

## RECEIVER SENSITIVITY / NOISE

### RECEIVER SENSITIVITY

Sensitivity in a receiver is normally taken as the minimum input signal ( $S_{\min}$ ) required to produce a specified output signal having a specified signal-to-noise (S/N) ratio and is defined as the minimum signal-to-noise ratio times the mean noise power, see equation [1]. For a signal impinging on the antenna (system level) sensitivity is known as minimum operational sensitivity (MOS), see equation [2]. Since MOS includes antenna gain, it may be expressed in dBLi (dB referenced to a linear isotropic antenna). When specifying the sensitivity of receivers intended to intercept and process pulse signals, the minimum pulse width at which the specified sensitivity applies must also be stated. See the discussion of post-detection bandwidth ( $B_V$ ) in Section 5-2 for significance of minimum pulsewidth in the receiver design.

$$S_{\min} = (S/N)_{\min} k T_o B (NF) \quad \text{receiver sensitivity ("black box" performance parameter)} \quad [1]$$

or

$$\text{MOS} = (S/N)_{\min} k T_o B (NF) / G \quad \text{system sensitivity i.e. the receiver is connected to an antenna} \quad [2]$$

(transmission line loss included with antenna gain)

where:

$S/N_{\min}$	=	Minimum signal-to-noise ratio needed to <u>process</u> (vice just detect) a signal
NF	=	Noise figure/factor
k	=	Boltzmann's Constant = $1.38 \times 10^{-23}$ Joule/°K
$T_o$	=	Absolute temperature of the receiver input (°Kelvin) = 290°K
B	=	Receiver Bandwidth (Hz)
G	=	Antenna/system gain

We have a lower MOS if temperature, bandwidth, NF, or  $S/N_{\min}$  decreases, or if antenna gain increases. For radar, missile, and EW receivers, sensitivity is usually stated in dBm. For communications and commercial broadcasting receivers, sensitivity is usually stated in micro-volts or dB $\mu$ v. See Section 4-1.

There is no standard definition of sensitivity level. The term minimum operational sensitivity (MOS) can be used in place of  $S_{\min}$  at the system level where aircraft installation characteristics are included. The "black box" term minimum detectable signal (MDS) is often used for  $S_{\min}$  but can cause confusion because a receiver may be able to detect a signal, but not properly process it. MDS can also be confused with minimum discernable signal, which is frequently used when a human operator is used to interpret the reception results. A human interpretation is also required with minimum visible signal (MVS) and tangential sensitivity (discussed later). To avoid confusion, the terms  $S_{\min}$  for "black box" minimum sensitivity and MOS for system minimum sensitivity are used in this section. All receivers are designed for a certain sensitivity level based on requirements. One would not design a receiver with more sensitivity than required because it limits the receiver bandwidth and will require the receiver to process signals it is not interested in. In general, while processing signals, the higher the power level at which the sensitivity is set, the fewer the number of false alarms which will be processed. Simultaneously, the probability of detection of a "good" (low-noise) signal will be decreased.

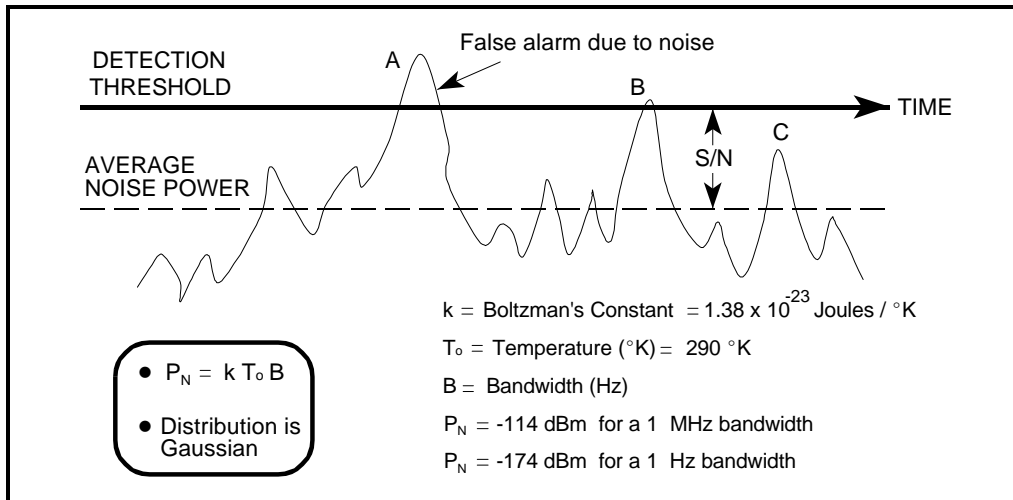
Sensitivity can be defined in two opposite ways, so discussions can frequently be confusing. It can be the ratio of response to input or input to response. In using the first method (most common in receiver discussions and used herein), it will be a negative number (in dBm), with the more negative being "better" sensitivity, e.g. -60 dBm is "better" than -50 dBm sensitivity. If the second method is used, the result will be a positive number, with higher being "better." Therefore the terms low sensitivity or high sensitivity can be very confusing. The terms  $S_{\min}$  and MOS avoid confusion.

