

## JAMMING TO SIGNAL (J/S) RATIO - CONSTANT POWER [SATURATED] JAMMING

The following table contains a summary of the equations developed in this section.

<p style="text-align: center;"><b>JAMMING TO SIGNAL (J/S) RATIO (MONOSTATIC)</b></p> <p style="text-align: center;"><math>J/S = (P_j G_{ja} 4\pi R^2) / (P_t G_t \sigma)</math> (ratio form)* or:</p> <p><math>10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - 10\log \sigma^* + 10.99 \text{ dB} + 20\log R^*</math></p> <p>Note (1): Neither <math>f</math> nor <math>\lambda</math> terms are part of these equations</p> <hr/> <p>If simplified radar equations developed in previous sections are used:</p> <p><math>10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - G_\sigma + \alpha_1</math> (in dB)</p> <p>Note (2): the <math>20\log f_1</math> term in <math>-G_\sigma</math> cancels the <math>20\log f_1</math> term in <math>\alpha_1</math></p>	<p style="text-align: center;">* Keep R and <math>\sigma</math> in same units</p> <p>Target gain factor, (in dB)</p> <p><math>G_\sigma = 10\log \sigma + 20\log f_1 + K_2</math></p> <p><math>K_2</math> Values (dB):</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: left;">RCS (<math>\sigma</math>)</td> <td style="text-align: center;"><math>f_1</math> in MHz</td> <td style="text-align: center;"><math>f_1</math> in GHz</td> </tr> <tr> <td style="text-align: left;">(units)</td> <td style="text-align: center;"><math>K_2 =</math></td> <td style="text-align: center;"><math>K_2 =</math></td> </tr> <tr> <td style="text-align: left;">m<sup>2</sup></td> <td style="text-align: center;">-38.54</td> <td style="text-align: center;">21.46</td> </tr> <tr> <td style="text-align: left;">ft<sup>2</sup></td> <td style="text-align: center;">-48.86</td> <td style="text-align: center;">11.14</td> </tr> </table>	RCS ( $\sigma$ )	$f_1$ in MHz	$f_1$ in GHz	(units)	$K_2 =$	$K_2 =$	m <sup>2</sup>	-38.54	21.46	ft <sup>2</sup>	-48.86	11.14						
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<p style="text-align: center;"><b>JAMMING TO SIGNAL (J/S) RATIO (BISTATIC)</b></p> <p><math>R_{Tx}</math> is the range from the radar transmitter to the target. See note (1).</p> <p style="text-align: center;"><math>J/S = (P_j G_{ja} 4\pi R_{Tx}^2) / (P_t G_t \sigma)</math> (ratio form) * or:</p> <p><math>10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - 10\log \sigma^* + 10.99 \text{ dB} + 20\log R_{Tx}^*</math></p> <hr/> <p>If simplified radar equations developed in previous sections are used: see note (2).</p> <p><math>10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - G_\sigma + \alpha_{Tx}</math> (in dB)</p>	<p>One-way free space loss (dB)</p> <p><math>\alpha_1</math> or <math>\alpha_{Tx} = 20\log (f_1 R) + K_1</math></p> <p><math>K_1</math> Values (dB):</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: left;">Range</td> <td style="text-align: center;"><math>f_1</math> in MHz</td> <td style="text-align: center;"><math>f_1</math> in GHz</td> </tr> <tr> <td style="text-align: left;">(units)</td> <td style="text-align: center;"><math>K_1 =</math></td> <td style="text-align: center;"><math>K_1 =</math></td> </tr> <tr> <td style="text-align: left;">NM</td> <td style="text-align: center;">37.8</td> <td style="text-align: center;">97.8</td> </tr> <tr> <td style="text-align: left;">km</td> <td style="text-align: center;">32.45</td> <td style="text-align: center;">92.45</td> </tr> <tr> <td style="text-align: left;">m</td> <td style="text-align: center;">-27.55</td> <td style="text-align: center;">32.45</td> </tr> <tr> <td style="text-align: left;">ft</td> <td style="text-align: center;">-37.87</td> <td style="text-align: center;">22.13</td> </tr> </table>	Range	$f_1$ in MHz	$f_1$ in GHz	(units)	$K_1 =$	$K_1 =$	NM	37.8	97.8	km	32.45	92.45	m	-27.55	32.45	ft	-37.87	22.13
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This section derives the J/S ratio from the one-way range equation for J and the two-way range equation for S, and deals exclusively with active (transmitting) ECM devices or systems. Furthermore, the only purpose of the ECM considered is to prevent, delay, or confuse the radar processing of target information.

