-order intercept $IIP3_i$, filter response $H_i(f)$, analogue-to-digital converter range, decimation factor, detector function, and data-route latency.

The preferred allocation gives each X, Y, and Z probe an uninterrupted receiver path, reserving additional channels for the illumination reference, terminated or dummy control, and guard or independent confirmation function.

This prevents a switch matrix from converting simultaneity into a sequence and avoids the undocumented settling, contact resistance, leakage, and state uncertainty introduced by rapid multiplexing. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Receiver architecture and measurement terminology are treated in references [10], [44], [127], and [128].

In operational practice, the examiner freezes a channel map before deployment, labels each physical connector and cable, records the complete gain and filter state, verifies that software channel names agree with hardware routing, and subjects every route to a known-source continuity and polarity test. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Any internal switching that cannot be eliminated is driven by a deterministic state machine, time stamped against the common epoch, allowed to settle for a validated interval, and followed by a verification sample before evidential acquisition is admitted.

The interpretive boundary is explicit. A channel number is not evidence of a signal path. The evidential record must be able to reconstruct which probe, cable, front end, converter, processing chain, and storage object produced each datum. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.3 Complex amplitude and phase calibration matrix

Nine nominally identical channels will possess unequal complex transfer functions, and those inequalities must be measured before vector magnitude, direction, phase closure, or coherent summation is attempted. The governing quantities include complex channel response $H_i(f) = A_i(f)e^{j\phi_i(f)}$, calibration matrix $C(f)$, measured vector $y(f)$, corrected vector $\hat{x}(f) = C^{-1}(f)y(f)$, residual magnitude error, residual phase error, group delay $\tau_g = -d\phi/d\omega$, covariance matrix Σ_C, and condition number $\kappa(C)$. A scalar gain correction is insufficient where cable delay, filter phase, preamplifier group delay, anti-alias response, or mutual coupling changes with frequency.

A complex calibration matrix permits amplitude and phase de-embedding, but inversion becomes unstable when channels are poorly separated or the matrix is ill-conditioned, and regularisation can conceal rather than cure that deficiency. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Array calibration, multiport response, and probe compensation are addressed in references [44], [129], and [130].

In operational practice, a traceable source is applied through characterised splitters or a calibrated radiating fixture; the response is measured across each operational band and tuning state; the correction matrix is version controlled; and residuals are tested at frequencies not used to fit the correction. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The uncorrected record, the correction coefficients, the corrected record, the covariance terms, and the software version are all preserved. Calibration extrapolation beyond the characterised frequency, gain, temperature, or probe configuration is prohibited unless separately justified.

The interpretive boundary is explicit. A corrected vector is an estimate conditioned upon the calibration model. It is not a direct observation, and its uncertainty must include both measurement noise and uncertainty in the correction matrix. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.4 Pod geometry, orthogonality, and mutual coupling

A three-axis pod samples a local vector field only to the extent that the sensing axes, phase centres, transfer functions, and mutual interactions are known. The governing quantities include axis unit vectors a_x, a_y, a_z, orthogonality error $\varepsilon_{ij} = a_i \cdot a_j$, phase-centre displacement Δr_i, probe separation d_{ij}, coupling coefficients $S_{ij}(f)$, local field vector F, measured voltage vector v, orientation matrix R, and coupling matrix M(f). Mechanical right angles do not guarantee electromagnetic orthogonality, particularly when ferrite bars, concentrator rings, shields, preamplifiers, cables, or nearby structure perturb the field. The measured response may be represented as $v = M(f)R\,F + n$, which shows that vector recovery requires both geometric orientation and electromagnetic cross-coupling to be characterised.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Relevant array, mutual-coupling, and antenna-measurement principles appear in references [44], [129], and [130].

In operational practice, each pod is surveyed mechanically, rotated in a known field, tested for cross-axis rejection, mapped for phase-centre displacement, and assessed for pod-to-pod coupling at the deployed spacing. The support structure is made from materials whose electrical and magnetic influence has been separately measured. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Cable routing is fixed and strain relieved; the pods are tested in the actual tripod, carriage, or robotic mount; and the array is rechecked after transport, impact, winding replacement, preamplifier substitution, or any change to concentrator geometry.

The interpretive boundary is explicit. An apparent field direction is withheld when the inversion is dominated by cross-axis leakage, unknown phase-centre motion, or coupling that approaches the strength of the environmental signal. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.5 Band-segmented probe pods and multiple coherent chassis

The physics of a useful sensor changes across the twenty-hertz to seven-hundred-megahertz search domain, so one nominally broadband probe cannot be presumed to preserve sensitivity, vector fidelity, and calibration throughout that span. The governing quantities include electrical size ka, wavelength λ, effective aperture A_e, magnetic-core complex permeability $\mu'(f)-j\mu''(f)$, winding self-resonance f_{SRF}, antenna impedance $Z_a(f)$, noise matching, dynamic range, phase centre, and site reference coherence. Low-frequency induction probes may require long high-turn windings and selected magnetic materials, whereas higher-frequency work can employ air-core loops, electrically short dipoles, biconical antennas, log-periodic structures, or calibrated near-field probes.

Several band-specific nine-probe systems may therefore be more credible than one compromised universal head, provided that every chassis remains disciplined to the same site reference and its relative epoch is verified. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Field-region, antenna, and probe principles are addressed in references [39], [44], [129], [130], and [131].

In operational practice, the band plan is fixed before the survey; overlap regions are deliberately measured by adjacent systems; cross-band reference sources are recorded; and the examiner documents where a source family crosses from magnetic induction sensing to electric-field or radiative sensing. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. At least one overlap test is performed at each band boundary to reveal discontinuities caused by probe substitution, filter change, local-oscillator plan, or chassis-specific calibration. Conflicting results are investigated rather than averaged.

The interpretive boundary is explicit. Agreement between different band systems strengthens a source hypothesis only when their spatial, temporal, and spectral responses are physically compatible.

Mere coincidence of nominal frequency is insufficient. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.6 Frequency-slaved resonance control and the measurement transaction

A resonant magnetic probe whose varactor bias is commanded from the analyser frequency axis can remain near peak transfer during a search, but only if tuning is treated as a verified measurement transaction rather than an invisible software convenience.

The governing quantities include commanded frequency f_c, measured resonant frequency f_r, tuning error $e_f = f_r - f_c$, varactor bias V_b, capacitance $C_v(V_b)$, total capacitance C_T, loaded quality factor Q_L, resonance bandwidth $B = f_r/Q_L$, settling time t_s, pilot amplitude, and lock-valid flag.

The analyser frequency coordinate must not be confused with the physical X orientation of an antenna. It generates a calibrated frequency command that is translated into a separately filtered bias for each applicable probe.

Because capacitance-voltage curves, temperature, hysteresis, bias leakage, and mutual loading differ among probes, one global tuning voltage cannot be assumed to place nine resonators at the same frequency. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Varactor and analyser-triggering references include [124] through [128], with resonant-probe principles in [31] through [38].

In operational practice, the system executes a command, coarse tune, fine tune, settle, resonance verify, calibration-source removal, bias hold, acquisition, and post-acquisition verification sequence. Samples acquired while the probe is slewing, the pilot remains present, or the resonance-valid flag is false are marked non-evidential. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The fixed-capacitor bank and sapphire piston capacitor establish the stable tuning region, while the varactor provides limited electronic correction. A fixed-capacitance bypass record and a known-source intermodulation test are obtained to expose false products generated by the tuning junction.

The interpretive boundary is explicit. Resonance maximises a defined transfer response. It does not prove that the source lies at the tuned frequency, does not create active antenna power gain, and does not excuse separate characterisation of bandwidth, phase, noise, and nonlinearity. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.7 Triggered acquisition of intermittent and low-duty-cycle events

Signals that exist for seconds per day, milliseconds per interrogation, or a few pulse intervals cannot be characterised reliably by a conventional sequential sweep unless the observation probability is quantified.

The governing quantities include event duration T_e, repetition interval T_r, duty factor $\delta = T_e/T_r$, sweep revisit time T_v, probability of intercept P_i, pre-trigger duration T_{pre}, post-trigger duration T_{post}, trigger latency τ_{tr}, trigger jitter u_{tr}, real-time bandwidth B_{RT}, and record length N_s. A fixed-span real-time or vector I/Q receiver observes all frequencies within its instantaneous bandwidth, while a swept analyser observes a moving subset.

An independent illumination or event-reference channel can establish a common trigger, and iterative delay adjustment can move the acquisition window until the onset, steady response, pulse displacement, and decay are all contained within the record. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Triggered and fixed-span acquisition principles are addressed in references [127] and [128], with pulse analysis in [42] and [80].

In operational practice, the examiner first captures a passive baseline, then verifies the reference channel, applies negative and sham triggers, acquires with generous pre-trigger memory, and iterates delay in coarse and fine steps only after a repeatable latency has emerged. Trigger thresholds and hold-off are varied to expose threshold-induced selection bias.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A second receiver with a different local-oscillator and intermediate-frequency plan is used for confirmation, and the record includes missed-trigger tests, artificially injected short events, and an estimate of probability of intercept for the declared waveform class.

The interpretive boundary is explicit. Temporal correlation is a necessary observation, not a sufficient attribution. Direct breakthrough, shared power transients, switching artefacts, and receiver overload must be excluded before a response is described as environmentally generated.

A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

26.8 Channel health, data throughput, storage, and provenance

A coherent array can lose evidential integrity through dropped samples, silent clipping, channel substitution, clock discontinuity, or file-handling error even when its displayed traces appear orderly. The governing quantities include sample word length b, sample rate f_s, channel count N_c, sustained data rate $R_d = N_c f_s b$, buffer depth, dropped-sample count, clip count, packet sequence, time-stamp continuity, storage latency, file hash, configuration hash, and audit-event identifier. Twelve simultaneous high-rate channels can produce data volumes that exceed ordinary storage or network capacity, and software may respond by decimation, compression, selective recording, or discarded frames. Each such operation changes the measurement and must be deliberate, declared, and validated rather than left to an automatic performance mode.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The quality-system and data-integrity principles align with references [1] through [9] and the receiver documentation in [127] and [128].

In operational practice, the acquisition controller performs a pre-run health check, writes a cryptographically bound configuration manifest, monitors lock, clipping, temperature, storage margin, and sample continuity during the run, and closes the record with post-run calibration and hashes. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Raw or minimally processed I/Q data are retained for consequential events together with display traces, derived spectra, correction coefficients, and software logs. Any lossy representation is labelled and is never substituted for the source record.

The interpretive boundary is explicit. A visually persuasive spectrum is not admissible as a complete measurement when the underlying samples, timing continuity, channel identity, or processing history cannot be demonstrated. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 26-1. Preferred twelve-channel allocation for the coherent mother chassis.

Channel	Primary assignment	Metrological purpose
1	Pod A, X-axis probe	Simultaneous first-site vector component
2	Pod A, Y-axis probe	Simultaneous first-site vector component
3	Pod A, Z-axis probe	Simultaneous first-site vector component

Channel	Primary assignment	Metrological purpose
4	Pod B, X-axis probe	Second-site vector and spatial-gradient component
5	Pod B, Y-axis probe	Second-site vector and spatial-gradient component
6	Pod B, Z-axis probe	Second-site vector and spatial-gradient component
7	Pod C, X-axis probe	Third-site vector and spatial-gradient component
8	Pod C, Y-axis probe	Third-site vector and spatial-gradient component
9	Pod C, Z-axis probe	Third-site vector and spatial-gradient component
10	Illumination sync for event-reference receiver	Independent confirmation of interrogating field and common trigger epoch
11	Terminated, dummy, or calibration path	Receiver artefact, cable, switching, and reference-source control
12	Guard, narrow tracking, or independent-confirmation receiver	Selectivity enhancement, perimeter comparison, or alternative receiver architecture

Chapter Glossary

Terms used in Chapter 33: Coherent Multichannel Array and Receiver Metrology.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

E

EFFECTIVE APERTURE — The equivalent area that relates incident power density to the available received power of an antenna for a specified polarization and direction.

M

MAGNETIC INDUCTION — Generating a voltage in a circuit by the creation of relative motion between a magnetic field and the circuit. The relative motion can be the result of physical movement or the rise and fall of a magnetic field created by a changing current.

N

NOISE FIGURE — The degradation of signal-to-noise ratio caused by a device or system, expressed relative to an ideal noiseless reference at a standard temperature.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

V

VERIFICATION — The confirmation, through examination or objective evidence, that specified requirements have been fulfilled.

27. Three-Dimensional Search Geometry, Scene Control, and Inverse Localisation

The physical scene is not merely the place in which instruments are carried. It is a spatial experiment whose geometry, occupancy, conductive structures, human movement, and equipment state can alter the fields being measured. The search therefore borrows the disciplined control, measured drawing, access isolation, hard-point registration, and progressive subdivision used in forensic scene processing, while adapting those practices to electromagnetic evidence. The principal exhibit is not an object removed from the room. It is a reproducible, time-stamped field observation associated with a defined coordinate, orientation, configuration, and environmental state.

The nested sequence of 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet, and 3 feet, followed by stationary three-inch decrements and a three-dimensional three-inch lattice, is consequently treated as a hierarchy of increasingly constrained questions. The outer stations characterise regional and building-scale fields. The intermediate rings test structural and service-path coupling. The inner stations resolve room boundaries, local gradients, and candidate volumes. The final lattice does not simply make the grid smaller. It changes the experiment from broad reconnaissance to a controlled inverse localisation problem.

Crime-scene discipline is copied for its capacity to preserve context, not because the inspection necessarily concerns an offence. Entry and exit are controlled, hard points are declared, rooms are drawn, furniture is located by measured geometry, evidence triangles or coordinate markers are placed adjacent to observations, and every movement is recorded as an intervention. The room is then represented as a set of addressable cubes and surface cells. Each cube is examined in a declared order, and its physical, electrical, acoustic, magnetic, and procedural conditions are compared with neighbouring and control cubes.

27.1 The 300-foot reference baseline and regional field model

The first station at approximately three hundred feet establishes the broad electromagnetic and temporal environment before the inspection team, its cables, its power supplies, and its movement become part of the scene. The governing quantities include station coordinate r_0, source-to-station distance r, frequency f, wavelength λ, ambient field E_0 and H_0, noise power spectral density $N_0(f)$, occupancy state, weather, nearby transmitters, utility state, instrument self-emission, and observation duration T_{obs}. At low frequency, three hundred feet may remain electrically close relative to wavelength, while at microwave frequency it may be a far-field observation.

The station is therefore a reference in the evidential sequence rather than a universal propagation boundary, and it must be interpreted through frequency-scaled geometry and the surrounding conductive environment. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The principles of field regions and propagation are developed in references [39], [43], [129], and [130].

In operational practice, the team records broad and narrow spectra, long-duration waterfall and I/Q data, mains and timing families, intermittent activity, known transmitters, traffic and machinery cycles, and reference-channel behaviour before approaching the premises. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A second regional control point, offset in azimuth or elevation where practical, is used to distinguish a building-associated gradient from a wider-area emitter. The instrument package is also operated into terminated and dummy inputs to establish its own emissions.

The interpretive boundary is explicit. A feature present at the 300-foot station may remain relevant, but it is not attributed to the premises merely because it persists inward. The later path must demonstrate a physically credible gradient, coherence, structural route, or localised maximum. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.2 Nested search rings as a sequential measurement experiment

Each inward ring is a planned comparison against the immediately preceding and remote reference conditions, not a casual stopping point on a walk towards a stronger display. The governing quantities include ring radius r_k, station azimuth θ_k, elevation z_k, dwell T_k, field vector F_k, corrected amplitude A_k, phase ϕ_k, coherence γ_k, gradient $\Delta F/\Delta r$, environmental covariates q_k, and advancement decision d_k. A source may produce non-monotonic amplitude because of standing waves, conductive reradiation, shielding apertures, multipath, probe orientation, or near-field structure. The ring sequence therefore evaluates several observables together, including vector direction, phase continuity, harmonic family, burst timing, and response to perpendicular or reverse-path measurements.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The progressive search logic is adapted from scene-search discipline in reference [71] and measurement principles in references [1] through [9].

In operational practice, the examiner completes the full station record at 300, 150, 100, 50, 30, 15, 12, and 3 feet, using fixed probe height, orientation, bandwidth, gain, dwell, and reference state wherever the geometry permits. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Advancement is controlled by predeclared gates. A candidate must survive terminated-input checks, gain-step tests, probe substitution, known-source checks, and a comparison with at least one neighbouring azimuth before the grid is narrowed around it.

The interpretive boundary is explicit. Failure to increase monotonically does not disprove a source, and an increase does not prove one. The value of the ring method lies in the ensemble of spatially and temporally consistent observations. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.3 Hard points, baselines, triangulation, trilateration, and room drawings

A room drawing becomes evidentially useful only when every reported point can be reconstructed from stable references with a known coordinate convention and measured closure. The governing quantities include origin O, orthogonal axes x, y, z, hard points H_i, baseline length b, measured ranges d_i, bearing angles α_i, elevation angles β_i, coordinate vector $r = [x,y,z]^T$, residual closure e_c, and positional covariance Σ_r. Triangulation estimates position from angles, while trilateration estimates position from distances. Rectangular offsets are efficient in regular rooms, but diagonal measurements to two or more hard points provide redundancy.

For two-dimensional trilateration, $x = (d_1^2-d_2^2+b^2)/(2b)$ and $y = \pm\sqrt{d_1^2-x^2}$ under the idealised baseline geometry, with the sign resolved from the declared room orientation. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Measured scene-sketch and fixed-point principles are adapted from reference [71], with uncertainty treatment from reference [9].

In operational practice, the scene surveyor selects durable hard points, photographs or describes them where non-imaging restrictions permit only textual description, measures the inter-hard-point network, declares the origin and positive axes, and records furniture, fixtures, penetrations, service routes, doors, and probe stations by redundant coordinates. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Closure residuals are compared with an acceptance criterion before electronic measurements begin. Any hard point that moves, flexes, or cannot be recovered is retired through a recorded change-control event and replaced by a newly surveyed network.

The interpretive boundary is explicit. A coordinate does not imply more precision than the survey supports. Reported locations are accompanied by positional uncertainty and by a description of whether the point denotes a probe phase centre, a marker, a surface cell, or a bounded candidate volume. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.4 Three-foot, twelve-inch, and three-inch volumetric sampling

Progressive cube subdivision permits the sampling density to increase only where the observations justify it, preserving both efficiency and an auditable account of the path by which a candidate volume was selected. The governing quantities include cell edge a, cell volume $V=a^3$, cell index (i,j,k), cell centre r_{ijk}, surface normal n, probe standoff s, sampling pitch Δ, spatial Nyquist consideration, field gradient ∇F, and localisation covariance. A three-foot cube is a coarse discovery element, a twelve-inch cube is an intermediate refinement element, and a three-inch cube is a fine convergence element.

These dimensions are procedural sampling scales, not claims that electromagnetic fields are uniform inside a cube or that a source can always be resolved to the cell size. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The search-grid logic is adapted from reference [71]; field sampling and near-field measurement principles are treated in references [44], [129], and [130].

In operational practice, each room is tessellated from the declared origin; cells receive persistent identifiers; inaccessible and excluded volumes are logged; and the probe centre, orientation, standoff, dwell, receiver state, environmental state, and file identifiers are recorded for every measured cell. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Refinement occurs around a cluster rather than a single maximum where noise or spatial aliasing could dominate. At least one ring of neighbouring cells and one matched control cell are retained after every subdivision.

The interpretive boundary is explicit. The finest cell reached is not automatically the uncertainty of localisation. The reported uncertainty includes sampling pitch, phase-centre uncertainty, positional survey error, field variability, coupling path, and model ambiguity. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.5 Movement, access, and environmental change as experimental interventions

Opening a door, moving a chair, rerouting a cable, carrying a receiver, or placing a human body near a probe can alter shielding, capacitance, magnetic coupling, multipath, grounding, and source operating state. The governing quantities include intervention identifier I_m, before-state q_b, after-state q_a, affected-cell set C_m, time t_m, moved-object coordinates, path through the scene, personnel proximity, power-state change, and response difference $\Delta Y = Y_a - Y_b$.

The scene log therefore treats movement as a controlled intervention. A result obtained after an unrecorded change cannot be compared cleanly with a pre-change baseline because the physical system is no longer known to be the same. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Scene-control and documentation principles are adapted from references [1], [2], and [71].

In operational practice, access is restricted through an inner measurement boundary; personnel, equipment, batteries, cables, wireless devices, and conductive articles are registered; movement routes are marked; and each authorised change receives an identifier, reason, responsible person, and before-and-after measurement plan. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Affected, adjacent, traversed, service-connected, and control cells are remeasured after a significant intervention. The acquisition clock and scene log are synchronised so that every data record can be associated with the correct room state.

The interpretive boundary is explicit. A change-correlated signal may reveal a coupling mechanism, but it may equally be produced by the moved object, the operator, or the measurement system. The intervention is interpreted through controls rather than as self-proving evidence. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.6 Vector gradients, null planes, and non-imaging localisation

Non-imaging localisation relies upon the geometry of measured fields and their change through space, rather than upon a photograph, radiograph, or reconstructed picture of the concealed object. The governing quantities include complex field vector $F(r,f)$, magnitude $|F|$, phase $\phi(r,f)$, gradient $\nabla|F|$, directional derivative $n\cdot\nabla|F|$, null orientation, polarisation ellipse, coherence $\gamma^2(f)$, cross-spectral matrix $S_F(f)$, and estimated source region Ω_s. A magnetic loop or rod exhibits orientation-dependent response and may show a null when its sensitive axis is orthogonal to the relevant field component. Three-axis simultaneous measurements permit a local vector estimate, while three spatially separated pods permit gradient and phase comparisons.

Inverse localisation remains non-unique when extended conductors, multiple sources, reflections, or unknown material boundaries dominate. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Vector reception, polarisation, effective aperture, and array concepts are treated in references [39], [44], [129], and [130].

In operational practice, the examiner rotates or electronically compares orthogonal probes, maps nulls and maxima, calculates local gradients, compares cross-spectral phase, and advances towards the intersection of compatible directional constraints rather than the largest single amplitude. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The result is challenged by reversing the path, exchanging pod positions, substituting a different probe family, altering standoff, and repeating the measurement after a controlled time interval.

The interpretive boundary is explicit. The output is a bounded region with declared uncertainty and source-model qualifications. It is not an image, a component inventory, or a statement of intended function. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.7 Extended conductors, service paths, and distributed sources

Cables, pipes, reinforcing steel, screens, earth conductors, ducts, and building services can convey or reradiate a weak signal so that the strongest external field is remote from its originating circuit. The governing quantities include conductor path coordinate s, propagation constant $\gamma=\alpha+j\beta$, common-mode current $I_{cm}(s)$, transfer impedance $Z_t(f)$, attenuation α, phase constant β, discontinuity position, shield aperture, termination impedance, and distributed source density $J_s(s)$. An extended conductor can behave as a transmission line, an electrically short electrode, a magnetic loop, or an unintended antenna according to frequency and geometry. A local maximum on a cable therefore identifies a coupling or current condition, not necessarily the location of the active device.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Transmission-line and antenna principles are addressed in references [43], [129], and [130].

In operational practice, the 30-foot and 15-foot rings explicitly examine utility entries, cable routes, external plant, protective earth, fences, and structural transitions. Inside the room, conductor-following measurements are paired with perpendicular transects and reference probes positioned away from the path. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Where authority and safety permit, non-invasive state changes at an accessible termination may be used as controlled interventions. Continuity, conducted current, field response, and phase progression are documented without opening, disconnecting, or altering the suspected device.

The interpretive boundary is explicit. Localisation is reported as origin-associated, path-associated, or unresolved distributed coupling according to the evidence. The examiner does not equate the hottest cable segment with the source. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

27.8 Reverse-path closure and temporal stationarity

A localisation path is credible only when the observed spatial structure can be recovered after the team reverses direction or repeats the sequence under a documented equivalent state. The governing quantities include forward observation $Y_f(r,t)$, reverse observation $Y_r(r,t+\Delta t)$, closure residual $e(r)=Y_f-Y_r$, temporal drift dY/dt, source intermittency, environmental covariance, repeatability standard deviation s_r, and acceptance threshold e_max. Forward and reverse traces separate a stable spatial gradient from time drift, operator approach, instrument warm-up, hysteresis, or one-way procedural contamination. Exact equality is neither expected nor required, but departures must be compatible with the combined uncertainty and observed temporal behaviour.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Repeatability and uncertainty principles follow references [7] through [10], with scene repetition informed by reference [71].

In operational practice, the team repeats the critical segment in reverse order, preserves reference channels during the interval, reoccupies matched coordinates and orientations, and calculates closure for magnitude, phase, timing, and classification state. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. If the feature is intermittent, the comparison uses event-conditioned records and reports probability of observation rather than treating a missed event as disappearance. A stationary control probe remains fixed throughout the traverse to expose common temporal change.

The interpretive boundary is explicit. Failure of closure weakens spatial attribution and normally returns the examination to a broader grid or longer dwell. It is not repaired by selecting only the measurements that agree.

A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 27-1. Spatial scale, governing question, principal observables, and expected output.

Scale or station	Governing question	Principal observables	Expected output
300 feet	What is the regional baseline before scene approach?	Ambient spectra, long-duration events, reference channels, known services	Remote baseline and candidate-family register
150 feet	Does a premises-associated gradient or timing relationship begin to emerge?	Vector amplitude, phase, coherence, azimuthal comparison	Outer-transition comparison
100 feet	Is the observation reproducible on a closer controlled ring?	Matched configuration, gain-step and dummy-path controls	Confirmed or rejected regional candidate
50 feet	Does the field follow the building, a service route, or a wider emitter?	Multiple azimuths, structural routes, reference probe	Building-scale source model
30 feet	Do cables, pipes, earths, fences, or penetrations convey the signal?	Conductor-following and perpendicular measurements	Service-path association or exclusion
15 feet	What stable boundary-referenced condition exists before threshold work?	Wall, door, glazing, service and exterior-control comparisons	Pre-boundary record
12 feet	How does the field behave across the controlled threshold?	Threshold dwell, entry controls, before-and-after state	Boundary-transfer model
3 feet	Which local zone warrants volumetric refinement?	Three-pod vector gradient, nulls, phase and repeatability	Candidate room region

Scale or station	**Governing question**	**Principal observables**	**Expected output**
3-foot cubes	Which coarse volume contains the strongest compatible evidence?	Cell-wise vector, timing, controls and environment	Coarse candidate cluster
12-inch cubes	How does the candidate cluster refine?	Neighbour comparisons, probe substitution, reverse path	Intermediate candidate volume
3-inch cubes and decrements	What bounded volume is supported by the highest-resolution non-contact measurements?	Fine vector gradients, phase, nulls, timing, uncertainty	Non-imaging localised region with uncertainty

Chapter Glossary

Terms used in Chapter 34: Three-Dimensional Search Geometry, Scene Control, and Inverse Localisation.

A

ALIASING — The indistinguishable mapping of different continuous-time frequencies to the same sampled representation when the sampling process is insufficiently constrained.

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

E

EFFECTIVE APERTURE — The equivalent area that relates incident power density to the available received power of an antenna for a specified polarization and direction.

I

IMPEDANCE — The complex ratio of voltage to current at a stated frequency and reference plane, including both resistive and reactive components.

P

PROPAGATION — Waves traveling through a medium.

T

TRANSFER IMPEDANCE — A frequency-dependent measure relating current on one side of a cable shield or enclosure boundary to the voltage developed on the other side.

TRANSMISSION LINE — A device designed to guide electrical or electromagnetic energy from one point to another.

28. Advanced Signal, Modulation, Timing, Interface, SAW, and Audio Analysis

A weak electronic emission is seldom understood by carrier frequency alone. The information required for discrimination may reside in harmonic spacing, sideband symmetry, instantaneous phase, pulse position, cyclic statistics, burst cadence, clock division, common drift, or the relationship between a radiated field and a conducted or magnetic companion. This chapter therefore treats a candidate signal as a multidimensional object whose frequency, time, phase, modulation, spatial behaviour, and equipment-state dependence must be examined together.

The analytical objective is classification and source association, not the recovery of private content. Demodulation is used only to the extent necessary to characterise bandwidth, deviation, symbol or pulse timing, periodicity, clock relationships, and modulation family.

The protocol does not authorise pairing, authentication attempts, packet injection, credential use, payload reconstruction, intelligible speech monitoring, or other interaction that would exceed the inspection authority. Where an audio-related path is suspected, the preferred record consists of field strength, spectral envelope, coherence, and timing metadata rather than reproduced programme material.

Particular attention is given to timing oscillators, SAW resonators, sleeping-device clocks, narrowband FM, intermittent microphones, nested subcarriers, and retroreflective responses. These cases reward a expert practitioner who can move fluently between the oscilloscope, spectrum analyser, vector I/Q display, spectrogram, cyclic spectrum, broadband energy recording systems and spatial field map.

No one display is privileged. Each is a projection of the same physical event through a different measurement operator, and the conclusions must remain compatible across those projections.

28.1 Clock families, harmonics, dividers, and evidence of common origin

Clock and timing circuits can be traced through a family of fundamentals, harmonics, divider products, sidebands, and burst cadences, but an integer frequency relationship is only the beginning of the analysis. The governing quantities include fundamental frequency f_0, harmonic order n, harmonic frequency $f_n=nf_0$, divider ratio m, subharmonic f_0/m, frequency offset Δf, fractional error $\Delta f/f_0$, drift df/dt, phase $\phi_n(t)$, Allan deviation $\sigma_y(\tau)$, sideband spacing f_m, and coherence $\gamma^2(f)$.

Finite rise and fall times, asymmetrical duty cycles, switching-current loops, package leads, cable common mode, apertures, and nonlinear junctions can suppress the fundamental while coupling one or more higher harmonics efficiently.

For that reason, a harmonic often gives the clearest spatial gradient even though the timing circuit operates at the lower fundamental. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Clock selection and oscillator context appear in references [24] through [26], with signal-analysis principles in [42], [72], and [80].

In operational practice, the examiner searches the complete declared clock register and its harmonic families, records the first ten harmonics and relevant higher landmarks, and compares frequency error, drift, start-stop cadence, sideband spacing, phase continuity, and spatial response across the family.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A common-origin hypothesis is challenged by changing receiver architecture, bandwidth, probe family, orientation, and station while a reference clock monitors analyser error. Independent environmental sources at integer-related frequencies are actively sought.

The interpretive boundary is explicit. Harmonic leakage may be the easiest path to localisation, but it does not reveal the purpose of the oscillator or prove that all family members arise from one device without shared temporal and spatial evidence. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.2 Complex-envelope analysis of amplitude, frequency, phase, and sideband structure

Amplitude modulation, frequency modulation, phase modulation, suppressed-carrier systems, and single-sideband systems are most consistently compared through their complex envelope rather than through isolated display shapes. The governing quantities include analytic signal $z(t)=I(t)+jQ(t)=A(t)e^{j\phi(t)}$, envelope $A(t)$, instantaneous phase $\phi(t)$, instantaneous frequency $f_i(t)=(1/2\pi)d\phi/dt$, modulation index m_a or β, carrier f_c, modulation frequency f_m, deviation Δf, occupied bandwidth B_{occ}, and sideband amplitudes. A conventional AM waveform changes envelope while retaining a carrier, DSB-SC suppresses the carrier, SSB retains one translated sideband, ISB places independent information in two sidebands, and FM or PM primarily changes instantaneous phase.

Receiver local-oscillator error, multipath fading, limiting, clipping, and insufficient I/Q balance can make one family resemble another. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Modulation definitions and bandwidth principles are treated in references [42], [72], and [73].

In operational practice, the examiner acquires calibrated I/Q where available, removes only declared receiver offsets, plots envelope and instantaneous frequency, compares upper and lower sidebands, measures occupied bandwidth and deviation, and verifies the result at more than one resolution bandwidth. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The record includes detector type, window function, sample rate, decimation, carrier estimator, phase-unwrapping method, and any carrier or clock recovery applied. A raw-data copy is preserved before analytical transformations.

The interpretive boundary is explicit. A modulation label is reported at the narrowest defensible level. Where the evidence supports only angle modulation, narrowband occupancy, or an asymmetrical sideband structure, the report does not force a more specific name. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.3 Pulse modulation, pulse-position measurement, and timing uncertainty

Pulse-amplitude, pulse-width, pulse-position, pulse-frequency, pulse-repetition, pulse-code, pulse-density, delta, burst, and ultra-wideband methods require separate timing and amplitude descriptors. The governing quantities include pulse arrival time t_i, reference epoch t_{ref}, pulse-position displacement $\Delta t_i = t_i - t_{ref}$, pulse width τ_p, rise time t_r, repetition interval T_r, repetition frequency $f_r = 1/T_r$, amplitude A_i, duty factor δ, jitter standard deviation σ_t, timing covariance, and measurement uncertainty u_t. In pulse-position modulation, the information-bearing variable is the displacement of a pulse relative to an expected slot or reference interval. A threshold detector can bias that displacement when amplitude changes, so constant-fraction timing, matched filtering, or model-based edge estimation may be required. Instrument bandwidth and group delay place a lower bound upon resolvable timing structure.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Pulse and digital communication principles appear in references [42], [73], and [80].

In operational practice, the examiner records the reference waveform and response waveform on a common time base, measures pulse descriptors over an ensemble, evaluates missing and extra pulses, and reports both central tendency and dispersion rather than a single attractive trace. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Timing is repeated at several thresholds or estimator settings, and an injected pulse standard is used to characterise channel delay and jitter. Pre-trigger, trigger latency, gate delay, and record-length effects are included in the uncertainty budget.

The interpretive boundary is explicit. A repeated pulse displacement supports a timing relationship. It does not, without spatial and control evidence, establish that the pulse was produced by a particular concealed circuit. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.4 Nested modulation, subcarriers, and same-family modulation

A host carrier may contain one or more subcarriers whose own amplitude, frequency, phase, pulse, or noise-like structure carries the diagnostically useful timing. The governing quantities include host carrier f_c, subcarrier f_s, nested modulation index, frequency translation $f_c \pm k f_s$, cross-modulation products, baseband spectrum $B(f)$, cyclostationary frequency α, spectral-correlation function $S_x^\alpha(f)$, and coherence between host and subcarrier features.

Examples include a nominally continuous carrier with a pulse-position subcarrier, an AM or NFM host carrying a noise-like subcarrier, and an NFM carrier whose subcarrier is itself NFM. Such combinations can look complicated in an ordinary sweep while remaining conspicuous in cyclic statistics, instantaneous-frequency traces, sideband spacing, or a demodulated spectrum. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Nested and cyclostationary analysis draws upon references [42], [73], and [80].

In operational practice, the examiner analyses the undemodulated I/Q record first, then applies successive, reversible demodulation stages while preserving the output of each stage and documenting every filter, deviation, centre frequency, and phase reference. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A candidate subcarrier is confirmed by returning to the original RF and demonstrating the corresponding sideband or cyclic structure. Synthetic test signals are used to establish that the analysis chain does not create the nested feature.

The interpretive boundary is explicit. Nested modulation can increase classification difficulty while providing several independent observables for detection. The added structure is treated as evidence only when it survives alternate receiver and processing methods. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.5 Bursts, voice-operated activity, hopping, and cyclostationary structure

Low-duty-cycle transmitters and voice-operated devices can be absent during a short search, while hopping and burst systems can distribute their energy so thinly that no conventional narrow sweep retains the complete event. The governing quantities include burst duration T_b, inter-burst interval T_i, duty cycle δ, hop set F_h, dwell T_d, hop rate R_h, revisit time, occupancy probability, cyclic frequency α, spectral occupancy $O(f,t)$, probability of intercept P_i, and false-event rate. Energy detection alone is unreliable in a busy spectrum, but periodic burst timing, repeated hop transitions, clock-related slot structure, and cyclic spectral correlation can reveal a process whose instantaneous carrier changes. Conversely, ordinary digital networks can produce equally intricate patterns and must be treated as competing explanations.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Relevant signal and standards contexts appear in references [72], [73], [80] through [95], [127], and [128].

In operational practice, the examiner combines long-duration channelised monitoring with high-probability-of-intercept real-time capture, uses event clustering rather than isolated maxima, and correlates candidate events with room state, reference channels, known wireless activity, and spatial gradients. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Known radios and networks are inventoried and, where authority permits, placed through documented state changes without pairing or traffic generation. Source-absent and quiet-period observations are retained to estimate the event background.

The interpretive boundary is explicit. A failure to observe a rare burst within a finite dwell is a non-detection, not proof of absence. The report states observation time, estimated coverage, and the waveform classes for which the probability of intercept was evaluated. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.6 Digital interfaces, spread-spectrum clocks, and sleep-state signatures

Modern devices can remain electromagnetically active when their main processor appears asleep because power-management, wake, charging, real-time-clock, interface-detection, memory-retention, or network-paging domains remain energised. The governing quantities include power state S_p, reference clock f_{ref}, spread-spectrum deviation Δf_{ssc}, modulation rate f_{ssc}, interface lane rate R_l, common-mode current I_{cm}, wake interval T_w, discontinuous-reception cycle, hot-plug or configuration-channel state, and state-transition time t_s. USB, USB3, USB4, Type-C, Power Delivery, HDMI, DisplayPort, Ethernet, PCI Express, SATA, FireWire, serial buses, digital audio, and wireless subsystems can produce fundamentals, harmonics, reference clocks, framing periodicities, and cable-mode radiation.

Spread-spectrum clocking broadens a line into a deterministic skirt rather than eliminating the timing source. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The applicable standards register is contained in references [81] through [120].

In operational practice, the examiner records the declared device state, external power and cable condition, wake-capable interfaces, charger and battery-management activity, and the complete spectral family before and after an authorised state transition. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Matched control devices and disconnected cables are used where available. Interface clocks are compared with official or manufacturer specifications, but catalogue frequencies are treated as hypotheses because implementation, power state, divider plan, and spread-spectrum settings vary.

The interpretive boundary is explicit. A timing signature may indicate an energised domain. It does not by itself identify the application, data content, ownership, or whether the observed device is the source rather than a coupled conductor. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.7 SAW resonators, SAW filters, passive sensors, and ultra-low-power sources

Surface-acoustic-wave devices may stabilise an oscillator, select a passband, encode a reflective delay pattern, or form a passive sensor, and each role produces a different search signature. The governing quantities include nominal resonance f_r, series and parallel resonances, insertion loss L_i, loaded quality factor Q_L, motional resistance R_m, frequency tolerance, temperature coefficient, ageing, group delay $\tau_g(f)$, reflection coefficient $\Gamma(f)$, interrogation frequency f_i, and response delay τ_d. A SAW-stabilised transmitter can radiate near the resonator frequency with drift limited by the device specification, while a SAW filter may reveal only the active circuitry around it. A passive reflective structure can return same-frequency, delayed, coded, harmonic, or translated energy during authorised illumination.

Historical frequency lists are therefore useful search seeds but not universal device signatures. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Relevant material appears in references [53] through [62] and [67] through [70].

In operational practice, the examiner searches the exact supplied and manufacturer-derived candidate frequencies, their tolerance windows and harmonics, while maintaining broad continuous coverage from the low-frequency timing domain through the authorised RF bands. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

A passive baseline precedes illumination. Candidate responses are tested with frequency offsets, polarisation changes, azimuth changes, source-off records, sham triggers, alternative receivers, and spatial convergence before any device-associated wording is used.

The interpretive boundary is explicit. A response near a familiar SAW frequency supports a resonator hypothesis only when its bandwidth, stability, delay, spatial behaviour, and control response are compatible. Frequency coincidence alone is weak evidence. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

28.8 Microphone-scale circuits and voice-frequency conductor fields

A miniature microphone or audio front end can produce magnetic and electric leakage through bias current, transducer current, preamplifier activity, digital clocking, cable imbalance, and return-path geometry even when no radio-frequency transmitter is present. The governing quantities include audio frequency f_a, current $I_a(f)$, loop area A_l, magnetic field $H(f,r)$, probe effective area $A_e(f)$, induced voltage $V_{ind}=\omega NAB$, conductor separation, common-mode and differential-mode currents, weighting function $W_C(f)$, coherence with test stimulus, and privacy-preserving feature vector.

The thirty-hertz to fourteen-kilohertz band can be examined with bar probes whose core, winding, resonance, and preamplifier are designed for the relevant frequency segment. Additionally, a 1 kHz tuned bar antenna, with a concentrator ring is used in order to detect a pulsed 1 kHz test audio signal, which is synchronized with th receiver.

C-message weighting is a derived analytical view of a flat acquisition, not a resonance to which the probe itself should be tuned. Digital microphones may also reveal PDM clocks and harmonics far above the voice band. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Audio weighting, module, and microphone contexts appear in references [57], [63] through [66].

In operational practice, the examiner uses controlled non-speech acoustic stimuli where lawful and necessary, records magnetic and electric field features without listening for intelligibility, compares balanced and common-mode probe responses, and follows wiring through spatial gradients and phase. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Probe microphonics are tested by mechanical tapping away from the scene, acoustic shielding, dummy cores, cable immobilisation, and comparison with an electrical reference channel. Environmental hum, lighting, motors, loudspeakers, and hearing-aid systems are inventoried as competing sources.

The interpretive boundary is explicit. A voice-band-correlated field supports an audio-current or acoustically responsive circuit hypothesis. It does not authorise content recovery or establish surveillance purpose. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 28-1. Signal-family observables and minimum confirmation requirements.

Signal family	Most informative observables	Minimum confirmation before stronger classification
Clock or timing family	Fundamental, harmonics, divider products, common drift, start-stop cadence, spatial gradient	Shared temporal behaviour, compatible spatial response, reference-clock control, receiver substitution
AM, SSB, ISB, or VSB	Envelope, carrier presence, sideband symmetry, occupied bandwidth, phase relation	I/Q review, alternate bandwidth, known-signal exclusion, repeatable source geography

Signal family	**Most informative observables**	**Minimum confirmation before stronger classification**
NFM, WFM, or PM	Instantaneous frequency or phase, deviation, modulation spectrum, limiter response	Calibrated I/Q, phase-noise and LO controls, second receiver, spatial localisation
Pulse or PPM	Arrival time, slot displacement, width, repetition, jitter, reference correlation	Common time base, timing uncertainty, threshold variation, negative triggers, spatial correlation
Nested subcarrier	Sideband spacing, cyclic frequencies, successive demodulation outputs, host-subcarrier coherence	Reconstruction from original I/Q, synthetic-chain control, alternate processing
Burst, VOX, or hopping	Event duration, recurrence, hop set, dwell, cyclic structure, probability of intercept	Long-enough observation, known-network exclusion, event clustering, spatial behaviour
Digital interface or sleep-state domain	Reference clock, spread-spectrum skirt, framing cadence, cable common mode, state dependence	Documented state transition, cable and power controls, standards comparison, localised field
SAW or passive resonant response	Narrow resonance, tolerance, delay, group delay, illumination dependence, spatial return	Passive baseline, source-off and sham controls, frequency and polarisation offsets, independent receiver
Microphone or audio-current path	30 Hz to 14 kHz magnetic/electric field, acoustic correlation, PDM clock, conductor gradient	Privacy-preserving stimulus, microphonic controls, environmental-source exclusion, non-content analysis

The clock and timing analysis is supplemented by Chapter 35. Its harmonic ledger is not merely a list of integer multiples. It establishes a comparative test in which frequency ratio, residual error, common fractional drift, phase stability where measurable, simultaneous state transitions, spatial gradient and probe-orientation response are examined together.

The method is particularly important when a low-power device suppresses or confines its fundamental while a buffered edge, divider output, power-rail current or enclosure aperture radiates a higher-order member more efficiently.

Chapter Glossary

Terms used in Chapter 35.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

ANGLE MODULATION — Modulation in which the angle of a sine-wave carrier is varied by a modulating wave.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

D

DEMODULATION — The removal of intelligence from a transmission medium.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

M

MICROPHONE — An energy converter that changes sound energy into electrical energy.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

MODULATION INDEX — The ratio of frequency deviation to the frequency of the modulating signal.

R

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

29. Controlled Illumination, Retroreflection, Nonlinear Response, and Safety-Governed Interpretation

Controlled illumination is an exceptional, secondary measurement mode. It is not an ordinary continuation of passive spectrum work, because the inspection system becomes an active participant in the electromagnetic scene and may create responses through direct leakage, receiver overload, rectification, harmonic generation, passive intermodulation, cable coupling, thermal effects, or state changes in lawful equipment.

The procedural burden therefore increases at the moment illumination is proposed. Written authority, frequency legality, exposure assessment, electromagnetic-compatibility review, medical-device review, equipment protection, fire controls, and an evidential contamination plan must all be complete before energy is intentionally introduced.

A putative retroreflector can return energy at the illuminating frequency, at a harmonic or subharmonic, through frequency translation, through load modulation, through a delayed SAW response, or through an internally energised transmitter.

These mechanisms cannot be distinguished by the appearance of a peak alone. They require a source reference, synchronised capture, controlled changes in frequency, polarisation, azimuth, elevation, amplitude, and timing, together with sham trials and independent receiver architectures.

The governing question is not whether the display changed when a transmitter was switched on. It is whether a repeatable environmental response remains after every credible instrumental and structural explanation has been tested.

Retroreflective or remotely powered functions may be concealed within or attached to keyboards, video cables, input peripherals, printer cables, telephone or data leads, charging cords, power adaptors, connectors, shielding assemblies, printed-circuit structures, and numerous components inside otherwise ordinary electronics. That possibility does not justify indiscriminate accusation or intrusive dismantling. It broadens the source hypotheses that a non-contact inspection must consider, and it reinforces the need to distinguish a device-associated response from the lawful nonlinear, switching, protective, or resonant behaviour of the host equipment.

29.1 Passive-first doctrine and authorisation gates

Active excitation is considered only after passive observations have been completed, preserved, and reviewed, because illumination can alter the very state the examination seeks to characterise. The governing quantities include authorised frequency set F_a, maximum permitted field E_{max} or H_{max}, exposure duration T_x, duty factor δ, source power P_t, antenna gain G_t, exclusion distance r_x, equipment susceptibility, implanted-device status, scene baseline B_0, and authorisation record A_u.

The permissibility of an illumination waveform depends upon jurisdiction, location, frequency allocation, occupied bandwidth, spurious emissions, power, antenna, exposure, medical environment, and the equipment present. A candidate frequency appearing in a technical register is never itself authority to transmit.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Applicable spectrum, exposure, EMC, and risk references include [17] through [23], [29], [30], [45], [61], [62], [70], [118], and [119].

In operational practice, the team freezes and hashes the passive record, completes a written risk assessment, confirms spectrum and site authority, surveys vulnerable equipment and persons, establishes stop conditions, and obtains approval from the designated legal, safety, clinical, and technical authorities. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The transmitter remains physically disconnected and terminated during baseline and sham stages. Source power begins at the minimum justified level, is monitored independently, and is increased only through recorded gates that preserve exposure and equipment margins.

The interpretive boundary is explicit. The absence of an observed passive signal does not by itself justify illumination, and an authorised illumination trial does not diminish the requirement for evidential restraint. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.2 Independent illumination reference and common triggering

A transmitter command does not prove that the intended field reached the scene at the intended time, frequency, polarisation, or amplitude, so a separate receiving path must observe the actual illumination. The governing quantities include reference-channel waveform $x_{ref}(t)$, received reference amplitude A_{ref}, carrier frequency f_i, pulse or burst timing t_i, polarisation p_i, field uncertainty u_E, trigger threshold η, trigger time t_0, latency τ_{ref}, and reference-channel isolation I_{ref}. The independent reference antenna and receiver establish the environmental presence of the interrogating field and furnish the common epoch for response acquisition.

Direct electrical triggering from the source may supplement this record, but it cannot replace measurement of the radiated or conducted field at the scene. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Triggered-receiver practice is supported by references [127] and [128].

In operational practice, the reference channel is calibrated, placed to avoid the suspected response direction where practical, checked for receiver compression, and recorded continuously with the response channels. Trigger threshold, hold-off, pre-trigger, and polarity are validated using known benign events.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. A source-off trigger, a sham command, and a reference-path substitution are used to expose software triggers, electromagnetic leakage inside the chassis, and common power transients. The reference waveform is retained with every candidate response.

The interpretive boundary is explicit. A response described as illumination-correlated must be correlated with the independently measured field, not merely with an operator action or transmitter status message. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.3 Coarse-to-fine delay iteration and real-time response capture

A remotely powered or delayed structure may respond after rectification, energy storage, resonator delay, oscillator start-up, encoding, or receiver processing, so the acquisition window must be positioned empirically rather than assumed. The governing quantities include candidate delay τ, coarse delay increment $\Delta\tau_c$, fine increment $\Delta\tau_f$, pre-trigger T_{pre}, gate length T_g, record duration T_{rec}, response onset t_{on}, response duration T_{resp}, decay constant τ_d, pulse displacement, and timing uncertainty u_τ.

The protocol begins with a broad record covering negative pre-trigger time, zero delay, and a generous post-trigger interval. Once a repeatable response region is observed, the delay is bracketed and the increment reduced until onset, steady-state structure, pulse position, and decay are captured without truncation.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Time-domain and triggering principles appear in references [42], [80], [127], and [128].

In operational practice, the system uses fixed-span real-time or vector I/Q capture for fleeting events and uses a swept analyser as a secondary frequency confirmation. Delay schedules, missed events, trigger failures, and rejected records are retained rather than silently discarded.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. The examiner alternates illumination-on, illumination-off, sham, frequency-offset, polarisation-change, and position-change trials in a controlled order. Delay is not optimised exclusively on positive trials, because doing so would create selection bias.

The interpretive boundary is explicit. An apparently optimal delay is a property of the source, propagation, receiver, and trigger chain together. It is not interpreted as an internal device delay until instrumental contributions have been separately measured. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.4 Rejection of direct leakage, overload, mixing, and intermodulation

The illumination source can generate false response peaks through antenna-to-antenna coupling, cable leakage, receiver front-end overload, harmonics, local-oscillator products, image responses, passive intermodulation, and nonlinear tuning components. The governing quantities include source frequency f_i, response frequency f_r, harmonic order n, intermodulation product $mf_1 \pm nf_2$, receiver input P_{in}, compression margin M_c, IIP3, spur-free dynamic range, isolation I_{tx-rx}, image frequency f_{img}, local-oscillator frequency f_{LO}, and gain-step response. A genuine environmental response should exhibit behaviour that cannot be reproduced with terminated inputs, dummy probes, altered intermediate-frequency plans, shielded receiver paths, or source coupling directly into the instrument. Overload often causes many unrelated peaks to rise together, while a real narrow response may maintain a stable transfer relationship over a limited source range.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Microwave and nonlinear measurement principles are treated in references [43], [124] through [128].

In operational practice, the examiner maps source harmonics and spurs into a calibrated load, measures transmitter-to-receiver isolation, performs receiver gain and attenuation steps, substitutes filters, changes local-oscillator architecture, and repeats the trial with a second instrument. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Varactor tuning branches, electrostatic-discharge diodes, connectors, corroded joints, and dissimilar-metal contacts are tested as potential mixers. Any product that follows the measurement system rather than the scene is classified as an artefact.

The interpretive boundary is explicit. A peak at a mathematically plausible mixing product is not evidence of a concealed device. It is first a requirement to identify every nonlinearity capable of generating that product. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.5 Same-frequency backscatter, frequency translation, harmonic return, and internal transmission

Retroreflective responses must be classified by their physical relationship to the interrogating field because same-frequency scattering, load modulation, frequency conversion, harmonic generation, and internally generated transmission have different evidential implications. The governing quantities include incident frequency f_i, returned frequency f_r, frequency offset $\Delta f = f_r - f_i$, reflection coefficient $\Gamma(t)$, radar cross section σ, conversion loss L_c, harmonic order n, modulation transfer function, delay τ, illumination-response coherence, and bistatic geometry. Same-frequency backscatter modifies amplitude or phase near f_i, load modulation produces structured sidebands, a frequency translator produces a stable offset, a nonlinear junction can produce nf_i or mixed products, and an energised oscillator can produce a return controlled by its own resonator.

A narrow response near 300 MHz during illumination in another band is one possible hypothesis, not a universal signature. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Backscatter, RFID, SAW, radar, and microwave contexts appear in references [27], [28], [41], [43], and [67] through [70].

In operational practice, the examiner measures the incident and response frequencies simultaneously, changes f_i by small authorised offsets, observes whether f_r follows, remains fixed, or changes by a harmonic law, and repeats the geometry over multiple angles and polarisations. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Source amplitude is stepped within the approved range to examine response order and threshold behaviour. The same trial is performed against benign reference objects and known nonlinear fixtures to provide comparative response classes.

The interpretive boundary is explicit. Classification remains mechanism-level unless the response is spatially localised and host-equipment alternatives have been evaluated. The protocol does not infer intent from a scattering law. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.6 Wideband nonlinear-junction detection and harmonic-ratio interpretation

A nonlinear-junction detector observes nonlinear material behaviour, not a concealed electronic device as such, and wideband operation increases both discovery opportunity and the burden of artefact control. The governing quantities include fundamental excitation f_0, second harmonic $2f_0$, third harmonic $3f_0$, harmonic powers P_2 and P_3, ratio $R_{23}=P_2-P_3$ in decibels, sweep frequency, polarisation, standoff, source level, receiver isolation, junction memory, and spatial repeatability.

Semiconductor junctions often produce a strong even-order response under some conditions, while corroded or dissimilar-metal contacts can produce substantial odd and even products. The frequently used second-to-third-harmonic comparison is therefore a screening descriptor rather than a universal semiconductor test.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Nonlinear and microwave principles are treated in reference [43], with active-test governance in references [17] through [23] and [45].

In operational practice, the examiner performs low-level stepped or swept interrogation only within authorised bands, records both harmonics and the fundamental reference, varies orientation and standoff, repeats at reduced power, and maps the response in three dimensions. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Known benign electronics, empty construction materials, oxidised joints, cable connectors, furniture fasteners, and instrument hardware are used as controls. Receiver breakthrough and transmitter harmonics are measured into shielded loads before scene use.

The interpretive boundary is explicit. A nonlinear response establishes the presence of a nonlinear junction within the measured field volume. Device association requires additional spatial, structural, and functional evidence. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.7 Exposure, medical-device, EMC, fire, and data-integrity governance

The active-test plan must protect people, implanted and external medical devices, building systems, evidence, batteries, memories, and lawful communications from foreseeable electromagnetic and thermal effects.

The governing quantities include electric field E, magnetic field H, power density S, specific absorption or coupling metric applicable to the band, exposure duration T, duty factor δ, separation r, equipment immunity level, safety factor, battery temperature ΔT, stop threshold, and incident log.

Compliance with a public or occupational exposure limit does not prove compatibility with a susceptible medical device, sensitive laboratory instrument, fire alarm, access-control system, or stored electronic evidence. Safety therefore requires layered review rather than one numerical limit.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Relevant governance is found in references [17] through [23], [45], [118], and [119].

In operational practice, the team identifies vulnerable persons and equipment, establishes exclusion zones, monitors field and temperature where relevant, maintains emergency shutdown, coordinates with clinical engineering and facilities, and records every source state and anomaly. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

Illumination ceases immediately upon unexpected equipment operation, heating, odour, sound, alarm, communication disruption, physiological concern, or loss of monitoring. The passive baseline is repeated after the trial to check for persistent alteration.

The interpretive boundary is explicit. The protocol records that no illumination method is harmless by default. Approval is specific to the waveform, band, level, geometry, duration, site, and date assessed. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

29.8 Evidential classification and bounded reporting

The strength of language used for a response must increase only as independent temporal, spectral, spatial, instrumental, and control evidence accumulates. The governing quantities include observation class C, repeatability R, spatial localisation L, illumination dependence I, receiver-artefact exclusion A, path-control result P, uncertainty U, alternative-source assessment, and reviewer disposition. The sequence proceeds from observed signal, to candidate device-correlated signal, illumination-correlated response, reproducible frequency-translated response, spatially localised response, and confirmed device-associated response.

Each step has prerequisites and can be reversed when a later control exposes an alternative explanation. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The interpretation and reporting framework aligns with references [1] through [9].

In operational practice, the examiner completes a classification matrix, identifies evidence supporting and opposing the class, states missing controls, and obtains independent review before a consequential class is assigned. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Reports include raw observations, uncertainty, source and receiver settings, negative trials, failed trials, spatial bounds, alternative hypotheses, and the exact meaning of the classification term. Causal or medical claims are outside the electronic measurement classification.

The interpretive boundary is explicit. No response becomes device-associated merely because it appears during illumination. Confirmation requires localisation, reproducibility, negative controls, receiver-artifact exclusion, illumination-path controls, and a defensible uncertainty statement. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 29-1. Controlled-illumination response classes and minimum evidential gates.

Classification	What has been established	What remains prohibited without further evidence
Observed signal	A reproducible instrument indication above the declared threshold	Environmental origin, device association, function, or causation
Candidate device-correlated signal	Signal behaviour is compatible with a device-related hypothesis and survives elementary controls	Illumination dependence or spatially bounded source attribution
Illumination-correlated response	Response timing is repeatably associated with independently measured illumination	Proof that the environment rather than the receiver generated the response
Reproducible frequency-translated response	A stable frequency relationship survives source offsets and principal receiver controls	Identification of the translation mechanism or host object

Classification	What has been established	What remains prohibited without further evidence
Spatially localised response	The response converges to a bounded region under repeatable vector and gradient measurements	Identification of a particular component, purpose, or operator
Confirmed device-associated response	Spatial, temporal, spectral, control, and uncertainty requirements have been satisfied and the lawful host alternatives addressed	Medical causation, unlawful purpose, ownership, or intent unless independently established

Example 29-1. Electrical scale of a 32.768 kHz timing field at the 300-foot station. Let $c = 299{,}792{,}458$ metres per second be the speed of light in vacuum, $f = 32{,}768$ hertz the candidate timing frequency, and $r = 300$ feet × 0.3048 = 91.44 metres the station distance. The free-space wavelength is $\lambda = c/f = 9{,}148.94$ metres. The normalised range is $r/\lambda = 91.44/9{,}148.94 = 0.009995$. Thus the station is only about one-hundredth of a wavelength from the notional source at this frequency. This calculation does not establish a field regime by itself because source dimensions, conductive structures, and reactive coupling remain material. It does show why a free-space far-field path-loss model must not be applied automatically to the 32.768 kHz search merely because the physical distance appears large.

Example 29-2. Induced voltage in a high-turn magnetic bar probe. Let $f = 1{,}000$ hertz, angular frequency $\omega = 2\pi f$, winding turns $N = 2{,}000$, effective turn area $A = 1.00 \times 10^{-4}$ square metre, effective permeability multiplier $\mu_{eff} = 50$, free-space permeability $\mu_0 = 4\pi \times 10^{-7}$ henry per metre, and incident magnetic field strength $H = 1.00 \times 10^{-6}$ ampere per metre. Under a simplified sinusoidal, uniform-flux model, $B = \mu_0 \mu_{eff} H = 6.283 \times 10^{-11}$ tesla and the open-circuit magnitude is $|V| = \omega NAB = 7.90 \times 10^{-8}$ volt, or approximately 79 nanovolts. The model neglects demagnetising factor, leakage flux, winding distribution, parasitic capacitance, core loss, preamplifier loading, and field non-uniformity. Those effects must be measured for the completed probe.

Example 29-3. Capacitance required to tune a ten-henry probe at 400 Hz. Let L = 10 henries and target resonance f_0 = 400 hertz. For an ideal lumped LC network, $f_0 = 1/(2\pi\sqrt{LC})$, so $C = 1/[(2\pi f_0)^2 L] = 1.583 \times 10^{-8}$ farad, or 15.83 nanofarads. The fixed capacitor bank should place the circuit near this value, the sapphire piston capacitor should provide stable fine mechanical trimming, and the varactor branch should provide only the validated electronic correction range. The calculation is preliminary because the winding self-capacitance, core loss, temperature, and preamplifier input impedance alter the realised resonance.

Example 29-4. Loaded bandwidth and settling scale of a 32.768 kHz resonator. Let the measured loaded quality factor be Q_L = 100 at f_0 = 32,768 hertz. The approximate half-power bandwidth is $B = f_0/Q_L$ = 327.68 hertz. For a lightly damped second-order resonator, an indicative amplitude time constant is $\tau \approx Q_L/(\pi f_0)$ = 0.971 millisecond. Several time constants are ordinarily required before a step-tuned probe is accepted as settled. The actual transaction time must be established experimentally because switching, varactor bias filtering, digital detector averaging, and automatic gain control can dominate the theoretical resonator constant.

Example 29-5. Thermal-noise floor in a one-kilohertz receiver bandwidth. Let Boltzmann's constant $k = 1.380649 \times 10^{-23}$ joule per kelvin, temperature T = 290 kelvin, resistance R = 50 ohms, and noise bandwidth B = 1,000 hertz. The ideal rms noise voltage is $v_n = \sqrt{4kTRB} = 2.83 \times 10^{-8}$ volt, or 28.3 nanovolts. The corresponding available thermal-noise power is approximately -174 dBm/Hz + 10 log10(1,000) = -144 dBm. With a receiver noise figure of 3 dB, the idealised input-referred level becomes about -141 dBm before implementation loss, interference, mismatch, and detector statistics. Selectivity can reduce integrated noise, but it cannot remove coherent interference or uncharacterised internal spurs.

Example 29-6. Ideal coherent-integration gain. Let N = 10,000 independent, phase-aligned repetitions of the same deterministic waveform be coherently accumulated. Signal voltage adds in proportion to N while uncorrelated noise amplitude grows approximately as $\sqrt{N}$, giving an ideal power signal-to-noise improvement $G_p = 10 \log10(N) = 40$ dB. This is an upper-bound calculation. Phase drift, timing jitter, source instability, coloured noise, event selection, missing records, and channel decorrelation reduce the realised gain. The report must state the coherence criterion and compare the observed improvement with this theoretical bound.

Example 29-7. Phase error created by one hundred picoseconds of channel skew. Let the residual channel skew be $\Delta t = 100$ picoseconds. Phase error is $\Delta\phi$ = 360 degrees × f × Δt. At f = 100 MHz, $\Delta\phi$ = 3.6 degrees. At f = 700 MHz, $\Delta\phi$ = 25.2 degrees. A timing tolerance that appears excellent in an audio or low-frequency instrument can therefore make high-frequency vector reconstruction unreliable. The calibration requirement must be expressed as a function of frequency and intended phase accuracy, not as one undifferentiated time specification.

Example 29-8. Combined timing uncertainty for a measured response delay. Assume independent standard uncertainties of 2.0 microseconds from trigger detection, 1.5 microseconds from channel calibration, and 0.5 microsecond from numerical pulse estimation. The combined standard uncertainty is $u_c = \sqrt{(2.0^2 + 1.5^2 + 0.5^2)} = 2.55$ microseconds. Using coverage factor k = 2 gives expanded uncertainty U = 5.10 microseconds. Independence must be justified. If common-clock or common-threshold effects correlate the terms, covariance must be included rather than relying upon root-sum-square addition.

Example 29-9. Spatial amplitude gradient over a three-inch decrement. Suppose corrected amplitude rises by 6.0 dB between two probe centres separated by three inches along the declared x direction. The local logarithmic gradient is 6.0/3 = 2.0 dB per inch. The linear voltage or field-amplitude ratio is $10^{(6/20)}$ = 1.995, approximately two. This strong local change warrants refinement, but it does not give source distance under an inverse-square model because the field may be reactive, guided, reflected, or orientation dependent. Perpendicular and reverse-path measurements are required.

Example 29-10. Illustrative free-space link budget for a five-microwatt source at 433.92 MHz. Let transmitted power P_t = 5 microwatts = -23.01 dBm, frequency f = 433.92 MHz, range r = 300 feet = 91.44 metres, and assume unity transmit and receive antenna gains with unobstructed far-field free-space propagation. Free-space path loss is L_FS = 20 log10(4πrf/c) = 64.42 dB, giving ideal received power P_r = -87.43 dBm. This number is not a guaranteed detection level.

The assumptions may fail for electrically small, poorly matched, shielded, near-field, polarisation-mismatched, or structure-coupled sources, and the actual result also depends upon bandwidth, receiver noise, interference, antenna factor, cable loss, fading, and duty cycle.

Suppose corrected amplitude rises by 6. 0 dB between two probe centres separated by three inches along the declared x direction. The local logarithmic gradient is 6. 0/3 = 2. 0 dB per inch. The linear voltage or field-amplitude ratio is 10^(6/20) = 1. 995, approximately two. This strong local change warrants refinement, but it does not give source distance under an inverse-square model because the field may be reactive, guided, reflected, or orientation dependent. Perpendicular and reverse-path measurements are required.

Chapter Glossary

Terms used in Chapter 36.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

E

EMC — Electromagnetic compatibility: the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to other systems.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

L

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

N

NONLINEAR JUNCTION — An electrical contact or material interface whose current-voltage relationship is nonlinear and can therefore generate harmonics, intermodulation products, rectification, or load-modulated responses.

R

RADAR CROSS SECTION — A directional and frequency-dependent measure of how strongly a target scatters incident electromagnetic energy toward a specified observation direction.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

30. Expert Practitioner Competence, Quality Systems, and Technical Prose

The apparent educational level of a technical work is not raised reliably by multiplying adjectives or lengthening sentences. It is raised when the prose discloses the governing model, defines its variables, identifies assumptions, distinguishes observations from inferences, anticipates rival explanations, and limits conclusions to the demonstrated capability of the method.

This final chapter codifies those habits for the EERF practitioner. Its purpose is to make the document read and operate as the work of a mature advanced technical engineer, forensic specialist, and senior technical inspector, without misrepresenting the framework as a completed formal academic research programme.

Expert practice in this field is necessarily collective. No single professional title guarantees competence in low-frequency magnetics, microwave measurement, digital communications, forensic scene control, uncertainty analysis, clinical safety, spectrum regulation, and evidential reporting. The commissioning body must therefore assemble and govern a multidisciplinary team, define which person is competent for each decision, and ensure that technical language does not conceal a missing discipline. The authorial voice may be unified, but the method remains accountable to several domains of specialised knowledge.

The enlarged framework should be used as an advanced professional reference, training text, and proposed inspection standard. It remains subject to method validation, jurisdictional authority, equipment qualification, site-specific risk assessment, and independent review. Its erudition is intended to improve reasoning and reproducibility, not to create an aura of certainty. Where the evidence is weak, the most educated sentence is often the one that states precisely what could not be determined.

30.1 Competence domains and multidisciplinary team architecture

EERF examinations require competence to be demonstrated by task, frequency range, instrument class, source mechanism, and interpretive responsibility rather than presumed from a general job title. The governing quantities include competence matrix K, authorised task T_i, frequency band B_i, instrument family I_i, method version M_i, training record, witnessed demonstration, proficiency result, review authority, and recency interval. A radio-frequency engineer may not be competent to control a forensic scene, while a forensic scientist may not be competent to interpret phase noise, complex permeability, or receiver intermodulation.

Clinical, legal, safety, privacy, and spectrum decisions require their own accountable specialists. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Competence and quality-system principles are reflected in references [6] through [9].

In operational practice, the technical leader creates a competence matrix, assigns a named person to every critical decision, records limitations and supervision requirements, and prevents staff from approving work outside the demonstrated scope. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

Continuing competence is maintained through reference-source exercises, blind samples, instrument-fault drills, spatial reconstruction exercises, uncertainty reviews, and periodic observation by an independent senior practitioner.

The interpretive boundary is explicit. A long curriculum vitae or advanced vocabulary is not a substitute for demonstrated competence in the exact task performed. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.2 Terminology, scholarly register, and technical precision

Advanced professional papers uses specialised terminology when the terminology carries a defined technical distinction, and avoids it when a simpler expression is equally exact. The governing quantities include defined term, symbol, unit, normative verb, modal qualifier, source class, uncertainty expression, classification term, cross-reference, and glossary entry. Words such as sensitivity, selectivity, gain, coherence, resonance, phase, uncertainty, localisation, confirmation, and validation have technical meanings that differ from colloquial use.

The document should state which meaning applies and should avoid rhetorical intensifiers that imply performance not supported by measurement. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The vocabulary and reporting structure should remain aligned with references [1] through [5] and [39].

In operational practice, every equation defines its variables and units; every frequency includes an unambiguous unit; every normative requirement uses a consistent modal verb; and every classification term is linked to a decision rule. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Editors check singular and plural consistency, hyphenation, frequency notation, mathematical symbols, abbreviations, British spelling, table captions, figure references, and the distinction between the analyser frequency axis and the physical X-axis probe.

The interpretive boundary is explicit. Erudition is demonstrated by precise distinctions, not by obscurity. A sentence is revised when its syntax makes the physical actor, measurement operation, or evidential boundary uncertain. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.3 Separation of observation, inference, attribution, and causation

A mature technical report distinguishes what the instrument displayed from what physical process is inferred, what object is associated, and what consequence is alleged. The governing quantities include observation O, corrected result Y, source hypothesis H_s, alternative hypothesis H_a, likelihood or weight of support, spatial association L, device attribution D, causal claim C, and uncertainty U.

An observed spectral line may support the existence of periodic energy at the probe, a coherent harmonic family may support a common timing source, and a repeatable spatial gradient may support a bounded source region. None of those propositions alone identifies a particular component, owner, purpose, medical effect, or unlawful act.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Interpretation and reporting principles appear in references [3] through [5], [8], and [9].

In operational practice, the examiner writes separate findings for observation, control result, interpretation, limitation, and recommended next step. Each inferential transition names the evidence upon which it depends. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. An independent reviewer checks for collapsed reasoning, especially sentences that move directly from frequency coincidence to device identity or from temporal correlation to causation.

The interpretive boundary is explicit. Attribution and causation are withheld unless the examination authority, method capability, controls, and external evidence support them. The electronic inspection does not diagnose illness. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.4 Quality management, configuration control, and method change

A method that changes silently between sites cannot accumulate reliable professional experience because the meaning of its results changes with the equipment, software, probe, and decision rule. The governing quantities include method identifier M, revision r, equipment configuration E_c, firmware and software versions, calibration status, change request C_r, validation impact V_i, approval authority, effective date, and superseded record.

Changes to a winding, core alloy, concentrator ring, varactor curve, preamplifier, filter, sample rate, detection algorithm, search-ring dwell, or classification threshold may alter performance materially. A configuration-management process determines whether the change is editorial, equivalent, limited, or method-significant. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Quality and validation principles are addressed in references [6] through [10].

In operational practice, the organisation maintains controlled master documents, approved equipment lists, calibration records, software hashes, change logs, validation cross-references, training acknowledgements, and a mechanism for withdrawing superseded forms.

The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Before field use, a modified configuration is compared with the preceding configuration using declared acceptance criteria and representative sources. Unresolved changes are labelled experimental and are not used for consequential conclusions.

The interpretive boundary is explicit. Document size does not compensate for uncontrolled implementation. The operative method is the version actually executed at the scene and recoverable from the record. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.5 Independent review, reproducibility, and defensible disagreement

Independent review is not ceremonial proofreading; it is a technical attempt to reconstruct the measurement, challenge the source model, and identify conclusions that exceed the data. The governing quantities include reviewer competence, review scope, raw-data access, configuration manifest, recalculation set, alternative processing, discrepancy log, adjudication record, and final disposition. A reviewer should be able to select a candidate record, reproduce its spectrum or timing result from the retained data, verify the calibration and uncertainty terms, and follow the spatial coordinates back to the scene drawing. Where an alternative processing choice materially changes the result, that sensitivity is reported. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Review and reproducibility principles align with references [1] through [9] and [44].

In operational practice, the case package is reviewed by a technically independent person who did not make the original classification; discrepancies are logged; corrections preserve the original record; and unresolved professional disagreement is stated rather than concealed. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. For high-consequence conclusions, a second instrument, probe family, operator, or laboratory is used where practical. Reviewers distinguish a reproducible result from a merely repeated use of the same hidden assumption.

The interpretive boundary is explicit. Agreement among colleagues is not independent confirmation when all rely upon the same unverified channel, calibration file, source list, or software defect. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.6 Negative findings, limitations, and statements of scope

A negative electronic inspection establishes only that no qualifying observation was obtained within the declared spatial, temporal, spectral, sensitivity, waveform, and state coverage. The governing quantities include searched frequency interval F_s, observation duration T_s, spatial coverage Ω_s, minimum detectable level $MDL(f)$, probability of intercept P_i, device-state coverage, excluded volumes, inaccessible services, environmental interference, and method limitation L_m. A dormant source, rare burst, shielded device, out-of-band signal, untested illumination dependency, distributed conductor path, or background-masked emission can remain undetected. The report must therefore avoid universal statements such as no device was present unless a separate lawful physical inspection and evidential basis justify that proposition. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Reporting and uncertainty principles are addressed in references [4], [5], [8], and [9].

In operational practice, the examiner summarises coverage in a limitations table, identifies inaccessible or compromised areas, reports significant interference and instrument outages, and states the signal classes for which detection probability was or was not evaluated. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Negative controls and source-absent trials are reported with the same care as positive candidates. A null result that contradicts the expected model is investigated and retained.

The interpretive boundary is explicit. A bounded negative finding is a technically strong conclusion because its conditions can be understood and tested. An unqualified assurance is not. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.7 Legal authority, ethics, privacy, and clinical separation

Technical capability does not create legal authority, and the most sophisticated measurement remains improper when it exceeds consent, warrant, licence, safety approval, privacy limitation, or clinical governance. The governing quantities include authorising instrument A, jurisdiction J, premises consent, spectrum authority, data minimisation rule, retention period, protected information class, human-subject boundary, clinical responsibility, and escalation route. The protocol is designed for non-contact, non-imaging measurement and must not be repurposed to intercept content, defeat access controls, impersonate devices, inject traffic, disrupt services, or diagnose a medical condition. Active testing receives separate scrutiny because it can affect people and equipment beyond the immediate search volume.

The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. Legal, privacy, risk, and clinical boundaries are reflected in references [17] through [23], [28] through [30], [45], and [119].

In operational practice, the case leader verifies authority before deployment, briefs the team on data minimisation, separates technical records from clinical records, restricts access, and stops work when the requested inference lies outside the authorised scope. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence. Potentially sensitive waveforms are transformed into privacy-preserving descriptors where possible, and retention of raw content-bearing data is justified, access-controlled, and time-limited.

The interpretive boundary is explicit. The report may describe measured electromagnetic conditions and their uncertainty. Questions of illness, legal culpability, ownership, or intent require independent evidence and appropriately qualified decision-makers. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

30.8 Practice-oriented publication, training, and controlled revision

An expert-practitioner framework matures through transparent technical revision, inter-laboratory comparison, case-derived lessons, and training that exposes failure modes as carefully as successful detections. The governing quantities include training objective, learning outcome, competency assessment, reference fixture, inter-comparison result, corrective action, revision proposal, stakeholder review, publication status, and implementation date.

The framework need not become a formal academic dissertation to attain intellectual seriousness. It can function as an advanced professional monograph and proposed standard by maintaining a critical bibliography, worked engineering examples, controlled terminology, verifiable procedures, and honest records of where the method succeeds or fails. The section therefore treats the measurement as a coupled physical and instrumental problem rather than as a direct reading of an unknown object. The framework remains a proposed professional discipline whose claims must stay within the demonstrated competence and validation of the implementing organisation.

In operational practice, the organisation publishes or circulates validation summaries appropriate to security and privacy constraints, develops case exercises with known benign sources, trains staff on false positives and instrument artefacts, and revises the document through recorded technical review. The examiner records the configuration, the applicable reference state, the environmental influence quantities, and the reason for every departure from the nominal sequence.

New frequencies, alloys, standards, interfaces, and instrument capabilities are inserted only after provenance and applicability review. Historical threat material remains clearly distinguished from current standards and measured case evidence.

The interpretive boundary is explicit. A larger edition is valuable only when its added scope remains navigable, internally consistent, and operationally testable. Revision should improve the chain from physical principle to field decision rather than merely increase page count. A stronger conclusion is withheld until the additional controls and measurement capability required for that conclusion have been demonstrated.

Table 30-1. Examples of progressively more rigorous professional formulation.

Less rigorous formulation	Advanced technical and expert-practitioner formulation
The receiver found a signal.	Under the declared probe, bandwidth, detector, gain, time-base, and calibration configuration, the receiver recorded a reproducible spectral feature above the stated decision threshold.
The antenna had very high gain.	The completed probe exhibited the measured resonant transfer factor, loaded quality factor, bandwidth, noise contribution, and uncertainty reported for the specified frequency and orientation.
The device was located.	Compatible vector, gradient, phase, and control observations bounded the candidate source region to the stated coordinates and uncertainty; component identity was not inferred.

Less rigorous formulation	Advanced technical and expert-practitioner formulation
Illumination activated the device.	A response was repeatably time-correlated with an independently measured illuminating field and survived the stated source-off, sham, offset, overload, and alternative-receiver controls.
No device was present.	No qualifying signal was observed within the declared frequency, spatial, temporal, state, sensitivity, and waveform coverage; the listed limitations prevent an unqualified absence conclusion.
The method is field-proven.	The method has been validated or field-evaluated for the declared use, equipment configuration, source classes, range, decision thresholds, and operating conditions.
The harmonics prove the clock.	The observed lines form a candidate harmonic family whose shared drift, timing, sidebands, phase behaviour, and spatial gradient support, but do not alone prove, a common clock source.
The analyser shows the true field.	The displayed result is the calibrated output of a declared source-propagation-probe-receiver-processing chain, with residual transfer uncertainty and competing artefacts stated.

The advanced edition concludes with a deliberate boundary. It demonstrates disciplined physical modelling, metrological language, rival-hypothesis testing, explicit controls and bounded reporting. It does not convert the proposed discipline into a consensus standard, nor does it replace empirical validation, lawful authority, site-specific safety review, independent professional judgement or the obligation to disclose uncertainty and incompleteness.

Chapter Glossary

Terms used in Chapter 37: Expert Practitioner Competence, Quality Systems, and Technical Prose.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

D

DECISION THRESHOLD — A declared criterion that separates actions or classifications. It must be tied to the measured quantity, uncertainty, costs of error, and authority.

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

31. Regional Five-Mile Spectrum Inventory, Angular Station Density and Nested Annular Search Discipline

This chapter converts the five added regional radii into a disciplined measurement programme. Its purpose is to discover what the electromagnetic environment already contains before an examiner approaches the inspected premises closely enough for expectation, receiver overload, metallic infrastructure or site access to distort the interpretation. The outer annuli are neither a claim of five-mile detection capability nor a substitute for the later interior search. They are a contextual control system.

A typical weak source originating from an eavesdropping inside the premises may not be measurable at any regional station, while a strong transmitter many miles away may remain the dominant signal at every station. Both outcomes are useful because they establish the limits within which the later premises-centred observations must be interpreted.

Expert-practitioner interpretation. A regional spectral inventory is analogous to the scene-orientation phase of forensic work. It maps the larger environment, separates known and recurring populations, preserves the temporal state before entry, and prevents a striking signal at the premises from being treated as novel merely because the operator did not look elsewhere. Its evidential value arises from contemporaneous comparison, measured geometry and controlled instrument state, not from the nominal radius printed on a map.

31.1 Governing search sequence and operational meaning

The full radial progression is 5 miles, 2.5 miles, 1 mile, 0.5 mile, 0.25 mile, 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet, 3 feet and 3-inch convergence. In certain cases, there also must be a 10-mile and 30-mile rings, with 24 test sites for each monitoring location. The first five are regional annuli. The 300-foot station family is the site-transition ring. The remaining rings and cells are premises and interior localisation stages. The outermost three annuli use sixteen planned stations each, or twenty-four each for high-risk work. The 0.5-mile annulus ordinarily uses twelve stations and never fewer than eight. The 0.25-mile annulus should use twelve and likewise never fewer than eight. An annulus may contain unequal actual angular spacing where roads, terrain, property rights or safety require displacement, but the measured geometry, angular gap and missing sectors are reported.

For a small residential property, every regional station will ordinarily be outside the premises. For an airport, defence establishment, university, industrial estate, hospital campus, research park or very large corporate facility, the 0.25-mile, 0.5-mile and even 1-mile stations may fall inside a single controlled site. In such cases the annulus still serves the same analytical purpose. The examiner records whether the station is outside the facility perimeter, within the facility but outside the inspected building, or within a connected complex. The terms regional and exterior describe evidential function, not ownership.

Table 31-1. Regional annuli and the 300-foot site-transition ring

Annulus or ring	**Nominal radius**	**Primary function**	**Interpretive restriction**
5 mi	8.04672 km / 26,400 ft	Sixteen normal stations; twenty-four in high-risk work. Broad regional census, long-duration occupancy, strongest bearings and receiver stress test.	No attribution to inspected site.

Annulus or ring	**Nominal radius**	**Primary function**	**Interpretive restriction**
2.5 mi	4.02336 km / 13,200 ft	Sixteen normal stations; twenty-four in high-risk work. Matched regional comparison, terrain and urban-clutter change, persistent burst timing.	Retain one or more 5-mile sentinels.
1 mi	1.609344 km / 5,280 ft	Sixteen normal stations; twenty-four in high-risk work. Local services, transport, utility, cellular, fixed-link and industrial population.	Record local infrastructure and altitude.
0.5 mi	804.672 m / 2,640 ft	Twelve stations ordinarily; never fewer than eight. Neighbourhood discrimination, adjacent premises and service corridors.	Do not infer site ownership from amplitude.
0.25 mi	402.336 m / 1,320 ft	Twelve stations preferred; never fewer than eight. Immediate site-adjacent comparison before 300 feet.	Multiple bearings and feasible vertical tiers.
300 ft	91.44 m	First controlled premises-referenced transition ring.	Common-timebase reference mandatory.

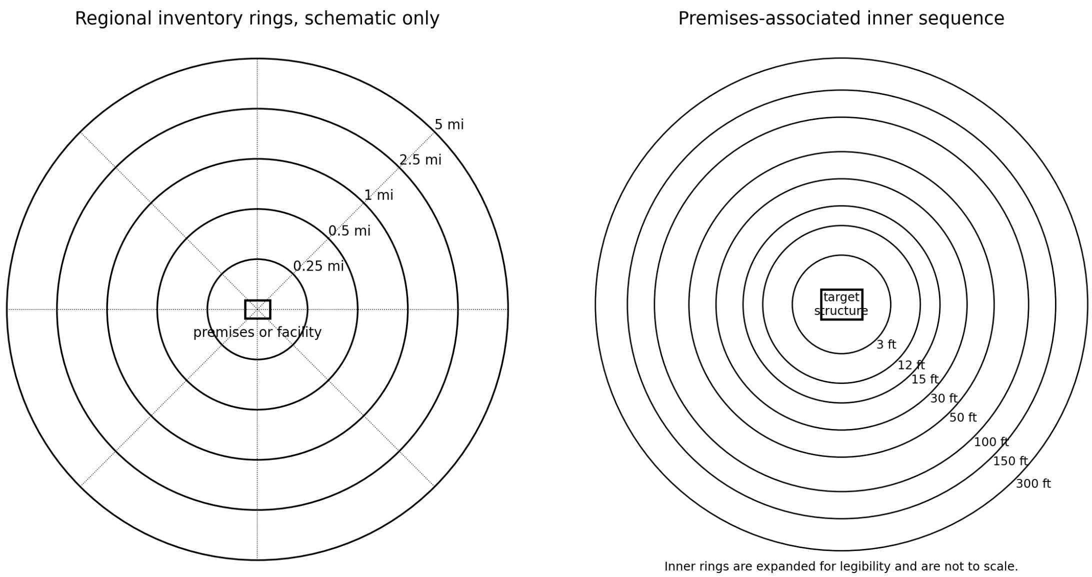


Figure 31-1. Nested regional annuli leading to the controlled 300-foot transition and interior search.

31.2 Coordinate system, datum and station identity

Every station receives a stable identifier that encodes the ring, nominal bearing sector, station number and vertical tier. A suitable form is R05-N-01-L for the first low-elevation northern station at 5 miles, or R025-SE-03-H for the third high-elevation south-eastern station at 0.25 mile.

The identifier never substitutes for measured coordinates. Latitude, longitude or local East-North-Up coordinates, ground elevation, sensing-centre height, uncertainty and the coordinate reference system are retained in the record.

A single site datum is selected before inward movement. For a compact site it may be the geometric centre of the authorised building footprint. For a campus it may be a surveyed hard point adjacent to the inspected structure.

For a multi-building complex it may be a declared local origin with an explicit transformation to geodetic coordinates. The selected datum is an administrative reference, not an assertion that the source lies at that point. If a later candidate centre differs, the original datum is retained so that the search history remains reproducible.

$$R_s = \sqrt{\rho^2 + (z_s - z_0)^2} (4)$$

In this slant-range relation, R_s is the straight-line separation from station to datum, rho is horizontal plan separation, z_s is station sensing-centre elevation and z_0 is datum elevation. The equation describes geometry only. It does not establish line of sight or free-space propagation.