### SIGNAL-TO-NOISE (S/N) RATIO

The Signal-to-Noise Ratio (S/N) (a.k.a. SNR) in a receiver is the signal power in the receiver divided by the mean noise power of the receiver. All receivers require the signal to exceed the noise by some amount. Usually if the signal power is less than or just equals the noise power it is not detectable. For a signal to be detected, the signal energy plus the

noise energy must exceed some threshold value. Therefore, just because N is in the denominator doesn't mean it can be increased to lower the MOS. S/N is a required minimum ratio, if N is increased, then S must also be increased to maintain that threshold. The threshold value is chosen high enough above the mean noise level so that the probability of random noise peaks exceeding the threshold, and causing false alarms, is acceptably low.

Figure 1 depicts the concept of required S/N. It can be seen that the signal at time A exceeds the S/N ratio and indicates a false alarm or target. The signal at time B is just at the threshold, and the signal at time C is clearly below it. In the sample, if the temperature is taken as room temperature ( $T_o = 290^\circ\text{K}$ ), the noise power input is -114 dBm for a one MHz bandwidth. Normally  $S/N_{\text{min}}$  may be set higher than S/N shown in Figure 1 to meet false alarm specifications.



**Figure 1.** Receiver Noise Power at Room Temperature

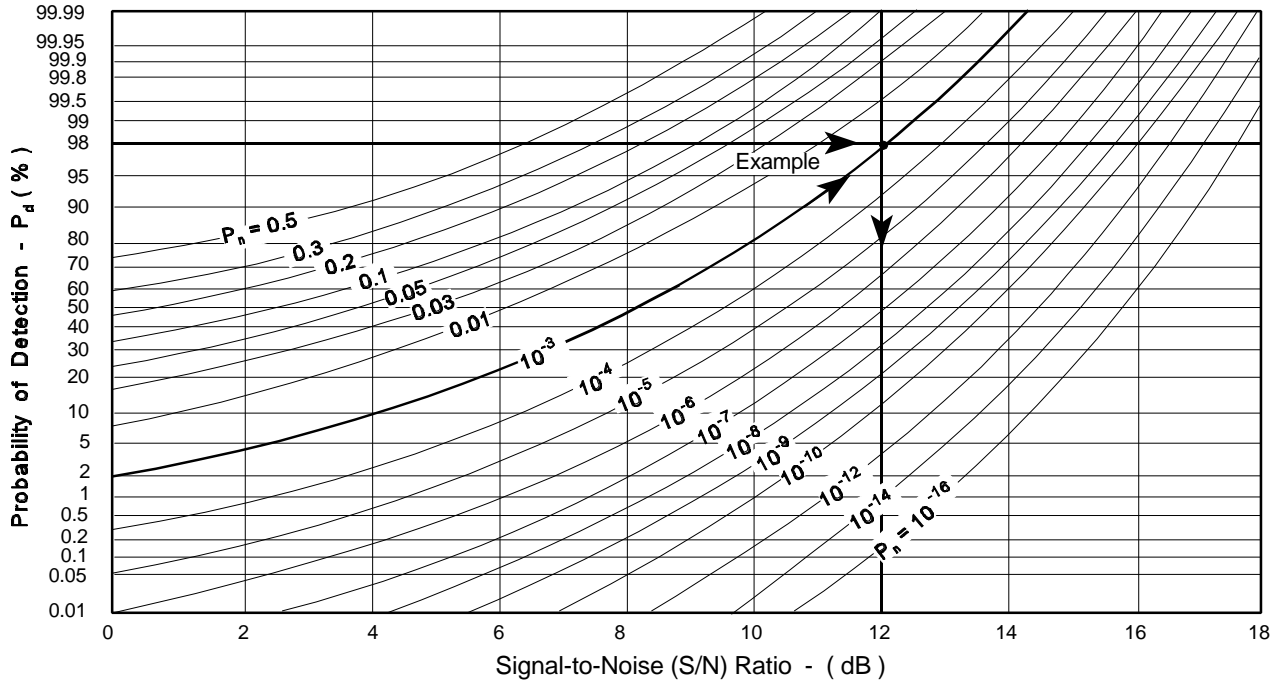
The acceptable minimum Signal-to-Noise ratio (or think of it as Signal **above** Noise) for a receiver depends on the intended use of the receiver. For instance, a receiver that had to detect a single radar pulse would probably need a higher minimum S/N than a receiver that could integrate a large number of radar pulses (increasing the total signal energy) for detection with the same probability of false alarms. Receivers with human operators using a video display may function satisfactorily with low minimum S/N because a skilled operator can be very proficient at picking signals out of a noise background. As shown in Table 1, the setting of an acceptable minimum S/N is highly dependant on the required characteristics of the receiver and of the signal.