By official definition, ECM can be either Jamming or Deception. This may be somewhat confusing because almost any type of active ECM is commonly called "jamming", and the calculations of ECM signal in the radar compared to the target signal in the radar commonly refer to the "jamming-to-signal" ratio ("J-to-S" ratio). Therefore this section uses the common jargon and the term "jammer" refers to any ECM transmitter, and the term "jamming" refers to any ECM transmission, whether Deception or Concealment.

**Jamming:** "Official" jamming should more aptly be called Concealment or Masking. Essentially, Concealment uses ECM to swamp the radar receiver and hide the targets. Concealment (Jamming) usually uses some form of noise as the transmitted ECM signal. In this section, Concealment will be called "noise" or "noise jamming".

**Deception:** Deception might be better called Forgery. Deception uses ECM to forge false target signals that the radar receiver accepts and processes as real targets.

"J" designates the ECM signal strength whether it originates from a noise jammer or from a deception ECM system.

Basically, there are two different methods of employing active ECM against hostile radars:

Self Protection ECM  
Support ECM

For most practical purposes, Self Protection ECM is usually Deception and Support ECM is usually noise jamming. As the name implies, Self Protection ECM is ECM that is used to protect the platform that it is on. Self Protection ECM is often called "self screening jamming", and also "DECM", which is an acronym for either "Defensive ECM" or "Deception ECM". The top half of Figure 1 shows self screening jamming (DECM).

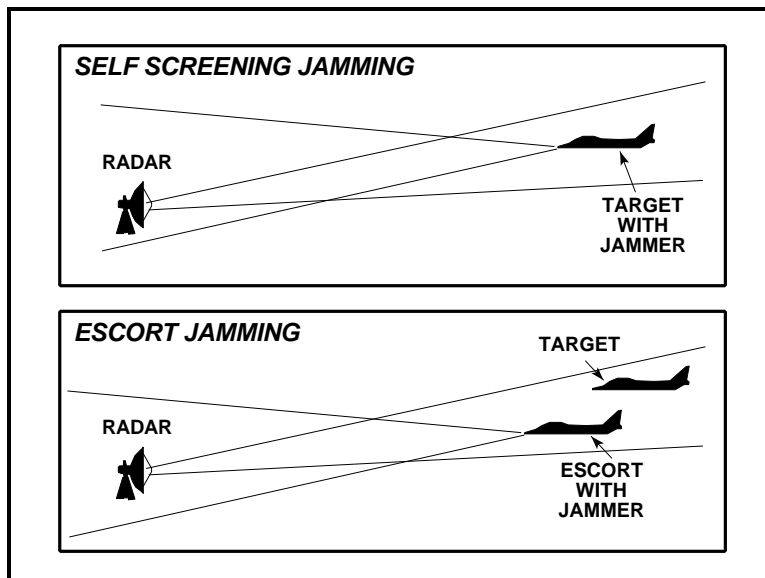


Figure 1. Self Protection and Escort Jamming

The bottom half of Figure 1 illustrates escort jamming which is a special case of support jamming. If the escort platform is sufficiently close to the target, the J-to-S calculations are the same as for DECM.