31.3 Station selection and angular coverage

The station plan is determined before field deployment and is not reduced to the easiest parking places. The 5-mile, 2.5-mile and 1-mile annuli each require sixteen nominal bearing sectors. High-risk projects increase the outermost three rings to twenty-four sectors. The 0.5-mile ring ordinarily uses twelve sectors, with eight as the minimum practical configuration. The 0.25-mile ring should use twelve sectors and shall not use fewer than eight.

Additional infill stations are justified near ridgelines, river valleys, railways, major roads, utility corridors, cellular sites, broadcast towers, airports, industrial plant, hospital complexes, data centres or large conductive structures. Repeat occupancy of one station does not count as additional angular coverage.

Angular coverage is reported as planned sectors, occupied sectors, substituted sectors and missing sectors. If the north-west quadrant is inaccessible, the final diagram displays that gap rather than interpolating a result. An alternative station may be placed at the nearest lawful bearing, but its true azimuth and range are retained, and the substitution does not erase the original gap.

A lawful high point supplements rather than replaces grade-level bearings because elevation changes line of sight, obstruction, polarisation, multipath and exposure to distant emitters. The combination of lower and upper tiers is more informative than either alone.

31.4 Safe and lawful high-ground discipline

The maxim of controlling the high ground is applied as a measurement principle. Elevation can reveal a signal hidden at grade, improve a bearing, expose a roof-mounted transmitter population, or reduce building shadowing. It can also make distant services stronger, increase wind and mechanical noise, change cable geometry, expose the team to fall and electrical hazards, and create privacy concerns. Accordingly, the method seeks the highest feasible and safe authorised station, not the highest physical point.

Preferred elevated stations include an occupied upper floor, a client-controlled balcony, a structurally approved roof with protected access, a parking structure, an adjacent hill, or a fixed platform approved by the site safety authority. Ladders, temporary masts, mobile elevating work platforms and aerial systems require separate competence, risk assessment and authority.

No operator improvises an elevated station while carrying a delicate resonant probe, exposed cable or battery assembly. Where upper access is impossible, the limitation is recorded and the missing upper solid angle is treated explicitly in the uncertainty and coverage statement.

31.5 Common-timebase multichannel architecture at regional distances

The regional stage uses the same common-timebase philosophy as the close search. At least three simultaneous X, Y and Z channels are required for an evidential vector observation, and the preferred arrangement remains three spatially separated pods with nine probe or antenna pathways plus illumination-reference, terminated-control and guard or tracking channels.

Above the magnetic-resonant range, broadband loops, biconical antennas, log-periodic antennas, calibrated monopoles, active electric-field sensors or horns may replace ferrite rods, but the channel identity, phase relation and calibration state remain controlled.

A regional inventory is particularly vulnerable to analyser front-end overload and internally generated products because strong broadcast, cellular, aviation, radar and fixed-link signals may coexist. Each channel therefore records preselector state, attenuation, preamplifier state, compression margin and a terminated-input comparison.

The high-selectivity tracking receiver follows the search analyser input but is not allowed to create an apparent improvement by silently changing bandwidth or detector law. Wideband discovery and narrowband confirmation are retained as separate data products.

31.6 Band segmentation and antenna families

No single antenna and receiver state can credibly cover the complete 20 Hz to microwave range with constant sensitivity, phase fidelity and dynamic range.

The regional inventory is divided into band families determined by physics rather than by a marketing frequency span.

Extremely low frequency and audio-related magnetic fields require long-duration samples, magnetic shielding discipline and specialised cores. VLF and LF require attention to electric-field noise, mains coupling and very long wavelengths. HF through low VHF require a mixture of loops, rods and electrically short structures. VHF and UHF permit compact broadband arrays.

Microwave and millimetre-wave work requires calibrated apertures, horns or waveguide structures and careful cable-loss correction.

Table 31-2. Band segmentation by receiving physics and confounder class

Band family	Representative receiving structure	Principal regional concern
20 Hz to 3 kHz	Low-frequency magnetic bar, gradiometer, reference coil	Mains, 400 Hz power, audio currents, vibration and sensor microphonics
3 kHz to 300 kHz	Resonant ferrite or nanocrystalline bars, shielded loops, E-field probe	Timing families, carrier current, VLF services, winding self-resonance
300 kHz to 30 MHz	Shielded loops, active whips, calibrated H-field and E-field probes	Broadcast, utility, conducted escape, common-mode cable radiation
30 MHz to 700 MHz	Orthogonal broadband loops, biconical or compact log-periodic sets	Land mobile, broadcast, low-power transmitters, harmonics and intermodulation
700 MHz to 7 GHz	Log-periodic, ridged horn, calibrated near-field and planar probes	Cellular, WLAN, satellite downlink, ISM, fixed and intermittent digital systems
Above 7 GHz	Band-specific horn, waveguide or calibrated aperture	High cable loss, narrow beams, reflections and strict exposure or access constraints

31.7 Regional transmitter and emission inventory taxonomy

The inventory does not attempt to identify every transmitter by owner or decode content. It groups observed energy by source class and measured behaviour. Classes include continuous broadcast, cellular and private mobile infrastructure, fixed point-to-point links, satellite and navigation signals, aviation and maritime systems, public-safety and business radio, industrial control, utility and metering, wireless networking, consumer devices, vehicle electronics, medical or scientific equipment, switch-mode converters, power-line carriers, clock families, harmonics, intermodulation products, broadband noise, impulsive activity and unidentified signals. A class assignment is provisional unless supported by bandwidth, timing, direction, known allocation, station geometry and independent controls.

Known-source information may be obtained from public spectrum records, site documentation and client inventories when lawful and relevant. Such records are treated as hypotheses. A licensed transmitter may be off, misconfigured or shadowed; an unlicensed device may be lawful; a receiver product may mimic a real allocation; and a signal in a familiar band may have an unrelated origin.

The field record therefore separates observed centre frequency, occupied bandwidth, timing and bearing from the later source-class interpretation.

31.8 Temporal inventory and dwell design

A transmitter population is not static. Cellular scheduling, paging, telemetry, vehicle movement, aircraft, building controls, intermittent scientific instruments, duty-cycled sensors and burst transmitters may appear for milliseconds, seconds, minutes or only at particular times of day. The regional plan therefore combines rapid spectral discovery, fixed-span real-time or I/Q capture, long occupancy records and return visits.

Dwell is selected by the slowest plausible repetition interval in the authorised hypothesis, subject to practical limits and explicit disclosure. A protocol intended to detect a source that may transmit once a day or once a week cannot be represented honestly by a short afternoon sweep. Thus, all surveys and studies of this nature normally spans days and weeks, and sometimes months...

The examiner records local time, coordinated universal time, clock offset, weather, traffic state, building occupancy, nearby events and major equipment changes in both the paper field ledger and the digital event record.

A burst observed once is retained but not promoted merely because it is unusual. Promotion requires recurrence, coherent timing, spatial behaviour or a controlled trigger. Where a source is believed to occur only once per day or less frequently, the protocol ordinarily requires multi-day or multi-week passive sentinels and segmented return visits rather than an operator waiting at every ring. Such monitoring is privacy-limited and captures spectral and timing metadata rather than intelligible content unless separate authority exists.

A typical field cycle consists of approximately four to five days of acquisition, followed by seven to fourteen days of off-site analysis and authorised unattended monitoring, then a return that begins with reference-station closure before any inward work resumes.

This is an operational model rather than a rigid calendar rule. The interval is lengthened when the candidate has a longer apparent repetition period, when the site state varies across weekdays and weekends, or when a deliberate pause is needed to determine whether visible field activity itself changes the observed behaviour.

31.9 Descriptive propagation slopes and their limits

Ring-to-ring amplitude change is useful only when antenna transfer factor, gain state, bandwidth, polarisation, height and time are comparable. In an unobstructed far-field approximation, field magnitude can decline approximately in proportion to inverse range and power density approximately in proportion to inverse range squared. Urban, interior and near-field environments rarely obey that simple model across all radii. Terrain, diffraction, reflections, shielding, conductive services and antenna mismatch can produce reversals, plateaux and nulls. The protocol uses propagation slopes as descriptive features, not as conclusive range estimates.

$$\textit{Delta}\ L_{\mathrm{dB}} = 20\log_{10}(r_2/r_1) \quad (5)$$

For a far-field amplitude-like quantity under unchanged geometry, Delta L_dB is the idealised level change between ranges r_1 and r_2. A measured departure from this relation may indicate clutter, changing coupling, source variation, receiver error or an incorrect source model. It is not proof of concealment or proximity.

A robust comparison calculates level differences together with uncertainty and contemporaneous sentinel change. If the mobile channel rises by 8 dB while the sentinel rises by 7 dB, the net premises-related change may be negligible. If the mobile channel rises by 8 dB while two sentinels remain stable within their uncertainty, the geometry warrants closer examination. Phase and vector orientation can add discrimination when the source is sufficiently coherent and the channels are calibrated.

31.10 Frequency-scaled geometry and field-region awareness

A fixed physical radius represents very different electrical distances at 400 Hz, 32.768 kHz, 30 MHz, 300 MHz and 3 GHz. At very low frequencies the entire regional sequence may lie within a complex quasi-static or induction-dominated environment relative to the relevant conductors.

At VHF and above, many regional stations are in the radiating field of ordinary antennas, but the inspected building and nearby structures still create multipath and scattering. The report therefore states wavelength, approximate electrical separation and the reason a particular probe family was used.

The familiar far-field estimate R_ff approximately equals 2D squared divided by lambda applies to an antenna of maximum dimension D and wavelength lambda under stated assumptions. It is not automatically applicable to an unknown source distributed across wiring, a building, a cable network or a conductive service. The examiner avoids declaring a ring to be far field merely because it is geographically distant. Instead, the source model and observable are declared.

31.11 Bearing, polarisation and vector comparison

At every annulus the three orthogonal components are recorded simultaneously. A dominant component can change with bearing because the local field, antenna polarisation and reflecting environment change.

The examiner therefore retains the complex vector rather than selecting the largest trace and discarding the others. Where calibration permits, the magnitude |E| or |H| is derived from the orthogonal components, and the covariance among channels is preserved.

Bearings inferred from loop nulls or array phase are reported with ambiguity, calibration uncertainty and multipath limitations.

$$|\mathrm{F}| = \sqrt{|\mathrm{F}_x|^2 + \left|\mathrm{F}_y\right|^2 + |\mathrm{F}_z|^2} \quad (6)$$

Here F represents either an electric-field or magnetic-field vector after channel calibration. The expression is not valid as a simple scalar combination when the channels do not share time, phase reference, location, bandwidth or transfer calibration.

31.12 Receiver-generated products and strong-signal controls

The regional bands contain signals capable of creating harmonics, images, intermodulation, reciprocal mixing, phase-noise skirts, ADC clipping, aliasing and local-oscillator leakage inside the receiving system. Every promoted line is therefore challenged by attenuation steps, preselector changes, preamplifier bypass, alternate sample rates, changed intermediate-frequency architecture, terminated inputs and an independent receiver. A genuine external signal should follow the appropriate antenna and spatial path, while an internally generated product may shift, disappear or change nonlinearly when the receiver configuration changes.

Two-tone intermodulation predictions are calculated whenever two strong regional carriers could generate a candidate frequency. For input frequencies f_1 and f_2, common third-order products occur at $2f_1 - f_2$ and $2f_2 - f_1$. Higher-order combinations are considered where the front end is stressed. The purpose is not to identify every mathematical combination, but to show whether the candidate can be reproduced by known strong inputs under controlled gain and filtering changes.

31.13 Fixed sentinels, mobile arrays and closure

At least one fixed sentinel records continuously while the mobile team changes rings, and the sentinel programme may continue through the intervals between four-to-five-day, or multi-month field deployments. The sentinel channel allocation, antenna, position, gain, time base and privacy controls remain unchanged except for documented safety or maintenance intervention. A second sentinel on a materially different bearing is preferred for long surveys. The sentinels preserve technical presence while the visible field team withdraws, provide temporal correction, detect regional bursts, reveal changes in broadcast or mobile activity and preserve the pre-entry state. They are not used to normalise away genuine spatial behaviour without an uncertainty analysis.

Closure occurs in spatial, temporal and documentary dimensions. The mobile array revisits selected outer stations after the close search and at the beginning of each return deployment. The data system confirms clock continuity, channel calibration, file hashes, missing records, equipment state and station coordinates. The field custodian reconciles every digital acquisition identifier with its paper page, movement entry and operator initials. A candidate that vanishes during withdrawal or after an intermission may be intermittent, state-dependent, human-responsive or instrument-related. The report states the observation and competing explanations without inventing a cause.

31.14 Advancement gates from regional annuli to the premises

Table 31-3. Regional-to-site advancement gates

Gate	Minimum condition	Failure consequence
Gate R1	Signal or feature recurs in time or survives a justified long dwell.	Single isolated burst retained as observation only.
Gate R2	Mobile change exceeds combined uncertainty and is not mirrored by sentinel change.	Temporal or regional change remains primary explanation.
Gate R3	At least two materially different bearings, heights or polarisations support a coherent geometry.	Single-path result remains vulnerable to local clutter.
Gate R4	Receiver artefact controls, attenuation tests and independent architecture do not explain the feature.	No inward promotion until artefact hypothesis is addressed.
Gate R5	The feature has a stated reason for closer examination at 300 feet.	A strong known regional service is inventoried but not pursued.

Passing a gate does not establish that a transmitter or device is present. It establishes that an observation merits the next controlled comparison. The examiner may advance with no candidate at all because the purpose of the sequence is also to document absence within capability. Conversely, the examiner may stop a candidate at the 1-mile or 0.5-mile stage when its bearing, timing and independent identification show that it belongs to an unrelated external service.

31.15 Worked regional example: strong external carrier. A narrow carrier appears at every 5-mile station and is strongest on the western bearing. At 2.5 miles it rises by 6 dB at the western station but falls elsewhere. The 1-mile and 0.5-mile stations show a consistent bearing toward a known communications site west of the inspected premises. At 0.25 mile the signal remains strong but does not converge on the building, and its level changes are reproduced by the outer sentinel. The correct result is a documented regional source-class candidate, not a premises-associated signal. The carrier remains in the exclusion and overload-control register during the close search.

31.16 Worked regional example: intermittent site-vicinity burst. A 40-millisecond burst recurs approximately every 37 minutes. It is absent during the first 5-mile pass, appears at one 2.5-mile station, and is captured simultaneously by the 1-mile sentinel and the 0.5-mile mobile array.

Its level does not increase consistently, but the burst epoch remains coherent to the common time base. At 0.25 mile three bearings show a modest premises-centred gradient while the 1-mile sentinel remains stable.

This justifies a 300-foot controlled comparison. It does not justify attributing the burst to a concealed device. The later rings must still exclude vehicle, utility, building-control, neighbouring-premises and receiver hypotheses.

31.17 Worked regional example: receiver intermodulation. A candidate near 300 MHz appears only with the preamplifier enabled at the 0.5-mile ring. Two much stronger local carriers satisfy a third-order combination within the analyser frequency uncertainty.

Adding input attenuation reduces the candidate by approximately three times the attenuation applied to each strong input, while the parent carriers decline linearly.

A narrower preselector removes the candidate, and an independent receiver does not reproduce it. The correct classification is receiver-generated intermodulation. The observation is retained because it documents a condition that could otherwise reappear during the interior search.

31.18 Regional record fields

Table 31-4. Regional annulus station record

Record group	Mandatory fields
Station identity	Ring, sector, station, vertical tier, coordinate system, latitude/longitude or ENU, altitude, sensing-centre height and uncertainty.
Access and environment	Land authority, weather, traffic, nearby electronics, topography, visible infrastructure without photographing the target, and missing sectors.
Instrument state	Chassis, channel, antenna or probe, calibration file, preselector, attenuation, gain, bandwidth, detector, sample rate, time base and clock offset.
Signal observation	Frequency, uncertainty, occupied bandwidth, amplitude or field value, phase where valid, polarisation, burst timing, duty cycle and raw-file identifier.
Comparative result	Sentinel change, preceding-ring change, bearing, altitude effect, artefact controls, source-class hypothesis and confidence.
Decision	Advance, hold, repeat, classify as regional, classify as instrument-related, or retain as unresolved observation.

31.19 Reporting language for the regional inventory

The report uses language such as: "A narrowband emission at the stated frequency was observed at four regional stations and displayed its greatest calibrated level on the western bearing. The same temporal variation was present at the fixed sentinel. The evidence therefore supports a regional external-source interpretation and does not support premises association." Where the evidence is weaker, the report states: "The observation was not sufficiently recurrent or geometrically constrained to distinguish a regional source, a mobile source, a receiver product or a premises-associated source."

The report does not state that a missing regional signal proves absence, that a rising signal proves proximity, that a familiar frequency proves a device type, or that an unresolved burst is malicious. The professional value of the regional search lies precisely in its ability to support non-attribution when the larger environment explains the observation.

31.20 Mandatory station-count architecture for the five regional annuli

The numerical station plan is part of the measurement design, not a decorative map and not an estimate prepared after the survey. The 5-mile, 2.5-mile and 1-mile annuli each begin with sixteen distinct measurement locations distributed around the full bearing circle. A project classified as high risk increases each of those three annuli to twenty-four distinct locations. The 0.5-mile annulus ordinarily contains twelve locations. Where access, terrain, traffic safety or property rights make twelve impracticable, the ring may be processed with eight, but it shall not be described as complete with fewer than eight. The 0.25-mile annulus should contain twelve locations and shall likewise contain no fewer than eight. Repeat visits to one station improve temporal sampling but do not create new angular coverage.

High-risk escalation is justified by the consequence and uncertainty of the commission rather than by theatrical language. Relevant factors include credible prior evidence of technical compromise, a critical facility or decision process, an expected remotely activated or very low-duty-cycle device, a dense or rapidly changing emitter environment, severe multipath, incomplete access, an inability to repeat the work later, or a foreseeable requirement that the record withstand independent technical and legal scrutiny. The escalation decision is signed before the ring is occupied. It is not made retrospectively because a candidate signal appears interesting.

Table 31-5. Required 96 site regional station density and angular sampling

Ring	Ordinary plan	High-risk plan	Nominal angular interval	Completion rule
5 miles	16 stations	24 stations	22.5° ordinary; 15° high risk	Sixteen is the governing ordinary plan. Any inaccessible sector is reported, not silently removed.
2.5 miles	16 stations	24 stations	22.5° ordinary; 15° high risk	Match the 5-mile bearing architecture as closely as lawful access permits.
1 mile	16 stations	24 stations	22.5° ordinary; 15° high risk	Retain outer sentinels and preserve the same time base and channel map.
0.5 mile	12 stations	12 plus justified infill	30° preferred; 45° at the eight-station minimum	No fewer than eight. A reduction from twelve requires an access and coverage limitation.
0.25 mile	12 stations preferred	12 plus justified infill	30° preferred; 45° at the eight-station minimum	No fewer than eight. Twelve is the preferred site-adjacent plan.

31.21 Equal-angle design, actual station geometry and missing-sector treatment

For a ring containing N nominal stations, the intended angular increment is Delta beta = 360 degrees / N. If beta_0 is the declared starting bearing, the nominal bearing of station i is beta_i = beta_0 + (i - 1)Delta beta, reduced modulo 360 degrees. Sixteen stations therefore create 22.5-degree sectors, twenty-four create 15-degree sectors, twelve create 30-degree sectors and eight create 45-degree sectors. These equations define the sampling design. They do not pretend that public roads, property boundaries or safe standing positions form a perfect circle.

For a circular ring of radius r, the nominal arc spacing between N equally separated stations is s = 2 pi r / N. Here s is the arc length along the idealised ring, r is the nominal radius and N is the planned station count. The value supports logistics and reveals large gaps, but it is not the road distance, walking distance or electromagnetic path length. Actual latitude, longitude or East-North-Up coordinates, slant range, sensing-centre height and angular departure from the planned sector remain the controlling geometry.

Table 31-6. Nominal arc spacing produced by the prescribed station counts

Ring and plan	Stations N	Angular interval	Nominal arc spacing
5 mi, ordinary	16	22.5°	1.963 mi, approximately 10,367 ft
5 mi, high risk	24	15°	1.309 mi, approximately 6,912 ft
2.5 mi, ordinary	16	22.5°	0.982 mi, approximately 5,184 ft
2.5 mi, high risk	24	15°	0.654 mi, approximately 3,456 ft
1 mi, ordinary	16	22.5°	0.393 mi, approximately 2,073 ft
1 mi, high risk	24	15°	0.262 mi, approximately 1,382 ft
0.5 mi, preferred	12	30°	0.262 mi, approximately 1,382 ft
0.5 mi, minimum	8	45°	0.393 mi, approximately 2,073 ft
0.25 mi, preferred	12	30°	0.131 mi, approximately 691 ft
0.25 mi, minimum	8	45°	0.196 mi, approximately 1,037 ft

A station displaced by access constraints remains assigned to its intended sector but is marked substituted, with the actual bearing and range entered beside the nominal values. The largest unmeasured angular gap is calculated and reported. Two stations crowded into one convenient sector do not compensate for an unmeasured opposite sector. When a gap spans more than one nominal sector, the ring is incomplete unless an elevated station, an alternate lawful road position or another documented geometry provides a technically defensible view of that sector. The report preserves the incompleteness even when later inner rings produce an apparently persuasive gradient.

31.22 Deliberate measurement tempo and contemporaneous paper documentation

The governing tempo resembles major-scene processing, archaeological excavation and precision metrology rather than a retail sweep. The team pauses before occupying each station, confirms the station identity, reconciles the intended and actual coordinates, checks the common time base, verifies the channel map, records the environmental state and only then permits acquisition. The field custodian writes the entry while the event occurs.

Notes are not reconstructed at the hotel, in the vehicle or during later analysis and then represented as contemporaneous. Where a late clarification is necessary, it is labelled retrospective, dated, timed, signed and linked to the original entry without altering the original page.

Every evidential acquisition therefore has two inseparable records. The first is the machine record containing raw samples, spectra, trigger states, channel metadata, calibration references and cryptographic hashes.

The second is the paper record containing the human and spatial context that an instrument cannot know. It identifies who was present, where the probe centre stood, how the equipment was oriented, what moved, what the operator heard or observed in the environment without decoding private content, why the setting was changed and what decision followed. Neither record substitutes for the other.

Table 31-7. Contemporaneous field-documentation controls

Event	Paper entry required before departure from event	Machine or custody record
Station opening	Station ID, ring, nominal sector, actual coordinates, height, UTC and local time, access basis, personnel and weather.	Clock status, channel map, calibration file, system health and baseline file ID.
Equipment placement	Pod, probe, axis, sensing-centre coordinate, cable route, support, distance from local objects and any deviation from plan.	Channel serial, transfer file, gain, attenuation, preselector, resonance state and overload margin.
Acquisition	Start and stop time, dwell, operating state, nearby activity, anomaly notation and operator initials.	Raw data, sample rate, bandwidth, detector, trigger, timestamps and hash.
Movement or intervention	Item moved, original and final coordinate, route, reason, persons involved, before-and-after event IDs.	Pre-movement and post-movement records; affected channel and cube list.
Decision	Advance, hold, repeat, substitute, stop or close; stated reason and authorised reviewer.	Analysis version, comparison set, control results and decision file.
Correction	Single-line strike-through, legible original, corrected entry, initials, date, UTC and explanation. No erasure.	Append-only audit event; original file remains retained and hashed.

31.23 Equipment movement as an experimental intervention and scene-preservation event

Every movement of equipment, personnel, furniture, doors, blinds, cables, vehicles or portable power sources is treated as an experimental intervention because it can change the measured field. The change may arise through shielding, reflection, diffraction, common-mode current, magnetic reluctance, dielectric loading, cable reorientation, ground coupling, preamplifier self-emission or human-body capacitance.

The examiner therefore moves one controlled item at a time, records its initial and final position, repeats the relevant reference channel and waits for mechanical, thermal and electronic settling before the next evidential sample.

The requirement for grave, quiet and unhurried handling has two connected purposes. First, it preserves the physical and electromagnetic state of a scene that may contain suspected technical interference, a lawful but poorly understood device, or an environmental anomaly. Secondly, it reduces measurement reactivity.

Conspicuous activity can cause a person, an automated controller or an intermittent device to change state, while hurried handling can manufacture the very noise, modulation or coupling change that the team later tries to explain. The method therefore minimises disturbance without authorising covert entry, impersonation, interference with communications or evasion of lawful security controls.

When a candidate changes during movement, the team stops. It restores the previous geometry if safe and lawful, acquires a closure record, repeats the dummy and sentinel channels, and identifies the minimum set of affected stations or cubes. The change is not dismissed as operator error, nor is it immediately attributed to a concealed source. It becomes a documented intervention response requiring its own rival hypotheses.

31.24 Multi-week campaign architecture and segmented field presence

The complete protocol is planned as a campaign, not a visit. A single four-to-five-day period may be a useful field segment, but it is not ordinarily the whole commission. The outer annuli, the site-transition stages, the interior cube system, the long-dwell sentinel record, the off-site analytical review and the return closure each consume different kinds of time. The schedule is therefore divided into acquisition blocks and observation intervals. The visible field team may withdraw for one or two weeks while client-authorised passive sentinels continue to collect privacy-limited spectral and timing metadata.

The technical record remains continuous even though the operators are not visibly present in the inspected area.

The purpose of segmentation is analytical rather than theatrical. It allows weekday, weekend, occupancy and equipment-state variation to be compared; it prevents operator fatigue from corrupting thousands of station records; it permits detailed off-site examination of weak or nested modulation; and it tests whether a signal changes when the conspicuous measurement apparatus is absent. A commission involving a burst that occurs only every several days, a remotely activated response or several connected buildings may therefore extend for months.

Duration is justified by the authorised hypotheses and reported without embarrassment or exaggeration.

Table 31-8. Illustrative extended-campaign cadence

Campaign element	Illustrative duration	Principal work	Closure requirement
Planning and authority	Several days or as required	Scope, safety, privacy, station design, high-risk decision, equipment characterisation and logistics.	Signed plan, map, channel architecture and paper-log issue record.
Field segment A	Approximately 4 to 5 days	5-mile, 2.5-mile and 1-mile annuli; sentinel deployment; initial emitter census.	Outer-station review, missing-sector report and clock closure.
Observation and analysis interval	Approximately 7 to 14 days	Passive sentinel monitoring, off-site FFT, occupancy, burst and modulation analysis.	Custody, health, clock, privacy and data-completeness review.

Campaign element	Illustrative duration	Principal work	Closure requirement
Field segment B	Approximately 4 to 5 days	0.5-mile, 0.25-mile and 300-foot transition; targeted high-ground or service-path comparisons.	Reoccupation of selected outer references and advancement decision.
Second observation interval	Approximately 7 to 14 days or longer	Test recurrence, absence of visible team, daily or weekly cycles and candidate timing.	Sentinel continuity and rival-hypothesis review.
Field segment C	Approximately 4 to 5 days or as required	Close rings, threshold, interior cube system, 3-inch convergence and independent confirmation.	Reverse path, movement reconciliation, hashes and preliminary findings.
Extended continuation	Weeks to months where justified	Rare bursts, multiple buildings, repeated state conditions, controlled illumination under separate authority.	Periodic scope renewal, safety review and interim limitation report.

31.25 Intermission monitoring and re-entry closure

An intermission is not an evidential void. Each unattended sentinel has a declared antenna, orientation, location, gain state, time reference, storage capacity, health channel, privacy rule and custody owner. Any maintenance visit is logged as an intervention. The data system records power interruption, clock reacquisition, storage rollover, thermal excursions, overload and channel failure. A silent period caused by a dead battery is not presented as absence of the signal.

A return deployment begins with closure rather than immediate pursuit of the previous candidate. The team first reoccupies selected outer or transition stations, verifies the instrument self-spectrum, repeats the dummy and terminated paths, compares sentinel and mobile clocks, and tests whether the earlier background population is still recognisable. Only after those checks can the later measurements be joined to the earlier campaign. If closure fails, the epochs remain analytically separate and the report explains why.

31.26 High-risk escalation, incomplete coverage and stopping rules

High-risk work ordinarily uses twenty-four stations at each of the 5-mile, 2.5-mile and 1-mile annuli, at least two independent sentinels, duplicate time-of-day observations, a second receiver architecture for promoted candidates and additional elevated or infill stations where the terrain creates large blind sectors.

The 0.5-mile and 0.25-mile annuli retain twelve as the preferred plan and receive targeted infill where a regional bearing, service corridor or vertical path warrants it. The additional stations reduce angular ambiguity. They do not justify stronger attribution unless the measurement controls also succeed.

When the prescribed count cannot be completed, the project does not manufacture compliance. The ring is labelled incomplete, the actual station count and largest angular gap are reported, and the authorised reviewer decides whether to substitute another geometry, add a different elevation, hold the inward progression or proceed with an express limitation.

Work stops when a station is unsafe, unlawful, likely to obstruct traffic, incompatible with medical or aviation safety, or incapable of protecting the instruments and records. The seriousness of the commission never converts a hazard into an acceptable station.

31.27 Reporting duration, station completeness and non-perturbation

The final report states the planned and completed station count for every annulus, the ordinary or high-risk sampling plan, actual dates, field-segment durations, intermission durations, sentinel coverage, re-entry closure results, inaccessible sectors and the total period over which the environment was observed. It distinguishes hours of active field acquisition from days of passive monitoring and from off-site analytical time. This prevents a weeks-long campaign from being reduced to a misleading statement that a team attended on three dates, and it prevents a short visit from being dressed in the language of continuous monitoring.

The report also explains the non-perturbation discipline. Equipment and personnel were moved slowly and one at a time, ordinary site states were preserved unless a controlled intervention was authorised, and contemporaneous paper records were created as measurements occurred. The report does not claim that this discipline made the activity invisible to an adversary. It states the narrower and defensible proposition that the team sought to minimise scene disturbance and behavioural reactivity while preserving lawful authority, safety and technical traceability.

A narrow carrier appears at every 5-mile station and is strongest on the western bearing. At 2. 5 miles it rises by 6 dB at the western station but falls elsewhere. The 1-mile and 0. 5-mile stations show a consistent bearing toward a known communications site west of the inspected premises. At 0. 25 mile the signal remains strong but does not converge on the building, and its level changes are reproduced by the outer sentinel. The correct result is a documented regional source-class candidate, not a premises-associated signal. The carrier remains in the exclusion and overload-control register during the close search.

A 40-millisecond burst recurs approximately every 37 minutes. It is absent during the first 5-mile pass, appears at one 2. 5-mile station, and is captured simultaneously by the 1-mile sentinel and the 0. 5-mile mobile array. Its level does not increase consistently, but the burst epoch remains coherent to the common time base. At 0. 25 mile three bearings show a modest premises-centred gradient while the 1-mile sentinel remains stable. This justifies a 300-foot controlled comparison. It does not justify attributing the burst to a concealed device. The later rings must still exclude vehicle, utility, building-control, neighbouring-premises and receiver hypotheses.

A candidate near 300 MHz appears only with the preamplifier enabled at the 0. 5-mile ring. Two much stronger local carriers satisfy a third-order combination within the analyser frequency uncertainty. Adding input attenuation reduces the candidate by approximately three times the attenuation applied to each strong input, while the parent carriers decline linearly. A narrower preselector removes the candidate, and an independent receiver does not reproduce it. The correct classification is receiver-generated intermodulation. The observation is retained because it documents a condition that could otherwise reappear during the interior search.

Chapter Glossary

Terms used in Chapter 38.

A

ANTENNA — A transducer that couples guided electrical energy to radiated electromagnetic fields, or converts incident electromagnetic fields into guided electrical energy.

ATTENUATION — The ability of a filter circuit to reduce the amplitude of unwanted frequencies to a level below that of the desired output frequency.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BEARING — An angular direction from a defined reference meridian or axis to a source, target, or line of sight.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

E

EXTREMELY LOW FREQUENCY — The band of frequencies up to 300 hertz.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

L

LINE OF SIGHT — Straight line from a radar antenna to a target.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

32. Comparative Room Geometry, Twenty-Seven-Cell Volumetric Processing, and Vertical High-Ground Sampling

A room is not processed as a two-dimensional rectangle with a single probe height. It is treated as a three-dimensional measurement volume bounded by floors, ceilings, walls, openings, services, furnishings and connected spaces. At each scale the candidate region occupies the centre of a 3 by 3 by 3 neighbourhood.

The surrounding twenty-six cells provide face, edge and corner comparisons. The same geometry can represent an entire room at coarse scale, a group of furniture bays at intermediate scale, or a few cubic inches at final convergence. The cell dimensions are therefore declared for every pass rather than implied by the word cube.

Expert-practitioner interpretation. Crime-scene diagrams preserve where objects were, how they related to fixed points and what changed during processing. The electronic-emission scene requires the same discipline, but the measured quantity is a field whose value depends upon position, orientation, time, bandwidth, probe transfer function and the state of the environment. Furniture, cables, doors, occupants and test equipment are not merely background objects. They are components of the electromagnetic boundary condition and must be located, moved and remeasured accordingly.

32.1 Room-size references and the 12-to-15-foot operational module

There is no universal residential, office or classroom room size for Canada, the United States or the United Kingdom. Building codes, housing standards, workplace rules and educational guidance define minima or planning allocations rather than a single typical dimension. The often encountered 12-to-15-foot span is therefore used in this framework as an operational search module, not as a legal definition or statistical national average. A room smaller than that module is still processed volumetrically. A room larger than it is divided into adjoining modules with overlap and closure.

Selected official references illustrate the range. The United Kingdom nationally described space standard specifies at least 7.5 square metres for a single bedroom and 11.5 square metres for a double or twin bedroom, with minimum widths [132]. Ontario guidance illustrating Building Code room minima gives 13.5 square metres for a separated living area, 9.8 square metres for a principal bedroom without a built-in closet and 7 square metres for another bedroom [133]. A selected United States residential-code implementation requires at least 70 square feet for a habitable room and a minimum horizontal dimension of 7 feet [134]. These are minimum or reference requirements, not evidence that an actual room will have those dimensions.

Office and academic spaces are frequently larger and more varied. Current United States General Services Administration policy uses a maximum all-in allocation of 150 usable square feet per person for future internal workplace projects rather than a fixed room size [135]. The United Kingdom Health and Safety Executive explains that 11 cubic metres per person corresponds, in a typical room with a 2.4-metre ceiling, to approximately 4.6 square metres of floor area, while warning that furniture and equipment consume usable space [136]. United Kingdom BB103 guidance places many standard classrooms for 30 pupils in the 55-to-62-square-metre range [137].

British Columbia area standards state that a new classroom including ancillary space shall not be less than 75 square metres [138]. These figures demonstrate why the protocol must scale from a bedroom to a large classroom or open office without pretending that one cell size suits all premises.

Table 32-1. Selected room-area references and their limited use in search planning

Jurisdiction and use	Selected official reference	Status of figure	EERF geometric consequence
United Kingdom residence	Single bedroom at least 7.5 m^2; double or twin at least 11.5 m^2 under NDSS.	Minimum standard, not average.	Divide actual dimensions into 3 by 3 plan cells and three height tiers.
Canada residence, Ontario example	Living area 13.5 m^2; principal bedroom 9.8 m^2; other bedroom 7 m^2 in provincial guide.	Illustrative code minima for separated spaces.	Use measured room dimensions; include open-concept boundaries and service routes.
United States residence, selected code example	Habitable room at least 70 ft^2 and at least 7 ft in a horizontal dimension.	Local and model-code adoption varies.	Do not infer national typical size; record actual geometry.
United Kingdom workplace	11 m^3 per person; about 4.6 m^2 at a 2.4 m ceiling for illustrative minimum space.	Per-person volume, not office-room size.	Furniture and equipment remain part of the measurement scene.
United States federal workplace	Up to 150 usable ft^2 per person all-in for future GSA internal projects.	Allocation benchmark, not enclosed office dimension.	Open offices require multiple overlapping 12-to-15-ft modules.
United Kingdom classroom	Many standard 30-pupil classrooms 55 to 62 m^2 under BB103.	Planning guidance.	Process as adjoining volumetric modules with wall, ceiling and floor pairs.

Jurisdiction and use	Selected official reference	Status of figure	EERF geometric consequence
Canada classroom, British Columbia example	New classroom including ancillary space at least 75 m^2.	Provincial area standard.	Expect larger spans, suspended services and multiple electronic zones.

32.2 The twenty-seven-cell neighbourhood

Let the cell of interest be C(0,0,0). Its complete first neighbourhood contains C(i,j,k) for i, j and k in {-1, 0, +1}. The central cell is surrounded by six face-sharing neighbours, twelve edge-sharing neighbours and eight corner-sharing neighbours. Face neighbours test the most direct Cartesian gradients. Edge neighbours test diagonal propagation and structural coupling. Corner neighbours test the oblique volume that is easily missed by a floor-only grid. The complete neighbourhood therefore contains twenty-seven cells.

$$N_{27} = C(i,j,k): i,j,k\text{in} - 1,0,+1 (7)$$

The set N_27 is a local indexing system. It does not assume that the field is rectilinear or that the source is centred. It ensures that the examiner samples the centre, all six faces, all twelve edges and all eight corners before reducing the search volume.

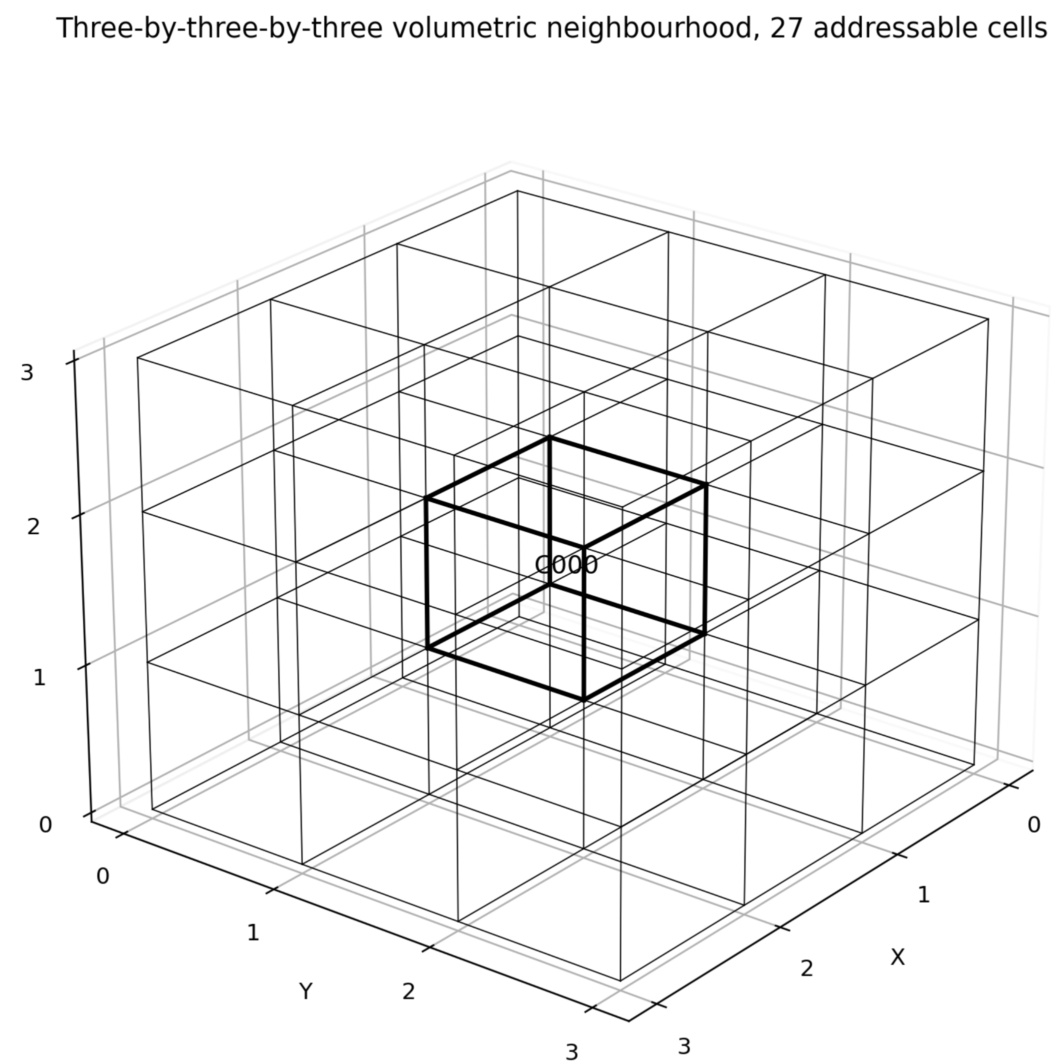


Figure 32-1. Twenty-seven-cell neighbourhood with the area of interest in the centre cell.

32.3 Cell size at coarse, intermediate and fine scales

The word cube describes the indexing topology, but the physical cell may be a rectangular cuboid where room dimensions do not divide equally. At the room scale, a 12-foot by 15-foot by 9-foot room divided into three parts on each axis yields cells approximately 4 feet by 5 feet by 3 feet. At an intermediate scale, a selected 3-foot cube may be divided into twenty-seven 12-inch cubes. At final convergence, a 9-inch cube may be divided into twenty-seven 3-inch cubes. The record states the actual cell edge lengths and sensing-centre coordinates.

Adjacent modules overlap by at least one cell layer when a large room, corridor, open-plan office or classroom cannot be represented by a single twenty-seven-cell assembly. Overlap creates closure and prevents a source lying on a module boundary from receiving less attention. A module is not advanced to a smaller scale until its surrounding comparison cells have been measured or formally excluded for access, safety or scope.

Table 32-2. Scale-dependent twenty-seven-cell processing

Scale	Cell dimension rule	Purpose
Room-scale module	One-third of actual room length, width and accessible height	Find broad horizontal and vertical gradients; compare walls and services.
Coarse localisation	Nominal 3 ft cells or validated equivalent	Contain candidate within furniture, service or structural region.
Intermediate localisation	Nominal 12 in cells	Resolve wall bay, cable route, object face or compact equipment region.
Fine localisation	Nominal 3 in cells or exact 3-in decrements	Produce smallest non-contact bounding volume supported by probe aperture and uncertainty.

32.4 Room origin, axes and hard-point survey

Before electronic measurements begin, the room receives a declared origin and right-handed axis convention. A suitable default places the origin at the floor projection of a stable hard point, with X increasing along the principal room length, Y along the principal width and Z upward. Door swings, windows, columns, service penetrations, ceiling grids, floor boxes, fixed furniture and major conductive objects are located relative to at least two hard points. The hard points themselves are measured redundantly so that gross drawing error can be detected by closure.

Triangulation uses measured angles from known baselines. Trilateration uses distances from known points. In an ordinary rectangular room, perpendicular offsets may be sufficient, but the method retains at least one redundant diagonal or independent check. Furniture corners and probe stations are not located by visual estimate when they influence a candidate interpretation. The scene drawing displays both physical objects and the volumetric cell lattice without implying a photograph or electronic image of any device.

$$d_{\mathrm{AB}} = \sqrt{(x_B - x_{\mathrm{A}})^2 + (y_B - y_{\mathrm{A}})^2 + (z_B - z_{\mathrm{A}})^2} \quad (8)$$

The Euclidean distance d_AB provides a closure check between measured coordinates A and B. Disagreement between direct distance and coordinate-derived distance beyond the survey tolerance is resolved before fine localisation.

32.5 Opposite-wall and opposite-face pairing

Every wall-associated candidate is tested from both accessible sides. A point on the room side of a wall is paired with the corresponding point on the opposite side, corrected for wall thickness, construction and accessible standoff. The pair uses matched probe orientation, sensing-centre height, bandwidth, gain, dwell and time reference. Where the opposite side is another room, corridor or external face, that space becomes part of the controlled measurement scene. Where it is inaccessible, the missing comparison is reported as a depth and attribution limitation.

Paired-surface analysis distinguishes a localised source near one face from a conductor running within the wall, a service penetration, a shield seam or an external source. A larger field on one side is not by itself proof that the source lies on that side, because wall materials, conductive foil, reinforcement, studs, cable routes, resonances and probe standoff can alter coupling. The interpretation uses calibrated gradients, phase where valid, null orientation and adjacent-cell behaviour.

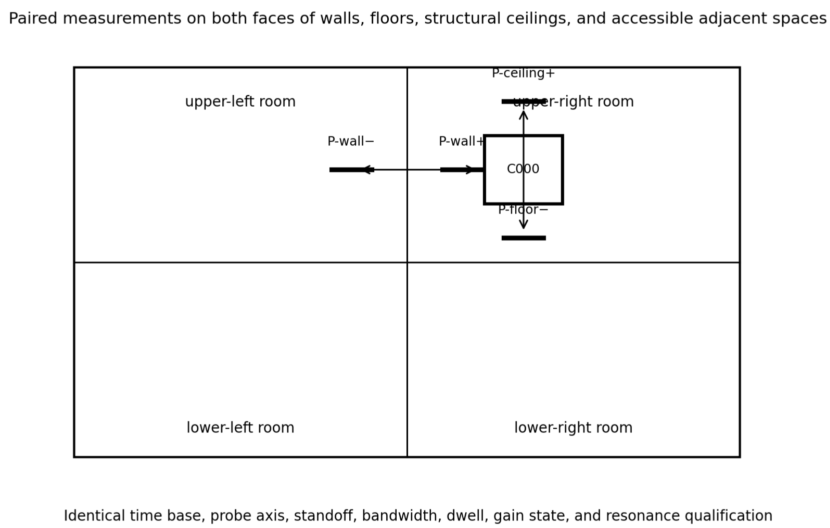


Figure 32-2. Paired measurements across opposite walls, floor and ceiling boundaries.

32.6 Floor-below and ceiling-above comparisons

A floor measurement is incomplete when the storey below is accessible but unexamined. Similarly, a ceiling measurement is incomplete when the plenum, roof space or upper storey can be accessed safely and lawfully.

The protocol therefore creates vertical pairs: the floor-side point in the inspected room, the corresponding ceiling-side point below, the ceiling-side point in the inspected room, and the corresponding floor-side point above. Suspended ceilings, raised floors and deep structural voids may require separate near and far surfaces.

Vertical access is frequently constrained. Residences may have no accessible lower room or loft. Offices may have tenants above or below. Academic buildings may have laboratories, plant or occupied classrooms. The examiner coordinates access without disrupting life-safety systems or moving hidden services. When access is not possible, the report describes the unmeasured vertical volume and avoids a conclusion that depends upon knowing source depth.

32.7 The centre cell and angular radiation paths

The centre cell is a hypothesis volume, not a presumed source. Measurements radiate outward from it along face-normal, edge-diagonal and corner-diagonal paths. The six face paths correspond to positive and negative X, Y and Z. The twelve edge paths combine two axes. The eight corner paths combine all three axes. These twenty-six directions provide a disciplined set of angular comparisons around the centre. Additional angles are added where the probe radiation pattern, room geometry or candidate nulls require them.

The examiner preserves both inward and outward traverses. If an apparent gradient exists only on the inward pass, drift, operator carriage or state change remains plausible. If the centre cell is strongest but one corner path points toward a cable riser, the source model may be an extended conductor rather than a compact object. The twenty-seven-cell discipline is therefore a mechanism for testing alternatives rather than merely drawing smaller boxes around the largest reading.

32.8 Spherical and ellipsoidal shell sampling

After a candidate centre is estimated, the measurement points may be reorganised into shells of approximately equal range. In a homogeneous far-field environment, equal-range points might be expected to form a sphere around a compact isotropic source. A real room is neither homogeneous nor far-field at many frequencies. Conductive walls, floors, cables and anisotropic materials distort the field, while electric and magnetic near-field components have different range dependence. The sphere is therefore a sampling scaffold, not an assumed physical truth.

When the measured field shows different apparent scale lengths along X, Y and Z, an ellipsoidal shell may describe the data more honestly. The semi-axes are reported as fitted descriptive parameters with uncertainty. A shell is considered adequately sampled only when opposite directions and feasible vertical tiers are represented. A floor-only circle is not called a sphere.

$$\left((x - x_c)/a\right)^2 + \left((y - y_c)/b\right)^2 + \left((z - z_c)/c\right)^2 = 1 \quad (9)$$

This ellipsoid is centred at (x_c,y_c,z_c) with semi-axes a, b and c. It may summarise anisotropic spatial decay, but it does not identify the physical source mechanism without independent evidence.

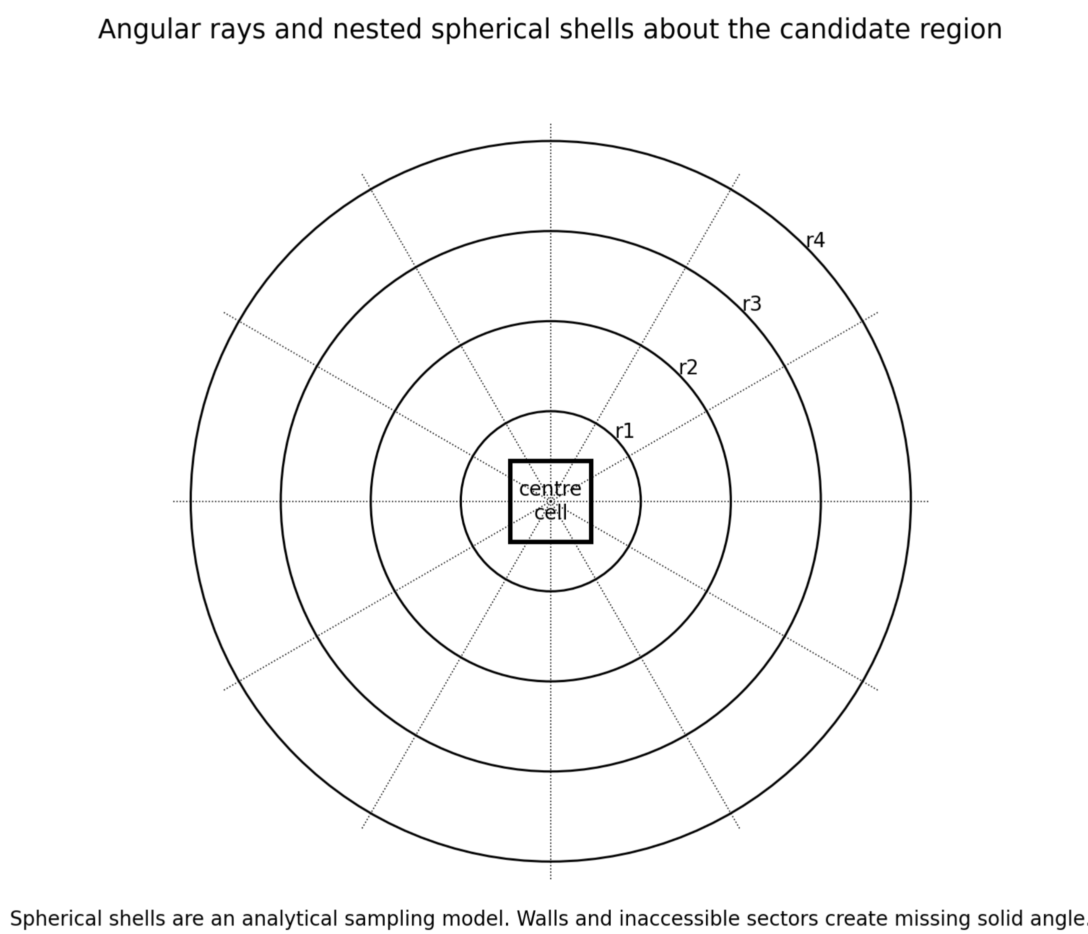


Figure 32-3. Spherical-shell sampling around a centre cell, with upper and lower solid-angle limitations.

32.9 Missing solid angle and the practical high-ground rule

A room searched only at waist height leaves substantial upper and lower solid angle unobserved. Ceiling services, luminaires, cable trays, wireless access points, smoke detectors, projectors, raised floors, underfloor power, ducts and upper-storey conductors may produce or redirect fields. The practical high-ground rule requires measurements at the highest safe and authorised sensing-centre elevation that the room permits, together with lower and mid-height tiers. In a standard-height room, a stable floor-mounted mast or approved platform may be sufficient. In a tall hall, atrium or industrial space, multiple elevations or upper walkways may be necessary.

No high-ground requirement overrides fall protection, electrical clearance, fire systems, ceiling-load restrictions, asbestos controls, confined-space rules or occupied-room safety. A pole-mounted passive probe can increase sensing height without placing the operator aloft, but its support, cable and operator coupling must be characterised. The highest feasible point is recorded along with the unmeasured cap above it. The conclusion is then bounded to the measured volume.

32.10 Room-scale example: 12 by 15 by 9 feet

Consider a room measuring 12 feet in X, 15 feet in Y and 9 feet in Z. A first twenty-seven-cell decomposition produces cell dimensions of 4 feet by 5 feet by 3 feet. The lower tier sensing centres are nominally 1.5 feet above the floor, the middle tier 4.5 feet and the upper tier 7.5 feet, subject to furniture, ceiling and probe geometry. The central cell spans X = 4 to 8 feet, Y = 5 to 10 feet and Z = 3 to 6 feet. A candidate in the central cell is compared with all face, edge and corner neighbours before any 3-foot or 12-inch refinement.

If the strongest measurement occurs near the east wall at upper height, the operator does not immediately re-centre the room on that point. The east face cells are first paired with the opposite side of the wall, the ceiling above, the room below or above where accessible, and adjacent cells along the wall. The movement of a bookcase, monitor or cable is recorded as an experimental intervention. The affected cells and controls are remeasured before the gradient is interpreted.

Table 32-3. Complete twenty-seven-cell identity matrix

Cell identifier	Room-relative position	Neighbour class
C(-1,-1,-1)	West / South / Lower	Corner neighbour
C(+0,-1,-1)	Centre-X / South / Lower	Edge neighbour
C(+1,-1,-1)	East / South / Lower	Corner neighbour
C(-1,+0,-1)	West / Centre-Y / Lower	Edge neighbour
C(+0,+0,-1)	Centre-X / Centre-Y / Lower	Face neighbour
C(+1,+0,-1)	East / Centre-Y / Lower	Edge neighbour
C(-1,+1,-1)	West / North / Lower	Corner neighbour
C(+0,+1,-1)	Centre-X / North / Lower	Edge neighbour
C(+1,+1,-1)	East / North / Lower	Corner neighbour
C(-1,-1,+0)	West / South / Middle	Edge neighbour
C(+0,-1,+0)	Centre-X / South / Middle	Face neighbour
C(+1,-1,+0)	East / South / Middle	Edge neighbour
C(-1,+0,+0)	West / Centre-Y / Middle	Face neighbour
C(+0,+0,+0)	Centre-X / Centre-Y / Middle	Centre cell
C(+1,+0,+0)	East / Centre-Y / Middle	Face neighbour
C(-1,+1,+0)	West / North / Middle	Edge neighbour
C(+0,+1,+0)	Centre-X / North / Middle	Face neighbour
C(+1,+1,+0)	East / North / Middle	Edge neighbour

Cell identifier	Room-relative position	Neighbour class
C(-1,-1,+1)	West / South / Upper	Corner neighbour
C(+0,-1,+1)	Centre-X / South / Upper	Edge neighbour
C(+1,-1,+1)	East / South / Upper	Corner neighbour
C(-1,+0,+1)	West / Centre-Y / Upper	Edge neighbour
C(+0,+0,+1)	Centre-X / Centre-Y / Upper	Face neighbour
C(+1,+0,+1)	East / Centre-Y / Upper	Edge neighbour
C(-1,+1,+1)	West / North / Upper	Corner neighbour
C(+0,+1,+1)	Centre-X / North / Upper	Edge neighbour
C(+1,+1,+1)	East / North / Upper	Corner neighbour

32.11 Large rooms, open offices and classrooms

A classroom of 55 to 75 square metres or an open office cannot be reduced to one centre cell without losing spatial resolution. The space is divided into overlapping modules approximately 12 to 15 feet across where practicable, adjusted to the structural bay, furniture system, ceiling grid and service pattern. Each module has its own twenty-seven-cell index and at least one shared cell layer with its neighbour. Fixed reference pods remain stationary while the mobile or additional pods traverse the modules.

In open-plan offices, workstations, floor boxes, cable baskets, luminaires, wireless access points, display systems, printers and collaborative equipment create repeated structures. The examiner treats repeated bays as matched controls. A candidate present in every identical bay may reflect the normal system. A candidate confined to one bay may justify closer work, but only after power, network, occupant and furniture state are compared. In classrooms, projectors, interactive displays, hearing-assistance systems, chargers, laboratory equipment and ceiling services are inventoried before interpretation.

32.12 Furniture, movable objects and the intervention ledger

Furniture placement is recorded by coordinates to hard points or by measured corners and orientation. An evidence-style triangle may be placed adjacent to a furniture leg, wall point or surface coordinate, but never on a suspected device or in a manner that disturbs the scene. The marker identifies a measurement location and orientation. Photographs are not required by this non-imaging protocol. A dimensioned drawing, coordinate ledger and contemporaneous narrative preserve the arrangement. At a later time, thermal imaging and traditional photograph of the space and its contents will take place. This delay of imaging is to maintain engineering discipline to prioritize the creation of engineering documents.

Every movement receives an intervention identifier. The record states who moved the object, why, start and finish time, original coordinates, final coordinates, cable changes, door or drawer state, and cells potentially affected. Measurements are taken immediately before movement, during a controlled intermediate state if safe, and after movement. A signal that follows the object differs analytically from one that remains with the wall, floor or cable route. Neither outcome by itself identifies an unlawful device.

32.13 Probe posture, orientation and cell occupancy

A cell measurement is valid only when the sensing centre, not the operator hand or instrument display, lies at the declared coordinate. Probe axis, polarisation, azimuth, elevation, roll, standoff and support geometry are recorded. For resonant rods the analyser-controlled varactor tuning state, sapphire piston setting, resonance verification and settled time are retained.

For broadband probes the transfer factor and calibration band are retained. The operator avoids occupying a neighbouring cell inconsistently, because the body can alter electric and magnetic coupling.

Where the probe cannot physically reach the cell centre because of furniture, a reachable substitute point is declared and the offset retained. The cell is not silently marked complete. Robotic, pole or cable-supported sensing may be used when validated, but the support structure becomes part of the measurement system and receives a blank and self-emission characterisation.

32.14 Spatial derivative, gradient and curvature records

The twenty-seven-cell array permits finite-difference estimates of gradient and, where spacing and signal quality permit, curvature. The gradient indicates the direction of greatest local increase.

Curvature helps distinguish a compact local maximum from an extended ridge along a cable or wall. These quantities are calculated from calibrated values and accompanied by uncertainty. They are not used when the field changes materially during the cell sequence or when probes are not comparable.

$$dF/dx \text{ approximately } [F(x+h)-F(x-h)]/(2h)$$

The central finite difference estimates the local X-axis gradient for cell-centre separation h. Equivalent expressions apply to Y and Z. The estimate assumes sufficiently stable field, matched transfer functions and a smooth local field over the interval.

$$d2F/dx2 \text{ approximately } [F(x+h)-2F(x)+F(x-h)]/h^2$$

The second difference estimates local curvature. A strong curvature on all three axes may be consistent with a compact local maximum, while low curvature along one axis may be consistent with an extended conductor. These are model comparisons, not device identifications.

32.15 Vertical pair and room-neighbour matrix

Table 32-4. Opposite-surface and vertical-pair matrix

Primary surface	Paired comparison	Control requirement
Inspected room floor	Ceiling of room below or underfloor void	Same X-Y coordinate; matched orientation and standoff where feasible.
Inspected room ceiling	Floor of room above or roof/ceiling void	Same X-Y coordinate; document slab, plenum and inaccessible depth.
Interior wall face	Adjacent-room or exterior wall face	Correct for wall thickness and surface standoff.
Furniture or equipment face	Opposite face or rear access	Do not touch target; use declared surrounding standoff shell.
Door or opening	Closed and authorised open states	Treat state change as intervention; repeat controls.
Service penetration	Upstream and downstream accessible points	Test extended-path coupling before compact-source inference.

32.16 Repeated measurement sequence for each cell

Table 32-5. Minimum cell-acquisition sequence

Step	Cell operation
1	Verify room state, clock, reference channel and cell identity.
2	Position sensing centre and record coordinate, standoff and support.
3	Acquire X, Y and Z simultaneously at discovery bandwidth.

Step	Cell operation
4	Verify resonance or transfer calibration and acquire narrowband/tracking record.
5	Record phase, coherence, null, burst and environmental state where valid.
6	Acquire scheduled blank, dummy or terminated control.
7	Advance only after data file, hash and field note are linked.
8	Repeat in reverse or after a declared intervention when required.

32.17 Spherical-shell example and missing upper cap

Suppose the candidate centre lies 1.2 metres above the floor in a room with a 2.7-metre ceiling. A shell of radius 1 metre can be sampled laterally and downward, but the uppermost point would lie at 2.2 metres and may be accessible with a pole-mounted probe. A shell of radius 2 metres would extend above the ceiling and below the floor. The room alone cannot sample it.

The examiner therefore obtains matched points in the room above and below where authorised, or reports an unsampled upper and lower cap. The shell is not described as complete merely because the horizontal circumference was measured.

Where the building fabric prevents geometric equality of standoff, the record preserves actual range and surface material. A point 0.5 metre from the candidate on the room side of a reinforced wall is not physically equivalent to a point 0.5 metre from the geometric centre on the opposite side if steel, foil or services intervene. The paired result is still valuable, but the medium becomes part of the model.

32.18 Spatial uncertainty and bounded localisation

The final bounding volume combines coordinate uncertainty, probe-aperture dimensions, standoff uncertainty, channel calibration, field variability, resonance error and the finite cell size. A 3-inch grid does not create 3-inch localisation accuracy when the probe aperture is 8 inches long, the wall depth is unknown or the field varies with occupant movement. The report therefore states a supported volume and its confidence basis rather than a point coordinate with spurious precision.

$$u_r = \sqrt{u_x^2 + u_y^2 + u_z^2 + u_p^2 + u_s^2} \quad (10)$$

This simplified combined spatial standard uncertainty includes coordinate components u_x, u_y and u_z, probe-centre or aperture contribution u_p, and standoff contribution u_s. Correlated terms require covariance rather than simple root-sum-square treatment.

32.19 Twenty-seven-cell decision rules

Table 32-6. Twenty-seven-cell spatial decision patterns

Spatial pattern	Minimum observation	Required response
Local maximum	Centre exceeds face, edge and corner neighbours beyond combined uncertainty; reverse pass reproduces.	Proceed to smaller scale and paired surfaces.
Planar ridge	Cells along a wall or ceiling remain similar while normal direction changes.	Test extended surface, shield seam or service path.
Linear ridge	Cells along one axis remain elevated with low axial curvature.	Test cable, pipe, conduit, structural member or distributed source.

Spatial pattern	Minimum observation	Required response
Diffuse field	Most cells change together or sentinel shows same temporal change.	Retain environmental or regional model; do not re-centre prematurely.
Single-cell transient	One cell contains an unrepeated burst.	Retain raw record; repeat dwell and timing controls before advancement.
Movement-correlated change	Field changes after furniture, door, person or cable movement.	Treat movement as intervention; repeat affected and control cells.

32.20 Reporting the room geometry

The report includes a dimensioned non-imaging room drawing, hard-point coordinates, axis convention, cell dimensions, station identifiers, missing cells, vertical access, paired surfaces, movement events and the smallest supported candidate volume. It distinguishes the physical room boundary from the analytical module boundary. It also states whether the centre cell was selected before measurement, after a coarse gradient, or after a controlled intervention, because those histories carry different risks of expectation bias.

A suitable conclusion reads: "The calibrated field formed a reproducible local maximum within cells C(0,0,0), C(+1,0,0) and C(0,0,+1) at the 12-inch scale. Opposite-wall measurements were lower by the stated amount, while the upper-storey comparison was unavailable. The evidence supports localisation to a bounded region adjacent to the east wall and below the ceiling. It does not determine whether the source is a compact circuit, an extended conductor, a service penetration or an object within the inaccessible ceiling volume."

Chapter Glossary

Terms used in Chapter 39.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

E

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

H

HASH — A fixed-length value produced by a deterministic function and used to detect whether digital content has changed.

R

RADIATION PATTERN — A plot of the radiated energy from an antenna.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

T

TEST EQUIPMENT — A general term applied to devices used to test electrical and electronic circuits.

V

VERIFICATION — The confirmation, through examination or objective evidence, that specified requirements have been fulfilled.

33. Multilayer Composite Modulation, Noise-Like Hosts, Nested Subcarriers, and Low-Duty-Cycle Response Analysis

This chapter addresses signals whose visible carrier, noise floor, envelope, phase or pulse timing contains one or more additional information-bearing structures. The defensive problem is not limited to naming a modulation family. The examiner must determine whether a weak feature is a real external emission, a component of an ordinary communications waveform, an instrument product, an illumination-correlated reradiation, a nested subcarrier, or random noise. The method therefore analyses the same acquisition in time, frequency, phase, complex-envelope, cyclostationary and cross-channel domains.

Defensive-use boundary. The examples are synthetic recognition models intended to improve detection, classification and artefact rejection. They do not specify a clandestine transmitter design, optimum concealment parameters, unauthorised interception method or means of evading lawful inspection. Any active illumination remains subject to the legal, spectrum, exposure, medical-device, safety and evidence-preservation controls elsewhere in this framework.

33.1 Layered vocabulary and the distinction between carrier, subcarrier and timing

The outer carrier is designated Layer 0. A first subcarrier or modulating process is Layer 1. A signal that modulates Layer 1 is Layer 2, and a further embedded process is Layer 3. The terms describe analytical nesting, not circuit topology.

A frequency offset, pulse train or noise process may be a subcarrier even when it is not a pure sinusoid. A response may also be load-modulated or backscattered without generating an independent high-power carrier.

The abbreviation PPS is ambiguous. It can mean one pulse per second, pulse-position signalling, or another context-specific term.

This framework writes 1 PPS for a one-pulse-per-second timing reference and PPS for pulse-position signalling. Pulse-position modulation, PPM, describes information conveyed by displacement of pulse timing relative to a reference interval. The record must state which meaning applies.

Table 33-1. Layered composite-modulation vocabulary

Analytical layer	Role	Representative examples
Layer 0	Outer RF, optical or conducted host	CW, AM, NFM, WFM, OOK, backscatter, noise-like carrier or conducted baseband
Layer 1	First modulation or subcarrier	Audio, tone, FSK, pulse train, PPM/PPSig, low-rate telemetry, noise process
Layer 2	Modulation impressed upon Layer 1	NFM subcarrier carrying another NFM signal, pulse timing applied to a tone, coded gating
Layer 3	Further nested timing or data structure	Sparse event marker, synchronisation word, slow periodic envelope or illumination-dependent gate

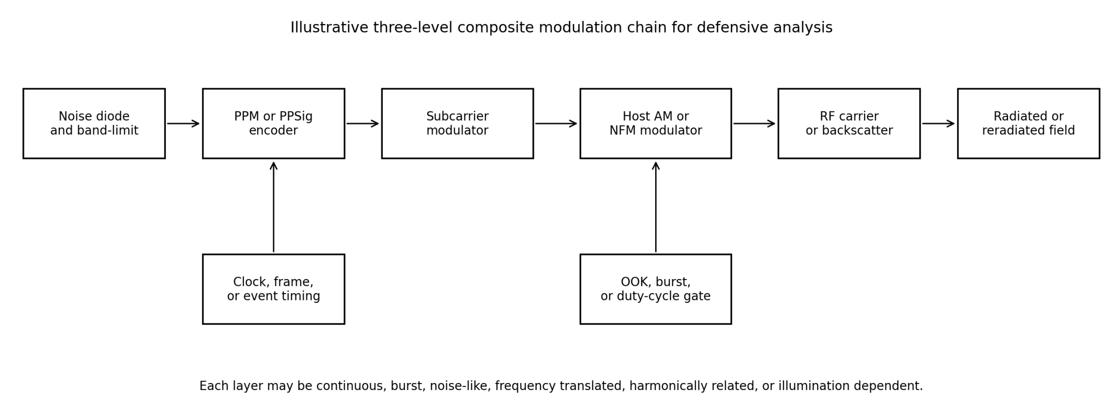


Figure 33-1. Defensive analytical model for an outer host and two or three nested subcarrier levels.

33.2 Continuous wave as the reference case

A nominal continuous wave is represented by a stable sinusoid at carrier frequency f_c. In practice, no source is perfectly continuous or spectrally pure. Oscillator phase noise, amplitude noise, supply ripple, temperature drift, vibration, reference spurs and switching products create measurable structure.

A CW line is therefore the reference against which interruption, amplitude modulation, frequency modulation, phase modulation and nested sidebands are assessed. The examiner retains sufficient dynamic range to observe both the carrier and low-level skirts without driving the receiver into compression.

$$s_0(t) = A_c\cos(2\pi f_c t + \phi_0) \quad (11)$$

Here A_c is carrier amplitude, f_c is carrier frequency and phi_0 is initial phase. Departures from constant A_c, f_c or phase identify modulation, drift or noise, subject to receiver contributions.

33.3 Band-limited noise-diode host or masking component

A noise diode or other avalanche source can produce broadband noise that is subsequently filtered, amplified or used to modulate another signal. The measured result may resemble an elevated noise floor rather than a discrete carrier. The examiner does not infer a noise diode from spectral appearance alone.

Thermal noise, switching converters, digital buses, impulsive interference, spread-spectrum systems, receiver noise and environmental electronics can produce similar displays. A defensible classification requires spatial localisation, repeatable bandwidth edges, cross-channel coherence or other structure inconsistent with ordinary random noise.

A band-limited noise process n_B(t) may modulate the amplitude or instantaneous frequency of a host. If the noise is stationary and truly random, ordinary averaging smooths its details. If it is gated, repeated, filtered by a stable resonator, or carries a pulse-position subcarrier, cyclostationary or correlation methods can expose periodic structure that a conventional power spectrum obscures. The examiner therefore retains raw I/Q and trigger-reference data rather than preserving only a max-hold image.

$$\mathrm{m}_1(t) = \alpha n_B(t) + \beta p(t) \quad (12)$$

In this synthetic defensive model, n_B(t) is a band-limited noise process, p(t) is a pulse or pulse-position process, and alpha and beta are relative scaling factors. The equation illustrates coexistence. It is not a construction prescription.

33.4 CW or OOK host carrying a pulse-position subcarrier

A carrier that appears continuous at a coarse resolution bandwidth may contain small interruptions, phase excursions or sideband clusters caused by a pulse-position subcarrier. Conversely, a visibly OOK carrier may carry timing within the positions of its on intervals. The oscilloscope or complex-envelope display reveals pulse location, while the spectrum shows a carrier, repetition lines and sidebands determined by pulse shape, interval and jitter. A max-hold trace may display the full occupied region but discard the temporal relation that identifies PPM.

$$p(t) = \mathrm{sum}_k g(t - kT - \tau_k) \quad (13)$$

The pulse train p(t) is formed from pulse shape g(t), nominal interval T and position displacement tau_k. The information or timing lies in tau_k. Pulse-width, amplitude and repetition-rate variation must be examined separately.

The analyst tests whether the pulse displacement is referenced to a stable clock, to an illumination event, to the start of a burst, or to another subcarrier cycle. If no reference is preserved, apparent PPM may be ordinary jitter or trigger wander.

A common-timebase channel containing the host, illumination or known timing marker is therefore essential.

33.5 AM host with noise and pulse subcarriers

In an amplitude-modulated composite signal, the envelope may contain a noise-like component and a lower-rate pulse structure simultaneously. A wide resolution bandwidth may show a broad pedestal. A narrow bandwidth may show carrier and sideband detail but miss short pulses.

Envelope extraction, synchronous averaging to a pulse epoch and spectral correlation can reveal whether the pedestal is independent noise or periodically modulated noise. The examiner compares raw RF, calibrated envelope and receiver detector outputs because detector attack, decay and logarithmic processing can manufacture apparent pulse shape.

$$\mathrm{s_{AM}}(t) = \mathrm{A}_c\left[1 + \mu_n n_B(t) + \mu_p p(t)\right]\cos(2\pi f_c t)(14)$$

The coefficients mu_n and mu_p describe illustrative modulation depth for noise and pulse components. Overmodulation, clipping and receiver AGC can alter the observed envelope and must be tested.

33.6 NFM host carrying noise and a pulse-position subcarrier

A narrowband FM host can convey a composite baseband containing filtered noise and a pulse-position process. On a conventional spectrum analyser the occupied bandwidth may resemble ordinary NFM noise or low-rate telemetry. In complex I/Q, the instantaneous phase and frequency can reveal short deviations associated with pulse positions. A discriminator output can assist, but the discriminator bandwidth, de-emphasis, limiting and receiver group delay must be calibrated before the timing is treated as evidence.

$$\mathrm{s_{NFM}}(t) = \mathrm{A}_c\cos\left[2\pi f_c t + k_f \int (\mathrm{m}_1(t)\mathrm{dt})\right](15)$$

The constant k_f is the frequency sensitivity of the illustrative host, and m_1(t) may contain noise and pulse terms. For small modulation index the spectrum may be compact, but short edges can still generate wider low-level sidebands.

Detection begins with a modulation-neutral I/Q capture at sufficient sample rate. The analyst then derives instantaneous phase, unwraps it under controlled signal-to-noise conditions, differentiates phase to obtain instantaneous frequency, and compares the result with the pulse-reference channel.

A pulse-like feature that appears only after aggressive filtering is treated cautiously. The unfiltered and filtered derivatives, filter impulse response and timing shift are retained.

33.7 NFM subcarrier conveyed by an NFM outer carrier

Same-family nesting can be especially deceptive because the outer signal and its subcarrier share similar statistical appearance. An NFM outer carrier may be modulated by a tone or intermediate subcarrier whose instantaneous frequency is itself varied by a second NFM signal.

A simple discriminator can collapse the outer layer and expose the inner NFM waveform, but receiver nonlinearity or multipath can also create low-frequency components. The analyst therefore repeats the demodulation with independent software and hardware paths, changes bandwidth and verifies the result against the raw complex samples.

$$\mathrm{m}_1(t) = \mathrm{A}_\mathrm{s}\cos\left[2\pi f_\mathrm{s} t + k_\mathrm{s}\int (\mathrm{m}_2(t)\mathrm{d}t)\right] (16)$$

Here f_s is a nominal subcarrier frequency, k_s is its frequency sensitivity and m_2(t) is the second-layer modulation. Substituting m_1(t) into the outer NFM equation creates a two-level FM-on-FM analytical model.

The spectrum may display clusters around the outer carrier separated by the subcarrier frequency, with each cluster broadened by the inner modulation. In low signal-to-noise conditions those clusters may merge into a noise-like skirt. Cepstral, autocorrelation, spectral-correlation and repeated-epoch averaging can reveal the separation without requiring intelligible demodulation.

The purpose is classification and timing localisation, not content recovery.

33.8 Three-level nesting and sparse event markers

A third layer can be a slow gate, sparse event marker, synchronisation sequence or illumination-dependent enable. For example, an outer NFM carrier can contain a noise-like first layer, a pulse-position second layer and a slow periodic gate at the third layer. Another example is an NFM host carrying an NFM subcarrier whose amplitude is briefly gated by a pulse-position sequence. These models produce observations at several time scales, from carrier phase to subcarrier period to rare event interval. No single sweep setting captures all of them optimally.

The acquisition plan therefore uses simultaneous products: a broad real-time span for discovery, a narrow fixed span for carrier and sidebands, baseband I/Q for modulation, a pulse-event detector, and a long-duration occupancy timeline. Each product is linked to the same time base. The analyst avoids serially changing instruments in a way that makes a transient appear to move between domains.

33.9 Waveform and spectrum representations

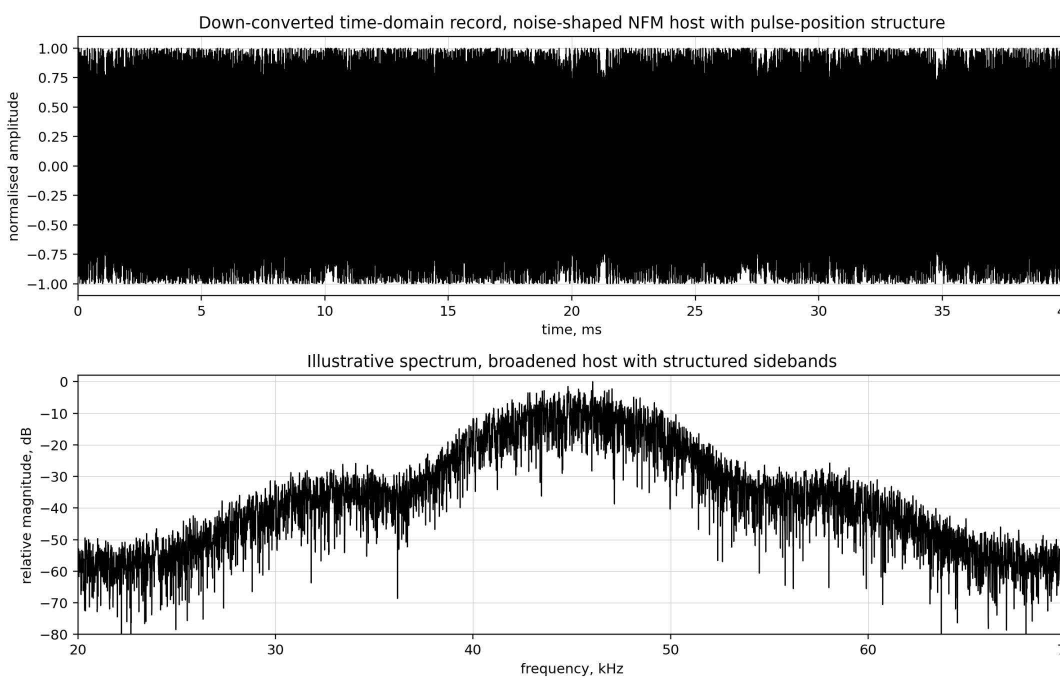


Figure 33-2. Synthetic oscilloscope and spectrum views of a nested noise-like host with pulse-position structure.

The oscilloscope representation is a down-converted or envelope view, not necessarily the raw microwave carrier. The spectrum representation may be an FFT of complex baseband or a calibrated analyser trace. Captions state the centre frequency, span, sample rate, resolution bandwidth or FFT bin width, window, detector, averaging and amplitude reference. Synthetic diagrams are labelled as such and never presented as field evidence.

A spectrum line does not uniquely identify a waveform, and a time trace does not uniquely identify occupied bandwidth. The protocol always pairs time and frequency representations, and adds phase or instantaneous-frequency plots when FM, PM, PPM or nested subcarriers are plausible. Waterfalls are used to show persistence and drift, while persistence displays reveal rare bursts. Max hold is a discovery aid, not a substitute for raw data.

33.10 Composite-modulation acquisition architecture

The preferred twelve-channel chassis allocates nine channels to three X-Y-Z pods, one to the illumination or interrogation reference where authorised, one to a terminated or dummy path, and one to a guard, tracking or independent reference. Every channel shares the sample clock, frequency reference and trigger epoch. The antenna tuning command is derived from the analyser frequency abscissa but is distributed separately to each varactor-controlled resonant head. The command, settle, resonance-verify, hold and acquire states are recorded so that a waveform is admitted only when the applicable probe was at its verified resonance.

Composite signals demand simultaneous capture because the outer host, subcarrier and rare gate may not recur while an operator retunes a second instrument. A real-time search receiver supplies continuous discovery and trigger generation. The spectrum-analysis engine controls band-segmented heads and stores complex samples. High-selectivity tracking receivers follow each input to improve narrowband sensitivity and selectivity, but their filtered outputs are recorded alongside the unfiltered path so that pulse distortion and false structure can be identified.

33.11 Triggering on illumination or interrogation presence

When authorised retroreflector testing is performed, the response acquisition is triggered by an independent receiver that confirms the illumination or interrogation waveform is physically present at the scene. A transmitter command or software status flag is not sufficient. The trigger is distributed to the response analyser, real-time receiver, I/Q recorder, oscilloscope, illumination-reference recorder and environmental logger. Pre-trigger memory preserves the state before illumination.

The response delay is iterated from coarse to fine. Negative pre-trigger intervals test whether the candidate precedes illumination. Zero and short positive delays test direct leakage and immediate backscatter. Longer microsecond, millisecond and second delays test rectification, energy storage, oscillator start-up, coding latency and decay. Once a repeatable interval is identified, the delay and gate length are bracketed and reduced until the response onset and duration are resolved. A sequential swept analyser is secondary for short events. Fixed-span real-time or vector I/Q capture is primary.

Table 33-2. Source-referenced trigger and delay-iteration controls

Control or trial	Purpose
Illumination absent, source terminated	Measure passive baseline and receiver noise.
Sham trigger, no RF illumination	Test digital trigger feedthrough and software artefact.
Illumination on, response path terminated	Measure direct chassis or cable coupling.
Frequency offset	Test whether response follows authorised excitation frequency or remains unrelated.

Control or trial	Purpose
Polarisation/azimuth/elevation change	Test spatial and coupling dependence.
Delay sweep	Resolve onset, latency, pulse position and decay.
Independent receiver architecture	Exclude common local oscillator, ADC and intermediate-frequency products.

33.12 Retroreflective and frequency-translated composite responses

A remotely illuminated response may occur at the illumination frequency, at sidebands around it, at a harmonic or subharmonic, at an internally determined resonator frequency, or at a frequency translated by mixing or load modulation. The response may be continuous, pulse-position modulated, burst-gated, noise-like or nested. The examiner therefore records both the incident field and every candidate response on a common time base. The candidate is not called a retroreflector merely because it appears during illumination.

A defensible illumination-correlated response disappears when the illumination ceases, reappears under restored conditions, follows spatial and polarisation changes consistent with the scene, survives sham and offset controls, is not reproduced on terminated paths, and can be localised independently. Direct transmitter leakage usually follows the illumination reference with minimal delay and broad spatial uniformity. A stored-energy response may exhibit delayed onset or decay. Receiver overload may generate many products simultaneously and change nonlinearly with attenuation. These patterns are compared explicitly.

33.13 Cyclostationary analysis of noise-like composite signals

A signal can have noise-like instantaneous samples while retaining periodic statistics. Gating, symbol clocks, pulse intervals, cyclic prefixes, frame structures and repeated filters create cyclostationarity. The spectral correlation function tests correlation between frequency components separated by a cyclic frequency alpha. Random stationary noise ideally lacks stable non-zero cyclic features, while a modulated or periodically gated process may reveal them. The method is powerful but sensitive to finite record length, leakage, sample-clock error and receiver spurs.

$$S\_x\hat{}\alpha(f) = EX(f+\alpha/2)X \cdot (f-\alpha/2) \quad (17)$$

This conceptual spectral-correlation relation evaluates frequency-separated coherence at cyclic frequency alpha. Practical estimators require declared windows, averaging, record length and significance thresholds. A cyclic feature is not source attribution; it is evidence of structured modulation.

The analyst searches expected and blind cyclic frequencies, but controls the multiple-comparison problem. A peak is promoted only when it recurs, exceeds a predeclared threshold or false-alarm model, survives receiver substitution and exhibits spatial behaviour. The illumination reference can supply a cyclic epoch for backscatter analysis. Harmonic clocks can supply additional candidate cyclic frequencies, but integer coincidence alone remains insufficient.

33.14 Cross-channel coherence and spatial discrimination

A genuine external composite signal should appear in a physically plausible subset of the nine probe channels with repeatable phase, delay, polarisation or amplitude relationships. A chassis spur may appear identically on terminated and antenna paths. Cable coupling may favour channels sharing a harness. A local compact source may produce a steep spatial gradient across pods. The analysis therefore computes magnitude-squared coherence, cross-correlation, relative delay and channel covariance over the carrier, subcarrier and pulse-event bands.

$$\gamma_{\mathrm{xy}}^2(f) = \left|\mathrm{S}_{\mathrm{xy}}(f)\right|^2 / \left[\mathrm{S}_{\mathrm{xx}}(f)\mathrm{S}_{\mathrm{yy}}(f)\right] \quad (18)$$

The magnitude-squared coherence gamma_xy^2 compares cross-spectrum S_xy with autospectra S_xx and S_yy. A high value indicates linear relationship at that frequency under the observation conditions, not common physical origin by itself.

33.15 Envelope, phase and instantaneous-frequency products

The complex baseband z(t) = I(t) + jQ(t) supports three primary derived products. The envelope is |z(t)|. The phase is angle z(t), unwrapped only when signal-to-noise and continuity support it. Instantaneous frequency is the time derivative of unwrapped phase divided by 2 pi. Each operation changes noise and can create edge artefacts. The software version, filter, derivative method, sample rate and excluded low-amplitude intervals are therefore retained.