Table 1. Typical Minimum S/N Required				
Skilled Operator	Auto-Detection	Auto-detection with Amplitude, TOA, and Frequency Measurements	AOA Phase Interferometer	AOA Amplitude Comparison
3 to 8 dB	10 to 14 dB	14 to 18 dB	14 to 18 dB	16 to 24 dB

A complete discussion of the subject would require a lengthy dissertation of the probability and statistics of signal detection, which is beyond the scope of this handbook, however a simplified introduction follows. Let's assume that we have a receiver that we want a certain probability of detecting a single pulse with a specified false alarm probability. We can use Figure 2 to determine the required signal-to-noise ratio.

S/N EXAMPLE

If we are given that the desired probability of detecting a single pulse ( $P_d$ ) is 98%, and we want the false alarm rate ( $P_n$ ) to be no more than  $10^{-3}$ , then we can see that S/N must be 12 dB (see Figure 2).



**Figure 2.** Nomograph of Signal-to-Noise (S/N) Ratio as a Function of Probability of Detection ( $P_d$ ) and Probability of False Alarm Rate ( $P_n$ )

**MAXIMUM DETECTION RANGE (ONE-WAY)**

From Section 4-3, the one way signal strength from a transmitter to a receiver is:  $S \text{ (or } P_R) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 R^2}$

For calculations involving receiver sensitivity the "S" can be replaced by  $S_{min}$ . Since  $S_{min} = (S/N)_{min} kT_o B(NF)$ , given by equation [1], the one-way radar equation can be solved for any of the other variables in terms of receiver parameters. In communication, radar, and electronic warfare applications, you might need to solve for the maximum range ( $R_{max}$ ) where a given radar warning receiver could detect a radiated signal with known parameters. We would then combine and rearrange the two equations mentioned to solve for the following one-way equation:

$$R_{max} \cong \sqrt{\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 (S/N)_{min} kT_o B(NF)}} \quad \text{or} \quad \sqrt{\frac{P_t G_t G_r c^2}{(4\pi f)^2 (S/N)_{min} kT_o B(NF)}} \quad \text{or} \quad \sqrt{\frac{P_t G_t A_e}{4\pi (S/N)_{min} kT_o B(NF)}} \quad [3]$$

We could use standard room temperature of 290° K as  $T_o$ , but NF would have to be determined as shown later.

In this calculation for receiver  $R_{max}$  determination,  $P_t$ ,  $G_t$ , and  $\lambda$  are radar dependent, while  $G_r$ ,  $S/N_{min}$ , NF, and B are receiver dependent factors.

Equation [3] relates the maximum detection range to bandwidth (B). The effects of the measurement bandwidth can significantly reduce the energy that can be measured from the peak power applied to the receiver input. Additional bandwidth details are provided in Sections 4-4, 4-7, and in other parts of this section

**NOISE POWER,  $kT_0B$**

Thermal noise is spread more or less uniformly over the entire frequency spectrum. Therefore the amount of noise appearing in the output of an ideal receiver is proportional to the absolute temperature of the receiver input system (antenna etc) times the bandwidth of the receiver. The factor of proportionality is Boltzmann's Constant.

**Mean noise power of ideal receiver =  $kT_0B = P_N$  (Watts)**

**Mean noise power of a real receiver =  $(NF)kT_0B$  (Watts)**

The convention for the temperature of  $T_0$  is set by IEEE standard to be 290°K, which is close to ordinary room temperature. So, assuming  $T_0 = 290^\circ\text{K}$ , and for a bandwidth  $B = 1 \text{ Hz}$ ,  $kT_0B = 4 \times 10^{-21} \text{ W} = -204 \text{ dBW} = -174 \text{ dBm}$ .