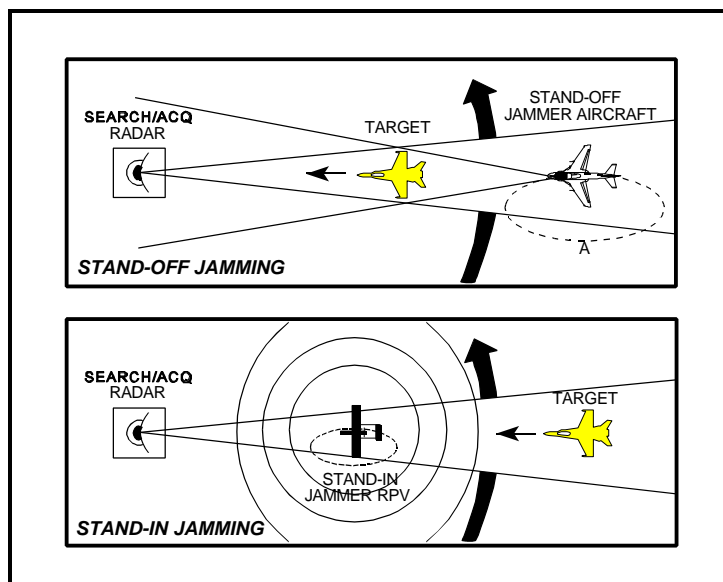


Figure 2. Support Jamming

Support ECM is ECM radiated from one platform and is used to protect other platforms. Figure 2 illustrates two cases of support jamming - stand-off jamming (SOJ) and stand-in jamming (SIJ). For SOJ the support jamming platform is maintaining an orbit at a long range from the radar - usually beyond weapons range. For SIJ, a remotely piloted vehicle is orbiting very close to the victim radar. Obviously, the jamming power required for the SOJ to screen a target is much greater than the jamming power required for the SIJ to screen the same target.

When factoring ECM into the radar equation, the quantities of greatest interest are "J-to-S" and Burn- Through Range.

"J-to-S" is the ratio of the signal strength of the ECM signal (J) to the signal strength of the target return signal (S). It is expressed as "J/S" and, in this section, is always in dB. J usually (but not always) must exceed S by some amount to be effective, therefore the desired result of a J/S calculation in dB is a positive number. Burn-through Range is the radar to target range where the target return signal can first be detected through the ECM and is usually slightly farther than crossover range where J=S. It is usually the range where the J/S just equals the minimum effective J/S (See Section 4-8).

The significance of "J-to-S" is sometimes misunderstood. The effectiveness of ECM **is not** a direct mathematical function of "J-to-S". The magnitude of the "J-to-S" required for effectiveness is a function of the particular ECM technique and of the radar it is being used against. Different ECM techniques may very well require different "J-to-S" ratios against the same radar. When there is sufficient "J-to-S" for effectiveness, increasing it will rarely increase the effectiveness at a given range. Because modern radars can have sophisticated signal processing and/or ECCM capabilities, in certain radars too much "J-to-S" could cause the signal processor to ignore the jamming, or activate special anti-jamming modes. Increasing "J-to-S" (or the jammer power) does, however, allow the target aircraft to get much closer to the threat radar before burn-through occurs, which essentially means more power is better if it can be controlled when desired.

**IMPORTANT NOTE:** If the signal S is CW or PD and the Jamming J is amplitude modulated, then the J used in the formula has to be reduced from the peak value (due to  $\sin x/x$  frequency distribution). The amount of reduction is dependent upon how much of the bandwidth is covered by the jamming signal. To get an exact value, integrals would have to be taken over the bandwidth. As a rule of thumb however:

- If the frequency of modulation is less than the BW of the tracking radar reduce J/S by  $10 \text{ Log}(\text{duty cycle})$ .
- If the frequency of modulation is greater than the BW of the tracking radar reduce J/S by  $20 \text{ Log}(\text{duty cycle})$ .

For example; if your jamming signal is square wave chopped (50% duty cycle) at a 100 Hz rate while jamming a 1 kHz bandwidth receiver, then the J/S is reduced by 3 dB from the maximum. If the duty cycle was 33%, then the reduction would be 4.8 dB. If the 50% and 33% duty cycle jamming signals were chopped at a 10 kHz (vice the 100 Hz) rate, the rule of thumb for jamming seen by the receiver would be down 6 dB and 9.6 dB, respectively, from the maximum since the 10 kHz chopping rate is greater than the 1 kHz receiver BW.