AM and OOK are most visible in the envelope. FM and PM are most visible in phase and instantaneous frequency. PPM is visible in event times relative to a reference. Nested modulation may require demodulating one layer and then repeating the analysis on the recovered subcarrier. At each layer the analyst returns to the raw I/Q to ensure that a software transformation has not manufactured the feature.

33.16 Pulse descriptor words and event statistics

Every detected pulse or burst receives an event record containing start time, peak time, end time, width, amplitude, carrier frequency, occupied bandwidth, phase, instantaneous-frequency excursion, rise time, fall time, channel set and trigger relation. Pulse position is expressed relative to a declared epoch. Jitter, missed events and false events are reported. The threshold is validated against noise and detector hysteresis rather than selected after inspecting the desired pattern.

$$\tau_k = t_k - (t_0 + kT) \quad (19)$$

The pulse-position displacement tau_k is the difference between observed pulse time t_k and the nominal epoch t_0 + kT. Its uncertainty includes trigger time, sample clock, interpolation, threshold and waveform noise.

33.17 Distinguishing PPM, PWM, PAM, PRF and OOK

Table 33-3. Pulse and gating modulation discrimination

Modulation family	Primary variable	Discrimination note
PPM / PPSig	Pulse position relative to epoch changes	Stable width and amplitude are common but not required; timing reference essential.
PWM / PDM	Pulse width or duration changes	Edges move in opposite directions around or from a reference edge.
PAM	Pulse amplitude changes	Position and width comparatively stable; receiver AGC must be controlled.
PRF / PFM	Pulse interval or repetition frequency changes	Analyse inter-arrival time and long-term cadence.
OOK / burst gating	Carrier presence changes	May carry additional timing within on/off intervals.
Load modulation	Incident carrier amplitude/phase perturbed	Requires incident reference and direct-leakage controls.

33.18 Receiver and processing artefacts that imitate nested modulation

Automatic gain control can create slow envelopes. Log detectors can compress pulse amplitudes. Sweep timing can turn intermittent carriers into periodic stripes. FFT windows can create sidelobes. Decimation filters can ring. Phase unwrapping can create steps during fades. Clock mismatch can create apparent drift. Trigger hysteresis can create pulse-position bias. Digital transport can drop or repeat blocks. Varactor-tuning commands can couple into the RF path and produce frequency-related sidebands. Every composite interpretation is therefore challenged by a control targeted at the transformation that revealed it.

The nine antenna pathways and the terminated or dummy channels are acquired simultaneously. If the same pulse train appears on a terminated channel, the chassis or trigger distribution is implicated. If it appears only when a particular preamplifier is enabled, amplifier oscillation or intermodulation is tested. If it moves when sample rate changes, aliasing is considered. If it follows the analyser sweep rather than wall-clock time, sweep artefact is considered. The control record is part of the finding, not an appendix added after classification.

33.19 Synthetic example A: CW with PPSig subcarrier. A weak carrier at a stable frequency appears continuous in a 10-kHz resolution bandwidth. A fixed-span I/Q capture reveals 200-microsecond phase and amplitude perturbations every 100 milliseconds, with each perturbation displaced among four permitted positions. The raw carrier remains present between events. The envelope and phase both show the perturbation, while a sham trigger produces none. The appropriate provisional description is a CW-dominant carrier with a pulse-position-signalling component. It is not described as data content, device type or retroreflector without spatial and illumination evidence.

33.20 Synthetic example B: noise-like NFM with PPM structure. A narrow FM emission has a 12-kHz occupied bandwidth and a discriminator output resembling filtered noise. Spectral correlation reveals a stable 250-Hz cyclic feature. Epoch averaging at 4 milliseconds shows a brief repeatable instantaneous-frequency excursion whose position changes among eight slots. The feature is reproduced on two independent receivers and strongest in one spatial cell, while the terminated channel remains quiet. The appropriate interpretation is a structured noise-like NFM signal with pulse-position behaviour. The result remains a signal classification until source association is completed.

33.21 Synthetic example C: NFM on NFM with sparse outer gate. A carrier appears for only three seconds during a twelve-hour observation. Within the burst, the outer NFM discriminator contains a 9-kHz subcarrier. Demodulating that subcarrier reveals a second NFM process with a 400-Hz timing component. The entire burst begins 18 milliseconds after an independently detected illumination event and is absent during sham illumination. Direct leakage controls and a second receiver support further examination. The correct evidential progression is observed signal, illumination-correlated response, reproducible nested-modulation response, and only after three-dimensional localisation, device-associated response. The modulation hierarchy alone does not establish retroreflection.

33.22 Synthetic example D: apparently easy yet analytically difficult signal. A broad pedestal rises 6 dB above the local noise floor during each authorised illumination interval. It is easy to notice because it occupies a conspicuous band, yet difficult to classify because the same transmitter raises the receiver noise floor through reciprocal mixing. A pulse-position feature appears only after normalising each interval. Attenuation and preselection show that part of the pedestal is receiver-induced, while a narrower spatially localised component survives. This example illustrates why a composite low-power response can be visually obvious and nevertheless require extensive controls before attribution.

33.23 Integration with the five-mile-to-three-inch search sequence

At the 5-mile through 0.25-mile annuli, composite analysis establishes whether a carrier, noise pedestal, cyclic feature or burst cadence is already present regionally. At 300 feet through 30 feet, the method tests premises-centred spatial behaviour and service-path coupling. At 15 feet and 12 feet, it compares wall, aperture, cable and interior hypotheses. At 3 feet and within the twenty-seven-cell lattice, it localises the carrier and each subcarrier feature separately. A carrier may peak in one cell while a low-frequency magnetic leakage or cable current peaks along another path. The report preserves that distinction.

The same modulation classifier is applied at each ring using locked settings or documented transformations. A signal is not reclassified merely because the operator changed resolution bandwidth or demodulator. When a different setting is necessary, an overlap acquisition demonstrates how the feature maps between settings. The outer sentinels remain active during rare burst and illumination trials so that regional coincidences are visible.

33.24 Composite-modulation analysis record

Table 33-4. Composite-modulation field and analysis record

Record block	Required content
Raw acquisition	File hash, I/Q format, sample rate, centre frequency, bandwidth, channel map, clock and trigger epoch.
Layer 0	Carrier or host type, frequency, amplitude, bandwidth, drift, duty cycle and uncertainty.
Layer 1	Subcarrier or modulation feature, nominal frequency or timing, extraction method and controls.
Layer 2	Second nested process, pulse slots, FM/AM structure, cyclic frequency and uncertainty.
Layer 3	Slow gate, sparse event, illumination relation or frame timing.
Spatial result	Ring, station, cell, X-Y-Z vector, gradient, null, paired-surface and high-ground comparison.
Artefact tests	Terminated path, dummy probe, gain step, preselector, sample rate, receiver substitution and sham trigger.

Record block	Required content
Classification	Observed, candidate-correlated, illumination-correlated, reproducible translated, spatially localised or confirmed associated.

33.25 Bounded reporting language

A suitable technical statement reads: "The emission contained a stable outer carrier and a repeatable 9.2-kHz subcarrier. The subcarrier displayed pulse-position displacements relative to the recorded illumination epoch. The feature was reproduced on two independent receive paths, was absent on the terminated path and formed a spatial maximum within the stated cells. These observations support classification as a spatially localised, illumination-correlated composite response. They do not establish device function, content, ownership, legality or medical effect."

Where controls fail, the language changes accordingly: "A noise-like rise and apparent pulse cadence were observed during illumination. Comparable structure appeared on the terminated channel and changed with analyser attenuation. Receiver overload or trigger coupling therefore remains sufficient to explain the observation, and no device-associated conclusion is supported." Such negative results are evidence of competent method application, not failed inspection.

A weak carrier at a stable frequency appears continuous in a 10-kHz resolution bandwidth. A fixed-span I/Q capture reveals 200-microsecond phase and amplitude perturbations every 100 milliseconds, with each perturbation displaced among four permitted positions. The raw carrier remains present between events. The envelope and phase both show the perturbation, while a sham trigger produces none. The appropriate provisional description is a CW-dominant carrier with a pulse-position-signalling component. It is not described as data content, device type or retroreflector without spatial and illumination evidence.

A narrow FM emission has a 12-kHz occupied bandwidth and a discriminator output resembling filtered noise. Spectral correlation reveals a stable 250-Hz cyclic feature. Epoch averaging at 4 milliseconds shows a brief repeatable instantaneous-frequency excursion whose position changes among eight slots. The feature is reproduced on two independent receivers and strongest in one spatial cell, while the terminated channel remains quiet. The appropriate interpretation is a structured noise-like NFM signal with pulse-position behaviour. The result remains a signal classification until source association is completed.

A carrier appears for only three seconds during a twelve-hour observation. Within the burst, the outer NFM discriminator contains a 9-kHz subcarrier. Demodulating that subcarrier reveals a second NFM process with a 400-Hz timing component. The entire burst begins 18 milliseconds after an independently detected illumination event and is absent during sham illumination. Direct leakage controls and a second receiver support further examination. The correct evidential progression is observed signal, illumination-correlated response, reproducible nested-modulation response, and only after three-dimensional localisation, device-associated response. The modulation hierarchy alone does not establish retroreflection.

A broad pedestal rises 6 dB above the local noise floor during each authorised illumination interval. It is easy to notice because it occupies a conspicuous band, yet difficult to classify because the same transmitter raises the receiver noise floor through reciprocal mixing. A pulse-position feature appears only after normalising each interval. Attenuation and preselection show that part of the pedestal is receiver-induced, while a narrower spatially localised component survives. This example illustrates why a composite low-power response can be visually obvious and nevertheless require extensive controls before attribution.

Chapter Glossary

Terms used in Chapter 40.

A

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

C

CARRIER FREQUENCY — The frequency of an unmodulated transmitter output.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

L

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

M

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

P

PULSE-POSITION MODULATION (PPM) — Pulse modulation in which the position of the pulses is varied by the modulating voltage.

R

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

T

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

34. Sub-Audio, Infrasonic, Quasi-Static, Extremely Low-Frequency and Geophysical Environmental Measurement

This chapter establishes the evidence-bounded 0.001 Hz to 20 Hz workstream. It is intended to prevent two opposite errors: ignoring a slow physical process because a conventional receiver cannot display it, and attributing a symptom or anomalous trace to a hostile electronic source merely because its frequency resembles a biological, geophysical or military-associated value. The method therefore expands measurement scope while narrowing the language of inference.

34.1 Purpose, scope and compulsory inclusion criterion

Every EERF project for which the commission provides sufficient time, lawful access, competent personnel, calibrated instrumentation and safety support shall include a documented survey of the 0.001 Hz to 20 Hz interval. The requirement is satisfied only when the relevant physical domains are considered separately and the observation duration supports the frequencies claimed. A project may omit or curtail the workstream where time, access, weather, safety, clinical-site restrictions or instrument capability make it impracticable, but the report must identify the omitted domain, the lowest supported frequency and the resulting limitation.

The workstream has five principal aims. First, it inventories natural and built-environment sources that can contaminate a weak-signal inspection. Secondly, it detects local pressure, vibration, electric-field or magnetic-field anomalies that deserve controlled localisation. Thirdly, it establishes whether a feature is regional, building-wide, room-centred, service-path-centred or instrument-centred. Fourthly, it supplies exposure quantities that can be compared with an applicable acoustic, vibration or electromagnetic standard. Fifthly, it creates a defensible record for clinical, occupational-health, geophysical or engineering referral without purporting to make the referral discipline's diagnosis.

The term signal is used neutrally. It denotes a measurable variation above the validated system floor and does not imply intelligence content, intentional transmission, biological potency or device association. The term source denotes a physical origin supported by spatial, temporal and control evidence. The term exposure denotes a measured or modelled field, pressure or motion at a stated location and time. It does not itself establish an adverse effect.

34.2 Terminology and the six-domain rule

The examiner shall assign every sub-20 Hz observation to one or more provisional domains: airborne acoustic pressure, structure-borne motion, electric field, magnetic field, biological measurement, or instrument and environmental state. A seventh category, unresolved composite, may be used while the evidence is incomplete. The categories are not mutually exclusive because a machine can generate pressure, vibration, current and magnetic field at once. They are nevertheless analytically indispensable because the same number in hertz has different units, sensors, noise mechanisms and propagation laws in each domain.

Airborne infrasound is a pressure phenomenon measured in pascals or decibels referenced to 20 micropascals. Structure-borne motion is measured as displacement, velocity or acceleration, ordinarily in metres, metres per second or metres per second squared. Electric field is measured in volts per metre. Magnetic field is measured as magnetic-field strength in amperes per metre or magnetic flux density in tesla. Biological electrical activity is ordinarily acquired through electrodes as voltage differences, while biomagnetic activity requires extremely sensitive close-coupled instrumentation. Instrument state includes offset, temperature, time-base error, sensor tilt, gain, overload and cable motion.

The expression low frequency is context dependent. Acoustics ordinarily uses infrasound for frequencies below the nominal 20 Hz lower limit of hearing. Electromagnetic standards may use low frequency for 1 Hz to 100 kHz. Geophysics often uses ULF for sub-hertz to tens-of-hertz magnetic or seismic phenomena, while ITU radio-band terminology assigns different boundaries. Reports shall therefore state both the numerical range and the physical domain rather than relying upon an unqualified acronym.

Provisional domain	**Measured quantity and unit**	**Preferred sensor family**	**Dominant propagation or coupling**	**Principal confounders**
Airborne acoustic pressure	Instantaneous or rms pressure, Pa; sound-pressure level, dB re 20 μPa; G-weighted level where applicable	DC-capable microbarometer, infrasound microphone, differential pressure sensor with wind-noise reduction	Compression and rarefaction in air; ducts, apertures, room modes and atmospheric waveguides	Wind, door motion, HVAC, sensor port turbulence, pressure equalisation and microphone self-noise
Structure-borne motion	Displacement, m; velocity, m/s; acceleration, m/s^2; phase and coherence	Force-balance accelerometer, broadband seismometer, velocity sensor or characterised geophone	Elastic waves and quasi-rigid-body motion through floors, walls, foundations and machinery supports	Footfall, vehicles, lifts, pumps, cable tug, sensor rocking, thermal tilt and local resonance

Provisional domain	Measured quantity and unit	Preferred sensor family	Dominant propagation or coupling	Principal confounders
Electric field	Electric-field strength, V/m; electrode potential, V; charge-related response	Field mill, guarded plate, high-impedance differential electrode or calibrated quasi-static field probe	Capacitive coupling, surface charge, contact and common-mode pathways	Triboelectric cable noise, humidity, clothing, personnel motion, mains fields and instrument leakage
Magnetic field	Magnetic flux density, T or nT; field strength, A/m; vector phase	Fluxgate, induction coil, search coil, optically pumped magnetometer or specialised SQUID system	Quasi-static magnetic coupling, current loops, ferromagnetic concentration and geomagnetic variation	Vehicles, lifts, steel movement, power wiring, sensor offset, temperature drift and magnetic contamination
Biological electrical or biomagnetic	Electrode voltage, V; magnetic flux density, T; clinically defined channel	EEG, ECG, EOG electrodes; close-coupled MEG or research magnetometry	Volume conduction within tissue or extremely weak near-body magnetic field	Movement, electrode impedance, muscle activity, mains pickup, expectation and unrelated physiology
Instrument and environmental state	Temperature, pressure, wind, humidity, tilt, time error, gain, offset and power	Calibrated environmental sensors and internal health telemetry	Not a source domain; explanatory and quality-control record	Unlogged configuration changes, firmware filtering, battery drift and clock discontinuity

34.3 Why 0.001 Hz to 20 Hz is not a single RF band

It is physically misleading to describe the entire interval as ordinary radio frequency. At 20 Hz, the free-space electromagnetic wavelength is approximately 14,990 kilometres; at 0.001 Hz it is approximately 299.8 billion metres. A building, campus or five-mile annulus is therefore electrically minute at these frequencies. The electric and magnetic components may not exhibit the plane-wave impedance and inverse-distance behaviour assumed in far-field radio analysis. Current paths, conductor geometry, capacitive coupling, inductive coupling, ground return and local field gradients usually dominate.

The acoustic and structural wavelengths are much shorter because sound and elastic waves propagate far more slowly than electromagnetic energy. At 17 Hz in air, using 343 metres per second, the wavelength is about 20.2 metres. In a solid, the relevant longitudinal, shear or bending-wave velocity depends upon material and geometry, so the structural wavelength may range from metres to hundreds of metres. A room can therefore be electrically negligible yet acoustically modal and structurally resonant at the same numerical frequency.

For operational convenience, a project plan may refer to a sub-20 Hz search channel. The evidential report must be more exact. It shall identify the acoustic, vibration, electric, magnetic or biological measurement chain, the calibration quantity, the transfer function, the noise floor and the domain-specific uncertainty.

34.4 Frequency, period, observation duration and defensible lower bound

A frequency claim is inseparable from observation duration. The period T of a sinusoidal component is $T = 1/f$, where T is seconds and f is hertz. At 0.001 Hz one cycle lasts 1,000 seconds. Three cycles require 50 minutes; ten cycles require approximately 2 hours 47 minutes; thirty cycles require approximately 8 hours 20 minutes. A ten-minute station can reveal drift or a transient but cannot resolve a stable 0.001 Hz periodic component. When encryption keys are being exfiltrated through a SCIF power line filters, or room audio collected when a secure phone is being used, it is useful to utilize “long cycle” transmitters, which is to say the system only transmits classified information at the rate of a few bit per minute, successfully bypassing the protective filters installed in SCIF to protect either high value data, encryption keys, or classified audio.

The nominal Fourier-bin spacing is Δf = 1/Tobs, where Tobs is the contiguous observation duration. Windowing, detrending, overlap, estimator bias, non-stationarity and gaps affect the practical resolution. A 24-hour record has a nominal bin spacing of about 11.6 microhertz, while a seven-day record has about 1.65 microhertz. Long records are therefore assigned to fixed sentinels rather than obtained by immobilising the mobile team at every annulus station.

Every report shall state a supported lower frequency for each record. The supported lower frequency is not the instrument's catalogue lower limit. It is the lowest frequency for which observation duration, calibration, drift control and signal stationarity permit a defensible estimate. Below that boundary the record may be described as trend, offset or slow variation, but not as a resolved spectral line.

Frequency	**Period of one cycle**	**Three-cycle minimum**	**Ten-cycle preferred characterisation**	**Typical use in EERF**
0.001 Hz	1,000 s (16 min 40 s)	50 min	2 h 46 min 40 s	Fixed sentinel and long stationary room record; not a rapid mobile station
0.003 Hz	333.3 s	16 min 40 s	55 min 33 s	Long mobile confirmation or fixed sentinel
0.01 Hz	100 s	5 min	16 min 40 s	Regional screening plus confirmatory dwell

Frequency	Period of one cycle	Three-cycle minimum	Ten-cycle preferred characterisation	Typical use in EERF
0.03 Hz	33.3 s	1 min 40 s	5 min 33 s	Building sway, pressure and very slow machinery envelopes
0.1 Hz	10 s	30 s	1 min 40 s	Seismic, pressure-control, transport and mechanical motion
0.2 Hz	5 s	15 s	50 s	Microbarom region and slow vibration hypotheses
0.5 Hz	2 s	6 s	20 s	Volcanic and mechanical pressure or motion features
1 Hz	1 s	3 s	10 s	Building motion, biological-rate coincidence and control envelopes
3 Hz	333 ms	1 s	3.33 s	Lower ELF, structure-borne vibration and machinery
8 Hz	125 ms	375 ms	1.25 s	Natural electromagnetic background, vibration and biological-band coincidence
17 Hz	58.8 ms	176 ms	588 ms	Infrasonic candidate, mechanical sources and historical concert example
20 Hz	50 ms	150 ms	500 ms	Upper boundary of the workstream; transition to ordinary audio methods

34.5 Source-class taxonomy

The source taxonomy begins with natural atmospheric and geophysical processes, proceeds through buildings and machinery, then addresses electric-power and control systems, transport, communications and intentional test sources, and concludes with biological and instrument-origin phenomena. The order is deliberate. A weak-signal examiner who begins with an adversarial explanation is likely to misclassify the ubiquitous slow signals produced by weather, structures, people and instruments.

A candidate source is recorded with a source model, not merely a label. The source model states expected domain, spatial extent, directional behaviour, temporal pattern, harmonics, phase relation, environmental dependence, activation state and plausible coupling path. The model is then tested against negative controls and competing explanations. A signal may remain unresolved without diminishing the value of the measurement.

Source class	Representative phenomena in or near 0.001-20 Hz	Expected cross-domain signature	Primary discriminants
Atmospheric and oceanic	Microbaroms, storms, fronts, wind, surf, thunder-related pressure and pressure equalisation	Pressure coherence over wide area; possible structure response; weak or absent local magnetic gradient	Regional station coherence, wind data, meteorology, propagation delay and array azimuth

Source class	**Representative phenomena in or near 0.001-20 Hz**	**Expected cross-domain signature**	**Primary discriminants**
Seismic and volcanic	Earthquakes, microseisms, long-period tremor, volcanic explosions, gas movement and ground deformation	Seismic motion with or without infrasound; broad spatial reach; possible local timing differences	Co-located seismic and pressure sensors, regional observatories, waveform velocity and arrival order
Geomagnetic and magnetospheric	Slow geomagnetic variation, pulsations, Schumann resonances and space-weather effects	Magnetic coherence across separated stations; limited premises-centred gradient	Exterior reference, vector direction, geomagnetic data and common-mode behaviour
Building and machinery	Fans, pumps, lifts, chillers, compressors, diesel engines, doors, pressure systems and structural sway	Structure and pressure; often electrical or magnetic harmonics tied to motor or drive state	Equipment-state log, start-stop tests, phase with current, floor/wall gradients and service-path tracing
Power and control systems	0-10 V controls, thermostat cycles, inverter envelopes, load management, battery management and slow duty cycles	Electric and magnetic components near wiring; conducted voltage; possible mechanical response	Conductor following, current probe, state intervention, harmonics and common-timebase correlation

Source class	Representative phenomena in or near 0.001-20 Hz	Expected cross-domain signature	Primary discriminants
Transport and platform	Road, rail, aircraft, rotor, ship, heavy vehicle and nearby construction activity	Pressure and motion transients; magnetic signatures from vehicles; characteristic movement across stations	Time of passage, direction, delay, traffic record and moving-source geometry
Communications and intentional test	Exceptionally low-frequency carriers, keying envelopes, slow subcarriers, beat products, platform timing and authorised test signals	May be magnetic or electric near-field; may correlate with higher-frequency carrier or system state	Allocation and intelligence review, harmonic or envelope relation, reproducibility and source geometry
Biological and clinical instrumentation	ECG rate, EEG bands, EOG movement, respiration, muscle and biomagnetic activity	Close-coupled electrode or extremely weak near-body magnetic signal; strong motion artefact susceptibility	Consent, clinical instrumentation, standoff dependence, shielded reference and medical governance
Instrumental	1/f noise, drift, offset, settling, tilt, thermal cycling, cable motion, clock discontinuity and numerical leakage	Appears in one channel, follows configuration or temperature, persists on terminated input	Dummy channel, sensor substitution, reversal, thermal log, power-cycle test and independent instrument

34.6 Natural atmospheric sources and microbaroms

Infrasound monitoring is an established geophysical discipline. The Comprehensive Nuclear-Test-Ban Treaty Organization identifies volcanoes, earthquakes, meteors, storms and auroras among natural infrasound sources, and explosions, aircraft and rocket launches among anthropogenic sources. Microbarometers detect very small pressure changes and are commonly deployed in arrays because time delay and coherence across elements permit azimuth and apparent velocity estimation [150].

Ocean-wave interactions during storms generate persistent microbaroms, commonly near 0.1 to 0.5 Hz, that can travel great distances through atmospheric ducts. The exact spectrum and arrival direction vary with ocean state and upper-atmospheric conditions. A pressure feature in this region that appears across several outer-ring stations may therefore be a regional atmospheric phenomenon rather than a local emitter. Wind-noise reduction, meteorological logging and array processing are essential because wind turbulence can exceed the signal by orders of magnitude.

The EERF examiner does not need to become a global infrasound observatory. The operational requirement is to preserve enough pressure, wind, temperature and timing information to recognise when the measured phenomenon is spatially broad, meteorologically correlated or propagating at acoustic velocity. A localised premises-centred attribution is withheld when the regional evidence is the better explanation.

34.7 Earthquakes, volcanic activity, magma movement and long-period geophysical signals

Earthquakes, microseisms, volcanic tremor, gas release, eruptive activity, landslides and other geophysical processes can produce signals within the workstream. USGS guidance notes that volcanic activity may produce very-long-period signals and infrasound, with energetic volcanic infrasound often in the 0.5 Hz to 20 Hz region. Co-located seismic and infrasound channels are more informative than either alone because they help separate ground motion from atmospheric pressure and can reveal arrival order and source process [151].

The phrase magma movement requires caution. Some volcanic or magmatic processes are inferred from seismicity, deformation, gravity, gas and infrasound, but a local EERF instrument does not directly identify magma from a spectral peak. Where a candidate feature coincides with known volcanic or seismic activity, the record is referred to a competent geophysicist or official observatory. The EERF report may describe timing, amplitude, waveform and coherence; it shall not diagnose a geological process without the relevant external evidence.

The same restraint applies to earthquakes. A low-frequency floor motion can be local machinery, traffic, building sway or a regional seismic arrival. Apparent velocity across the pod array, correlation with an exterior seismometer, comparison with official earthquake catalogues and persistence across structures provide a basis for discrimination. A single accelerometer line in one room is insufficient.

34.8 Natural electromagnetic background and Schumann resonances

The Earth-ionosphere cavity supports natural electromagnetic resonances whose first mode is commonly observed near 7.8 Hz, with higher modes near approximately 14 Hz and 20 Hz. Their exact frequencies and amplitudes vary with ionospheric conditions and global lightning activity. These resonances are a natural background phenomenon and may be visible only with sensitive, quiet and appropriately oriented magnetic or electric sensors [159].

A resemblance to a Schumann-mode frequency does not establish source identity. Local power systems, machinery, digital envelopes and numerical leakage can produce nearby lines. A natural-background hypothesis requires broad spatial coherence, suitable polarisation, absence of a premises-centred gradient and comparison with an exterior reference. It is also incorrect to infer a specific biological effect merely because a natural electromagnetic mode numerically overlaps an EEG band.

At these frequencies, the site is electrically minute. A local conductor current can produce a much larger magnetic gradient than the remote natural background. The examiner therefore records both absolute field and spatial derivative. Common-mode behaviour across separated pods suggests a broad source; a steep gradient aligned with wiring suggests a local current path.

34.9 Biological electrical and biomagnetic phenomena

Human physiological processes occupy low temporal frequencies. Heart rate is commonly near 1 Hz, respiration is slower, electrooculography contains slow eye-movement components, and EEG nomenclature includes delta, theta and alpha bands. These values describe patterns measured through electrodes or close-coupled sensors. They do not mean that the body is functioning as a useful free-space transmitter at those frequencies.

Biopotentials measured by ECG, EEG or EOG arise from ionic currents and volume conduction. The measurement depends upon electrode placement, contact impedance, differential amplification, common-mode rejection and clinical artefact control. Biomagnetic fields are extraordinarily weak. The NIMH MEG facility describes SQUID sensors detecting brain fields on the order of 10^-14 tesla outside the head, using hundreds of sensors in a close-fitting helmet and specialised localisation procedures [158]. Ordinary room-scale magnetic surveys are dominated by environmental fields many orders of magnitude larger.

Consequently, a frequency match between an environmental signal and a biological band is not evidence that the signal originated from the body or altered the body. Claims of entrainment, resonance or selective psychological effect require exposure magnitude, waveform, geometry, dosimetry, biological mechanism and controlled clinical evidence. EERF shall not infer these from frequency coincidence.

34.10 Industrial, architectural and control-system sources

Modern premises contain many slow control loops. Heating, ventilation and air-conditioning systems cycle dampers, valves, fans and compressors. Building-management systems typically use 0-10 V controls (although 96 volt systems may be found in some older buildings), pulse-width control, serial buses and scheduled duty cycles. Lifts, water pumps, refrigeration plant, pressure regulators, generators, uninterruptible power supplies and battery systems create mechanical, acoustic, electric and magnetic signatures that can extend below 20 Hz or appear as envelopes on higher-frequency switching.

The protocol treats each state change as an intervention. The field team records whether a lift moved, a pump started, a door opened, a fan changed speed or a pressure-control valve actuated. The affected pods and control channels are marked, and the event is compared with current, pressure, vibration and magnetic records. An event that appears in several physical domains at a consistent delay is more readily assigned than a spectral line viewed without context.

Building sway and floor compliance also matter. Tall or lightweight structures may move at fractions of a hertz under wind or occupancy. Sensor tilt can convert gravity into an apparent low-frequency acceleration. The accelerometer mount, orientation and levelling record therefore form part of the evidence, and a tilt channel or colocated inclinometer is desirable below approximately 0.1 Hz.

34.11 Military, maritime and specialised communications context

Extremely low-frequency and very-low-frequency methods have historically been associated with communications to submerged platforms because long wavelengths and conductive seawater make ordinary radio links difficult. The phrase ELF communications, however, must not be used as a blanket explanation for every line below 20 Hz. Operational systems have used different frequencies and architectures, and direct carrier communications at millihertz or single-digit hertz would entail exceptionally limited bandwidth and immense radiating structures.

Within the present workstream, a military-associated hypothesis may concern a true low-frequency field, a slow keying or traffic envelope, an amplitude or frequency modulation of a higher carrier, a platform mechanical signature, a power-system component, a beat product, or a test signal, and in some cases live ciphers or encryption keys. The examiner searches simultaneously for the slow component and any coherent higher-frequency family. A 5 Hz envelope on a 300 MHz carrier is not a 5 Hz free-space transmitter, even though the envelope appears in a demodulated spectrum.

Attribution requires lawful spectrum and intelligence review, consistent source geometry, reproducibility, exclusion of civil infrastructure, and preferably an independent receiver. The EERF report may state that a signal is compatible with a communications or platform process. It shall not name a state actor, military service or operational system without reliable external evidence.

34.12 Diplomatic, consular and international-organisation sites

Reports of acute symptoms among personnel at diplomatic and related locations have generated legitimate medical and security concern. The existence and seriousness of reported symptoms must be respected. It does not follow that a common sub-20 Hz acoustic, vibration or electromagnetic cause has been established, or that such a field is widespread at embassies, consulates, United Nations offices or associated residences.

The January 2025 United States Intelligence Community assessment states that most components continue to judge it very unlikely that a foreign adversary was responsible for the events reported as possible anomalous health incidents, while acknowledging differing confidence and continuing investigation of a small number of events. NIH studies reported severe and sometimes disabling symptoms but found no significant evidence of MRI-detectable brain injury or differences in most clinical measures compared with controls [156], [157]. These findings do not prove that every event has the same explanation, and they do not validate a low-frequency field hypothesis.

An EERF examination at such a site shall therefore use heightened methodological restraint. Symptom timing is recorded separately from instrument data. The analyst is blinded to symptom labels where practicable during primary signal screening. Sham periods, source-absent controls, environmental references and independent review are required. No measured line is characterised as the cause of a symptom unless a properly governed clinical and exposure investigation supports that conclusion.

Question	**Permissible EERF statement**	**Statement that is not permitted without external evidence**
Was a physical signal measured?	A calibrated pressure, motion, electric or magnetic variation was measured with stated uncertainty.	A hostile device caused the signal.
Did the signal coincide with a symptom report?	The records were temporally coincident within the declared clock uncertainty.	The signal caused the symptom.
Did the signal appear at a diplomatic site?	The signal was measured at the named authorised location.	The signal is characteristic of diplomatic sites or a foreign intelligence operation.
Did the frequency overlap an EEG, ECG or EOG band?	The numerical frequency overlaps a named physiological measurement band.	The signal entrained, resonated with or controlled the corresponding physiological system.

Question	Permissible EERF statement	Statement that is not permitted without external evidence
Was a nonlinear or electronic source localised?	The measured response converged spatially and survived the declared controls.	The source was designed to affect health or collect intelligence, unless additional evidence establishes purpose.
Were symptoms severe?	The individual reported severe symptoms and was referred for clinical evaluation.	The engineering team diagnosed injury, seizure, vestibular disease or psychiatric cause.

34.13 Health-effects evidence hierarchy and bounded interpretation

Health interpretation begins with exposure quantity, not frequency alone. For infrasound, sound pressure level, waveform, duration, audibility, modulation and coupling matter. For vibration, acceleration, direction, posture, contact and duration matter. For electromagnetic fields, electric-field strength, magnetic flux density, frequency, waveform, spatial distribution and induced internal field matter. A bare statement that 17 Hz, 8 Hz or 1 Hz was present is scientifically inadequate.

The United Kingdom Health Protection Agency review concluded that very high infrasound levels may produce acute effects such as aural pain and body vibration, but that ill effects had not been established at levels commonly experienced in the everyday environment. It also emphasised limited epidemiological and long-term data. Low-frequency audible noise can produce annoyance and sleep disturbance, with large inter-individual variability and important roles for expectation, fluctuation and context [149].

Mechanical vibration is a distinct exposure. NASA human-performance guidance notes that vibration can degrade vision by moving the retinal image and can impair manual performance in frequency-dependent conditions. This evidence concerns physical vibration at stated acceleration and coupling, not a weak airborne tone or magnetic field at the same frequency [152].

Low-frequency electric and magnetic fields can produce established acute interactions at sufficiently high exposure, particularly nerve stimulation and surface-charge effects. Exposure assessment shall use current guidance such as ICNIRP and relevant IEC or IEEE measurement standards. The existence of exposure limits does not imply that a measured environmental field below the limit is harmless in every imaginable circumstance, nor that a field above a screening reference automatically caused a reported symptom. It triggers competent exposure assessment and risk control [143]-[147].

Claim or observation	**Current evidential position adopted by this framework**	**Required action**
Ordinary environmental infrasound selectively causes dread, awe or spiritual ecstasy	Partially established. Emotional response is context-sensitive, and frequency alone is not a selective psychological control mechanism.	Record pressure and context; avoid causal language; refer clinical questions appropriately.
High-level infrasound can produce acute physical sensations	Supported in authoritative reviews at sufficiently high levels, including aural discomfort or intense pain and body vibration.	Measure unweighted and G-weighted pressure where applicable; compare with competent acoustic guidance; stop unsafe exposure.
Low-frequency audible noise can affect annoyance or sleep	Plausible and supported in environmental-noise literature, with strong individual and contextual variation.	Use acoustic specialist review, audibility analysis and long-duration sleep-context records.

Claim or observation	Current evidential position adopted by this framework	Required action
Mechanical vibration can cause nausea, motion sickness or visual-performance degradation	Supported under specified motion, acceleration, frequency, coupling and duration conditions.	Measure acceleration and motion with ISO-compatible instrumentation; distinguish from airborne sound.
A sub-20 Hz field causes seizures, eye-muscle spasms or salivary-gland effects	Established as a general environmental-frequency effect. Such outcomes require clinical diagnosis and exposure-specific evidence.	Treat as a medical safety concern, stop active testing, and refer to clinical governance.
Frequency overlap with brain, heart or eye signals proves resonance or control	Incorrect. Numerical frequency coincidence does not demonstrate coupling or causation.	Require dosimetry, mechanism, controlled exposure evidence and clinical review.
Diplomatic-site symptoms prove an external field weapon	Well established. Symptoms may be real and disabling while mechanism remains unresolved.	Preserve records, apply blinded analysis and cite current official assessments.

34.14 The 17 Hz Purcell Room concert experiment

On 31 May 2003, the Infrasonic project conducted two experimental concerts in the Purcell Room in London. A 17 Hz component was added to two of four pieces in each concert, with the assignment counterbalanced between performances. Approximately 700 people attended, and 522 questionnaires were analysed. Participants rated emotion and reported unusual experiences [153].

The project summary reported no significant change in the measured emotional-response scales attributable to the infrasound. It did report associations between the presence of infrasound and some self-reported unusual experiences in parts of the design, while also discussing suggestion and conscious detection as possible explanations. The often-repeated assertion that 22 per cent of the audience experienced a particular adverse response is not a faithful statement of the summary; the 22 per cent figure in the document relates to uncertainty about paranormal belief, not a uniform treatment effect.

The event was innovative and useful as a hypothesis-generating demonstration, but it was not a clinical exposure trial establishing selective induction of dread, sorrow, revulsion, spiritual experience or disease. The musical context, self-report design, possible audibility, multiple comparisons, differing audiences and limited exposure characterisation constrain generalisation. EERF may cite the study as a reason to measure pressure and context carefully. It shall not cite it as proof that a precise 17 Hz tone can reliably control emotion.

34.15 Expectation, nocebo, blinding and symptom-report separation

Low-frequency investigations are unusually susceptible to expectation. Slow pressure, vibration and electromagnetic environments are difficult for participants to identify reliably, yet information about alleged effects can alter symptom reporting. Sham-controlled research has shown that expectation can contribute materially to reported symptoms attributed to infrasound, and a 72-hour double-blind crossover study of simulated wind-turbine infrasound did not support the proposition that inaudible infrasound itself produced the claimed syndrome in the tested conditions [154], [155].

The protocol therefore separates engineering acquisition from symptom interpretation. The field team uses neutral event identifiers. The primary analyst is not shown symptom narratives until an automated and blinded candidate list has been frozen where this is practicable. Clinical personnel retain the symptom record. After unblinding, temporal association is evaluated with correction for multiple comparisons and with sham or control periods.

This separation does not suggest that symptoms are imagined. Symptoms can be severe, persistent and disabling while their cause remains uncertain. The purpose of blinding is to prevent the engineering record from being shaped by expectation and to prevent an incidental spectral feature from being promoted into a causal explanation.

34.16 Airborne acoustic measurement architecture

A sub-20 Hz pressure channel requires a transducer and front end whose low-frequency response is known. Conventional studio microphones, sound cards and handheld sound-level meters may incorporate high-pass filters or pressure-equalisation paths that make them unsuitable below 20 Hz. The preferred instrument is a calibrated microbarometer or infrasound microphone with documented transfer function, self-noise, dynamic range, environmental limits and phase response. ISO 7196 specifies G-weighting for infrasound measurements from 1 Hz to 20 Hz, but unweighted narrowband spectra and time histories must also be retained because weighting is an exposure descriptor rather than a source-identification tool [142].

Wind is often the dominant contaminant. A porous-hose or spatially distributed wind-noise-reduction system averages turbulent pressure while preserving coherent infrasonic arrivals. The hose geometry, inlet spacing, blockage state and orientation are photographed or drawn and recorded. The instrument is placed away from local wakes where possible, and a wind channel is sampled synchronously.

Pressure sensors require leak checks and step-response characterisation. A blocked port can create false low-frequency drift, while an excessively open equalisation path can attenuate the target band. The pre-deployment record therefore includes static-pressure offset, calibration-piston or reference-source response where available, self-noise with ports appropriately terminated, and cross-comparison between at least two sensors. These acoustic measurements are taken so that they may be correlated to electromagnetic signals in the infrasonic range, as doing so will often reveal hidden microphones.

34.17 Structure-borne vibration and seismic measurement architecture

Structure-borne motion is measured separately from pressure. Force-balance accelerometers and broadband seismometers are preferred for the lowest frequencies because a passive geophone has reduced sensitivity below its natural frequency unless its response is accurately equalised. A DC accelerometer can capture slow tilt and translation but is vulnerable to thermal drift and gravity projection. A velocity sensor can offer lower noise for selected seismic bands but requires integration or differentiation for comparison with acceleration.

Each sensor is rigidly coupled to the surface through a documented mount. Soft foam, loose tripods or rocking bases create local resonances and false low-frequency motion. The mount material, preload, orientation and surface condition are recorded. Where the surface cannot be touched or altered, a non-invasive heavy base or approved clamp is used and its transfer function is validated.

Three orthogonal channels are required where vector direction matters. A fourth tilt or rotational channel is desirable for very-low-frequency building motion. ISO 2631 and ISO 8041 provide frameworks for human-vibration measurement and instrumentation, but EERF retains the unweighted waveform and uses the standard weighting only for the question within its scope [148].

34.18 Quasi-static magnetic-field sensors

Fluxgate magnetometers are suitable for DC and very-low-frequency vector measurements, subject to offset, scale-factor, orthogonality, temperature and magnetic-history controls. Induction coils and ferrite or alloy-core search coils respond to dB/dt and therefore lose voltage sensitivity as frequency approaches zero. They can nevertheless be exceptionally useful above their practical lower corner when their turns, area, permeability, resistance, capacitance and preamplifier noise are matched to the band.

The existing EERF alloy-core programme is therefore extended downward with caution. High-permeability nickel-iron, amorphous and nanocrystalline materials can increase inductance and flux concentration, but open-bar demagnetising factor, magnetic loss, Barkhausen noise, remanence, stress and temperature may dominate. No alloy table value is accepted as the completed probe response. Each finished bar or ring is measured for complex transfer function, noise, saturation, orientation and self-resonance.

Optically pumped magnetometers and SQUID systems may be used for specialised comparison, but they introduce their own environmental, shielding, heating, laser, cryogenic and calibration constraints. A biomagnetic-grade instrument is not automatically a superior scene probe if it saturates, drifts or cannot operate in the ambient field.

34.19 Quasi-static electric-field sensors

Slow electric fields are measured with field mills, guarded electrodes, capacitive plates or other calibrated quasi-static sensors. The input impedance, leakage current, guarding, cable dielectric, humidity response and personnel influence are critical. A person walking near the probe can create a much larger field change than the candidate source. The field team therefore establishes exclusion distances and uses remote fibre control.

Static and slowly varying electric fields can arise from charged surfaces, high-voltage equipment, mains wiring, clothing, moving belts, air handling and weather. A field mill periodically modulates the exposure of a sensing electrode and can translate a static field into an AC signal, but the instrument's chopping frequency and harmonics must be quarantined from the EERF evidence channels. Guarded passive plates avoid moving parts but are more susceptible to leakage and drift.

The report states whether the measured quantity is electric-field strength, electrode voltage or charge-related instrument output. It does not use volts at the preamplifier as though they were volts per metre unless a calibration factor and geometry support that conversion.

34.20 The forty-four-channel sub-20 Hz allocation

The common-timebase preprocessing head can support a forty-four-channel multiphysics configuration without sacrificing provenance. The allocation below is a recommended full configuration rather than a universal minimum. A smaller commission may use fewer channels, but every omitted comparison channel is identified in the limitations. The architecture keeps sensor excitation, analogue conditioning, digitisation, time tagging and health telemetry at the central head, then conveys digital records over an armoured fibre link to the analyst position.

The head remains physically near the antenna and sensor cluster so that analogue leads are short. The analyst position remains outside the controlled area. Power conversion, clocks, switching and displays are contained, shielded, filtered and characterised. Fibre provides galvanic and common-mode isolation, but the optical transceivers and switching regulators are still potential local emitters and are included in the instrument self-emission library.

Channels	Allocation	Purpose
1-9	Pod A, B and C magnetic Bx, By, Bz	Vector magnetic field, gradient and phase across three spatial pods
10-18	Pod A, B and C electric Ex, Ey, Ez	Vector quasi-static electric field and spatial comparison
19-27	Pod A, B and C motion X, Y, Z	Orthogonal structure-borne acceleration or velocity
28-30	Pod A, B and C pressure	Local infrasonic pressure and room or exterior phase
31-33	Exterior reference magnetic vector	Broad-area magnetic common-mode and geomagnetic control

Channels	Allocation	Purpose
34	Exterior reference pressure	Regional pressure and atmospheric control
35-37	Exterior reference motion X, Y, Z	Ground or structural reference and regional seismic discrimination
38	Wind speed and direction or turbulence reference	Pressure-channel contamination and propagation context
39	Temperature, humidity and barometric state multiplex	Drift and environmental correction
40	Master-time loopback and pulse-per-second verification	End-to-end clock and timestamp validation
41	Terminated analogue path	Electronic self-noise and common chassis artefacts
42	Dummy sensor and cable path	Triboelectric, motion and electromagnetic pickup control
43	Guard or independent confirmation sensor	Independent architecture or local background
44	Reserve / event-specific reference	Machine-state, current, illumination or specialist transducer

34.21 Analogue front ends, 1/f noise and drift

Below 20 Hz, flicker noise, dielectric absorption, input-bias-current variation, thermoelectric voltages, mechanical stress and temperature drift may dominate the white-noise floor. The front-end design therefore cannot be judged solely by a wideband noise density quoted at 1 kHz. The procurement specification requires noise spectral density down to the intended lower frequency, input offset and drift, common-mode rejection, input-current noise, overload recovery, dielectric material, temperature coefficient and long-term stability.

Chopper-stabilised and auto-zero amplifiers can reduce offset and 1/f noise, but their switching residues may create deterministic lines. Those lines are measured with terminated and dummy channels and entered in the self-emission library. The analogue chain includes a selectable DC path, a characterised very-low-frequency high-pass path where saturation control is required, and anti-alias filtering before digitisation. Filter phase is measured because cross-channel delay is central to source discrimination.

Connectors and cables are selected for low triboelectric and microphonic response. Cable movement is prohibited during acquisition and logged when unavoidable. Thermal gradients across dissimilar metals can create microvolt-level offsets. The head is allowed to reach thermal equilibrium, and internal temperatures are sampled with the evidence data.

34.22 ADC, FPGA, timing and digital signal processing

A nominal sample rate of 200 or 256 samples per second provides adequate anti-alias guard for a 20 Hz upper band while retaining simple decimation ratios. Higher rates may be used where the same converter also serves audio or timing channels. The converter resolution, effective number of bits, integral non-linearity, reference noise and aperture jitter are documented. At very low frequency, reference stability and front-end drift usually matter more than aperture jitter.

The first FPGA calculates overlapped FFT or filter-bank products, power spectral density, time-domain statistics and cross-spectra. The second FPGA or processing stage identifies features that rise above an adaptive noise estimate, change coherence, exhibit a spatial gradient or correlate with a machine-state channel. Detection thresholds are validated against synthetic and physical reference signals. Constant-false-alarm-rate processing can assist triage, but the algorithm is not permitted to erase subthreshold data.

The master clock distributes sample timing and an event epoch to every channel. A loopback pulse is recorded through an analogue or digital path so that end-to-end latency is verified. Where separate chassis are required, each is disciplined to the same site reference and the residual skew is measured. Cross-domain phase is reported only when the sensor, filter and channel group delay have been calibrated.

34.23 Spectral estimators and non-stationarity

A long low-frequency record is rarely stationary. Weather changes, occupancy, equipment cycling and sensor drift can alter its mean and variance. The analyst therefore uses multiple representations: raw time history, detrended time history, short-time spectrum, Welch power spectral density, wavelet or multiresolution view, cross-spectral density, coherence, event-triggered average and, where justified, parametric modelling. No single FFT plot is treated as the complete evidence.

Detrending is documented because an aggressive polynomial can remove a real slow component, while insufficient detrending can leak a large DC offset across the lowest bins. Window function, segment length, overlap and averaging are preserved in metadata. The unprocessed raw I/Q data and records is retained so that an independent examiner can reproduce or challenge the chosen processing.

A line is characterised by centre frequency, uncertainty, bandwidth, stability, amplitude, phase, coherence, modulation, persistence and spatial behaviour. A broad hump is not converted into a narrow tone by selecting an excessively long FFT without considering non-stationarity. Conversely, a stable line should be tested at several resolutions to distinguish physical bandwidth from estimator bandwidth.

34.24 Ring-by-ring deployment and observation schedule

The outer annuli use a combination of mobile stations and fixed sentinels. The mobile station establishes spatial diversity and identifies local contamination. The sentinels establish long-period continuity. At 5 miles, 2.5 miles and 1 mile, at least one pressure, magnetic and motion reference remains fixed during the completion of the ring where lawful and practical. In high-risk work, three or more sentinels on different and diverse bearings are preferred.

The 0.5-mile and 0.25-mile rings increase spatial relevance to the premises and therefore add more detailed service-path and infrastructure notes. The 300-foot through 12-foot stages add exterior-wall, utility, ground, roof and foundation comparisons. The 3-foot and three-inch stages emphasise gradients and paired surfaces, while fixed channels preserve the long-period context so that a slow regional wave is not mistaken for local convergence.

The schedule below is a minimum planning framework. It does not override a longer dwell required by the candidate period or by non-stationary behaviour. A shorter dwell can be used for safety or access, but the supported lower frequency is raised accordingly.

Stage	**Mobile station minimum**	**Fixed-sentinel expectation**	**Sub-20 Hz objective**
5-mile ring, 16 or 24 stations	30 min screening; 60 min preferred	At least one 72 hr reference; multi-week preferred	Inventory regional pressure, magnetic and seismic background; identify broad sources
2.5-mile ring, 16 or 24 stations	30 min screening; 60 min preferred	Continue same sentinel or establish clock-closed replacement	Assess azimuth, broad coherence and regional change
1-mile ring, 16 or 24 stations	30-60 min	24 h overlap with outer reference where possible	Separate campus, transport and utility sources from wider region
0.5-mile ring, 12 preferred, 8 minimum	45-90 min	Overnight at one or more bearings	Identify local infrastructure, building clusters and moving-source routes
0.25-mile ring, 12 preferred, 8 minimum	45-90 min	Overnight or occupancy-cycle record	Establish premises approach and exterior service-path background
300-50 ft rings	30-60 min at each controlled station	Continuous exterior reference	Compare envelope, foundation, utilities and wall-normal gradients

Stage	Mobile station minimum	Fixed-sentinel expectation	Sub-20 Hz objective
30-12 ft rings and threshold	20-60 min, with state-controlled repeats	Exterior plus interior guard channel	Establish wall, door, roof, floor and service-path transfer
Interior 3-ft grid	10-30 min per cell; selected long dwells	One room reference remains fixed	Map pressure, motion, electric and magnetic gradients
3-inch convergence	Stationary repeated acquisitions; duration set by candidate period	Matched control cell and exterior reference	Localise without confusing broad modes or sensor artefacts with a point source
Reverse path	Repeat critical stations with same dwell and geometry	Sentinel continuity preserved	Demonstrate closure, drift and scene stability

34.25 Twenty-seven-cell room processing and paired surfaces

The room is treated as a three-by-three-by-three neighbourhood in which the area of interest occupies the centre cell. Six face-sharing cells, twelve edge-sharing cells and eight corner-sharing cells provide the immediate volumetric comparison. At sub-20 Hz, this geometry is not merely a search grid. It is a set of paired transfer measurements across walls, floor, ceiling, corners, cavities, plenums and adjacent rooms.

Opposite-wall pairs are measured at matched height, standoff, orientation and time. Floor and ceiling pairs are measured from both sides where access exists. The highest safe and authorised point provides a vertical comparison, while a lower-floor or foundation sensor provides the opposite reference. The centre cell remains a hypothesis region, and the surrounding cells test whether the apparent maximum is local, structural, modal or regional.

The method also constructs nested spherical or ellipsoidal shells around the candidate region. A true local quasi-static source may show a systematic gradient and vector rotation. A room mode may show alternating nodes and antinodes without a point-like centre. A structural source may follow beams and supports. A regional pressure wave may remain nearly coherent across the volume. The interpretation is based upon the full pattern, not the brightest cell.

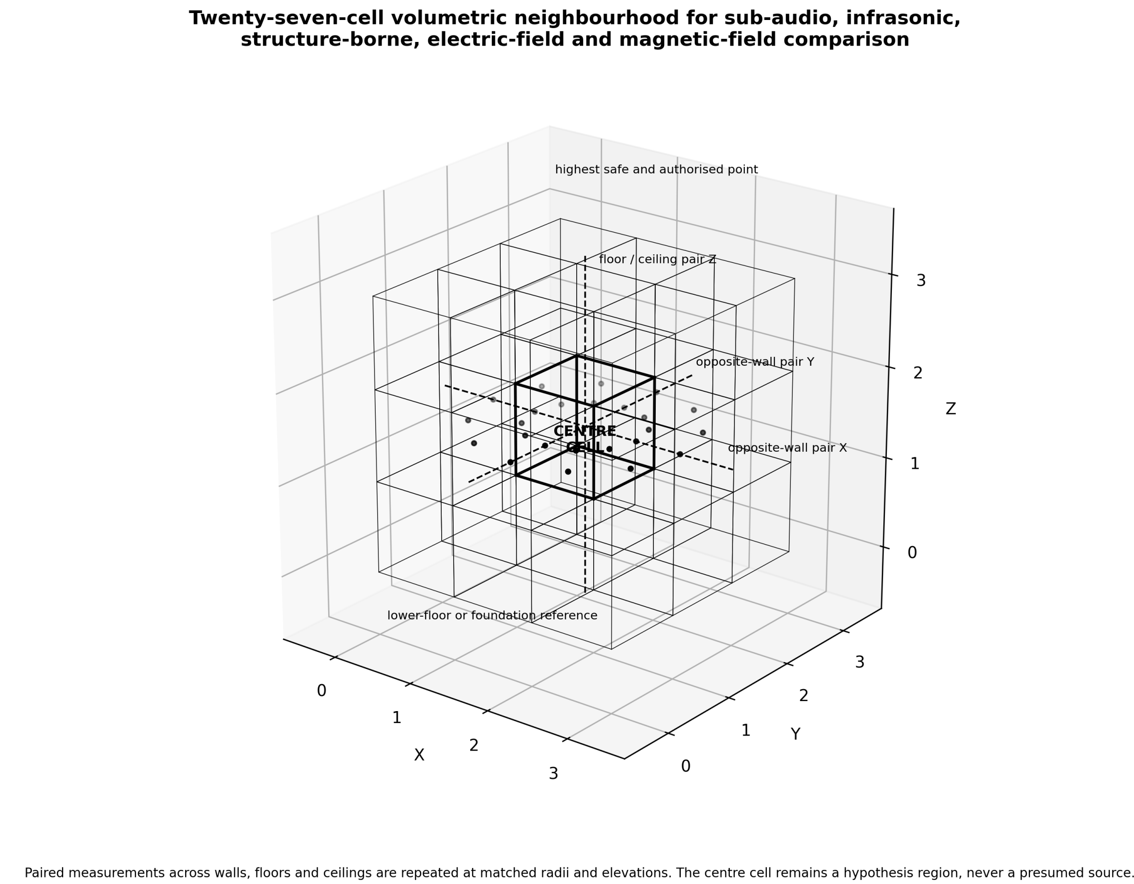


Figure 34.2. Twenty-seven-cell volumetric neighbourhood for paired sub-audio, infrasonic, structure-borne, electric-field and magnetic-field comparison. The centre cell is a hypothesis region, never a presumed source.

34.26 The high-ground principle and vertical access

The practical axiom of controlling the high ground is translated into a lawful measurement principle: obtain the highest safe, structurally suitable and authorised comparison point that contributes independent geometry. Roofs, upper floors, lofts, plenums, balconies, towers and elevated external positions can improve bearing diversity and reveal vertical propagation. They can also create serious fall, weather, lightning, wind-noise and field-exposure risks.

No measurement objective justifies unsafe climbing, unauthorised access or structural loading. A competent person approves access, fall protection, weather limits and equipment restraint. The vertical station records height, slant range, local wind, structure motion and cable route. The analyst shall not compare an exposed rooftop pressure channel directly with a sheltered interior channel without accounting for the radically different wind and boundary conditions.

Below the target, access may be limited by ground, foundation or occupancy. Where a lower floor, basement, service tunnel or crawl space is available, it is processed with the same scene controls. Where it is unavailable, the missing lower hemisphere is shown explicitly in the volumetric drawing and treated as a localisation limitation.

34.27 Cross-domain coherence, phase and propagation-delay discrimination

Cross-domain timing is one of the strongest discriminants. An electromagnetic event traverses a 100-metre site in roughly 0.33 microseconds, while an acoustic event in air takes approximately 0.29 seconds. A seismic or structural event follows a material-dependent velocity and pathway. These differences are large enough to test when sensors are synchronised and group delay is calibrated.

Magnitude-squared coherence between two channels is calculated as $|Sxy(f)|^2$ divided by Sxx(f)Syy(f), where Sxy is the cross-power spectral density and Sxx and Syy are auto-spectral densities. High coherence shows a stable linear relationship at the analysed frequency but does not prove source direction or causation. Phase, delay, geometry, sensor transfer functions and common interference must also be considered.

The analyst uses pressure-to-pressure, motion-to-motion, magnetic-to-magnetic and electric-to-electric coherence first. Cross-domain coherence is then examined. A fan may show coherent current, magnetic field, vibration and pressure. A regional microbarom may show pressure coherence without a local magnetic gradient. Cable motion may show apparent electric and magnetic events only in the moved channels. The combined pattern supports a source model.

Observed pattern	**Favoured preliminary explanation**	**Required counter-test**
High pressure coherence across separated stations; acoustic-speed delay; weak local magnetic gradient	Regional or airborne infrasonic source	Wind-noise control, meteorology, array bearing and pressure-sensor substitution
Strong floor motion with weak pressure; follows beams or foundations	Structure-borne machinery, transport or seismic source	Lower-floor reference, machine-state log, mount test and geophone/accelerometer comparison
Magnetic gradient aligned with wiring; coherent with current or power state	Local current path or power/control system	Conductor tracing, power-state intervention, orientation reversal and independent magnetometer
Common magnetic variation at all pods and exterior reference	Geomagnetic or broad-area source	Regional comparison, vector direction and local-gradient check
Line remains on terminated or dummy input	Instrument, clock, processing or cable artefact	Independent chassis, changed sample rate, power isolation and firmware bypass

Observed pattern	Favoured preliminary explanation	Required counter-test
Event appears only after sensor or cable movement	Triboelectric, microphonic, magnetic-history or settling artefact	Settling dwell, stationary repeat, cable substitution and movement log
Temporal coincidence with symptom report but no spatial or domain consistency	Coincidence unresolved; no physical attribution	Blinded analysis, sham periods, multiple-comparison control and clinical separation
Spatial convergence plus repeatable state dependence and negative controls	Candidate local source in the measured domain	Independent instrument, reverse path, uncertainty analysis and bounded classification

34.28 Confounders and compulsory negative controls

The sub-20 Hz band is dominated by confounders. Personnel movement changes electric field, magnetic field, pressure and floor motion simultaneously. Wind produces pressure and mechanical motion. Temperature alters sensor offsets. Vehicles carry ferromagnetic material and generate vibration. Doors and lifts change pressure and structure. Cables generate triboelectric and microphonic voltages. The controls therefore operate continuously, not merely at the end of the survey.

A minimum control set includes a terminated electronic channel, a dummy sensor and cable, an exterior reference, a sensor-substitution trial, a polarity or orientation reversal, a mount test, an instrument-power test, a time-base loopback and a reverse-path repeat. Where active equipment is present, machine-state controls are added. Where symptoms are being reported, sham intervals and blinded analysis are added under clinical and ethical governance.

A candidate is invalidated or downgraded when it follows the analyser sample rate, FFT length, chopper frequency, card slot, preamplifier temperature, cable movement or data-link state. A physically real environmental signal can still be irrelevant to the assignment. The report distinguishes real-but-background, real-and-local, instrument-generated, unresolved and absent.

34.29 Exposure comparison and applicable standards

The measurement standard is selected by physical domain and purpose. ISO 7196 provides G-weighting for infrasound from 1 Hz to 20 Hz. ISO 2631 and ISO 8041 address human response to mechanical vibration and instrumentation. IEC 61786-1 and 61786-2 address instruments and procedures for DC magnetic and AC electric and magnetic fields from 1 Hz to 100 kHz, while IEEE 1308 addresses field meters from 10 Hz to 3 kHz. ICNIRP provides low-frequency exposure guidance from 1 Hz to 100 kHz [142]-[148].

The nominal 0.001 Hz lower bound extends below several exposure standards. Below the standard's scope, the examiner may still characterise the physical signal, but shall not extrapolate a limit or weighting without competent justification. Static and slowly varying fields may require separate static-field guidance, and motion below 1 Hz may require transport or motion-sickness expertise rather than an infrasound standard.

Comparison values are reported with measurement uncertainty, spatial averaging, time averaging, waveform and duty cycle. A single peak, rms value and weighted level answer different questions. The report identifies which quantity was compared and why.

34.30 Clinical, ethical and safety stop conditions

Passive measurement is generally preferred, but it is not automatically risk-free. Sensors, cables and personnel can obstruct routes, interfere with medical equipment, create fall hazards or alter a sensitive environment. Active acoustic, vibration or electromagnetic excitation is outside the routine sub-20 Hz survey and requires a separate written protocol, exposure assessment, legal authority, clinical-site approval and emergency stop.

The field team stops and seeks appropriate assistance when a person reports acute neurological symptoms, loss of consciousness, seizure, severe vertigo, chest pain, sudden hearing change or other medical emergency. Engineers do not conduct challenge testing to reproduce symptoms. The scene record preserves time, location, instrument state and environmental conditions without delaying care.

Research involving deliberate human exposure, symptom provocation, EEG, ECG, EOG or other physiological monitoring requires informed consent, ethics review and competent clinical governance. The EERF inspection authorisation alone is not sufficient.

34.31 Reporting language and evidential classifications

The report begins with the measured domain and quantity. Preferred language is: a 0.23 Hz pressure component was measured at stated amplitude and uncertainty; a 4.1 Hz vertical acceleration component was coherent between the floor and lower-floor reference; an 8.0 Hz magnetic component was common to the exterior and interior sensors; or a 17 Hz pressure line was local to a ventilation path. These statements are testable and do not outrun the instrument.

A candidate is classified as observed, environmentally correlated, regional, premises-associated, room-associated, service-path-associated, spatially localised, exposure-relevant, instrument-generated or unresolved. Device-associated is reserved for a response that converges spatially, survives controls and is supported by an identified or independently confirmed electronic object or pathway. Health-effect-associated is not an EERF classification.

Prohibited formulations include: the frequency attacked the brain; the signal matched alpha waves and therefore caused sleep disturbance; a 17 Hz tone created fear; the embassy contained the same weapon reported elsewhere; or an unexplained line proves technical mischief. Such statements are replaced with the measurement, uncertainty, alternative explanations and referral recommendation.

Classification	**Minimum basis**	**Permitted conclusion**
Observed sub-20 Hz feature	Above validated system floor; raw record preserved	A feature was measured in the stated domain and configuration.
Environmentally correlated	Coherent with wind, weather, transport, machine state or official geophysical event	The environmental variable provides a supported explanation.
Regional feature	Appears at multiple outer stations without premises-centred convergence	The feature is broader than the inspected premises within measurement limits.
Premises-associated	Strengthens or changes systematically near the premises and survives controls	The feature is associated spatially with the premises, not necessarily with a device.
Service-path-associated	Follows a conductor, duct, pipe, structural member or utility state	The measured pathway is consistent with coupling or transmission.
Spatially localised	Convergent gradient, vector behaviour, reverse-path closure and independent confirmation	A bounded source region is supported.
Exposure-relevant	Calibrated exposure quantity and applicable standard comparison	The measured exposure is reported relative to the standard, with uncertainty.
Instrument-generated	Persists on dummy or terminated path or follows instrument configuration	The feature originates in or is materially produced by the measurement system.

Classification	Minimum basis	Permitted conclusion
Unresolved	Competing explanations remain	The source is not established. Further work may be recommended.

34.32 Validation programme

Before consequential use, the sub-20 Hz method is validated with known pressure, vibration, electric-field and magnetic-field sources. The programme measures amplitude accuracy, phase accuracy, timing skew, frequency response, self-noise, dynamic range, overload recovery, drift, temperature sensitivity, orientation error, cross-axis sensitivity, crosstalk, wind rejection, mount response and long-duration data integrity.

Blind source-present and source-absent trials are conducted in multiple rooms and outdoor environments. The test set includes regional pressure fields, local machinery, structure-borne sources, current loops, charged surfaces, geomagnetic variation simulations, sensor artefacts and combined sources. Operators must classify the domain and source region without being told the condition.

Acceptance limits are established before testing. The validation record includes failures and conditions under which the method is not reliable. A system that localises a strong laboratory source but fails in wind, building motion or long-duration drift is not validated for the corresponding field claim.

Validation characteristic	Proposed acceptance evidence	Failure consequence
Amplitude response	Traceable comparison at multiple points across each sensor band; uncertainty stated	No quantitative exposure or source comparison

Validation characteristic	Proposed acceptance evidence	Failure consequence
Phase and group delay	Common-source test across channels and domains after transfer-function correction	No propagation-delay or vector-phase conclusion
Noise floor	Terminated, dummy and physical-sensor records for representative durations and temperatures	Detection threshold raised or channel excluded
Long-term drift	At least 24 hr stable-reference test; multi-day test for 0.001 Hz claim	Lower supported frequency increased
Cross-axis sensitivity	Known orthogonal excitation or calibrated rotation	Vector direction qualified or withheld
Wind rejection	Paired exposed and wind-noise-reduced pressure tests	Outdoor infrasound claim limited
Mount response	Reference shaker or side-by-side mount comparison	Structure-borne localisation limited
Crosstalk	One-channel excitation with all other channels terminated	Affected channels corrected or invalidated
Event detection	Blind signals across amplitude, duration and drift; false-alarm rate reported	Automated flags used only for navigation
Spatial localisation	Blind source-present and source-absent room trials with error distribution	No device- or source-region confirmation
Data integrity	Clock closure, hashes, gap detection, metadata and recovery testing	Affected interval excluded from evidential use

34.33 Worked engineering examples

The following examples are explanatory calculations. They illustrate the physics and planning implications of the workstream. They are not guaranteed detection ranges, exposure conclusions or substitutes for calibration.

34.33.1 Period and minimum dwell at 0.001 Hz

Here f is frequency in hertz and T is period in seconds. A 20-minute station observes only 1.2 cycles and cannot support a stable 0.001 Hz line claim.

34.33.2 Free-space electromagnetic wavelength at 20 Hz

$$\lambda = c/f = 299{,}792{,}458/20 = 14{,}989{,}623\text{m}, \approx 14{,}990\text{km}.(20)$$

Here c is free-space wave speed in metres per second. A 15-foot room is about one millionth of this wavelength, so plane-wave assumptions are generally inappropriate.

34.33.3 Acoustic wavelength at 17 Hz

$$\lambda_a = v_a/f = 343/17 = 20.18\text{m}.(21)$$

Here v_a is acoustic velocity in air at the stated conditions. The wavelength is comparable with a large room dimension, so boundaries and modes matter.

34.33.4 Nominal frequency resolution of a 24-hour record

This is nominal bin spacing. Windowing, drift and non-stationarity determine practical resolution.

34.33.5 Sound pressure corresponding to 100 dB SPL

$$p_{\text{rms}} = p_0 \times 10^{(Lp/20)} = 20 micro Pa x 10^5 = 2\text{Pa}.(22)$$

Here p0 is 20 micropascals and Lp is sound-pressure level in decibels. The calculation does not by itself state audibility, weighting or health significance.

34.34 Final operational doctrine

The sub-20 Hz workstream is comprehensive in measurement and conservative in interpretation. It expands the inspection beyond ordinary radio receivers and recognises that slow pressure, vibration, electric and magnetic phenomena can influence the noise floor, mimic device timing, reveal machinery or service paths, and in some circumstances create exposure questions. It also recognises that the scientific and clinical literature does not support a catalogue in which each frequency reliably produces a particular emotion, vision, seizure, glandular response or diplomatic-site syndrome.

The examiner therefore proceeds in the manner already required throughout EERF: slowly, deliberately, silently, with contemporaneous paper and digital records, stable geometry, common time, independent controls, repeat measurements and bounded language. The purpose is not to make the most dramatic story fit the trace. It is to discover which physical quantity changed, where it changed, what else changed with it, and which explanations survived an exacting attempt to disprove them.

Chapter Glossary

Terms used in Chapter 41.

A

ACCELEROMETER — A device that measures the acceleration to which it is subjected and develops a signal proportional to it.

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

CURRENT — The movement of electrons past a reference point. The passage of electrons through a conductor.

F

FERROMAGNETIC MATERIAL — A highly magnetic material, such as iron, cobalt, nickel, or their alloys.

FLUX DENSITY — The number of magnetic lines of force passing through a given area.

L

LOW FREQUENCY — The band of frequencies from 30 kHz to 300 kHz.

M

MAGNETIC FIELD — (1) The region in which the magnetic forces created by a permanent magnet or by a current-carrying conductor or coil can be detected. (2) The field that is produced when current flows through a conductor or antenna.

V

VERY LOW FREQUENCY — The band of frequencies from 3 kilohertz to 30 kilohertz.

W

WAVELENGTH — The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

35. Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis

This chapter establishes a controlled, frequency-ordered method for detecting and localising timing families associated with inexpensive digital and analogue electronics, communications devices, recorders, sensors, low-power transmitters and other authorised subjects of inspection. Its purpose is defensive and metrological.

The chapter does not treat a familiar frequency as proof of a particular device, nor does it presume that every listed value is the mechanical resonance of a quartz element. The same numerical value may represent a passive crystal, a ceramic resonator, a MEMS oscillator, a complete XO or TCXO module, a PLL reference, a divided output, a buffered system clock, a periodic interrupt, a modulation cadence or a distributor search-filter entry.

The following integration extends 35. Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis with saw resonators as emission signatures and diagnostic components. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

SAW Resonators as Emission Signatures and Diagnostic Components

The measurement problem for One-port SAW resonator physics begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records center frequency, insertion loss, motional admittance, loaded Q, antiresonance, temperature shift, and package parasitics. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A rigorous procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are fixture capacitance, ESD damage, aging, mounting stress, source/load mismatch, and spurious acoustic modes.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to one-port saw resonator physics within saw resonators as emission signatures and diagnostic components, with the local volume retaining ownership of the final inference.

Uncertainty analysis for Package-dependent behavior must include both numerical error and model uncertainty. Numerical uncertainty arises from calibration, resolution, repeatability, positioning, timing, and noise; model uncertainty arises when the wrong source, path, boundary condition, or causal mechanism has been assumed. Relevant failure mechanisms include substituting package families on frequency alone, ignoring board layout, poor grounding, and mechanically induced frequency pulling.

A mature report distinguishes random variation, systematic bias, and epistemic uncertainty, then shows which term dominates the conclusion. Sensitivity analysis should test whether a plausible change in an uncertain input reverses the decision or merely changes its margin. When the evidence supports several explanations, the report should retain competing hypotheses and state what additional observation would discriminate among them.

That is preferable to burying uncertainty in a generic caveat, because decision makers need to know whether confidence is limited by instrument performance, missing access, incomplete source material, or a fundamentally nonunique inverse problem. In this placement, that control is applied specifically to package-dependent behavior within saw resonators as emission signatures and diagnostic components, with the local volume retaining ownership of the final inference.

Uncertainty analysis for Frequency-family recognition must include both numerical error and model uncertainty. Numerical uncertainty arises from calibration, resolution, repeatability, positioning, timing, and noise; model uncertainty arises when the wrong source, path, boundary condition, or causal mechanism has been assumed.

Relevant failure mechanisms include frequency coincidence, multiple vendors, local oscillators at related frequencies, image responses, and channelized interferers. A mature report distinguishes random variation, systematic bias, and epistemic uncertainty, then shows which term dominates the conclusion. Sensitivity analysis should test whether a plausible change in an uncertain input reverses the decision or merely changes its margin. Where the evidence supports several explanations, the report should retain competing hypotheses and state what additional observation would discriminate among them.

This is preferable to burying uncertainty in a generic caveat, because decision makers need to know whether confidence is limited by instrument performance, missing access, incomplete source material, or a fundamentally nonunique inverse problem. In this placement, that control is applied specifically to frequency-family recognition within saw resonators as emission signatures and diagnostic components, with the local volume retaining ownership of the final inference.

Validation of ESD and latent damage requires a control structure proportionate to the consequence of the claim. A minimum credible suite includes ESD-controlled handling, reference-device comparison, low-drive characterization, microscopy where justified, and accelerated thermal observation. These controls test different parts of the inference: some verify the instrument, some challenge the proposed mechanism, and some test whether the observation recurs under changed geometry, state, or examiner. Validation should be prospective wherever possible, with acceptance criteria defined before the result is known.

Negative and null results belong in the evidence package because they delimit the conditions under which the effect appears. When the source is a historical report, commercial datasheet, or public-release standard, validation also includes checking edition, page image, units, and current applicability.

A conclusion that survives independent methods and adversarial controls is stronger than one supported by repeated measurements from the same chain, because repeated use of one chain can reproduce the same hidden bias. In this placement, that control is applied specifically to esd and latent damage within saw resonators as emission signatures and diagnostic components, with the local volume retaining ownership of the final inference.

The measurement problem for Forensic localization of resonant components begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records near-field amplitude, phase, harmonic relation, startup timing, response to shielding or detuning, and correlation with device power states. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state.

A rigorous procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are probe loading, reradiation from cables, receiver overload, unrelated carriers, and thermal drift.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to forensic localization of resonant components within saw resonators as emission signatures and diagnostic components, with the local volume retaining ownership of the final inference.

This integrated treatment returns the discussion to 35. Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

The following integration extends 35. Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis with crystal frequency ecology, clock trees, and forensic signatures. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Crystal Frequency Ecology, Clock Trees, and Forensic Signatures

The measurement problem for Standard microcontroller frequencies begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records fundamental and harmonics, PLL multiplication, clock gating, duty cycle, startup sequence, spread spectrum, and peripheral activity. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A rigorous procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are aliasing, frequency division, multiple oscillators, clock-domain crossing, and board-level reradiation.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to standard microcontroller frequencies within crystal frequency ecology, clock trees, and forensic signatures, with the local volume retaining ownership of the final inference.

The measurement problem for Procurement ecology as prior information begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records stock frequency, package, tolerance, stability, load capacitance, temperature grade, and lifecycle status. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A rigorous procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are dynamic web content, incomplete snapshots, obsolete listings, vendor relabeling, and supply-chain substitution.

Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading. The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to procurement ecology as prior information within crystal frequency ecology, clock trees, and forensic signatures, with the local volume retaining ownership of the final inference.

Validation of Procurement ecology as prior information requires a control structure proportionate to the consequence of the claim. A minimum credible suite includes archive the exact source, date, and page; corroborate with manufacturer data and physical inspection; preserve part markings. These controls test different parts of the inference: some verify the instrument, some challenge the proposed mechanism, and some test whether the observation recurs under changed geometry, state, or examiner. Validation should be prospective wherever possible, with acceptance criteria defined before the result is known. Negative and null results belong in the evidence package because they delimit the conditions under which the effect appears.

When the source is a historical report, commercial datasheet, or public-release standard, validation also includes checking edition, page image, units, and current applicability. A conclusion that survives independent methods and adversarial controls is stronger than one supported by repeated measurements from the same chain, because repeated use of one chain can reproduce the same hidden bias. In this placement, that control is applied specifically to procurement ecology as prior information within crystal frequency ecology, clock trees, and forensic signatures, with the local volume retaining ownership of the final inference.

This integrated treatment returns the discussion to 35. Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

The central operational proposition is that a timing source should be approached as a family of related observables. The fundamental may be weak, magnetically confined, heavily filtered or situated within a high environmental noise floor. A harmonic, divider product, reference spur, sideband, buffered copy or cable-borne common-mode current may therefore provide the clearest spatial gradient.

The examiner shall exploit that possibility without confusing detectability with identity. Every reported family must survive common-drift analysis, state correlation, geometry controls, receiver reconfiguration and independent confirmation.

35.1 Device classes and terminology

A quartz crystal unit is a passive piezoelectric resonator. It requires an active circuit to sustain oscillation. A ceramic resonator performs a related function with generally lower precision and wider tolerance.

An oscillator module combines the resonator and sustaining electronics, and may provide a sine, clipped-sine, CMOS, LVDS, LVPECL or other logic output.

A TCXO adds temperature compensation, a VCXO adds voltage control, and an OCXO adds temperature-controlled enclosure regulation.

MEMS oscillators and silicon clock generators may produce the same nominal frequencies without a quartz element. Programmable PLLs and fractional-N synthesisers may distribute multiple clocks from one reference and may produce fractional spurs that are not integer harmonics of the final carrier.

A fundamental-frequency crystal is designed to operate principally at its lowest intended mechanical mode. An overtone crystal is engineered to operate at a selected higher mechanical mode, commonly an odd overtone. This distinction matters. A line at three times a candidate frequency may be an electrical third harmonic, an intended overtone mode, a multiplied reference or an unrelated source. The report shall use the neutral term candidate family member until the generating mechanism has been tested.

Table 35-1. Implementation classes and characteristic forensic implications

Implementation class	Characteristic behaviour	Forensic implication
Tuning-fork quartz crystal	Low-frequency, high-Q resonator, commonly 32.768 kHz; drive level and load capacitance affect frequency and start-up.	Use narrow windows after broad discovery. Examine temperature drift, harmonics, divider products and sleep-state persistence.
AT-cut or other MHz quartz crystal	Fundamental or overtone operation, usually with ppm-class tolerance and low phase noise.	Search the nominal frequency, tolerance window, harmonics, PLL products and buffered clock copies.
Ceramic resonator	Lower cost and generally wider tolerance than precision quartz. Often used in inexpensive microcontroller products.	Use wider search windows and do not infer a quartz crystal merely from a nominal value such as 16 MHz.
XO / SPXO module	Self-contained oscillator with logic or sine output. Output buffer edges can produce a rich harmonic series.	Harmonics may be substantially easier to detect than the internal resonator waveform.
TCXO / VCXO / OCXO	Compensated, tunable or oven-controlled oscillator with improved stability or controllability.	Expect narrower drift, but account for control-voltage modulation, warm-up, holdover and pulling.
MEMS oscillator	Silicon or micromechanical timing source, often programmable and robust against shock.	A nominal crystal-like frequency does not prove quartz. Search supply-current signatures, PLL spurs and digital output harmonics.
PLL / clock generator	Produces one or more outputs from a reference through integer or fractional multiplication and division.	Map reference, VCO, output, divider, beat and fractional-spur families. Integer harmonic analysis alone is insufficient.

Implementation class	Characteristic behaviour	Forensic implication
Divided timing output	A low-rate output generated from a higher-frequency parent, such as 1 Hz from 32.768 kHz.	Search parent and descendant frequencies. Establish shared drift and state transitions.
Periodic interrupt or wake cadence	A software or hardware event interval, not necessarily a continuous spectral line.	Use long time records, event detection and duty-cycle analysis rather than a narrow CW assumption.
Distributor filter token	A catalogue search value that may represent discontinued, inactive, zero-stock or specialised products.	Preserve provenance, but do not equate category presence or stock count with field prevalence.

35.2 Canonical corrections and bounded use statements

- 32.768 kHz equals 32,768 Hz, which is 2^15 Hz. A 15-stage binary divider can therefore yield a one-second interval. The expression “215 Hz” is a typographical loss of the exponent and shall not be reproduced.
- The UART reference is 1.8432 MHz. The value 1.8342 MHz is a transposition error. In a conventional 16-times oversampling relationship, 1.8432 MHz divided by 16 yields 115.2 kHz, and further integer division yields familiar serial rates.
- A 16 MHz reference is common in low-cost microcontroller products, but it may be provided by quartz, ceramic resonance, a MEMS oscillator, an internal RC oscillator or a PLL. Its presence is not unique to any Arduino, Zigbee or Bluetooth implementation.
- A 19.2 MHz reference is documented in numerous mobile and wireless platforms, frequently alongside a 32.768 kHz sleep-clock domain. It is not universal across all cellular generations or manufacturers.
- A 23.104 MHz reference is documented in some GPS receiver front ends and modules. It shall be described as an implementation-specific GNSS candidate, not as the GPS reference frequency.

- A 27.12 MHz reference may be divided to 13.56 MHz in RFID or NFC circuitry and may also appear in other ISM-related or embedded systems. The integer relationship is a search hypothesis only.
- The 100 MHz and 122.88 MHz entries are common high-rate logic, networking, data-converter and coherent-radio clock values. They require stringent rejection of test-equipment, network-infrastructure and receiver-generated spurs.
- Sub-hertz and hertz-rate entries are ordinarily divided outputs, event cadences, modulation envelopes or catalogue tokens. A standard RF spectrum analyser may not measure them directly. DC-coupled electric, magnetic, pressure or motion channels and long observation intervals are required.

35.3 Why the harmonic may be easier to detect than the fundamental

The sustaining loop of a crystal oscillator may contain a waveform approaching a sinusoid, yet the clock delivered to digital logic is commonly clipped, squared, level-shifted or buffered. Rapid edges contain Fourier energy at higher orders. A symmetrical square wave emphasises odd harmonics, while duty-cycle error, asymmetrical drive, rectification, supply modulation and nonlinear loading introduce even harmonics and intermodulation products.

The physical circuit then selects which members escape. A short conductor that is electromagnetically negligible at 32.768 kHz may couple more effectively at 327.68 kHz, 3.2768 MHz or a still higher family member. A cable shield, seam, connector, ground return or enclosure aperture can similarly favour one order over another.

Receiver conditions also change with frequency. The environmental magnetic-noise floor is often severe at the fundamental of a low-frequency clock, while a higher harmonic may fall within a quieter band and within the efficient range of a smaller loop, electric-field probe or conventional RF antenna. Conversely, dielectric loss, conductor loss, filtering and limited edge rate may attenuate higher orders. The protocol therefore measures the family rather than assuming which order must dominate.

A candidate is accepted as a coherent harmonic family only when the observed frequency ratio agrees within the combined uncertainty and the members exhibit compatible fractional drift, start-stop behaviour, burst cadence, modulation sidebands and spatial response. A mere numerical coincidence between two spectral lines is insufficient. The examiner shall repeat the acquisition with an independent reference, altered sample rate, altered resolution bandwidth, alternate probe geometry and a terminated-input or dummy-probe control.

Equation 35-1. Harmonic-family model

For an ideal integer harmonic, $f_n = n f_0$, where f_0 is the measured fundamental in hertz, n is a positive integer and f_n is the expected nth harmonic in hertz. This chapter lists H2 through H11. The residual $r_n = f_{measured,n} - n f_{measured,0}$ shall be compared with the combined frequency uncertainty, drift during the record and any known modulation or pulling. The ratio alone does not establish common origin.

35.4 Frequency-sorted candidate register

Table 35-2 preserves every distinct supplied frequency, orders the values numerically and states the bounded interpretation that shall accompany its use. The “numerical value in hertz” column supports sorting and computation. It does not convert a catalogue token into a verified component.

Table 35-2. Candidate clock, crystal, resonator, module and divided-output frequencies

Supplied frequency	Numerical value (Hz)	Implementation class or representative use	Search and interpretation note
0 Hz	0	DC, static state or catalogue filter token	Not an oscillatory frequency. Record offset, drift, state changes and very-slow trends. Harmonics are not applicable.
0.125 Hz	0.125	Divided timer or eight-second event cadence	Requires long DC-coupled records. Treat as an output cadence or modulation envelope unless a specific divided-frequency module is documented.
0.64 Hz	0.64	Divided timer or 1.5625-second event cadence	Search as a periodic envelope, housekeeping process or divided output. Do not assume a quartz element resonates mechanically at this rate.
1 Hz	1	RTC tick, one-pulse-per-second or divided clock	A common terminal output from 32.768 kHz RTC chains and GNSS timing devices. Confirm relation to a higher-frequency parent.
2 Hz	2	Divided timing output or periodic state machine	Use long observation and state correlation. Check for parent clocks and harmonics.
3 Hz	3	Divided timing output or slow modulation	May represent an event cadence, beacon envelope or control loop. Frequency alone is non-specific.
4 Hz	4	Divided timing output or periodic state machine	Commonly obtainable by binary division. Check coherence with 32.768 kHz, 1.024 kHz or other parent families.
6 Hz	6	Divided timing output or slow modulation	Treat as an envelope or task cadence and distinguish it from vibration and geophysical activity.

Supplied frequency	Numerical value (Hz)	Implementation class or representative use	Search and interpretation note
7 Hz	7	Divided or synthesised low-rate output	Not a preferred binary division product. Require direct evidence of the generating process.
10 Hz	10	Periodic control, wake cycle or low-rate modulation	Use DC-coupled channels and compare electric, magnetic, pressure and motion domains.
12.288 Hz	12.288	Catalogue filter value or divided clock output	Preserve exactly as supplied. Do not silently reinterpret it as 12.288 MHz.
13.56 Hz	13.56	Catalogue filter value or divided clock output	Preserve exactly as supplied. It is numerically distinct from the 13.56 MHz ISM and RFID family.
16 Hz	16	Binary-divided timer output	A plausible low-rate descendant of 32.768 kHz. Confirm common drift, phase or state change.
16 kHz	16000	Low-frequency crystal, resonator, audio or control timing candidate	Search with magnetic bars, loops and electric-field probes. Compare against audio converters, switching supplies and ultrasonic controls.
20 kHz	20000	Low-frequency crystal, ceramic-resonator or switching candidate	Near the upper audio boundary. Separate airborne acoustic energy from electrical timing leakage.
24 kHz	24000	Low-frequency timing or converter candidate	May be a clock, switching rate, audio-family rate or divided output. Apply source-state controls.
25.6 kHz	25600	Binary-related low-frequency timing candidate	Compatible with exact digital division families. Search harmonics and subharmonics.
26.667 kHz	26667	Catalogue frequency or synthesised timing candidate	Use a tolerance window. The displayed value may be rounded and should not be treated as an exact physical constant.