For any receiver bandwidth, multiply  $4 \times 10^{-21} \text{ W}$  by the bandwidth in Hz, or if using dB;

$10 \log kT_0B = -174 \text{ dBm} + 10 \text{ Log (actual Bandwidth in Hz)}$

or  $-114 \text{ dBm} + 10 \text{ Log (actual Bandwidth in MHz)}$

and so on, as shown by the values in Table 2.

Typical values for maximum sensitivity of receivers would be:

- RWR -65 dBm
- Pulse Radar -94 dBm
- CW Missile Seeker -138 dBm

Bandwidth	Bandwidth Ratio (dB)	Watts	dBW	dBm
1 Hz	0	$4 \times 10^{-21}$	-204	-174
1 kHz	30	$4 \times 10^{-18}$	-174	-144
1 MHz	60	$4 \times 10^{-15}$	-144	-114
1 GHz	90	$4 \times 10^{-12}$	-114	-84

If antenna contributions are ignored (see note in Table 4) for a CW receiver with a 4 GHz bandwidth, the ideal mean noise power would be  $-174 \text{ dBm} + 10 \text{ Log}(4 \times 10^9) = -174 \text{ dBm} + 96 \text{ dB} = -78 \text{ dBm}$ . A skilled operator might only be able to distinguish a signal 3 dB above the noise floor (S/N=3 dB), or -75 dBm. A typical radar receiver would require a S/N of 3 to 10 dB to distinguish the signal from noise, and would require 10 to 20 dB to track. Auto tracking might require a S/N of approximately 25 dB, thus, a receiver may only have sufficient sensitivity to be able to identify targets down to -53 dBm. Actual pulse receiver detection will be further reduced due to  $\sin x/x$  frequency distribution and the effect of the measurement bandwidth as discussed in Sections 4-4 and 4-7. Integration will increase the S/N since the signal is coherent and the noise is not.

**Noise Bandwidth**

Equivalent Noise Bandwidth ( $B_N$ ) - Set by minimum pulse width or maximum modulation bandwidth needed for the system requirements. A choice which is available to the designer is the relationship of pre- and post-detection bandwidth. Pre-detection bandwidth is denoted by  $B_{IF}$ , where r stands for RF, while post-detection is denoted  $B_V$ , where V stands for video. The most affordable approach is to set the post-detection filter equal to the reciprocal of the minimum pulse width, then choose the pre-detection passband to be as wide as the background interference environment will allow. Recent studies suggest that pre-detection bandwidths in excess of 100 MHz will allow significant loss of signals due to "pulse-on-pulse" conditions. Equations [4] and [5] provide  $B_N$  relationships that don't follow the Table 3 rules of thumb.

S/N out	Linear Detector	Square Law Detector
High S/N (>15 to 20 dB)	$B_N = B_V (> 20 \text{ to } 30 \text{ dB})$	$B_N = 4 B_V (> 10 \text{ to } 15 \text{ dB})$
Low S/N (< 0 dB)	$B_N = \sqrt{(2B_{IF}B_V - B_V^2) / 4(S/N)_{out}}$	$B_N = \sqrt{(2B_{IF}B_V - B_V^2) / (S/N)_{out}}$

For a square law detector: <sup>(1)</sup>

$$B_N = B_V \left[ 2 + \sqrt{4 + \frac{(2 B_{IF} / B_V) - 1}{(S/N)_{out}}} \right] \quad [4]$$

At high  $(S/N)_{out}$ , the  $1/(S/N)_{out}$  term goes to zero and we have:

$$B_N = B_V [ 2 + \sqrt{4} ] = 4 B_V$$

At low  $(S/N)_{out}$ , the  $1/(S/N)_{out}$  term dominates, and we have:

$$B_N = B_V \sqrt{\frac{(2 B_{IF} / B_V) - 1}{(S/N)_{out}}} = \sqrt{\frac{2 B_{IF} B_V - B_V^2}{(S/N)_{out}}}$$

For a linear detector: <sup>(1)</sup>

$$B_N = \frac{B_V}{2} + \frac{1}{4} \cdot \sqrt{B_V \left( 4 B_V + \frac{H^2 (2 B_{IF} - B_V)}{(S/N)_{out}} \right)} \quad [5]$$

H is a hypergeometric (statistical) function of  $(S/N)_{in}$

$$H = 2 \text{ for } (S/N)_{in} \ll 1$$

$$H = 1 \text{ for } (S/N)_{in} \gg 1$$

At high  $(S/N)_{out}$ , the  $1/(S/N)_{out}$  term goes to zero and we have:  $B_N = \frac{B_V}{2} + \frac{1}{4} \sqrt{B_V (4 B_V)} = B_V$

At low  $(S/N)_{out}$ , the  $1/(S/N)_{out}$  term dominates, and we have:  $B_N = \frac{1}{4} \sqrt{\frac{B_V H^2 (2 B_{IF} - B_V)}{(S/N)_{out}}} = \sqrt{\frac{2 B_{IF} B_V - B_V^2}{4 (S/N)_{out}}}$

Note (1): From Klipper, *Sensitivity of crystal Video Receivers with RF Pre-amplification*, The Microwave Journal, August 1965.