### J/S for DECM vs. MONOSTATIC RADAR

Figure 3 is radar jamming visualized. The Physical concept of Figure 3 shows a monostatic radar that is the same as Figure 1, Section 4-4, and a jammer (transmitter) to radar (receiver) that is the same as Figure 3, Section 4-3. In other words, Figure 3 is simply the combination of the previous two visual concepts where there is only one receiver (the radar's).

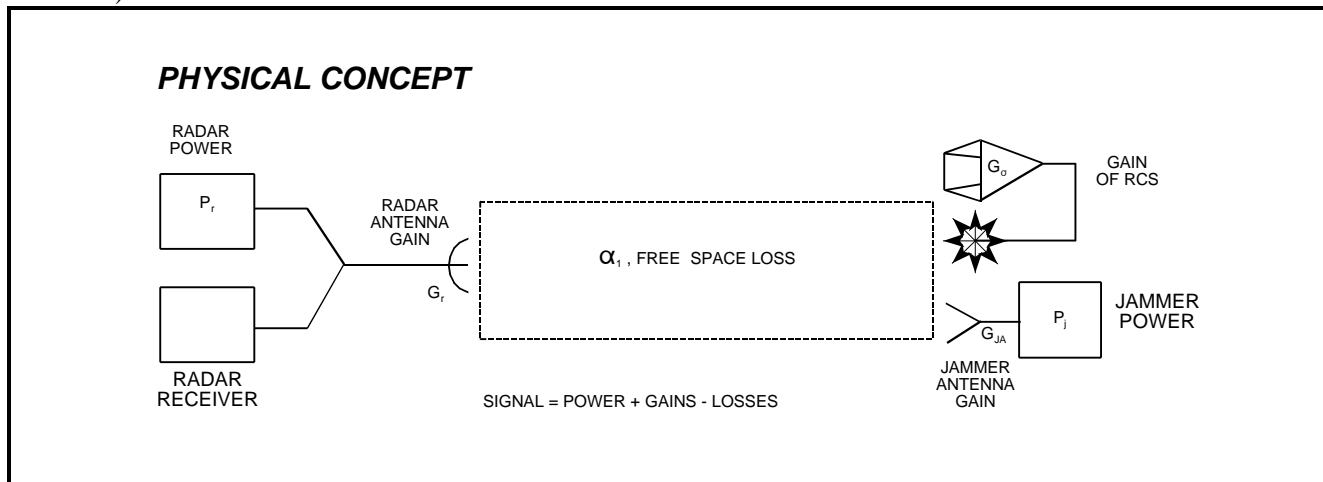


Figure 3. Radar Jamming Visualized

The equivalent circuit shown in Figure 4 applies to jamming monostatic radars with either DECM or support ECM. For DECM (or escort) v.s. a monostatic radar, the jammer is on the target and the radar receive and transmit antennas are collocated so the three ranges and three space loss factors ( $\alpha$ 's) are the same.