Supplied frequency	Numerical value (Hz)	Implementation class or representative use	Search and interpretation note
28 kHz	28000	Low-frequency resonator, control or switching candidate	Compare against ultrasonic systems, power electronics and alarm or access-control equipment.
30.72 kHz	30720	Digital timing or divided-rate candidate	A decimal/binary-related value that may arise from divider chains. Confirm by family relationships.
31.20 kHz	31200	Low-frequency timing candidate	Preserve the supplied two-decimal notation in provenance records. Search around tolerance and drift.
31.25 kHz	31250	Binary-related timing candidate	May arise from exact division of MHz-class references. Search parent and descendant frequencies.
31.999 kHz	31999	Near-32 kHz catalogue or tolerance candidate	Broader 32 kHz family.
32 kHz	32000	Nominal low-frequency oscillator or divided clock	Do not conflate with 32.768 kHz. Search both exact families and their harmonics.
32.768 kHz	32768	Tuning-fork quartz RTC and low-power sleep clock	Exactly 2^15 Hz. A 15-stage binary divider can produce a 1 Hz output. Search the fundamental, divider products and higher harmonics.
1.8432 MHz	1843200	UART and serial-communications reference family	Supports exact standard baud-rate division in many architectures. Correct value is 1.8432 MHz, not 1.8342 MHz.
8 MHz	8000000	Microcontroller, serial, radio or system reference	Common but non-unique. It may be a crystal, ceramic resonator, MEMS oscillator, divided PLL clock or internal RC output.
12 MHz	12000000	USB, microcontroller and system reference family	Common in full-speed USB and embedded designs, but implementation is platform-specific.

Supplied frequency	Numerical value (Hz)	Implementation class or representative use	Search and interpretation note
16 MHz	16000000	Microcontroller and embedded-system reference family	Used by numerous low-cost systems. Some boards use a ceramic resonator rather than a quartz crystal, so stability and harmonic structure vary.
19.200 MHz	19200000	Cellular, application-processor and wireless reference family	Documented as a principal reference in many mobile platforms. Often accompanied by a 32.768 kHz sleep-clock domain.
23.104 MHz	23104000	Legacy or specialised GPS receiver reference family	Documented in some GPS front ends and modules. It is not a universal GNSS reference frequency.
24 MHz	24000000	Microcontroller, USB and wireless-system reference family	Common platform clock. Search PLL products, interface clocks and state-dependent leakage.
25 MHz	25000000	Ethernet PHY, networking and system reference family	A widespread reference value. Its presence is not probative without localisation and state correlation.
27.12 MHz	27120000	RFID, NFC, ISM-related and system reference family	Some 13.56 MHz RFID devices accept 27.12 MHz and divide it. Treat the relationship as a testable family, not an attribution.
32 MHz	32000000	Bluetooth Low Energy, wireless SoC and embedded reference family	Common in low-power radios and microcontrollers, but vendor-dependent. Search sleep-state transitions and PLL descendants.
40 MHz	40000000	Wireless, networking and embedded reference family	Common in Wi-Fi, Ethernet and radio designs. Verify device state, harmonic family and spatial gradient.
48 MHz	48000000	USB and microcontroller system-clock family	Often generated directly or by PLL multiplication. Search 12 MHz and 24 MHz parent relationships where appropriate.

Supplied frequency	Numerical value (Hz)	Implementation class or representative use	Search and interpretation note
100 MHz	100000000	Digital logic, networking, test and sampling-clock family	Very common in legitimate equipment. Require stringent instrument-spur and environmental controls.
122.88 MHz	122880000	Telecommunications, RF data-converter and coherent-radio clock family	Common in radio and JESD204-class clock trees.

35.5 Band allocation and sensor selection

Table 35-3. Measurement architecture by candidate-frequency band

Band	Principal sensors	Acquisition requirement	Frequent confounders
0 Hz to below 0.01 Hz	DC-coupled fluxgate, guarded electric-field probe, electrode or conductor-potential channel where authorised, environmental references.	Records of hours to weeks; offset, drift and trend characterisation; no ordinary AC coupling.	Thermal drift, battery drift, electrochemistry, sensor tilt, geomagnetic variation, building movement.
0.01 Hz to 20 Hz	Fluxgate, induction coil where sensitivity permits, microbarometer, accelerometer or seismometer, guarded electric-field channel.	Long records with common time base and cross-domain coherence. Establish whether the phenomenon is electrical, magnetic, acoustic or mechanical.	Weather, microseisms, lifts, pumps, fans, transport, biological movement and instrument 1/f noise.

Band	Principal sensors	Acquisition requirement	Frequent confounders
16 kHz to 100 kHz	High-permeability bar probes, tuned loops, electric-field probes, differential cable-current probes.	Broad discovery followed by resonant confirmation. Record probe transfer function and loaded Q.	Switch-mode supplies, ultrasonic controls, lighting, audio converters, receiver clocks.
100 kHz to 3 MHz	Ferrite or nanocrystalline bars where qualified, air-core loops, electric-field probes and cable-current probes.	Use multiple probe materials and geometries because permeability and winding self-resonance become limiting.	Broadcast, powerline communications, switching supplies, instrument local oscillators.
3 MHz to 30 MHz	Air-core loops, shielded near-field probes, active electric-field probes and broadband receiving antennas.	Simultaneous X-Y-Z capture. Search fundamentals, harmonics, reference spurs and conducted paths.	HF communications, computers, displays, Ethernet, power electronics and test equipment.
30 MHz to 700 MHz	Calibrated loops, biconical or log-periodic antennas, monopoles and near-field E/H probes.	Nine-path or larger common-timebase array with phase and group-delay calibration.	Broadcast, land mobile, paging, cellular, wireless microphones and analyser images.
700 MHz to 1.36 GHz for listed harmonics	Log-periodic, ridged-horn or other calibrated broadband antennas and near-field probes.	Preselection and overload control. Confirm high-order clock-family members by common drift and state change.	Cellular, GNSS, ISM, aviation, radar and high-rate digital equipment.

Fundamental	Harmonic order	Calculated harmonic frequency
0.125 Hz	H2	0.25 Hz
0.125 Hz	H3	0.375 Hz
0.125 Hz	H4	0.5 Hz
0.125 Hz	H5	0.625 Hz
0.125 Hz	H6	0.75 Hz
0.125 Hz	H7	0.875 Hz
0.125 Hz	H8	1 Hz
0.125 Hz	H9	1.125 Hz
0.125 Hz	H10	1.25 Hz
0.125 Hz	H11	1.375 Hz
0.64 Hz	H2	1.28 Hz
0.64 Hz	H3	1.92 Hz
0.64 Hz	H4	2.56 Hz
0.64 Hz	H5	3.2 Hz
0.64 Hz	H6	3.84 Hz
0.64 Hz	H7	4.48 Hz
0.64 Hz	H8	5.12 Hz
0.64 Hz	H9	5.76 Hz
0.64 Hz	H10	6.4 Hz
0.64 Hz	H11	7.04 Hz
1 Hz	H2	2 Hz
1 Hz	H3	3 Hz
1 Hz	H4	4 Hz
1 Hz	H5	5 Hz
1 Hz	H6	6 Hz
1 Hz	H7	7 Hz
1 Hz	H8	8 Hz
1 Hz	H9	9 Hz
1 Hz	H10	10 Hz
1 Hz	H11	11 Hz

Fundamental	Harmonic order	Calculated harmonic frequency
2 Hz	H2	4 Hz
2 Hz	H3	6 Hz
2 Hz	H4	8 Hz
2 Hz	H5	10 Hz
2 Hz	H6	12 Hz
2 Hz	H7	14 Hz
2 Hz	H8	16 Hz
2 Hz	H9	18 Hz
2 Hz	H10	20 Hz
2 Hz	H11	22 Hz
3 Hz	H2	6 Hz
3 Hz	H3	9 Hz
3 Hz	H4	12 Hz
3 Hz	H5	15 Hz
3 Hz	H6	18 Hz
3 Hz	H7	21 Hz
3 Hz	H8	24 Hz
3 Hz	H9	27 Hz
3 Hz	H10	30 Hz
3 Hz	H11	33 Hz
4 Hz	H2	8 Hz
4 Hz	H3	12 Hz
4 Hz	H4	16 Hz
4 Hz	H5	20 Hz
4 Hz	H6	24 Hz
4 Hz	H7	28 Hz
4 Hz	H8	32 Hz
4 Hz	H9	36 Hz
4 Hz	H10	40 Hz

Fundamental	Harmonic order	Calculated harmonic frequency
4 Hz	H11	44 Hz
6 Hz	H2	12 Hz
6 Hz	H3	18 Hz
6 Hz	H4	24 Hz
6 Hz	H5	30 Hz
6 Hz	H6	36 Hz
6 Hz	H7	42 Hz
6 Hz	H8	48 Hz
6 Hz	H9	54 Hz
6 Hz	H10	60 Hz
6 Hz	H11	66 Hz
7 Hz	H2	14 Hz
7 Hz	H3	21 Hz
7 Hz	H4	28 Hz
7 Hz	H5	35 Hz
7 Hz	H6	42 Hz
7 Hz	H7	49 Hz
7 Hz	H8	56 Hz
7 Hz	H9	63 Hz
7 Hz	H10	70 Hz
7 Hz	H11	77 Hz
10 Hz	H2	20 Hz
10 Hz	H3	30 Hz
10 Hz	H4	40 Hz
10 Hz	H5	50 Hz
10 Hz	H6	60 Hz
10 Hz	H7	70 Hz
10 Hz	H8	80 Hz
10 Hz	H9	90 Hz

Fundamental	Harmonic order	Calculated harmonic frequency
10 Hz	H10	100 Hz
10 Hz	H11	110 Hz
12.288 Hz	H2	24.576 Hz
12.288 Hz	H3	36.864 Hz
12.288 Hz	H4	49.152 Hz
12.288 Hz	H5	61.44 Hz
12.288 Hz	H6	73.728 Hz
12.288 Hz	H7	86.016 Hz
12.288 Hz	H8	98.304 Hz
12.288 Hz	H9	110.592 Hz
12.288 Hz	H10	122.88 Hz
12.288 Hz	H11	135.168 Hz
13.56 Hz	H2	27.12 Hz
13.56 Hz	H3	40.68 Hz
13.56 Hz	H4	54.24 Hz
13.56 Hz	H5	67.8 Hz
13.56 Hz	H6	81.36 Hz
13.56 Hz	H7	94.92 Hz
13.56 Hz	H8	108.48 Hz
13.56 Hz	H9	122.04 Hz
13.56 Hz	H10	135.6 Hz
13.56 Hz	H11	149.16 Hz
16 Hz	H2	32 Hz
16 Hz	H3	48 Hz
16 Hz	H4	64 Hz
16 Hz	H5	80 Hz
16 Hz	H6	96 Hz
16 Hz	H7	112 Hz
16 Hz	H8	128 Hz

Fundamental	Harmonic order	Calculated harmonic frequency
16 Hz	H9	144 Hz
16 Hz	H10	160 Hz
16 Hz	H11	176 Hz
16 kHz	H2	32 kHz
16 kHz	H3	48 kHz
16 kHz	H4	64 kHz
16 kHz	H5	80 kHz
16 kHz	H6	96 kHz
16 kHz	H7	112 kHz
16 kHz	H8	128 kHz
16 kHz	H9	144 kHz
16 kHz	H10	160 kHz
16 kHz	H11	176 kHz
20 kHz	H2	40 kHz
20 kHz	H3	60 kHz
20 kHz	H4	80 kHz
20 kHz	H5	100 kHz
20 kHz	H6	120 kHz
20 kHz	H7	140 kHz
20 kHz	H8	160 kHz
20 kHz	H9	180 kHz
20 kHz	H10	200 kHz
20 kHz	H11	220 kHz
24 kHz	H2	48 kHz
24 kHz	H3	72 kHz
24 kHz	H4	96 kHz
24 kHz	H5	120 kHz
24 kHz	H6	144 kHz
24 kHz	H7	168 kHz

Fundamental	Harmonic order	Calculated harmonic frequency
24 kHz	H8	192 kHz
24 kHz	H9	216 kHz
24 kHz	H10	240 kHz
24 kHz	H11	264 kHz
25.6 kHz	H2	51.2 kHz
25.6 kHz	H3	76.8 kHz
25.6 kHz	H4	102.4 kHz
25.6 kHz	H5	128 kHz
25.6 kHz	H6	153.6 kHz
25.6 kHz	H7	179.2 kHz
25.6 kHz	H8	204.8 kHz
25.6 kHz	H9	230.4 kHz
25.6 kHz	H10	256 kHz
25.6 kHz	H11	281.6 kHz
26.667 kHz	H2	53.334 kHz
26.667 kHz	H3	80.001 kHz
26.667 kHz	H4	106.668 kHz
26.667 kHz	H5	133.335 kHz
26.667 kHz	H6	160.002 kHz
26.667 kHz	H7	186.669 kHz
26.667 kHz	H8	213.336 kHz
26.667 kHz	H9	240.003 kHz
26.667 kHz	H10	266.67 kHz
26.667 kHz	H11	293.337 kHz
28 kHz	H2	56 kHz
28 kHz	H3	84 kHz
28 kHz	H4	112 kHz
28 kHz	H5	140 kHz
28 kHz	H6	168 kHz

Fundamental	Harmonic order	Calculated harmonic frequency
28 kHz	H7	196 kHz
28 kHz	H8	224 kHz
28 kHz	H9	252 kHz
28 kHz	H10	280 kHz
28 kHz	H11	308 kHz
30.72 kHz	H2	61.44 kHz
30.72 kHz	H3	92.16 kHz
30.72 kHz	H4	122.88 kHz
30.72 kHz	H5	153.6 kHz
30.72 kHz	H6	184.32 kHz
30.72 kHz	H7	215.04 kHz
30.72 kHz	H8	245.76 kHz
30.72 kHz	H9	276.48 kHz
30.72 kHz	H10	307.2 kHz
30.72 kHz	H11	337.92 kHz
31.20 kHz	H2	62.4 kHz
31.20 kHz	H3	93.6 kHz
31.20 kHz	H4	124.8 kHz
31.20 kHz	H5	156 kHz
31.20 kHz	H6	187.2 kHz
31.20 kHz	H7	218.4 kHz
31.20 kHz	H8	249.6 kHz
31.20 kHz	H9	280.8 kHz
31.20 kHz	H10	312 kHz
31.20 kHz	H11	343.2 kHz
31.25 kHz	H2	62.5 kHz
31.25 kHz	H3	93.75 kHz
31.25 kHz	H4	125 kHz
31.25 kHz	H5	156.25 kHz

Fundamental	Harmonic order	Calculated harmonic frequency
31.25 kHz	H6	187.5 kHz
31.25 kHz	H7	218.75 kHz
31.25 kHz	H8	250 kHz
31.25 kHz	H9	281.25 kHz
31.25 kHz	H10	312.5 kHz
31.25 kHz	H11	343.75 kHz
31.999 kHz	H2	63.998 kHz
31.999 kHz	H3	95.997 kHz
31.999 kHz	H4	127.996 kHz
31.999 kHz	H5	159.995 kHz
31.999 kHz	H6	191.994 kHz
31.999 kHz	H7	223.993 kHz
31.999 kHz	H8	255.992 kHz
31.999 kHz	H9	287.991 kHz
31.999 kHz	H10	319.99 kHz
31.999 kHz	H11	351.989 kHz
32 kHz	H2	64 kHz
32 kHz	H3	96 kHz
32 kHz	H4	128 kHz
32 kHz	H5	160 kHz
32 kHz	H6	192 kHz
32 kHz	H7	224 kHz
32 kHz	H8	256 kHz
32 kHz	H9	288 kHz
32 kHz	H10	320 kHz
32 kHz	H11	352 kHz
32.768 kHz	H2	65.536 kHz
32.768 kHz	H3	98.304 kHz
32.768 kHz	H4	131.072 kHz

Fundamental	Harmonic order	Calculated harmonic frequency
32.768 kHz	H5	163.84 kHz
32.768 kHz	H6	196.608 kHz
32.768 kHz	H7	229.376 kHz
32.768 kHz	H8	262.144 kHz
32.768 kHz	H9	294.912 kHz
32.768 kHz	H10	327.68 kHz
32.768 kHz	H11	360.448 kHz
1.8432 MHz	H2	3.6864 MHz
1.8432 MHz	H3	5.5296 MHz
1.8432 MHz	H4	7.3728 MHz
1.8432 MHz	H5	9.216 MHz
1.8432 MHz	H6	11.0592 MHz
1.8432 MHz	H7	12.9024 MHz
1.8432 MHz	H8	14.7456 MHz
1.8432 MHz	H9	16.5888 MHz
1.8432 MHz	H10	18.432 MHz
1.8432 MHz	H11	20.2752 MHz
8 MHz	H2	16 MHz
8 MHz	H3	24 MHz
8 MHz	H4	32 MHz
8 MHz	H5	40 MHz
8 MHz	H6	48 MHz
8 MHz	H7	56 MHz
8 MHz	H8	64 MHz
8 MHz	H9	72 MHz
8 MHz	H10	80 MHz
8 MHz	H11	88 MHz
12 MHz	H2	24 MHz
12 MHz	H3	36 MHz

Fundamental	Harmonic order	Calculated harmonic frequency
12 MHz	H4	48 MHz
12 MHz	H5	60 MHz
12 MHz	H6	72 MHz
12 MHz	H7	84 MHz
12 MHz	H8	96 MHz
12 MHz	H9	108 MHz
12 MHz	H10	120 MHz
12 MHz	H11	132 MHz
16 MHz	H2	32 MHz
16 MHz	H3	48 MHz
16 MHz	H4	64 MHz
16 MHz	H5	80 MHz
16 MHz	H6	96 MHz
16 MHz	H7	112 MHz
16 MHz	H8	128 MHz
16 MHz	H9	144 MHz
16 MHz	H10	160 MHz
16 MHz	H11	176 MHz
19.200 MHz	H2	38.4 MHz
19.200 MHz	H3	57.6 MHz
19.200 MHz	H4	76.8 MHz
19.200 MHz	H5	96 MHz
19.200 MHz	H6	115.2 MHz
19.200 MHz	H7	134.4 MHz
19.200 MHz	H8	153.6 MHz
19.200 MHz	H9	172.8 MHz
19.200 MHz	H10	192 MHz
19.200 MHz	H11	211.2 MHz
23.104 MHz	H2	46.208 MHz

Fundamental	Harmonic order	Calculated harmonic frequency
23.104 MHz	H3	69.312 MHz
23.104 MHz	H4	92.416 MHz
23.104 MHz	H5	115.52 MHz
23.104 MHz	H6	138.624 MHz
23.104 MHz	H7	161.728 MHz
23.104 MHz	H8	184.832 MHz
23.104 MHz	H9	207.936 MHz
23.104 MHz	H10	231.04 MHz
23.104 MHz	H11	254.144 MHz
24 MHz	H2	48 MHz
24 MHz	H3	72 MHz
24 MHz	H4	96 MHz
24 MHz	H5	120 MHz
24 MHz	H6	144 MHz
24 MHz	H7	168 MHz
24 MHz	H8	192 MHz
24 MHz	H9	216 MHz
24 MHz	H10	240 MHz
24 MHz	H11	264 MHz
25 MHz	H2	50 MHz
25 MHz	H3	75 MHz
25 MHz	H4	100 MHz
25 MHz	H5	125 MHz
25 MHz	H6	150 MHz
25 MHz	H7	175 MHz
25 MHz	H8	200 MHz
25 MHz	H9	225 MHz
25 MHz	H10	250 MHz
25 MHz	H11	275 MHz

Fundamental	Harmonic order	Calculated harmonic frequency
27.12 MHz	H2	54.24 MHz
27.12 MHz	H3	81.36 MHz
27.12 MHz	H4	108.48 MHz
27.12 MHz	H5	135.6 MHz
27.12 MHz	H6	162.72 MHz
27.12 MHz	H7	189.84 MHz
27.12 MHz	H8	216.96 MHz
27.12 MHz	H9	244.08 MHz
27.12 MHz	H10	271.2 MHz
27.12 MHz	H11	298.32 MHz
32 MHz	H2	64 MHz
32 MHz	H3	96 MHz
32 MHz	H4	128 MHz
32 MHz	H5	160 MHz
32 MHz	H6	192 MHz
32 MHz	H7	224 MHz
32 MHz	H8	256 MHz
32 MHz	H9	288 MHz
32 MHz	H10	320 MHz
32 MHz	H11	352 MHz
40 MHz	H2	80 MHz
40 MHz	H3	120 MHz
40 MHz	H4	160 MHz
40 MHz	H5	200 MHz
40 MHz	H6	240 MHz
40 MHz	H7	280 MHz
40 MHz	H8	320 MHz
40 MHz	H9	360 MHz
40 MHz	H10	400 MHz

Fundamental	Harmonic order	Calculated harmonic frequency
40 MHz	H11	440 MHz
48 MHz	H2	96 MHz
48 MHz	H3	144 MHz
48 MHz	H4	192 MHz
48 MHz	H5	240 MHz
48 MHz	H6	288 MHz
48 MHz	H7	336 MHz
48 MHz	H8	384 MHz
48 MHz	H9	432 MHz
48 MHz	H10	480 MHz
48 MHz	H11	528 MHz
100 MHz	H2	200 MHz
100 MHz	H3	300 MHz
100 MHz	H4	400 MHz
100 MHz	H5	500 MHz
100 MHz	H6	600 MHz
100 MHz	H7	700 MHz
100 MHz	H8	800 MHz
100 MHz	H9	900 MHz
100 MHz	H10	1 GHz
100 MHz	H11	1.1 GHz
122.88 MHz	H2	245.76 MHz
122.88 MHz	H3	368.64 MHz
122.88 MHz	H4	491.52 MHz
122.88 MHz	H5	614.4 MHz
122.88 MHz	H6	737.28 MHz
122.88 MHz	H7	860.16 MHz
122.88 MHz	H8	983.04 MHz
122.88 MHz	H9	1.10592 GHz

Fundamental	Harmonic order	Calculated harmonic frequency
122.88 MHz	H10	1.2288 GHz
122.88 MHz	H11	1.35168 GHz

Table 35-4. Harmonic ledger, H2 through H11, ordered by fundamental frequency

35.6 Fundamental and first ten harmonics

Table 35-4 provides the first ten harmonics after each non-zero fundamental, namely H2 through H11. The table is a search register, not a prediction that all orders will be present. Low-cost digital devices frequently reveal themselves most clearly through one or more higher orders, but absence of a listed order does not exclude the source. The actual distribution depends upon waveform symmetry, edge rate, loading, shielding, coupling geometry, probe transfer function and receiver noise.

35.7 Frequency tolerance, pulling, ageing and temperature

A nominal frequency is never a zero-width search instruction. The window shall include component initial tolerance, load-capacitance error, temperature coefficient, ageing, supply sensitivity, mechanical stress, control-voltage range, PLL reference error, modulation sidebands, Doppler where material, and the measurement system uncertainty. Tuning-fork crystals commonly exhibit a parabolic temperature characteristic about a turnover temperature. Ceramic resonators and internal RC oscillators may require windows orders of magnitude wider than a precision TCXO. The examiner shall use a documented component class or an empirically measured drift history rather than imposing one universal parts-per-million value.

Equation 35-2. Minimum half-width of a candidate search window

A conservative half-width may be expressed as $\Delta f\_search >= |f\_0|(|\varepsilon\_initial| + |\varepsilon\_temperature| + |\varepsilon\_ageing| + |\varepsilon\_control|) + \Delta f\_modulation + U\_f$, where each ε term is expressed as a fractional frequency error, Δf_modulation is the expected sideband or deviation allowance in hertz, and U_f is the expanded measurement uncertainty in hertz. Correlated terms shall not be summed as if independent. A formal uncertainty model shall state the chosen treatment.

Table 35-5. Practical search-window classes

Source class	Initial discovery window	Refinement after observation	Caution
Precision TCXO / OCXO	Manufacturer tolerance, control range and warm-up allowance plus measurement uncertainty.	Narrow around the observed line and track drift continuously.	Do not assume a precision source is benign or hostile from stability alone.
Commodity MHz quartz XO	Tens of ppm to the documented product limit, plus temperature and ageing.	Use measured drift and sideband structure.	Buffered outputs may produce many harmonics.
32.768 kHz tuning-fork crystal	Documented ppm range, load pulling and temperature parabola.	Track the fundamental and selected harmonics across temperature and state.	Nearby 32 kHz and 31.999 kHz entries are separate candidates.
Ceramic resonator	Wider, often tenths of a percent according to the specific component.	Refine from the observed centre and repeat after state changes.	Do not apply quartz-level ppm assumptions.
Internal RC or low-power silicon oscillator	Potentially percent-level or device-specified range.	Use state-dependent drift and family relations.	Frequency may vary strongly with voltage and temperature.

Source class	Initial discovery window	Refinement after observation	Caution
PLL / synthesised output	Reference tolerance plus divider and fractional-spur map.	Analyse reference, VCO, outputs and spur spacing together.	Final carrier need not be an integer harmonic of the reference.
Divided output or wake cadence	Time-domain interval tolerance and duty-cycle allowance.	Estimate period and phase from long records.	A short FFT may not resolve or even observe the event.

35.8 Sleep, standby and intermittent operation

The absence of a high-rate application clock does not establish that a device is de-energised. Real-time clocks, power-management controllers, embedded controllers, secure elements, battery management, charger logic, USB Type-C configuration detection, wake-on-LAN circuits, Bluetooth or Wi-Fi wake functions, cellular paging and discontinuous-reception logic may retain one or more timing domains.

A low-power reference can remain continuous, appear periodically for calibration, or awaken only when a timer expires. The examiner shall therefore record active, idle, standby, suspend, hibernation, soft-off and mechanically disconnected conditions where those states can be established lawfully and safely.

Intermittent timing families are detected by continuous common-timebase recording, pre-trigger memory and event detectors that operate on amplitude, spectral kurtosis, cyclostationarity, coherence or matched family features.

The event detector shall preserve the raw pre-event and post-event samples. A derived alarm is not a substitute for the underlying record. For a candidate that appears once per day, the commission may require weeks of sentinel monitoring rather than a faster sweep.

35.9 Ring-to-room search procedure for timing families

1. At the five-mile, 2.5-mile and one-mile annuli, inventory persistent clock-like carriers, coherent spurs and infrastructure references that might remain visible throughout the inward survey. These stations establish regional confounders, not premises attribution.

2. At the 0.5-mile, 0.25-mile and 300-foot stages, repeat the candidate windows with identical reference-clock discipline. Note whether the line strengthens, weakens or changes bearing in a manner compatible with the premises.

3. At 150, 100, 50, 30, 15 and 12 feet, deploy simultaneous X-Y-Z channels and at least one independent reference or control path. Compare magnetic, electric and cable-current coupling rather than relying upon received amplitude alone.

4. At the three-foot ring and three-inch lattice, retune the relevant resonant probe at each measurement point, allow settling, verify resonance, freeze the tuning state and acquire all channels at one common epoch.

5. For every candidate fundamental, search the H2-through-H11 register, relevant subharmonics, divider descendants, modulation sidebands, PLL reference spurs and nearby tolerance windows. Record which family member supplies the steepest reproducible spatial gradient.

6. Repeat the decisive measurements after probe substitution, receiver reconfiguration, reference-clock change or independent instrument confirmation. A source classification shall not rest upon one analyser architecture.

7. Withdraw along the reverse path and repeat selected stations. The family must exhibit temporal and spatial closure within uncertainty before it is advanced.

35.10 Common-timebase multichannel analysis

The normative electromagnetic record uses three orthogonal channels at each pod and three pods, providing nine simultaneous measurement paths, with additional reference, terminated-input and guard channels within the twelve-channel or larger chassis.

Every channel shares the master time base, frequency reference, trigger epoch and calibrated group-delay model. The low-frequency magnetic pod, the mid-frequency loop or electric-field pod and the higher-frequency broadband pod may occupy different physical architectures, yet their event times shall remain traceable to the same site epoch.

Table 35-6. Suggested channel allocation for clock-family work

Channels	Allocation	Purpose
1-3	Pod A, X-Y-Z	Simultaneous vector measurement at the first surveyed position.
4-6	Pod B, X-Y-Z	Spatial gradient, bearing and common-mode discrimination.
7-9	Pod C, X-Y-Z	Triangulation, field curvature and independent spatial comparison.
10	Environmental or infrastructure reference	Regional carrier, mains, vibration, pressure or known-equipment reference as appropriate.
11	Terminated input or dummy probe	Receiver-spur, clock breakthrough and analyser self-emission control.
12	Independent tracking receiver or guard channel	Narrowband confirmation, trigger generation or overload monitoring.
13-44 where fitted	Band-specific probe sets and sentinels	Concurrent low-frequency, intermediate-frequency and RF coverage without unsafe or non-deterministic switching.

35.11 Provenance-controlled distributor inventory snapshot

Table 35-7 reproduces the inventory observations supplied for this revision. It is intentionally described as a snapshot. Distributor stock changes continuously, several rows may represent overlapping category or substitute views, and a zero quantity can mean no immediate stock, factory availability, an inactive product, a category token or no qualifying result at the time of the search. The quantities shall not be summed, extrapolated or used as a threat-probability model.

Table 35-7. DigiKey frequency and inventory snapshot, retained as provenance

Frequency	Quantity shown	Status or product-class notation supplied
32.768 kHz	1,519	In stock
32.768 kHz	88,296	In stock
16 MHz	66,496	In stock
24 MHz	36,397	In stock
24 MHz	17,442	In stock
25 MHz	11,267	In stock
25 MHz	20,662	In stock
25 MHz	2,569	In stock
25 MHz	13,529	In stock
25 MHz	14,092	In stock
100 MHz	1,627	In stock
122.88 MHz	0	No stock / out of stock
0 Hz	0	Listed frequency filter; inactive-status coverage
0.64 Hz	0	Listed frequency filter; inactive-status coverage
1 Hz	0	Listed frequency filter; inactive-status coverage
2 Hz	0	Listed frequency filter; inactive-status coverage

Frequency	Quantity shown	Status or product-class notation supplied
3 Hz	0	Listed frequency filter; inactive-status coverage
4 Hz	0	Listed frequency filter; inactive-status coverage
6 Hz	0	Listed frequency filter; inactive-status coverage
7 Hz	0	Listed frequency filter; inactive-status coverage
10 Hz	0	Listed frequency filter; inactive-status coverage
12.288 Hz	0	Listed frequency filter; inactive-status coverage
13.56 Hz	0	Listed frequency filter; inactive-status coverage
16 Hz	0	Listed frequency filter; inactive-status coverage
16 kHz	0	Crystal listed-frequency filter; inactive-status coverage
20 kHz	0	Crystal listed-frequency filter; inactive-status coverage
24 kHz	0	Crystal listed-frequency filter; inactive-status coverage
25.6 kHz	0	Crystal listed-frequency filter; inactive-status coverage
26.667 kHz	0	Crystal listed-frequency filter; inactive-status coverage
28 kHz	0	Crystal listed-frequency filter; inactive-status coverage
30.72 kHz	0	Crystal listed-frequency filter; inactive-status coverage
31.2 kHz	0	Crystal listed-frequency filter; inactive-status coverage
31.25 kHz	0	Crystal listed-frequency filter; inactive-status coverage
31.999 kHz	0	Crystal listed-frequency filter; inactive-status coverage
32 kHz	0	Crystal listed-frequency filter; inactive-status coverage
32.768 kHz	13,655	Oscillator; in stock
32.768 kHz	97,449	Oscillator; in stock

Frequency	Quantity shown	Status or product-class notation supplied
32.768 kHz	32,198	Oscillator; in stock
32.768 kHz	21,795	Oscillator; in stock
32.768 kHz	18,151	Oscillator; in stock
32.768 kHz	920	Oscillator; in stock
32.768 kHz	227,401	Crystal; in stock
32.768 kHz	26,364	Crystal; in stock
32.768 kHz	2,445	Crystal; in stock
32.768 kHz	14,772	Crystal; in stock
32.768 kHz	2,974	Crystal; in stock
32.768 kHz	44,661	Crystal; in stock
32.768 kHz	0	Oscillator; available to order / not stocked
32.768 kHz	22,903	Crystal; in stock
32.768 kHz	646,924	Crystal; in stock
32.768 kHz	13,007	Crystal; in stock
32.768 kHz	1,519	Oscillator; in stock
32.768 kHz	2,041	Oscillator; immediate stock
32.768 kHz	564	Oscillator; immediate stock
32.768 kHz	757	Oscillator; immediate stock
32.768 kHz	719	Oscillator; immediate stock
32.768 kHz	0	Oscillator; immediate stock 0 / factory stock available
32.768 kHz	8,893	Crystal; in stock
32.768 kHz	4,187	Crystal substitute; in stock
32.768 kHz	1,746	Crystal substitute; in stock
32.768 kHz	68,846	Crystal substitute; in stock
32.768 kHz	29,117	Crystal substitute; in stock
32.768 kHz	10,540	Crystal substitute; in stock
32.768 kHz	2,406	Oscillator substitute; in stock

Note. This table records supplied procurement observations and is not represented as a live distributor query. Current availability must be checked directly at the date of procurement. Catalogue frequency descriptions can assist hypothesis generation, but they do not establish that a corresponding source exists within the inspected premises.

35.12 Artefact rejection and competing explanations

Clock searches are unusually vulnerable to self-contamination because the measurement system itself contains oscillators, ADC sample clocks, FPGA clocks, display refresh systems, Ethernet references, USB clocks, switching regulators, GPS-disciplined references and PLLs.

The complete spur map shall be measured with terminated inputs, dummy probes, changed sample rates, changed analyser centre frequencies, preselector changes, fibre isolation and, where feasible, a second architecture whose internal frequency plan is materially different.

A line that moves when the analyser sample rate or local oscillator changes is presumptively instrumental until proved otherwise.

- Receiver image, local-oscillator feedthrough and fractional-N spurs.
- ADC aliasing and FFT-bin leakage.
- Preamplifier oscillation, overload recovery and intermodulation.
- Varactor-bias ripple, tuning-control feedthrough and resonant-probe self-oscillation.
- USB, Ethernet, HDMI, DisplayPort, memory, storage and processor clocks within the analysis equipment.
- Switch-mode power supplies, LED lighting, building-management controls and alarm systems.

- Known mobile devices, chargers, network equipment, displays, cameras and laboratory instruments.
- Regional broadcast, cellular, aviation, satellite, navigation and industrial sources.
- Mechanical vibration or infrasound that shares a numerical frequency with a slow electrical cadence but not the same physical domain.

35.13 Evidential classification and reporting language

Table 35-8. Clock-family evidential classifications

Classification	Minimum basis	Permitted report language
Observed spectral or temporal component	Calibrated observation above the declared detection criterion.	A component was observed at the stated frequency, time, channel and uncertainty.
Candidate timing component	Frequency and waveform are compatible with a timing process, but alternatives remain.	The component is consistent with a timing or periodic process and is not uniquely identified.
Candidate harmonic or divider family	Two or more components have compatible ratios and shared behaviour within uncertainty.	The components form a candidate integer-related or divided family; common origin remains under test.
State-correlated timing family	The family follows a controlled or naturally observed device state reproducibly.	The family is correlated with the documented state change under the stated conditions.
Spatially localised timing family	Reproducible X-Y-Z gradients, nulls or phase relationships bound the source region.	The family is localised to the stated volume and uncertainty; the generating device is not yet identified.
Confirmed device-associated timing family	Localisation, lawful device examination or equivalent independent evidence, controls and uncertainty support association.	The measured family is associated with the identified device under the tested states. No broader functional or medical inference is made.

35.14 Ten worked engineering examples

35.14.1 Binary division of 32.768 kHz. 32,768 Hz equals 2^15 Hz. Fifteen successive divide-by-two stages yield 32,768 / 32,768 = 1 Hz. The result explains the frequency's utility for RTCs, but does not imply that every observed 1 Hz component originates from a 32.768 kHz crystal.

35.14.2 UART reference division. 1.8432 MHz equals 1,843,200 Hz. Dividing by 16 gives 115,200 Hz. Dividing by 32 gives 57,600 Hz, and dividing by 192 gives 9,600 Hz. These exact relationships make the reference useful in conventional UART architectures.

35.14.3 32.768 kHz harmonic landmarks. H2 is 65.536 kHz, H5 is 163.84 kHz, H10 is 327.68 kHz and H11 is 360.448 kHz. A probe may detect one of these more readily than the fundamental because the coupling path and receiver noise are frequency dependent.

35.14.4 19.2 MHz mobile-platform family. For a 19.2 MHz reference, H2 is 38.4 MHz, H4 is 76.8 MHz, H5 is 96 MHz and H10 is 192 MHz. Several values are themselves common system frequencies, so common drift and state correlation are essential to avoid false grouping.

35.14.5 23.104 MHz GPS-reference multiplication. A documented legacy GPS front end used 23.104 MHz with a multiplication relationship of 64, giving 1,478.656 MHz. The calculation illustrates how a low-level reference can organise a much higher RF process. It is not a universal GPS architecture.

35.14.6 27.12 MHz RFID-related division. Dividing 27.12 MHz by 2 gives 13.56 MHz, and dividing by 4 gives 6.78 MHz. Observing both values can justify a candidate family test, but does not by itself identify an RFID device.

35.14.7 PPM search window at 32.768 kHz. For a provisional plus-or-minus 50 ppm discovery allowance, the crystal-only contribution is 32,768 × 50 × 10^-6 =

1.6384 Hz. The preliminary window is therefore 32,766.3616 Hz to 32,769.6384 Hz before temperature, pulling, modulation and measurement uncertainty are added.

35.14.8 PPM search window at 100 MHz. Atplus — or — minus$\mathbf{25}$ppm,thenominaltolerancecontributionis$\mathbf{100,000,000} \times \mathbf{25} \times \mathbf{10^{-6}} = \mathbf{2,500}$Hz. A 99.9975 MHz to 100.0025 MHz preliminary window may still be inadequate if the source is modulated, synthesised, spread or thermally unstable.(23)

35.14.9 Observation length for 0.125 Hz. Ten cycles require 80 seconds, while a defensible drift or intermittency study may require hours. A brief swept display cannot characterise the process.

35.14.10 Common fractional drift test. Suppose a candidate fundamental changes from 32,768.000 Hz to 32,768.328 Hz, a fractional change of approximately 10 ppm. A genuine H10 member should change from 327,680.000 Hz to approximately 327,683.280 Hz, subject to uncertainty and modulation. A materially different fractional change argues against a simple common source.

32, 768 Hz equals 2^15 Hz. Fifteen successive divide-by-two stages yield 32, 768 / 32, 768 = 1 Hz. The result explains the frequency's utility for RTCs, but does not imply that every observed 1 Hz component originates from a 32. 768 kHz crystal.

1. 8432 MHz equals 1, 843, 200 Hz. Dividing by 16 gives 115, 200 Hz. Dividing by 32 gives 57, 600 Hz, and dividing by 192 gives 9, 600 Hz. These exact relationships make the reference useful in conventional UART architectures.

H2 is 65. 536 kHz, H5 is 163. 84 kHz, H10 is 327. 68 kHz and H11 is 360. 448 kHz. A probe may detect one of these more readily than the fundamental because the coupling path and receiver noise are frequency dependent.

For a 19. 2 MHz reference, H2 is 38. 4 MHz, H4 is 76. 8 MHz, H5 is 96 MHz and H10 is 192 MHz. Several values are themselves common system frequencies, so common drift and state correlation are essential to avoid false grouping.

A documented legacy GPS front end used 23. 104 MHz with a multiplication relationship of 64, giving 1, 478. 656 MHz. The calculation illustrates how a low-level reference can organise a much higher RF process. It is not a universal GPS architecture.

Dividing 27. 12 MHz by 2 gives 13. 56 MHz, and dividing by 4 gives 6. 78 MHz. Observing both values can justify a candidate family test, but does not by itself identify an RFID device.

For a provisional plus-or-minus 50 ppm discovery allowance, the crystal-only contribution is 32, 768 × 50 × 10^-6 = 1. 6384 Hz. The preliminary window is therefore 32, 766. 3616 Hz to 32, 769. 6384 Hz before temperature, pulling, modulation and measurement uncertainty are added.

Atplus-or-minus25ppm, thenominaltolerancecontributionis100, 000, 000×25×10-6=2, 500Hz. A 99. 9975 MHz to 100. 0025 MHz preliminary window may still be inadequate if the source is modulated, synthesised, spread or thermally unstable.

Suppose a candidate fundamental changes from 32, 768. 000 Hz to 32, 768. 328 Hz, a fractional change of approximately 10 ppm. A genuine H10 member should change from 327, 680. 000 Hz to approximately 327, 683. 280 Hz, subject to uncertainty and modulation. A materially different fractional change argues against a simple common source.

35.15 Validation and acceptance requirements

1. Construct traceable reference sources at representative low, medium and high candidate frequencies, including 32.768 kHz, 1.8432 MHz, 16 MHz, 19.2 MHz, 27.12 MHz, 100 MHz and 122.88 MHz.

2. Measure fundamental and harmonic transfer functions for every probe, preamplifier, cable, digitiser and channel combination. Do not infer harmonic sensitivity from the fundamental calibration.

3. Challenge the method with quartz, ceramic, MEMS, RC and PLL sources whose nominal frequencies overlap.

4. Quantify probability of detection and false alarm across source power, distance, orientation, shielding, duty cycle, sleep state and environmental noise.

5. Test whether common fractional drift and state-correlation criteria correctly group genuine families and reject unrelated coincident lines.

6. Perform analyser self-emission, alias, overload, intermodulation, sample-rate and local-oscillator substitution tests.

7. Validate long-duration capture for sub-hertz and intermittent wake cadences, including missing-event and clock-discontinuity handling.

8. Freeze software, FPGA logic, calibration files, frequency lists and reporting templates under configuration control before consequential use.

Chapter Glossary

Terms used in Chapter 42: Crystal, Ceramic-Resonator, Oscillator-Module, Divided-Clock and Harmonic-Family Analysis.

A

ALIASING — The indistinguishable mapping of different continuous-time frequencies to the same sampled representation when the sampling process is insufficiently constrained.

C

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

F

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

I

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

M

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

O

OSCILLATOR — An oscillator is a nonrotating device that produces alternating current. The frequency is determined by the characteristics of the device.

R

REFERENCE PLANE — The physical or mathematical location at which a signal, impedance, power, field, or calibration quantity is defined.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

Appendix A. Master Field Checklist

A.1 Authority and governance

[ ] Written commission defines neutral technical question.

Advanced practitioner analysis. A technically mature treatment of Authority and governance begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

[ ] Property and access authority verified.

[ ] Privacy and incidental-communications plan approved.

[ ] Active-transmission authority expressly granted or expressly prohibited.

[ ] Clinical-engineering review completed where relevant.

[ ] Inspection manager, lead examiner, data custodian and reviewer assigned.

[ ] Stop-work authority and emergency route confirmed.

A.2 Instrument readiness

[ ] Calibration certificates current and applicable to selected bands.

[ ] Pre- and post-use check sources available.

[ ] Receiver, firmware, software, filter and script versions recorded.

[ ] Self-emission spectra current for each instrument state.

[ ] Terminations, dummy probe, bypass path and overload checks prepared.

[ ] Reference clock status and time synchronisation verified.

[ ] Batteries inspected; chargers and switch-mode supplies excluded from CEIA.

[ ] Fibre links, remote storage and cryptographic hashing tested.

A.3 Scene establishment

[ ] Regional and close-search geometry established: 5 mi, 2.5 mi, 1 mi, 0.5 mi, 0.25 mi, 300 ft, 150 ft, 100 ft, 50 ft, 30 ft, 15 ft, 12 ft, 3 ft and 3-inch convergence, with actual coordinates and missing sectors recorded.

Spatial-measurement interpretation. At expert-practitioner level, Scene establishment is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

[ ] Known-source inventory and ordinary operating state recorded.

[ ] CEIA boundary and entry log established.

[ ] Personal electronics removed or characterised.

[ ] Terminated-input and ambient baselines acquired.

[ ] Outer ring and approach transects completed.

[ ] Threshold dwell completed before entry.

[ ] Single controlled entry route, access log and equipment staging boundary established.

[ ] Three stable hard points and the room x-y-z datum verified by closure measurements.

[ ] Baseline room drawing, dimensions and furniture coordinates sealed before movement.

[ ] Sixteen stations planned and reconciled for each of the 5-mile, 2.5-mile and 1-mile annuli, or twenty-four for each outer annulus where the commission is classified high risk.

[ ] Twelve stations planned for the 0.5-mile annulus; any reduction is not below eight and is supported by an access and coverage record.

[ ] Twelve stations planned for the 0.25-mile annulus where practicable; the completed ring contains no fewer than eight.

[ ] Pre-numbered paper station forms and maps, bound field notebooks, correction convention and common event-identification scheme issued before measurements began.

[ ] Campaign schedule, four-to-five-day field segments, intermission monitoring, return dates and sentinel custody assigned.

[ ] Equipment-placement and movement ledger active; each introduction, displacement, tuning change and withdrawal recorded before the next acquisition.

A.4 Interior examination

[ ] Alphanumeric grid and coordinate origin recorded.

System-level interpretation. For expert practice, Interior examination is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

[ ] Probe heights, axes, standoff, dwell and path fixed.

[ ] Unaltered-state coarse grid completed.

[ ] Candidate criteria applied as predeclared.

[ ] Fine grid performed only for reproducible candidates.

[ ] Dummy-probe, gain-step, preselector and independent-instrument tests completed.

[ ] Known-source state changes, if any, made one at a time and restored.

[ ] Optional active module executed only under separate written plan.

[ ] Reverse-path control completed.

[ ] Coarse three-foot cube lattice and required twelve-inch or three-inch subdivisions assigned unique identifiers.

[ ] Floor, wall, ceiling and surface marker triangles reconciled to the marker register.

[ ] Cube behaviour records include all probe axes, dwell, controls, environmental state and uncertainty.

[ ] Every movement or state change has a before-and-after coordinate record and affected-cube repeat.

A.5 Closure and reporting

[ ] Raw files made read-only and SHA-256 hashes recorded.

Three-dimensional search analysis. The mature treatment of Closure and reporting replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

[ ] Acquisition IDs reconcile with field log and coordinate table.

[ ] Deviations and nonconformities recorded.

[ ] Post-use instrument check passed.

[ ] Observation, inference and opinion separated in draft report.

[ ] Measurement uncertainty and validated capability stated.

[ ] Medical-causation and absence limitations included.

[ ] Independent technical and quality review completed.

A.6 Controlled-illumination readiness and execution

☐ Passive dataset closed, hashed, reviewed and segregated from the active series.

Active-test metrology. An advanced technical analysis of Controlled-illumination readiness and execution separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. Pre-trigger memory and a coarse-to-fine delay search are used because rectification, energy storage, logic wake-up, resonator settling, pulse encoding, and decay can introduce latency from microseconds to seconds. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

☐ Legal, spectrum, safety, exposure, EMC and clinical approvals are signed and current.

☐ Candidate illumination and response bands are stated as hypotheses, with no universal-frequency claim.

☐ Transmit chain, coupler, antenna, feed line, harmonics, spurs and field monitor are calibrated or characterised.

☐ Receive-chain compression, desensitisation, preselector rejection, image frequencies and intermodulation products are documented.

☐ Source terminated, receiver-only, dummy-path and independent-receiver baselines are complete.

☐ Minimum-field, source-off, sham, valid-on, frequency-offset, polarisation-change and position-change sequence is predeclared.

☐ PPM or other modulation estimator, sampling rate, timing reference and uncertainty are defined before classification.

☐ Hardware emergency stop and real-time safety monitoring are functional.

☐ Post-illumination passive repeat, equipment status check, reverse path and final hashes are complete.

A.7 Coherent multichannel and resonance-control readiness

[ ] At least three simultaneous channels are active for each evidential X-Y-Z measurement; the nine-channel three-pod baseline is used unless a documented limitation applies.

Synchronous measurement elaboration. The purpose of Coherent multichannel and resonance-control readiness is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

[ ] Chassis, expansion-card, channel, pod, probe and cable serials reconcile with the configuration register.

[ ] Site master reference, sample-clock, trigger and epoch lock are verified, with channel skew and group delay within the validated limits.

[ ] Channels 1 through 9 are mapped to pod and axis; channels 10 through 12 are mapped to source reference, terminated or calibration control, and guard or independent confirmation.

[ ] Frequency-abscissa-to-varactor calibration files are current for every tuned channel, and the physical X axis is not confused with the analyser frequency axis.

[ ] Fixed bank, sapphire piston, varactor bias, resonance-lock result and settling time are recorded before each tuned acquisition.

[ ] Calibration pilot is absent and bias is in hold during evidential sampling.

[ ] Wideband analyser and high-selectivity tracking-receiver paths have known gain, splitter loss, noise bandwidth, latency and overload limits.

[ ] Long-dwell burst capture, pre-trigger memory, storage continuity and probability-of-intercept claim have been validated for the selected bands.

[ ] Common-chassis and cross-chassis self-emission blanks are complete for tune, hold, trigger and record states.

[ ] Any SCIF or controlled-space filter-path test has separate facility authority, handling controls and interior, exterior and control-channel geometry.

Appendix B. Signal Catalogue and Data Dictionary

Each candidate or confirmed signal receives a record capable of standing alone. The catalogue should be machine-readable and accompanied by a human-readable case index. Field names may be implemented in CSV, JSON, a laboratory information management system or another controlled format.

Field	Definition	Illustrative entry
case_id	Unique commission identifier.	EERF-2026-001
acquisition_id	Unique raw acquisition identifier.	ACQ-00482
signal_id	Candidate or confirmed signal identifier.	SIG-017
classification	Outcome 0 or evidential Class 1-6 under Section 19.	4. Reproducible frequency-translated response
timestamp_utc	Acquisition start in UTC with precision.	2026-07-12T14:35:22.184Z
time_uncertainty	Estimated timestamp uncertainty.	+/- 2 ms
zone_grid	Zone, grid cell, height and axis.	Z8-F4-H2-X
coordinates	Metric or imperial coordinates from declared origin.	
standoff	Probe-centre distance to reference surface.	0.20 m +/- 0.01 m
sensor	Type, model, serial and calibration ID.	Shielded loop, SL-03, CAL-119
receiver	Model, serial, firmware and reference source.	EMI-RX2, SN 4811, FW 3.4, OCXO-2
pre filter(s)	Model, serial, type, parameters	BP433.92, SN 772, Bandpass, 433.75-434 MHz

Field	Definition	Illustrative entry
pre amplifier	Model, serial, type, parameters, nf	310x, 000989, LNA, 30 Hz – 1 GHz, .3 dB
centre_frequency	Measured centre frequency and uncertainty.	32767.9 Hz +/- 1.2 Hz, $k = 2(24)$
span_bandwidth	Span, RBW, VBW or digital filter bandwidth.	Span 200 Hz; RBW 1 Hz; VBW 1 Hz
detector_dwell	Detector, averaging and dwell.	RMS, coherent average, 120 s
amplitude	Calibrated field or receiver quantity and uncertainty.	42 nT +/- 9 nT, $k = 2(25)$
noise_background	Local background and estimation method.	18 nT RMS, adjacent-bin median
temporal_features	Duty cycle, burst period, jitter or stability.	Continuous; Allan interval 10 s
spectral_relations	Harmonics, sidebands or mixing relations.	2f and 3f observed
spatial_relations	Gradient, null, bearing or bounding region.	Maximum F4-H6; X-axis null east-west
controls	Blank, dummy, gain-step and independent checks.	Passed all; see ACQ-00483-00491
known_source_tests	Authorised state changes and result.	Lighting off: no change; HVAC off: no change
raw_hash	Cryptographic hash of the raw file.	SHA-256: [recorded in case system]
analyst_note	Neutral observation and limitations.	Consistent with timing source; not unique
review_status	Technical and quality review state.	Approved

Field	Definition	Illustrative entry
target_tier	Tier 1 timing, Tier 2 radiated or Tier 3 controlled-illumination record.	Tier 3
illumination_state	Physical and commanded source state.	Source on, authorised step 4
illumination_frequency	Measured source frequency and uncertainty.	1.600000 GHz +/- 150 Hz, $k = 2$(26)
illumination_waveform	CW, stepped, swept, pulsed or other authorised waveform.	CW with 5 s on and 15 s off
source_power	Forward and reflected power at the directional coupler.	+10.0 dBm forward; return loss 18 dB
illumination_geometry	Antenna, coordinate, azimuth, elevation, polarisation and distance.	ANT-TX2; az 084 deg; el 6 deg; vertical; 10.0 m
incident_field	Measured or modelled field quantity and uncertainty.	0.42 V/m +/- 0.09 V/m, $k = 2$(27)
response_frequency	Suspected backscatter, side channel, NONSTOP, HIJACK, or reradiated response and uncertainty.	300.0042 MHz +/- 1.4 kHz, $k = 2$(28)
response_mechanism	Same-frequency, sideband, harmonic, nonlinear, translated or internally generated hypothesis.	Frequency-translated candidate
ppm_frame_reference	Frame period, reference definition and timebase.	10.000 ms frame, coupler trigger, REF-CLK2

Field	Definition	Illustrative entry
ppm_displacement	Pulse position displacement and uncertainty.	2.416 ms +/- 0.012 ms, $k = 2(29)$
response_latency	Time from measured source transition to response onset.	38 ms +/- 4 ms
active_controls	Source-off, sham, offset, polarisation, position and leakage controls.	All passed; see ACQ-00610 to ACQ-00642
independent_receiver	Second architecture and confirmation result.	RX-B confirmed same physical frequency and timing
probe_core_material	Core alloy or ceramic grade, manufacturer, lot, form and permeability grade.	VITROPERM 550 HF, tape lot VP55-24-017
probe_core_geometry	Rod, stack, tape core, powder core, gap and principal dimensions.	Open segmented return, 180 mm x 12 mm, two 0.8 mm gaps
probe_core_state	Heat treatment, stress-relief, degaussing and DC bias state.	Manufacturer annealed; degaussed 14:02 UTC; ambient $HDC = 38$A/m(30)
probe_mu_file	Identifier for measured μ'(f), μ''(f), impedance and transfer-factor data.	CAL-LF32-CORE17-20260713.csv
probe_core_temperature	Core temperature and uncertainty during acquisition.	22.6 °C +/- 0.4 °C
probe_core_orientation	Material rolling, ribbon, easy-axis or magnetic-axis orientation relative to the probe coordinate system.	Ribbon direction parallel to probe X axis

Field	Definition	Illustrative entry
modulation_family	Controlled vocabulary for the observed family, including unknown or composite	NFM, PPM, nested NFM-on-NFM, unknown
carrier_frequency_hz	Estimated carrier, pilot or centre frequency with uncertainty	398605002.4
subcarrier_frequency_hz	Estimated subcarrier frequency or null when none is supported	4200.0
symbol_or_pulse_rate_hz	Estimated symbol, pulse, hop or frame rate and method	125.0 cyclic frequency
pulse_width_s	Pulse duration at declared amplitude points	0.000020
pulse_position_s	Displacement from declared frame reference	0.000080
pulse_interval_s	Interval to next pulse or frame reference	0.008000
modulation_index	Declared AM, FM or PM index and estimator	0.45
cyclic_frequency_hz	Cyclic frequency detected by spectral-correlation analysis	125.0
composite_hierarchy	Ordered description of carrier, subcarrier and nested modulation layers	Outer $NFM >$ NFMsubcarrier $>$ low $-$ ratepulsesequence(31)
direct_leakage_dbm	Measured illumination leakage at receiver input or test point	-35.0

Field	Definition	Illustrative entry
response_margin_db	Candidate response separation from leakage, noise or threshold	12.4

Appendix C. Thirty-Three Worked Technical Calculations

The examples below explain variables, assumptions and limitations. They are design aids, not substitutes for instrument calibration or site-specific electromagnetic modelling. Values are rounded sensibly so that the apparent precision does not exceed the underlying assumptions.

Example 1. Wavelength of a 32.768 kHz timing signal

Variable	Meaning	Value
c	Speed of light in free space	299,792,458 m/s
f	Frequency	32,768 Hz
lambda	Free-space wavelength	unknown

$$\lambda = c/f \quad (32)$$

Working:.

Interpretation: a room-scale survey is tiny compared with the wavelength. The field is generally not a simple plane wave, and magnetic or electric near-field probes are more useful than a far-field direction-finding assumption.

Example 2. Heuristic reactive near-field distance at 32.768 kHz

Variable	Meaning	Value
lambda	Wavelength from Example 1	9,148.94 m
pi	Circular constant	3.14159265
r_nf	Heuristic lambda/(2*pi) distance	unknown

$$r_{\mathrm{nf}} = \lambda/(2 \cdot \pi) \quad (33)$$

Working:.

Interpretation: 300 feet equals 91.44 m and is still far inside the 1,456.10 m heuristic distance. The 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and 3-foot stages lie progressively deeper within the same electrically small scale. The exact transition depends on source geometry, but the calculation explains why low-frequency localisation relies on controlled gradients, vector components and probe coupling rather than a simple radiating-wave bearing.

Example 3. Wavelength of the NTSC colour subcarrier

Variable	**Meaning**	**Value**
c	Speed of light	299,792,458 m/s
f_sc	NTSC chrominance subcarrier	3,579,545 Hz
lambda_sc	Free-space wavelength	unknown

$$\lambda_{\mathrm{sc}} = c/f_{\mathrm{sc}} \quad (34)$$

Working:.

Interpretation: 300 feet equals 91.44 m, approximately 1.092 wavelengths at 3.579545 MHz. The 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and 3-foot rings are approximately 0.546, 0.364, 0.182, 0.109, 0.0546, 0.0437 and 0.0109 wavelength respectively. The staged survey therefore crosses several possible propagation behaviours. Reflections and cable coupling can displace an amplitude maximum, so each radius requires lateral, height and polarisation controls.

Example 4. Heuristic transition distance at 3.579545 MHz

Variable	Meaning	Value
lambda_sc	Wavelength from Example 3	83.7516 m
pi	Circular constant	3.14159265
r_t	lambda/(2*pi) heuristic	unknown

$$r_t = \lambda_{\mathrm{sc}}/(2 \cdot \pi) \quad (35)$$

Working:.

Interpretation: the 300-foot, 150-foot and 100-foot stages lie outside the 43.73-foot heuristic scale, the 50-foot and 30-foot stages straddle its order of magnitude, and the 15-foot, 12-foot, 3-foot and 3-inch stages lie inside it. The result is not a hard boundary, but it supports the prescribed nested sampling and warns against applying one propagation model from the remote reference through the final localisation region.

Example 5. Deriving the NTSC horizontal line frequency

Variable	Meaning	Value
f_sc	NTSC chrominance subcarrier	3,579,545 Hz
455	Established frequency ratio denominator	455
f_H	Horizontal line frequency	unknown

$$f_{\mathrm{H}} = (2 \cdot f_{\mathrm{sc}})/455 \quad (36)$$

Working:, which is approximately 15.734 kHz.

Interpretation: this explains the more precise legacy timing value. It remains a candidate relationship, not proof of a camera, because other systems can generate nearby periodicity and modern digital equipment may use unrelated clocks.

Example 6. Thermal noise in a 1 Hz bandwidth

Variable	Meaning	Value
k	Boltzmann constant	1.380649 x 10^-23 J/K
T	Reference temperature	290 K
B	Noise bandwidth	1 Hz
P_n	Available thermal-noise power	unknown

$$P_n = k \cdot \mathrm{T} \cdot B (37)$$

Working:. In dBm,.

Interpretation: narrowing bandwidth lowers ideal thermal noise, but real field surveys are often limited by environmental interference, receiver phase noise, amplifier noise, cable pickup and instrument spurs rather than thermal noise alone.

Example 7. Receiver noise floor in a 10 Hz bandwidth

Variable	Meaning	Value
N_0	Thermal noise density at 290 K	-174 dBm/Hz
B	Resolution bandwidth	10 Hz
NF	Receiver-chain noise figure	2 dB

Variable	Meaning	Value
N	Estimated receiver noise floor	unknown

$$N = N_0 + 10\log_{10}(B) + \mathrm{NF}(38)$$

Working:.

Interpretation: this is a receiver-input power estimate. Converting it to V/m, A/m or tesla requires the calibrated sensor factor, impedance, cable loss, gain and geometry. A spectrum trace reading without that chain is not an exposure measurement.

Example 8. Filter quality factor around 32.768 kHz

Variable	Meaning	Value
f_0	Filter centre frequency	32,768 Hz
BW	3 dB bandwidth	1 Hz
Q	Quality factor	unknown

$$Q = f_0/\mathrm{BW}(39)$$

Working:.

Interpretation: a 1 Hz filter is exceptionally selective. It can improve signal-to-noise ratio for a stable oscillator, but it has a long settling response and can miss a crystal pulled by temperature, load or ageing. Discovery therefore begins wider and narrows only after the frequency behaviour is known.

Example 9. Frequency error in parts per million

Variable	Meaning	Value
f_obs	Observed centre frequency	32,767.4 Hz
f_nom	Nominal frequency	32,768.0 Hz
epsilon_ppm	Frequency error in ppm	unknown

$$\epsilon_{\text{ppm}} = \left((f_{\text{obs}} - f_{\text{nom}})/f_{\text{nom}}\right) \cdot 1{,}000{,}000 \quad (40)$$

Working:.

Interpretation: the negative sign means the observed line is below nominal. The value may be plausible for a watch crystal under load and temperature variation, but the inference requires the measurement uncertainty to be materially smaller than the 0.6 Hz difference.

Example 10. Combined and expanded frequency uncertainty

Component	Standard uncertainty
Reference accuracy	0.2 Hz
Receiver centre-frequency contribution	0.1 Hz
Observed short-term drift	0.5 Hz
Repeat positioning effect	0.3 Hz

$$u_c = \sqrt{0.2^2 + 0.1^2 + 0.5^2 + 0.3^2} \quad (41)$$

Working:. For coverage factor, expanded uncertainty.

Interpretation: a defensible report would state 32,767.9 Hz +/- 1.25 Hz,. The uncertainty interval overlaps the nominal 32,768 Hz value, so the measurement is consistent with the nominal timing family but does not prove it.

Interpretation: a defensible report would state 32, 767. 9 Hz +/- 1. 25 Hz, k=2, subjecttothestatedmodel. The uncertainty interval overlaps the nominal 32, 768 Hz value, so the measurement is consistent with the nominal timing family but does not prove it.

Assumptions and limitation. The components are treated as independent standard uncertainties. Correlation, trigger latency and non-Gaussian detector errors require a different model. Coverage probability is not asserted solely from k=2.

The Fraunhofer distance is estimated for an antenna with maximum dimension D=0. 30m at 1. 6 GHz and 4. 6 GHz. The calculation indicates where a plane-wave far-field approximation becomes more defensible.

Example 11. Resonating a 1 H ferrite-rod coil at 32.768 kHz

Purpose: determine the ideal parallel tuning capacitance for a measured inductance of 1.000 H at the nominal watch-crystal frequency. Let f0 be the desired resonant frequency in hertz, L be inductance in henries, C be capacitance in farads and pi be 3.14159265. For an ideal lossless LC network, f0 = 1 / (2 pi square-root(L C)). Rearranging gives C = 1 / ((2 pi f0)^2 L). Substitution gives C = 1 / ((2 pi x 32,768)^2 x 1.000), which equals 2.3591 x 10^-11 F, or 23.59 pF. This value is the ideal total capacitance seen by the winding, not merely the added component.

The measured winding self-capacitance, amplifier input capacitance, cable capacitance, shield capacitance and trimmer minimum must all be included. If those parasitic contributions already total 18 pF, only about 5.6 pF of added capacitance is available before resonance is reached.

Engineering consequence: a sapphire piston trimmer in a low-picofarad range can provide much of the adjustment for a one-henry coil, but it should still be paired with a measured fixed or stray-capacitance model. The calculation is repeated with the coil installed in its final housing because the concentrator, electrostatic shield and preamplifier can change both L and C. The measured resonant frequency, bandwidth and phase crossing are the acceptance quantities. The numerical value does not by itself establish that the probe has adequate Q, low noise or a useful magnetic pattern. A coil can resonate correctly while suffering excessive copper loss, dielectric loss, microphonics or amplifier loading.

Example 12. Resonating a 100 mH coil at 32.768 kHz with fixed capacitance and sapphire trim

Let the measured inductance be L = 0.1000 H and the target be f0 = 32,768 Hz. Using C = 1 / ((2 pi f0)^2 L), C = 1 / ((2 pi x 32,768)^2 x 0.1000) = 2.3591 x 10^-10 F = 235.91 pF. Assume the assembled winding and amplifier contribute 31 pF. The external network must therefore contribute approximately 204.9 pF. One practical calibration architecture is a stable fixed bank near 200 pF plus a sapphire piston trimmer and small parallel pads that cover the remaining range. The actual bank is selected from measured values, not nominal markings. If a 200.0 pF fixed element and 5.0 pF of trimmer contribution are fitted, the estimated total becomes 236.0 pF and lies close to the target.

The example shows why a sapphire piston is usually the fine calibration element rather than the entire tuning capacitor at these frequencies. A 1 pF change around 236 pF is about 0.424 per cent in capacitance. For small changes, resonant frequency changes by approximately minus one half of the fractional capacitance change, so 1 pF would move frequency by roughly 0.212 per cent, or about 69.5 Hz at 32.768 kHz. Fine adjustment may therefore require fractions of a picofarad once the fixed bank is correct. The trimmer setting is locked, the housing is closed and resonance is rechecked because adjustment tools and open covers can add capacitance.

Example 13. Resonating a 1 H probe at 15.734 kHz

Let f0 = 15,734 Hz and L = 1.000 H. C = 1 / ((2 pi x 15,734)^2 x 1.000) = 1.0232 x 10^-10 F = 102.32 pF. If the winding self-capacitance is 45 pF and the preamplifier input contributes 8 pF, the deliberate network should contribute about 49.3 pF. A fixed capacitor near 47 pF with a small sapphire trim range can therefore be appropriate, subject to measured loss and temperature behaviour. The complete response must be measured because the effective inductance of an open ferrite rod depends on rod geometry, winding position, core material, magnetic bias and nearby metal.

At 15.734 kHz, a high-turn coil can have substantial resistance and inter-winding capacitance. Increasing turns raises induced voltage approximately in proportion to N in the simplest model, but copper resistance rises and self-resonance falls. The chosen design maximises validated signal-to-noise ratio rather than turn count alone. A sectioned winding, fine litz conductor, controlled pitch and guarded high-impedance input can be superior to one extremely long random winding. The calculated capacitor is therefore an initial design value. The field-ready probe is accepted only after impedance, noise, Q, ring-down, orientation pattern and temperature shift have been measured.

Example 14. Bandwidth and settling time of a high-Q 32.768 kHz probe

Let the measured centre frequency be f0 = 32,768 Hz and loaded quality factor be Q = 500. The approximate 3 dB bandwidth is B = f0 / Q = 32,768 / 500 = 65.536 Hz. The amplitude time constant of a lightly damped resonator is approximately tau = Q / (pi f0) = 500 / (pi x 32,768) = 0.004857 s, or 4.86 ms. Five time constants equal about 24.3 ms and reduce a simple exponential transient to below one per cent of its starting value. The acquisition delay after an electrical step must therefore exceed this value, and mechanical movement may require longer because the coil, cable and support can continue moving after electrical ring-down has ended.

The bandwidth result also governs frequency tolerance. A candidate that drifts 50 Hz during a dwell remains near the edge of this 3 dB passband, while a broader discovery channel would show the full movement. A high-Q probe should consequently be used after the candidate frequency has been measured with a broader architecture. The case record states f0, Q, bandwidth, temperature and the delay between movement and acquisition. If the probe is retuned, the old and new data belong to separate series. An apparently stronger result after retuning is not a spatial increase unless transfer factor has been recalibrated.

Example 15. Thermal-noise voltage of a high-turn winding

Let Boltzmann constant k = 1.380649 x 10^-23 J/K, absolute temperature T = 293.15 K, winding resistance R = 2,000 ohms and equivalent noise bandwidth B = 1 Hz. The root-mean-square Johnson noise is vn = square-root(4 k T R B). Substitution gives vn = square-root(4 x 1.380649 x 10^-23 x 293.15 x 2,000 x 1) = 5.69 x 10^-9 V rms, or 5.69 nV rms. In a 100 Hz equivalent bandwidth the noise rises by square-root(100) and becomes 56.9 nV rms. This is the winding contribution before amplifier voltage noise, amplifier current noise, dielectric loss and environmental interference are included.

If the resonant impedance is high, amplifier current noise can generate a larger voltage than its data-sheet voltage-noise figure suggests. Suppose current noise is 2 fA per square-root hertz and source impedance at resonance is 100 kilohms. Its equivalent contribution is 0.2 nV per square-root hertz, small compared with the 5.69 nV winding value in this example. At 5 megohms, the same current noise contributes 10 nV per square-root hertz and becomes dominant. The input device must therefore be selected against the measured complex source impedance. The lowest advertised voltage-noise amplifier is not automatically the quietest complete front end.

Example 16. Induced voltage in a long ferrite-rod winding

For a first-order sinusoidal estimate, induced peak voltage is Vp = N Aeff omega Bp, where N is turns, Aeff is effective magnetic area in square metres, omega = 2 pi f and Bp is peak flux density in teslas. Let N = 10,000 turns, Aeff = 1.0 x 10^-4 m^2, f = 32,768 Hz and Bp = 1.0 pT = 1.0 x 10^-12 T. Vp = 10,000 x 1.0 x 10^-4 x 2 pi x 32,768 x 1.0 x 10^-12 = 2.059 x 10^-7 V, or 0.206 microvolts peak. The rms value for a sine wave is about 0.146 microvolts.

This value is illustrative because Aeff for a ferrite rod is not simply its physical cross-section multiplied by intrinsic permeability. Demagnetising effects, rod aspect ratio, winding length and core loss determine the effective response. Calibration in a known magnetic field supplies the actual transfer factor. Nevertheless, the calculation shows why microvolt and sub-microvolt signals are plausible and why low-noise amplification, cable control and narrow equivalent bandwidth matter. It also shows that a local digital converter or switching regulator emitting tens of microvolts into the probe can overwhelm the intended measurement unless physically separated and characterised.

Example 17. Idealised magnetic-dipole increase from 12 feet to 3 feet

In the reactive near field of a small magnetic dipole, one useful idealised term varies approximately as 1/r^3. Let r1 = 12 ft and r2 = 3 ft. The expected amplitude ratio is (r1 / r2)^3 = (12 / 3)^3 = 4^3 = 64. Expressed in decibels for an amplitude quantity, increase = 20 log10(64) = 36.12 dB. This is not a universal law for rooms. Conductors, magnetic structures, extended cables, several sources and source dimensions can change the gradient. The value is a comparison against which the observed trend can be tested.

If the measured increase is only 3 dB, the team should not force a compact-dipole interpretation. The candidate may be distant, extended, conducted along wiring, time variable or dominated by background. If the increase is far greater than 36 dB, one point may be close to a shield aperture, the receiver may have left its linear range, or the source state may have changed. A reverse path and fixed reference channel are needed. The distance model is therefore a hypothesis-testing tool, not a localisation formula that converts one amplitude into one range.

Example 18. Measurement burden of the 3-inch decrement ladder

The prescribed radial sequence from 36 inches to 3 inches, inclusive, in 3-inch decrements contains n = ((36 - 3) / 3) + 1 = 12 radii. If each complete ring uses 12 azimuths, there are 12 x 12 = 144 spatial stations at one height and one probe axis. Three orthogonal axes produce 432 acquisitions. Two heights produce 864 acquisitions. Adding a second probe architecture doubles the primary set to 1,728 acquisitions before repeats, blanks and reverse-path controls. A 20-second dwell with 10 seconds for movement and settling would require 51,840 seconds, or 14.4 hours, for that full set.

The calculation explains why the protocol uses adaptive convergence rather than applying the maximum grid to every candidate. Coarse rings identify the region, and each fine ring is completed before re-centring. Probe axes and heights are selected from validation and the observed field model. The team shall not discard controls merely to save time, but it may reduce uninformative dimensions under a predeclared rule. For example, a wall-bound candidate may use a planar 3-inch raster with two standoffs and three orientations rather than full circles in inaccessible space. The report states the actual geometry and does not imply that an unmeasured volume was excluded.

Example 19. Combined spatial uncertainty at the final bounding region

Assume independent standard uncertainty contributions of 1.5 inches from coordinate placement, 2.0 inches from effective probe-aperture localisation and 1.0 inch from non-contact standoff. The combined standard uncertainty is uc = square-root(1.5^2 + 2.0^2 + 1.0^2) = square-root(7.25) = 2.69 inches. With a coverage factor k = 2, the expanded uncertainty is U = 2 x 2.69 = 5.39 inches. A peak recorded on a 3-inch lattice therefore does not support a 3-inch absolute location when these contributions apply. The bounding interval must be expanded accordingly.

The components may also be correlated. Probe aperture and standoff can interact, and coordinate error can repeat in the same direction if the datum is mis-set. A complete uncertainty analysis considers covariance or uses validation coverage from blind placements. Spatial uncertainty is ordinarily anisotropic. A wall scan may have a 5-inch expanded interval along the surface and a 12-inch unresolved depth. The report gives separate x, y and z bounds rather than one deceptively precise radius.

Example 20. Gradiometer common-mode rejection from amplitude and phase mismatch

Consider two nominally identical channels exposed to a uniform field. Let fractional amplitude mismatch be ea = 0.005, equal to 0.5 per cent, and phase mismatch be ephi = 0.5 degrees = 0.008727 radians. For small errors, residual fraction can be approximated by er = square-root(ea^2 + ephi^2) = square-root(0.005^2 + 0.008727^2) = 0.01006. Common-mode rejection ratio is CMRR = 20 log10(1 / er) = 39.95 dB. A uniform 1,000 nT component would therefore leave about 10 nT residual solely from mismatch.

If the intended local gradient is 1 nT, this residual is unacceptable despite a seemingly respectable 40 dB CMRR. Better matching, digital complex calibration, shorter baseline or a different geometry is required. The CMRR shall be measured across frequency, field amplitude, temperature and orientation. A result at one laboratory frequency does not establish performance in a building where each sensor sees a different conductive and magnetic environment. Channel interchange and physical reversal tests help distinguish true gradient from fixed channel imbalance.

Example 21. Free-space path loss for a 1.6 GHz illumination path

This example estimates ideal free-space loss over a 10 m path. It is a planning calculation for receiver protection and power budgeting, not a guarantee of field at an unknown device.

Variable	Meaning	Value
c	Speed of light	299,792,458 m/s
f	Illumination frequency	1.6 x 10^9 Hz
d	Path distance	10 m
lambda	Free-space wavelength	$\mathrm{c}/f = 0.18737\mathrm{m}$(42)

$$\mathrm{FSPL_{dB}} = 20\log_{10}(4\pi d/\lambda) \quad (43)$$

$\mathrm{FSPL_{dB}} = 20\log10[(4x\pi x10)/0.18737]$.(44)

The dimensionless path ratio is approximately 670.7. Therefore.

Result. The ideal free-space path loss is approximately 56.53 dB.

Assumptions and limitation. The model assumes unobstructed far-field propagation, matched polarisation and no cable, mismatch, absorption or multipath loss. Indoor fields may be higher or lower at a particular coordinate.

Example 22. Received power available at a candidate receiving aperture

The Friis power budget is used to estimate the power available to a hypothetical 0 dBi receiving aperture at 10 m from a 1.6 GHz directional source.

Variable	Meaning	Value
P_t	Transmitter conducted power	+10 dBm
G_t	Transmit antenna gain	+12 dBi
G_r	Candidate receive gain	0 dBi
FSPL	Free-space path loss from Example 21	56.53 dB
L	Combined feed and mismatch loss	2.00 dB

$$P_r(\text{dBm}) = P_t(\text{dBm}) + G_t(dBi) + G_r(dBi) - \text{FSPL}(\text{dB}) - L(\text{dB})(45)$$

$$P_r = 10 + 12 + 0 - 56.53 - 2.00.(46)$$

$$P_r = -36.53\text{dBm}.(47)$$

Result. The ideal available power is approximately -36.53 dBm, or 0.222 microwatt.

Assumptions and limitation. The calculation assumes far-field Friis conditions and a 0 dBi matched receiving antenna. It excludes shielding, detuning, orientation, impedance and rectifier losses. It must not be used as an activation-distance guarantee.

Example 23. Effective aperture of a 2 dBi response antenna at 300 MHz

Effective aperture relates the incident power density of a plane wave to the maximum available power at a matched antenna terminal.

Variable	Meaning	Value
f	Response frequency	300 x 10^6 Hz
lambda	Wavelength	$299{,}792{,}458/300{,}000{,}000 = 0.99931$m(48)
G_dBi	Antenna gain	2 dBi
G	Linear gain	$10^{(2/10)} = 1.5849$(49)

$$\mathrm{A}_e = G\lambda^2/(4\pi)\text{(50)}$$

$\mathrm{A}_e = 1.5849 \times (0.99931)^2/(4x\pi)$.(51)

$\mathrm{A}_e = 0.12595$squaremetre.(52)

Result. The ideal effective aperture is approximately 0.126 square metre.

Assumptions and limitation. This is maximum available aperture for a matched antenna in a plane wave. Polarisation mismatch, near-field geometry, ground effects, cable loss and antenna-factor uncertainty reduce or alter the practical value.

Example 24. Rectifier activation-threshold margin

A hypothetical energy-harvesting circuit requires -20 dBm at its rectifier input, while the estimated available power is -23 dBm. The margin determines whether the ideal estimate reaches the threshold.

Variable	Meaning	Value
P_threshold	Rectifier activation threshold	-20 dBm $= 10$microwatts(53)
P_available	Estimated available power	-23 dBm $= 5.012$microwatts(54)
M	Power margin	P_available - P_threshold

$$M_{\text{dB}} = P_{\text{available}}(\text{dBm}) - P_{\text{threshold}}(\text{dBm})(55)$$

$M_{\text{dB}} = -23 - (-20) = -3\text{dB}.(56)$

The linear power ratio is 10^(-3/10) = 0.501. The available power is therefore approximately one half of the stated threshold.

Result. The ideal estimate is 3 dB below threshold and does not satisfy the assumed activation requirement.

Assumptions and limitation. Thresholds can vary with waveform, charging interval, impedance, temperature and device state. The example does not justify increasing field. Any progression remains subject to the authorised minimum-field plan and safety limits.

Example 25. Monostatic backscatter power approximation

A simplified monostatic radar and side channel equation estimates the returned power when the transmit and receive antenna are co-located and a small structure has an assumed radar cross section.

Variable	Meaning	Value
P_t	Transmitted power	0.010 W
G	Transmit and receive antenna gain	12 $dBi = 15.849$linear(57)
lambda	Wavelength at 1.6 GHz	0.18737 m
sigma	Assumed radar cross section	0.001 square metre

Variable	Meaning	Value
R	Range	10 m
L	Combined loss factor	2 linear

$$P_r = P_t G^2 \lambda^2 \sigma / [(4\pi)^3 R^4 L] \quad (58)$$

$$P_r = 0.010 \times 15.849^2 \times 0.18737^2 \times 0.001 / [(4\pi)^3 \times 10^4 \times 2]. \quad (59)$$

. Converting to dBm gives 10.

Result. The ideal monostatic return is approximately -86.53 dBm.

Assumptions and limitation. Radar cross section can vary by many orders of magnitude with angle, material, resonance and polarisation. Multipath and direct leakage may exceed the calculated return. This equation is a planning approximation, not proof of detectability.

Example 26. Bistatic backscatter power approximation

The bistatic form separates the transmitter-to-target distance from the target-to-receiver distance and permits different antenna gains.

Variable	Meaning	Value
P_t	Transmitted power	0.010 W
G_t	Transmit gain	12 $dBi = 15.849$(60)
G_r	Receive gain	10 $dBi = 10$(61)
lambda	Wavelength	0.18737 m
sigma_b	Assumed bistatic cross section	0.001 square metre
R_t	Transmitter-to-target distance	8 m
R_r	Target-to-receiver distance	12 m
L	Combined loss factor	2 linear

$$P_r = P_t G_t G_r \lambda^2 \sigma_b / [(4\pi)^3 R_t^2 R_r^2 L] (62)$$

$P_r = 0.010 \times 15.849 \times 10 \times 0.18737^2 \times 0.001/[(4\pi)^3 \times 8^2 \times 12^2 \times 2]$.(63)

$P_r = 1.52 \times 10^{-12}$W $= -88.18$dBm.(64)

Result. The ideal bistatic return is approximately -88.18 dBm.

Assumptions and limitation. The cross section and propagation paths are assumed. Indoor multipath, angular scattering and near-field coupling can invalidate the simple model. The result is used to set dynamic-range and leakage-control requirements only.

Example 27. Pulse-position displacement and sample statistics

Five pulses are measured within nominal 10 ms frames. Their positions relative to the frame reference are 2.400, 2.427, 2.414, 2.438 and 2.401 ms.

Variable	Meaning	Value
T_frame	Frame period	10.000 ms
t_i	Measured pulse positions	2.400, 2.427, 2.414, 2.438, 2.401 ms
N	Number of pulses	5
mean_t	Arithmetic mean position	sum(t_i)/N
s_t	Sample standard deviation	sqrt[sum(t_i-mean_t)^2/(N-1)]

$$\mathrm{mean}_t = (1/N)\sum t_i; \mathrm{s}_t = \sqrt{\sum[(t_i - \mathrm{mean}_t)^2]/(N-1)} (65)$$

The sum of the five positions is 12.080 ms, so.

The sample standard deviation is approximately 0.01651 ms, or 16.51 microseconds.

Result. The estimated mean pulse position is 2.416 ms with an observed sample jitter of 16.51 microseconds.

Assumptions and limitation. Five pulses are too few to characterise a complex PPM code or long-term jitter. The result also depends upon detector bias, sampling and timebase uncertainty, which are considered separately.

Example 28. Combined timing-jitter measurement uncertainty

The standard uncertainty of a pulse-position estimate includes timebase calibration, detector repeatability, sample quantisation and model-fit uncertainty.

Variable	Meaning	Value
u_clock	Clock contribution	2.0 microseconds
u_detector	Pulse detector repeatability	5.0 microseconds
u_sample	Sampling quantisation at 1 MS/s, rectangular	1/(sqrt(12) x 10^6) s = 0.289microsecond(66)
u_fit	Waveform-fit contribution	3.0 microseconds
k	Coverage factor	2

$$u_c = \sqrt{u_{\text{clock}}^2 + u_{\text{detector}}^2 + u_{\text{sample}}^2 + u_{\text{fit}}^2}; U = ku_c \text{(67)}$$

$u_c = \sqrt{2.0^2 + 5.0^2 + 0.289^2 + 3.0^2}$microseconds.(68)

Result. The expanded timing uncertainty is approximately +/- 12.34 microseconds.

Assumptions and limitation. The components are treated as independent standard uncertainties. Correlation, trigger latency and non-Gaussian detector errors require a different model. Coverage probability is not asserted solely from.

Example 29. Ideal processing gain from coherent integration

When N phase-coherent repetitions contain the same signal and uncorrelated noise, coherent integration can improve power signal-to-noise ratio by N.

Variable	Meaning	Value
N	Number of coherent repetitions	100
G_p	Ideal processing gain	10 log10(N) dB

$$G_p(\mathrm{dB}) = 10\log_{10}(N) \quad (69)$$

$G_p = 10\log_{10}(100) = 10 \times 2.$(70)

$G_p = 20\mathrm{dB}.$(71)

Result. The ideal coherent-integration gain is 20 dB.

Assumptions and limitation. The result requires phase coherence, correct timing alignment and uncorrelated noise. Clock drift, PPM displacement, source jitter, missed pulses and non-stationary interference reduce the gain. Processing gain does not improve receiver linearity or eliminate direct leakage.

Example 30. Duty-cycle correction for a pulsed response

A pulsed response has a measured peak power of -70 dBm and is active for 0.5 percent of the observation interval. The time-average power is calculated for a rectangular pulse model.

Variable	Meaning	Value
P_peak	Peak power during the pulse	-70 dBm
D	Duty cycle	0.005

Variable	Meaning	Value
P_avg	Time-average power	P_peak + 10 log10(D)

$$P_{\text{avg}}(\text{dBm}) = P_{\text{peak}}(\text{dBm}) + 10\log_{10}(D) \quad (72)$$

10.