#### TRADITIONAL "RULE OF THUMB" FOR NARROW BANDWIDTHS (Radar Receiver Applications)

Required IF Bandwidth For Matched Filter Applications:

$$B_{IF} = \frac{1}{PW_{min}} \quad \text{Where: } \begin{array}{l} B_{IF} = \text{Pre-detection RF or IF bandwidth} \\ PW_{min} = \text{Specified minimum pulse width} = \tau \end{array}$$

Matched filter performance gives maximum probability of detection for a given signal level, but: (1) Requires perfect centering of signal spectrum with filter bandwidth, (2) Time response of matched pulse does not stabilize at a final value, and (3) Out-of-band splatter impulse duration equals minimum pulse width. As a result, EW performance with pulses of unknown frequency and pulse width is poor.

*Required Video Bandwidth Post-Detection*  
*Traditional "Rule of Thumb"*  $B_V = \frac{0.35}{PW_{min}}$  Where:  $B_V = \text{Post-detection bandwidth}$

Some authors define  $B_V$  in terms of the minimum rise time of the detected pulse, i.e.,  $B_V = (0.35 \text{ to } 0.5)/t_r$  min, where  $t_r$  = rise time.

#### REVISED "RULE OF THUMB" FOR WIDE BANDWIDTHS (Wideband Portion of RWRs)

$$B_{IF} = \frac{2 \text{ to } 3}{PW_{min}} \quad \text{and} \quad B_V = \frac{1}{PW_{min}}$$

The pre-detection bandwidth is chosen based upon interference and spurious generation concerns. The post-detection bandwidth is chosen to "match" the minimum pulse width. This allows (1) Half bandwidth mistuning between signal and filter, (2) Half of the minimum pulse width for final value stabilization, and (3) The noise bandwidth to be "matched" to the minimum pulse width. As a result, there is (1) Improved EW performance with pulses of unknown frequency and pulse width, (2) Measurement of in-band, but mistuned pulses, and (3) Rejection of out-of-band pulse splatter.

**NOISE FIGURE / FACTOR (NF)**

Electrical noise is defined as electrical energy of random amplitude, phase, and frequency. It is present in the output of every radio receiver. At the frequencies used by most radars, the noise is generated primarily within the input stages of the receiver system itself (Johnson Noise). These stages are not inherently noisier than others, but noise generated at the input and amplified by the receiver's full gain greatly exceeds the noise generated further along the receiver chain. The noise performance of a receiver is described by a figure of merit called the noise figure (NF). The term noise factor is synonymous, with some authors using the term "factor" for numeric and "figure" when using dB notation. (The notation "F<sub>n</sub>" is also sometimes used instead of "NF".) The noise figure is defined as:

$$NF = \frac{\text{Noise output of actual receiver}}{\text{Noise output of ideal receiver}} = \frac{N_{out}}{GN_{in}} \quad \text{or in dB:} \quad 10\text{Log} \left[ \frac{\text{Noise output of actual receiver}}{\text{Noise output of ideal receiver}} \right] = 10\text{log} \frac{N_{out}}{GN_{in}}$$

A range of NF values is shown in Table 4.

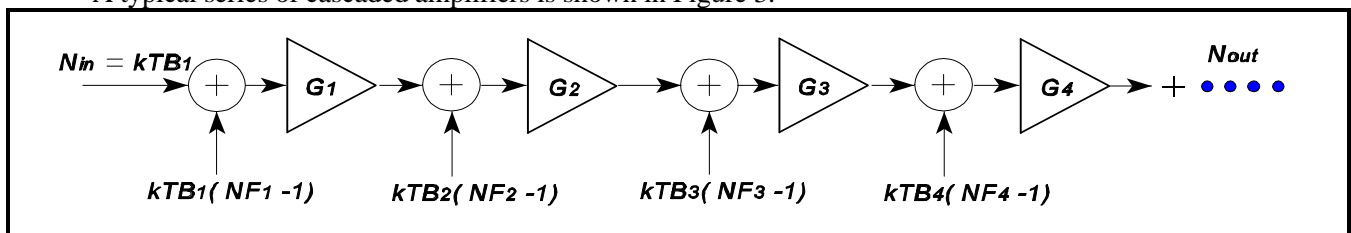
<b>Table 4.</b> Typical Noise Figure / Factor Value	Decimal	dB
Passive lossy network (RF transmission line, attenuator, etc.) Example: 20 dB attenuator (gain = 0.01)	Same as reciprocal of gain value ex: 100	Same as dB value ex: 20
Solid State Amplifier (see manufacturers specifications)	4	6
Traveling Wave Tube (see manufacturers specifications)	10 to 100	10 to 20
Antennas (Below ≈ 100 MHz, values to 12 dB higher if pointed at the sun) Note: Unless the antenna is pointed at the sun, its negligible NF can be ignored. Additionally, antenna gain is not valid for NF calculations because the noise is received in the near field.	1.012 to 1.4	0.05 to 1.5