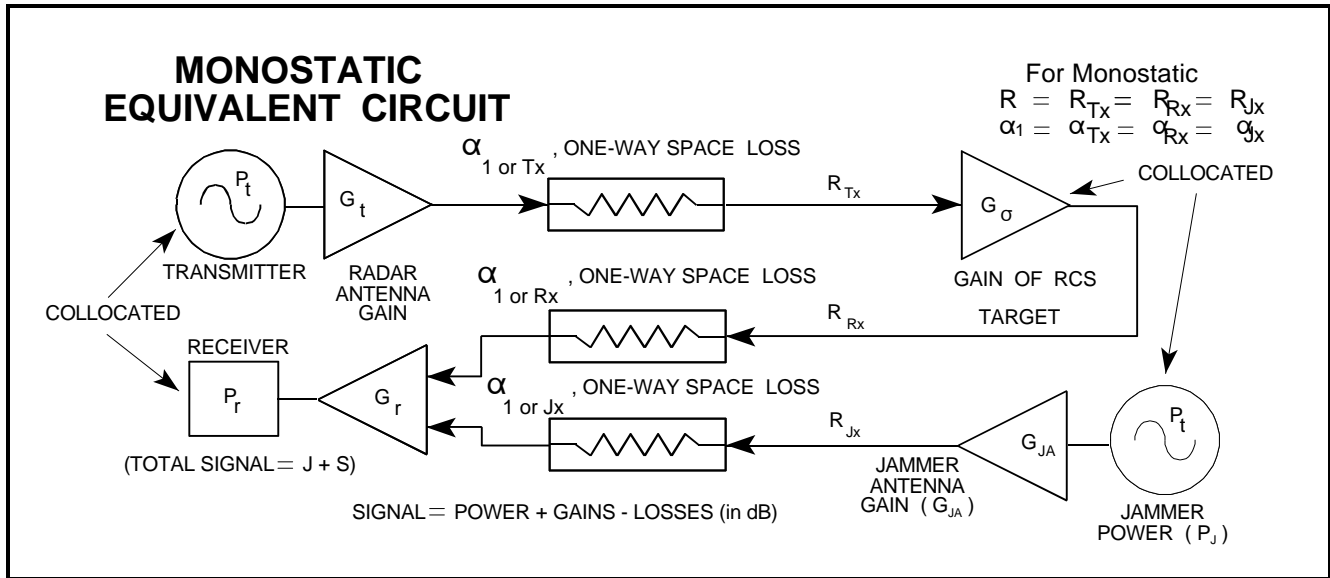


Figure 4. Monostatic Radar ECM Equivalent Circuit

J-S Ratio (Monostatic) The ratio of the power received ( $P_{r1}$  or J) from the jamming signal transmitted from the target to the power received ( $P_{r2}$  or S) from the radar skin return from the target equals J/S.

$$\text{From the one way range equation in Section 4-3: } P_{r1} \text{ or } J = \frac{P_j G_{ja} G_r \lambda^2}{(4\pi R)^2} \quad [1]$$

Note: To avoid having to include additional terms for these calculations, always combine any transmission line loss with antenna gain.

$$\text{From the two way range equation in Section 4.4: } P_{r2} \text{ or } S = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \quad [2]$$

$$\text{so } \frac{J}{S} = \frac{P_j G_{ja} G_r \lambda^2 (4\pi)^3 R^4}{P_t G_t G_r \lambda^2 \sigma (4\pi R)^2} = \frac{P_j G_{ja} 4\pi R^2}{P_t G_t \sigma} \quad (\text{ratio form}) \quad [3]$$

\* Keep R and  $\sigma$  in the same units.

On reducing the above equation to log form we have:

$$10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - 10\log \sigma + 10\log 4\pi + 20\log R \quad [4]$$

$$\text{or } 10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - 10\log \sigma + 10.99 \text{ dB} + 20\log R \quad [5]$$

Note: Neither  $f$  nor  $\lambda$  terms are part of the final form of equation [3] and equation [5].

J/S Calculations (Monostatic) Using a One Way Free Space Loss - The simplified radar equations developed in previous sections can be used to express J/S.

From the one way range equation Section 4-3:

$$10\log (P_{r1} \text{ or } J) = 10\log P_j + 10\log G_{ja} + 10\log G_r - \alpha_1 \quad (\text{in dB}) \quad [6]$$

From the two way range equation in Section 4.4:

$$10\log (P_{r2} \text{ or } S) = 10\log P_t + 10\log G_t + 10\log G_r + G_\sigma - 2\alpha_1 \quad (\text{in dB}) \quad [7]$$