$P_{\text{avg}} = -70 - 23.0103 = -93.01\text{dBm}.$(73)

Result. The rectangular-pulse time-average power is approximately -93.01 dBm.

Assumptions and limitation. The calculation assumes constant pulse power and an accurately measured duty cycle. Detector bandwidth, pulse shape and missed events can bias both peak and average estimates.

Example 31. Harmonic and intermodulation prediction near 300 MHz

Two strong signals at 1.300 GHz and 1.600 GHz can create a 300 MHz difference product in a nonlinear transmitter, receiver, cable junction or ordinary electronic device.

Variable	Meaning	Value
f_1	First strong frequency	1.600 GHz
f_2	Second strong frequency	1.300 GHz
f_diff	First-order difference	|f_1 - f_2|
f_IM3a	Third-order product	2 f_2 - f_1
f_IM3b	Third-order product	2 f_1 - f_2

$$f_{\text{product}} = |\mathrm{m} f_1 \text{plusorminus} n f_2| (74)$$

$f_{\text{diff}} = |1.600 - 1.300|\text{GHz} = 0.300\text{GHz} = 300\text{MHz}.(75)$

2 f_2 -.

2 f_1 -.

Result. A 300 MHz feature can be an intermodulation difference product and must not be presumed to be a device reradiation.

Assumptions and limitation. The arithmetic predicts possible frequencies, not amplitudes. Product strength depends upon nonlinearities and signal levels. Preselection, attenuation, source offsets and an independent mixer architecture are required to distinguish the mechanisms.

Example 32. Far-field boundary estimate for a 0.30 m directional antenna

The Fraunhofer distance is estimated for an antenna with maximum dimension at 1.6 GHz and 4.6 GHz. The calculation indicates where a plane-wave far-field approximation becomes more defensible.

Variable	Meaning	Value
D	Maximum antenna dimension	0.30 m
lambda_1	Wavelength at 1.6 GHz	0.18737 m
lambda_2	Wavelength at 4.6 GHz	0.06517 m
R_F	Fraunhofer distance	2 D^2 / lambda

$$R_{\text{F}} = 2D^2/\lambda (76)$$

At 1.6 GHz,.

At 4.6 GHz,.

Result. The estimated far-field boundaries are approximately 0.96 m at 1.6 GHz and 2.76 m at 4.6 GHz.

Assumptions and limitation. The Fraunhofer formula is a conventional antenna-region estimate, not an abrupt physical boundary. Antenna structure, ground, nearby objects and reactive coupling can require greater separation or a measured field map.

Example 33. Combined uncertainty of an illumination-response power budget

Five independent standard-uncertainty components are expressed in decibels and combined by root-sum-square for a power-level result.

Variable	**Meaning**	**Value**
u_source	Source power calibration	0.5 dB
u_gain	Antenna gain	0.3 dB
u_path	Path or field model	0.7 dB
u_receiver	Receiver amplitude	0.4 dB
u_repeat	Repeatability	0.6 dB
k	Coverage factor	2

$$u_c = \sqrt{u_{\mathrm{source}}^2 + u_{\mathrm{gain}}^2 + u_{\mathrm{path}}^2 + u_{\mathrm{receiver}}^2 + u_{\mathrm{repeat}}^2}; U = ku_c (77)$$

$u_c = \sqrt{0.5^2 + 0.3^2 + 0.7^2 + 0.4^2 + 0.6^2}$.(78)

. With,.

Result. The expanded power-budget uncertainty is approximately +/- 2.32 dB for.

Assumptions and limitation. The components are treated as independent and approximately symmetric in decibel space. Correlated calibration components, nonlinearity and strongly asymmetric field models require a more complete uncertainty analysis or Monte Carlo propagation.

Appendix D. Model Report Structure and Exemplar Findings

Report section	Required content
D.1 Commission and authority	Identify client, authorised question, premises, dates, authority, intended use, exclusions and recipients.
D.2 Personnel and competence	List roles, qualifications, conflicts, independence and reviewer.
D.3 Site and operational state	Describe the CEIA, regional annuli, 300-foot transition, zones, known emitters, life-safety systems, ordinary state, room datum, twenty-seven-cell modules, vertical access and authorised changes without implying a physical image.
D.4 Instruments and traceability	List sensors, receivers, serial numbers, firmware, calibration, check results, reference clock and uncertainty budgets.
D.5 Method	State the 5-mile, 2.5-mile, 1-mile, 0.5-mile, 0.25-mile, 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot, threshold, 3-foot and 3-inch geometry; actual coordinates and altitude; missing sectors; sentinel plan; twenty-seven-cell dimensions; paired surfaces; shell coverage; and composite-modulation analysis settings.
D.6 Observations	Report measured features, raw-file identifiers, calibrated values, uncertainty, regional and ring-to-ring behaviour, sentinel changes, 27-cell gradients, vertical and opposite-face results, carrier and subcarrier layers, pulse timing, cyclic features, nulls and phase where valid.
D.7 Artefact and alternative-source tests	Report terminated input, dummy probe, gain, preselector, independent instrument, known-source and external-bearing results.
D.8 Interpretation	Separate observation from source-class consistency, discuss alternatives, state classification and avoid medical inference.
D.9 Limitations	State method capability, inaccessible annular sectors, unavailable high ground, unmeasured upper or lower storeys, incomplete spherical shells, probe-aperture and depth limits, out-of-band and dormant-device limitations, environmental changes, incomplete dwell and untested composite-modulation hypotheses.
D.10 Conclusions	Answer only the authorised technical questions in proportionate language.

Report section	Required content
D.11 Data index	Provide hashes, raw and derivative lineage, logs, calibration records, deviations and reviewer sign-off.

D.12 Exemplar negative finding

System-level interpretation. For expert practice, Exemplar negative finding is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

MODEL TEXT
No signal met the validated confirmation criteria in the examined bands and operating states. The result means that no reportable signal was observed above the stated method capability. It does not exclude a device that was dormant, intermittently inactive, outside the examined bands, more strongly shielded than the validation envelope, powered only by an absent incident field, or obscured by environmental interference.

D.13 Exemplar confirmed but unlocalised finding

Advanced practitioner analysis. At expert-practitioner level, Exemplar confirmed but unlocalised finding is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

MODEL TEXT
A reproducible component at the stated frequency was measured with two independent receiver paths and was absent from terminated-input controls. Its spatial pattern did not support localisation within the available access area. The signal is classified as a confirmed electronic signal, not as an identified device or internal source.

D.14 Exemplar source-class finding

Advanced technical elaboration. For expert practice, Exemplar source-class finding is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

MODEL TEXT
The measured fundamental, harmonic relationship, stability and spatial gradient are consistent with a low-power timing circuit operating near 32.768 kHz. The frequency family is widely used and is not source-specific. The examination did not determine the physical device, its purpose, its ownership or any medical effect.

D.15 Exemplar illumination-correlated finding

A response at the stated frequency was observed only during the authorised illumination states and was absent during physical termination, sham and field-off controls. The response recurred during three time-separated source-on cycles and was confirmed by an independent receiver. The data support classification as an illumination-correlated response. They do not yet establish frequency translation, spatial association with a device, intended function or medical effect.

Retroreflective-response analysis. A advanced technical analysis of Exemplar illumination-correlated finding separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. Pre-trigger memory and a coarse-to-fine delay search are used because rectification, energy storage, logic wake-up, resonator settling, pulse encoding, and decay can introduce latency from microseconds to seconds. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

D.16 Exemplar frequency-translated and spatially localised finding

A response near 300 MHz changed in the predeclared relation to small authorised illumination-frequency offsets, survived transmitter-harmonic, receiver-image, attenuation, preselector and two-receiver controls, and exhibited a repeatable maximum within the stated three-dimensional coordinate interval. The data support classification as a spatially localised, reproducible frequency-translated response under the tested conditions. The result does not identify a SAW component, ownership, purpose or legality.

Three-dimensional search analysis. For Exemplar frequency-translated and spatially localised finding, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

D.17 Exemplar controlled-illumination limitation paragraph

Controlled illumination was limited to the authorised frequencies, levels, antenna positions, waveforms and dwell times. No inference is made about untested bands or higher fields. Calculated incident power and activation thresholds are model-dependent. The examination did not touch, open, photograph, image, decode, alter or remove a candidate object, and it did not evaluate medical causation.

Active-test metrology. A advanced technical analysis of Exemplar controlled-illumination limitation paragraph separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. Pre-trigger memory and a coarse-to-fine delay search are used because rectification, energy storage, logic wake-up, resonator settling, pulse encoding, and decay can introduce latency from microseconds to seconds. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

Appendix E. Glossary

Term	Definition
Aliasing	Apparent frequency content created when sampling is insufficient or anti-alias filtering is inadequate.
Ambient backscatter	Modulation or reflection of an already present radio signal by a passive or low-power device. See also NONSTOP and HIJACK.
Antenna factor	Frequency-dependent conversion between receiver voltage and incident electric or magnetic field under defined calibration conditions.
Baseband	The lower-frequency information, control or timing domain before modulation onto a carrier, or after demodulation.
Coherent averaging	Averaging that preserves phase relationship to a stable reference, improving repeatable components relative to uncorrelated noise.
Common-mode current	Current flowing in the same direction on multiple conductors relative to a reference, often creating unintended radiation.
Compression	Non-linear receiver or amplifier operation in which output no longer increases proportionally with input.
Detection limit	The lowest signal or field that a validated method can detect with stated probabilities of detection and false alarm.
Duty cycle	Fraction of time that a source is active during a defined interval.
Electric near field	A region where electric-field coupling and source geometry dominate and plane-wave assumptions may fail.
Harmonic	A spectral component at an integer multiple of a fundamental frequency.
Intermodulation	False or genuine frequencies formed by non-linear mixing of two or more signals.
Lock-in detection	Narrowband coherent measurement referenced to a known or estimated frequency and phase.

Term	Definition
Magnetic near field	A region where magnetic coupling and current-loop geometry dominate.
Noise figure	Degradation of signal-to-noise ratio introduced by a receiver component or chain.
Non-linear junction detector	An active instrument that transmits a fundamental and observes harmonic responses from non-linear junctions. It is not device-specific.
OCXO	Oven-controlled crystal oscillator used as a stable frequency reference.
Preselector	A filter placed before high gain or conversion to limit strong out-of-band signals and reduce overload.
RBW	Resolution bandwidth used by a receiver or spectrum analyser to separate spectral components.
Retroreflection or backscatter	Return of incident electromagnetic energy, with or without modulation, from a passive or semi-passive structure.
Spurious response	An instrument-generated or unintended response that can be mistaken for an environmental signal.
Transfer impedance	Relationship between an incident field or current and the output voltage of a probe or coupling device.
Uncertainty	A quantified parameter describing dispersion of values reasonably attributable to the measurand.
VBW	Video or post-detection bandwidth used to smooth or limit displayed response.
Controlled illumination	A separately authorised incident electromagnetic field applied to test a predeclared resonance, backscatter, nonlinear or remotely powered response hypothesis.
Direct breakthrough	Coupling of the illumination source into the receive system without requiring an environmental response.
Frequency translation	Production or reradiation of energy at a frequency different from the incident frequency through mixing, internal oscillation, division, multiplication or another conversion process.

Term	Definition
Illumination-correlated response	A reproducible measured response that follows controlled source states and survives the specified negative and receiver controls, without yet establishing device association.
Pulse-position modulation (PPM)	A modulation method in which information or timing is represented by displacement of a pulse relative to a defined frame or reference time.
SAW resonator or filter	A surface acoustic wave component that provides frequency selection, delay or resonance. A measured frequency alone does not prove its presence.
Sham illumination	A control state that reproduces commands, timing, operator movement and recording without delivering the test field.
Spatially localised response	A confirmed response that exhibits a repeatable gradient, null, bearing or coordinate bound with stated uncertainty.
Target tier	One of the three operational categories: Tier 1 timing and clock phenomena, Tier 2 radiated or conducted emissions, or Tier 3 illumination-dependent responses.
Complex permeability	Frequency-dependent permeability represented as $\mu^* = \mu' - j\mu''$, where μ' describes the field-storing component and μ'' describes the dissipative component under the stated excitation.
Initial permeability	The small-signal permeability measured near the origin of the magnetisation curve under a stated frequency, temperature, geometry and test amplitude.
Maximum permeability	The greatest differential or apparent permeability reached on a specified magnetisation curve. It is not automatically the permeability available in a weak-signal receiving probe.
Effective permeability	The permeability presented by the completed magnetic circuit after demagnetising geometry, air gaps, winding position, stress and leakage flux are included.
Incremental permeability	The small AC permeability measured about a declared DC bias point. It is essential where the probe is exposed to the Earth field, permanent magnets, mains current or magnetised steel.

Term	Definition
Demagnetising factor	A dimensionless geometry factor that opposes magnetisation in an open magnetic body. It can limit rod effective permeability far below the material intrinsic permeability.
Magnetic loss tangent	The ratio tan. Its reciprocal approximates magnetic Q only when other losses are negligible.
Saturation flux density	The flux-density region beyond which magnetisation no longer rises approximately linearly with applied field. Operation near saturation reduces sensitivity and produces harmonics and memory effects.
Skin depth	The characteristic depth over which alternating magnetic-field-induced current penetrates a conductive magnetic material. It depends on resistivity, frequency and complex permeability.
Distributed-gap powder core	A compacted, insulated alloy-powder core whose microscopic non-magnetic gaps reduce effective permeability and improve bias tolerance while introducing material-specific loss.
Magnetostriction	Dimensional change associated with magnetisation. In a receiving core it can couple vibration, mounting stress and acoustic energy into the electrical record.
Magnetic conditioning	A documented degaussing, biasing or reset process applied before calibration or deployment to control remanence and establish a reproducible magnetic state.
Composite modulation	A waveform in which more than one modulation process, information stream or subcarrier contributes to the emitted or reflected signal.
Nested modulation	A composite arrangement in which one modulated waveform becomes the baseband or subcarrier that modulates another carrier.
Subcarrier	A periodic waveform above baseband that carries information or timing and in turn modulates a higher-frequency carrier or reflective coefficient.
Cyclostationarity	Statistical periodicity in mean, variance, autocorrelation or spectral correlation, often revealing structure in an apparently noise-like signal.

Term	Definition
Pulse-position signalling, PPS	A shorthand used in this framework for a pulse-position-coded subcarrier or sequence. It is distinct from a one-pulse-per-second timing reference, written 1 PPS.
Instantaneous frequency	The time derivative of unwrapped signal phase divided by 2 pi, after a defined analytic-signal or I/Q transformation.
Independent sideband, ISB	An amplitude-modulation arrangement in which the upper and lower sidebands carry independent information or channel sets.
H-CPM	Harmonised continuous-phase modulation used in the P25 Phase 2 family, particularly the subscriber-to-infrastructure direction in the cited NTIA description.
H-DQPSK	Harmonised differential quadrature phase-shift keying used in the P25 Phase 2 family, particularly the infrastructure-to-subscriber direction in the cited NTIA description.
Modulation-neutral acquisition	Raw I/Q, waveform and spectrum acquisition that does not depend upon a demodulator label being correct.

Appendix F. Probe and Sensor Engineering Specification

This appendix converts the proposed ferrite-rod, concentrator and low-noise instrumentation concepts into a design-control specification. It does not prescribe one commercial component or one coil geometry. It defines the records, measurements and acceptance evidence required before a probe can be used for evidential interpretation. Prototype sensitivity is not sufficient. Every field configuration shall have a configuration identifier that links core material and lot, dimensions, winding design, capacitor network, concentrator geometry, shield construction, preamplifier version, cable, firmware or software dependencies, calibration results and authorised operating bands.

F.1 Probe family and intended measurement function

The probe family shall contain distinct discovery, confirmation and localisation instruments. A broad air-core loop provides predictable magnetic response and low hysteresis over a wide band, although it may lack the sensitivity of a tuned ferrite sensor. A long ferrite rod supplies directional gain at low frequencies. A shorter ferrite rod or miniature shielded loop supplies smaller spatial aperture near the candidate. A balanced electric-field plate identifies capacitive coupling. A gradiometer suppresses spatially uniform background. A calibrated higher-frequency loop, monopole or log-periodic antenna addresses the megahertz bands. Each instrument has a declared measurand, frequency range, field component, transfer factor, aperture, dynamic range and limitations.

Probe-engineering analysis. For Probe family and intended measurement function, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

No probe is labelled a device detector. The probe detects a field component or a change in field. The intended-use statement shall distinguish absolute field measurement from comparative localisation. An uncalibrated resonant rod may be highly useful for locating a relative maximum, but its output cannot be reported in teslas without a traceable transfer factor. A gradiometer output is a spatial difference over its baseline, not field at a point. An electric-field plate mounted near a person or wall measures the combined field and local capacitance. These distinctions are entered in the configuration record and repeated in the report method.

F.2 Frequency-specific configuration matrix

Configuration	Primary band and function	Mandatory companion measurement
LF-15	Tuned magnetic channel centred near 15.734 kHz, with broad discovery coverage around the line and its harmonics.	Untuned air-core loop or alternate-core rod, plus terminated-input and gain-step controls.
LF-32	Tuned magnetic channel centred near the measured 32.768 kHz family, including nearby drift and divider products.	Moderate-Q magnetic channel, independent reference clock and time-separated confirmation.
HF-3.58	Calibrated loop or small antenna around 3.579545 MHz and adjacent timing-family components.	Second antenna geometry, changed height and external-bearing comparison.
E-FIELD	Balanced electric-field plate or guarded monopole for capacitive and common-mode paths.	Magnetic probe at the same coordinate and personnel-position control.

Configuration	Primary band and function	Mandatory companion measurement
GRAD	Matched differential magnetic pair for local-gradient discrimination.	Single-ended records from both elements and channel-reversal control.
MICRO	Small-aperture loop or short rod for 3-inch convergence.	Overlap series with the outgoing larger-aperture probe.
LF-ALLOY-HIμ	Thin-ribbon, laminated or segmented high-permeability alloy channel for approximately 1 kHz to 100 kHz, subject to measured dispersion and bias limits.	Air-core or ferrite reference, DC-bias measurement, degaussing record and complex-permeability file.
MF-POWDER	Low- or moderate-permeability distributed-gap alloy powder core for approximately 100 kHz to the lower megahertz region.	Air-core or nickel-zinc ferrite reference, unloaded and loaded Q, self-resonance and receiver-overload control.

The matrix is completed for each deployed set with actual serial numbers, calibration files, preamplifier gain states, filters, sample rates and expected noise. Bands are not confined to a single bin. The 32.768 kHz configuration, for example, must preserve enough bandwidth to reveal modest frequency offset and sidebands. The 3.579545 MHz configuration must consider the receiver image and local-oscillator plan. A named centre frequency does not excuse the team from surveying the surrounding spectrum for parent signals, aliases and ordinary interference.

F.3 Ferrite and magnetic-alloy core selection

Ferrite is a ceramic magnetic material, not an iron alloy. Low-frequency rod candidates commonly use manganese-zinc ferrite because high permeability can increase inductance and effective area, while nickel-zinc ferrite commonly offers higher resistivity and useful performance at higher frequencies. Manufacturer data identify candidate material ranges, but the open magnetic circuit of a rod produces an apparent permeability strongly dependent upon length-to-diameter ratio and winding placement. Fair-Rite material 77, for example, is described for inductive designs up to 100 kHz and is available in rods [31]. Material 78 is described for power applications to 200 kHz and low-loss inductive applications to 500 kHz, including antenna or RFID rods [32]. These statements guide prototyping rather than certify the completed forensic probe.

Resonant receiving-system perspective. The technically mature interpretation of Ferrite and magnetic-alloy core selection treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

Fe-based amorphous and nanocrystalline alloys can provide high permeability and may be useful for a flux concentrator, return path or differential core. They are electrically conductive. Thin insulated tape, segmented stacks or cut-core geometry is therefore necessary to limit eddy currents. A solid iron, permalloy or other conductive alloy ring surrounding the primary winding can act as a shorted turn, introduce phase error and damp the signal. The engineering record shall state alloy, heat treatment, lamination or tape thickness, insulation, gap, saturation flux density, coercivity, loss data and expected frequency range. The assembled transfer function is decisive because machining stress and mounting pressure can alter magnetic behaviour.

The expanded profiles and engineering comparisons below use representative published data from the cited alloy manufacturers and technical reports [46-52].

These data are not imported as casework calibration values. They establish candidate materials and test conditions only.

F.3.1 Permeability is a conditional transfer property

Permeability is not a single immutable number stamped upon a core. In the linearised relation $B = \mu_0 \mu_r H$, B is magnetic flux density in teslas, μ_0 is the permeability of free space, μ_r is relative permeability and H is magnetic field strength in amperes per metre. That relation is useful only over the field, frequency and temperature region in which the material behaves approximately linearly. A very weak receiving probe normally operates near the origin of a minor hysteresis loop, while a manufacturer may publish maximum permeability measured at a larger field on a closed ring after a specialised anneal. The two values answer different engineering questions. EERF shall therefore record the permeability type, test frequency, excitation amplitude, DC bias, temperature, specimen geometry, heat treatment and measuring method whenever a permeability value is used.

Resonant receiving-system perspective. The technically mature interpretation of Permeability is a conditional transfer property treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Initial permeability μ_i is the limiting small-signal slope near zero field. Maximum permeability μ_{max} is the largest slope or apparent ratio reached along a specified magnetisation curve. Amplitude permeability μ_a describes a cyclic excursion of declared amplitude. Incremental permeability μ_Δ describes a small alternating field superimposed upon a DC operating point. Reversible permeability is the limiting response to a very small reversible perturbation. Effective permeability μe is the value presented by the assembled magnetic circuit after gaps, demagnetising field, leakage flux, winding location and mounting stress are included. Grain-oriented and stress-annealed materials may also require a permeability tensor or an explicitly stated easy-axis direction, because a scalar value conceals strong directional behaviour.

For EERF, the primary design quantity is not the largest published μmax. It is the probe transfer factor and equivalent input noise across the validated band. A core with lower intrinsic permeability can outperform an ultra-high-permeability core if it has lower loss, less Barkhausen noise, greater bias headroom, a more reproducible gap, a higher self-resonant frequency or a better directional pattern. Conversely, a material that produces impressive inductance in a bridge measurement may be unsuitable for localisation if its effective aperture is too large, its null rotates with frequency, or its permeability changes when the housing is handled.

F.3.2 Complex permeability, loss and usable bandwidth

Under alternating excitation the useful representation is complex permeability, $\mu^*(f,H,T) = \mu'(f,H,T) - j\,\mu''(f,H,T)$. The real component μ' describes the in-phase field-storing response. The loss component μ'' describes magnetic dissipation and appears electrically as loss resistance and phase rotation. A commonly used screening ratio is the magnetic loss tangent $\tan \delta m = \mu''/\mu'$. When winding resistance, dielectric loss, shield loss and amplifier loading are negligible, the core-related quality factor is approximately $Qm = \mu'/\mu''$. In a practical probe, those other losses are not negligible, so the loaded Q shall be measured rather than inferred from material data alone.

Resonant receiving-system perspective. For Complex permeability, loss and usable bandwidth, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Permeability dispersion means that μ' normally falls and μ'' may rise as frequency approaches domain-wall, spin-rotation or structural relaxation regions. A high DC or 60 Hz permeability therefore does not prove high sensitivity at 15.734 kHz, 32.768 kHz, 100 kHz or 3.579545 MHz. The EERF material coupon and completed probe shall be swept over at least one decade below and one decade above the authorised operating band, where the fixture permits, and the record shall retain complex impedance rather than only inductance. The sweep is repeated at several field amplitudes to reveal non-linearity, and with representative DC bias to reveal incremental permeability loss.

A steep permeability roll-off may still be useful for a broad absorbing or interference-suppression element, but it is usually unsuitable for a high-Q receiving resonance because the desired flux is converted into heat and phase uncertainty. The distinction is crucial for nanocrystalline and amorphous cores sold for common-mode attenuation. Their strong impedance at high frequency can arise partly from μ'', which is beneficial in an EMC suppressor but may not maximise the voltage signal or spectral selectivity of a receiving coil. EERF shall report whether a core is being used as a low-loss resonator, a broadband flux concentrator, a deliberately lossy common-mode suppressor, or a shielding element.

F.3.3 Demagnetising factor and the geometry ceiling on rod permeability

A closed toroid has a nearly continuous magnetic path and can exhibit a permeability close to the material test value. An open rod, strip stack or split concentrator has poles at its ends and develops an opposing demagnetising field. For an ellipsoidal approximation, the effective permeability may be screened by $\mu_{eff} \approx \mu_r / [1 + N_d(\mu_r - 1)]$, where Nd is the dimensionless demagnetising factor along the sensing axis. The approximation does not replace finite-element analysis or calibration of a finite cylinder, but it demonstrates the dominant effect. When μr is very large, μeff approaches approximately 1/Nd. An open rod with Nd = 0.01 is therefore geometrically limited to roughly 100, even if the intrinsic material permeability is 50,000 or 500,000.

Resonant receiving-system perspective. For Demagnetising factor and the geometry ceiling on rod permeability, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

This geometry ceiling explains why a tenfold increase in intrinsic permeability may yield almost no increase in assembled rod inductance. It also explains why long, slender rods, tapered pole pieces and carefully positioned windings can be more valuable than selecting the highest catalogue permeability. The winding samples the local flux distribution rather than an abstract average. A winding extended too close to the ends may add copper resistance and capacitance while contributing little useful flux. The EERF design series shall therefore vary aspect ratio, winding-zone length, gap, pole shape and concentrator position while holding receiver noise and calibration fixture constant.

For anisotropic sheet or ribbon, the material easy axis shall be aligned with the intended flux path and recorded in the probe coordinate system. A stack assembled with alternating or uncertain rolling direction can have lower and more variable μ_{eff}. Gaps, joints and insulating layers dominate reluctance in high-permeability circuits. Their dimensions shall be measured, not merely described as small. If a concentrator is removable, keyed mechanical features shall reproduce its axial and angular position to a tolerance demonstrated by repeated transfer-factor measurements.

F.3.4 Conductivity, skin depth, lamination and ribbon thickness

Metallic magnetic alloys conduct electricity. A changing magnetic field induces circulating current within the core, and that current opposes flux penetration, increases loss and rotates phase. For a preliminary homogeneous-material estimate, skin depth is $\delta = \sqrt{[2\rho/(\omega \mu_0 \mu_r)]}$, where δ is in metres, ρ is resistivity in ohm-metres, $\omega = 2\pi f$ is angular frequency in radians per second, μ_0 is free-space permeability and μ_r is the assumed relative permeability. Real soft magnetic material has complex, frequency-dependent permeability, so this formula is a screening calculation rather than a final model. It nevertheless shows why thick solid permalloy, iron-cobalt or silicon-steel rods can be poor high-sensitivity receivers at tens of kilohertz.

Advanced practitioner analysis. A technically mature treatment of Conductivity, skin depth, lamination and ribbon thickness begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Eddy-current control requires thin insulated laminations, amorphous or nanocrystalline ribbon, insulated powder particles, axial slots, segmented stacks or an intentionally open magnetic path. The lamination plane and ribbon winding direction must force induced current into the smallest practical loop. A circumferential metallic sleeve, closed alloy ring or unbroken shield around the primary winding is prohibited unless its electromagnetic function and loss have been explicitly validated, because it can behave as a shorted turn. Tape-wound cores require interlaminar insulation and may need a physical gap or cut to prevent the core itself from forming an electrically continuous loop around the sensing winding.

The material resistivity and thickness shall be retained in the design file, but the decisive test is the complex impedance of the final assembly. Machining a slot can introduce stress and burrs that bridge insulation. Stacking laminations with conductive adhesive can restore eddy-current paths. Metallic fasteners can close a loop across a deliberate gap. The inspection includes four-wire resistance where applicable, optical examination of insulating barriers during manufacture, and a frequency sweep before and after the core is installed in the housing.

F.3.5 Saturation, remanence, magnetic noise and mechanical stress

High permeability is useful only while the core remains in a reproducible minor-loop region. The Earth field, magnetised structural steel, loudspeaker magnets, motors, current-carrying cables and the probe own fastening hardware can impose a DC bias that reduces incremental permeability. Low-saturation alloys such as high-nickel or cobalt-rich ultra-high-permeability ribbon can lose sensitivity before a high-saturation iron-cobalt or silicon-iron material does. A probe intended for a premises containing lifts, transformers, medical magnets or heavy current distribution shall therefore be tested under representative DC and low-frequency bias, not solely inside a quiet calibration shield.

Remanence creates history dependence. Two otherwise identical scans can differ because the probe approached a magnetised object from a different direction or experienced a transport shock. A documented degaussing or magnetic reset process may be used before calibration and deployment, provided it does not create emissions in the controlled scene. The residual field is measured after conditioning. If the probe cannot be reset reproducibly, the uncertainty budget and deployment sequence shall include magnetic history as a contribution. Recovery after deliberate overdrive is tested because some materials retain a changed permeability or offset for minutes or hours.

Magnetic noise includes hysteretic loss, Barkhausen discontinuities, magnetic viscosity, thermally driven magnetisation fluctuation and magneto-mechanical conversion. Magnetostriction couples vibration and clamp stress into the winding. A high-permeability core may therefore raise both signal and low-frequency noise. EERF qualification measures output noise with the probe in a magnetically quiet enclosure, then repeats it while the support is gently loaded, the cable is moved outside the active interval, the temperature is changed and the core is exposed to a declared bias. The accepted material is the one that improves validated signal-to-noise ratio and localisation, not merely unloaded inductance.

F.3.6 Metallurgical families and the meaning of the comparative ratings

The candidate materials fall into five broad families. Nickel-iron and nickel-iron-molybdenum alloys minimise anisotropy and can achieve exceptional weak-field permeability after specialised annealing, but their saturation and conductivity limit some uses. Iron-cobalt-vanadium and silicon-iron steels provide greater saturation and bias tolerance, although their permeability is lower and thin laminations are essential as frequency rises. Distributed-gap powder alloys deliberately trade permeability for bias tolerance, controlled inductance and broad frequency response. Rapidly quenched amorphous ribbon removes long-range crystalline order and can combine high resistivity, low coercivity and thin sections. Nanocrystalline iron-based ribbon uses exchange-coupled nanoscale grains to obtain high permeability, low coercivity and useful high-frequency behaviour.

Advanced technical elaboration. For expert practice, Metallurgical families and the meaning of the comparative ratings is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The tables below use Preferred, Conditional and Normally exclude as engineering screening categories. Preferred means the material is a strong prototype candidate for at least one sensing, return-path or concentrator role in the stated band. Conditional means a selected grade, thickness, gap and geometry may work, but frequency-dependent loss, bias, stress or self-resonance must be demonstrated. Normally exclude means another material family is ordinarily a better starting point for a low-noise receiving core, although a special shielding or absorber role may remain. The ratings do not authorise a material for casework and do not replace calibration.

Manufacturer data are usually obtained on closed rings, toroids, Epstein strips, single-sheet specimens or power-inductor geometries. EERF uses open rods, split concentrators and small-signal receiving coils. Published permeability, loss and saturation values are therefore representative markers only. The final selection is based on measured μ', μ'', transfer factor, equivalent input noise, Q, self-resonance, bias response, temperature drift, axial pattern, cross-axis rejection and transport stability in the completed probe.

Table F-3A. Permeability quantities that shall not be conflated

Quantity	Meaning	EERF control
μr, relative permeability	Dimensionless ratio used in a stated linearised condition.	Only with frequency, field, temperature and geometry stated.
μi, initial permeability	Small-signal slope near the origin of the magnetisation curve.	Useful for weak fields, but vulnerable to bias, stress and test-fixture differences.
μmax, maximum permeability	Largest slope or apparent ratio on a specified curve.	Can greatly exceed the permeability available in an actual receiving minor loop.
μa, amplitude permeability	Ratio for a declared cyclic field amplitude.	Changes with excitation amplitude and hysteresis.
μΔ, incremental permeability	Small AC response about a declared DC bias point.	Mandatory for probes used near permanent magnets or current-carrying services.
μrev, reversible permeability	Limiting reversible response to a minute perturbation.	Relevant to ultra-weak sensing, but difficult to reproduce without controlled magnetic history.
μe, effective permeability	Assembled value after gaps, demagnetising field and leakage.	The most relevant permeability for inductance and transfer modelling of an open probe.
μ'	Real component of complex permeability.	Supports flux storage and induced signal.
μ''	Loss component of complex permeability.	Contributes loss, phase rotation, heating and magnetic noise.

Quantity	Meaning	EERF control
tan δm	Magnetic loss tangent μ''/μ'.	Screening indicator. Loaded Q still requires direct measurement.

Table F-3B. Illustrative skin-depth screening for a conductive high-permeability nickel alloy

Frequency	Calculated δ	Interpretation
15.734 kHz	31.1 μm	Even a 0.10 mm lamination is more than three skin depths under the assumed μr.
32.768 kHz	21.5 μm	Thin ribbon or insulated laminations are strongly preferred to solid stock.
100 kHz	12.3 μm	Permeability dispersion and interlaminar insulation become decisive.
3.579545 MHz	2.06 μm	The simple model indicates severe penetration loss. Use air-core, NiZn ferrite or qualified low-μ powder first.

Assumptions for Table F-3B: resistivity ρ = 60 μΩ·cm, constant μr = 10,000, homogeneous material and sinusoidal excitation. The calculation is intentionally conservative and illustrative. Actual μr is complex and frequency-dependent, while laminations, ribbon insulation, gaps and open geometry change current paths. The completed-probe impedance measurement governs.

F.3.7 Comparative register of sixteen alloy core and concentrator candidates

The following register identifies representative commercially documented grades or alloy classes. Trade names are retained where they anchor a published material data set. Equivalent material from another supplier shall not be presumed equivalent merely because its nominal chemistry is similar.

Anneal, impurity control, grain size, powder insulation, ribbon thickness, gap, stress state and quality control can produce materially different permeability and loss.

Probe-engineering analysis. For Comparative register of sixteen alloy core and concentrator candidates, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response.

The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map.

The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Table F-3C. Comparative screening register

Alloy or representative grade	Representative published marker	EERF suitability and limiting mechanism
1. PERMIMPHY, 80Ni-5Mo-Fe strip	DC μ at 0.4 A/m: 470,000 to 520,000 depending thickness; AC permeability marker 75,000 at 60 Hz; Bsat 0.75 T; ρ 60 μΩ·cm after specified hydrogen anneal [46].	Preferred for shielded weak-field DC to low-kilohertz work. Conditional at 15.734 and 32.768 kHz only as thin, insulated, segmented material. Low saturation, stress sensitivity and eddy currents limit bias and upper frequency.
2. IMPHY SUPRA 50, 48Ni-Fe strip	μmax 200,000; AC permeability marker 12,500; Bsat 1.50 T; ρ 45 μΩ·cm in the published ring condition [47].	Preferred where more bias headroom is required than 80Ni alloy. Conditional through tens of kilohertz in thin lamination. Conductivity and lower high-frequency permeability limit MHz use.
3. IMPHY AFK 502 R, 49Co-49Fe-2V	μr,max about 8,000 to 11,000 by thickness; saturation about 2.35 T; ρ about 40 μΩ·cm; supplied in 0.05 to 0.35 mm strip [48].	Preferred as a high-saturation pole or concentrator near strong bias. Not the first choice for the weakest signals. Thin 0.05 to 0.10 mm laminations are required as frequency rises.
4. Grain-oriented 3% Si-Fe	Representative 0.10 mm sheet, saturation about 2.0 T; strong rolling-direction behaviour; published loss rises markedly from 400 Hz to 5-20 kHz [49].	Preferred below several kilohertz when flux follows the rolling direction. Conditional at 15.734 kHz. Normally excluded for isotropic miniature rods and high-Q MHz channels.

Alloy or representative grade	Representative published marker	EERF suitability and limiting mechanism
5. JNEX uniform 6.5% Si-Fe sheet	10JNEX900, 0.10 mm; saturation 1.8 T; very low magnetostriction; improved high-frequency loss compared with ordinary 3% Si steel [49].	Preferred prototype for 1-20 kHz laminated concentrators and conditional near 32.768 kHz. Brittle sheet and conductive loss limit small solid rods and MHz resonators.
6. JNHF/JNSF/JNRF Si-gradient steels	0.10 to 0.15 mm; saturation 1.9 to 2.0 T. JNHF/JNSF are optimised around high-frequency loss, especially 10-20 kHz; JNRF favours lower-frequency high flux [49].	Select grade by band. JNHF/JNSF are strong 15.734 kHz candidates. JNRF is better where DC to several kilohertz bias tolerance dominates. All require laminated, oriented construction.
7. MPP, 81Ni-17Fe-2Mo powder	Distributed-gap permeability grades 14 to 550; Bsat about 0.8 T; very low core loss, high Q and strong temperature stability. Frequency flatness depends sharply on permeability grade [50].	Preferred for reproducible tuned probes from kilohertz through sub-megahertz. Lower-μ grades can extend into lower MHz. High-μ grades lose bandwidth and saturation headroom.
8. High Flux, 50Ni-50Fe powder	Distributed-gap permeability 14 to 160; Bsat about 1.5 T; 60μ grade approximately flat to 1 MHz in the manufacturer toroid data [50].	Preferred when DC bias or strong ambient field would compress MPP or high-μ ribbon. Higher loss than MPP reduces weak-signal Q. Use low-μ grades for MHz work.
9. Sendust/Kool Mμ, Fe-Si-Al powder	Distributed-gap permeability 14 to 125; Bsat about 1.0 T; low magnetostriction; 60μ grade approximately flat to 5 MHz in manufacturer toroid data [50].	Preferred broad prototype for 15.734 kHz, 32.768 kHz and selected 3.579545 MHz work. Moderate permeability limits absolute sensitivity but improves stability, headroom and self-resonance.

Alloy or representative grade	Representative published marker	EERF suitability and limiting mechanism
10. XFlux, 6.5% Si-Fe powder	Distributed-gap permeability 19 to 125; Bsat about 1.6 T; 60μ grade approximately flat to 4 MHz in manufacturer toroid data [50].	Preferred where high saturation and broad response outweigh higher core loss. Conditional for 3.579545 MHz, using low-μ grade and measured Q. Not an ultra-high-sensitivity core.
11. Metglas 2605SA1, Fe-based amorphous ribbon	23 μm ribbon; Bsat 1.56 T; maximum DC permeability up to 600,000 after anneal; ρ 130 μΩ·cm; magnetostriction 27 ppm [51].	Preferred for very sensitive 15.734 and 32.768 kHz tape or segmented structures. High magnetostriction requires exceptional mechanical control. Conditional above 100 kHz.
12. Metglas 2605S3A, Fe-based amorphous ribbon	18 μm ribbon; Bsat 1.41 T; maximum DC permeability about 35,000 annealed; ρ 138 μΩ·cm [51].	Preferred for lower-loss, broader tens-to-hundreds-of-kilohertz structures where 2605SA1 is too stress-sensitive or too sharply permeable. Conditional in lower MHz after direct characterisation.
13. Metglas 2826MB, Fe-Ni-based amorphous ribbon	29 μm ribbon; Bsat 0.88 T; maximum DC permeability up to 800,000 annealed; ρ 138 μΩ·cm [51].	Preferred for shielded ultra-weak low- and mid-kilohertz sensing. Lower saturation and thicker ribbon demand bias screening. Normally excluded from strong-field and high-Q MHz work.
14. Metglas 2705M, Co-based amorphous ribbon	22 μm ribbon; Bsat 0.77 T; maximum DC permeability about 290,000 as cast; ρ 136 μΩ·cm; near-zero magnetostriction [51].	Preferred where low microphonic coupling and strong weak-field response are needed from kilohertz into selected sub-megahertz ranges. Low saturation requires strict bias control.

Alloy or representative grade	Representative published marker	EERF suitability and limiting mechanism
15. Metglas 2714A, Co-based amorphous ribbon	15 μm ribbon; Bsat 0.57 T; maximum DC permeability up to 1,000,000 annealed; ρ 142 μΩ·cm; near-zero magnetostriction [51].	Preferred for the weakest fields in magnetically quiet 15.734 and 32.768 kHz service. Very low saturation and extreme stress sensitivity limit use near magnets, steel and strong mains fields.
16. VITROPERM 500 F / 550 HF, Fe-Si-B-Nb-Cu nanocrystalline ribbon	Typical |μ| about 20,000 to 100,000 at 10 kHz for 550 HF; Bsat about 1.21 T; ρ 115 μΩ·cm; 17-25 μm ribbon. 550 HF improves permeability above 100 kHz relative to 500 F [52].	Preferred from tens of kilohertz through sub-megahertz as tape-wound, split or gapped structures. At MHz the material may be intentionally lossy, so receiving Q and phase must be measured rather than inferred from EMC impedance.

F.3.8 80Ni-5Mo-Fe high-permeability nickel alloy

The 80% nickel, 5% molybdenum, iron-balance family is the classic very-high-permeability shielding and sensing alloy. The current PERMIMPHY sheet data report DC permeability of approximately 470,000 for 1.0 mm material and 520,000 for 0.34 mm material at 0.4 A/m, together with an AC permeability marker of 75,000 at 60 Hz. Saturation induction is approximately 0.75 T and resistivity approximately 60 μΩ·cm after the stated 1,170 °C dry-hydrogen heat treatment [46]. Those figures illustrate the attraction and the danger. The alloy can strongly concentrate a minute field, yet it has modest saturation and remains conductive.

Sensor and front-end elaboration. At advanced-practitioner level, 80Ni-5Mo-Fe high-permeability nickel alloy is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

For EERF, 80Ni-5Mo-Fe is a preferred candidate for a shielded low-frequency flux concentrator, split return yoke, differential sensor core or laminated open rod below approximately 10 kHz. It may be tested at 15.734 kHz and 32.768 kHz when supplied as thin strip or foil with insulation, an interrupted circumferential path and a measured complex-permeability curve. It is not to be machined into a thick solid sleeve around the winding. At the upper end of the 10-100 kHz band, eddy-current loss, permeability roll-off and phase rotation can outweigh the gain in μi.

Heat treatment and mechanical handling are controlling variables. Bending, punching, spot welding, clamp pressure and even cure shrinkage can degrade permeability. The final part should be formed before the approved anneal wherever the supplier process permits. Field staff shall not undertake hydrogen annealing. The supplier or qualified magnetic-materials facility shall certify the cycle and atmosphere. Acceptance includes residual-field measurement, three-axis bias testing, vibration sensitivity, repeated assembly and a comparison against a lower-permeability reference core. A high reading is rejected if it is accompanied by unstable baseline, strong memory, shallow null or excessive μ''.

F.3.9 48Ni-Fe high-saturation nickel alloy

The approximately 48% nickel, iron-balance family occupies a useful middle ground between ultra-high-permeability 80Ni alloys and high-saturation iron-cobalt or silicon steel. The IMPHY SUPRA 50 data report saturation induction about 1.50 T, maximum permeability about 200,000, an AC permeability marker of 12,500 in the published 400 Hz ring condition, resistivity 45 μΩ·cm and coercive force about 2.8 A/m after the specified hydrogen anneal [47]. Compared with 80Ni-5Mo-Fe, it sacrifices some weak-field permeability but roughly doubles the saturation induction.

Probe-engineering analysis. At advanced-practitioner level, 48Ni-Fe high-saturation nickel alloy is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

This trade is valuable where a probe must operate near building steel, current-carrying conductors or permanent-magnet fringe fields. Thin SUPRA 50 laminations can serve as a split concentrator, pole piece or return path for DC through several kilohertz, and may remain useful at 15.734 kHz when lamination thickness, rolling direction and loss are controlled. A 0.35 mm sheet value must not be extrapolated to 32.768 kHz without a complex-impedance test. For that band, thinner stock, insulated laminations or a short segmented path is preferable.

SUPRA 50 is usually less appropriate for a high-Q 3.579545 MHz receiving core. Its conductivity and lamination scale make the eddy-current and dispersion burden substantial. It can still be useful as a remote magnetic shield or low-frequency flux guide that is physically separated from the MHz coil, provided it does not distort the desired antenna pattern. The qualification comparison should include an 80Ni alloy, a high-saturation powder core and an air-core sensor under the same bias field so the engineering decision is based on signal-to-noise ratio rather than saturation alone.

F.3.10 Fe-49Co-2V iron-cobalt-vanadium alloy

Iron-cobalt-vanadium alloys such as IMPHY AFK 502 R are selected for exceptional saturation rather than exceptional initial permeability. The representative chemistry is 49% cobalt, 49% iron and 2% vanadium. Published data show saturation near 2.35 T, maximum relative permeability commonly around 8,000 to 11,000 depending strip thickness and processing, resistivity about 40 μΩ·cm, and available strip examples from 0.05 to 0.35 mm [48]. The material therefore tolerates a much larger DC or alternating flux excursion than 80Ni or cobalt-rich ultra-high-permeability amorphous ribbon.

Sensor and front-end elaboration. At advanced-practitioner level, Fe-49Co-2V iron-cobalt-vanadium alloy is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

For EERF, AFK 502 R is a conditional receiving-core material but a preferred high-bias pole, flux collector or overload-resistant concentrator. It is useful where a very permeable core would be partially saturated by nearby magnetised steel, a transformer, a loudspeaker, an MRI fringe-field boundary or a heavy current service. The lower permeability means fewer turns may not suffice, so winding noise and capacitance must be reconsidered. Its high saturation does not excuse a bias survey, because the probe can still develop non-linearity and harmonics before nominal saturation if the magnetic circuit contains narrow pole regions or gaps.

The alloy is conductive and its loss depends strongly on thickness. The 0.05 mm and 0.10 mm forms are substantially more credible at tens of kilohertz than 0.20 mm or 0.35 mm sheet. A laminated stack shall preserve interlaminar insulation and rolling direction. The material requires post-forming heat treatment under a controlled supplier process. It is normally excluded from the 3.579545 MHz resonant core unless a very thin, small, open structure demonstrates acceptable μ', μ'', Q and self-noise. Even then, a NiZn ferrite and air-core comparison is mandatory.

F.3.11 Grain-oriented 3% silicon-iron electrical steel

Grain-oriented approximately 3% silicon-iron is engineered so that its best magnetic properties lie along the rolling direction. The silicon raises electrical resistivity and reduces magnetostriction relative to pure iron, while the crystallographic texture produces high permeability and low loss in the preferred direction. Representative 0.10 mm grain-oriented material has saturation about 2.0 T. The JFE comparison shows low loss at 50 Hz and 400 Hz but a pronounced rise by 5 kHz, 10 kHz and 20 kHz, and it emphasises poor properties away from the rolling direction [49].

This material can be a useful low-frequency laminated return path, long pole piece or directional concentrator when the flux direction is known and the assembly can maintain alignment. It is preferred below approximately 1 kHz and conditional from 1 to 20 kHz. At 15.734 kHz, thin 0.10 mm sheet may be investigated for a split yoke, but the measured loss and angular response must be compared with high-silicon, amorphous and nanocrystalline alternatives. At 32.768 kHz, ordinary grain-oriented sheet is usually a secondary candidate rather than the first choice.

A stack of narrow strips can create a highly directional probe, but the rolling direction of every strip shall be marked and recorded. Burrs, shorted laminations and transverse joints destroy the expected advantage. The material is unsuitable for a cylindrical isotropic rod unless the assembly geometry deliberately accommodates its anisotropy. It is normally excluded from high-Q MHz receiving cores. At those frequencies, thin NiZn ferrite, lower-permeability powder or air-core structures generally provide more predictable transfer and lower conductive loss.

F.3.12 Uniform 6.5% silicon-iron sheet, JNEX class

Uniform 6.5% silicon-iron reaches a composition at which permeability and electrical resistivity improve and magnetostriction approaches zero, although the sheet becomes difficult to process by conventional rolling. JFE 10JNEX900 is produced as 0.10 mm sheet by siliconising a thinner low-silicon substrate. Published representative values include saturation about 1.8 T, iron loss 0.5 W/kg at 50 Hz and 1.0 T, 5.7 W/kg at 400 Hz and 1.0 T, and materially controlled loss through 5 kHz to 20 kHz at lower flux densities. Magnetostriction is reported near 0.1 × 10^-6 in the cited condition [49].

Evidential reasoning elaboration. A mature forensic approach to Uniform 6.5% silicon-iron sheet, JNEX class separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

JNEX is a strong candidate for a low-microphonic laminated concentrator covering 1 kHz through the 15.734 kHz region. The 0.10 mm thickness is still much greater than the illustrative skin depth calculated for an ultra-high-permeability nickel alloy, but JNEX has a different permeability, resistivity and loss mechanism. It must be assessed from its own complex permeability and transfer factor. At 32.768 kHz it is conditional. A narrow, segmented, axially oriented stack may provide useful saturation headroom and mechanical stability, while a closed ring or thick block is likely to be too lossy.

The material is brittle compared with ordinary electrical steel. Cutting, punching and bending can create edge damage and stress. The EERF build shall use supplier-approved processing, insulated layers and low-stress clamping. JNEX is normally excluded from the 3.579545 MHz high-Q core, although a very small thin-lamination flux guide might be tested as a secondary structure. Its principal value is the combination of respectable saturation, low magnetostriction and better tens-of-kilohertz loss than conventional 3% silicon steel.

F.3.13 Silicon-gradient JNHF, JNSF and JNRF electrical steels

JFE silicon-gradient steels place more silicon near the sheet surfaces and less in the centre. This distribution can reduce eddy-current loss while preserving higher saturation than uniform 6.5% silicon steel. Representative grades include 10JNHF600 at 0.10 mm and approximately 1.9 T saturation, 15JNSF950 at 0.15 mm and approximately 2.0 T, and 10JNRF at 0.10 mm and approximately 2.0 T. The manufacturer reports that JNHF and JNSF are particularly effective in the 10 kHz to 20 kHz region, while JNRF is optimised for lower-frequency high-flux operation up to several kilohertz [49].

This family permits the probe designer to choose metallurgy by target band rather than treating silicon steel as one material. JNHF or JNSF is a preferred prototype for a 15.734 kHz laminated pole or concentrator, because that frequency lies directly within the region for which the cited eddy-current advantage is discussed. A 32.768 kHz channel remains conditional and requires measured μ' and μ'', since the published power-core loss points do not establish receiving sensitivity at that frequency. JNRF is preferred where DC to several kilohertz bias tolerance and approximately 2 T saturation are more important than the lowest 15-20 kHz loss.

The three grades shall not be grouped under one configuration identifier. Grade, thickness, silicon profile, rolling direction and lot are separate controlled attributes. The stack shall use insulated layers and an open or gapped path. Because the published comparisons use specified flux densities, the EERF team shall also test at weak-field amplitudes representative of passive receiving. A material that has low power loss at 0.1 T may still exhibit a different small-signal permeability, noise and stress response near the nanotesla or picotesla measurement domain.

F.3.14 Molypermalloy powder, MPP

Molypermalloy powder is an insulated distributed-gap alloy powder containing approximately 81% nickel, 17% iron and 2% molybdenum. The distributed microscopic gaps lower effective permeability and provide a smooth bias characteristic. Magnetics publishes permeability grades from 14 to 550, saturation flux density about 0.8 T, and describes MPP as having very low core loss, high Q and strong temperature stability. The manufacturer frequency table illustrates the grade trade-off. A 60μ grade is approximately flat to 2 MHz, 125μ to 300 kHz, 200μ to 100 kHz, 300μ to 90 kHz and 550μ to only about 20 kHz in the stated toroidal conditions [50].

Sensor and front-end elaboration. The technically mature interpretation of Molypermalloy powder, MPP treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

For the 15.734 kHz and 32.768 kHz timing channels, MPP offers a highly controllable alternative to ultra-high-permeability ribbon. The 125μ, 200μ or 300μ grades can provide useful inductance while retaining materially better bias tolerance and reproducibility than a closed 80Ni sheet core. The 550μ grade may be attractive at 15.734 kHz but is already beyond the manufacturer flatness marker at 32.768 kHz, so it is not automatically the more sensitive choice. The final decision requires loaded Q, noise and transfer-factor testing with the actual winding.

For 3.579545 MHz, only the lower-permeability MPP grades should enter the prototype set. The 14μ or 26μ grade can provide modest flux concentration without imposing the capacitance and loss of a high-μ core, but an air-core and NiZn ferrite reference remain mandatory. Powder cores are usually supplied as toroids, E-cores or blocks rather than long antenna rods. A custom cylinder or segmented bar must therefore be treated as a new geometry, with density, binder, particle insulation and machining damage included in qualification.

F.3.15 High Flux 50Ni-50Fe powder

High Flux powder is a distributed-gap 50% nickel, 50% iron alloy. It combines moderate controlled permeability with approximately 1.5 T saturation, about twice the saturation of MPP according to the manufacturer comparison. Published grades extend from 14 to 160. The frequency-flatness markers vary from approximately 3 MHz for 14μ, 1.5 MHz for 26μ, 1 MHz for 60μ, 700 kHz for 125μ, 500 kHz for 147μ and 400 kHz for 160μ in the stated toroidal data [50]. Core loss is higher than MPP, but bias tolerance is substantially better.

System-level interpretation. A technically mature treatment of High Flux 50Ni-50Fe powder begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

High Flux is therefore a preferred material when the premises contain strong DC or low-frequency magnetic bias that would compress a high-nickel ribbon core. A 60μ or 125μ grade can be effective for 15.734 kHz and 32.768 kHz discovery while remaining stable near current-carrying services. The lower permeability may require more turns, so copper noise, distributed capacitance and self-resonance must be jointly optimised. The probe should include a bias monitor because the apparent stability of inductance does not prove absence of local non-linearity.

At 3.579545 MHz, the 14μ or 26μ grades are conditional candidates. The published flatness marker is not a receiving-antenna Q guarantee. Core loss, winding loss and housing capacitance shall be measured. A high-bias powder core can also be valuable as a compact differential or gradiometer element, where matched permeability and temperature tracking matter more than maximum absolute sensitivity. Matched pairs are accepted only after complex-impedance and field-transfer matching over temperature.

F.3.16 Sendust or Kool Mμ iron-silicon-aluminium powder

Sendust-class iron-silicon-aluminium powder combines distributed gap, near-zero magnetostriction, moderate saturation and useful high-frequency stability. The current Magnetics comparison labels Kool Mμ as FeSiAl, with permeability grades 14 to 125, saturation about 1.0 T and a 60μ frequency-flatness marker around 5 MHz. Lower-permeability grades extend farther, while higher-permeability grades roll off sooner. The same data show lower loss than conventional powdered iron and no thermal ageing from an organic binder process [50].

This is one of the most versatile EERF prototype materials. It is preferred for robust 15.734 kHz and 32.768 kHz tuned probes where the team values predictable permeability, low audible magnetostriction and greater bias headroom over the ultimate weak-field gain of an ultra-high-μ ribbon. A 60μ or 90μ core can produce a moderate-Q channel with manageable settling time. A 14μ, 26μ or 40μ grade is a credible 3.579545 MHz candidate, especially when the required inductance can be obtained without excessive turns.

The limitation is sensitivity per unit volume. A distributed-gap core does not concentrate flux as strongly as an annealed 80Ni or cobalt-rich amorphous ribbon. Increasing turn count to compensate can raise copper resistance and self-capacitance. The design should compare larger core cross-section, lower-noise preamplifier and moderate resonance rather than automatically adding turns. Because powder material can vary with compaction, particle insulation and machining, a custom rod or block is qualified by lot and geometry. Chipped surfaces are sealed only with a low-loss non-magnetic coating whose dielectric effect has been measured.

F.3.17 XFlux 6.5% silicon-iron powder

XFlux is an insulated 6.5% silicon-iron powder core with distributed gap. The manufacturer publishes permeability grades from 19 to 125, saturation about 1.6 T and strong DC-bias capability. Representative frequency-flatness markers are approximately 6 MHz for 19μ, 5 MHz for 26μ, 4 MHz for 40μ and 60μ, and approximately 1 MHz for 125μ. Core loss is higher than MPP and the lower-loss sendust variants, but saturation and soft-bias behaviour are attractive [50].

System-level interpretation. For expert practice, XFlux 6.5% silicon-iron powder is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

For EERF, XFlux is preferred where a probe must retain response in a magnetically cluttered setting and where moderate permeability is acceptable. The 60μ or 125μ grades suit the 15.734 kHz and 32.768 kHz channels, subject to winding optimisation. The 19μ to 60μ grades are conditional candidates at 3.579545 MHz. Their value is not that they create an enormous magnetic gain, but that they can provide a reproducible inductance and limited flux concentration while tolerating stronger fields than high-nickel material.

The higher loss must be treated as an electrical and metrological cost. It broadens resonance, increases equivalent series resistance and may increase thermal magnetic noise. A broad response can be desirable for initial discovery, but it shall not be misrepresented as a high-Q spectral filter. The probe portfolio may deliberately pair XFlux as a stable broadband discovery core with MPP, NiZn ferrite or air core as the confirmation channel. Agreement across different loss mechanisms is stronger evidence than two nominally identical XFlux probes.

F.3.18 Metglas 2605SA1 iron-based amorphous ribbon

Metglas 2605SA1 is an iron-based amorphous ribbon supplied at approximately 23 μm thickness. Representative manufacturer data give saturation induction 1.56 T, maximum DC permeability about 600,000 after anneal and 45,000 as cast, resistivity 130 μΩ·cm and saturation magnetostriction about 27 ppm [51]. Rapid solidification produces a thin non-crystalline ribbon with low coercivity and substantially reduced eddy-current path compared with conventional sheet.

Advanced practitioner analysis. For expert practice, Metglas 2605SA1 iron-based amorphous ribbon is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The combination of high saturation and very high annealed permeability makes 2605SA1 a strong candidate for 15.734 kHz and 32.768 kHz tape-wound, folded-strip or segmented concentrator structures. It can provide more bias headroom than 80Ni-5Mo-Fe while retaining high weak-field response. The ribbon shall be insulated between layers, and the magnetic path shall be split or gapped to avoid a shorted conductive ring. A narrow stack aligned with the sensing axis may be more suitable than a closed toroid for a directional probe.

Its principal forensic-instrument limitation is magnetostriction. Mechanical vibration, adhesive shrinkage, clamping and thermal expansion can modulate permeability and create microphonic output. The completed probe requires vibration and handling tests at the same gain used for weak-signal acquisition. A soft support and quiet housing may reduce mechanical transfer, but excessive damping material can add dielectric loss or magnetic contamination. Above approximately 100 kHz the material is conditional. At 3.579545 MHz it is normally a poor starting point for a high-Q core unless a small thin-ribbon structure demonstrates favourable complex permeability and noise.

F.3.19 Metglas 2605S3A iron-based amorphous ribbon

Metglas 2605S3A is an 18 μm iron-based amorphous ribbon with representative saturation induction 1.41 T, maximum DC permeability around 35,000 after anneal, resistivity 138 μΩ·cm and saturation magnetostriction about 20 ppm [51]. Its permeability is much lower than annealed 2605SA1, but the thinner ribbon and material design support useful high-frequency core performance and lower loss above approximately 1 kHz in its intended applications.

For EERF, 2605S3A is a preferred candidate when a 2605SA1 probe is too mechanically sensitive, too sharply resonant or too lossy above tens of kilohertz. It is well placed for 32.768 kHz and the 100 kHz to several-hundred-kilohertz development band, provided the final μ' and μ'' are measured. At 15.734 kHz it may deliver less gain than a higher-permeability ribbon but better stability and a broader capture range for drift or modulation sidebands.

The material is conditional in the lower MHz region. The thin ribbon helps, but the designer shall not equate a high-frequency transformer application with a low-noise receiving resonator. The test must separate magnetic loss, winding loss and amplifier loading. Because magnetostriction remains appreciable, the same microphonic controls used for 2605SA1 apply. A comparative blind localisation trial should determine whether the broader, lower-gain response improves practical source convergence.

F.3.20 Metglas 2826MB iron-nickel amorphous ribbon

Metglas 2826MB is an iron-nickel-based amorphous ribbon approximately 29 μm thick. Representative data show saturation induction 0.88 T, maximum DC permeability up to 800,000 after anneal and greater than 50,000 as cast, resistivity 138 μΩ·cm and magnetostriction about 12 ppm [51]. It offers extremely high weak-field permeability with better resistivity and thinner section than conventional crystalline nickel-iron sheet, but lower saturation than iron-based amorphous grades.

The material is preferred for shielded 15.734 kHz and 32.768 kHz probes intended to detect minute magnetic timing leakage in a relatively quiet bias environment. It can be configured as a split tape core, layered pole pair or differential element. The designer should use a deliberate gap to stabilise effective permeability and increase bias headroom. Because the intrinsic μ can be very high, open-rod geometry will often dominate μeff. More material permeability may therefore add little signal while increasing loss and memory.

2826MB is less suitable near strong magnets, steel corners and high-current cables. A DC-bias map is required before the probe is advanced into such regions. Its 29 μm ribbon is thicker than 2714A and 2605S3A, so upper-frequency loss shall be measured carefully. It is conditional above 100 kHz and normally excluded as the first choice at 3.579545 MHz. A lower-μ powder or NiZn ferrite core usually offers a more predictable MHz resonator.

F.3.21 Metglas 2705M cobalt-based amorphous ribbon

Metglas 2705M is a cobalt-based amorphous ribbon approximately 22 μm thick, with representative saturation induction 0.77 T, maximum DC permeability about 290,000 as cast, resistivity 136 μΩ·cm and saturation magnetostriction below 0.5 ppm [51]. Near-zero magnetostriction is a major advantage for a forensic receiving probe because mechanical stress and vibration are less readily converted into permeability modulation than in strongly magnetostrictive iron-based ribbon.

System-level interpretation. For expert practice, Metglas 2705M cobalt-based amorphous ribbon is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

2705M is preferred for sensitive 15.734 kHz and 32.768 kHz channels where microphonics have limited 2605SA1. It is also a strong sub-megahertz candidate, subject to complex-permeability measurement, because the thin ribbon and high resistivity control eddy currents. A gapped, segmented tape assembly can provide useful sensitivity without the extreme low-saturation vulnerability of 2714A. The probe should still include a bias monitor and degaussing record because 0.77 T is modest compared with high-flux steels and powders.

The trade-offs are cost, material availability and lower saturation than iron-based amorphous or FeCo alloys. At 3.579545 MHz it is conditional rather than preferred. The loss component may be useful for a broad detector but detrimental to a narrow resonator. The material shall be compared with low-μ sendust, XFlux, MPP, NiZn ferrite and air core in the same winding fixture. A decision based only on DC permeability is rejected.

F.3.22 Metglas 2714A ultra-high-permeability cobalt-based ribbon

Metglas 2714A is a cobalt-based amorphous ribbon approximately 15 μm thick. Representative manufacturer values include saturation induction 0.57 T, maximum DC permeability up to 1,000,000 after anneal and greater than 80,000 as cast, resistivity 142 μΩ·cm and saturation magnetostriction below 0.5 ppm [51]. It combines very thin ribbon, near-zero magnetostriction and extraordinary weak-field permeability, but it has the lowest saturation among the principal alloys considered here.

Probe-engineering analysis. The technically mature interpretation of Metglas 2714A ultra-high-permeability cobalt-based ribbon treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

In a magnetically quiet enclosure, 2714A is a preferred prototype for the weakest 15.734 kHz and 32.768 kHz fields. A small split core or open layered concentrator can produce high inductance and low microphonic response. The geometry ceiling described in F.3.3 is especially important. An open rod with Nd near 0.01 cannot exploit an intrinsic permeability of one million directly. Deliberate gapping may improve reproducibility and bias tolerance with little practical loss of μeff.

The material is normally excluded from unshielded work near strong permanent magnets, magnetised structural steel or high-current services unless the bias map proves adequate margin. Saturation or minor-loop distortion can create harmonics that resemble timing products. Recovery and degaussing are therefore mandatory tests. 2714A is conditional above 100 kHz and normally excluded as a high-Q 3.579545 MHz core without direct evidence. Its best role is ultra-sensitive low-frequency confirmation, paired with a more bias-tolerant independent probe.

F.3.23 VITROPERM 500 F and 550 HF nanocrystalline ribbon

VITROPERM is an iron-silicon-boron nanocrystalline alloy with niobium and copper additions. The ribbon is rapidly solidified, then heat treated to form nanoscale crystalline grains within an amorphous residual phase. Representative 550 HF data include typical permeability magnitude about 17,000 to 100,000 at 10 kHz, saturation flux density 1.21 T, resistivity 115 μΩ·cm, coercivity below 2 A/m and ribbon thickness in the approximate 17 to 25 μm range [52]. VAC reports that 550 HF provides improved permeability and attenuation above 100 kHz relative to standard 500 F, with the largest relative improvement around 100 kHz in the illustrated core.

This family is preferred for 15.734 kHz, 32.768 kHz and 100 kHz to sub-megahertz structures where a stable combination of permeability, saturation, low coercivity and thin ribbon is required. A split tape core can be used as a concentrator or differential element. A grade with nominal μi = 100,000 may show a flat real-permeability region ending at only tens of kilohertz, while a lower-permeability or 550 HF grade can preserve useful response farther upward. The exact grade and frequency curve therefore matter more than the family name.

VITROPERM is widely used as an EMC attenuation material. Strong impedance in that role can include a substantial loss component. EERF shall measure μ' and μ'' separately and shall not infer high receiving Q from insertion-loss data. At 3.579545 MHz the material is conditional. It may provide broadband flux concentration or controlled damping, but NiZn ferrite, low-μ powder and air-core references are normally more suitable for a narrow receiving resonance. Tape edges, gaps, casing pressure and winding placement are controlled configuration attributes.

F.3.24 Band-by-band material selection matrix

The matrix is a prototype-priority tool. P means Preferred candidate for at least one receiving, return-path or concentrator role. C means Conditional, requiring selected grade, thin form, gap and direct complex-permeability evidence. N means Normally exclude as the primary low-noise receiving core. The rating is not a manufacturer frequency guarantee. All metallic cores are normally excluded from the .950 GHz to 2.2 GHz, 3.9 GHz and 5.6 GHz illumination radiators. Those microwave antennas use validated air, dielectric, waveguide or printed structures.

System-level interpretation. For expert practice, Band-by-band material selection matrix is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table F-3D. Prototype priority by frequency band

Material	**10 Hz-1 kHz**	$> 1 -$ 10kHz(79)	$> 10 -$ 100kHz(80)	$>$ 100kHz $-$ 1MHz(81)	$> 1 -$ 10MHz(82)
80Ni-5Mo-Fe	P	P	C	N	N
48Ni-Fe	P	P	C	N	N
Fe-49Co-2V	C	P	C	N	N
Grain-oriented 3% Si-Fe	P	P	C	N	N

Material	10 Hz-1 kHz	$> 1 -$ 10kHz(79)	$> 10 -$ 100kHz(80)	$>$ 100kHz $-$ 1MHz(81)	$> 1 -$ 10MHz(82)
JNEX 6.5% Si-Fe	C	P	P	C	N
JNHF/JNSF/JNRF	P	P	P	C	N
MPP powder	C	P	P	P	C
High Flux powder	C	P	P	P	C
Sendust/Kool Mμ powder	C	P	P	P	P
XFlux powder	C	P	P	P	C
Metglas 2605SA1	P	P	P	C	N
Metglas 2605S3A	C	P	P	P	C
Metglas 2826MB	P	P	P	C	N
Metglas 2705M	P	P	P	P	C
Metglas 2714A	P	P	P	C	N
VITROPERM 500 F/550 HF	P	P	P	P	C

F.3.24A Resonant stick, bar, winding, sapphire-trim, concentrator-ring and preamplifier matrix

This breakout converts the earlier material register into a completed-probe design screen. The useful band is the band in which a finished open bar, laminated stick, tape stack or powder cylinder can plausibly provide weak-field gain without unacceptable complex-permeability loss, eddy current loss, magnetostriction, self-capacitance or mechanical noise. It is not a guarantee. Each finished probe requires measured inductance, resistance, self-resonant frequency, loaded quality factor, transfer factor, overload recovery, cross-axis response and magnetic noise. The number of copper turns shall never be maximised blindly. More turns increase induced open-circuit voltage and inductance, but also increase winding resistance, inter-turn capacitance, dielectric absorption, triboelectric sensitivity and settling time. The released turn count is therefore the smallest count that meets sensitivity while preserving a self-resonant-frequency margin above the highest intended observation band.

Sensor and front-end elaboration. For Resonant stick, bar, winding, sapphire-trim, concentrator-ring and preamplifier matrix, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Universal tuned-probe rule. Every row in Table F-18 that is implemented as a dedicated resonant stick or bar shall include a switchable high-reverse-voltage varactor trim branch, a hard bypass and a fixed-capacitance substitution point. The branch is omitted only from a deliberately broadband or flat probe. The X-axis member of a vector set is the resonance reference, while the Y-axis and Z-axis members retain independent calibration. No material grade is excused from varactor-noise, leakage, intermodulation, temperature and bias-line testing.

CRITICAL TUNING RULE
A sapphire piston capacitor is a precision fine-trim element. It is not the principal tuning capacitor at 30 Hz through most of the VLF range. A switched bank of low-loss polypropylene, polystyrene, C0G or NP0 capacitors provides the bulk capacitance. The piston trimmer acts directly only where the required tank capacitance is of the same order, or through a calculated series, parallel or capacitive-divider network. Every trim setting is recorded as a calibrated capacitance or resonance, not merely as turns of a knob. A switchable high-reverse-voltage varactor branch is now mandatory in every dedicated tuned rod or bar. It provides only the final electronic correction after the fixed bank and sapphire piston are set. The branch shall have a hard bypass, a quiet held-bias state and a calibration-pilot-off blank. The varactor is passive and supplies no active power gain.

Table F-18. Material-specific useful band and completed resonant-probe architecture

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
PERMIMPHY 80Ni-5Mo-Fe	Preferred 30 Hz-32.768 kHz. Conditional to about 100 kHz with very thin laminations and short winding sections.	High-turn differential winding for 30 Hz-14 kHz. Section aggressively above 15 kHz. Fixed film bank dominates; piston only trims through a pad network.	Split or tape-wound return ring for low-frequency flux closure. Ultra-low-noise differential voltage preamplifier. Guard against saturation and post-anneal stress.
IMPHY SUPRA 50, 48Ni-Fe	Preferred 30 Hz-14 kHz where mains-field headroom is needed. Conditional 15.734-100 kHz with thin laminations.	Moderate-to-high turns. Lower turn count than 80Ni where ambient bias is large. Fixed bank plus fine trim.	Laminated ring or yoke. Better saturation, lower weak-field gain. Preamplifier must tolerate large 50/60 Hz components without recovery tails.

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
AFK 502R, Fe-Co-V	Conditional 30 Hz-15.734 kHz. Normally not selected for the weakest fields above that band.	Relatively low-turn, low-impedance winding. Resonance used for selectivity rather than permeability gain.	Gapped concentrator where exceptional saturation is required. Low-voltage-noise bipolar input may suit the lower source impedance.
Grain-oriented 3% Si-Fe	Preferred 30 Hz-3 kHz along rolling direction. Conditional 3-15.734 kHz in very thin aligned stacks.	High turns are practical only with insulated laminations and distributed sections. Large fixed capacitance may be required at voice frequencies.	Tape-wound or laminated ring, with directionality and remanence recorded. Avoid use where cross-axis isotropy is essential.
10JNEX900 uniform 6.5% Si-Fe	Preferred about 300 Hz-32.768 kHz. Conditional to 100 kHz depending cut, thickness and lot.	Sectioned copper or litz winding. Near-zero magnetostriction favours low microphonics. Fixed C bank and small trim network.	Stacked split ring or tape ring. Differential preamplifier with high common-mode rejection. Protect brittle edges.
10JNHF600 Si-gradient steel	Preferred 3 kHz-100 kHz. Conditional below 3 kHz and to several hundred kilohertz after measurement.	Moderate turns, short winding zones and litz wire. Direct piston trim becomes more useful toward the upper VLF and MF region.	Thin laminated ring or gapped yoke. Good headroom. Mechanical strain and magnetostriction require validation.

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
15JNSF950 Si-gradient steel	Preferred 10 kHz-100 kHz. Conditional to approximately 500 kHz only after complex-permeability testing.	Moderate or low turns to protect self-resonance. Use C0G/NP0 bank; piston can provide direct fine trim above roughly 100 kHz.	Ring or short bar where saturation is valued. Not preferred for sub-kilohertz weak fields.
10JNRF high-flux gradient steel	Preferred 30 Hz-14 kHz. Conditional at 15.734 and 32.768 kHz.	Moderate-to-high turns, laminated stack aligned to the field. Bulk film capacitor bank.	Ring or bar for voice-band and mains-adjacent work. Higher saturation than ultra-high-mu nickel alloys.
MPP Fe-Ni-Mo powder	Preferred 3 kHz-1 MHz. Conditional 1-3.58 MHz in lower-permeability grades and short geometries.	Moderate turns on bar or cylinder. Distributed gap and low loss support predictable Q. Direct piston trim practical in upper MF and low HF.	Powder toroid or split ring. Stable, damped response. Preamplifier selected from measured source impedance, not material name.
High Flux 50Ni-50Fe powder	Preferred 10 kHz-500 kHz under bias. Conditional to about 3 MHz in low-mu grades.	Moderate turns. Use where DC or mains bias would compress MPP or high-mu ribbon.	Ring concentrator with strong bias tolerance. Higher loss requires lower Q or narrower released band.

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
Sendust / Kool Mmu Fe-Si-Al	Preferred 300 Hz-3.58 MHz depending permeability grade. Conditional to about 10 MHz only for low-mu, low-turn confirmation probes.	Low magnetostriction permits mechanically quiet windings. Moderate turns at VLF, low turns at MHz. Piston trim becomes directly effective above roughly 0.5-1 MHz.	Powder ring or split concentrator. Strong general-purpose material for broadband and tuned confirmation.
XFlux Fe-Si powder	Preferred 15.734 kHz-1 MHz where saturation and temperature margin dominate. Conditional 1-3 MHz.	Moderate or low turns. Higher core loss limits very high Q.	Ring or short bar under substantial bias. Use an overload monitor and confirm noise against MPP or Sendust.
Metglas 2605SA1 Fe amorphous	Preferred 3 kHz-100 kHz. Conditional to about 500 kHz with narrow ribbon and careful potting.	Sectioned winding and mechanical isolation are mandatory because magnetostriction can create false audio-band signals.	Tape-wound ring or bonded laminated bar. Differential preamplifier and mechanical blank control required.
Metglas 2605S3A Fe amorphous	Preferred 3 kHz-500 kHz. Conditional near 1 MHz after lot testing.	Moderate turns and short sections. Thin ribbon lowers eddy-current loss, but the winding must not clamp the core.	Tape ring or laminated stick. Compare microphonic response against a nonmagnetic dummy.
Metglas 2826MB Fe-Ni amorphous	Preferred 30 Hz-100 kHz. Conditional to 500 kHz.	High-turn weak-field bar with strain relief. Bulk fixed capacitance at audio and VLF.	High-mu ring or return path with moderate saturation. Guard against stress-induced permeability change.

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
Metglas 2705M Co amorphous	Preferred 30 Hz-1 MHz. Conditional 1-3.58 MHz in short, low-turn structures.	Excellent low-magnetostriction candidate. Turn count still limited by capacitance. Direct piston trim becomes useful in the low-MHz range.	Split tape ring or laminated bar. Preferred low-noise reference, but low saturation demands ambient-field monitoring.
Metglas 2714A Co amorphous	Preferred 30 Hz-500 kHz for the smallest fields. Conditional to about 3 MHz with short low-turn bars.	Very high permeability permits fewer turns than expected once geometry is optimised. Piston trim only near the upper band.	Strain-isolated ring or short bar. Lowest saturation and lower Curie point require conservative handling and overload gates.
VITROPERM 500 F nanocrystalline	Preferred 30 Hz-1 MHz. Conditional 1-10 MHz in low-permeability anneals and compact structures.	Turn count matched to anneal and effective permeability. Sectioned winding. Fixed bank at low bands, direct piston trim increasingly practical above 1 MHz.	Split or closed tape ring, gapped yoke or stacked-ribbon bar. Broadest general-purpose range after lot qualification.
VITROPERM 550 HF nanocrystalline	Preferred 3 kHz-3.58 MHz. Conditional to about 10 MHz in compact, low-turn forms.	Moderate turns at VLF, low turns at MHz. Particularly suited to 32.768 kHz through low-MHz confirmation.	Split concentrator or tape ring feeding a shielded RF preamplifier. Verify winding capacitance and phase linearity.

Material	Stick or bar useful band	Copper winding and hybrid resonance control	Concentrator ring and preamplifier interface
MnZn ferrite comparator	Preferred 30 Hz-100 kHz by grade. Conditional to several hundred kilohertz.	Long commercial rod with high-turn sectioned winding. Fixed capacitor bank. Piston trim is normally indirect at these frequencies.	Segmented ferrite return path. High electrical resistivity reduces eddy currents, but brittleness and grade dependence remain.
NiZn ferrite comparator	Preferred 100 kHz-10 MHz by grade. Conditional below 100 kHz where lower sensitivity is accepted.	Moderate-to-low turns. Direct sapphire trim is practical through much of the MHz range.	Ferrite ring, sleeve or compact rod. Useful as a low-MHz reference and for common-mode path studies.

F.3.24B Band-specific tuning and self-resonance limits

Table F-19. Frequency-band tuning architecture and material shortlist

Field-theory elaboration. The advanced treatment of Band-specific tuning and self-resonance limits begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

Band	Bar or stick behaviour	Tuning method	Leading prototype materials
30 Hz-300 Hz	Open bar or stacked ribbon with very high effective area. Resonant tuning may demand impractically large L or C.	Use broad low-noise acquisition or a switchable film-capacitor bank. Sapphire piston is not a useful direct main tuning element.	Co-based amorphous, 80Ni-Mo, 2826MB, VITROPERM 500 F, grain-oriented Si-Fe comparator.
300 Hz-3 kHz	High-turn bar remains feasible, but winding resistance and mains harmonics dominate.	Film capacitor bank, differential winding, damping option and 50/60 Hz notch only after raw acquisition.	80Ni-Mo, 48Ni-Fe, 2826MB, 2705M, 2714A, VITROPERM 500 F, JNRF.
3 kHz-14 kHz	Long bar or laminated stick, sectioned winding, explicit microphonic control.	Bulk film or C0G bank. Piston used through a divider only if measurable trim is required.	JNEX, JNHF, JNSF, amorphous ribbons, nanocrystalline ribbon, MPP, Sendust.
15.734 kHz	Timing and legacy-video search band. High-Q tuning is feasible but settling time must be recorded.	Fixed bank establishes resonance. Piston performs fine correction. Include a damping switch for discovery.	JNEX, JNHF, JNSF, 2605 series, 2705M, 2714A, VITROPERM, MPP, Sendust, MnZn.
32.768 kHz	Watch-crystal timing band. Harmonics and nearby switch-mode products require narrow yet stable tuning.	Fixed bank plus calibrated fine trim. Record temperature coefficient and post-movement settling.	80Ni-Mo, JNEX/JNHF/JNSF, 2826MB, 2705M, 2714A, VITROPERM, MPP, Sendust, MnZn.

Band	Bar or stick behaviour	Tuning method	Leading prototype materials
100 kHz-500 kHz	Shorter bar, fewer turns and lower permeability are often superior.	C0G/NP0 bank; piston increasingly direct. Validate SRF at least 3 times the highest analysis frequency.	JNHF/JNSF, MPP, High Flux, Sendust, XFlux, 2605S3A, 2705M, VITROPERM, MnZn/NiZn by grade.
500 kHz-1 MHz	Compact bar, powder cylinder or tape stack. Parasitic capacitance becomes a first-order design variable.	Low-turn coil and direct piston trim. Preamplifier input capacitance is included in the calibration model.	MPP, Sendust, High Flux, 2605S3A, 2705M, VITROPERM 500 F/550 HF, NiZn.
1 MHz-3.579545 MHz	Magnetic probe is a confirmation instrument, not necessarily the discovery antenna.	Very low turns, short winding, direct piston trim, guarded RF preamplifier and measured phase response.	Sendust, low-mu MPP/High Flux, 2705M, VITROPERM 550 HF, NiZn.
3.58 MHz-10 MHz	Only compact, low-loss, low-turn magnetic structures remain plausible.	Direct piston tuning. Use network-analyser characterisation and compare with air-core loop.	Sendust low-mu, VITROPERM 550 HF, NiZn grade selected from measured complex permeability.
Above 10 MHz and SAW bands	High-turn alloy bars are generally self-capacitive and magnetically lossy.	Do not force a bar-resonance architecture into VHF, UHF or microwave work.	Use calibrated air-core loops, shielded near-field loops, dipoles, log-periodic antennas, horns or waveguide probes.

F.3.24C Split concentrator ring and shielded preamplifier integration

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Probe or antenna	Preselector and overload monitor	Low-noise gain or passive bypass	Synchronous I/Q acquisition	Oscilloscope, FFT and waterfall	Feature extraction, controls and evidential classification

The concentrator is a magnetic return structure, not a conductive screen. It shall be split, gapped, laminated or segmented so that no closed conductive turn encircles the measured flux. Any electrostatic shield around the winding likewise carries a longitudinal interruption. A closed copper foil, metal clamp or continuous housing can behave as a shorted turn, flatten the desired response and create position-dependent eddy currents. The primary bar winding, secondary ring winding and shield are characterised separately and together. Mutual inductance, loaded Q, phase, noise and overload recovery are entered in the released configuration record.

Sensor and front-end elaboration. At advanced-practitioner level, Split concentrator ring and shielded preamplifier integration is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

The preamplifier is mounted close enough to limit cable capacitance, but far enough from the highest-flux portion of the core to avoid magnetic materials, switching currents and semiconductor package fields becoming part of the measurement. Its enclosure is electrically continuous except for engineered feedthroughs, while the magnetic path remains intentionally open or gapped. Battery power, analogue regulation, fibre or optical data transfer, and a separately monitored overload channel are preferred. The amplifier input network includes the coil resistance, leakage inductance, total capacitance, piston setting, secondary-winding impedance and any damping resistor. A change in any one of these quantities creates a new probe configuration identity.

F.3.25 Application to 15.734 kHz and 32.768 kHz timing searches

The 15.734 kHz and 32.768 kHz channels occupy the band in which several high-permeability metallic alloys can be valuable, but also the band in which conductive thickness becomes consequential. For the highest weak-field sensitivity in a magnetically quiet environment, the preferred prototype group is Metglas 2714A, Metglas 2826MB, 80Ni-5Mo-Fe, Metglas 2605SA1 and selected VITROPERM grades. For greater bias tolerance, the preferred comparison group is SUPRA 50, JNHF or JNSF, MPP, High Flux, sendust and XFlux. Metglas 2705M provides an intermediate option with near-zero magnetostriction.

Clock and timing interpretation. A technically mature analysis of Application to 15.734 kHz and 32.768 kHz timing searches distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Periodic bursts are analysed in both frequency and time because a stable pulse interval can reveal a clock domain even when the carrier frequency changes or the spectral line is intermittent. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

At 15.734 kHz, high-silicon JNHF/JNSF and the 550μ MPP grade may enter the prototype set because the frequency lies near their documented useful region. At 32.768 kHz, lower-permeability MPP, sendust, XFlux, 2605S3A and VITROPERM 550

HF often provide better bandwidth and bias tolerance than the highest-permeability grade. The probe family should contain at least one high-μ ribbon channel, one distributed-gap powder channel and one air-core or ferrite reference. A candidate is strengthened when its spatial and temporal features persist across cores with different noise and loss mechanisms.

F.3.26 Application to 100 kHz through 3.579545 MHz

As frequency rises above 100 kHz, the prototype priority shifts towards lower-permeability powder, thin amorphous or nanocrystalline ribbon, NiZn ferrite and air core. VITROPERM 550 HF, 2605S3A, 2705M, MPP, sendust and XFlux may remain useful through selected sub-megahertz regions. The chosen grade shall have a self-resonant frequency comfortably above the operating band, a measured loaded Q appropriate to the signal search and a loss component that does not dominate the induced voltage.

Time-domain elaboration. A technically mature analysis of Application to 100 kHz through 3.579545 MHz distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. Harmonic order is calculated from measured frequency with uncertainty, and the comparison allows for crystal tolerance, temperature, ageing, pulling, spread-spectrum clocking, divider quantisation, and receiver frequency error. The timing conclusion is stated with the applicable frequency uncertainty, observation duration, drift model, and alternative sources [9, 24-26].

At the 3.579545 MHz legacy colour-reference frequency, the default confirmation sensors are an air-core loop and a characterised NiZn ferrite or calibrated small antenna. Metallic alloy cores are secondary. Low-μ sendust, XFlux, MPP or High Flux grades may be tested when they reduce winding turns or improve directional response, but catalogue frequency flatness does not establish low magnetic noise or high receiving Q. Ultra-high-permeability 80Ni, 2714A, 2826MB and thick silicon steel are normally excluded from the primary MHz resonator.