An ideal receiver generates no noise internally. The only noise in its output is received from external sources. That noise has the same characteristics as the noise resulting from thermal agitation in a conductor. Thermal agitation noise is caused by the continuous random motion of free electrons which are present in every conductor. The amount of motion is proportional to the conductor's temperature above absolute zero. For passive lossy networks, the noise factor equals the loss value for the passive element:

$$NF = \frac{N_{out}}{G N_{in}} = \frac{kTB}{\frac{1}{L}kTB} = L \quad \text{Where } L = \text{Ratio Value of Attenuation}$$

i.e. For a 3 dB attenuator,  $G=0.5$  and  $L=2$   
∴  $NF = 2$  and  $10\text{log}NF = 3\text{dB}$

A typical series of cascaded amplifiers is shown in Figure 3.



**Figure 3.** Noise Factors for Cascaded Amplifiers (NF<sub>CA</sub>)

Loss (negative gain) can be used for the gain value of attenuators or transmission line loss, etc to calculate the noise out of the installation as shown in the following equation:

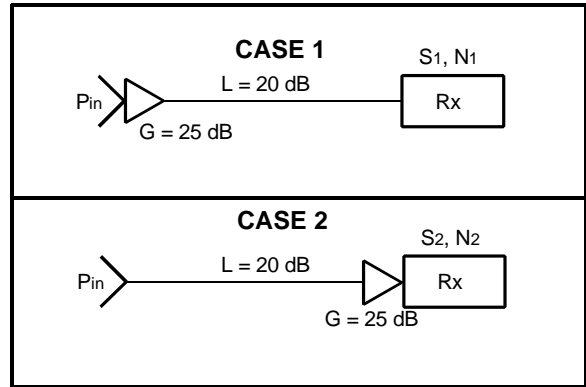
$$N_{out} = N_{in} G NF_{CA} = kTB_1(G_1G_2G_3\dots) \left( NF_1 + \frac{B_2(NF_2-1)}{B_1G_1} + \frac{B_3(NF_3-1)}{B_1G_1G_2} + \frac{B_4(NF_4-1)}{B_1G_1G_2G_3} + \dots \right) \quad (\text{ratio form}) \quad [6]$$

If the bandwidths of the amplifiers are the same, equation [6] becomes:

$$N_{out} = N_{in} G NF_{CA} = kTB(G_1G_2G_3\dots) \left( NF_1 + \frac{NF_2-1}{G_1} + \frac{NF_3-1}{G_1G_2} + \frac{NF_4-1}{G_1G_2G_3} + \dots \right) \quad (\text{ratio form}) \quad [7]$$

**Pre-amplifier Location Affects Receiver Input Noise**

As shown in Figure 4, if a 2 to 12 GHz receiver installation doesn't have enough sensitivity, it is best to install an additional amplifier closer to the antenna (case 1) instead of closer to the receiver (case 2). In both cases, the line loss (L) and the amplifier gain (G) are the same, so the signal level at the receiver is the same. For case 1,  $S_1 = P_{in} + G - L$ . In case 2,  $S_2 = P_{in} - L + G$ , so  $S_1 = S_2$ . The noise generated by the passive transmission line when measured at the receiver is the same in both cases. However, the noise generated inside the amplifier, when measured at the receiver input, is different.



**Figure 4.** Pre-Amp S/N

For this example, case 2 has a noise level at the input to the receiver which is 19.7 dB higher than case 1 (calculations follow later).

Table 5a	Case 1 Gain		Case 1 NF	
	Amp	L	Amp	L
dB	25	-20	6 *	20
ratio	316.2	0.01	4 *	100

Table 5b	Case 2 Gain		Case 2 NF	
	L	Amp	L	Amp
dB	-20	25	20	6 *
ratio	0.01	316.2	100	4 *

\* Amplifier NF value from Table 4.