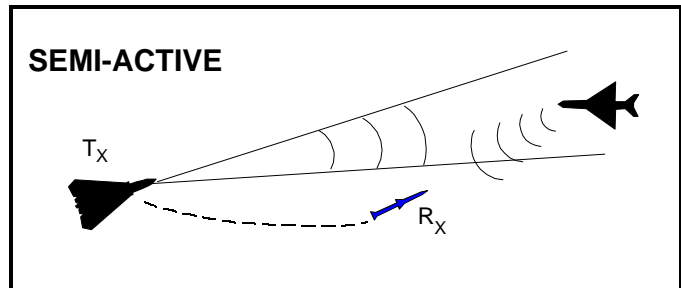
$$10\log (J/S) = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - G_\sigma + \alpha_1 \quad (\text{in dB}) \quad [8]$$

Note: To avoid having to include additional terms for these calculations, always combine any transmission line loss with antenna gain. The  $20\log f_1$  term in  $-G_\sigma$  cancels the  $20\log f_1$  term in  $\alpha_1$ .

Target gain factor, $G_\sigma = 10\log \sigma + 20\log f_1 + K_2$ (in dB)				One-way free space loss, $\alpha_1 = 20\log (f_1 R) + K_1$ (in dB)			
<b>K<sub>2</sub> Values</b> (dB)    RCS ( $\sigma$ ) $f_1$ in MHz $f_1$ in GHz				<b>K<sub>1</sub> Values</b> (dB)    Range (units) $f_1$ in MHz $f_1$ in GHz			
	(units)	$K_2 =$	$K_2 =$		$K_1 =$	$K_1 =$	
	m <sup>2</sup>	-38.54	21.46	NM	37.8	97.8	
	ft <sup>2</sup>	-48.86	11.14	km	32.45	92.45	
				m	-27.55	32.45	
				yd	-28.33	31.67	
				ft	-37.87	22.13	

**J/S for DECM vs. BISTATIC RADAR**

The semi-active missile illustrated in Figure 5 is the typical bistatic radar which would require the target to have self protection ECM to survive. In this case, the jammer is on the target and the target to missile receiver range is the same as the jammer to receiver range, but the radar to target range is different. Therefore, only two of the ranges and two of the  $\alpha$ 's (Figure 6.) are the same.



**Figure 5.** Bistatic Radar

In the following equations:

$\alpha_{Tx}$  = The one-way space loss from the radar transmitter to the target for range  $R_{Tx}$

$\alpha_{Rx}$  = The one-way space loss from the target to the missile receiver for range  $R_{Rx}$

Like the monostatic radar, the bistatic jamming and reflected target signals travel the same path from the target and enter the receiver (missile in this case) via the same antenna. In both monostatic and bistatic J/S equations this common range cancels, so both J/S equations are left with an  $R_{Tx}^2$  or  $20 \log R_{Tx}$  term. Since in the monostatic case  $R_{Tx} = R_{Rx}$  and  $\alpha_{Tx} = \alpha_{Rx}$ , only R or  $\alpha_1$  is used in the equations. Therefore, the bistatic J/S equations [11], [13], or [14] will work for monostatic J/S calculations, but the opposite is only true if bistatic  $R_{Tx}$  and  $\alpha_{Tx}$  terms are used for R or  $\alpha_1$  terms in monostatic equations [3], [5], and [8].

The equivalent circuit shown in Figure 6 applies to jamming bistatic radar. For DECM (or escort) vs. a bistatic radar, the jammer is on the target and the radar receive and transmit antennas are at separate locations so only two of the three ranges and two of the three space loss factors ( $\alpha$ 's) are the same.