None of the low-frequency magnetic-core selections is extrapolated to the GHz illumination antennas. At 1.2 GHz to 1.9 GHz, 3.2 GHz or 4.9 GHz, ferromagnetic permeability is generally highly dispersive and lossy, and conventional radiator geometry controls performance.

The material chapter remains relevant only to low-frequency monitors, bias sensors, current probes and response channels that accompany the microwave source.

F.3.27 Ten worked permeability and core-selection calculations

These calculations are screening examples, not probe calibrations. Variables are defined within each example.. Dimensions are converted to SI units before substitution. The examples use linear approximations and shall not be extended beyond the stated assumptions.

Resonant receiving-system perspective. At advanced-practitioner level, Ten worked permeability and core-selection calculations is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier.

The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map.

The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Worked example	Calculation	Engineering interpretation
1. Effective permeability of an open rod		The open geometry limits the working permeability to approximately 100, despite the very high intrinsic material value.
2. Diminishing return from still higher intrinsic μ		Once geometry dominates, a tenfold catalogue-permeability increase produces almost no rod gain. Aspect ratio and gap control are more valuable.
3. Inductance of the qualified rod model		The estimated inductance is 31.4 mH. The final value must be measured because leakage, winding zone and distributed flux are omitted.

Worked example	Calculation	Engineering interpretation
4. Tuning capacitance at 32.768 kHz		A fixed bank near 750 pF plus a small sapphire piston trimmer is plausible, provided coil self-capacitance is included in the measured total.
5. Skin depth at 32.768 kHz		A 0.35 mm nickel-alloy sheet is many skin depths thick under the assumption. Thin ribbon, insulated lamination or powder is preferred.
6. Skin depth at 3.579545 MHz		The screening result explains why high-μ solid metallic cores are normally excluded from the primary 3.579545 MHz resonator.
7. Magnetic loss tangent and core-related Q		A high impedance can coexist with modest Q. Winding, capacitor and amplifier losses will reduce the loaded Q further.
8. Induced voltage from a one-picotesla field		The predicted signal is about 10.3 nV RMS before transfer losses. Preamplifier voltage noise, winding resistance and magnetic noise are therefore central.
9. Saturation screening under a strong local bias		The linear model ceases to be valid as saturation is approached. The example supports a bias-tolerant core near strong magnetic infrastructure.

Worked example	Calculation	Engineering interpretation
10. Lamination-thickness effect on classical eddy-current loss	For similar material, frequency and flux, classical lamination eddy-current loss scales approximately with thickness squared. Comparing 0.10 mm sheet with 23 µm ribbon gives $(0.10/0.023)^2 = 18.9$.	The thin ribbon can have roughly one-nineteenth of the thickness-related loss term, although actual loss also depends on resistivity, permeability, waveform, insulation and domain structure.

These calculations are screening examples, not probe calibrations. Variables are defined within each example. μ0=4π×10-7H/m. Dimensions are converted to SI units before substitution. The examples use linear approximations and shall not be extended beyond the stated assumptions.

F.3.28 Qualification tests and acceptance gates

Every alloy-core probe shall pass a staged qualification. Incoming inspection verifies supplier, grade, chemistry where certified, lot, form, dimensions, mass, coating, ribbon or lamination thickness and visible damage. The material certificate and published data sheet are retained. A representative coupon or closed-ring specimen is measured where practicable, but the final probe remains the release article. The same winding, capacitor, concentrator, shield, cable and preamplifier used in the field are included in the transfer calibration.

Frequency qualification measures complex impedance, μ', μ'', equivalent series resistance, unloaded and loaded Q, self-resonance and phase from below the intended band to beyond the nearest relevant resonance. Amplitude qualification uses several magnetic field strengths to identify hysteresis, compression and harmonic generation. Bias qualification superimposes positive and negative DC field along and across the core axis. Temperature qualification covers the declared field range after thermal equilibrium.

Mechanical qualification includes mounting-force repeatability, transport, controlled vibration and cable-strain tests.

The probe is accepted only if its transfer factor, noise floor, phase, null direction, cross-axis response, Q and resonance remain within predeclared limits. A superior peak response does not compensate for failed stability or artefact controls. Acceptance limits are established through method validation and may differ by discovery, confirmation and localisation role. The report identifies the role and does not imply that one core is optimal for all bands.

F.3.29 Heat treatment, stress relief, cutting and assembly controls

Soft magnetic properties are created as much by processing as by chemistry. High-nickel and iron-cobalt strip often requires a specialised post-forming anneal in pure dry hydrogen, vacuum or another supplier-approved atmosphere. Amorphous and nanocrystalline ribbon may require a field anneal that establishes a transverse or longitudinal anisotropy. Powder cores rely on particle insulation and compaction. EERF shall purchase finished or professionally processed material and shall not conduct hazardous hydrogen heat treatment in an ordinary electronics workshop or field location.

System-level interpretation. For expert practice, Heat treatment, stress relief, cutting and assembly controls is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Cutting, punching, grinding and bending introduce residual stress and can short laminations. Laser or water-jet processes can create heat-affected or conductive edge regions. The fabrication plan therefore specifies the approved process, edge treatment, insulation restoration and post-process magnetic test. The core is mounted with a repeatable low-stress support. Clamp force or torque is recorded. Adhesive is applied outside the highest-flux region where practicable, and cure shrinkage is measured through before-and-after inductance and noise tests.

The magnetic axis, rolling direction, ribbon winding direction and any field-anneal direction are marked on the hidden engineering support, not on the inspected object. The assembled probe is degaussed or reset by a validated method and its residual field is measured. A transport case contains no permanent magnet, ferromagnetic latch or loudspeaker. Post-transport verification compares inductance, Q, noise and null direction with the release baseline before the probe enters the controlled inspection area.

F.3.30 Evidential configuration record and reporting rule

The configuration record shall state material family, commercial grade, supplier, lot, nominal chemistry, ribbon or lamination thickness, powder permeability grade, density where relevant, core dimensions, mass, gap, insulation, heat treatment, magnetic-axis orientation, degaussing state, mounting force, winding design, capacitor network, housing, preamplifier, cable and calibration file. It shall also state the complex-permeability or impedance test conditions, DC bias, temperature, field amplitude and date. A shorthand such as mu-metal rod or nanocrystalline core is insufficient.

Forensic interpretation. For Evidential configuration record and reporting rule, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

Field data are not merged across different core configurations unless a validated correction and uncertainty are applied. A change from 2714A to 2705M, from 60μ to 125μ powder, from 0.10 mm to 0.20 mm lamination, or from a 0.5 mm to a 1.0 mm gap starts a new series. The report may state that several independent probes detected a common signal family, but it shall not average their uncorrected voltages as though they shared one antenna factor.

The material-selection conclusion is limited to instrument performance. Detection of a signal with a particular core does not identify the alloy, shield or magnetic circuit inside an unknown device. The probe alloy is part of the measurement system, not a spectral fingerprint of the source. The examiner reports which configuration produced the observation, which controls confirmed it, the frequency and spatial uncertainty, and the limitations caused by core bandwidth, bias, aperture and noise.

Table F-3E. Mandatory alloy-core qualification record

Qualification element	Required evidence	Release gate
Identity and traceability	Grade, supplier, lot, certificate, form, thickness, mass and dimensions.	Reject untraceable substitution or mixed lots.
Metallurgical state	Anneal, field-anneal direction, stress relief, coating and handling history.	Reject undocumented or post-anneal mechanically damaged parts.
Geometry and assembly	Gap, lamination stack, ribbon direction, mounting force, winding zone and shield spacing.	Repeat assembly shall remain within validated transfer limits.

Qualification element	Required evidence	Release gate
Complex response	Z(f), μ'(f), μ''(f), phase, Q and self-resonance at multiple amplitudes.	No unexplained resonance, roll-off or loss peak within the authorised band.
Noise	Equivalent input noise, low-frequency drift, Barkhausen events and microphonic response.	Noise shall meet role-specific detection and false-alarm limits.
Bias and saturation	Positive and negative axial and transverse DC bias, harmonic generation and recovery.	No unrecognised compression in the declared field environment.
Temperature	Cold, nominal and warm transfer factor, resonance, Q and noise.	Drift shall fit the correction model and uncertainty budget.
Angular response	Three-axis pattern, null depth, cross-axis response and frequency dependence.	Pattern shall support the intended localisation method.
Transport and ageing	Pre- and post-transport checks, repeated conditioning and storage interval.	No material change beyond the stability limit.
Independent comparison	Air-core, ferrite or different-alloy probe in the same field fixture.	Core-specific artefacts shall be identified before release.

F.4 Rod geometry, demagnetising factor and winding zone

A long slender rod generally has a more favourable demagnetising factor than a short thick rod, but sensitivity does not grow without limit. Mechanical fragility, distributed capacitance, winding resistance and pattern complexity increase with length. The active winding may occupy the centre portion where effective permeability and field coupling are most useful, rather than covering the entire rod. Alternative prototypes shall vary rod length, diameter, material, winding length and position while holding the measurement fixture constant. The selected geometry is the one with the best validated signal-to-noise ratio, directional null and spatial response for the intended band.

Sensor and front-end elaboration. The technically mature interpretation of Rod geometry, demagnetising factor and winding zone treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

Core ends shall be protected without adding conductive caps or magnetic fasteners that alter the field. The rod is supported at low-stress points by electrically insulating, low-loss material. Adhesive selection considers dielectric loss, cure shrinkage, moisture absorption and magnetic contamination. The completed probe is inspected for cracks by visual examination and comparison of inductance, Q and transfer factor with its baseline. A cracked ferrite can retain apparent electrical continuity while changing its effective permeability and null pattern. Post-transport verification is therefore mandatory.

F.5 High-turn, sectioned copper winding and sectioning strategy

The phrase extremely long winding refers to total conductor length and turn count, not to an uncontrolled single-layer helix extending along the housing. Winding design begins with required inductance and effective area, then limits direct-current resistance, skin and proximity loss, inter-turn capacitance and mechanical movement.

Fine enamelled copper or litz wire may be used. Litz construction is selected from strand diameter and frequency, not from turn count alone.

At 15.734 kHz and 32.768 kHz, strand dimensions can be chosen so that current distribution remains useful, while the bundle remains flexible enough to wind without damaging the core.

Sensor and front-end elaboration. At advanced-practitioner level, High-turn, sectioned copper winding and sectioning strategy is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier.

High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Sectioned winding is preferred when one continuous bank would produce excessive distributed capacitance. Each section is wound on a non-magnetic former with controlled width, pitch and direction. Connections between sections are routed to minimise loop area and capacitive coupling. A basket, honeycomb or multi-section arrangement may improve self-resonant frequency but must be reproducible. The build record includes turns per section, wire type, measured conductor length, winding sense, layer insulation, inter-section spacing, termination method and resistance at a declared temperature. Photographs may be retained as manufacturing records even though the field examination itself remains non-imaging.

F.6 Self-capacitance, self-resonance and loss characterisation

Before external capacitance is fitted, the winding shall be measured over a frequency range extending beyond the intended band and through its first self-resonance. The self-resonant frequency should exceed the operating frequency by a validated margin so that the probe behaves as the intended inductive network. The measurement uses a fixture whose own capacitance and magnetic coupling are known. Several drive levels are used to reveal non-linearity or core effects. Equivalent-series and parallel models are recorded, but raw complex impedance remains primary because a simple model may conceal distributed behaviour.

Field-theory elaboration. A advanced technical account of Self-capacitance, self-resonance and loss characterisation distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The section is technically complete only when the relevant field regime and the limits of the adopted approximation are stated [129-131].

Loss is separated into copper resistance, core loss, dielectric loss, shield loss and amplifier loading where practicable. Q is measured with the final housing, concentrator and cable arrangement. A high unloaded Q that collapses when the preamplifier is connected indicates excessive loading. A broad, stable probe may outperform a sharper probe when the source drifts or the environment contains close components. The design review shall therefore consider sensitivity, bandwidth, settling time and robustness together. Maximum Q is not the sole optimisation objective.

F.7 Fixed tuning bank and sapphire piston calibration capacitor

The tuning network uses a stable fixed bank to provide the majority of required capacitance and a variable sapphire-dielectric piston capacitor to trim the assembled resonance. The fixed bank is selected from measured values with low dielectric absorption, low loss, suitable temperature coefficient and adequate insulation. The piston capacitor is treated as a precision mechanical component. Its minimum and maximum capacitance, resolution, backlash, body capacitance, mounting torque, temperature behaviour and magnetic properties are entered in the design file. Commercial sapphire trimmers cover limited capacitance ranges and are well suited to fine adjustment rather than arbitrary coarse tuning [34-36].

Metrological interpretation. The mature treatment of Fixed tuning bank and sapphire piston calibration capacitor distinguishes calibration, verification, adjustment, characterisation, and validation. These activities are related, but they are not interchangeable and they do not support the same evidential claim. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

The adjustment shaft shall be non-magnetic or sufficiently remote, and the operator shall not leave a conductive tool near the winding during verification. A mechanical lock preserves the setting without distorting the capacitor body. Calibration proceeds from both directions so that hysteresis and backlash are observed. The final setting is encoded by measured capacitance or a mechanical index, then sealed against inadvertent movement. A field probe is not tuned while viewing an unexplained scene signal. It is tuned in the calibration zone against a reference and is returned to the scene only after a blank confirms that the calibration source is absent.

F.7.1 High-reverse-voltage varactor branch and X-axis resonance stabilisation

The varactor branch is installed as a separately identifiable subassembly between the quiet tank node and the low-noise bias feed. The preferred device is a high-Q abrupt or hyperabrupt tuning diode whose rated reverse voltage, capacitance range and series resistance are appropriate to the target band. Manufacturer families include 30 V high-Q abrupt devices, 60 V abrupt devices, and 22 V to 30 V hyperabrupt devices with broad capacitance ranges [124-126]. The rating is a component-selection parameter. The field probe shall not expose personnel or premises equipment to hazardous voltage.

Sensor and front-end elaboration. At advanced-practitioner level, High-reverse-voltage varactor branch and X-axis resonance stabilisation is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

For low-frequency rods, a single diode may have too little capacitance to act directly across the complete tank. The diode may therefore trim a smaller series, parallel or capacitive-divider branch. A matched anti-series pair reduces signal-dependent asymmetry and permits the junctions to remain reverse biased through the small tank swing. The design is accepted only after the complete C-V range, loaded Q, noise, leakage and centre-frequency span are measured with the actual core, winding, piston, concentrator, shield and preamplifier.

The X-axis lock channel uses a calibrated internal winding or external field fixture. The control algorithm approaches the set point from both sides, records the selected bias, removes the pilot and holds the bias without clocked updates. An analogue sample-and-hold, low-leakage storage network or continuously connected low-noise source may be used after validation. Bias droop, dielectric absorption, leakage current and temperature drift are included in the uncertainty. An apparent sensitivity improvement obtained only while the servo is moving is not accepted as field gain.

The branch includes a physical bypass and a fixed-capacitance substitution state so the examiner can prove that a candidate is not generated by junction nonlinearity, bias feedthrough or control electronics. The varactor, protection devices, bias resistor or choke, feedthrough capacitor, cable and monitor point are all treated as possible nonlinear junctions during strong-field and controlled-illumination testing.

Table F-20A. Varactor branch selection and qualification screen

Candidate class	Potential role	Principal limitation	Required acceptance evidence
30 V class high-Q abrupt silicon	Narrow electronic trim with comparatively linear C-V behaviour	Capacitance range may be limited for very low-frequency tanks	C-V, Q or series resistance, leakage, temperature, bypass and intermodulation
60 V class abrupt silicon	Greater reverse-voltage headroom and large-signal linearity margin	Often lower capacitance or reduced tuning ratio	Operating bias margin, noise, capacitance range and held-bias drift
22 V to 30 V hyperabrupt silicon	Larger capacitance ratio for a wider trim span	Greater C-V nonlinearity can create signal-dependent tuning	Anti-series comparison, two-tone test and amplitude-dependent centre frequency
High-Q GaAs hyperabrupt	Low parasitics and high-Q trim at higher-frequency probe bands	Very small capacitance may be unsuitable for LF tanks	Package parasitics, ESD handling, pair matching and complete-probe calibration
Matched anti-series pair	Symmetric small-signal tuning and reduced even-order response	Half or altered effective capacitance and added package parasitics	Pair match, bias symmetry, harmonic test and bypass comparison

F.8 Concentrator ring, gapped yoke and secondary sense winding

The concentrator may be a split ferrite ring, a gapped nanocrystalline tape-wound yoke, laminated high-permeability segments or another characterised magnetic circuit. Its purpose is specified as flux concentration, rear rejection, differential coupling or mechanical integration. The gap prevents an electrically continuous conductive loop and can also control magnetic reluctance and saturation. The element is separated from the primary winding by a defined dielectric spacer. Its angular position, gap width and distance from the rod are fixed by a keyed support because millimetre changes can alter transfer factor and null direction.

Probe-engineering analysis. The technically mature interpretation of Concentrator ring, gapped yoke and secondary sense winding treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

A secondary sense winding may be placed on the concentrator as an independent channel. It shall not be assumed independent merely because it is physically separate. Mutual inductance with the primary, capacitive coupling, common shield currents and shared preamplifier power can create correlated artefacts. Calibration measures the two-port impedance matrix, channel leakage, common-source response and response to a local test dipole at several positions. The secondary channel may confirm that a field interacts with the concentrator, but it does not constitute an independent instrument unless its failure modes are demonstrably different.

F.9 Electrostatic shield and prohibition on closed conductive turns

An electrostatic shield around a magnetic winding shall contain a deliberate gap that interrupts circumferential current. Copper foil, conductive fabric or metallised film can reduce electric-field pickup, but an unbroken band forms a shorted turn. The gap is wide enough to remain open under assembly tolerance, and overlapping layers are arranged so that they do not restore conductive continuity through screws, adhesive foil or cable braid. The shield is connected at one controlled point to the quiet analogue reference unless a validated balanced design specifies otherwise.

System-level interpretation. At expert-practitioner level, Electrostatic shield and prohibition on closed conductive turns is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support.

A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Shield effectiveness is measured separately for electric and magnetic fixtures. A successful shield reduces electric response without materially reducing magnetic transfer factor, increasing noise or rotating the null. Measurements are repeated with the cable connected because cable shield current can bypass the local gap. The mechanical shell, concentrator and preamplifier enclosure are examined for unintended loops. A continuity test alone is insufficient. Low-resistance paths, capacitive bridges and eddy-current effects require impedance and field-response tests across the band.

F.10 Preamplifier architecture and electromagnetic cleanliness

The low-frequency front end should contain no unnecessary oscillator, display, radio, switching converter or digital controller. A battery-powered analogue preamplifier with linear regulation is preferred where its thermal and operational limits are acceptable. Input topology is matched to the measured source impedance. Voltage noise, current noise, 1/f behaviour, input capacitance, bias current, common-mode range, overload recovery and intermodulation are evaluated with the actual probe. Protection devices and relays are included in the non-linearity assessment because strong out-of-band fields can mix in junctions and generate false narrowband products.

Probe-engineering analysis. At advanced-practitioner level, Preamplifier architecture and electromagnetic cleanliness is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

The amplifier offers a lower-gain state or bypass, a calibrated gain table and a quiet means of state identification. Any remote control is optical or otherwise characterised. Indicator lamps remain extinguished during sensitive acquisition. The output is differential, strain-relieved and transferred to fibre at a distance demonstrated not to contaminate the probe. Battery state, temperature and regulator operating point are logged. The self-emission library covers start-up, idle, gain change, overload, low battery and shutdown. A line that appears during one internal state is excluded from environmental interpretation until an independent path confirms it.

F.11 Mechanical silence, microphonics and thermal control

Audibly silent operation requires more than disabling a loudspeaker. Fans, relays, stepper motors, loose windings and cable movement can create sound and electrical microphonics. The probe is mounted on a rigid non-conductive support with damping outside the active magnetic region. Windings are secured by a low-loss method that does not impose damaging stress on the ferrite. Cables are clamped at two points and form no moving loop near the aperture. The tuning piston is locked before deployment. Mechanical taps and controlled vibration are used only during laboratory validation, never to excite an unknown object in the premises.

System-level interpretation. A technically mature treatment of Mechanical silence, microphonics and thermal control begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Temperature affects copper resistance, core permeability and capacitance. The probe carries a quiet temperature sensor only if its emissions have been characterised, otherwise temperature is measured by a remote or intermittent method outside acquisition. A field series begins after thermal equilibration within a declared band. The team avoids holding the probe by hand because body heat and motion change its state. Where outdoor rings and indoor measurements differ greatly in temperature, a transfer check is performed at the transition and the uncertainty budget includes temperature dependence.

F.12 Calibration fixtures, acceptance tests and configuration release

Low-frequency magnetic transfer factor is measured in a calibrated coil system whose dimensions, current and field uniformity are documented. The probe is tested along three axes and at several positions to measure sensitivity, cross-axis response and effective aperture. Electric-field response is measured in a separate fixture. Higher-frequency antennas follow suitable calibration practice and are checked with known fields. Each result includes uncertainty, environmental conditions, instrument traceability and raw data identifiers. A field substitution source may verify daily stability, but it does not replace periodic calibration.

Traceability and uncertainty analysis. At expert-practitioner level, Calibration fixtures, acceptance tests and configuration release begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

Release criteria include centre frequency, bandwidth, Q, transfer factor, noise spectral density, dynamic range, overload recovery, null depth, cross-axis response, electric-field rejection, cable sensitivity, mechanical settling, temperature coefficient and repeat assembly. Limits are based on validation and intended use. Failure of one criterion can restrict a probe to discovery rather than require disposal. The configuration label states the permitted role. Repairs, rewinding, capacitor replacement, shield movement, firmware change or concentrator adjustment trigger documented review and, where material, recalibration or revalidation.

F.13 Directional illumination antenna and feed-system specification

The transmit antenna shall have documented gain, polarisation, return loss, phase-centre convention, principal-plane patterns and maximum dimension across each authorised band. The feed line, connectors, attenuators, coupler and filters are characterised as an assembled path. Cable leakage and common-mode current are surveyed because an apparently directional source can radiate substantially from its feed system.

Active-test metrology. For Directional illumination antenna and feed-system specification, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. A nonlinear or harmonic response remains a junction or material observation unless additional evidence supports an electronic device interpretation [17-23].

F.14 Response antenna, transmit-band rejection and receiver protection

The response sensor is selected for the hypothesised response band and spatial resolution. A 300 MHz-region search may use a calibrated antenna for far-field work and a smaller shielded loop or electric-field probe for near-field localisation. The analogue preselector provides sufficient rejection at every authorised illumination frequency and known transmitter harmonic before the first high-gain stage. Limiting or protection devices are characterised for distortion and recovery.

Resonant receiving-system perspective. At advanced-practitioner level, Response antenna, transmit-band rejection and receiver protection is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

F.15 Reference coupler, field monitor and synchronised state logger

A directional coupler or equivalent calibrated monitor records forward and reflected power. A separate field monitor verifies the environmental field at a representative coordinate and alarms at the operational limit. The state logger records hardware source enable, waveform state, frequency, level, antenna geometry, interlock and emergency-stop events against the same or cross-calibrated timebase as the response data.

Coherent-array interpretation. The purpose of Reference coupler, field monitor and synchronised state logger is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition.

A twelve-channel card in a multicard chassis can support nine orthogonal probe paths per card, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

F.16 Common-chassis multichannel analyser and pod-interface specification

The receiver platform shall provide at least twelve independently addressable channels, of which at least nine are simultaneously sampled probe pathways. The chassis shall distribute or deterministically relate the frequency reference, local-oscillator reference, sample clock, trigger and event epoch. A front-panel RF switch feeding one receiver does not satisfy this specification. Modular expansion cards are acceptable only when the assembled chassis, cards, firmware, driver, backplane and external pod interface are released as one configuration.

Digital-system elaboration. The mature treatment of Common-chassis multichannel analyser and pod-interface specification distinguishes normative air-interface or cable specifications from implementation leakage, board-level clocks, power-management activity, spread-spectrum clocking, and enclosure coupling. Sleep does not necessarily mean electrically silent; real-time clocks, embedded controllers, wake detectors, charging circuits, memory retention, paging cycles, auxiliary channels, and security processors may remain active. Current specifications and national allocations are verified for the date and place of examination because standards and permitted bands evolve [81-120].

The pod interface carries only the signals required for the sensing function. Varactor bias, relay or solid-state switch commands, first-stage power, temperature telemetry and calibration control are filtered, shielded and logged. Control lines are quiescent during evidence acquisition except for a declared emergency or safety function.

A remote first-stage preamplifier is permitted when necessary to prevent cable loss or noise, but it remains clockless, linear, serialised and powered from a characterised low-noise source controlled by the chassis.

Each RF channel contains a discovery path and a tracking-receiver function. The discovery path preserves instantaneous bandwidth and transient probability. The tracking path supplies selectivity through a narrower analogue or digital bandwidth and coherent integration. The two paths share a traceable amplitude scale or have a measured transfer relationship. Automatic gain control, frequency tracking or adaptive filtering is disabled for evidential records unless its complete state is recorded and its effect has been validated.

Characteristic	Minimum release evidence	Failure consequence
Simultaneous channel count	At least 9 probe inputs acquired in the same sample epoch; 12 or more chassis channels available.	Restriction to reconnaissance or reduced array, with explicit limitation.
Common reference	Frequency, sample clock, trigger and epoch distribution characterised under all deployed card populations.	No phase, vector or latency claim.
Amplitude and phase equality	Per-channel complex transfer function with uncertainty for every gain, filter and cable state.	Uncorrected comparative use only.
Interchannel timing skew	Measured across band and temperature, including trigger fan-out and digital pipeline delay.	No high-frequency coherence claim beyond measured uncertainty.
Crosstalk and reverse isolation	Adjacent and non-adjacent channels tested with strong in-band and out-of-band signals.	Affected channels excluded or guarded.
Varactor control	Channel-specific V-to-f calibration, noise, ripple, settling, hold and spur tests.	Tuned samples invalid unless bypassed and independently verified.
Tracking receiver	Noise bandwidth, selectivity, latency, detector and raw-data relationship documented.	Tracking output treated as non-quantitative indicator.

Characteristic	Minimum release evidence	Failure consequence
Burst capture	Validated instantaneous bandwidth, dead time, pre-trigger depth, trigger probability and storage continuity.	No claim that unobserved bursts were absent.
Pod geometry	Surveyed axes, virtual centres, offsets, mutual coupling and mechanical stability.	No three-dimensional vector or localisation fusion.
Self-emission	All-channel tune, hold, trigger, write and illumination-monitor states recorded with inputs terminated.	Candidate matching a chassis artefact remains unclassified.

Table F-24. Acceptance matrix for the 12-or-more-channel coherent analyser and nine-probe pod system.

The preferred channel map reserves channels 1 through 9 for the three pods, channel 10 for illumination or interrogation reference, channel 11 for a terminated, dummy or calibration path, and channel 12 for a guard or independent reference. The system may reassign channels only through a controlled configuration record. A report shall state the actual assignment rather than imply that the preferred map was used.

When several chassis are used for separate band-physics modules, a site master reference disciplines each chassis. A cross-chassis calibration event establishes event-time offset, amplitude relationship and any supported phase relationship. The lower-frequency systems may include five or more specialised bar and loop families. The 30 MHz to 700 MHz system may use broadband heads, but it still deploys three X-Y-Z pods when vector and transient localisation are intended.

Appendix G. Staged Field Operations Manual

Thus version adds a regional deployment phase before the existing close search. Field teams shall process the 5-mile, 2.5-mile, 1-mile, 0.5-mile and 0.25-mile annuli under Chapter 31, retain outer sentinels, and document the transition at 300 feet before applying the established interior procedure.

This appendix provides a detailed operational sequence for an unknown source location within authorised premises. The geometry is fixed at 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet and 3 feet, followed by 3-inch convergence, but the method does not presume that a detectable signal will exist at every distance. Each stage has a different inferential purpose. The outer stations establish environmental and directional context. The 30-foot stage challenges service-path explanations. The 15-foot and 12-foot stages distinguish pre-boundary from boundary behaviour. The inner stations test local gradient. The final lattice bounds a source-associated region without touching an object or creating an image.

G.1 Command, access control and instrument convoy

The scene commander establishes a single entry point, personnel log, equipment manifest and time reference. The authorised premises datum is selected before candidate interpretation. Team members deposit unnecessary electronics outside the remote zone. Necessary medical devices remain with their users and are documented. The instrument convoy is divided into a remote analysis station, a quiet sensor assembly and calibration or safety equipment that remains sealed until required. The receiver, recorder and reference clock are characterised before any environmental input is connected.

Advanced practitioner analysis. For expert practice, Command, access control and instrument convoy is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Movement is one-way during each principal series. The team does not shuttle uncontrolled equipment between rings. At every boundary, the equipment state is recorded, a terminated-input or dummy-probe check is acquired and the sensor is allowed to settle. Paper tags or passive markers define coordinates. Radios, wireless tablets and audible alarms are excluded unless essential and independently characterised. Spoken communication during dwell is avoided because movement and nearby electronics, rather than sound itself, can perturb sensitive measurements.

G.2 Stage A at the 300-foot remote-reference ring

The 300-foot station is measured from the premises datum or documented boundary reference. Where a full circle is lawful and practicable, at least eight azimuths are acquired, with twelve or sixteen preferred. Where access is partial, arcs and radial points are recorded with missing sectors. The long ferrite rod, broadband loop and higher-frequency antenna are measured at declared heights and axes. A fixed reference sensor remains at one remote point throughout later stages when feasible. The purpose is to establish ordinary regional signals, strong bearings, temporal cycles and the combined self-emission of the deployed system.

Scene-geometry elaboration. For Stage A at the 300-foot remote-reference ring, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

No weak line is promoted merely because it lies near 15.734 kHz, 32.768 kHz or 3.579545 MHz. A candidate must exceed the stage-specific background rule, recur in a repeat acquisition and survive a terminated-input comparison. The 300-foot ring may be below method sensitivity for an ultra-low-power source. That negative result remains valuable because it documents the external floor and later permits an inward gradient to be evaluated. If the candidate is strongest on one exterior azimuth and does not increase toward the premises, an external-source hypothesis is retained.

G.3 Stage B at the 150-foot ring

The 150-foot ring repeats the principal 300-foot azimuths with the same large-aperture magnetic probe, electric-field channel, receiver state, reference clock, height, axis and dwell. The fixed 300-foot channel remains active. The team records nearby roads, conductors, fences, neighbouring buildings and moving emitters, then completes the planned ring before adding target-directed points. A lateral control outside the apparent bearing and a repeat of the strongest and weakest stations are required where access permits.

Spatial-measurement interpretation. At expert-practitioner level, Stage B at the 150-foot ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system.

Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

Advancement to 100 feet requires a stable instrument, satisfactory blanks and a stated spatial question. The candidate may increase, decrease or remain unchanged, but the behaviour must be reproducible and distinguishable from common temporal change, team carriage and receiver artefact. The output identifies actual station coordinates, uncertainty, matched 300-foot comparisons, external-source observations and the reason for advancing or holding the 150-foot stage.

G.4 Stage C at the 100-foot ring

The 100-foot ring uses the same principal azimuths, probe configuration, gain, bandwidth, height and dwell as the matched 150-foot comparison set, while the 300-foot reference remains active. If obstacles require displacement, the actual coordinates are measured and the deviation is recorded. The team first repeats one 150-foot control station, verifies the remote channel, then advances the quiet sensor assembly. A broad acquisition precedes tuned confirmation. Candidate features are assessed for frequency stability, phase or bearing where available, harmonic-family behaviour and change relative to both outer rings.

Spatial-measurement interpretation. The mature treatment of Stage C at the 100-foot ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Advancement to 50 feet requires more than a larger amplitude. The candidate should recur, remain absent from instrument blanks, avoid overload or non-linear gain behaviour and exhibit a spatial pattern consistent with further testing across the 150-foot and 100-foot records. A line that grows equally in all directions may reflect a time change. A line that follows the cable or operator position requires a carriage control. A line that changes frequency with the receiver sample rate requires alias investigation. The decision and supporting file identifiers are entered before movement begins.

G.5 Stage D at the 50-foot ring

The 50-foot ring begins source discrimination around the immediate site and designs the 30-foot service-path examination. Measurements include the principal comparison points and additional stations near service entries, overhead conductors, utility equipment, neighbouring structures and strong exterior bearings. Magnetic and electric probes are compared because a signal conducted on wiring may produce a different component pattern from a compact internal source. At megahertz frequencies, antenna height and orientation are varied in separate series. At low frequencies, the ferrite rod is rotated through a full angular scan at selected points to identify null planes.

Spatial-measurement interpretation. The mature treatment of Stage D at the 50-foot ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

If a candidate appears only at one 50-foot point, that point and its neighbours are repeated before the team advances. A local outdoor device, buried service, vehicle or building plant may explain the feature. If the signal is intermittent, a stationary reference is used to separate time from position. The report retains all 50-foot data, including points that weaken the premises-centred hypothesis. Selective presentation of only the inward-growing path is prohibited.

G.6 Stage E at the 30-foot service-path ring

The 30-foot ring repeats selected 50-foot radial stations and adds short transects along and across accessible service routes, fences, pipes, protective-earth conductors, buried cables, drains and structural members. Actual distance to the premises datum and boundary surface is recorded. The outgoing large probe is used first. A medium-aperture rod, compact loop or gradiometer is introduced only through an overlap station, with low-gain discovery preceding high-Q confirmation and resonance checks performed before and after near-metal work.

Three-dimensional search analysis. The mature treatment of Stage E at the 30-foot service-path ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Advancement to 15 feet requires a reproducible premises-centred sector, a documented extended-path association or a complete negative 30-foot survey that justifies near-boundary work. A line that follows a service conductor is not re-described as an internal source. Along-path and transverse gradients, probe loading, dummy-probe behaviour, reference-channel stability and repeat 50-foot controls are recorded before the team moves inward.

G.7 Stage F at the 15-foot pre-boundary ring

The 15-foot ring is referenced to accessible wall faces, doors, windows, floor or roof boundaries and service penetrations. Probe axes are wall normal, wall tangent and vertical. The same primary settings intended for the 12-foot ring are used while doors remain closed and ordinary systems remain in their authorised state. Principal approach sectors and lateral offsets around penetrations are measured before any threshold activity. No person enters and no unknown object is touched.

Three-dimensional search analysis. At expert-practitioner level, Stage F at the 15-foot pre-boundary ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

The 15-foot output is a stable pre-boundary reference and a matched station plan for 12 feet. A fixed near-boundary reference may be established only after its self-emission and mechanical influence are characterised. Where geometry permits only one near-boundary distance, the actual standoff and lost discrimination are stated. The 15-foot ring does not authorise threshold crossing and is not silently merged with the 12-foot ring.

G.8 Stage G at the 12-foot building-envelope ring

The 12-foot ring follows the accessible building envelope or the perimeter of the authorised area after the 15-foot pre-boundary comparison. The nominal distance is measured from the probe centre to the reference surface. Points are matched to 15-foot wall-normal, wall-tangential and vertical stations at corners, doors, windows, service penetrations, cable routes and regular intervals. A wall or aperture can concentrate electric fields, while steelwork can distort magnetic fields. The strongest point is therefore treated as a coupling location until interior evidence establishes otherwise.

Three-dimensional search analysis. At expert-practitioner level, Stage G at the 12-foot building-envelope ring is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

The team pauses before crossing the threshold. A threshold dwell records the ordinary state with personnel outside, then one examiner and the quiet probe assembly enter under a defined geometry. The outside reference continues recording. If the candidate changes when a door opens or a person enters, the effect is repeated before further movement. The change may arise from shielding, body capacitance, a door contact, lighting control or source activation. It is not automatically evidence of a concealed device responding to entry.

G.9 Interior coarse survey and declaration of the 3-foot local origin

The authorised interior is divided into nominal 3-foot cells at validated heights. The path is serpentine, and each cell receives the same core acquisition set before detailed candidate ranking. Furniture and surfaces remain undisturbed. The probe is stationary during dwell. A broad magnetic channel, tuned low-frequency channel, electric-field channel and higher-frequency channel are used according to the matrix. Inaccessible cells are recorded. Adjacent rooms, floors and ceilings are considered because a maximum at a surface does not establish which side contains the source.

A local origin is declared only after neighbouring cells show a repeatable gradient and the candidate survives instrument controls. The origin is a navigation coordinate within a provisional region, not a claim that the device lies at that exact point. The outgoing larger-aperture probe and incoming smaller-aperture probe are overlapped at the centre, surrounding points and a low-response point. If they do not track the same frequency family, the region is not ready for fine convergence.

Before the three-foot local origin is declared, the team shall establish the hard-point network, room measurement drawing, furniture coordinate register and coarse three-dimensional cube lattice required by Appendix N. No unlogged object movement or route change is permitted after this baseline is sealed.

G.10 Stage J at the 3-foot candidate-containment ring

The 3-foot ring is centred on the provisional region and uses twelve positions at 30-degree intervals where space permits. Constrained sites use an equivalent orthogonal perimeter. Each point is measured on the same plane, at the same standoff and with the same probe-centre reference. Long ferrite rods are supplemented by short rods, small loops and gradiometers. The examiner records amplitude, noise, null angle, phase where coherent, and electric-versus-magnetic response. A compact magnetic source may produce a directional null pattern, while an extended conductor may produce a ridge.

Spatial-measurement interpretation. The mature treatment of Stage J at the 3-foot candidate-containment ring replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

After the complete ring is acquired, the region may be re-centred under the predeclared algorithm. The algorithm may use a robust weighted centroid, intersecting null planes or a fitted validated source model. The calculation and coordinate uncertainty are preserved. Re-centring is not performed after each attractive point because that would bias the path toward noise maxima. A reverse 3-foot ring is acquired before the method enters the 3-inch phase.

G.11 Stage K with 3-inch decrement and lattice convergence

The radial decrement sequence is 36, 33, 30, 27, 24, 21, 18, 15, 12, 9, 6 and 3 inches. Each radius is completed before a new centre is declared. Where a circle cannot be formed, the same 3-inch interval is used in a Cartesian raster along accessible axes. The probe is moved to the measured coordinate, cables settle, the validated delay elapses and acquisition begins remotely. No probe touches the surface or suspected object. The minimum standoff can be greater than 3 inches if field perturbation, safety or fragile surroundings require it.

Fine convergence uses at least two independent observables. Amplitude gradient is combined with null angle, gradiometer difference, coherent phase or electric-versus-magnetic comparison. A single high-Q amplitude trace is insufficient because probe tuning, standing waves and conductive structures can create local maxima. The final bounding volume includes probe aperture, coordinate, standoff and model uncertainty. The output is a coordinate region. It is not a physical image and does not identify construction hidden inside the region.

G.12 Probe substitution, retuning and independent confirmation

Every change of probe, preamplifier, gain, capacitor setting, filter or sample rate begins a new series. The overlap set links the series. A tuned ferrite rod may establish exceptional sensitivity, but an air-core loop or differently constructed rod should confirm the candidate family. A second receiver path tests local-oscillator, digitiser and software artefacts. Retuning occurs only in the calibration area. The measured centre frequency, bandwidth and transfer factor are recorded before the probe returns.

Sensor and front-end elaboration. The technically mature interpretation of Probe substitution, retuning and independent confirmation treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

Where an ultra-narrow probe is used, a simultaneous or interleaved broader reference channel monitors drift. If the candidate moves outside the tuned passband, the team does not interpret the falling amplitude as spatial decay. The broader record supplies the actual frequency trajectory. The team also checks that the sapphire piston setting has not shifted after transport. A mechanical index alone is insufficient if temperature or housing capacitance changes.

G.13 Vertical search, adjacent spaces and extended conductors

An unknown source requires three-dimensional sampling. Outer stations use at least two heights where practicable. Interior cells may use floor, mid-level and upper positions. A wall maximum is scanned laterally and vertically. A ceiling maximum triggers consideration of the floor above, roof plant or lighting. A floor maximum triggers consideration of the space below or buried services. The report identifies unexamined adjacent volumes. It does not collapse them into the searched room merely because access was unavailable.

Advanced technical elaboration. At expert-practitioner level, Vertical search, adjacent spaces and extended conductors is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Extended conductors are tested by transverse scans. If a field follows a cable, pipe, wall stud or service path, the strongest accessible point may be a coupling maximum rather than the source. The team measures along and across the structure, compares phase and orientation and seeks termination or branching behaviour. A compact-source model is rejected when the spatial data support an extended path. The final conclusion then states that the candidate is associated with a conductor or structural route within the measured interval.

G.14 Reverse-path withdrawal and temporal control

The withdrawal series repeats the final 3-inch points, 3-foot ring, interior control cells, threshold, 12-foot, 15-foot, 30-foot, 50-foot, 100-foot, 150-foot and 300-foot stations in reverse order. Exact repetition may be shortened only under a validated rule and documented reason. The stationary reference continues. Differences are examined for source intermittency, temperature, battery state, instrument drift, building operations and personnel changes. A candidate that disappears on withdrawal is not discarded, but its localisation strength is reduced unless the temporal state can be reconstructed.

Scene-geometry elaboration. At expert-practitioner level, Reverse-path withdrawal and temporal control is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

Reference-normalised amplitudes may be used when the reference measures the same source state without sharing the search-channel artefact. The normalisation method is fixed and its uncertainty evaluated. If both channels share a cable, power supply or receiver clock, apparent agreement can be false. Raw unnormalised data remain preserved. The case record identifies every point where the ordinary premises state changed during the inward or outward path.

G.15 Close-out, catalogue entry and non-contact termination

The passive examination ends when the smallest defensible region has been bounded, further approach would violate non-contact conditions, the signal falls below validated capability, or confounders prevent localisation. The team does not open, move, dismantle or shield an object within this phase. Raw files are closed, hashed and copied to controlled storage. Coordinates, probe states, calibration files, blanks and deviations are reconciled. The signal catalogue records measured features without converting them into a medical or criminal conclusion.

Evidential reasoning elaboration. A mature forensic approach to Close-out, catalogue entry and non-contact termination separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions [1-9].

Any later controlled excitation is a separate authorised examination. It begins with a new equipment manifest, exposure and medical-device review, transmitter calibration, field monitor and stop rules. The passive dataset remains immutable. Active results are labelled as responses under the stated incident field and cannot be represented as spontaneous emissions. The field team leaves the premises in its authorised condition and documents restoration of any known source state changed during controlled comparisons.

G.16 Passive closure and active-equipment entry

The passive team completes final blanks, reverse path, hashes and a signed closure before active equipment crosses the CEIA boundary. The active equipment is inventoried and characterised at the 300-foot station or another designated staging location with its output physically terminated. Any new spur or timing line is entered into the self-emission library before illumination begins.

Three-dimensional search analysis. For Passive closure and active-equipment entry, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

G.17 Controlled-illumination state sequence

At each selected coordinate, conduct source terminated, receiver-only, sham, minimum-field on, source-off recovery, authorised level step, frequency-offset, polarisation-change, position-change and independent-receiver states. Record forward and reflected power, field monitor, source waveform, response waveform, clocks, geometry and stop conditions. Do not improvise additional frequencies or levels in response to an attractive display.

Active-test metrology. For Controlled-illumination state sequence, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. A nonlinear or harmonic response remains a junction or material observation unless additional evidence supports an electronic device interpretation [17-23].

The illumination monitor shall arm and trigger the response acquisition only after actual source presence is detected. Begin with a pre-trigger record and zero-delay capture. Then execute the approved delay schedule, using fixed-span real-time or vector acquisition where practicable and a triggered swept analyser only when validated for the event duration. At each delay, preserve the source monitor, response channel, independent receiver and overload channel. When a response is detected, bracket and refine its latency, then repeat live, sham and source-off trials in a randomised order. No equipment or antenna moves until the delay series at that coordinate is closed.

G.18 Active reverse path and post-test passive repeat

After the final active state, remove RF power by hardware, verify field-off, repeat the candidate response-band acquisition passively, retrace selected three-inch, three-foot and exterior controls, and compare instrument blanks. Any persistent or changed state is documented before equipment or personnel move. Active and passive files remain separate series linked by a common case identifier.

Appendix H. Validation, Uncertainty and Performance Studies

Validation shall now include regional-source discrimination, annulus-to-annulus temporal correction, high-ground versus grade comparisons, twenty-seven-cell gradient recovery, opposite-surface localisation, and detection of synthetic two- and three-layer composite modulation. Performance claims are limited to the tested source classes, bands, environments, dwell and access geometries.

Validation must establish what the method can detect, distinguish, localise and report under representative conditions. It must also show the conditions under which the method fails. The programme follows the general logic of method development, internal validation, independent replication, operational monitoring and periodic review. Results are configuration-specific. A new core material, winding, shield, preamplifier, algorithm or ring decision rule may require supplemental validation rather than being assumed equivalent.

H.1 Intended-use claims and validation propositions

Each study begins with a claim stated in measurable terms. Examples include: the LF-32 probe detects a sinusoidal magnetic field of a stated amplitude with a stated probability in a stated environment; the nested-ring procedure distinguishes an internal compact source from an external source with a stated error rate; the 3-inch convergence produces a bounding volume containing the true source in at least a stated proportion of blind trials; or the gradiometer rejects a uniform field by at least a stated amount across its band. Vague claims such as highly sensitive or finds miniature devices are not validation propositions.

Traceability and uncertainty analysis. A advanced metrological approach to Intended-use claims and validation propositions treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

Decision thresholds, candidate rules and exclusions are fixed before the final evaluation set is examined. Development data may be used to tune parameters, but test data remain sequestered. The study includes source-absent trials and ordinary confounders. Prevalence is concealed from examiners where practicable. Performance is reported with confidence intervals or other appropriate uncertainty, not as a single success percentage divorced from sample size.

H.2 Laboratory magnetic-field sensitivity study

A calibrated field coil generates known magnetic fields at 15.734 kHz, 32.768 kHz and selected neighbouring frequencies. Field amplitudes span well below to well above the expected detection threshold. The probe is tested on axis, at angular offsets and at several temperatures. Each amplitude is repeated in random order with blanks. The receiver configuration, dwell and analysis rule match field practice. Outcomes include detected or not detected, measured frequency, amplitude estimate, false-alarm occurrence and overload state.

Electromagnetic interpretation. The advanced treatment of Laboratory magnetic-field sensitivity study begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

The resulting detection curve relates probability of detection to field amplitude. Limit of detection is defined from the predeclared probability and false-alarm criterion. A separate estimate is produced for screened and ordinary interference environments because environmental noise often dominates thermal noise. The study also measures linearity, saturation, gain-state consistency and uncertainty of the transfer factor. A result based only on a clean sinusoid does not validate detection of intermittent or modulated sources, so those conditions receive separate trials.

H.3 Field-environment interference study

Representative residences, offices, clinical areas and industrial premises are surveyed without planted target sources. The objective is to measure background distributions, recurring timing-like lines, mains harmonics, switching combs, radio signals and receiver interactions. Sites are selected to cover lighting controls, chargers, solar equipment, lifts, medical systems and dense wireless environments. The same 300-foot, 150-foot, 100-foot, 50-foot, 30-foot, 15-foot, 12-foot and interior protocol is used where practicable. All candidate rules are applied to determine the source-absent false-positive rate.

Electromagnetic interpretation. The advanced treatment of Field-environment interference study begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

Background libraries are not used as universal subtraction templates. They identify common confounders and challenge the candidate criteria. A line common in many sites may still arise from a target in one case, while a rare line may still be ordinary. The study therefore records spatial pattern, time behaviour, harmonic relationships and known-source state, not frequency alone. Findings inform band plans, preselectors and training scenarios.

H.4 Blind nested-ring localisation trials

An independent controller places compact sources at unknown positions inside representative premises, outside the premises and along service conductors. Sources vary in field strength, orientation, duty cycle, shielding and timing frequency. Some trials contain several sources, and some contain none. The examination team receives only the authorised area and neutral question. It performs the complete staged geometry and reports a bounded candidate region with classification and uncertainty.

Spatial-measurement interpretation. At expert-practitioner level, Blind nested-ring localisation trials is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Primary performance measures are coverage probability of the true source, volume or dimensions of the reported region, false localisation rate, rate of correctly recognising an external or extended source, and examination time. A small average error is not sufficient if the reported interval excludes the true source too often. Results are stratified by source type, environment, access limitation and probe configuration. The validation also records when the team correctly refuses to localise because the evidence is insufficient.

H.5 3-inch convergence and resolution-floor study

Known sources are placed within walls, behind non-conductive panels, near metal, beside cables and at different depths. The final probe is moved on a calibrated positioning system using the intended 3-inch sequence. The study compares radial, Cartesian and three-dimensional strategies. It measures how probe aperture, standoff, source orientation and structural distortion affect the final bounds. The team reports coordinates before the placement is disclosed.

Advanced practitioner analysis. A technically mature treatment of 3-inch convergence and resolution-floor study begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Resolution is reported separately along each axis. A method may resolve position along a wall while remaining unable to determine depth. The validated floor becomes the minimum reportable interval. Grid spacing cannot be used as a substitute for resolution. Where a 3-inch lattice produces a 7-inch coverage interval, case reports use the larger figure. The study also tests whether re-centring algorithms remain stable in the presence of noise and multiple maxima.

H.6 Probe-pattern, null-angle and cross-axis validation

The magnetic angular response is measured in a uniform field and with local dipole sources at several distances. The tests determine main-axis sensitivity, null angle, null depth, side lobes, cross-axis pickup and pattern change caused by the concentrator and shield. Rotation is performed in both directions to reveal backlash or cable torque. The probe is then mounted on its field tripod and retested because supports and cables can alter the pattern.

Metrological interpretation. A advanced metrological approach to Probe-pattern, null-angle and cross-axis validation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

Null-angle uncertainty is translated into spatial bearing uncertainty. Two bearing planes are intersected only after their angular errors and coordinate errors are propagated. Multiple-source trials quantify null filling and apparent rotation. The protocol requires amplitude or gradient confirmation because a null alone can be ambiguous. A pattern that changes materially with temperature, cable placement or nearby metal is restricted to controlled comparative use.

H.7 Instrument artefact challenge study

The receiver chain is exposed to strong out-of-band signals, sample-rate changes, gain changes, preselector substitutions, cable movement, dummy probes and terminated inputs. Deliberate parent frequencies are chosen to create plausible intermodulation and alias products near the candidate bands. The study tests whether the mandatory controls identify those products. Local digitiser clocks, storage writes, displays, optical converters and battery regulators are exercised through all states.

Acceptance requires both a documented self-emission library and successful rejection of blind artefact trials. A line that survives one control but fails another is retained as an example for training. Software versions and analysis parameters are archived. Independent reprocessing of raw data must reproduce spectra and decision outputs within specified numerical tolerances. Any proprietary algorithm used for a material conclusion requires sufficient validation evidence and version control to permit meaningful review.

H.8 Measurement uncertainty budget

Contribution	Typical evaluation route	Effect on result
Reference field	Calibration certificate and fixture model	Absolute magnetic or electric field scale
Probe transfer factor	Repeated calibration over frequency and orientation	Amplitude scale and frequency response
Gain and filter response	Traceable injection and independent analyser	Amplitude, phase and bandwidth
Frequency reference	Calibrated clock comparison	Frequency and harmonic relationship
Position and standoff	Surveyed coordinate checks and spacers	Spatial bounds and gradients
Probe aperture and model	Blind localisation trials	Resolution floor and source-region size
Repeatability and time variation	Replicate and reverse-path data	Comparative confidence
Temperature	Environmental chamber or field transfer checks	Tuning, Q, gain and permeability
Core permeability dispersion	Measured $\mu'(f)$ and $\mu''(f)$ for the finished geometry at several field amplitudes.	Frequency response, sensitivity, phase and Q
Demagnetising geometry and gap	Dimensional survey, finite-element or empirical transfer calibration and repeated assembly.	Effective permeability, angular pattern and aperture
DC bias, remanence and saturation	Fluxgate or Hall measurement, controlled bias test, degaussing and recovery test.	Compression, harmonics, memory and sensitivity

Contribution	Typical evaluation route	Effect on result
Mechanical and thermal state	Temperature cycling, clamp-force control, vibration test and transport check.	Drift, microphonics, null depth and repeatability

Absolute field uncertainty and comparative localisation uncertainty are maintained separately. A relative survey can be precise even when absolute calibration is poor, provided the instrument remains stable. Conversely, an accurately calibrated field value does not guarantee a precise source location. Standard uncertainties are combined by an appropriate model, including covariance where contributions are correlated. Expanded uncertainty uses a stated coverage factor and degrees-of-freedom method where applicable. Validation coverage may replace an incomplete analytic model when it better represents real premises.

Traceability and uncertainty analysis. A advanced metrological approach to Measurement uncertainty budget treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

H.9 Proficiency testing and examiner competence

Proficiency tests contain positive, negative, external-source, multiple-source and instrument-artefact cases. Examiners are assessed on scene control, instrument set-up, data completeness, candidate restraint, localisation coverage, uncertainty and reporting language. A correct final answer reached through undocumented or biased procedure is not a full pass. Tests should sometimes place an ordinary device at the client-suspected location while the actual signal lies elsewhere, thereby challenging expectation bias.

Metrological interpretation. The mature treatment of Proficiency testing and examiner competence distinguishes calibration, verification, adjustment, characterisation, and validation. These activities are related, but they are not interchangeable and they do not support the same evidential claim. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

Competence records include electronics, electromagnetic measurement, metrology, forensic process, data integrity, safety and report interpretation. Specialist roles may be divided among team members, but responsibility is explicit. Refresher training follows equipment changes and significant nonconformities. Proficiency outcomes are reviewed for systematic overcalling, undercalling, poor source-absent performance or excessive confidence. Corrective action is documented and its effectiveness checked.

H.10 Ongoing quality control, nonconformity and method change

Daily or deployment checks use a stable transfer source, termination, dummy probe and coordinate verification. Control charts may monitor centre frequency, Q, noise, gain and reference response. Limits are derived from historical performance. A result outside limit stops evidential use until the cause is resolved. The organisation records damaged cores, shifted trimmers, battery faults, software errors, missing data, unauthorised equipment and scene-state deviations as nonconformities.

Measurement-science elaboration. At expert-practitioner level, Ongoing quality control, nonconformity and method change begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains.

The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

Method changes are classified by risk. Editorial changes need document control. A replacement of an equivalent capacitor may require calibration. A new core material, concentrator geometry, preamplifier topology, localisation algorithm or active-excitation band may require partial or full revalidation. Casework affected by a discovered defect is identified and reviewed. Validation records, raw data, calculations and decisions remain available for independent technical review.

H.11 Illumination-path leakage and intermodulation challenge

Inject authorised source levels into the complete field configuration while the environmental response input is terminated. Measure direct leakage, harmonics, spurs, noise-floor rise, compression and all predicted m f1 plus or minus n f2 products. Repeat with altered preselection, attenuation, cable routing and receiver architecture. The validated operating envelope excludes states in which a false response can meet the candidate criterion.

Active-test metrology. For Illumination-path leakage and intermodulation challenge, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern.

Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. The method stops when spectrum authority, exposure, implanted-device, medical-equipment, fire, heating, data-alteration, or evidential-contamination controls are not satisfied [17-23, 29-30].

H.12 PPM timing accuracy and false-classification study

Use traceable pulse generators and synthetic records to test pulse-position estimates across amplitude, width, rise time, jitter, missing pulses, overlapping pulses, PAM, PWM, PRF modulation, OOK and receiver gain transients. Report bias, standard deviation, false PPM rate and uncertainty over the claimed signal-to-noise and sampling range.

Waveform and modulation elaboration. The expert treatment of PPM timing accuracy and false-classification study begins with the complex analytic signal rather than a visual resemblance on a single spectrum display. Carrier, envelope, instantaneous phase, instantaneous frequency, pulse timing, and cyclic structure are examined as separate observables. The examiner compares predicted sideband spacing, occupied bandwidth, deviation, pulse repetition interval, duty cycle, phase continuity, frequency error, and temporal recurrence with the measured record. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

H.13 Blind remotely powered and frequency-translated response trials

Conduct blind trials with responsive devices, non-responsive resonators, ordinary electronics, corrosion or junction confounders, external transmitters and empty placements. Randomise illumination frequency, level, geometry and device state.

Measure detection probability, false-alarm rate, classification accuracy, localisation error, threshold repeatability and analyst agreement.

Controlled-illumination interpretation. For Blind remotely powered and frequency-translated response trials, temporal coincidence with an illumination command is insufficient. The actual field at the scene must be measured by an independent reference channel and related to the response through a reproducible latency and spatial pattern. Direct breakthrough is challenged by isolation measurements, couplers, terminated inputs, attenuation steps, antenna relocation, independent intermediate-frequency architecture, and tests for harmonics, intermodulation, compression, and desensitisation. No response is described as device-associated until it is spatially localised, repeatable, control-compliant, and supported by an uncertainty statement [17-30, 127-128].

H.14 Varactor-tuned rod stability, X-axis lock and artefact validation

Validate every tuned rod in varactor-enabled, varactor-bypassed and fixed-substitution states. Measure centre frequency, loaded Q, transfer factor, phase, noise spectral density, leakage, bias-feed spurs, temperature drift, bias droop, lock acquisition, held-bias stability, X-axis error, cross-axis response, overload recovery and microphonics. Challenge the branch with strong out-of-band fields and two-tone excitation to quantify harmonics and intermodulation. Establish acceptance limits for the permitted bias range and the maximum change that can occur without closing and restarting a spatial comparison series.

Measurement-science elaboration. A advanced metrological approach to Varactor-tuned rod stability, X-axis lock and artefact validation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

H.15 Illumination-trigger latency, pre-trigger and delay-search validation

Use traceable source bursts, programmable delays and blind response fixtures to measure source-monitor detection latency, trigger-distribution latency, analyser arming latency, pre-trigger accuracy, delay accuracy, capture-window coverage, missed-event probability and false-trigger rate. Include immediate responses, microsecond SAW-like echoes, millisecond start-up responses, second-scale energy-storage responses, no-response trials and direct-leakage confounders. The released delay schedule shall demonstrate overlapping temporal coverage and shall identify the longest response latency for which the claimed method has been validated.

Measurement-science elaboration. An advanced metrological approach to Illumination-trigger latency, pre-trigger and delay-search validation treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Where a result depends upon subtraction, ratios, phase differences, or spatial gradients, covariance between channels and stations is considered rather than assuming every input quantity is independent. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

H.16 Multichannel coherence, analyser-slaved resonance and burst-array validation

A known three-component field is generated at surveyed positions while all nine probe channels acquire simultaneously. The study measures channel gain and phase, timing skew, group delay, vector reconstruction, pod-to-pod gradient, mutual coupling and localisation error across the intended bands. Blind trials include point sources, extended conductors, multiple sources and broad environmental fields. The acceptance criteria distinguish amplitude-only, event-time, phase-coherent and full vector claims.

Metrological interpretation. At expert-practitioner level, Multichannel coherence, analyser-slaved resonance and burst-array validation begins with a formal declaration of the measurand. Frequency, field strength, phase, time delay, spatial coordinate, modulation parameter, and classification score are different measurands and require different calibration chains. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

The analyser sweeps or steps through every authorised resonant band while each probe follows its individual varactor calibration law. At each point the validation records commanded frequency, achieved resonance, lock error, settling time, bias, Q, transfer factor, pilot blanking, noise and spur level. Trials intentionally introduce a wrong bias, missing lock, late channel, clock unlock and varactor-generated intermodulation to prove that the system invalidates the affected block.

Burst validation uses controlled events of decreasing duration and duty cycle, including delayed returns after a measured illumination reference. All nine probes, the source-reference channel, the terminated control and the guard receiver are assessed for probability of intercept, trigger latency, pre-trigger preservation, relative timing and storage continuity. A short-lived signal is considered localisable only when the same physical event is present on the required channels within the validated timing uncertainty.

Where a secure-facility filter or penetration-path workstream is intended, a benign test fixture represents a low-pass feedthrough and parallel structural paths. The validation determines whether simultaneous interior, exterior and control channels can discriminate direct coupling, filter leakage, common mode, ground paths and receiver crosstalk without describing or constructing an operational bypass device.

H.17 Crystal, resonator and harmonic-family validation. The validation study shall include blinded source-present and source-absent trials using quartz crystals, ceramic resonators, oscillator modules, PLL clock generators and divided outputs. Trials shall measure detection probability, false-alarm probability, family-grouping accuracy, harmonic-order coverage, sleep-state capture, source localisation error and inter-operator reproducibility. Each channel path shall be calibrated at the actual harmonic frequencies used in the decision, because a fundamental-frequency transfer calibration cannot be presumed to apply at H11.

The validation study shall include blinded source-present and source-absent trials using quartz crystals, ceramic resonators, oscillator modules, PLL clock generators and divided outputs. Trials shall measure detection probability, false-alarm probability, family-grouping accuracy, harmonic-order coverage, sleep-state capture, source localisation error and inter-operator reproducibility. Each channel path shall be calibrated at the actual harmonic frequencies used in the decision, because a fundamental-frequency transfer calibration cannot be presumed to apply at H11.

Appendix I. Forms, Data Schema and Reporting Templates

The field schema is extended by Appendix O to include regional annulus stations, altitude and missing-sector records, twenty-seven-cell identifiers, vertical and opposite-surface pairs, intervention events, shell completeness, composite-modulation layers, trigger delays and cyclostationary features.

The following records are minimum structures. They may be implemented on paper or in a controlled digital system, provided that timestamps, authorship, revisions and raw-file links are preserved. The schema is designed for alphanumeric and numerical evidence. It does not require a photographic or reconstructed image of the premises or device. A lawful architectural plan may be referenced separately for coordinate context.

I.1 Rings, Radials and Station Record

Field	Required entry	Control purpose
Case and series ID	Unique identifiers	Links station to immutable raw files
Stage	300 ft, 150 ft, 100 ft, 50 ft, 30 ft, 15 ft, 12 ft, 3 ft or 3-inch	Defines inferential role
Coordinate	Datum, x, y, z and uncertainty	Reproducible probe-centre position
Orientation	Axis and angle with uncertainty	Preserves directional response
Probe configuration	Serial, tuning, gain, filter and cable	Prevents configuration mixing
Time and dwell	Start, end, settling delay	Separates time from position
Premises state	Known equipment and changes	Supports confounder analysis
Blank status	Termination or dummy file ID	Instrument artefact control
Raw file hashes	Cryptographic digest values	Integrity and chain of custody

Field	Required entry	Control purpose
Target tier	Tier 1, Tier 2 or Tier 3	Separates passive timing, passive RF and active response evidence
Illumination state	Terminated, sham, source on, source off, offset, polarisation or position control	Preserves causal chronology
Illumination and response frequencies	Measured values and uncertainties	Tests translation, harmonics and receiver products
Waveform and modulation	Source waveform, response PPM or other modulation metrics	Supports mechanism discrimination
Azimuth, elevation and polarisation	Transmit and receive geometry	Permits spatial and coupling reconstruction
Independent confirmation	Receiver, antenna and clock architecture	Supports evidential class
Core material state	Alloy or ferrite grade, lot, form, anneal, dimensions, gap and configuration ID	Prevents unrecorded substitution of magnetically dissimilar material
Magnetic conditioning	Degaussing or reset method, time, residual field and ambient DC field	Controls remanence and bias-history effects
Complex permeability data	Calibration file for μ', μ'', impedance, Q and transfer factor at the deployed temperature	Binds the field record to the validated frequency response
Mechanical stress state	Mounting torque, clamp position, inspection for cracks or ribbon displacement	Controls stress-induced permeability and microphonic changes

The record stores nominal and actual distance. A point called 150 feet may in fact be 146.8 feet, and a point called 30 feet may be 28.9 feet because of a boundary or obstruction. Both nominal and actual values are needed. Coordinates refer to the sensing centre, not the tripod foot. Orientation conventions are defined once for the case. If magnetic north is used, declination and local disturbance are considered. A building-axis convention is often more reproducible indoors. The station record is completed before the team moves to the next point.

Three-dimensional search analysis. For Ring and station record, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

I.2 Probe configuration record

The configuration record contains probe serial number, core material and lot, rod dimensions, winding sections and turns, wire construction, measured resistance, inductance, self-resonance, fixed capacitance, sapphire piston type and setting, varactor manufacturer and part number, lot, rated reverse voltage, C-V data, enabled or bypass state, anti-series pairing where used, held bias, bias-source identity, X-axis reference status, lock error and hold drift, concentrator material and gap, shield geometry, preamplifier version, battery, cable, transfer factor, calibration date and permitted role. A diagram may exist in the controlled engineering file, but case records identify it by configuration revision. Field personnel do not alter the winding, shield or concentrator.

Probe-engineering analysis. The technically mature interpretation of Probe configuration record treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

A tuning event creates a new configuration suffix. The record states the reference source, target frequency, measured centre, 3 dB bandwidth, Q, temperature and post-lock verification. It also records the blank acquired after tuning. If the probe experiences impact, excessive field, temperature excursion or suspected mechanical shift, it is quarantined pending verification. The case log notes any period during which its status was uncertain.

Table I-2A. Varactor-controlled tuned-probe supplement

Field	Required entry	Control purpose
Varactor identity	Manufacturer, part, package, lot and rated reverse voltage	Traceability and substitution control
Capacitance data	C at stated biases, pair matching and effective branch range	Reconstructs the tuning span
Bias system	Source, filtering, monitor, noise and maximum current	Identifies bias-line contamination
Operating state	Enabled, bypassed or fixed substitution	Separates tuning-network effects
X-axis lock	Set point, error, acquisition time and pilot source	Defines the reference-axis condition
Evidence hold	Held bias, start, stop, drift and temperature	Preserves spatial comparability
Artefact tests	Two-tone, strong-field, terminated bias lead and independent receiver	Rejects junction and control-electronics products
Release status	Permitted band, role, Q, transfer factor and uncertainty	Bounds the configuration claim

A varactor adjustment is a tuning event. The supplementary record states whether the adjustment occurred in calibration, an interleaved blank or evidence acquisition. Evidence acquisition normally uses hold. Any active correction, bias step or loss of X-axis lock closes the current series. The record links the hard-bypass and fixed-capacitance-substitution controls to the same station or laboratory release file.

I.3 Candidate signal record

Each candidate has a unique identifier and a neutral description. Required fields include measured frequency and uncertainty, bandwidth, amplitude quantity and units, noise estimate, duration, duty cycle, modulation or burst features, harmonics and residuals, phase reference, probe and orientation, coordinates, strongest and weakest repeated values, blanks, reverse-path result, known-source comparisons and artefact tests. The record states whether the signal is detected, confirmed, localised, source-class associated or unresolved.

Evidential reasoning elaboration. For Candidate signal record, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

Frequency names such as watch crystal or colour subcarrier appear only in the hypothesis field. The observation field contains measured numbers. A candidate at 32.766 kHz is not silently rounded to 32.768 kHz. Its offset is calculated, and the uncertainty and drift are reported. The record distinguishes nominal frequency, measured frequency and tuning centre. This prevents the instrument setting from being mistaken for the source result.

I.4 Advancement-gate form

Before entering the next ring, the examiner marks whether the candidate recurred, whether a blank was satisfactory, whether the receiver was linear, whether the frequency remained physically consistent, whether a spatial or directional trend exists, whether a stationary reference supports comparability, and whether the next geometry can distinguish competing hypotheses. A supervisor or second examiner reviews material advancement decisions where staffing permits. A failed gate does not force abandonment. It directs a repeat, lateral point, altered control or classification as unresolved.

Reporting and custody perspective. For Advancement-gate form, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

The form also records reasons for deviations. Access, safety, weather, patient care or legal boundaries can prevent a complete ring. The substitute geometry and its limitation are entered before interpretation. The form is not a tick-box substitute for reasoning. It links each answer to raw-file and log identifiers so that an independent reviewer can examine the basis.

I.5 3-inch convergence record

The convergence record lists every radius or raster coordinate, actual standoff, probe aperture, axis, height, dwell, amplitude, null angle, gradient, phase and quality flags. Re-centring calculations are versioned and preserve the previous centre. The record identifies skipped points and why they were inaccessible. It also states the stop condition and the resulting x, y and z intervals before uncertainty expansion. No colour-filled spatial image is required. A line plot or coordinate table is sufficient.

Reporting and custody perspective. The advanced technical treatment of 3-inch convergence record distinguishes recognition, recording, acquisition, analysis, interpretation, and reporting as separate stages. A conclusion is not allowed to migrate backwards and reshape the raw record. Raw files are preserved in their native form and hashed before derived filtering, plotting, resampling, demodulation, or spatial fusion; every transformation is versioned and linked to the source record. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

The final region is expanded for coordinate, aperture, standoff and model uncertainty. The report distinguishes measured support from extrapolation behind an inaccessible surface. If only one side of a wall was measured, depth remains an interval. If multiple maxima remain, separate regions are reported or the signal is classified as unlocalised. The form prohibits selecting only the maximum cell and calling it the device location.

I.6 Artefact and confounder checklist

The checklist covers terminated input, dummy probe, gain step, amplifier bypass, preselector change, sample-rate change, independent receiver, probe rotation, cable movement control, self-emission library, local clock comparison, source-state inventory, external bearing, reverse path and time-separated revisit. Each item records expected and observed outcomes. Not applicable requires a reason. A candidate cannot receive the highest confirmation class when a material artefact test was omitted without justification.

Confounder records include ordinary electronics, building services, neighbouring sources, mains and harmonics, switch-mode combs, known clocks, medical equipment, vehicles, environmental monitors and team equipment. The purpose is not to catalogue every electron in the building. It is to identify plausible alternatives in the measured band and location. The report names the alternatives actually tested and those remaining.

I.7 Model report language

A positive localisation statement should identify the measured signal, its frequency and uncertainty, field component, configuration, spatial sequence, repeatability, controls, final bounding region and uncertainty. It should then state the limited proposition supported. Example: A repeatable narrowband magnetic component at 32.76786 kHz was confirmed by two probe architectures and two receiver paths. Its relative behaviour remained compatible across the 30-foot, 15-foot and 12-foot comparisons, increased through the 3-foot ring and was strongest within the stated wall coordinate interval. The data support a local electronic timing source or coupled conductor within that interval. They do not identify a particular device or establish a medical effect.

Evidential reasoning elaboration. A mature forensic approach to Model report language separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions [1-9].

A negative statement identifies capability and examined conditions. Example: No candidate meeting the predeclared criteria was detected during the stated operating states and frequency bands. This result does not exclude a dormant passive structure, an intermittently inactive circuit, a source below the method detection limit, a source outside the authorised volume or a device using other frequencies. A report shall not use no device present unless an independent identification method supports that proposition.

I.8 Release review and retention record

Before release, a technical reviewer confirms that the report matches raw data, calibration and uncertainty. A second review examines impartiality, legal scope, privacy and medical boundaries. File hashes, media copies, software versions and analysis scripts are reconciled. Tables and charts remain black and white unless red, green or amber status indicators are necessary. Colour never carries the only meaning. Every status also has a word or symbol. For controlled-illumination work, the reviewer additionally reconciles the source-state log, forward and reflected power, field monitor, receiver-overload evidence, intermodulation map, PPM timing analysis, independent-receiver result and classification gate.

Forensic interpretation. For Release review and retention record, the evidential object comprises the original data, instrument state, coordinates, calibration status, operator actions, controls, derived products, decision rule, and documented chain of custody. Contemporaneous notes distinguish planned actions from reactive changes, and the report identifies any unvalidated method variation, missing control, inaccessible sector, environmental disturbance, or failed channel. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

Retention policy covers raw digitiser files, metadata, instrument states, calibration certificates, coordinate records, field logs, analysis outputs, report versions and review comments. Access is role-controlled. Personal and medical information is minimised and separated from technical data where practicable. Disposal follows legal and contractual requirements and is documented. The retained record permits a competent independent examiner to reproduce the material calculations and understand every limitation.

I.9 Controlled-illumination acquisition record

The form records authority identifier, source and antenna serials, calibration, frequency, waveform, conducted power, forward and reflected power, estimated or measured field, azimuth, elevation, polarisation, source coordinate, candidate coordinate, response antenna, preselector, gain, receiver, clocks, start and stop times, safety monitoring, control state and raw-file hashes.

Controlled-illumination interpretation. A advanced technical analysis of Controlled-illumination acquisition record separates same-frequency reflection, load-modulated backscatter, harmonic generation, frequency translation, nonlinear-junction response, direct leakage, receiver mixing, and internally generated transmission. The state sequence includes source disconnected and terminated, passive baseline, sham command, authorised low-level illumination, field-confirmed trigger, source-off recovery, frequency offset, polarisation change, position change, and independent receiver confirmation. A nonlinear or harmonic response remains a junction or material observation unless additional evidence supports an electronic device interpretation [17-23].

The same form also records illumination-monitor receiver and detector, source-presence threshold, hysteresis, holdoff, measured trigger latency, trigger distribution, common clock, pre-trigger interval, requested and measured trigger delay, acquisition mode, span or centre frequency, real-time bandwidth, capture-window duration, response onset, peak, duration, recovery, missed-event count and false-trigger count.

I.10 PPM and translated-response analysis record

The analysis form records frame reference, pulse detector, sample rate, threshold or model, displacement estimates, jitter, missed pulses, response frequency and uncertainty, illumination-response relation, source-offset result, receiver-image calculation, intermodulation calculation, independent-receiver result, spatial bound and classification decision.

Waveform and modulation elaboration. For PPM and translated-response analysis record, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

For a retroreflective or remotely powered candidate, the analysis record includes the complete delay-iteration series, temporal brackets, refined latency, source-detection correction, analyser trigger uncertainty, response jitter, direct-leakage latency, sham distribution and independent-receiver latency. The report states the temporal coverage actually tested.

I.11 Active stop-event and recovery record

Every stop event records UTC time, source state, forward and reflected power, field monitor, reason, equipment and persons affected, hardware shutdown confirmation, clinical or safety notification, data quarantine, recovery checks, authority to resume or terminate, and post-event passive findings.

Reporting and custody perspective. The advanced technical treatment of Active stop-event and recovery record distinguishes recognition, recording, acquisition, analysis, interpretation, and reporting as separate stages. A conclusion is not allowed to migrate backwards and reshape the raw record. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. The final language states what the data support, what they do not support, and what additional examination would be required for a stronger conclusion [1-9].

I.12 Source-synchronised trigger and latency-iteration record

This record links every source-on event to the measured illumination-present trigger, the pre-trigger data segment, the programmed and measured delay, the capture window and the corresponding response or no-response result. It preserves the raw source-monitor and response files, instrument states, trigger thresholds, latency corrections, overload indicators, negative controls and file hashes.

Synchronous measurement elaboration. The advanced technical treatment of Source-synchronised trigger and latency-iteration record regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. A twelve-channel chassis can support nine orthogonal probe paths, an illumination reference, a terminated or dummy control, and an independent guard channel, but that allocation remains valid only while the common backplane and front ends remain within their qualified state. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

The closing entry identifies the earliest and latest tested latency, any unobserved temporal gap, the response-latency estimate and uncertainty, the number and order of live and sham repetitions, the independent-receiver result, the spatial coordinate, and the evidential classification. A delay that was not tested is not silently included in a negative conclusion.

I.13 Coherent multichannel array and resonance-lock record

The record shall contain one row for every active channel and one summary block for the complete sample epoch. Mandatory fields are case identifier, acquisition identifier, chassis identifier, card and channel serial, pod, axis, coordinate, virtual-centre offset, probe configuration, band module, cable, preselector, gain, sample rate, instantaneous bandwidth, analysis bandwidth, tracking-receiver bandwidth, frequency command, fixed capacitance, sapphire piston setting, varactor bias, resonance error, Q or transfer check, settling interval, lock status, trigger source, trigger delay, pre-trigger duration, timebase source, clock status, amplitude correction, phase or group-delay correction, overload flag, file name and hash.

Multichannel receiver analysis. The advanced technical treatment of Coherent multichannel array and resonance-lock record regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. A channel that fails coherence, resonance, headroom, or self-noise checks is marked invalid for the affected epoch rather than silently replaced in the final plot [7-16].

Field group	**Required entries**
Common epoch	Date and time, event identifier, site master, reference lock, trigger source, trigger threshold, pre-trigger, post-trigger, cross-chassis offset.
Channels 1-9	Pod A/B/C, axis X/Y/Z, probe and cable serial, coordinate, band, gain, frequency, tuning state, lock, calibration and waveform hash.
Channel 10	Illumination or source-reference frequency, waveform, level, detector, trigger latency and coupling control.
Channel 11	Terminated, dummy or calibration state, observed spurs, pilot leakage and acceptance result.
Channel 12	Guard, tracking or independent receiver assignment, LO plan, bandwidth, result and comparison.

Field group	Required entries
Array result	Concurrent feature, coherence or correlation metric, vector or gradient result, uncertainty, invalidated channels and classification.
Operator declaration	All included channels were simultaneous, resonance-qualified, in hold, free of overload and linked to the stated raw files.

Table I-13. Minimum multichannel array and resonance-lock record.

I.14 Crystal, resonator and harmonic-family record. Required fields: case identifier; station and cube identifier; date and UTC epoch; nominal candidate frequency; observed centre frequency; uncertainty; hypothesised implementation class; harmonic or divider order; probe and channel; resonance command, verified resonance and settling status; amplitude, phase and coherence metrics; duty cycle; drift; source-state observation; spatial gradient; control results; alternative explanations; raw-file identifiers and hashes; examiner; reviewer; and evidential classification. The record shall distinguish a supplied catalogue value from a measured component.

Required fields: case identifier; station and cube identifier; date and UTC epoch; nominal candidate frequency; observed centre frequency; uncertainty; hypothesised implementation class; harmonic or divider order; probe and channel; resonance command, verified resonance and settling status; amplitude, phase and coherence metrics; duty cycle; drift; source-state observation; spatial gradient; control results; alternative explanations; raw-file identifiers and hashes; examiner; reviewer; and evidential classification. The record shall distinguish a supplied catalogue value from a measured component.

Appendix J. Ultra-Low-Power SAW, NFM and Microphone Search Protocol

SAW, NFM and microphone-related searches shall use the regional annuli to identify ordinary transmitter populations and recurring noise-like activity before premises convergence. Composite NFM and pulse-position features are analysed under Chapter 33 without decoding intelligible speech or unauthorised payload content.

STATUS AND AUTHORISATION NOTICE
This appendix is an inspection protocol for authorised defensive and forensic work. It is not a spectrum licence, not a warrant, not a medical diagnostic method, and not evidence that a listed frequency is unlawful. Passive acquisition is the default. Any intentional transmission, illumination, acoustic stimulus, line injection or device activation requires separate written authority, spectrum review, exposure review, EMC review and site approval.

J.1 Purpose and scope

This appendix converts the supplied low-power-transmitter frequency charts, the supplied SAW and microphone materials, and current component information into a reproducible search system. The system is designed to detect, classify and spatially localise extremely weak electronic signatures without touching, opening, imaging or mechanically disturbing the suspected source. It applies to naturally radiated carriers, cable-mode radiation, conducted RF, SAW-stabilised oscillators, intermittent narrowband transmitters, microphone front ends, digital microphone clocks and audio-frequency magnetic leakage from wiring.

The procedure begins with the 5-mile, 2.5-mile, 1-mile, 0.5-mile and 0.25-mile regional annuli under the station-density requirements of Chapter 31. It then advances through 300 feet, 150 feet, 100 feet, 50 feet, 30 feet, 15 feet, 12 feet and 3 feet before entering the three-inch convergence stage. Distance is measured from a predeclared scene datum, not from a moving guess about source position. Where the premises or surrounding road network is irregular, each nominal ring is represented by measured stations and every geometric departure is recorded.

The method is source-neutral. It may identify ordinary remote controls, alarms, telemetry, wireless microphones, hearing devices, building controls, radio-frequency identification equipment, broadcast leakage, consumer electronics and lawful communications. A frequency match therefore creates only a candidate measurement. Device association requires repeatability, spatial convergence, instrument controls, environmental controls and an uncertainty statement.

J.2 Scientific propositions and exclusions

A SAW resonator is a frequency-selective piezoelectric component capable of supporting a stable high-frequency resonance. When incorporated into an active oscillator, it can determine or strongly constrain the carrier frequency. A SAW filter is also frequency selective, but a filter does not generate a carrier merely by existing. Its presence becomes detectable only when energy passes through an active circuit, when the component is excited, or when a circuit leaks associated clocks and mixer products. A passive SAW sensor or coded delay line can return energy after interrogation, but may be silent during a purely passive survey.

Field-theory elaboration. In Scientific propositions and exclusions, the observable is not a free-standing property of the suspected circuit. It is the solution of a boundary-value problem involving source geometry, wavelength, material properties, apertures, conductors, nearby structures, and the receiving probe. At electrically small dimensions, terms proportional to 1/r cubed and 1/r squared may dominate over the radiating 1/r term, so amplitude-distance behaviour cannot be interpreted through free-space path loss alone. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

The inspection therefore avoids the false syllogism that a signal near a catalogue frequency proves a SAW device. It also avoids the inverse error that absence of a catalogue-frequency signal excludes a device. Custom resonators are commercially available across wide ranges, oscillators may be pulled by load capacitance and temperature, active circuits may multiply or divide a resonant frequency, and emissions may be shifted by mixers or modulation. Exact-channel searches and broadband searches are consequently mandatory companions.

The microphone element is treated as one component of a wider electrical system. An electret or analogue MEMS microphone can create small bias and audio currents. A digital MEMS microphone adds a clock and a pulse-density-modulated data stream. A hearing-aid microphone may feed a preamplifier or digital signal processor whose switching and clock fields are easier to detect than the acoustic transducer itself. The protocol reports the measured electronic phenomenon without claiming that the microphone is the source unless localisation and controlled testing establish that association.

J.3 Target hierarchy for this workstream

The first target class is the baseband and timing family. It includes audio-band current, sample-rate clocks, pulse-density-modulation clocks, microcontroller clocks, dividers, regulators, oscillator leakage and sidebands. The second target class is radiated or conducted RF, including narrowband FM, on-off keying, amplitude shift keying, frequency shift keying, pulse trains, telemetry bursts and apparently unmodulated carriers. The third target class is a passive or semi-passive response that appears only under separately authorised interrogation.

Advanced practitioner analysis. A technically mature treatment of Target hierarchy for this workstream begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Within each class, priority is assigned by evidential strength rather than dramatic appearance on a spectrum display. A stable signal that persists through the regional inventory, then maps smoothly from the 300-foot transition to a three-inch spatial maximum, survives receiver changes and exhibits a coherent timing relationship to a baseband family may be more probative than a stronger signal that varies with public radio traffic. Conversely, an exact frequency match without spatial convergence remains no more than an observed signal.

J.4 Use of the frequency register

Appendix contains four categories of frequency information.

> **Category A consists of exact case-supplied historical channels.**
>
> **Category B consists of SAW resonator and filter frequencies documented by component manufacturers.**
>
> **Category C consists of regulatory or service bands that explain why many lawful devices cluster in a region.**
>
> **Category D consists of derived frequencies, such as harmonics, subharmonics, divider products, clock sidebands and tolerance-expanded windows.**
>
> **The acquisition record identifies the category used for every search.**

Advanced practitioner analysis. A technically mature treatment of Use of the frequency register begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The register is a search accelerator, not a substitute for spectral reconnaissance. At every occupied ring, the team performs an exact-channel pass, a tolerance-window pass and a continuous sweep over the applicable receiver range. The exact pass may reveal a carrier buried in a crowded display. The continuous pass protects against custom frequencies, drift, old component variants, mixing products and sources absent from the supplied files.

J.5 Fixed geometry and movement control

Before deployment, the scene coordinator fixes a datum point, north reference, vertical reference and station naming convention. Stations are not silently moved to obtain a stronger reading. The 5-mile, 2.5-mile and 1-mile annuli use sixteen planned azimuthal stations, increased to twenty-four for high-risk work. The 0.5-mile ring ordinarily uses twelve and never fewer than eight. The 0.25-mile ring should use twelve and never fewer than eight. The subsequent close rings use the geometry prescribed in the main field procedure. Each occupied station uses the same nominal probe heights and orientation sequence unless a documented band-specific reason requires otherwise.

Spatial-measurement interpretation. The mature treatment of Fixed geometry and movement control replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Personnel and equipment movement is controlled because a human body, cable bundle, vehicle, metal tripod or switched power supply can alter weak fields. The remote reference receiver remains stationary while the mobile receiver advances. The remote receiver provides a concurrent environmental record, allowing a public or distant signal to be distinguished from a local field that changes as the mobile geometry changes. Radios, telephones, wireless accessories, smart watches and nonessential switching electronics are removed or placed in documented states.

The fixed geometry and movement-control rule continues inside the premises through the Appendix N cube protocol. Search personnel shall treat each cube as a discrete measurement unit, preserve the approach route and record every physical or operational change that could alter an ultra-low-level field.