Using equation [3] and the data in Tables 5a and 5b, the noise generated by the RF installation is shown in Tables 6a and 6b (the negligible noise contribution from the antenna is the same in both cases and is not included) (also see notes contained in Table 4):

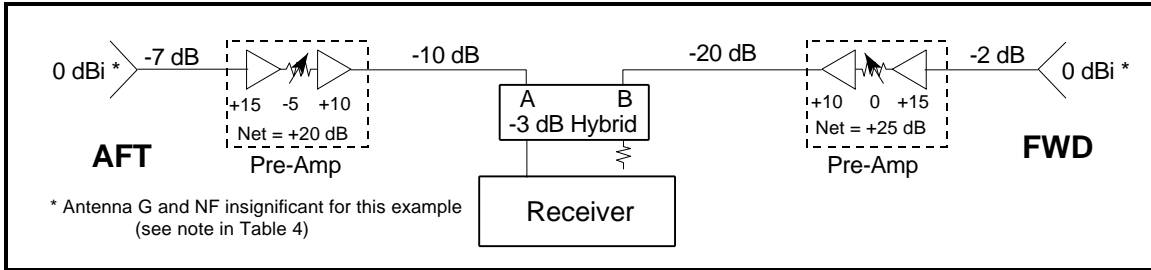
Table 6a. Case 1	Table 6b. Case 2
$G(NF) = 316.2(0.01) \left( 4 + \frac{100-1}{316.7} \right) = 13.64$	$G(NF) = 0.01(316.2) \left( 100 + \frac{4-1}{0.01} \right) = 1264.8$
$10 \log G(NF) = 11.34 \text{ dB}$	$10 \log G(NF) = 31 \text{ dB}$
Noise at receiver:	
$N_{out 1} = -74 \text{ dBm} + 11.34 \text{ dB} = -62.7 \text{ dBm}$	$N_{out 2} = -74 \text{ dBm} + 31 \text{ dB} = -43 \text{ dBm}$

$N_{out 2} - N_{out 1} = 19.7 \text{ dB}$ . The input noise of -74 dBm was calculated using  $10 \log (kTB)$ , where  $B = 10 \text{ GHz}$ .

Note that other tradeoffs must be considered: (1) greater line loss between the antenna and amplifier improves (decreases) VSWR as shown in Section 6-2, and (2) the more input line loss, the higher the input signal can be before causing the pre-amplifier to become saturated (mixing of signals due to a saturated amplifier is addressed in Section 5-7).

**Combining Receive Paths Can Reduce Sensitivity**

If a single aircraft receiver processes both forward and aft signals as shown in Figure 5, it is desirable to be able to use the receiver's full dynamic range for both directions. Therefore, one needs to balance the gain, so that a signal applied to the aft antenna will reach the receiver at the same level as if it was applied to the forward antenna.



**Figure 5.** Example of Pre-Amplifier Affecting Overall Gain/Sensitivity

Common adjustable preamplifiers can be installed to account for the excessive transmission line loss. In this example, in the forward installation, the level of the signal at the receiver is the same as the level applied to the antenna. Since the aft transmission line has 5 dB less attenuation, that amount is added to the preamplifier attenuator to balance the gain. This works fine for strong signals, but not for weaker signals. Because there is less loss between the aft preamplifier and the receiver, the aft noise dominates and will limit forward sensitivity. If the bandwidth is 2-12 GHz, and if port A of the hybrid is terminated by a perfect 50Ω load, the forward noise level would be -65.3 dBm. If port B is terminated, the aft noise level would be -60.4 dBm. With both ports connected, the composite noise level would be -59.2 dBm (convert to mw, add, then convert back to dBm). For this example, if the aft preamplifier attenuation value is changed to 12 dB, the gain is no longer balanced (7 dB extra loss aft), but the noise is balanced, i.e. forward = -65.6 dBm, aft = -65.3 dBm, and composite -62.4 dBm. If there were a requirement to see the forward signals at the most sensitive level, extra attenuation could be inserted in the aft preamplifier. This would allow the forward noise level to predominate and result in greater forward sensitivity where it is needed. Calculations are provided in Tables 7 and 8.