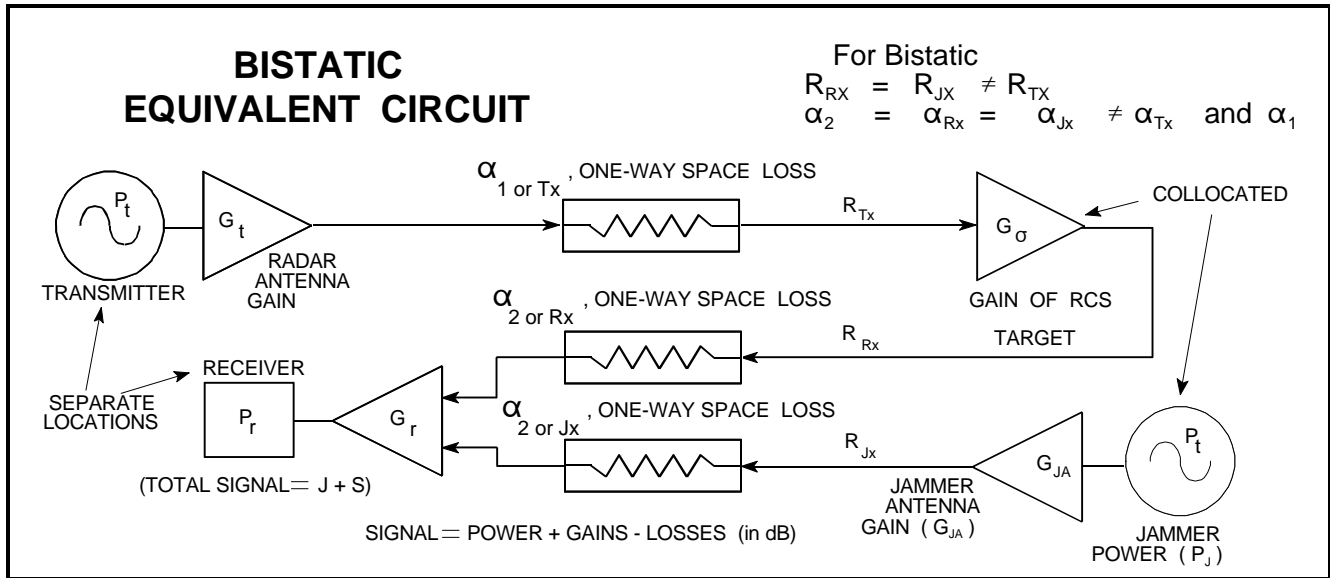


Figure 6. Bistatic Radar ECM Equivalent Circuit

J-to-S Ratio (Bistatic) When the radar's transmit antenna is located remotely from the receiving antenna (Figure 6), the ratio of the power received ( $P_{r1}$  or  $J$ ) from the jamming signal transmitted from the target to the power received ( $P_{r2}$  or  $S$ ) from the radar skin return from the target equals  $J/S$ . For jammer effectiveness  $J$  normally has to be greater than  $S$ .

$$\text{From the one way range equation in Section 4-3: } P_{r1} \text{ or } J = \frac{P_j G_{ja} G_r \lambda^2}{(4\pi R_{Rx})^2} \quad (R_{Jx} = R_{Rx}) \quad [9]$$

$$\text{From the two way range equation in Section 4.4: } P_{r2} \text{ or } S = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R_{Tx}^2 R_{Rx}^2} \quad [10]$$

$$\text{so } \frac{J}{S} = \frac{P_j G_{ja} G_r \lambda^2 (4\pi)^3 R_{Tx}^2 R_{Rx}^2}{P_t G_t G_r \lambda^2 \sigma (4\pi R_{Rx})^2} = \frac{P_j G_{ja} 4\pi R_{Tx}^2}{P_t G_t \sigma} \quad (\text{ratio form}) \quad [11]$$

\* Keep  $R$  and  $\sigma$  in the same units.

On reducing the above equation to log form we have:

$$10 \log J/S = 10 \log P_j + 10 \log G_{ja} - 10 \log P_t - 10 \log G_t - 10 \log \sigma + 10 \log 4\pi + 20 \log R_{Tx} \quad [12]$$

$$\text{or } 10 \log J/S = 10 \log P_j + 10 \log G_{ja} - 10 \log P_t - 10 \log G_t - 10 \log \sigma + 10.99 \text{ dB} + 20 \log R_{Tx} \quad [13]$$

Note: To avoid having to include additional terms for these calculations, always combine any transmission line loss with antenna gain. Neither  $f$  nor  $\lambda$  terms are part of the final form of equation [11] and equation [13].