J.6 The 300-foot remote reference stage

The 300-foot stage establishes the external noise floor, candidate-bearing set and receiver self-emission record. No claim of guaranteed detection is made at this radius. The stage is nevertheless retained because a highly stable, continuous carrier may be measurable at long range, and because the remote station provides a reference against which later increases can be judged. The station is occupied for enough time to observe low-duty-cycle activity, normally not less than thirty minutes for the priority channel bank and not less than one complete broad-spectrum cycle.

Advanced practitioner analysis. At expert-practitioner level, The 300-foot remote reference stage is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Three receive paths operate concurrently where resources permit.

> Path 1 is a high-dynamic-range spectrum or vector receiver using a broadband directional antenna and appropriate preselection.
>
> Path 2 is a narrow-channel receiver bank centred on Appendix K frequencies with carrier estimation bandwidths of 50 Hz to 300 Hz.
>
> Path 3 is an I/Q recorder or zero-span detector configured for short bursts. A terminated-input trace, dummy-antenna trace and receiver-with-antenna-rotated trace are acquired before the first evidential trace.

At each azimuth, the antenna is measured in at least horizontal and vertical linear polarisation. Circular polarisation is added where the antenna system supports it. The operator records azimuth, elevation, antenna factor, cable loss, preamplifier state, attenuator state, resolution bandwidth, video bandwidth, detector, dwell, reference-clock status and weather. A candidate bearing is not accepted unless it repeats after the antenna is returned to the original orientation.

J.7 The 150-foot transition stage

The 150-foot ring tests whether a candidate changes consistently with approach. The same channel set, dwell structure and antenna orientations used at 300 feet are repeated before any new frequencies are added. A local source hypothesis strengthens when the mobile receiver shows a reproducible increase while the remote reference remains substantially unchanged. The hypothesis weakens when both receivers rise and fall together or when the direction of maximum response remains fixed on an external transmitter.

This ring is also the first formal multipath challenge. Measurements are repeated after a modest lateral displacement and after a controlled antenna-height change. A genuine local source can still exhibit fading, but its aggregate bearing and gradient should remain intelligible. A single deep null or isolated maximum is not used to steer the team without confirming measurements at neighbouring points.

J.8 The 100-foot corroboration stage

At 100 feet, the team begins independent-channel corroboration. At least one candidate is observed on a second receiving chain with a different first local oscillator or direct-sampling architecture. The purpose is to reject images, local-oscillator leakage, reciprocal mixing and software artefacts. The second chain need not have identical amplitude calibration, but its frequency, timing and directional behaviour must be compatible after uncertainty is considered.

If the signal is narrowband FM or a similar narrow analogue emission, the team records raw I/Q before demodulation and then applies 8 kHz, 10 kHz, 12.5 kHz, 14 kHz and 16 kHz channel filters offline. Audio is represented by spectral statistics, modulation index, deviation estimate and envelope timing. Speech content is not monitored or transcribed. A signal that can be heard only after aggressive squelch or undocumented automatic frequency control is not promoted without the raw data.

J.9 The 50-foot source-separation stage

The 50-foot ring separates signals associated with the premises from signals associated with nearby streets, buildings, vehicles or utilities. Measurements are made on the source-facing and source-opposed sides of the available perimeter. The team notes whether walls, windows, service penetrations, earthing conductors, telephone cables, coaxial cables, pipes or fences coincide with the field maximum.

Advanced practitioner analysis. At expert-practitioner level, The 50-foot source-separation stage is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Directional antenna gain is reduced if the receiver approaches compression. A gain-step test is mandatory. If a candidate rises by materially less than the inserted gain change, or if unrelated lines rise together, overload or intermodulation is suspected. Preselector changes and antenna substitutions are used to identify strong out-of-band causes. A candidate is not followed inward merely because an overloaded display appears busier.

J.10 The 30-foot service-path stage

The 30-foot ring emphasises cable-mode and structure-borne paths. Broadband magnetic loops, electric-field probes and current-proximity probes are added to the directional RF antennas. The operator scans along accessible service routes without touching them, maintaining a recorded stand-off distance. A signal that follows a cable, pipe or earthing conductor may be conducted or reradiated rather than generated at the strongest external point.

Advanced practitioner analysis. A technically mature treatment of The 30-foot service-path stage begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Voice-frequency magnetic measurements begin at this ring if the noise environment permits. The flat 30 Hz to 14 kHz channel is acquired first. C-message and 3 kHz-flat views are calculated from the same calibrated waveform after acquisition. The raw unweighted waveform remains the evidential source record.

J.11 The 15-foot pre-boundary stage

The 15-foot ring creates the last stable exterior comparison before threshold effects dominate. The full exact-frequency bank is re-run with longer dwell on candidates. Polarisation is repeated, and a small-aperture directional antenna is introduced for frequencies where its calibration is valid. The team identifies the wall segment, opening, service path or structural member associated with the steepest repeatable gradient.

Advanced practitioner analysis. A technically mature treatment of the 15-foot pre-boundary stage begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

For intermittent sources, the team uses event-triggered I/Q capture with pre-trigger data. If lawful site operations create predictable equipment states, those states are logged, but they are not manipulated merely to provoke a signal unless the case plan expressly authorises controlled state testing.

J.12 The 12-foot threshold stage

The 12-foot stage is a formal advancement gate. Passive measurements, receiver controls, station coordinates and uncertainty entries must be complete before entry or close approach. The team verifies that the candidate is not produced by its own data network, reference clock, display, battery converter, active antenna or preamplifier. A second operator reviews the trace and the movement record.

A candidate that fails the gate is retained in the catalogue as an observed external or unresolved signal. It is not erased. A candidate that passes is assigned a provisional target identifier and a defined set of frequencies, tolerances, modulation features and spatial predictions for the 3-foot stage.

J.13 The 3-foot near-field stage

At 3 feet, the method changes from remote bearing to near-field discrimination. Large directional antennas are supplemented or replaced by successively smaller magnetic loops, electric-field probes, compact monopoles, shielded coils, differential magnetic probes and the voice-frequency bar probes specified in Appendix L. Receiver gain is stepped down as necessary, because near-field coupling can overload a chain that was quiet at 300 feet.

Electromagnetic interpretation. A advanced technical account of The 3-foot near-field stage distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. Spatial nulls, phase reversals, vector orientation, and response to controlled geometric changes are often more informative than a single amplitude maximum, particularly in reflective rooms and near extended conductors. The section is technically complete only when the relevant field regime and the limits of the adopted approximation are stated [129-131].

The operator records three orthogonal probe orientations at each point. A magnetic loop is rotated through its null as well as its maximum. An electric probe is kept at a constant stand-off. Phase and amplitude are recorded where the receiver supports coherent measurements. The search does not rely on a single signal-strength display, because cable currents, aperture coupling and reactive fields can create multiple maxima.

J.14 Three-inch decrement and three-dimensional lattice

Once the 3-foot gate is passed, the operator establishes a stationary line of approach and advances the probe in three-inch increments. This is most commonely performed by a series of vertical floor to ceiling masts, with a shuttle mechanism which slides form left to right on a shuttle assemble. Using a plurality of sensors on the shuttle for automated scanning of an area being inspected. The source object is not touched. At each increment, the same probe orientation, gain, bandwidth and dwell are used until the response approaches compression or the spatial gradient changes. When a two-dimensional maximum is bounded, measurements are repeated above, below and to each side to form a three-dimensional lattice.

Advanced technical elaboration. A technically mature treatment of three-inch decrement and three-dimensional lattice begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The final result is a coordinate volume and an electromagnetic signature, not a photograph or physical identification. The resolution statement includes the lattice spacing, probe aperture, stand-off, field type, multipath conditions and uncertainty. If the response follows a conductor out of the lattice, the conclusion describes a probable propagation path rather than falsely assigning the source to the point of maximum field.

J.15 Receiver and antenna architecture

The RF receiver chain uses interchangeable preselectors so that strong broadcast, mobile, paging, aeronautical and public-safety signals do not generate false products. The preferred architecture records calibrated I/Q and permits independent adjustment of resolution bandwidth, detector, dwell and trigger. A frequency-disciplined reference is used for narrow carriers, but the reference source is physically separated and its own leakage is measured with the receiving antenna terminated.

Sensor and front-end elaboration. At advanced-practitioner level, Receiver and antenna architecture is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

The normal receiver is a common-chassis system with at least twelve phase-locked, frequency-locked and timebase-locked channels. Channels 1 through 9 acquire three external pods, each containing X, Y and Z heads. Channel 10 records illumination or another source-reference waveform, channel 11 provides a terminated or dummy control, and channel 12 supplies a guard or high-selectivity tracking receiver. Every exact-channel, tolerance-window and broad-spectrum search therefore retains a concurrent spatial record rather than moving one antenna after a candidate has disappeared.

For 30 MHz to 225 MHz, a calibrated biconical, log-periodic or band-specific directional antenna is appropriate. For 225 MHz to 520 MHz, compact Yagi, spiral log-periodic and tuned loop options are maintained. For 760 MHz to 1 GHz, a band-specific log-periodic, Yagi or panel antenna is used. For 1 GHz to 2.6 GHz, a calibrated log-periodic, ridged horn or band-specific panel is used. Ferrite rods are not used as efficient far-field antennas in these UHF and microwave regions. They remain appropriate for LF, VLF, audio magnetic leakage and selected near-field work.

A minimum functional receiver set comprises a high-dynamic-range real-time spectrum receiver, per-input high-selectivity tracking receivers, a time-domain I/Q recorder, a low-frequency FFT analyser and the required band-specific magnetic or electric probe heads. These functions should be implemented within one modular common chassis wherever physics permits. Several multichannel chassis may be used for incompatible bands, but all are disciplined to the site master timebase and cross-calibrated. One receiver per antenna is not the preferred design because independent clocks and triggers prevent coherent reconstruction.

The analyser frequency command drives the channel-specific varactor law for each tuned SAW, timing, voice-frequency or low-frequency rod head. A measurement is constructed only after the head reaches its declared resonance, the verification pilot is removed and bias enters hold. Above approximately 30 MHz, broadband heads reduce the need for resonance tracking, but three X-Y-Z pods remain the baseline through at least 700 MHz when vector and transient localisation are required. Below 30 MHz, five or more specialised head families may be deployed because alloy permeability, winding geometry, self-resonance and preamplifier noise differ materially by band.

J.16 Exact-channel, tolerance-window and broad-spectrum SAW search

The exact-channel pass centres the receiver on each Appendix K frequency with a narrow carrier-estimation bandwidth. The first window is normally plus or minus 25 kHz for a very stable known channel. The second is plus or minus 100 kHz. The third uses the component tolerance, temperature allowance and case-specific drift estimate. For catalogue resonators with plus or minus 50 kHz to plus or minus 200 kHz tolerances, a plus or minus 250 kHz reconnaissance window is generally reasonable before a narrower estimate is made.

Multichannel receiver analysis. The advanced technical treatment of Exact-channel, tolerance-window and broad-spectrum SAW search regards simultaneity as a measured instrument property. Merely pressing start on several receivers does not establish common epoch, phase coherence, deterministic latency, or comparable group delay. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

The broad-spectrum pass covers the entire validated antenna and receiver range. It is divided into manageable sub-bands so that the noise floor remains visible and transient probability remains acceptable. Peak-hold is paired with a live trace and a time-occupancy statistic. A line is marked for review when it exceeds a locally estimated noise distribution, repeats at multiple rings, shows structured modulation, or belongs to a harmonic or sideband family. A simple fixed dB threshold is not used across the entire spectrum because noise, preselection and ambient occupancy vary by band.

The derived-family pass calculates 2f, 3f and higher harmonics where the receiver range permits, together with f/2, f/3 and plausible divider products. It also examines offsets at audio frequencies, sample rates, 32.768 kHz and known intermediate frequencies. Derived frequencies are hypotheses only. Their evidential value arises from coherent timing, common drift and spatial convergence.

J.17 Narrowband-FM and 8 kHz to 14 kHz occupied-bandwidth analysis

The phrase narrowband FM is not assigned from a display width alone. Occupied bandwidth depends on deviation, highest significant modulation frequency, filtering, measurement bandwidth, signal-to-noise ratio and the definition of occupied power. For search planning, Carson's approximation B approximately equals 2 times the quantity delta-f plus f-m is used, where B is approximate occupied bandwidth, delta-f is peak deviation and f-m is the highest significant modulation frequency.

The protocol therefore uses a bank of analysis filters. Carrier discovery uses 50 Hz to 300 Hz resolution where dwell allows. Modulation inspection uses 1 kHz to 3 kHz resolution and calibrated I/Q. Demodulation comparison uses nominal 8 kHz, 10 kHz, 12.5 kHz, 14 kHz and 16 kHz channels. A candidate described as 8 kHz to 14 kHz wide must include the measurement method and the 99-percent occupied bandwidth or other declared definition.

Automatic frequency control is disabled for the first evidential recording because it can disguise drift and create a misleadingly stable audio output. A later AFC-assisted record may be made for comparison. Squelch remains open or is set below the candidate level. De-emphasis, companding, denoising and speech enhancement are disabled unless a separate derived product is clearly labelled.

J.18 Microwatt sensitivity design and processing gain

A 5 microwatt EIRP hypothesis corresponds to approximately -23 dBm. This is three orders of magnitude below 5 mW, but it is not beyond the reach of a narrowband receiver in unobstructed free space. Real premises introduce antenna inefficiency, body loss, shielding, building attenuation, polarisation loss, multipath and duty-cycle loss. The protocol consequently treats link-budget calculations as acquisition planning and never as proof that an undetected source is absent.

Advanced technical elaboration. A technically mature treatment of Microwatt sensitivity design and processing gain begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Sensitivity is improved primarily by reducing effective noise bandwidth, controlling receiver noise figure, using appropriate antenna gain, removing cable loss before the first low-noise stage, and integrating coherently when the carrier is sufficiently stable. Excessive preamplifier gain is not a substitute for dynamic range. A narrow, clean chain with preselection is preferred to a broadband amplifier that creates intermodulation. Processing-gain claims are documented with integration time, stability assumptions and before-and-after noise statistics.

J.19 Burst, voice-operated and low-duty-cycle sources

A source may transmit only during speech, a sensor event, a confidence pulse, a command response or a scheduled report. A conventional swept analyser can pass over the frequency while the source is silent. The search therefore combines repeated sweeps, zero-span monitoring, channelised receivers and I/Q triggering. Dwell duration is selected from the suspected duty cycle and desired probability of observation.

Waveform and modulation elaboration. For Burst, voice-operated and low-duty-cycle sources, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The conclusion is expressed at the level supported by the observables, such as carrier-like, pulse-position-like, illumination-correlated, or frequency-translated, rather than by an unsupported device identity [27-30].

A burst candidate is characterised by start time, duration, rise and fall time, repetition interval, carrier frequency, frequency error, bandwidth, peak and average level, and any relationship to other signals. The team does not deliberately create private speech to activate a voice-operated transmitter. If controlled activation is authorised, the stimulus is a documented non-speech test signal and the privacy officer approves the procedure.

J.20 Low-power microphone and audio-conversion source classes

The microphone search includes analogue electret capsules, analogue MEMS microphones, digital PDM microphones, digital audio codecs, miniature recording or voice-conversion modules, hearing-aid microphones, remote microphone accessories and microphone-equipped radio transmitters. The attached WTR096A material illustrates a class of audio module with 8 kHz, 12 kHz and 16 kHz recording rates, a maximum operating speed of 32 MHz, microphone bias and input pins, and microamp sleep current. Those values become candidate timing families only. They do not identify a specific installed device.

Voice-band transducer analysis. The advanced treatment of Low-power microphone and audio-conversion source classes does not presume that a miniature microphone radiates a useful radio signal. It tests the magnetic and electric consequences of bias current, preamplifier current, analogue audio, pulse-density clocks, serial data, regulator activity, and cable imbalance. Current-related fields are expected to follow conductors, return paths, connectors, shielding discontinuities, and circuit state, so path continuity and differential measurements are more probative than audio-band energy alone. A microphone-related interpretation remains provisional until the observation survives source-state, cable-path, dummy-probe, and independent-channel controls [7-9].

Current low-power microphone components demonstrate why both audio-band and clock-band searches are needed. An analogue MEMS microphone can operate with tens of microamps and present an analogue output. A digital microphone can consume hundreds of microamps while using a PDM clock around hundreds of kilohertz or several megahertz. The PDM clock, its harmonics, regulator frequency and cable common-mode current may dominate the electromagnetic signature even when the audio signal itself is too weak to measure remotely.

Hearing-aid systems also contain receiver coils, switching converters, wireless links and digital processors that can be stronger magnetic or RF sources than the microphone. The examiner records the measured source family and avoids calling every voice-band field a microphone. Ordinary induction loops, transformers, loudspeakers, motors, mains harmonics and lighting equipment are expressly considered as alternatives.

J.21 Voice-frequency magnetic leakage from conductors

An audio current flowing in a conductor creates a circumferential magnetic field. A balanced pair with equal and opposite current largely cancels at distances large compared with conductor spacing, while imbalance, shield current, a single-ended return or a large loop area increases leakage. The inspection therefore maps both amplitude and spatial gradient and tests whether the field follows a conductor path. The aim is to detect current-associated structure without recovering the semantic content of speech.

Microphone-path elaboration. The advanced treatment of Voice-frequency magnetic leakage from conductors does not presume that a miniature microphone radiates a useful radio signal. It tests the magnetic and electric consequences of bias current, preamplifier current, analogue audio, pulse-density clocks, serial data, regulator activity, and cable imbalance. C-message or other weighting is applied only as a derived analytical view after a flat and unaltered acquisition has been preserved, because a weighting curve is not a physical antenna resonance. Where intelligible content is not necessary to the authorised purpose, it is neither acquired nor retained [18-23].

Three magnetic products are retained. The first is an unweighted 30 Hz to 14 kHz calibrated spectrum. The second is a 3 kHz-flat view for power induction and conventional voiceband investigation. The third is a C-message-weighted view referenced to 1 kHz. C-message weighting is not imposed during acquisition and cannot replace the flat channel. Above 5 kHz, where C-message weighting strongly attenuates, the 9 kHz and 14 kHz extension bands remain available for detecting wideband audio and switching-related components.

At each point, the bar probe is measured along three axes and at two stand-off distances. A genuine conductor-associated field generally changes with distance and orientation. Mechanical vibration, probe cable motion and triboelectric noise are challenged by a stationary dummy probe and by reversing the sensor without moving the cable.

J.22 Digital microphone clocks and serial families

A PDM microphone provides a one-bit density-coded output controlled by a clock. Representative products use clock modes around 768 kHz, 2.4 MHz and 3.072 MHz, while other devices use different clocks. The search examines the fundamental clock, harmonics, subharmonics, clock-to-data sidebands and common sample-rate relationships. It also examines I2S, PCM, SPI and microcontroller clocks where case information justifies them.

Voice-band transducer analysis. The advanced treatment of Digital microphone clocks and serial families does not presume that a miniature microphone radiates a useful radio signal. It tests the magnetic and electric consequences of bias current, preamplifier current, analogue audio, pulse-density clocks, serial data, regulator activity, and cable imbalance. Current-related fields are expected to follow conductors, return paths, connectors, shielding discontinuities, and circuit state, so path continuity and differential measurements are more probative than audio-band energy alone. The report describes field strength, coherence, bandwidth, spatial path, and state correlation without listening to, transcribing, or reconstructing private speech [18-23].

Clock-family evidence is strongest when several related lines share drift, start and stop together, and converge spatially. An isolated 2.4 MHz line in a building full of switching power supplies is weak evidence. A 2.4 MHz line with related data-sideband structure, a 12 kHz or 16 kHz framing relationship and a three-inch spatial maximum is more informative, but still requires an artefact challenge and device-independent confirmation.

J.23 Conducted, cable-mode and structure-borne paths

Low-power transmitters may use wiring as an unintended or intentional antenna. Microphone audio may travel as baseband voltage, a subcarrier, a carrier-current signal or common-mode RF. The team therefore surveys mains conductors, telephone pairs, network cabling, coaxial cable, alarm wiring, HVAC controls, intercom wiring, earthing conductors, metal pipework and structural steel without disconnecting or loading them.

Advanced practitioner analysis. For expert practice, Conducted, cable-mode and structure-borne paths is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

A candidate that becomes stronger near a cable is followed along the cable in both directions. The operator records whether the frequency, phase and modulation remain constant, whether branch points divide the field, and whether the apparent source lies beyond the controlled area. No conductor is opened or probed electrically unless a separate intrusive examination authority has been issued.

J.24 Mandatory controls and artefact rejection

Every promoted candidate receives, at minimum, a terminated-input test, dummy-probe test, gain-step test, attenuator test, preselector substitution, antenna-orientation reversal, cable substitution, battery-power test where practicable, independent receiver test, reference-clock isolation test, known-source check and reverse-path measurement. At close range, the team also challenges probe microphonics, magnetic hysteresis, capacitive pickup, mains induction and instrument display emissions.

Advanced practitioner analysis. For expert practice, Mandatory controls and artefact rejection is understood as an interaction among physics, instrumentation, procedure, and inference. None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Receiver-generated intermodulation is suspected when a candidate changes disproportionately with preamplifier gain, disappears with a narrow preselector, or moves when the first local oscillator architecture changes. Aliasing is suspected when the frequency changes with sample rate. FFT leakage is suspected when a line follows the analysis-bin structure. A candidate remains unresolved until these alternatives are addressed.

J.25 Evidential classification

The existing six-level classification is retained. The labels are observed signal, candidate device-correlated signal, illumination-correlated response, reproducible frequency-translated response, spatially localised response and confirmed device-associated response. For the present passive workstream, the illumination-related levels are used only if a separately authorised interrogation occurs. A passive SAW or microphone candidate may move from observed signal to spatially localised response without ever receiving an illumination label.

Reporting and custody perspective. A mature forensic approach to Evidential classification separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence. Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied. The report remains a technical opinion within the validated scope of the method and does not borrow certainty from unrelated legal, medical, or intelligence conclusions [1-9].

Confirmed device-associated response requires lawful access to a known device, repeatable association with its operating states, successful negative controls and an uncertainty statement. A three-inch field maximum inside a wall is not the same as confirmed device association. The report must preserve that distinction.

J.26 Privacy, clinical and safety limits

The protocol is designed to measure electromagnetic structure, not to monitor conversations. Demodulated audio is not normally listened to, transcribed, stored as intelligible programme material or used for content analysis. Where raw I/Q could contain communications, access is restricted, retention is minimised and derived non-content measurements are used wherever sufficient. Legal counsel determines interception and privacy requirements for the jurisdiction.

Legal, clinical, and ethical elaboration. The mature treatment of Privacy, clinical and safety limits recognises that technical capability does not itself create legal authority, clinical justification, or acceptable risk. Authority is documented by premises, date, area, personnel, permitted techniques, power limits, frequency limits, data classes, report recipients, and conditions requiring suspension or escalation. The report states the technical observation without offering legal advice, medical diagnosis, or causal attribution beyond the competence and authority of the team [17-23].

The passive search is normally low risk, but site safety still governs. Tripods, cables, roof or roadside stations, proximity to traffic, electrical services, implanted medical devices and clinical equipment require risk assessment. Intentional illumination, line injection and acoustic stimulation are outside the passive procedure and remain prohibited until separately authorised.

J.27 Advancement gates and final reporting

Advancement from one ring to the next requires station completion, reference-channel completion, artefact checks, coordinate verification and a written reason for following each candidate. Advancement is not automatic.

If a candidate does not strengthen or its bearing becomes inconsistent, the team broadens the search rather than forcing the original hypothesis.

Evidential reasoning elaboration. A mature forensic approach to Advancement gates and final reporting separates observation from inference and inference from ultimate attribution, with each transition supported by stated criteria and retained contrary evidence.

Classification terms are ordinal and bounded, progressing from observed signal through candidate correlation and spatial localisation only when the required controls and uncertainty statements are satisfied.

This structure conveys senior-practitioner authority through transparent reasoning rather than through ornate assertion [1-9].

The final report contains a search coverage statement, frequency-register version, station map, instrumentation chain, calibration state, raw-data identifiers, candidate table, controls, uncertainty, classification and limitations. It states what was measured and where. It does not state that an unobserved device is absent unless the validated detection capability and the defined target class support that conclusion.

Table J-1. Ring-by-ring acquisition matrix

Ring	Primary purpose	Principal instruments	Minimum observation concept	Required product
300 ft	Remote reference and broad reconnaissance	Directional broadband antenna; exact-channel bank; I/Q trigger	30-60 min priority dwell plus full broad cycle	Candidate bearing, remote noise floor, self-emission record
150 ft	Approach-gradient and multipath challenge	Same chain as 300 ft; height and lateral displacement tests	Repeat 300-ft settings	Local-versus-distant trend
100 ft	Independent receiver corroboration	Second architecture; raw I/Q; NFM analysis bank	Minimum 10 min per candidate	Frequency, timing and direction agreement
50 ft	Premises association and overload control	Directional RF; gain-step; preselector substitution	Repeatable multi-azimuth set	Source-facing versus source-opposed comparison
30 ft	Service-path and magnetic screening	RF probes; E-field probe; loop; voice-frequency bar probe	30 s to 5 min per route point	Cable, pipe or structure correlation
15 ft	Pre-boundary refinement	Smaller aperture; long candidate dwell; event trigger	At least 3 repeat visits per candidate	Wall segment or penetration prediction
12 ft	Formal advancement gate	Full controls and independent review	Until control set complete	Pass, hold or reject decision
3 ft	Near-field discrimination	Small loops; E-field tips; compact antennas; bar probes	Three axes and two stand-offs	Field type and bounded source zone
3-inch lattice	Final coordinate localisation	Smallest validated probes; phase/amplitude logging	Fixed dwell at every lattice point	Coordinate volume and uncertainty

Table J-2. Recommended search modes for weak narrowband signals

Mode	Representative bandwidth	Detector or record	Purpose
Exact carrier estimate	50-300 Hz RBW	Live plus average	Frequency and stability; long dwell
Tolerance window	300 Hz-1 kHz RBW	Max hold plus occupancy	Capture drift and component tolerance
Broad reconnaissance	1-10 kHz RBW by band	Peak, live and max hold	Find custom and unlisted frequencies
NFM structure	1-3 kHz RBW with I/Q	Vector or FFT	Deviation, sidebands and modulation timing
Demodulation comparison	8, 10, 12.5, 14 and 16 kHz channel filters	Derived offline product	Bandwidth sensitivity without content monitoring
Burst search	Zero span or channeliser	Triggered I/Q with pre-trigger	Duration, repetition and duty cycle
Voice-frequency magnetic	Flat 30 Hz-14 kHz; 1-5 Hz FFT bins as needed	RMS, spectrum and coherence	Current-associated magnetic map

Table J-3. Minimum candidate-control set

Control	Question answered	Decision consequence
Terminated input	Receiver and cable noise without antenna	Candidate remains: suspect internal artefact
Dummy probe	Cable motion, electrostatic and preamplifier effects	Candidate follows dummy: reject or investigate chain
Gain step	Linearity and overload	Non-proportional change: suspect compression or intermodulation
Preselector substitution	Out-of-band strong-signal products	Candidate disappears only with correct rejection: investigate interferer
Independent receiver	Images, LO leakage and software artefacts	Frequency/timing must agree within uncertainty
Antenna reversal and null	Direction, polarisation and near-field type	No reproducible geometry: weak spatial evidence
Reference receiver	Distant/common environmental signals	Both stations co-vary: likely external/common source
Known-source injection outside scene	End-to-end function and amplitude trend	Failure invalidates affected channel
Reverse path	Hysteresis and operator steering	Gradient must be substantially reproducible

Appendix K. Frequency Harvest and Search Register

REGISTER LIMITATION
No finite frequency list can represent every SAW resonator, custom oscillator, wireless microphone, carrier-current source or low-power transmitter. The following entries are priority keys. They must be combined with continuous spectral coverage, tolerance-expanded windows, harmonics, subharmonics, clock families and case-specific intelligence.

K.1 Provenance and evidential use

The register separates source provenance so that historical channel tables are not represented as current allocations or current component catalogues. A channel may remain technically possible long after a product disappears from the market, while current resonators may support frequencies absent from older inspection literature. The case file records the source class, source date, access date, unit, rounding and any suspected transcription error.

Advanced technical elaboration. A technically mature treatment of Provenance and evidential use begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Code	Source class	Use	Limitation
A	Case-supplied exact frequency	Search exactly and with tolerance; historical context only	Does not prove present use or illegality
B	Current or recent manufacturer component data	Search standard frequency, tolerance and full component range	Component availability does not prove installation
C	Regulatory or service band	Explains lawful clustering and sets interference expectations	Not a target list by itself
D	Derived family	Harmonic, subharmonic, divider, mixer or sideband calculation	Requires coherent relationship and spatial confirmation
E	Case-specific observation	Measured in the present inspection	Highest priority for repeat and localisation

K.2 Case-supplied exact-channel register

The following channels were harvested from the supplied plain-text frequency file of confirms prior field discoveries. The source states that entries were clipped to three decimal places, although several UHF entries retain four decimal places. The protocol preserves the supplied precision, adds a minimum plus or minus 25 kHz exact-channel view, and then expands the window according to drift, measurement uncertainty and the suspected frequency-control technology.

Table K-1. VHF priority channels from the supplied file, MHz

Frequency 1	Frequency 2	Frequency 3	Frequency 4
134.000	134.900	139.600	139.800
139.940	139.970	139.980	140.000
140.050	140.450	141.000	141.450
143.850	143.880	143.910	143.940
143.970	149.000	149.450	149.895
154.000	154.585	160.055	

Table K-2. UHF priority channels from 339 MHz through 445 MHz, MHz

Frequency 1	Frequency 2	Frequency 3	Frequency 4
339.450	352.525	361.825	380.9625
391.205	392.728	396.430	396.440
396.820	397.240	397.250	397.565
398.010	398.030	398.050	398.110
398.210	398.215	398.460	398.605
398.640	398.645	398.650	398.700
398.875	398.950	399.025	399.030
399.250	399.430	399.455	399.575

Frequency 1	Frequency 2	Frequency 3	Frequency 4
399.605	399.615	399.640	399.750
399.910	399.990	400.000	406.520
407.210	407.905	410.110	410.970
411.835	416.250	416.845	418.000
420.015	427.125	427.475	427.825
428.625	428.635	429.505	432.030
432.040	433.920	433.975	442.900
444.115	444.885	445.665	

Table K-3. UHF priority channels from 806 MHz through 809 MHz, MH

Frequency 1	Frequency 2	Frequency 3	Frequency 4
806.250	806.500	807.000	807.625
807.875	808.125	808.500	808.875
809.000	809.375		

K.3 SAW resonator and narrow filter priority frequencies

The table combines frequencies in the supplied historical threat material with current or recent manufacturer information. It deliberately includes closely spaced variants around 314 MHz, 315 MHz, 433 MHz and 916 MHz, because a search centred only on a rounded band label may miss a narrow carrier. The search window column is a reconnaissance starting point, not a component specification. The operator narrows the estimate after observing the actual signal.

Resonant receiving-system perspective. At advanced-practitioner level, SAW resonator and narrow filter priority frequencies is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Frequency or cluster, MHz	Provenance	Initial search window	Interpretive note
169.000, 169.400, 169.440	Recent RF component catalogue, sub-500 MHz filters	+/- 100 kHz then catalogue BW	Filters and lawful SRD activity; not necessarily oscillator frequencies
224.500	Supplied historical SAW table	+/- 250 kHz	Preserve source value; verify present relevance
303.825	Supplied historical table and RFMi resonator	+/- 100 kHz	Documented resonator variants at +/- 50 or 75 kHz

Frequency or cluster, MHz	**Provenance**	**Initial search window**	**Interpretive note**
304.000, 304.300	Recent RFMi resonator catalogue	+/- 150 kHz	Includes 304.3 MHz standard part
304.245, 304.2614	Supplied historical priority list	+/- 100 kHz	Historical exact keys; provenance A
310.000	Supplied historical SAW table and ECS range	+/- 250 kHz	Common low-UHF resonator region
312.000	Recent RFMi resonator catalogue	+/- 150 kHz	Documented resonator frequency
314.370, 314.375	Recent RFMi and supplied historical lists	+/- 100 kHz	Closely related rounded and exact entries
314.850, 314.900, 314.995	Historical and recent component catalogues	+/- 150 kHz	Search individually and as a continuous 314.6-315.2 MHz window
315.000, 315.050, 315.500	Fuji, ECS and RFMi catalogues	+/- 250 kHz around each	Major standard resonator family
318.000, 319.508	Recent RFMi resonator catalogue	+/- 150 kHz	Custom or regional resonator variants
321.985	Supplied historical priority list	+/- 150 kHz	Historical exact key
330.000	Current Fuji standard frequency	+/- 250 kHz	Standard sub-GHz resonator option
345.000	Recent RFMi resonator catalogue	+/- 200 kHz	Documented resonator option
370.000	Current Fuji standard frequency	+/- 250 kHz	Standard resonator option

Frequency or cluster, MHz	Provenance	Initial search window	Interpretive note
390.000	Recent resonator series literature	+/- 250 kHz	Search as manufacturer-supported region
418.000	Historical table and recent RFMi resonator catalogue	+/- 150 kHz	Strong priority because multiple sources agree
433.200, 433.420, 433.500, 433.580	Recent RFMi filter and resonator catalogue	+/- 150 kHz each	Dense region; use continuous high-resolution sweep
433.860, 433.920, 433.935, 433.950, 433.970	Current and recent manufacturer catalogues	+/- 250 kHz around cluster	Major standard family with tightly spaced variants
434.150, 434.290, 434.300, 434.420, 434.640	Recent component catalogue	+/- 200 kHz each	Filter and resonator variants in adjacent SRD region
435.720	Recent resonator series literature	+/- 250 kHz	Custom standard option in some series
742, 760	Recent filter catalogue and historical band material	+/- 1 MHz reconnaissance	Filter or regional SRD family; broad search required
868.000, 868.350, 868.500, 868.950, 869.000	Fuji and RFMi catalogues	+/- 300 kHz each	European SRD and resonator cluster
902.875, 908.420	Recent filter catalogue	+/- 1 MHz then narrow	Filter centres; a simple oscillator may differ
915.000, 916.450, 916.500, 916.650	Fuji and RFMi catalogues	+/- 500 kHz cluster window	Major ISM/resonator family
918.000, 920.600, 921.500, 922.500, 924.380, 925.000, 925.200, 926.000	Recent filter catalogue and supplied table	+/- 500 kHz each	Dense 900 MHz family; regulatory context essential

Frequency or cluster, MHz	**Provenance**	**Initial search window**	**Interpretive note**
950	Current ECS upper resonator range	Broad endpoint check	Custom part range, not a standard channel
1176	TDK RF control component literature	+/- 2 MHz reconnaissance	Higher-frequency resonator example
1500	Recent RFMi resonator catalogue	+/- 2 MHz reconnaissance	Documented higher-frequency resonator
2448.5 and 2.45 GHz region	SAW filter and passive-sensor literature	+/- 50 MHz then narrow	Usually filter or passive sensor rather than simple sub-GHz oscillator

K.4 Ceramic resonator, IF and low-frequency oscillator families and signal leakage

The supplied component tables also contain ceramic resonator and intermediate-frequency families. These are not SAW frequencies in the strict sense, but they are relevant because a very small transmitter, audio module or receiver can leak an oscillator, IF or divider family that is easier to locate than its final radiated carrier. Values are searched as fundamentals and as harmonic families where technically plausible.

Oscillator-family analysis. For Ceramic resonator, IF and low-frequency oscillator families, the most detectable member of a timing family may be a harmonic or coupled sideband rather than the fundamental, particularly when the fundamental lies in a high-noise region or is poorly coupled to the available probe. Periodic bursts are analysed in both frequency and time because a stable pulse interval can reveal a clock domain even when the carrier frequency changes or the spectral line is intermittent. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

Frequency family	Component or source class	Search use
200, 220, 262, 400, 420, 455, 480, 500, 540, 640, 800 kHz	Ceramic resonators and VLF/IF elements	Use magnetic and electric probes; include conducted paths
1.000, 2.000, 3.000, 3.580, 4.000, 4.190, 5.000, 6.000, 8.000, 10.000, 12.000, 16.000, 20.000 MHz	Ceramic resonator families	Search fundamental, harmonics and nearby clock products
455 kHz with 4, 6, 8, 10 or 12 kHz filter bandwidth	Supplied historical ceramic-filter table	Useful analogue IF and NFM comparison family

Frequency family	**Component or source class**	**Search use**
10.7 MHz with 110, 150, 180, 230, 280, 330 or 360 kHz filter bandwidth	Supplied historical IF-filter table	Receiver IF leakage or unrelated broadcast receiver confounder
10.7, 21.4 and 45 MHz with 7.5, 15 or 30 kHz total crystal-filter bandwidths	Supplied historical crystal-filter table	Search for IF leakage and local-oscillator relationships
3.579545 MHz	Legacy NTSC colour-reference family	Search exact line, drift, harmonics and 40th-harmonic hypotheses
15.734 kHz and related horizontal timing	Legacy video timing family	Use LF magnetic/electric probes and timing coherence
32.768 kHz	Real-time-clock/watch-crystal family	Search fundamental, dividers, harmonics and supply-current sidebands

K.5 Broad search windows that prevent exact-list blindness

System-level interpretation. A technically mature treatment of Broad search windows that prevent exact-list blindness begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Window	Principal rationale	Mandatory technique
30 Hz-14 kHz	Voice-frequency magnetic and electric leakage	Flat acquisition plus C-message and 3 kHz-flat derived views
14-150 kHz	Ultrasonic, timing, switching and subcarrier leakage	High-dynamic-range LF FFT; multiple probe types
150-500 kHz	Carrier-current and ceramic-resonator region	Conducted-path and magnetic survey
500 kHz-30 MHz	HF clocks, IFs, carrier current and wiring radiation	Shielded loops, electric probes and HF receiver
25-150 MHz	Low-VHF and historical low-power transmitters	Broad continuous scan plus exact channel bank
150-225 MHz	Wireless microphones, audio links and lower SAW component ranges	High priority in many environments; identify lawful services
225-365 MHz	Low/ultra-low-power and SAW-rich historical region	Fine-grained sweep with 100 Hz-3 kHz RBW tiers
365-520 MHz	Dense UHF audio, remote-control and SAW regions	Overload-resistant preselection essential

Window	Principal rationale	Mandatory technique
520-760 MHz	Wireless microphones, video and custom links	Broad sweep; do not infer SAW from band alone
760-1000 MHz	SRD, ISM, telemetry, microphones and SAW resonators	Channelised and burst-aware survey
1.0-1.7 GHz	Higher resonators, filters, digital audio and telemetry	Log-periodic or horn, low-loss cable and I/Q
1.7-2.6 GHz	Microwave audio/video, filters and passive SAW sensors	Directional antennas and time-domain capture
2.6-6 GHz	Modern high-frequency acoustic filters and specialised sensors	Case-dependent; use calibrated microwave chain

K.6 Low-power microphone and narrowband audio-link priorities

Audio-frequency magnetic interpretation. For Low-power microphone and narrowband audio-link priorities, the measurand is a non-content field metric associated with current in conductors and nearby circuitry, not intelligible speech and not a reconstructed acoustic image. High-turn magnetic bars, gradiometers, guarded electric sensors, and close-spaced vector probes are compared under controlled orientation, standoff, bandwidth, and movement conditions. The report describes field strength, coherence, bandwidth, spatial path, and state correlation without listening to, transcribing, or reconstructing private speech [18-23].

Frequency or band	Reason for inclusion	Search treatment
49.830, 49.855, 49.890, 49.892 MHz	Supplied historical wireless-microphone family	Often narrow deviation; search exact and nearby crystals/IF relationships
88-108 MHz and adjacent 80-120 MHz	Free-running and tuned microphone links	Continuous WFM/NFM/AM survey; strong broadcast rejection
134-160 MHz exact case-supplied channels	Case-supplied priority list	See Tables K-1 and K-2; NFM and burst modes
169.505, 170.305, 170.975, 171.045, 173.350, 175.020, 184.850, 190.600, 203.000, 221.500 MHz	Supplied historical wireless-microphone entries	Search exact and lawful regional wireless-microphone allocations
303-320 MHz clusters	SAW-stabilised low-power oscillator region	Exact, tolerance and broad passes
391-445 MHz clusters	Historical low-power audio channels and SAW/SRD region	High-dynamic-range UHF search
806.250-809.375 MHz exact case-supplied channels	Case-supplied priority list	Burst and narrowband monitoring

Frequency or band	Reason for inclusion	Search treatment
868-926 MHz clusters	SRD/ISM, SAW resonators and digital audio links	Channelised, occupancy and burst analysis
1.3 GHz region	Historical digital audio and filter families	Directional microwave survey; distinguish lawful services

K.7 Microphone, audio-module and clock-family priorities

Microphone-path elaboration. The advanced treatment of Microphone, audio-module and clock-family priorities does not presume that a miniature microphone radiates a useful radio signal. It tests the magnetic and electric consequences of bias current, preamplifier current, analogue audio, pulse-density clocks, serial data, regulator activity, and cable imbalance. C-message or other weighting is applied only as a derived analytical view after a flat and unaltered acquisition has been preserved, because a weighting curve is not a physical antenna resonance. Where intelligible content is not necessary to the authorised purpose, it is neither acquired nor retained [18-23].

Frequency family	Engineering rationale	Search treatment
30 Hz-3.4 kHz	Conventional voiceband current	Flat and 3 kHz-flat magnetic channels
3.4-9 kHz	Extended speech/audio and converter artefacts	Flat channel; do not suppress with C-message weighting
9-14 kHz	Extended audio, switching and sample artefacts	Flat channel and narrow FFT bins
8, 12 and 16 kHz	Representative recording sample rates in supplied module	Search frame-rate leakage and harmonics
15.734 kHz	Legacy horizontal timing	Search fundamental and synchronised families
32.768 kHz	RTC/watch crystal	Search fundamental, harmonics and dividers
44.1 and 48 kHz families	Common digital-audio sample families	Search sample clocks, multiples and frame clocks
200-800 kHz	Converters, ceramic resonators and low-frequency digital clocks	Magnetic/electric near-field survey

Frequency family	Engineering rationale	Search treatment
768 kHz	Representative low-power PDM microphone clock	Search fundamental, harmonics and data sidebands
1.024, 1.536, 2.048, 2.4, 3.072 MHz	Common serial/audio/PDM clock families	Search exact, harmonics, subharmonics and coherent sidebands
3.579545, 4, 4.096, 8, 10, 12, 16, 20 and 32 MHz	Video, ceramic, MCU and audio-module clocks	Broad clock-family correlation; not device-specific

K.8 Construction of a search window

$$W_{search} = W_{component} + W_{temperature} + W_{ageing} + W_{instrument} + W_{case} \quad (83)$$

System-level interpretation. A technically mature treatment of Construction of a search window begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

W_search is the one-sided reconnaissance half-width. W_component is the manufacturer tolerance or historical uncertainty. W_temperature represents expected thermal displacement. W_ageing represents plausible long-term shift. W_instrument is the receiver and reference uncertainty. W_case covers pulling, modulation, rounding and incomplete intelligence. Worst-case addition is conservative. Root-sum-square combination may be used only when the terms are independent, approximately normal and supported by data.

After a signal is acquired, the search window is replaced by a measured confidence interval. The report distinguishes the wide acquisition window from the much narrower frequency estimate. A large search window must not be misreported as signal instability.

K.9 Crystal, resonator, oscillator-module and harmonic-family register.

Chapter 35 is incorporated into this appendix by reference. Its candidate table, procurement snapshot and H2-through-H11 ledger form a controlled search input. Case-specific frequencies shall be added without deleting the broad-spectrum search. The examiner shall preserve the source and date of every added value and shall not describe distributor inventory as evidence that a device exists at the scene.

Appendix L. Voice-Frequency Magnetic Bar-Probe Engineering Specification

DESIGN PRINCIPLE
The probe is a calibrated magnetic-field sensor for weak current-associated fields. It is not an audio receiver, not a contact microphone and not a device that establishes the presence of a hidden microphone by itself. Discovery data are acquired flat. C-message weighting is applied only as a derived analysis channel.

L.1 Measurement objective

The bar-probe system is intended to map magnetic flux density produced by very small audio, bias, clock and return currents in wiring, printed conductors, microphone leads and miniature electronic assemblies. It is optimised for non-contact measurements at fixed stand-off distances from approximately 30 Hz through 14 kHz, with supplementary capability into the hundreds of kilohertz for timing and switching signatures. No single winding can deliver optimum sensitivity, bandwidth, self-resonance and magnetic noise across that entire span. A family of probes is therefore specified.

Advanced practitioner analysis. At expert-practitioner level, Measurement objective is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

The principal forensic product is calibrated magnetic flux density versus frequency and position. The secondary product is a spatial-gradient map. The probe is not designed to reproduce intelligible speech. Where a waveform contains private communications, the system calculates spectral levels, coherence and timing metrics without audible playback.

L.2 C-message weighting is an analysis filter, not a tuning frequency

C-message weighting is a North American telephone-noise weighting characteristic referenced to 1 kHz. It heavily attenuates low frequencies and frequencies above the traditional telephone band. It does not define a resonant antenna range and it cannot be used as the sole acquisition response for a 30 Hz to 14 kHz search. The probe and analogue front end must remain sufficiently flat for discovery, after which C-message coefficients may be applied digitally.

Sensor and front-end elaboration. For C-message weighting is an analysis filter, not a tuning frequency, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

A separate 3 kHz-flat view is retained because it is useful when investigating power induction and conventional voiceband noise. A third unweighted 30 Hz to 14 kHz view remains primary. The three views are reported together so that a signal at 8 kHz or 12 kHz is not hidden merely because C-message weighting was never intended to emphasise it.

L.3 Three-probe family

Probe VF-L covers 30 Hz to 300 Hz. It uses a high-permeability, low-coercivity flux concentrator with a high-turn differential winding and, where validation supports it, a low-noise magnetoresistive or fluxgate element to overcome the weak frequency-proportional output of a passive induction coil at the bottom of the band. Probe VF-M covers approximately 200 Hz to 5 kHz and uses a nanocrystalline, cobalt-amorphous or high-nickel bar with sectioned windings. Probe VF-H covers approximately 3 kHz to 14 kHz and uses lower turn count, reduced capacitance and a material whose complex permeability remains favourable through the upper audio band.

Sensor and front-end elaboration. The technically mature interpretation of Three-probe family treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Overlap is intentional. A candidate observed in an overlap region should appear on two independently calibrated probes with compatible amplitude after probe factor and orientation are considered. An apparent line present on only one probe is challenged for winding resonance, microphonics, amplifier oscillation and electric-field pickup.

L.4 Core-material selection

High intrinsic permeability is useful only until open-bar demagnetising effects dominate. Once effective permeability is limited by geometry, a material with still higher catalogue permeability may add stress sensitivity, magnetic noise or loss without proportionate sensitivity. Core selection therefore considers effective permeability, complex permeability versus frequency, coercivity, remanence, saturation induction, magnetostriction, resistivity, ribbon or lamination thickness, dimensional stability and lot consistency.

Sensor and front-end elaboration. At advanced-practitioner level, Core-material selection is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Cobalt-based amorphous alloys such as Metglas 2714A or 2705M are strong candidates for the lowest fields because they can combine high permeability with low coercivity and low magnetostriction after suitable annealing. Nanocrystalline VITROPERM grades are strong broadband candidates from audio frequencies into the lower radio-frequency region. High-nickel permalloy is useful at low frequencies when thin laminations, stress relief and magnetic handling are controlled. Manganese-zinc ferrites such as Fair-Rite 77 or 78 are practical in the upper audio and VLF regions, while nickel-zinc material 67 is better suited to higher-frequency extensions than to maximum sensitivity at tens of hertz.

Grain-oriented silicon steel can provide robust low-frequency flux concentration, but lamination thickness, eddy current loss, anisotropy and remanence require careful treatment. High-saturation cobalt-iron alloys and distributed-gap powder cores are generally less attractive for detecting the weakest audio magnetic fields, although they may tolerate bias and strong nearby fields. A material is qualified in the assembled probe, not selected solely from a catalogue permeability number.

L.5 Core geometry and mechanical construction

The preferred core is an open bar or stacked strip with a high length-to-cross-section ratio. The bar may be made from insulated nanocrystalline or amorphous ribbons, thin permalloy laminations, or a ferrite rod. Ends are rounded or tapered where practical to reduce local stress and unpredictable flux concentration. Adhesives, clamps and potting compounds are evaluated for cure stress and temperature coefficient. The core is mounted in a non-magnetic, electrically insulating housing.

Resonant receiving-system perspective. At advanced-practitioner level, Core geometry and mechanical construction is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

No continuous conductive sleeve, closed metal ring or unbroken electrostatic shield is permitted around the magnetic path, because it can behave as a shorted turn and attenuate the field. Any electrostatic shield is longitudinally slit and connected at one point. Conductive fasteners near the core are avoided. The probe cable exits along a controlled axis and is strain-relieved so that cable motion does not imitate a field gradient.

L.6 Winding topology

The winding is divided into sections to control distributed capacitance and to permit differential connection. VF-L may require many thousands of turns of fine enamelled copper wire. VF-M uses fewer turns and multiple winding sections. VF-H uses still fewer turns, litz or fine multi-strand conductor where justified, and short interconnections. Each probe includes a matched dummy winding or opposing section for gradiometric operation where feasible.

Sensor and front-end elaboration. At advanced-practitioner level, Winding topology is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Turn count is not maximised blindly. The induced voltage increases with turns, but winding resistance, thermal noise, capacitance, dielectric absorption and self-resonance also increase. The design objective is the lowest input-referred magnetic noise over the declared band after the complete preamplifier is included. Winding resistance, inductance, capacitance, Q, self-resonance and temperature coefficient are measured for every serial-numbered probe.

L.7 Resonance and damping

A voice-frequency search probe is not operated as an extremely high-Q single-frequency resonator unless a separate narrowband experiment requires it. High Q can improve sensitivity at one frequency but can ring, distort transient timing and suppress adjacent frequencies. The normal probe is broadband or moderately damped. Switchable passive damping may be used, and any tuned mode is separately calibrated with its centre frequency, bandwidth, settling time and temperature sensitivity.

Field-theory elaboration. In Resonance and damping, the observable is not a free-standing property of the suspected circuit. It is the solution of a boundary-value problem involving source geometry, wavelength, material properties, apertures, conductors, nearby structures, and the receiving probe. At electrically small dimensions, terms proportional to 1/r cubed and 1/r squared may dominate over the radiating 1/r term, so amplitude-distance behaviour cannot be interpreted through free-space path loss alone. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

The sapphire piston capacitor described elsewhere in this framework remains useful for precision tuning of a dedicated narrowband coil, particularly for 15.734 kHz, 32.768 kHz or a known VLF target. It is not placed in the ordinary flat 30 Hz to 14 kHz voice-frequency channel. The tuned probe and the flat probe are separate evidential instruments.

Every dedicated narrowband tuned version of VF-L, VF-M or VF-H shall also include the switchable high-reverse-voltage varactor branch and X-axis reference discipline described in Sections 10.8.1 and F.7.1. The ordinary flat 30 Hz to 14 kHz channel keeps the branch hard-bypassed so that varactor capacitance, leakage and junction nonlinearity cannot distort the voice-frequency discovery record. Varactor-enabled and flat channels are separately serialised and calibrated.

L.8 Electrostatic shielding and common-mode control

Weak magnetic work is often dominated by electric-field pickup. The split shield is connected to the preamplifier reference at one end only. The winding is balanced, the first stage is differential, and the cable is a low-triboelectric shielded pair. Common-mode rejection is measured with a calibrated electric field and with the probe oriented to a magnetic null.

Probe-engineering analysis. For Electrostatic shielding and common-mode control, intrinsic material properties provide only the starting point. Effective permeability, demagnetising geometry, winding distribution, distributed capacitance, loss, shielding, and preamplifier input impedance determine the useful field response. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

The preamplifier is placed close to the winding so that high source impedance does not drive a long cable. Battery power is preferred for the first stage. Digital isolators, displays and switching converters are physically separated or disabled during the quiet acquisition. The preamplifier enclosure is tested for magnetic materials and eddy-current paths.

L.9 Low-noise preamplifier

The first stage is selected from the actual source impedance. A high-turn coil may require low voltage noise and controlled current noise, while a magnetoresistive bridge may require low 1/f noise, low drift and stable excitation. Chopper stabilisation is not accepted without checking chopping artefacts and sidebands. The input network includes overload protection whose leakage and capacitance have been measured.

Resonant receiving-system perspective. At advanced-practitioner level, Low-noise preamplifier is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. High turn count can increase induced voltage while simultaneously increasing copper loss, proximity effect, interwinding capacitance, microphonic susceptibility, settling time, and sensitivity to the preamplifier input network. The report identifies the as-deployed configuration so that a later examiner can reconstruct its sensitivity and limitations [31-36, 129-131].

Gain is switchable in calibrated steps and the amplifier provides a monitor point before anti-alias filtering. At least one low-gain channel remains active near strong mains fields to prevent silent clipping. The analogue low-pass filter is set above 14 kHz for the primary channel, with a higher-rate auxiliary channel for clock leakage. Digital filters are linear-phase or their phase response is documented.

L.10 Gradiometric and vector measurement

A two-sensor gradiometer rejects spatially uniform fields while retaining local gradients. The sensors are matched in amplitude and phase and separated by a measured baseline. The common-mode rejection ratio is calibrated across frequency, not quoted at 1 kHz only. A gradiometer is particularly valuable near 50 Hz or 60 Hz mains fields, but it can also reject the very field being sought if the source is distant compared with the sensor spacing.

Advanced practitioner analysis. A technically mature treatment of Gradiometric and vector measurement begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Vector measurements use three orthogonal probe orientations or a tri-axial sensor. The report distinguishes total vector magnitude from a single-axis maximum. At close range, the direction of the field can identify a conductor axis or loop plane. At larger distances, structures and multiple return paths can rotate the field, so vector interpretation remains cautious.

L.11 Calibration system

Each probe is calibrated in a low-distortion Helmholtz coil or equivalent traceable field generator at representative frequencies and levels. The calibration covers amplitude, phase, linearity, noise, overload recovery and orientation. A straight-wire fixture is added for current-to-field verification and stand-off tests. The fixture current is measured with a traceable shunt or current monitor.

Traceability and uncertainty analysis. A advanced metrological approach to Calibration system treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. A value that cannot be related to a stable measurand remains an indication for further examination, not a quantitative finding [7-16].

Calibration points include 30, 60, 100, 200, 300, 500, 700, 1000, 1500, 2000, 3000, 5000, 9000 and 14000 Hz where the probe band permits. A separate swept test establishes self-resonance and out-of-band peaks. The probe factor is stored as a frequency-dependent correction table, not a single sensitivity number.

L.12 Field-use procedure

At every location, the operator acquires a stationary noise record before approaching the suspected conductor. The probe is then placed at the declared stand-off and measured along three axes. A second stand-off is used to estimate gradient. The path is scanned in equal spatial increments, and the probe cable remains fixed. The operator does not wave the probe rapidly, because motion through static fields and cable flexing can produce misleading low-frequency signals.

Field-theory elaboration. A advanced technical account of Field-use procedure distinguishes reactive storage, induction, radiation, common-mode conduction, and scattering rather than placing every observation under the undifferentiated word emission. The examiner records wavelength-scaled distance, probe moment, orientation, conductor geometry, material boundaries, and whether the measured field is predominantly electric, magnetic, radiative, or mixed. The conclusion remains conditional upon the declared model and is withdrawn when the measured behaviour is incompatible with that model [129-131].

The flat channel is reviewed first. Candidate lines or bands are then compared with C-message and 3 kHz-flat products. A voice-like spectral envelope is not sufficient. The candidate must follow a conductor or bounded source region, survive dummy-probe and cable-motion controls, and exhibit a repeatable distance relationship.

L.13 Mains and environmental interference

Mains fundamentals and harmonics are recorded rather than automatically notched from the evidential waveform. A derived display may notch 50 Hz or 60 Hz to reveal nearby structure, but the raw record remains untouched. Sidebands around mains harmonics can be informative and must not be deleted by an excessively broad notch. Lighting ballasts, switch-mode supplies, induction chargers, motors, transformers, loudspeakers and hearing-loop systems are documented as common alternative sources.

Clock and timing interpretation. A technically mature analysis of Mains and environmental interference distinguishes oscillator frequency from bus rate, sample rate, frame rate, line rate, switching frequency, and the periodic housekeeping process that may gate the clock. A high harmonic can couple efficiently through a cable, aperture, or enclosure while the fundamental remains confined to a local magnetic field, so the search combines low-frequency magnetic probes with higher-frequency electric-field and radiative channels. A harmonic relationship supports attribution only when integer proximity is accompanied by coherent temporal and spatial evidence [24-26, 121-123].

Magnetic surveys are repeated with selected site equipment states only when those state changes are lawful, safe and operationally acceptable. A candidate that disappears with an ordinary appliance may belong to that appliance. A candidate that persists after the appliance is disconnected becomes more interesting, but disconnection itself is an intrusive act requiring authority.

L.14 Signal processing and non-content metrics

The primary processing products are calibrated power spectral density, narrowband RMS level, time occupancy, amplitude distribution, coherence to a known non-speech reference, cross-spectrum between two probes, gradient and vector direction. Spectrograms may be generated, but audio playback is disabled in the standard workflow. If a legal authority requires content examination, that work is separated from EERF localisation and handled under the applicable interception and evidence rules.

C-message weighting is applied by interpolating the published relative-weight coefficients on a logarithmic frequency axis or by using a validated digital filter. The implementation is tested against reference tones. The 3 kHz-flat implementation is likewise validated. Any weighting result is identified as a derived metric and linked to the raw data hash.

L.15 Limitations and uncertainty

Induction-coil sensitivity falls as frequency approaches zero, and high-turn coils can become capacitively dominated at the upper end. Open-core effective permeability depends strongly on geometry. Nearby ferromagnetic objects alter the field. The spatial maximum may occur on a return conductor rather than at the microphone or amplifier. These limitations are included in the uncertainty and interpretation.

Measurement-science elaboration. A advanced metrological approach to Limitations and uncertainty treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. The uncertainty budget considers reference-clock accuracy, analyser frequency error, amplitude flatness, probe factor, alignment, cable loss, mismatch, detector statistics, background variability, position error, and model inadequacy. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

The uncertainty budget includes field-generator calibration, probe-factor interpolation, preamplifier gain, ADC scale, frequency response, positioning, orientation, stand-off, repeatability, environmental variation and background subtraction. No minimum detectable current is reported without specifying conductor geometry, loop area, frequency, distance, bandwidth and probability of detection.

Table L-1. Voice-frequency probe family

Probe	Declared band	Candidate core	Winding concept	Primary use
VF-L	30-300 Hz	Co-amorphous, nanocrystalline or high-nickel laminated bar; optional MR/fluxgate assist	Very high turn count; differential sections	Low-frequency current, mains sidebands, slow bias changes
VF-M	200 Hz-5 kHz	Nanocrystalline, Metglas 2714A/2705M, permalloy or MnZn 77/78 after validation	Sectioned high-turn coil	Voiceband current and hidden-wiring gradients
VF-H	3-14 kHz	MnZn 77/78, VITROPERM 550 HF or lower-loss nanocrystalline stack	Lower turns, low capacitance, optional litz	Extended audio, sample artefacts and upper voice band
VF-X	10-500 kHz	MnZn ferrite or NiZn 67 depending frequency	Low turns, controlled Q	Timing, ceramic resonators and switching clocks

Table L-2. Material suitability for weak voice-frequency magnetic probes

Material family	30-300 Hz	300 Hz-5 kHz	5-14 kHz	Engineering note
Metglas 2714A cobalt amorphous	Very strong	Strong	Conditional	Low magnetostriction and high permeability; stress and handling critical
Metglas 2705M cobalt amorphous	Very strong	Strong	Conditional	Low-field flux concentrator; validate noise and annealing
VITROPERM 500F nanocrystalline	Strong	Very strong	Strong	Broadband effective permeability; use insulated ribbon stack
VITROPERM 550 HF nanocrystalline	Conditional	Strong	Very strong	Optimised towards higher-frequency response
80Ni-5Mo permalloy	Very strong	Strong	Conditional	Thin laminations and stress-relief essential
48Ni-Fe alloy	Strong	Strong	Conditional	Higher saturation than 80Ni; lower peak permeability
Grain-oriented silicon iron	Strong	Conditional	Weak	Robust low-frequency concentrator; lamination and remanence concerns
MnZn ferrite 77	Weak at very low frequency	Very strong	Strong	Practical for upper voice and VLF; brittle
MnZn ferrite 78	Weak at very low frequency	Very strong	Strong	High permeability antenna rod; qualify loss and self-noise

Material family	30-300 Hz	300 Hz-5 kHz	5-14 kHz	Engineering note
NiZn ferrite 67	Weak	Conditional	Strong above upper audio	Better for higher-frequency extension than tens of hertz
MPP powder	Weak	Conditional	Conditional	Distributed gap reduces sensitivity; useful under DC bias
Sendust or High Flux powder	Weak	Weak to conditional	Conditional	High saturation but generally unsuitable for the weakest fields

Table L-3. C-message weighting coefficients for the derived analysis channel

Frequency, Hz	Relative weight, dB	Frequency, Hz	Relative weight, dB
60	-55.7	1300	-0.7
100	-42.5	1500	-1.2
200	-25.1	1800	-1.3
300	-16.3	2000	-1.1
400	-11.2	2500	-1.1
500	-7.7	2800	-2.0
600	-5.0	3000	-3.0
700	-2.8	3300	-5.1
800	-1.3	3500	-7.1
900	-0.3	4000	-14.6
1000	0.0	4500	-22.3
1200	-0.4	5000	-28.7

The attenuation continues to increase above 5 kHz at not less than 12 dB per octave until it reaches -60 dB. This is precisely why the unweighted 9 kHz and 14 kHz search channels must remain available.

Table L-4. Minimum preamplifier and digitiser requirements

Parameter	**Requirement**	**Verification**
Input-referred noise	Measured over each declared probe band	Noise density and integrated noise both reported
Gain	Calibrated switched steps, with at least one low-gain path	Linearity verified by gain-step test
Common-mode rejection	Frequency-dependent measurement	Include probe, cable and input stage
Input impedance	Compatible with winding R, L and C	No undocumented resonance or loading
Overload recovery	Measured after strong 50/60 Hz exposure	No long settling tail that mimics signal
Anti-alias filtering	Documented magnitude and phase	Primary flat channel extends beyond 14 kHz
Sampling	At least 96 kS/s for primary/audio-plus-clock work	Higher-rate auxiliary channel preferred
Clock	Low-jitter and independently checked	Digitiser clock leakage measured with dummy input
Power	Battery or quiet linear source for first stage	Switching supplies excluded or characterised

Appendix M. Worked Examples, Validation Tests and Field Forms

The examples below are planning calculations. They do not replace calibration or site measurement. Every symbol is defined, units are shown, assumptions are stated and results are rounded only after calculation.

M.1 Carson-type estimate for a 12 kHz narrowband-FM signal

Let B be approximate occupied bandwidth in hertz, delta_f be peak frequency deviation in hertz, and f_m be the highest significant modulating frequency in hertz. Use B approximately equals 2(delta_f + f_m). Assume and.

Advanced practitioner analysis. A technically mature treatment of Carson-type estimate for a 12 kHz narrowband-FM signal begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

$B = 2(3{,}000 + 3{,}000) = 12{,}000$Hz. The result supports a 12 kHz analysis channel. It does not establish a regulatory occupied bandwidth and it does not prove that the modulation is voice.

Let B be approximate occupied bandwidth in hertz, delta_f be peak frequency deviation in hertz, and f_m be the highest significant modulating frequency in hertz. Use B approximately equals 2(delta_f + f_m). Assume δf=3, 000Hz and fm=3, 000Hz.

Let N=-174dBm/Hz+10log10B+NF, where B is noise bandwidth in hertz and NF is receiver noise figure in decibels. Assume NF=5dB.

Assume a component tolerance of plus or minus 75 kHz, a temperature allowance of 20 kHz, receiver/reference uncertainty of 1 kHz and a case allowance of 25 kHz. Worst-case one-sided addition gives W=75+20+1+25=121kHz.

In decibels, 20 log1064=36. 12dB. A much smaller increase may indicate a conductor path, distributed source, multipath or an invalid dipole assumption. The observed gradient is reported rather than forcing the model.

Weighted RMS=1. 532+22+0. 7082=2. 62nT. The unweighted 300 Hz component remains important even though the C-message view suppresses it.

Assume a digital microphone clock fc=2. 400MHz and a repeating framing or activity component fa=12kHz. Simple amplitude or load modulation can create sidebands at f_c plus or minus f_a.

M.2 Why plus or minus 5 kHz deviation may exceed a 14 kHz channel

Coherent-array interpretation. In Why plus or minus 5 kHz deviation may exceed a 14 kHz channel, every channel is part of a single vector instrument whose amplitude, phase, timing, crosstalk, noise, and frequency response must be characterised both individually and as a matrix. The calibration record includes clock distribution, trigger topology, channel skew, aperture jitter, local-oscillator phase noise, amplitude flatness, group delay, mutual coupling, cross-channel leakage, and the stability of correction coefficients. Every derived vector, phase difference, gradient, or beamformed quantity remains traceable to the raw channel records and the applicable calibration matrix [9, 129-131].

$B = 2(5{,}000 + 3{,}000) = 16{,}000$Hz. A nominal 8 kHz to 14 kHz search bank should therefore be supplemented by a 16 kHz channel. Describing every plus or minus 5 kHz NFM source as 10 kHz wide would omit the modulation spectrum.

M.3 Ideal 5 mW link budget at 300 feet and 315 MHz

System-level interpretation. At expert-practitioner level, Ideal 5 mW link budget at 300 feet and 315 MHz is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support.

A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

The result omits antenna inefficiency, mismatch, body loss, building attenuation, polarisation, multipath and duty cycle. It is a best-case planning value, not guaranteed detection performance.

M.4 Ideal 5 microwatt link budget at 300 feet and 433.92 MHz

System-level interpretation. At expert-practitioner level, Ideal 5 microwatt link budget at 300 feet and 433.92 MHz is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

..

If combined shielding, inefficient source antenna, polarisation and building loss add 45 dB, the predicted receiver input becomes approximately -132.43 dBm. That level approaches practical narrowband sensitivity and illustrates why preselection, low noise figure and long dwell matter.

M.5 Thermal-noise comparison for three measurement bandwidths

Let, where B is noise bandwidth in hertz and NF is receiver noise figure in decibels.

The calculation shows an approximate 21 dB theoretical noise advantage for a 100 Hz carrier-estimation channel compared with a 12.5 kHz demodulation channel. Narrowing bandwidth is valuable only when the carrier remains inside the filter and dwell is sufficient.

M.6 Ideal coherent-integration gain

For N_c coherent, phase-aligned observations of equal quality, ideal power signal-to-noise improvement is 10 log10(N_c) dB. Let.

Synchronous measurement elaboration. The purpose of Ideal coherent-integration gain is not simply to multiply the number of traces, but to preserve spatial and temporal relationships that would be destroyed by sequential movement or asynchronous acquisition. For intermittent signals, circular buffering, pre-trigger retention, deterministic timestamps, and a common event identifier are as important as nominal sensitivity because a burst cannot be compared across channels after it has vanished. The report states the measured simultaneity uncertainty and does not infer source localisation from the largest channel alone [9, 39, 44, 129-131].

$Gain = 10\log_{10}(1{,}000) = 30$dB. Real gain is lower if phase drifts, timing is uncertain, the signal is modulated, or noise is correlated. The processing record must show the integration interval and coherence test.

M.7 Probability of observing a one-percent-duty-cycle burst

Assume independent observation intervals and a burst duty probability. The probability of at least one observation after N intervals is. Let.

Signal-analysis interpretation. A advanced technical analysis of Probability of observing a one-percent-duty-cycle burst preserves the raw I/Q record and uses time, frequency, phase, cyclostationary, and spatial domains to test whether the proposed modulation model explains the complete observation. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

$P = 1 - 0.99^{300} = 0.9510$,or ≈ 95.1percent. The independence assumption may fail for periodic or clustered bursts, so time-distributed monitoring is often better than one continuous block of equal duration.(87)

M.8 Tolerance-expanded search window at 433.92 MHz

Assume a component tolerance of plus or minus 75 kHz, a temperature allowance of 20 kHz, receiver/reference uncertainty of 1 kHz and a case allowance of 25 kHz. Worst-case one-sided addition gives.

Advanced practitioner analysis. A technically mature treatment of Tolerance-expanded search window at 433.92 MHz begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

A practical reconnaissance window may be rounded outward to plus or minus 150 kHz. After acquisition, the signal frequency is estimated from the data and the broad search window is not reported as drift.

M.9 Magnetic field from a 10 microampere single conductor

For a long straight conductor,, where B is flux density in tesla, is current in amperes and r is radial distance in metres..

Electromagnetic interpretation. The advanced treatment of Magnetic field from a 10 microampere single conductor begins with Maxwellian source decomposition. Electric charge density, conduction current, displacement current, magnetic flux, structural conductivity, and dielectric discontinuity can each contribute to the field that reaches the probe. Spatial nulls, phase reversals, vector orientation, and response to controlled geometric changes are often more informative than a single amplitude maximum, particularly in reflective rooms and near extended conductors. The report distinguishes measured field behaviour from inferred source identity and preserves the evidence needed for independent electromagnetic interpretation [9, 129-131].

$B = (4\pi x 10^{-7} \times 1 \times 10^{-5})/(2\pi x 0.01) = 2 \times 10^{-10}\text{T} = 0.2\text{nT}$.(88)

A balanced pair may produce much less external field. A larger loop, return imbalance or closer stand-off can produce more. The field model must match the conductor geometry.

M.10 Induced voltage in a high-turn bar-probe winding

For a sinusoidal field normal to the effective coil area, V_rms is approximated here by N A 2 pi f B_rms, where N is turns, A is effective area in square metres, f is frequency in hertz and B_rms is flux density in tesla. Let N = 10,000, A = 1 x 10^-4 m^2, f = 1,000 Hz and B = 0.2 nT = 2 x 10^-10 T.

Resonant receiving-system perspective. At advanced-practitioner level, Induced voltage in a high-turn bar-probe winding is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. Tuning commands, varactor bias, sapphire-piston setting, preamplifier gain, and resonance verification are recorded at the measurement epoch because a nominal centre frequency does not prove that the assembled probe was actually at resonance. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

$\mathrm{V} = 10{,}000 \times 1 \times 10^{-4} \times 2\pi x 1{,}000 \times 2 \times 10^{-10} = 1.26 \times 10^{-6}$V,or $\approx$ 1.26microvolts.(89)

The effective area and permeability of a real open core are frequency dependent. Winding resistance and preamplifier noise determine whether this voltage is measurable.

M.11 Spatial increase for a dipole-like near field

Assume, only as a local model, that magnetic-field amplitude varies as 1/r^3. Moving from 12 feet to 3 feet changes distance by a factor of 4. The amplitude ratio is 4^3 = 64.

Three-dimensional search analysis. For Spatial increase for a dipole-like near field, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

In decibels, 20. A much smaller increase may indicate a conductor path, distributed source, multipath or an invalid dipole assumption. The observed gradient is reported rather than forcing the model.

M.12 C-message-weighted combination of three magnetic components

Assume unweighted RMS magnetic components of 10 nT at 300 Hz, 2 nT at 1,000 Hz and 1 nT at 3,000 Hz. The C-message relative weights are -16.3 dB, 0 dB and -3.0 dB. Convert each weight to an amplitude factor 10^(W/20), multiply, then root-sum-square the weighted components.

Weighted. The unweighted 300 Hz component remains important even though the C-message view suppresses it.

M.13 PDM clock-sideband search family

Assume a digital microphone clock and a repeating framing or activity component. Simple amplitude or load modulation can create sidebands at f_c plus or minus f_a.

Advanced spectral-temporal analysis. For PDM clock-sideband search family, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Resolution bandwidth, video bandwidth, window function, sample rate, record length, detector law, dynamic range, frequency accuracy, and trigger condition are retained because each can create or suppress apparent spectral detail. The report distinguishes observed waveform features from decoded meaning and excludes unnecessary private content [27-30, 39-44, 75-80].

Lower. Upper. Harmonics may appear near 4.800 MHz, 7.200 MHz and higher.

The sidebands are only search hypotheses. Their evidential value depends on common timing, common drift and spatial convergence.

M.14 Combined measurement uncertainty

Assume independent standard uncertainties of 1.0 dB for amplitude calibration, 0.7 dB for repeatability, 1.2 dB for positioning and 0.8 dB for mismatch. The combined standard uncertainty is the root-sum-square.

Measurement-science elaboration. The mature treatment of Combined measurement uncertainty distinguishes calibration, verification, adjustment, characterisation, and validation. These activities are related, but they are not interchangeable and they do not support the same evidential claim. Repeated readings establish short-term precision, but they do not by themselves establish accuracy; traceability requires an unbroken and documented comparison to appropriate references, with the uncertainty of each link retained. The report states the standard uncertainty, the selected coverage factor where an expanded uncertainty is used, the confidence interpretation that is justified, and any contribution that could not be quantified [7-16].

The terms are illustrative. A real budget must consider correlation, frequency dependence, antenna factor, cable loss, field non-uniformity, dwell and environmental variation.

M.15 Validation programme for the new protocol

Traceability and uncertainty analysis. A advanced metrological approach to Validation programme for the new protocol treats uncertainty as a property of the reported quantity and method, not as a discretionary caveat added after the examiner has reached a preferred conclusion. Where a result depends upon subtraction, ratios, phase differences, or spatial gradients, covariance between channels and stations is considered rather than assuming every input quantity is independent. This makes the protocol auditable by a competent laboratory or inspection body without converting it into an academic thesis [1-16].

Study ID	Purpose	Method	Acceptance product
V-SAW-01	Exact-channel acquisition	Calibrated sources at 303.825, 315, 418, 433.92, 868.35 and 915 MHz	Frequency and amplitude within stated uncertainty at all valid rings
V-SAW-02	Custom-frequency robustness	Random frequencies inside 154-1000 MHz manufacturer range	Broad scan detects sources absent from exact list
V-SAW-03	Micro-watt sensitivity	Conducted and radiated levels from 5 mW down through 5 uW and lower	Probability-of-detection curve with false-alarm rate
V-SAW-04	NFM bandwidth classification	Known deviations and audio cut-offs yielding 8-16 kHz estimates	Correct classification without content monitoring
V-SAW-05	Burst and VOX detection	Programmable duty cycles and repetition intervals	Measured detection probability agrees with validation model
V-SAW-06	Intermodulation rejection	Strong multi-tone RF environment	False products identified by gain and preselector controls
V-MAG-01	Bar-probe amplitude calibration	Helmholtz coil, 30 Hz-14 kHz	Probe factor and phase within specification

Study ID	Purpose	Method	Acceptance product
V-MAG-02	Straight-wire current sensitivity	Known microampere audio current and stand-offs	Measured field agrees with geometry model within uncertainty
V-MAG-03	Balanced-pair cancellation	Adjustable current imbalance and spacing	Leakage trend follows imbalance model
V-MAG-04	C-message implementation	Reference tones at published coefficient frequencies	Digital weights within tolerance
V-MAG-05	Microphonic and triboelectric immunity	Controlled probe and cable motion with no applied field	Artefacts below declared threshold or correctly flagged
V-FIELD-01	Nested-ring localisation	Blind source placements with obstacles and service paths	Coordinate volume contains source at declared coverage probability
V-FIELD-02	Negative-scene false-alarm study	Occupied premises with ordinary electronics only	False-positive rate and alternative-source classification reported

M.16 Ring station field record

Field	Entry
Case identifier	
Station identifier	
Ring and nominal radius	
Coordinates and datum	
Date/time and time standard	
Operator	
Reference receiver station	
Antenna or probe serial	
Orientation/polarisation	
Height and stand-off	
Receiver serial and clock	
Preselector/LNA/attenuator	
Span/centre/RBW/VBW	
Detector/trace/dwell	
Candidate IDs observed	
Controls completed	
Environmental changes	
File names and hashes	
Advancement decision	
Reviewer	

M.17 SAW and narrowband candidate record

Advanced spectral-temporal analysis. For SAW and narrowband candidate record, classification is a hierarchy of tested features, not a label assigned because the trace resembles a familiar commercial waveform. Nested modulation is represented as a chain of transformations, so an NFM carrier containing an NFM or pulse-position subcarrier is not reduced to a single ambiguous bandwidth measurement. Classification confidence is reduced when alternative modulation families or instrument effects explain the same features with comparable economy [39-44, 75-80].

Field	**Entry**
Candidate ID	
Observed centre frequency	
Frequency uncertainty	
Register provenance code	
Search window used	
99-percent occupied bandwidth or declared metric	
Deviation estimate	
Modulation hypothesis	
Peak/average level and units	
Duty cycle/occupancy	
Burst duration/repetition	
Harmonics/subharmonics	
Clock/sideband relationships	
300-ft observation	
150/100/50-ft trend	
30/15/12-ft trend	
3-ft and 3-inch localisation	

Field	Entry
Independent receiver result	
Artefact controls	
Classification and uncertainty	

M.18 Voice-frequency magnetic-leakage record

Audio-frequency magnetic interpretation. An advanced technical account of Voice-frequency magnetic-leakage record separates true conductor-associated magnetic flux from acoustic pickup, probe microphonics, mains fields, loudspeakers, hearing loops, motors, and structural vibration. Current-related fields are expected to follow conductors, return paths, connectors, shielding discontinuities, and circuit state, so path continuity and differential measurements are more probative than audio-band energy alone. Where intelligible content is not necessary to the authorised purpose, it is neither acquired nor retained [18-23].

Field	**Entry**
Candidate ID	
Probe serial and band	
Core material and winding revision	
Probe factor file/hash	
Position and stand-off	
Axis/orientation	
Flat RMS and PSD	
C-message weighted result	
3 kHz-flat result	
30-300 Hz findings	
300 Hz-5 kHz findings	
5-14 kHz findings	
Clock-band findings	
Gradient between stand-offs	
Conductor-path correlation	
Dummy-probe result	
Cable-motion result	
Mains-harmonic assessment	

Field	Entry
Alternative-source assessment	
Classification and uncertainty	

M.19 Advancement-gate checklist

Advanced practitioner analysis. A technically mature treatment of Advancement-gate checklist begins by converting the stated activity into an explicit system model. The model names the source class, the coupling path, the sensor transfer function, the receiver state, and the environmental conditions under which comparison is legitimate. The recorded value is therefore the output of a coupled chain that includes probe geometry, orientation, cable loading, analogue preselection, gain distribution, detector law, sample clock, analysis bandwidth, and software processing. Where the required variables are not known or the controls cannot be completed, the limitation is recorded as part of the result rather than concealed by rhetorical certainty [7-9].

Gate item	**Status**	**Initials/date**
Passive baseline complete	Yes / No / N.A.	
Remote reference complete	Yes / No / N.A.	
Exact, tolerance and broad passes complete	Yes / No / N.A.	
Terminated input and dummy probe complete	Yes / No / N.A.	
Gain-step and preselector controls complete	Yes / No / N.A.	
Independent receiver confirmation complete	Yes / No / N.A.	
Coordinates, orientation and stand-off verified	Yes / No / N.A.	
Privacy review complete for retained I/Q	Yes / No / N.A.	
Uncertainty entries complete	Yes / No / N.A.	
Reason for advance/hold/reject documented	Yes / No / N.A.	
Second-person review complete	Yes / No / N.A.	

Appendix N. Magnetic-Core Alloy Register and Three-Dimensional Scene Processing Protocol

The existing alloy and three-dimensional procedures are extended by the twenty-seven-cell and paired-surface geometry in Chapter 32. Material-specific rods and rings are selected by frequency and transfer-characteristic evidence, while the cell lattice preserves the sensing-centre coordinate, axis, tuning state and completed-probe response at each measurement epoch.

N.1 Scope, status and governing distinction

This appendix has two linked purposes. First, it converts the magnetic-core discussion into a material-by-material engineering register for every metallic alloy family specified for EERF bars, rings, yokes and concentrators. Second, it adapts the disciplined scene-control, sketching, fixed-point measurement and systematic search principles used in forensic scene processing to a passive-first electronic inspection. The adaptation does not imply that a crime occurred, that an object is contraband or that a measured anomaly is evidence of wrongdoing. It provides repeatable spatial control for a non-contact scientific examination.

Advanced practitioner analysis. At expert-practitioner level, Scope, status and governing distinction is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Published material values are screening data, not certificates for a finished probe. Permeability is especially conditional on field amplitude, frequency, waveform, bias, heat treatment, geometry, demagnetising factor, mechanical stress, temperature and winding capacitance. No alloy is released for case use solely because its trade designation appears in this table. The final bar or ring assembly must be measured in its completed housing, with its actual winding, split, gap, shield and preamplifier. Sources [46] through [52] provide the principal manufacturer data. Crime-scene-derived process controls are adapted from the National Institute of Justice guide at [71].

N.2 Definitions used in the alloy register

Table N-1. Material-property definitions and metrological controls

Sensor and front-end elaboration. At advanced-practitioner level, Definitions used in the alloy register is specified by the complete complex transfer function of the assembled probe, not by the trade name of a core, capacitor, diode, or preamplifier. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. The probe is admitted to evidential use only after impedance, noise, linearity, intermodulation, thermal, mechanical, and field-coil tests support the intended band and dynamic range [31-36, 124-131].

Quantity	Meaning and EERF control
Intrinsic or material permeability	The ratio associated with a material specimen under stated conditions. It is not the effective permeability of a finite open rod.
Effective rod permeability	The permeability realised after the rod demagnetising factor, length-to-diameter ratio, winding zone and magnetic return path are included.
Complex permeability	The frequency-dependent quantity. The real component contributes inductive response. The imaginary component represents magnetic loss.
Saturation flux density, Bs	The approximate upper flux-density scale before incremental permeability collapses. A high Bs improves headroom but does not alone improve weak-field sensitivity.
Coercivity, Hc	The reverse field required to reduce induction following magnetisation. Lower coercivity generally supports low hysteretic loss and repeatable weak-field behaviour.
Saturation magnetostriction, lambda-s	Strain associated with magnetisation. Low magnitude reduces mechanical stress sensitivity and audio-frequency microphonic conversion.

Quantity	Meaning and EERF control
Electrical resistivity	A material property controlling eddy-current loss. Thin ribbon, thin lamination or insulated particles can be as important as bulk resistivity.
Frequency rating in this appendix	P means preferred prototype candidate. C means conditional or confirmation-only. N means normally unsuitable for the stated receiving-core role. R means reference comparator rather than metallic alloy.

N.3 Master physical and magnetic-property register

The table covers every alloy family already specified for EERF bar, ring, yoke or concentrator construction. JNHF, JNSF and JNRF are separated because their intended frequency regions differ. VITROPERM 500 F and 550 HF are likewise separated. The two ferrite rows are intentionally labelled as ceramic comparators, not alloys.

Values preceded by “about” are screening values or representative grades. A dash or qualitative phrase means that the cited summary does not provide a single transferable number, so the finished core must be characterised directly.

Advanced technical elaboration. For expert practice, Master physical and magnetic-property register is understood as an interaction among physics, instrumentation, procedure, and inference.

None of those elements is allowed to disappear behind a single receiver reading or an unqualified operator impression. A defensible comparison requires stable coordinates, declared bandwidth, dwell, detector mode, gain state, reference-clock condition, environmental status, and a retained record of every intervention that could have altered the field.