**Table 7.** Summary of Gain and NF Values for Figure 5 Components

		Aft					Fwd				
		RF Line	Amp	Attn	Amp	RF Line & hybrid	RF Line	Amp	Attn	Amp	RF Line & hybrid
Gain	dB	-7	15	-5	10	-13	-2	15	0	10	-23
	ratio	0.2	31.6	0.32	10	0.05	0.63	31.6	0	10	0.005
NF	dB	7	6	5	6	13	2	6	0	6	23
	ratio	5	4	3.16	4	20	1.585	4	0	4	200

Aft NF = 22.79 therefore  $10 \log \text{NF} = 13.58 \text{ dB}$ . Input noise level =  $-74 \text{ dBm} + 13.58 \text{ dB} = -60.42 \text{ dBm} \approx -60.4 \text{ dBm}$   
 Fwd NF = 7.495 therefore  $10 \log \text{NF} = 8.75 \text{ dB}$ . Input noise level =  $-74 \text{ dBm} + 8.75 \text{ dB} = -65.25 \text{ dBm} \approx -65.3 \text{ dBm}$   
 The composite noise level at the receiver =  $-59.187 \text{ dBm} \approx -59.2 \text{ dBm}$

**Table 8.** Effect of Varying the Attenuation (shaded area) in the Aft Preamplifier Listed in Table 7.

Aft Attn NF	Aft Attn Gain	Aft Noise	Fwd Noise	Composite Noise	Min Signal Received ***	Aft Input	Fwd Input
0 dB	0 dB	-55.8 dBm	-65.3 dBm	-55.4 dBm	-43.4 dBm	-48.4 dBm	-43.4 dBm
5	-5	-60.4	-65.3	-59.2	-47.2 *	-47.2 *	-47.2 *
10	-10	-64.4	-65.3	-61.8	-49.8	-44.8	-49.8
12	-12	-65.6 **	-65.3 **	-62.4	-50.4	-43.4	-50.4
15	-15	-67.1	-65.3	-63.1	-51.1	-41.1	-51.1

\* Gain Balanced

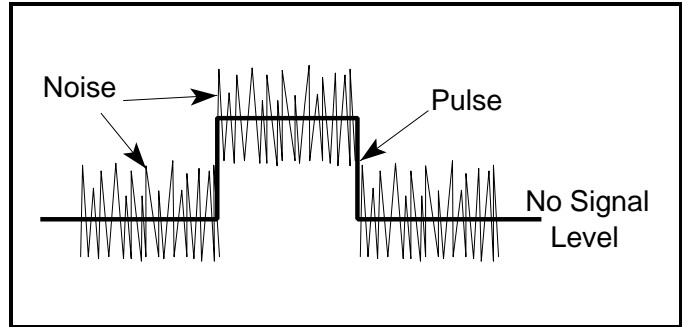
\*\* Noise Balanced

\*\*\* S/N was set at 12 dB



## TANGENTIAL SENSITIVITY

Tangential sensitivity (TSS) is the point where the top of the noise level with no signal applied is level with the bottom of the noise level on a pulse as shown in Figure 6. It can be determined in the laboratory by varying the amplitude of the input pulse until the stated criterion is reached, or by various approximation formulas.



**Figure 6.** Tangential Sensitivity

The signal power is nominally  $8 \pm 1$  dB above the noise level at the TSS point. TSS depends on the RF bandwidth, the video bandwidth, the noise figure, and the detector characteristic.

TSS is generally a characteristic associated with receivers (or RWRs), however the TSS does not necessarily provide a criterion for properly setting the detection threshold. If the threshold is set to TSS, then the false alarm rate is rather high. Radars do not operate at TSS. Most require a more positive S/N for track ( $> 10$  dB) to reduce false detection on noise spikes.

## SENSITIVITY CONCLUSION

When all factors effecting system sensitivity are considered, the designer has little flexibility in the choice of receiver parameters. Rather, the performance requirements dictate the limit of sensitivity which can be implemented by the EW receiver.

1. Minimum Signal-to-Noise Ratio (S/N) - Set by the accuracy which you want to measure signal parameters and by the false alarm requirements.
2. Total Receiver Noise Figure (NF) - Set by available technology and system constraints for RF front end performance.
3. Equivalent Noise Bandwidth ( $B_N$ ) - Set by minimum pulse width or maximum modulation bandwidth needed to accomplish the system requirements. A choice which is available to the designer is the relationship of pre- ( $B_{IF}$ ) and post-detection ( $B_V$ ) bandwidth. The most affordable approach is to set the post-detection filter equal to the reciprocal of the minimum pulse width, then choose the pre-detection passband to be as wide as the background interference environment will allow. Recent studies suggest that pre-detection bandwidths in excess of 100 MHz will allow significant loss of signals due to "pulse-on-pulse" conditions.
4. Antenna Gain (G) - Set by the needed instantaneous FOV needed to support the system time to intercept requirements.