Bistatic J/S Calculations (Bistatic) Using a One Way Free Space Loss - The simplified radar equations developed in previous sections can be used to express J/S.

From the one way range equation in Section 4-3:

$$10\log (P_{r1} \text{ or } J) = 10\log P_j + 10\log G_{ja} + 10\log G_r - \alpha_{Rx} \quad (\text{all factors dB}) \quad [14]$$

From the two way range equation in Section 4-4:

$$10\log (P_{r2} \text{ or } S) = 10\log P_t + 10\log G_t + 10\log G_r + G_\sigma - \alpha_{Tx} - \alpha_{Rx} \quad (\text{all factors dB}) \quad [15]$$

$$10\log (J/S) = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - G_\sigma + \alpha_{Tx} \quad (\text{all factors dB}) \quad [16]$$

Note: To avoid having to include additional terms for these calculations, always combine any transmission line loss with antenna gain. The  $20\log f_1$  term in  $-G_\sigma$  cancels the  $20\log f_1$  term in  $\alpha_1$ .

Target gain factor, $G_\sigma = 10\log \sigma + 20\log f_1 + K_2$ (in dB)				One-way free space loss $\alpha_{Tx \text{ or } Rx} = 20\log f_1 R_{Tx \text{ or } Rx} + K_1$ (in dB)			
<b>K<sub>2</sub> Values</b>				<b>K<sub>1</sub> Values</b>			
(dB)	RCS ( $\sigma$ )	$f_1$ in MHz	$f_1$ in GHz	(dB)	Range (units)	$f_1$ in MHz $K_1 =$	$f_1$ in GHz $K_1 =$
	(units)	$K_2 =$	$K_2 =$		NM	37.8	97.8
	m <sup>2</sup>	-38.54	21.46		km	32.45	92.45
	ft <sup>2</sup>	-48.86	11.14		m	-27.55	32.45
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Saturated J/S (Monostatic) Example (Constant Power Jamming)

Assume that a 5 GHz radar has a 70 dBm signal fed through a 5 dB loss transmission line to an antenna that has 45 dB gain. An aircraft is flying 31 km from the radar. The aft EW antenna has -1 dB gain and a 5 dB line loss to the EW receiver (there is an additional loss due to any antenna polarization mismatch but that loss will not be addressed in this problem). The aircraft has a jammer that provides 30 dBm saturated output if the received signal is above -35 dBm. The jammer feeds a 10 dB loss transmission line which is connected to an antenna with a 5 dB gain. If the RCS of the aircraft is 9 m<sup>2</sup>, what is the J/S level received by the tracking radar?

Answer: The received signal at the jammer is the same as the example in Section 4-3, i.e. answer (1) = -32.3 dBm @ 5 GHz. Since the received signal is above -35 dBm, the jammer will operate in the saturated mode, and equation [5] can be used. (See Section 4-10 for an example of a jammer operating in the linear region.)

$$10\log J/S = 10\log P_j + 10\log G_{ja} - 10\log P_t - 10\log G_t - 10\log \sigma + 10.99 \text{ dB} + 20\log R$$

Note: the respective transmission line losses will be combined with antenna gains, i.e.  $-5 + 45 = 40 \text{ dB}$  &  $-10 + 5 = -5 \text{ dB}$ .

$$10\log J/S = 30 - 5 - 70 - 40 - 9.54 + 10.99 + 89.8 = 6.25 \text{ dB @ 5 GHz}^*$$

\* The answer is still 6.25 dB if the tracking radar operates at 7 GHz provided the antenna gains and the aircraft RCS are the same at both frequencies.

In this example, there is inadequate jamming power at each frequency if the J/S needs to be 10 dB or greater to be effective. One solution would be to replace the jammer with one that has a greater power output. If the antenna of the aircraft and the radar are not the proper polarization, additional power will also be required (see Section 3-2).