This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Table N-2. Comprehensive physical-property register for bar, ring, yoke and concentrator materials

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
PERMIMPHY 80Ni-5Mo-Fe	80 Ni, 5 Mo, Fe balance. Cold-rolled strip.	8.7	60	0.75	420	DC 470,000-520,000 at 0.4 A/m; AC 75,000 at 60 Hz; Hc about 0.4 A/m. 0.10-3 mm strip. Finished-part hydrogen anneal is decisive. Very high weak-field gain but low saturation and strong stress sensitivity.
IMPHY SUPRA 50, 48Ni-Fe	48 Ni, Fe balance. Cold-rolled strip.	8.2	45	1.50	450	mu-max about 200,000; AC marker about 12,500; Hc about 2.8 A/m; 0.15 W/kg at 400 Hz, 1 T. 0.10-3.5 mm strip. Higher headroom than 80Ni alloy, but lower weak-field permeability and greater eddy-current concern.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
AFK 502R, 49Co-49Fe-2V	49 Co, 2 V, Fe balance. Cold-rolled strip.	8.12	40	2.40	900	Hc about 1.5 Oe after 760 C treatment, lower after higher-temperature treatment. Permeability is moderate relative to Ni alloys. 0.10-1.50 mm strip. Exceptional saturation and temperature margin. Costly and conductive; not the first choice for the weakest fields.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
Grain-oriented 3% Si-Fe	Approx. 3% Si electrical steel. Strong rolling-direction anisotropy.	about 7.65	about 45-50	about 2.0	about 740	JFE comparison at 0.10 mm: 0.7 W/kg at 50 Hz, 6.4 W/kg at 400 Hz, 1 T; magnetostriction about -0.8 ppm. High flux density and low-frequency efficiency in rolling direction. Cross-axis response and high-frequency loss limit open-bar use.
10JNEX900, uniform 6.5% Si-Fe	Uniform 6.5% Si electrical steel, 0.10 mm representative sheet.	about 7.5	high for Si steel	1.8	not stated in cited comparison	Loss at 1 T: 0.5 W/kg at 50 Hz and 5.7 W/kg at 400 Hz. Magnetostriction about 0.1 ppm. Near-zero magnetostriction, low noise and broad high-frequency efficiency. Brittle relative to ordinary electrical steel.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
10JNHF600, Si-gradient steel	6.5% Si at surfaces with lower-Si centre, 0.10 mm representative sheet.	about 7.5	gradient-dependent	1.9	not stated in cited comparison	Loss at 1 T: 1.1 W/kg at 50 Hz and 10.1 W/kg at 400 Hz. Lower loss than JNEX above about 10 kHz; magnetostriction 3.1 ppm. Higher saturation than JNEX and designed for high-frequency loss reduction above 5 kHz. More magnetostrictive and stress-sensitive.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
15JNSF950, Si-gradient steel	Si-gradient electrical steel, 0.15 mm representative sheet.	about 7.5	gradient-dependent	2.0	not stated in cited comparison	Loss comparable to thinner JNEX at high frequency; magnetostriction 2.8 ppm; 15.0 W/kg at 400 Hz and 1 T. High saturation and high-frequency performance despite 0.15 mm thickness. Less attractive for sub-kHz weak-field work.
10JNRF, high-flux Si-gradient steel	Lower-average-Si gradient steel, 0.10 mm representative sheet.	about 7.5	gradient-dependent	2.0	not stated in cited comparison	0.6 W/kg at 50 Hz and 7.5 W/kg at 400 Hz, 1 T; magnetostriction 2.3 ppm. Optimised for 50 Hz to several kHz. Combines 3% Si-steel-like saturation with lower loss than JNHF/JNSF below several kHz.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
MPP, Fe-Ni-Mo powder	Molypermalloy powder, insulated distributed-gap particles.	7.8 at 60 mu	distributed insulation	0.8	460	Commercial grades about 14-550. For 60-mu material, flat response marker about 6 MHz; 165/450 mW per cc at 50/100 kHz, 1000 G. Excellent stability and low loss among powder cores, with low saturation and lower sensitivity than continuous high-mu ribbon.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
High Flux, 50Ni-50Fe powder	Approx. 50 Ni, 50 Fe insulated powder.	7.6 at 60 mu	distributed insulation	1.5	500	Commercial grades about 14-160. For 60-mu material, flat-response marker about 3 MHz; 250/625 mW per cc at 50/100 kHz, 1000 G. Strong DC-bias and saturation performance. Greater core loss and lower weak-field gain than MPP.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
Sendust / Kool Mmu, Fe-Si-Al powder	Fe-Si-Al insulated powder.	5.8 at 60 mu	distributed insulation	1.0	500	Grades about 14-125. 60-mu response flat to about 5 MHz; near-zero magnetostriction; 215/550 mW per cc at 50/100 kHz, 1000 G. Low cost, low acoustic noise and useful high-Q filter behaviour. Moderate saturation and modest effective permeability.
XFlux, Fe-Si powder	Fe-Si insulated powder, approximately 6.5% Si class.	6.9 at 60 mu	distributed insulation	1.6	700	Grades about 19-125. 60-mu response flat to about 3-4 MHz; 575/1280 mW per cc at 50/100 kHz, 1000 G. High saturation and temperature margin, but materially higher loss than MPP or Kool Mmu.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
Metglas 2605SA1, Fe amorphous	Iron-based amorphous ribbon, about 25 +/- 4 micrometres.	7.18	130	1.56	395	High permeability after field anneal; transformer-core at 60 Hz, 1.3 T. Magnetostriction about 27 ppm. Thin ribbon suppresses eddy currents, but large magnetostriction and brittle edges create microphonic and stress risks.
Metglas 2605S3A, Fe amorphous	Iron-based amorphous ribbon, about 18 micrometres.	7.29	138	1.41	358	mu-max about 35,000 annealed; magnetostriction 20 ppm. Intended. Good high-frequency loss and temperature capability, but mechanically and magnetostrictively noisier than Co-based ribbon.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
Metglas 2826MB, Fe-Ni amorphous	Nickel-based amorphous ribbon, about 29 micrometres.	7.90	138	0.88	353	mu-max about 800,000 annealed; magnetostriction about 12 ppm. Very high weak-field gain with moderate saturation. Stress and anneal history strongly affect performance.
Metglas 2705M, Co amorphous	Cobalt-based amorphous ribbon, about 22 micrometres.	7.80	136	0.77	365	mu-max about 600,000 annealed and 290,000 as-cast;. Excellent low-field sensitivity, near-zero magnetostriction and high-frequency suitability, but low saturation and cost are limitations.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
Metglas 2714A, Co amorphous	Cobalt-based amorphous ribbon, about 18 micrometres.	7.59	142	0.57	225	mu-max about 1,000,000 annealed;. Highest listed permeability and very low loss, offset by the lowest saturation, lower Curie point and extreme handling sensitivity.
VITROPERM 500 F, Fe-Si-B-Nb-Cu nanocrystalline	Fe-Si-B with Nb and Cu. 14-20 micrometre ribbon family.	about 7.2	115	≥ 1.2(90)	about 600	Family permeability adjustable from hundreds to hundreds of thousands; Hc about 0.5-5 A/m; near-zero magnetostriction after proper anneal. Broadband, thermally stable, high-saturation nanocrystalline reference. Finished permeability depends on annealing and loop type.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
VITROPERM 550 HF, Fe-Si-B-Nb-Cu nanocrystalline	High-frequency nanocrystalline Fe-Si-B-Nb-Cu ribbon, 17-25 micrometre class.	about 7.2	115	1.21	> 600(91)	Absolute permeability about 20,000-100,000 at 10 kHz;; magnetostriction about 0.1 ppm. Improved response above 100 kHz versus 500 F. Excellent broadband HF attenuation and low stress noise. At very low frequencies, 500 F or higher-mu anneals may provide more gain.

Material / representative grade	Composition and form	Density g/cm3	rho, micro-ohm cm	Bs, T	Curie, C	Permeability, loss and physical control
MnZn ferrite comparator, not an alloy	Manganese-zinc ferrite ceramic.	grade-dependent	high relative to metal	about 0.3-0.5	grade-dependent	Often high initial permeability at audio and VLF. Loss rises with frequency and grade; brittle, electrically resistive ceramic. Reference material for long rods below roughly 100 kHz. The actual grade and rod demagnetising factor control response.
NiZn ferrite comparator, not an alloy	Nickel-zinc ferrite ceramic.	grade-dependent	very high	about 0.25-0.45	grade-dependent	Lower permeability than MnZn but useful to several MHz or tens of MHz depending grade. Reference material for 0.1-10 MHz confirmation. Lower low-frequency gain than high-mu alloys.

Interpretive rule. A large tabulated permeability does not guarantee the highest induced voltage in an open rod. Once intrinsic permeability substantially exceeds the inverse demagnetising factor, additional material permeability yields diminishing improvement. Rod length-to-diameter ratio, the winding zone, the magnetic return path and the final resonant-network noise frequently dominate. Conversely, a lower-permeability powder or NiZn ferrite may outperform a nominally superior alloy at several megahertz because its loss and self-resonance are better controlled.

N.4 Frequency-dependent suitability across the EERF bands

The ratings below concern weak-field receiving cores, not power conversion. “Preferred” means the material is a leading prototype candidate after lot testing. “Conditional” means it may be used where saturation, bias, cost, geometry or bandwidth justify it, but a better baseline material normally exists. “Normally unsuitable” means loss, anisotropy, saturation, permeability collapse or construction risk generally outweighs the expected benefit. A reference-comparator rating applies to ferrite ceramics. No magnetic bar or ring rating extends into the hundreds-of-megahertz SAW bands. Those bands require calibrated air-core loops, dipoles, log-periodic antennas, horns, waveguide structures or dielectric resonators.

Table N-3. Voice-band and timing-band prototype suitability

Material	30-300 Hz	300 Hz-3 kHz	3-14 kHz	15.734 kHz	32.768 kHz
PERMIMPHY 80Ni-5Mo-Fe	P	P	P	P	P
IMPHY SUPRA 50, 48Ni-Fe	P	P	P	C	C
AFK 502R, 49Co-49Fe-2V	C	C	C	C	N
Grain-oriented 3% Si-Fe	P	P	C	C	N
10JNEX900, uniform 6.5% Si-Fe	C	P	P	P	P
10JNHF600, Si-gradient steel	C	C	P	P	P
15JNSF950, Si-gradient steel	N	C	P	P	P
10JNRF, high-flux Si-gradient steel	P	P	P	C	C
MPP, Fe-Ni-Mo powder	C	C	P	P	P
High Flux, 50Ni-50Fe powder	C	C	P	P	P
Sendust / Kool Mmu, Fe-Si-Al powder	C	P	P	P	P

Material	30-300 Hz	300 Hz-3 kHz	3-14 kHz	15.734 kHz	32.768 kHz
XFlux, Fe-Si powder	N	C	C	P	P
Metglas 2605SA1, Fe amorphous	C	C	P	P	P
Metglas 2605S3A, Fe amorphous	C	C	P	P	P
Metglas 2826MB, Fe-Ni amorphous	P	P	P	P	P
Metglas 2705M, Co amorphous	P	P	P	P	P
Metglas 2714A, Co amorphous	P	P	P	P	P
VITROPERM 500 F, Fe-Si-B-Nb-Cu nanocrystalline	P	P	P	P	P
VITROPERM 550 HF, Fe-Si-B-Nb-Cu nanocrystalline	C	P	P	P	P
MnZn ferrite comparator, not an alloy	R	R	R	R	R
NiZn ferrite comparator, not an alloy	N	C	C	C	C

Table N-4. Medium-frequency and low-megahertz prototype suitability

Material	0.10-0.50 MHz	0.50-1 MHz	1-3.579545 MHz	3.58-10 MHz	Primary geometry or limiting mechanism
PERMIMPHY 80Ni-5Mo-Fe	C	C	N/N	N	Laminated long bar or carefully split/tape-wound return ring. Avoid bending after anneal.
IMPHY SUPRA 50, 48Ni-Fe	C	N	N/N	N	Thin laminated bar or ring where mains-field headroom is required.
AFK 502R, 49Co-49Fe-2V	N	N	N/N	N	Very thin laminations or a gapped concentrator where saturation, not ultimate sensitivity, controls.

Material	0.10-0.50 MHz	0.50-1 MHz	1-3.579545 MHz	3.58-10 MHz	Primary geometry or limiting mechanism
Grain-oriented 3% Si-Fe	N	N	N/N	N	Stacked laminations with rolling direction aligned to the bar axis, or tape-wound ring.
10JNEX900, uniform 6.5% Si-Fe	C	N	N/N	N	Thin laminated bar or stacked split ring, with protected edges and low clamping stress.
10JNHF600, Si-gradient steel	P	C	N/N	N	Thin laminated bar or ring for 10-100 kHz prototypes.
15JNSF950, Si-gradient steel	P	C	N/N	N	Laminated ring or shorter bar where 10-100 kHz response and headroom are valued.
10JNRF, high-flux Si-gradient steel	N	N	N/N	N	Laminated bar or ring for low-frequency voice and mains-adjacent environments.
MPP, Fe-Ni-Mo powder	P	P	P/C	N	Powder toroid, split ring or custom cylinder. Useful for damped broadband probes.
High Flux, 50Ni-50Fe powder	P	P	C/C	N	Powder ring or segmented concentrator where external DC or mains bias is substantial.
Sendust / Kool Mmu, Fe-Si-Al powder	P	P	P/P	C	Powder toroid, split ring or custom bar. Strong candidate for 3.58 MHz confirmation at low permeability.
XFlux, Fe-Si powder	P	P	P/C	N	Powder ring or short bar where bias headroom dominates sensitivity.

Material	0.10-0.50 MHz	0.50-1 MHz	1-3.579545 MHz	3.58-10 MHz	Primary geometry or limiting mechanism
Metglas 2605SA1, Fe amorphous	P	C	C/N	N	Tape-wound ring or bonded laminated bar with isolation from vibration.
Metglas 2605S3A, Fe amorphous	P	P	C/N	N	Tape-wound ring or carefully potted laminated bar.
Metglas 2826MB, Fe-Ni amorphous	P	C	N/N	N	Tape-wound ring or laminated bar with strain relief.
Metglas 2705M, Co amorphous	P	P	C/C	N	Tape-wound or split ring, and stress-relieved laminated bar. Preferred low-noise reference alloy.
Metglas 2714A, Co amorphous	P	P	C/C	N	Shielded, strain-isolated tape-wound ring or short laminated bar used with overload monitoring.
VITROPERM 500 F, Fe-Si-B-Nb-Cu nanocrystalline	P	P	P/C	C	Tape-wound split or closed ring, or stacked ribbon bar with controlled transverse/longitudinal anneal.
VITROPERM 550 HF, Fe-Si-B-Nb-Cu nanocrystalline	P	P	P/P	C	Tape-wound ring or split concentrator for 32.768 kHz through low-MHz work.
MnZn ferrite comparator, not an alloy	R	C	N/N	N	Commercial rod or segmented ring. Nonconductive and low eddy-current loss.
NiZn ferrite comparator, not an alloy	R	R	R/R	R	Commercial rod, sleeve or ring. Select by measured complex permeability.

Table N-5. Key-frequency material-selection rules

Frequency region	Leading prototype candidates	Controlling physical issue
30-300 Hz	PERMIMPHY, 2826MB, 2705M, 2714A, VITROPERM high-mu grade	Mains-field headroom, 1/f preamplifier noise, remanence, vibration and rod demagnetisation.
300 Hz-3 kHz	PERMIMPHY, SUPRA 50, JNRF, 2826MB, 2705M, 2714A, VITROPERM	Voice-band magnetic leakage can be broadband and unbalanced. Use flat calibration before any weighting.
3-14 kHz	JNEX, JNHF, JNSF, JNRF, amorphous and nanocrystalline ribbon, low-loss powder	Magnetostriction and mechanical mounting become prominent. Compare bar, ring and gradiometer channels.
15.734 kHz	JNEX/JNHF/JNSF, 2605S3A, 2705M, 2714A, VITROPERM 500 F/550 HF	Use broadband discovery and tuned confirmation. Verify settling and distinguish legacy video timing from unrelated switchers.
32.768 kHz	JNHF/JNSF, MPP, Kool Mmu, 2605S3A, 2705M, 2714A, VITROPERM 500 F/550 HF, MnZn comparator	High-turn resonance may be limited by winding self-capacitance before core loss. Record loaded Q and temperature drift.
0.1-0.5 MHz	MPP, High Flux, Kool Mmu, XFlux, amorphous ribbon, VITROPERM 500 F/550 HF, selected ferrites	Use thinner ribbon, lower permeability or distributed-gap material to preserve bandwidth and avoid self-resonance.
0.5-1 MHz	MPP, Kool Mmu, VITROPERM 500 F/550 HF, selected NiZn ferrite	Measure complex permeability and transfer impedance. Metallic strip laminations are usually loss-limited.
1-3.579545 MHz	Kool Mmu, selected MPP, VITROPERM 550 HF, NiZn ferrite, air-core companion	A magnetic core is confirmation-only. Air-core or active small-loop comparison is mandatory.

Frequency region	Leading prototype candidates	Controlling physical issue
3.58-10 MHz	Low-mu Kool Mmu or VITROPERM 550 HF only after validation; normally NiZn or air core	Coil capacitance, core loss and receiver breakthrough dominate. Do not infer superiority from low-frequency permeability.
SAW bands, 130 MHz-1 GHz and above	No bar or ring alloy as the primary antenna	Use air, dielectric or printed RF structures. Magnetic materials may appear only as absorber, shield or common-mode control, not as the calibrated receive aperture.

N.5 Bar, ring, yoke and concentrator construction controls

Table N-6. Fabrication form and mandatory acceptance testing

Sensor and front-end elaboration. The technically mature interpretation of Bar, ring, yoke and concentrator construction controls treats the sensor as a coupled electromagnetic, electrical, thermal, and mechanical system whose response changes with frequency, orientation, bias, temperature, stress, and loading. The qualified configuration includes core lot, geometry, winding turns, wire type, sectioning pattern, measured inductance, resistance, self-resonant frequency, tuning range, loaded quality factor, noise spectrum, and orientation map. This prevents an apparently sensitive sensor from becoming an unrecognised source of distortion, rectification, microphonics, or false spatial structure [31-36, 124-131].

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
PERMIMPHY 80Ni-5Mo-Fe	Strip / lamination	Laminated long bar or carefully split/tape-wound return ring. Avoid bending after anneal.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
IMPHY SUPRA 50, 48Ni-Fe	Strip / lamination	Thin laminated bar or ring where mains-field headroom is required.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
AFK 502R, 49Co-49Fe-2V	Strip / lamination	Very thin laminations or a gapped concentrator where saturation, not ultimate sensitivity, controls.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
Grain-oriented 3% Si-Fe	Strip / lamination	Stacked laminations with rolling direction aligned to the bar axis, or tape-wound ring.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
10JNEX900, uniform 6.5% Si-Fe	Strip / lamination	Thin laminated bar or stacked split ring, with protected edges and low clamping stress.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
10JNHF600, Si-gradient steel	Strip / lamination	Thin laminated bar or ring for 10-100 kHz prototypes.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
15JNSF950, Si-gradient steel	Strip / lamination	Laminated ring or shorter bar where 10-100 kHz response and headroom are valued.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
10JNRF, high-flux Si-gradient steel	Strip / lamination	Laminated bar or ring for low-frequency voice and mains-adjacent environments.	Rolling direction, lamination insulation, burr and shorted-turn inspection, anneal certificate, stress and axis tests.
MPP, Fe-Ni-Mo powder	Distributed-gap powder	Powder toroid, split ring or custom cylinder. Useful for damped broadband probes.	AL tolerance, complex permeability, bias curve, thermal drift, resonant Q and lot-to-lot density check.
High Flux, 50Ni-50Fe powder	Distributed-gap powder	Powder ring or segmented concentrator where external DC or mains bias is substantial.	AL tolerance, complex permeability, bias curve, thermal drift, resonant Q and lot-to-lot density check.
Sendust / Kool Mmu, Fe-Si-Al powder	Distributed-gap powder	Powder toroid, split ring or custom bar. Strong candidate for 3.58 MHz confirmation at low permeability.	AL tolerance, complex permeability, bias curve, thermal drift, resonant Q and lot-to-lot density check.

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
XFlux, Fe-Si powder	Distributed-gap powder	Powder ring or short bar where bias headroom dominates sensitivity.	AL tolerance, complex permeability, bias curve, thermal drift, resonant Q and lot-to-lot density check.
Metglas 2605SA1, Fe amorphous	Thin ribbon	Tape-wound ring or bonded laminated bar with isolation from vibration.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
Metglas 2605S3A, Fe amorphous	Thin ribbon	Tape-wound ring or carefully potted laminated bar.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
Metglas 2826MB, Fe-Ni amorphous	Thin ribbon	Tape-wound ring or laminated bar with strain relief.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
Metglas 2705M, Co amorphous	Thin ribbon	Tape-wound or split ring, and stress-relieved laminated bar. Preferred low-noise reference alloy.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
Metglas 2714A, Co amorphous	Thin ribbon	Shielded, strain-isolated tape-wound ring or short laminated bar used with overload monitoring.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
VITROPERM 500 F, Fe-Si-B-Nb-Cu nanocrystalline	Thin ribbon	Tape-wound split or closed ring, or stacked ribbon bar with controlled transverse/longitudinal anneal.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
VITROPERM 550 HF, Fe-Si-B-Nb-Cu nanocrystalline	Thin ribbon	Tape-wound ring or split concentrator for 32.768 kHz through low-MHz work.	Ring transfer impedance, anneal traceability, post-assembly stress shift, ring-down and microphonic test.
MnZn ferrite comparator, not an alloy	Ceramic comparator	Commercial rod or segmented ring. Nonconductive and low eddy-current loss.	Grade identity, dimensional inspection, fracture/chip check, complex permeability and completed-rod transfer factor.

Material	Construction family	Preferred bar or ring implementation	Minimum acceptance tests
NiZn ferrite comparator, not an alloy	Ceramic comparator	Commercial rod, sleeve or ring. Select by measured complex permeability.	Grade identity, dimensional inspection, fracture/chip check, complex permeability and completed-rod transfer factor.

N.6 Lot-specific material qualification

Advanced technical elaboration. At expert-practitioner level, Lot-specific material qualification is treated as a defined measurement proposition rather than a descriptive heading. The proposition identifies the measurand, the spatial and temporal boundary, the instrument state, and the decision that the observation is intended to support. The examiner separates discovery sensitivity from confirmatory specificity, since the settings that reveal an anomaly are not necessarily the settings that support attribution, spatial localisation, or quantitative comparison. This discipline requires an explicit source model, a controlled measurement state, documented uncertainty and bounded interpretation, so that the section functions as a professional engineering protocol rather than an accumulation of untested assertions [1-9].

Qualification element	Required record
Identity and provenance	Manufacturer, grade, lot, heat or batch, chemistry or commercial designation, form, thickness, width, delivery temper and date received.
Physical dimensions	Mass, density or calculated volume, ribbon or lamination thickness, stacking or lamination factor, bar length and diameter, ring dimensions, split and gap.
Low-field magnetics	Initial, incremental and complex permeability at the intended field amplitude; coercivity; remanence; bias sensitivity; degauss response.
Frequency response	Transfer factor, mu-prime, mu-double-prime or impedance from below the lowest intended band to at least one decade above the highest intended band.
Stress sensitivity	Before-and-after data for winding pressure, clamp torque, potting, housing assembly, drop/transport and temperature cycling.

Qualification element	Required record
Resonant assembly	Inductance, resistance, self-capacitance, self-resonant frequency, loaded Q, 3 dB bandwidth, ring-down, gain, noise and overload recovery.
Magnetic cleanliness	Residual magnetisation, degaussing procedure, response to a known DC bias and rejection of nearby ferromagnetic fasteners.
Release decision	Approved bands, prohibited bands, maximum permissible field, configuration identifier, calibration interval, examiner and reviewer signatures.

The material-selection table is a screening instrument, not a substitution chart. A bar made from an alloy with a million-level ring permeability can perform poorly if the rod demagnetising factor limits effective permeability to a few hundred, if the winding self-resonates below the search band, or if clamp stress increases magnetic loss.

Conversely, a low-permeability powder ring may provide a quieter, flatter and more reproducible measurement. The released configuration is therefore the entire probe, including core, winding, capacitor, shield, housing, cable, preamplifier and software state.

N.7 Scene isolation, access control and measurement command

The inspection area shall be placed under a scene-control regime before interior cube work begins. An outer administrative boundary separates the ordinary premises from the controlled operation. An inner measurement boundary identifies the room or zone in which instrument states, personal electronics, movement and environmental changes are controlled. A single entry route is preferred. Every person and item entering or leaving is logged, including tools, batteries, cables, markers, furniture-moving aids and temporary sources. Unauthorised doors remain closed and sealed by record, not by destructive means. The lead examiner may stop the search if the scene state cannot be reconstructed.

Scene-geometry elaboration. At expert-practitioner level, Scene isolation, access control and measurement command is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

Table N-8. Interior scene-control roles and boundaries

Control element	Required practice
Scene-control lead	Declares boundaries, approves entry, assigns roles and stops work when state integrity is lost.
Entry recorder	Records person or item, time in, time out, purpose, carried electronics and destination cube.
Measurement lead	Controls receiver, probe and reference states and signs each cube closure.

Control element	Required practice
Spatial recorder	Maintains hard-point network, room drawing, furniture coordinates, marker register and cube map.
Data custodian	Associates files with cube, station, marker and movement records; verifies time synchronisation and hashes.
Independent reviewer	Checks hard-point closure, coordinate calculations, control completeness and candidate promotion.
Equipment staging zone	Holds unused equipment outside the inner measurement boundary; each item is characterised before entry.
Controlled route	Defines the path personnel and equipment use so movement-induced changes remain attributable.

N.8 Hard-point datum network and room measurement drawing

The room drawing is a dimensional instrument record. It is not an artistic rendering and does not depict the internal appearance of a suspected device. Select a floor-level origin O and define +x, +y and +z. Where possible, designate three non-collinear hard points HP-A, HP-B and HP-C on permanent structure, such as masonry corners, column intersections or fixed service penetrations. A door leaf, loose skirting board or movable appliance is not a hard point unless no alternative exists and its conditional status is documented. Measure all inter-hard-point distances and compare them with the coordinate solution. A failed closure check invalidates later triangulation until the discrepancy is resolved.

Spatial-measurement interpretation. At expert-practitioner level, Hard-point datum network and room measurement drawing is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9].

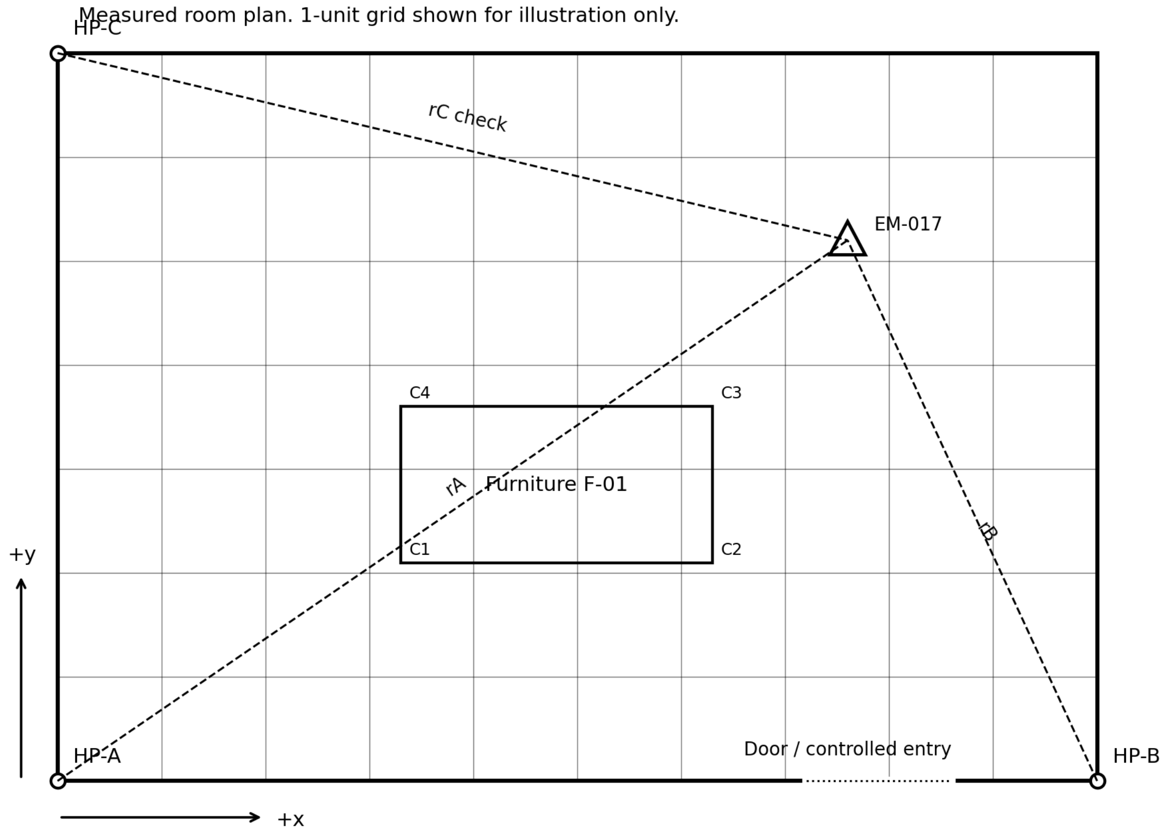


Figure N-1. Abstract room plan with fixed hard points, cube grid, furniture coordinates and redundant triangulation

Table N-9. Hard-point and datum register template

ID	Description	x	y	z	Uncertainty	Status
HP-A	Physical description and tamper-evident reference mark	xA	yA	zA	uA	Permanent / conditional
HP-B	Physical description and tamper-evident reference mark	xB	yB	zB	uB	Permanent / conditional
HP-C	Physical description and tamper-evident reference mark	xC	yC	zC	uC	Permanent / conditional

ID	Description	x	y	z	Uncertainty	Status
O	Declared room origin and axis convention	0	0	0	uO	Coordinate datum

The drawing shall include room dimensions, wall thickness where known, doors, windows, fixed services, floor and ceiling levels, furniture footprints, significant conductors, instrument stations, controlled routes, cube boundaries and all marker identifiers. The original rough drawing is signed and retained. A later fair copy must identify the original record and cannot replace it. Any revision states who changed what, why, when and which measurements support the change.

N.9 Triangulation, trilateration and rectangular-coordinate calculation

For a two-dimensional point E and a baseline from HP-A = (0,0) to HP-B = (L,0), let rA be the measured distance from HP-A to E and rB the measured distance from HP-B to E. The coordinate along the baseline is x = (rA^2 - rB^2 + L^2) / (2L). The perpendicular coordinate magnitude is y = sqrt(rA^2 - x^2). A third hard-point distance rC, or an unambiguous room-side constraint, resolves the sign of y and provides a residual check. The height z is measured independently from the declared floor datum. The method is trilateration in strict mathematical usage, although crime-scene manuals commonly describe the operational method as triangulation.

Spatial-measurement interpretation. At expert-practitioner level, Triangulation, trilateration and rectangular-coordinate calculation is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

Where two perpendicular walls are stable, rectangular coordinates may be more efficient. Record the normal distance from each wall and the height. A transecting baseline may be used when numerous points must be located along an irregular area. Angle-and-distance polar coordinates are reserved for cases in which a single reliable reference is available. EERF shall prefer redundant distance measurements because they are easier to audit than a single angle. The uncertainty record includes tape or laser calibration, endpoint definition, sag, temperature, alignment, target thickness, floor irregularity and calculation rounding.

Table N-10. Spatial variables and equations

Quantity	Equation or symbol	Definition
Baseline length	L	Distance from HP-A to HP-B, in metres or feet.
Hard-point ranges	rA, rB, rC	Measured distances from the hard points to the point or marker.
Point coordinate	x, y, z	Cartesian coordinates in the declared room frame.
Furniture orientation	$\theta = \operatorname{atan2}(y_2 - y_1, x_2 - x_1)$(92)	Angle of a designated furniture edge relative to +x.
Cube index	$i = \text{floor}\big((x - x_0)/\Delta - x\big)$(93)	Integer address along an axis. Equivalent rules define j and k.
Three-dimensional distance	$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$(94)	Distance between two measured points.
Amplitude gradient	$g = (M_2 - M_1)/d$(95)	Change in selected metric M per unit distance, with uncertainty and direction stated.
Closure residual	epsilon-$C = rC$,measured $-$ rC,predicted(96)	Independent check against the third hard point.

N.10 Furniture, fixture and service-path placement

Each movable item receives a furniture or fixture identifier. Rectangular objects are recorded by at least two diagonal or three corner coordinates, plus height, so that translation and rotation can be reconstructed. Irregular items receive a bounding polygon or a minimum of three fiducials. Doors and drawers are recorded by hinge point and opening angle. Cables, conduits and pipes are recorded as polylines with heights and visible entry or exit points. The baseline state is measured before any movement. If movement is authorised, the before and after coordinate sets, displacement vector, rotation, actor, purpose and affected cubes are entered before acquisition resumes.

Table N-11. Furniture and service-path coordinate record

Field	Required entry
Item ID	F-01, SVC-02 or equivalent unique identifier.
Type and material	Desk, chair, cabinet, conduit, cable bundle, pipe, blind, door, medical apparatus or other class.
Fiducials	At least three points or sufficient corners to define footprint and orientation.
Dimensions	Length, width, height and relevant cavity or surface levels.
Orientation	theta relative to +x, with stated reference edge.
Pre-movement state	Coordinates, state, timestamp and examiner signature.
Movement event	Reason, authorisation, person, route, displacement, rotation and contact points.
Post-movement state	New coordinates, timestamp, affected cube set and mandatory repeat measurements.
Electromagnetic effect	Observed change in amplitude, phase, null, noise floor, coupling path or candidate classification.

N.11 Marker triangles on floors, walls and surfaces

A physical marker identifies a measurement location or candidate region, not a device and not an evidential conclusion. Markers shall be non-damaging, low-lint, nonconductive and characterised for self-emission. They are placed adjacent to the location, with a measured offset, so no suspected object is touched. The same identifier appears in the room drawing, cube record, acquisition filename and candidate log. Markers on walls or vertical surfaces include height and surface normal. Markers on furniture include the furniture identifier and local surface coordinates so the point remains reconstructable if the furniture is later moved.

Scene-geometry elaboration. The mature treatment of Marker triangles on floors, walls and surfaces replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Markers are adjacent coordinate aids. They are not placed on, or represented as, a device.

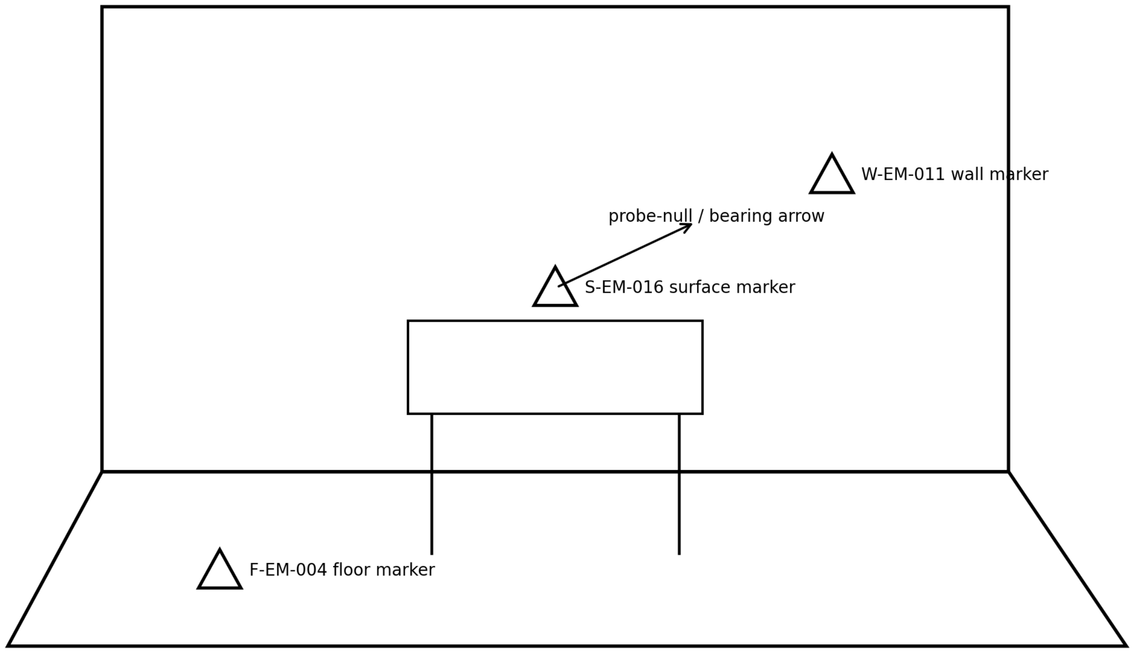


Figure N-2. Candidate marker triangles on floor, wall and furniture surface

Table N-12. Marker symbol and identifier system

Symbol or code	Meaning and control
Circle, HP	Hard point or datum. Must be permanent or explicitly conditional.
Triangle, EM	Electromagnetic observation point. Single outline means observed. Double outline means repeatable under declared controls.
Square, IS	Instrument station or receiver location.
Arrow, OR	Probe axis, loop null, polarisation, bearing or movement direction.
Dashed boundary, CV	Candidate volume or surface region. It does not imply a physical object.
Cross, CTL	Control point, dummy-probe point or source-absent comparison.
Surface prefix F/W/C/S	Floor, wall, ceiling or furniture/surface marker. Example: W-EM-011.
Marker offset	Measured distance and direction from the marker to the actual probe centre or candidate maximum.

N.12 Three-dimensional cube lattice

The interior is decomposed into cubes or rectangular voxels tied to the room datum. The default coarse cell has a nominal side of three feet, matching the interior coarse-grid stage. Candidate sectors are subdivided to twelve-inch cells, then to three-inch cells where the validated spatial resolution and access justify that step. Ceiling voids, raised floors and adjacent rooms receive separate room prefixes. Wall, floor, ceiling and furniture surfaces are linked to the nearest volume cell but retain a surface code. A cube identifier such as R01-X02-Y05-Z01 identifies the room and integer indices. The physical bounds and centre coordinate are stored, because a bare identifier is not sufficient if a later revision changes the grid origin.

Scene-geometry elaboration. At expert-practitioner level, Three-dimensional cube lattice is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Nested rings and cube lattices provide different scales of evidence: remote stations establish environmental context, intermediate rings test premises convergence and service paths, and fine cells test whether a candidate can be bounded within the validated spatial resolution. Reverse-path measurements and closure stations test whether the field remained sufficiently stationary for the inward sequence to support a spatial inference [7-9]. Rooms must be regarded to be an extended series of cube, and every element within the room must be regarded as a 27-cell cube, with intense documentation of every cell of every cube, in every room.

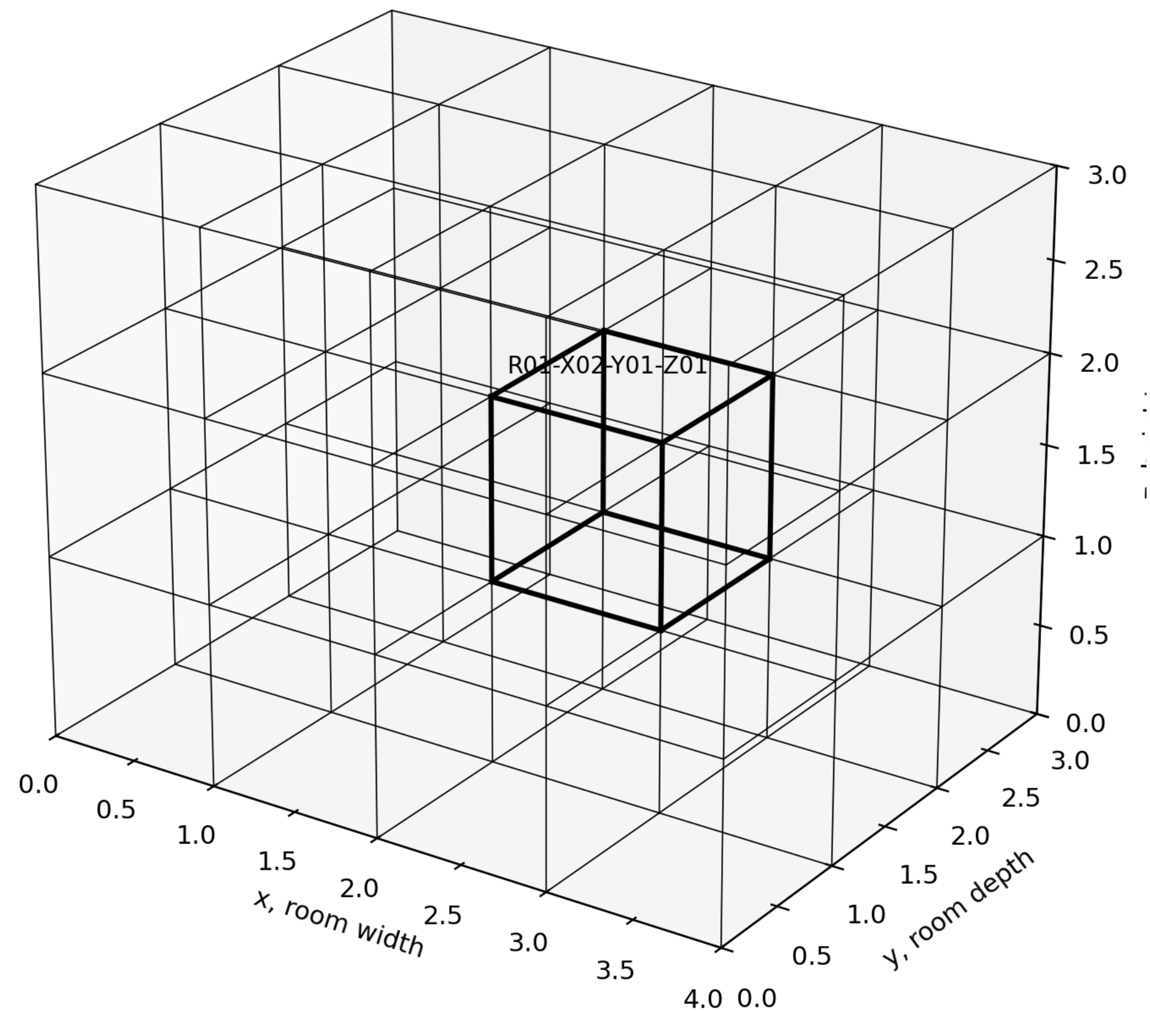


Figure N-3. Three-dimensional cube lattice with an addressable candidate volume

Table N-13. Cube hierarchy and permitted use

Cell class	Nominal dimension	Required treatment
Coarse discovery	3 ft nominal	Entire accessible room, three probe axes, broadband plus priority channels, fixed dwell and negative-control schedule.

Cell class	Nominal dimension	Required treatment
Intermediate refinement	12 in nominal	Only a predeclared candidate sector and immediate neighbours. Same datum, no freehand re-centring.
Fine convergence	3 in nominal	Validated candidate volume, stationary increments, exact probe centre and orientation, reverse and independent-sensor confirmation.
Surface cell	Same lateral step as adjacent volume	Floor, wall, ceiling or furniture plane with normal vector and standoff.
Exclusion cell	Recorded actual dimensions	Inaccessible, hazardous, occupied or physically blocked cell. State reason and capability limitation.
Control cell	Matched geometry	Known source absent, dummy probe, reference source or remote comparison cell.

N.13 Cube-by-cube acquisition sequence

Spatial-measurement interpretation. The mature treatment of Cube-by-cube acquisition sequence replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. Where coordinate or temporal closure fails, the result is reported as a time-specific observation rather than a stable source location [7-9].

Table N-14. Mandatory cube-processing sequence

Step	Required action
1. Verify identity	Confirm room, cube bounds, centre coordinate, surface association and route.
2. Verify state	Record occupants, doors, windows, lighting, HVAC, mains state, authorised equipment and immediately preceding movement.
3. Establish instrument position	Place the probe centre at the declared coordinate and height without touching a suspected item. Record standoff.
4. Allow settling	Wait the validated mechanical, thermal, filter and resonant ring-down interval.
5. Acquire broad baseline	Record broadband magnetic, electric and RF channels before narrow tuning.
6. Acquire priority bands	Measure voice-frequency, timing, oscillator, SAW/NFM and other authorised priority channels using the declared probe sequence.
7. Rotate and vectorise	Repeat on orthogonal axes, loop nulls, polarisation states or azimuth/elevation settings as applicable.
8. Apply controls	Use dummy probe, terminated input, gain step, preselector or independent receiver according to schedule and candidate status.
9. Record behaviour vector	Enter amplitude, noise, frequency, phase/coherence, null, gradient, drift, intermittency, environment and uncertainty.
10. Mark and classify	Place or update an adjacent marker only when criteria are met. State observed, candidate-correlated or higher classification.
11. Close cube	Sign primary and orthogonal passes, data hashes, deviations and remeasurement obligations.
12. Advance by controlled route	Move to the next cube in the declared sequence. Any unscheduled change suspends acceptance until logged and rebaselined.

The recommended route is a boustrophedon or serpentine pass through one horizontal layer, followed by a perpendicular pass and then a reverse-path check. The operator does not skip “quiet” cubes because a visually unremarkable area may contain the control needed to interpret a later maximum. When a candidate is found, the team freezes the route and scene state, finishes the predeclared local control set and only then authorises subdivision. This mirrors the forensic principle of preserving transient or easily altered information before more intrusive action, while remaining entirely non-contact.

N.14 Per-cube physics behaviour vector

Spatial-measurement interpretation. The mature treatment of Per-cube physics behaviour vector replaces impressionistic searching with a coordinate-controlled experiment whose stations, axes, elevations, orientations, dwell periods, and movement events are fixed or explicitly recorded. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Table N-15. Required fields in the continuously updated cube physics ledger

Field group	Minimum content
Identity	Room, cube, surface cell, marker and acquisition IDs.
Position	Probe centre x, y, z; standoff; coordinate uncertainty; hard-point network revision.
Configuration	Probe/core/alloy lot, winding, tuning, preamplifier, receiver, filter, sample rate, reference clock, gain and bandwidth.
Frequency observables	Centre frequency, occupied bandwidth, drift, harmonics, subharmonics, sidebands, burst timing and family relationships.
Field observables	Calibrated or relative amplitude, vector component, polarisation, loop null, bearing, phase, coherence and gradient.
Noise and artefact state	Noise floor, overload margin, intermodulation checks, self-emission, cable movement and dummy-path result.
Temporal state	Start, stop, dwell, settling time, duty cycle, intermittency and relation to authorised source states.
Environment	Temperature, humidity if material, mains phase or frequency, HVAC, doors, lights, nearby transport, radio services and personnel.

Field group	Minimum content
Uncertainty	Amplitude, frequency, timing and coordinate components, expanded interval and limitations.
Classification	Observed signal through confirmed device-associated response, with the exact advancement rule satisfied or not satisfied.
Change linkage	Movement or state-change event IDs and mandatory before/after repeat set.
Closure	Examiner, reviewer, file hashes, deviations and unresolved actions.

N.15 Movement, action and change-control protocol

Movement is treated as an experimental intervention. Even a small motion can alter a magnetic return path, cable common-mode current, multipath field, probe orientation or shield aperture. Therefore, no person may move furniture, open a drawer, shift a cable, change a switch, adjust a blind, enter a neighbouring room or substitute equipment without a recorded change event. The event is assigned an identifier before the next accepted measurement. Affected cubes include the object's old and new volumes, the traversed path, adjacent cells, cells containing connected conductors and any reference cell whose background changed.

Three-dimensional search analysis. At expert-practitioner level, Movement, action and change-control protocol is a controlled sampling operation on a three-dimensional and potentially non-stationary field. The room, furniture, services, personnel, and instruments are therefore treated as elements of the measurement system. Every movement is treated as an intervention because it can alter shielding, common-mode current, reflection, magnetic reluctance, cable geometry, or the operator-coupling path; affected and control cells are remeasured before interpretation resumes. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Table N-16. Movement and state-change record

Field	Required entry
Change ID and authority	Unique event number, authorising person and reason.
Pre-change state	Object or system ID, coordinates, orientation, electrical/operating state and last valid acquisition.
Action	Person, tools, route, contact points, duration and any temporary equipment introduced.

Field	Required entry
Post-change state	New coordinates, orientation and operating state, with time.
Immediate observations	Transient signal, noise-floor shift, phase change, mechanical sound, thermal change or instrument disturbance.
Affected cube set	Old and new object cubes, route cubes, neighbouring cubes, connected-service cubes and controls.
Required repeats	Predeclared measurements, axes, dwell and controls to be repeated before interpretation.
Causal result	No material change, reversible change, persistent change, ambiguous change or invalidated baseline.
Closure	Examiner and reviewer signatures, file IDs and any unresolved limitation.

N.16 Search completion, independent review and release

Table N-17. Scene and cube closure checklist

Closure element	Release requirement
Access reconciliation	Every entry and exit, equipment item and temporary marker is accounted for.
Spatial closure	Hard-point distances, room dimensions, marker coordinates and furniture records reconcile within the declared tolerance.
Cube closure	Each required cube is complete, excluded with reason, or carried as an explicit limitation.
Path closure	Primary, perpendicular and reverse-path passes are completed for candidate sectors.
Change closure	Every movement event has its required repeat set and causal assessment.
Data closure	Files, timestamps, identifiers, hashes and configuration records reconcile.
Candidate closure	Each marker has a final classification, uncertainty and disposition.
Restoration	Authorised furniture and service states are restored or the final state is documented.
Independent review	A reviewer recalculates selected coordinates, checks material/probe configuration and verifies advancement criteria.
Release statement	The inspection manager states which areas, heights, bands and source states were examined and what remained inaccessible or unvalidated.

N.17 Ten worked spatial-control examples

Scene-geometry elaboration. For Ten worked spatial-control examples, the central evidential object is a spatially indexed field record, not an anecdotal statement that a signal became stronger near a particular article. Triangulation, trilateration, rectangular coordinates, orientation vectors, and redundant closure measurements are used to locate furniture, markers, probes, and candidate maxima with a stated uncertainty. The final location is expressed as a bounded region, vector field feature, or extended path with uncertainty, not as an image of an unseen object [1-9, 129-131].

Example N-1. Baseline establishment. HP-A and HP-B are measured 20.000 ft apart. The baseline length is. A repeat gives 20.006 ft. The mean is 20.003 ft and the half-range is 0.003 ft. The record uses with the applicable instrument uncertainty added, rather than silently selecting the first reading.

Example N-2. Locating a floor marker by two ranges. Let L = 20.000 ft, rA = 13.000 ft and rB = 15.000 ft. Then x = (13^2 - 15^2 + 20^2)/(2 x 20) = 8.600 ft. Next y = sqrt(13^2 - 8.6^2) = 9.751 ft. The two mathematical solutions are y = +9.751 ft and y = -9.751 ft. The room plan and third hard point resolve the valid side.

Example N-3. Third-point closure. Suppose HP- and the point from Example N-2 is.. If the measured rC is 10.092 ft, the closure residual is +0.014 ft. The acceptance decision compares 0.014 ft with the predeclared combined uncertainty.

Example N-4. Furniture orientation. Two points on the long edge of a cabinet are and. The orientation is. Recording only a single corner would not preserve this rotation.

Example N-5. Furniture displacement. Before movement, the cabinet reference point is (4.00,3.00,0.00) ft. After movement it is (4.50,3.75,0.00) ft. The displacement magnitude is. The old volume, new volume and traversed path are all included in the affected cube set.

Example N-6. Cube assignment. Let the room origin be (0,0,0) and the coarse cube side be Delta = 3 ft. A probe centre at (7.4,10.1,4.2) ft has indices i = floor(7.4/3) = 2, j = floor(10.1/3) = 3 and k = floor(4.2/3) = 1. Its identifier is therefore R01-X02-Y03-Z01, subject to the document's zero- or one-based indexing convention.

Example N-7. Three-dimensional point separation. Two candidate maxima are and. Their separation is. The separation is compared with the validated spatial resolution before the maxima are reported as distinct.

Example N-8. Spatial field gradient. A coherent 32.768 kHz metric rises from -108.0 dB at E1 to -102.0 dB at E2 over 4.24 in. The level gradient is 6.0 dB / 4.24. The report also states amplitude uncertainty, orientation and whether the receiver remained linear.

Example N-9. Coordinate uncertainty screening. Assume independent standard uncertainties, and. A conservative three-axis standard position uncertainty is. With coverage factor, the expanded value is, before adding hard-point or model residuals.

Example N-10. Remeasurement envelope after a change. A metal cabinet moves through cubes X02-Y03-Z00 and X03-Y03-Z00 and remains connected to a cable entering X04-Y03-Z00. The mandatory repeat set includes the two traversed cubes, the final cube, all face-adjacent cubes, the cable-path cube and the matched control cube. The team does not limit the repeat to the cabinet's final position because the movement may have altered the coupling path throughout the route.

HP-A and HP-B are measured 20. 000 ft apart. The baseline length is L=20. 000ft. A repeat gives 20. 006 ft. The mean is 20. 003 ft and the half-range is 0. 003 ft. The record uses L=20. 003ft with the applicable instrument uncertainty added, rather than silently selecting the first reading.

Before movement, the cabinet reference point is (4. 00, 3. 00, 0. 00) ft. After movement it is (4. 50, 3. 75, 0. 00) ft. The displacement magnitude is 0. 502+0.

752=0. 901ft. The old volume, new volume and traversed path are all included in the affected cube set.

A coherent 32.768 kHz metric rises from -108. 0 dB at E1 to -102. 0 dB at E2 over 4. 24 in. The level gradient is 6. 0 dB / 4. 24 in=1. 42dBperinchalongtheE1-to-E2vector. The report also states amplitude uncertainty, orientation and whether the receiver remained linear.

A metal cabinet moves through cubes X02-Y03-Z00 and X03-Y03-Z00 and remains connected to a cable entering X04-Y03-Z00. The mandatory repeat set includes the two traversed cubes, the final cube, all face-adjacent cubes, the cable-path cube and the matched control cube. The team does not limit the repeat to the cabinet's final position because the movement may have altered the coupling path throughout the route.

Field forms for immediate use

Table N-18. Access isolation and scene-control form

Field	Entry
Case / inspection ID	
Room / zone	
Boundary declared	
Control lead	
Entry route	
Start / end time	
Authorised personnel	
Personal electronics disposition	
Equipment staging inventory	
Deviations / stop events	

Table N-19. Room datum, hard-point and drawing-control form

Field	Entry
Room drawing ID and revision	
Origin O	
Axis convention	
HP-A / HP-B / HP-C descriptions	
Inter-hard-point closure results	
Room dimensions	
Furniture / service IDs	
Grid side and indexing rule	
Excluded areas	
Spatial recorder / reviewer	

Table N-20. Cube physics-ledger form

Field	Entry
Cube ID and physical bounds	
Centre x, y, z and uncertainty	
Surface / marker associations	
Probe and alloy configuration	
Receiver / clock / filter configuration	
Broadband result	
Priority-band result	
Axes / null / polarisation result	
Controls completed	
Environment and preceding change ID	
Classification and uncertainty	
Files / hashes / signatures	

Table N-21. Electromagnetic marker register

Field	Entry
Marker ID / type	
Room / cube / surface	
Marker coordinate and offset	
Probe centre and orientation	
Candidate frequency / family	
Classification	
First observed / last confirmed	
Associated file IDs	
Movement linkage	
Final disposition	

Appendix O. Regional Ring, Twenty-Seven-Cell, Vertical-Pair and Composite-Modulation Field Forms

These forms are minimum field records. They may be implemented on paper or within a validated digital system. Blank cells are not interpreted as negative findings. They are marked not measured, not applicable, excluded, unavailable, corrupted or pending review. Every electronic record is linked to a raw-file identifier and hash.

O.1 Regional annulus station form

Table O-1. Regional annulus station form

Field	Entry	Field	Entry
Case / commission		Date / UTC window	
Outer Rings	5 mi / 2.5 mi / 1 mi / 0.5 mi / 0.25 mi / 300 ft	Station ID	
Coordinates / CRS		Altitude / sensing height	
Authority / access basis		Missing sector or obstruction	
Pod and channel map		Antenna / probe family	
Reference clock		Calibration file	
Preselector / attenuation / gain		Bandwidth / sample rate / detector	
Dwell and trigger state		Sentinel IDs	
Environmental and local electronics state		Raw file / hash	
Observed features		Decision / reviewer	
Planned ring count / station ordinal		Nominal sector / actual azimuth	
Campaign segment / return iteration		Paper log book / page	
Equipment placement event ID		Previous and next station closure IDs	

O.2 Regional emitter inventory form

Table O-2. Regional emitter and confounder inventory

Field	Entry
Observation ID	
Centre frequency / uncertainty	
Occupied bandwidth	
Amplitude or field value / uncertainty	
Modulation or timing features	
Bearings and vertical tiers	
Sentinel coherence	
Known-source hypothesis and provenance	
Artefact controls	
Regional / neighbourhood / site-vicinity classification	
Advance / hold / close decision	
Raw files and hashes	

O.3 High-ground safety and coverage form

Table O-3. Safe high-ground planning and coverage record

Field	Entry	Field	Entry
Proposed elevated station		Maximum authorised height	
Access method		Competent person / approval	
Structural and fall risks		Electrical / RF / weather risks	
Probe support and cable configuration		Self-emission / microphonic blank	
Measured upper solid angle		Unmeasured cap and limitation	
Stop conditions		Final safe station used	

O.4 Room datum and module form

Table O-4. Room datum, dimensions and volumetric-module form

Field	Entry	Field	Entry
Room / space ID		Use / occupancy state	
Origin and axes		Coordinate reference / hard points	
Length / width / height		Wall, floor and ceiling construction	
Operational module dimensions		Module overlap	
Furniture and fixed-service drawing ID		Movement-event register ID	
Lower-space access		Upper-space / high-ground access	
Unmeasured volumes		Safety / privacy limits	

O.5 Twenty-seven-cell physics ledger

Table O-5. Twenty-seven-cell physics ledger

Cell	Centre coordinate	Probe / axis	Frequency / band	Value / uncertainty	Control result	File / decision
C(-1,-1,-1)						
C(+0,-1,-1)						
C(+1,-1,-1)						
C(-1,+0,-1)						
C(+0,+0,-1)						
C(+1,+0,-1)						
C(-1,+1,-1)						
C(+0,+1,-1)						
C(+1,+1,-1)						
C(-1,-1,+0)						
C(+0,-1,+0)						
C(+1,-1,+0)						
C(-1,+0,+0)						
C(+0,+0,+0)						
C(+1,+0,+0)						
C(-1,+1,+0)						
C(+0,+1,+0)						
C(+1,+1,+0)						
C(-1,-1,+1)						
C(+0,-1,+1)						
C(+1,-1,+1)						
C(-1,+0,+1)						
C(+0,+0,+1)						
C(+1,+0,+1)						
C(-1,+1,+1)						

Cell	Centre coordinate	Probe / axis	Frequency / band	Value / uncertainty	Control result	File / decision
C(+0,+1,+1)						
C(+1,+1,+1)						

O.6 Opposite-surface and vertical-pair form

Table O-6. Opposite-surface and vertical-pair record

Field	Entry
Pair ID	
Primary cell / surface	
Opposite or vertical comparison	
Wall / slab / void thickness	
Primary coordinate and standoff	
Paired coordinate and standoff	
Matched probe and settings	
Time difference / sentinel correction	
Amplitude, phase, null and gradient comparison	
Depth or extended-path interpretation	
Limitations and inaccessible volume	
Raw files / hashes / reviewer	

O.7 Spherical or ellipsoidal shell record

Table O-7. Radial shell and coverage record

Field	Entry
Candidate centre and uncertainty	
Shell or ellipsoid identifier	
Nominal radius or semi-axes	
Measured face / edge / corner directions	
Upper and lower coverage	
Missing solid angle	
Actual point ranges	
Media crossed	
Fit residual / descriptive model	
Interpretive limitation	

O.8 Composite-modulation layer record

Table O-8. Multilayer composite-modulation analysis form

Field	Entry	Field	Entry
Observation / case ID		Ring / station / cell	
Raw I/Q file and hash		Channel map / time base	
Layer 0 host		Frequency / bandwidth / duty cycle	
Layer 1 process		Extraction method / uncertainty	
Layer 2 process		Pulse positions / cyclic features	
Layer 3 process		Sparse gate / illumination relation	
Envelope result		Phase / instantaneous-frequency result	
Cyclostationary result		Cross-channel coherence	
Artefact controls		Independent confirmation	
Classification / bounded conclusion		Reviewer	

O.9 Illumination trigger and delay-iteration form

Table O-9. Illumination trigger and response-delay iteration

Trial	Illumination	Trigger epoch	Delay	Gate	Response	Controls
01						
02						
03						
04						
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						
15						
16						

O.10 Movement and intervention form

Table O-10. Movement and experimental-intervention ledger

Field	Entry
Event ID	
Person / authority	
Start and finish time	
Object, door, cable or equipment changed	
Original coordinates and state	
Final coordinates and state	
Cells and paired surfaces affected	
Before, during and after files	
Sentinel state	
Result and interpretation	

O.11 Regional-to-site advancement checklist

Table O-11. Regional-to-site advancement checklist

Gate	Status	Record
R1 recurrence or justified dwell satisfied	Yes / No / N.A.	Evidence ID
R2 mobile change exceeds uncertainty and sentinel correction	Yes / No / N.A.	Evidence ID
R3 multiple bearings, heights or polarisations support geometry	Yes / No / N.A.	Evidence ID
R4 receiver artefact and overload controls passed	Yes / No / N.A.	Evidence ID
R5 reason for 300-foot examination documented	Yes / No / N.A.	Evidence ID
R6 prescribed station counts completed, or incomplete coverage expressly authorised	Yes / No / N.A.	Count / gap record
R7 contemporaneous paper log reconciled to digital events and movement records	Yes / No / N.A.	Book / page / audit ID
R8 sentinel continuity and return-closure checks completed	Yes / No / N.A.	Evidence ID
Authorised reviewer decision	Advance / Hold / Close	Signature / time

O.12 Regional station-density planning and completion form

Table O-12. Regional station-density planning and completion record

Ring	Required or preferred count	Actual count and station IDs	Missing sectors, substitutions and approval
5 miles	16 ordinary; 24 high risk		
2.5 miles	16 ordinary; 24 high risk		
1 mile	16 ordinary; 24 high risk		
0.5 mile	12 preferred; minimum 8, 16 high risk		
0.25 mile	12 preferred; minimum 8, 16 high risk		
300 feet	Per field plan; eight or more preferred, 16 high risk		

O.13 Campaign chronology and intermission-monitoring form

Table O-13. Field segment, intermission and sentinel chronology

Phase or segment	Start and stop UTC	Field-team and sentinel status	Data, custody and return-closure record
Planning and issue			
Field segment A			
Intermission 1			
Field segment B			
Intermission 2			
Field segment C			
Extended continuation			

O.14 Contemporaneous paper-log and movement reconciliation

Table O-14. Paper record, digital event and movement reconciliation

Event ID	Paper book, page, UTC and initials	Digital file, channel set and hash	Movement, setting change, decision or discrepancy

O.15 Sub-20 Hz Station Record

Complete contemporaneously at every station where the sub-20 Hz workstream is active. Attach raw-data identifiers, calibration records, site sketch and photographs or non-imaging coordinate drawings as authorised.

Field	Entry
Project / station / ring / cell identifier	
Date, UTC start, UTC stop and observer	
Surveyed coordinates, elevation, orientation and standoff	
Supported lower frequency based on actual observation duration	
Pressure sensor, serial number, port and wind-reduction configuration	
Motion sensors, axes, mount and surface	
Electric-field sensors, axes, guard and exclusion distance	
Magnetic sensors, axes, range and degauss / zero status	
Sample rate, filter, gain, ADC, card and channel assignments	
Master-clock and loopback status	
Weather, wind, pressure, temperature, humidity and building state	
Personnel, vehicles, doors, lifts, HVAC and machine events	
Candidate features by domain, frequency, amplitude and uncertainty	

Field	Entry
Control channels and control-test result	
Raw file, metadata file, hash and evidence record	
Examiner conclusion and limitations	

O.16 Multiphysics Sensor and Calibration Record

Channel	Domain / sensor	Serial / axis	Cal. / date	Noise / drift	Status
1					
2					
3					
4					
5					
6					
7					
8					
9					
10-44 continued on attached channel sheet					

O.17 Cross-Domain Coherence and Source-Discrimination Record

ID	f / band	P	Motion	E	B	Ctl.	Model

O.18 Symptom-Report Separation and Medical-Referral Record

This form does not diagnose or attribute symptoms. Engineering identifiers shall be neutral and, where practicable, primary signal screening shall be completed before symptom details are disclosed to the analyst.

Field	**Entry**
Clinical record custodian and authority	
Neutral symptom-event identifier	
Reported time interval and clock uncertainty	
Location and activity, recorded without causal wording	
Engineering data interval preserved	
Analyst blinded during primary screening, yes/no and method	
Candidate physical events frozen before unblinding	
Sham / control periods	
Temporal comparison method and multiple-comparison control	
Medical referral or emergency medical action	
Permitted engineering conclusion	
Prohibited causal conclusion expressly avoided	

O.19 Diplomatic-Site and Anomalous-Health-Incident Evidence-Boundary Checklist

Control question	Yes / no / not applicable	Evidence or limitation
Current official AHI assessment reviewed and dated		
Symptoms treated as real and clinically significant without presuming mechanism		
Sub-20 Hz domains measured separately		
Exterior and regional controls present		
Analyst blinding used where practicable		
Sham or source-absent intervals included		
Instrument and expectation artefacts tested		
No frequency-to-symptom lookup table used		
No actor, weapon or medical-cause attribution made without external evidence		
Independent technical review completed		
Clinical referral and privacy requirements satisfied		

The following integration extends O.19 Diplomatic-Site and Anomalous-Health-Incident Evidence-Boundary Checklist with health-incident evidence, exposure hypotheses, and causal restraint. It is positioned here because the source material clarifies the mechanism, observables, uncertainty, and validation controls needed to interpret the surrounding doctrine without changing its lawful-use boundary.

Health-Incident Evidence, Exposure Hypotheses, and Causal Restraint

The measurement problem for Retrospective-study limitations begins with observability. The desired conclusion is rarely measured directly. Instead, the examiner records latency, missing records, participation rate, measurement timing, control selection, and analytic flexibility. Those observables are conditioned by bandwidth, sampling, detector law, geometry, configuration, and environmental state. A defensible procedure preserves raw data and the transformation from raw data to the reported metric, including corrections, averaging, interpolation, and thresholds. It also records the reference plane and the time at which the configuration was valid. The dominant practical threats are survivorship bias, multiple testing, post hoc subgrouping, expectation effects, and unmeasured confounders. Because these effects may mimic the expected response, the field procedure should include deliberate state changes and comparative measurements rather than a single static reading.

The result must be expressed as a bounded estimate or discriminating observation, with enough metadata for an independent examiner to reproduce the calculation and challenge the interpretation. In this placement, that control is applied specifically to retrospective-study limitations within health-incident evidence, exposure hypotheses, and causal restraint, with the local volume retaining ownership of the final inference.

Uncertainty analysis for Exposure reconstruction must include both numerical error and model uncertainty. Numerical uncertainty arises from calibration, resolution, repeatability, positioning, timing, and noise; model uncertainty arises when the wrong source, path, boundary condition, or causal mechanism has been assumed. Relevant failure mechanisms include no contemporaneous sensor data, unknown source, spatial mismatch, implausible power budget, and incomplete occupancy records. A specialist report distinguishes random variation, systematic bias, and epistemic uncertainty, then shows which term dominates the conclusion. Sensitivity analysis should test whether a plausible change in an uncertain input reverses the decision or merely changes its margin. Where the evidence supports several explanations, the report should retain competing hypotheses and state what additional observation would discriminate among them.

This is preferable to burying uncertainty in a generic caveat, because decision makers need to know whether confidence is limited by instrument performance, missing access, incomplete source material, or a fundamentally nonunique inverse problem. In this placement, that control is applied specifically to exposure reconstruction within health-incident evidence, exposure hypotheses, and causal restraint, with the local volume retaining ownership of the final inference.

This integrated treatment returns the discussion to O.19 Diplomatic-Site and Anomalous-Health-Incident Evidence-Boundary Checklist with the evidentiary chain made explicit: source, configuration, measurement, correction, uncertainty, competing explanation, and conclusion remain independently reviewable.

Expert Specialist Synthesis, Formal Model, and Research Problems

Prerequisite structure and problem formulation

The governing problem is represented as a discretised forward operator A(m,g,ω)j=b with measured data y=Cj+n, where model parameters, geometry, material properties, and receiver calibration are uncertain. Before calculation or interpretation, the analyst must declare the system boundary, observables, unknowns, admissible interventions, temporal interval, and decision loss. Terms that appear familiar in ordinary practice are therefore treated as model components with explicit scope. The specialist reader must be able to explain which assumptions are constitutive, which are approximations, and which are merely convenient defaults.

$Core$relation: $\hat{j} = \mathrm{argmin}_j \| W(y - CAj) \|^2 + \lambda^2 \| Lj \|^2$ (97)

Mechanism, observables, and inferential warrant. The central mechanism is that basis selection, mesh geometry, boundary truncation, Green-function choice, conditioning, regularisation, and measurement operator mismatch determine whether a numerical result represents physics or merely the discretisation. A valid report separates the observation produced by an instrument, document, witness, or process from the latent state the analyst seeks to infer. It also identifies the warrant connecting them. Compatibility is not uniqueness; correlation is not mechanism; and numerical convergence is not proof that the model represents the system.

Uncertainty, validation, and adversarial alternatives. The minimum validation programme includes mesh refinement, residual norms, condition-number monitoring, manufactured solutions, reciprocity, conservation checks, uncertainty propagation, and comparison with controlled measurements. The analyst should formulate at least one benign alternative, one methodological artefact, one data-quality failure, and one adversarial explanation. The conclusion should state which alternatives were tested, which were only bounded, and which remain non-identifiable. Uncertainty should be propagated through the actual decision quantity rather than listed as disconnected instrument specifications.

Research-level application. Graduate research problem: solve a deliberately ill-conditioned inverse source problem under two regularisers, compare bias and variance, and identify which apparent spatial feature is stable under mesh, noise, and prior perturbations. The submission should include assumptions, derivation or model structure, raw or simulated data, code or calculation record, uncertainty budget, residual analysis, and a concise expert conclusion whose strength is proportional to the evidence.

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[55] Author-supplied file, TSCM101bugfreq.html, historical low-level frequency table and SAW-rich UHF search regions, Version 13 May 2026.

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[77] Cybersecurity and Infrastructure Security Agency, Statement of Project 25 User Needs, March 2025, and current P25 resources. Used for current standards context and public-safety interoperability scope.

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[82] IEEE Std 802.11be-2024, Enhancements for Extremely High Throughput, and current corrigenda or amendments.

[83] IEEE Std 802.11bf-2025, Enhancements for Wireless LAN Sensing; and IEEE Std 802.11bk-2025, 320 MHz Positioning.

[84] IEEE Std 802.11ba-2021, Wake-Up Radio Operation; IEEE Std 802.11bb-2023, Light Communications; and IEEE Std 802.11bd-2022, Next Generation V2X.

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[88] 3GPP TS 45-series GSM/EDGE radio-access specifications, current and historical releases applicable to the case.

[89] 3GPP TS 25-series UTRA specifications, 3GPP2 cdma2000 specifications and regional 2G/3G standards archives.

[90] 3GPP TS 36-series E-UTRA/LTE and TS 38-series NR specifications, including current band, RF, protocol and power-saving provisions.

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[94] Connectivity Standards Alliance, Zigbee and Matter specifications; Thread Group specifications; and Wi-SUN Alliance field-area-network profiles.

[95] LoRa Alliance LoRaWAN specifications and regional parameter documents; ETSI and national SRD rules for corresponding bands.

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[98] Wireless Power Consortium Qi specifications and AirFuel Alliance specifications, subject to current access and jurisdictional controls.

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[100] USB Implementers Forum, USB Type-C Cable and Connector Specification Release 2.5, published April 2026.

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[109] NXP I2C-bus specification, System Management Bus specifications, PMBus specifications and JEDEC serial-memory interface standards.

[110] ISO 11898 CAN family, SAE J2602 LIN, FlexRay, MOST, SENT, PSI5 and IEEE 802.3 automotive Ethernet specifications.

[111] IEC 61158 and IEC 61784 industrial-communication networks and profiles, together with protocol-organisation specifications for PROFIBUS, PROFINET, EtherCAT and EtherNet/IP.

[112] ASHRAE Standard 135 BACnet, KNX specifications, IEC 62386 DALI, FieldComm HART and FOUNDATION Fieldbus specifications.

[113] MIL-STD-1553, ARINC Specifications 429 and 664, SpaceWire standards and other authorised avionics or military bus specifications.

[114] ITU-T V-series modem, G-series transport and G.hn recommendations; applicable TIA/ETSI telephony, ISDN and digital-carrier standards.

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[116] Infrared Data Association specifications, IEEE 802.11bb optical WLAN standard and applicable IEC optical-safety requirements.

[117] UEFI Forum, Advanced Configuration and Power Interface Specification, current edition, for system power-state terminology and wake mechanisms.

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Historical Frequency Register Integration

Role: EMSEC, EMI, EMC, and coupling control

The frequencies are analysed as possible fundamentals, references, harmonics, intermodulation products, or conducted emissions, with shielding, grounding, bonding, cable geometry, and equipment state treated as causal variables.

Relationship to electronic-emission and resonance forensics. The frequency register extends the EERF framework by supplying a large historical population against which clock families, resonances, harmonics, conducted carriers, and receiver artifacts can be tested. It does not convert resonance-family reasoning into device attribution; rather, it provides a controlled set of hypotheses that must survive the same passive-first, correlation, and localization requirements developed in this volume.

Controlled cross-reference. No individual frequency record is duplicated into this volume because its subject does not require a primary frequency-by-frequency treatment. This is an editorial control, not an omission: all 3,098 identifiers remain accessible in Volume 38 and in Volumes 81-83, while the thematic volumes carrying individual treatments are listed in the series index.

Chapter Glossary

Terms used in Chapter 43.

C

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

M

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

MIXER — In radar, a circuit that combines the received RF signal with a local-oscillator signal to effectively convert the received signal to a lower IF frequency signal.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

R

RCS — Radar cross section: an equivalent area used to describe the scattering strength of a target for a specified frequency, polarization, aspect, and geometry.

REFERENCE PLANE — The physical or mathematical location at which a signal, impedance, power, field, or calibration quantity is defined.

V

VOLTAGE — (1) The term used to signify electrical pressure. Voltage is a force that causes current to flow through an electrical conductor.

Volume Glossary

The following definitions consolidate the principal technical vocabulary used in this volume.

A

ACCELEROMETER — A device that measures the acceleration to which it is subjected and develops a signal proportional to it.

ALIASING — The indistinguishable mapping of different continuous-time frequencies to the same sampled representation when the sampling process is insufficiently constrained.

AMPLITUDE — The size of a signal as measured from a reference line to a maximum value above or below the line. Generally used to describe voltage, current, or power.

AMPLITUDE MODULATION — Any method of varying the amplitude of an electromagnetic carrier frequency in accordance with the intelligence to be transmitted.

ANGLE MODULATION — Modulation in which the angle of a sine-wave carrier is varied by a modulating wave.

ANOMALY — An observation that differs from a defined baseline or expected model; an anomaly is not, by itself, a hostile finding.

ANTENNA — A transducer that couples guided electrical energy to radiated electromagnetic fields, or converts incident electromagnetic fields into guided electrical energy.

ATTENUATION — The ability of a filter circuit to reduce the amplitude of unwanted frequencies to a level below that of the desired output frequency.

AUTOMATIC GAIN CONTROL — A circuit used to vary radar receiver gain for best reception of signals that have widely varying amplitudes.

B

BANDWIDTH — The frequency interval over which a signal, instrument, circuit, or system satisfies stated criteria.

BASELINE — A documented reference condition against which later observations, measurements, or configurations are compared.

BEARING — An angular direction from a defined reference meridian or axis to a source, target, or line of sight.

C

CABLE — Either a stranded conductor (single-conductor cable) or a combination of conductors insulated from one another (multiple conductor cable). Small sizes are commonly referred to as stranded wire or as cords.

CALIBRATION — A documented comparison that relates an instrument or measurement system to a reference of known value and uncertainty under stated conditions.

CAPACITANCE — The property of an electrical circuit that opposes changes in voltage.

CARRIER FREQUENCY — The frequency of an unmodulated transmitter output.

CHAIN OF CUSTODY — The documented history of possession, handling, transfer, storage, examination, and disposition of an item of evidence.

COHERENCE — A measure of stable phase or statistical relationship between signals, observations, or fields over a defined interval and bandwidth.

COMMON-MODE CURRENT — Current that flows in the same direction on multiple conductors relative to a common reference or surrounding structure.

COUPLING PATH — The physical route by which energy transfers from a source to a victim, structure, conductor, sensor, or observer.

CURRENT — The movement of electrons past a reference point. The passage of electrons through a conductor.

D

DECISION THRESHOLD — A declared criterion that separates actions or classifications. It must be tied to the measured quantity, uncertainty, costs of error, and authority.

DEMODULATION — The removal of intelligence from a transmission medium.

DETECTION — The separation of low-frequency (audio) intelligence from the high-frequency carrier.

DETECTION LIMIT — The smallest quantity or signal that can be distinguished from background with a stated probability of detection and false-alarm performance.

DIRECTION FINDING — The estimation of the direction of arrival of a signal from measured amplitude, phase, time, polarization, pattern, or spatial-correlation differences.

DISPLACEMENT CURRENT — The current that appears to flow through a capacitor.

DUTY CYCLE — In a transmitter, ratio of time on to time off.

DYNAMIC RANGE — The span between the smallest and largest input levels that a system can process while meeting specified performance criteria.

E

EFFECTIVE APERTURE — The equivalent area that relates incident power density to the available received power of an antenna for a specified polarization and direction.

ELECTROMAGNETIC FIELD — The combination of an electric (E) field and a magnetic (H) field.

EMC — Electromagnetic compatibility: the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable disturbance to other systems.

ENVIRONMENTAL BASELINE — A time-, place-, configuration-, and instrument-specific model of ordinary signals, noise, occupancy, and infrastructure behaviour.

EVIDENCE — Information or material offered to support or refute a proposition, evaluated with regard to relevance, integrity, provenance, uncertainty, and alternative explanations.

EXTREMELY LOW FREQUENCY — The band of frequencies up to 300 hertz.

F

FERROMAGNETIC MATERIAL — A highly magnetic material, such as iron, cobalt, nickel, or their alloys.

FILTER — A selective network of resistors, capacitors, and inductors that offers comparatively little opposition to certain frequencies, while blocking or attenuating other frequencies.

FLUX DENSITY — The number of magnetic lines of force passing through a given area.

FUNDAMENTAL FREQUENCY — The basic frequency or first harmonic frequency.

G

GAIN — (1) The ratio between the amount of energy propagated from an antenna that is directional compared to the energy from the same antenna that would be propagated if the antenna were not directional. (2) Any increase in the strength of a signal.

H

HARMONIC — A sinusoidal component whose frequency is an integer multiple of a fundamental frequency.

HASH — A fixed-length value produced by a deterministic function and used to detect whether digital content has changed.

HYSTERESIS LOSS — The power loss in an iron-core transformer or other alternating-current device as a result of magnetic hysteresis.

I

IMPEDANCE — The complex ratio of voltage to current at a stated frequency and reference plane, including both resistive and reactive components.

INDUCED VOLTAGE — See INDUCED ELECTROMOTIVE FORCE.

INDUCTANCE — The property of a circuit that tends to oppose a change in the existing current flow. The symbol for inductance is L.

INTERMODULATION — The production of new frequency components when two or more signals interact in a nonlinear device or junction.

L

LINE OF SIGHT — Straight line from a radar antenna to a target.

LOAD MODULATION — Variation of an electrical load that changes current, voltage, reflection coefficient, or scattering and can thereby impress information on another signal.

LOOP — A curved conductor that connects the ends of a coaxial cable or other transmission line and projects into a waveguide or resonant cavity for the purpose of injecting or extracting energy.

LOW FREQUENCY — The band of frequencies from 30 kHz to 300 kHz.

M

MAGNETIC FIELD — (1) The region in which the magnetic forces created by a permanent magnet or by a current-carrying conductor or coil can be detected. (2) The field that is produced when current flows through a conductor or antenna.

MAGNETIC INDUCTION — Generating a voltage in a circuit by the creation of relative motion between a magnetic field and the circuit. The relative motion can be the result of physical movement or the rise and fall of a magnetic field created by a changing current.

MEASURAND — The quantity intended to be measured, defined with sufficient specificity that the result, method, reference plane, bandwidth, and environmental conditions are unambiguous.

MEASUREMENT UNCERTAINTY — A nonnegative parameter that characterizes the dispersion of quantity values reasonably attributable to a measurand under a stated measurement model.

METROLOGICAL TRACEABILITY — The property of a measurement result by which it can be related to a reference through a documented, unbroken chain of calibrations, each contributing to measurement uncertainty.

MICROPHONE — An energy converter that changes sound energy into electrical energy.

MIXER — In radar, a circuit that combines the received RF signal with a local-oscillator signal to effectively convert the received signal to a lower IF frequency signal.

MODULATION — The process of impressing intelligence upon a transmission medium, such as radio waves.

MODULATION INDEX — The ratio of frequency deviation to the frequency of the modulating signal.

N

NLJD — Nonlinear junction detector: an instrument that illuminates a search area with radio-frequency energy and observes harmonic or intermodulation responses associated with nonlinear junctions.

NOISE FIGURE — The degradation of signal-to-noise ratio caused by a device or system, expressed relative to an ideal noiseless reference at a standard temperature.

NONLINEAR JUNCTION — An electrical contact or material interface whose current-voltage relationship is nonlinear and can therefore generate harmonics, intermodulation products, rectification, or load-modulated responses.

O

OSCILLATOR — An oscillator is a nonrotating device that produces alternating current. The frequency is determined by the characteristics of the device.

P

PHASE NOISE — Random short-term variation in the phase of an oscillator or signal, commonly represented as spectral density relative to the carrier.

POLARIZATION — The time-varying orientation and trajectory of the electric-field vector at a point in space.

PRIMARY WINDING — The winding of a transformer connected to the electrical source.

PROPAGATION — Waves traveling through a medium.

PULSE-POSITION MODULATION (PPM) — Pulse modulation in which the position of the pulses is varied by the modulating voltage.

R

RADAR — Radio detection and ranging: the use of transmitted electromagnetic energy and received echoes or scattered signals to detect, locate, characterize, or track objects and phenomena.

RADAR CROSS SECTION — A directional and frequency-dependent measure of how strongly a target scatters incident electromagnetic energy toward a specified observation direction.

RADIATION PATTERN — A plot of the radiated energy from an antenna.

RCS — Radar cross section: an equivalent area used to describe the scattering strength of a target for a specified frequency, polarization, aspect, and geometry.

RECEIVER — (1) The object that responds to the wave or disturbance. Same as DETECTOR.

REFERENCE PLANE — The physical or mathematical location at which a signal, impedance, power, field, or calibration quantity is defined.

RESISTANCE — (1) The opposition a device or material offers to the flow of current. The effect of resistance is to raise the temperature of the material or device carrying the current.

RESOLUTION BANDWIDTH — The effective bandwidth of the intermediate-frequency or digital filter used to resolve spectral components in a receiver or analyzer.

RESONANCE — The condition in a circuit containing inductance and capacitance in which the inductive reactance is equal and opposite to the capacitive reactance. This condition occurs at only one frequency and the circuit in that condition is said to be in resonance.

RMS — Abbreviation of root mean square.

S

SDR — Software-defined radio: a programmable radio architecture in which tuning, filtering, demodulation, analysis, or related functions are implemented digitally.

SIGNAL-TO-NOISE RATIO — The ratio of signal power to noise power measured at a stated reference point and within a stated bandwidth.

SLANT RANGE — See RANGE.

SNR — Signal-to-noise ratio: signal power divided by noise power at a stated reference plane and bandwidth.

SPECTRUM ANALYSIS — The display of electromagnetic energy arranged according to wavelength or frequency.

SUSCEPTIBILITY — The degree to which equipment or a system is adversely affected by electromagnetic, electrical, acoustic, optical, mechanical, or environmental exposure.

T

TEST EQUIPMENT — A general term applied to devices used to test electrical and electronic circuits.

TRANSFER IMPEDANCE — A frequency-dependent measure relating current on one side of a cable shield or enclosure boundary to the voltage developed on the other side.

TRANSMISSION LINE — A device designed to guide electrical or electromagnetic energy from one point to another.

TRANSMITTER — Equipment that generates and amplifies an RF carrier, modulates the RF carrier with intelligence, and radiates the signal into space.

TSCM — Technical surveillance countermeasures: lawful defensive activity used to identify, assess, mitigate, and document technical surveillance risks.

U

UNCERTAINTY BUDGET — A documented set of significant uncertainty contributions, their distributions, sensitivity coefficients, correlations, and combination method.

V

VALIDATION — The demonstration that a method, model, process, or system is suitable for its intended use under specified conditions.

VERIFICATION — The confirmation, through examination or objective evidence, that specified requirements have been fulfilled.

VERY LOW FREQUENCY — The band of frequencies from 3 kilohertz to 30 kilohertz.

VOLTAGE — (1) The term used to signify electrical pressure. Voltage is a force that causes current to flow through an electrical conductor.

W

WAVELENGTH — The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

Volume Subject Index

Entries identify the chapters in which each term receives its principal treatment. Underlined chapter locators are live links.

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