Electronic Warfare Pocket Guide

David L. Adamy

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Contents

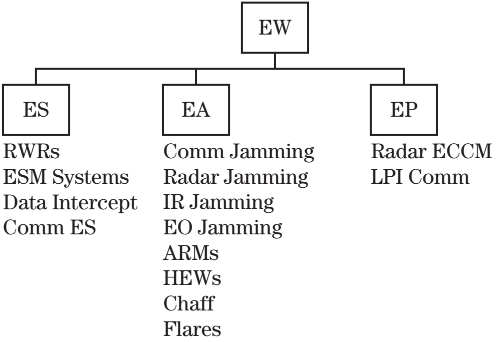
EW Definitions & Subareas	4
Frequency	5
Antennas	6
Radio Propagation	13
Receiver Sensitivity	20
Communication Jamming	24
Communications Electronic Protection	26
Jamming LPI Communications	27
Radar Characteristics	28
Radar Jamming	29
Radar Electronic Protection	31
Expendable Countermeasures	32
Decoys	33
Decibels (dB)	34
Graph & Nomograph Instructions	35
List of Symbols in Formulas	37
List of Abbreviations	38

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



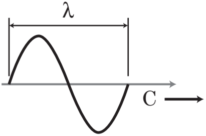
Frequency

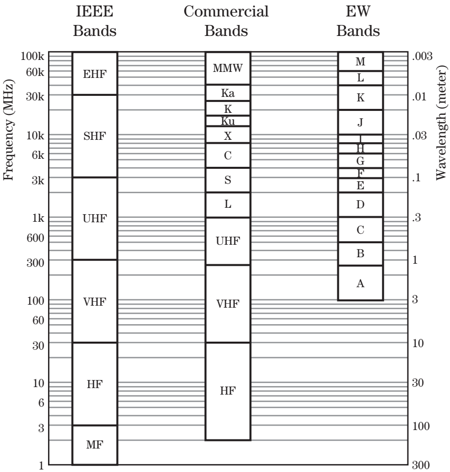
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

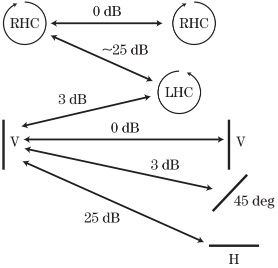
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

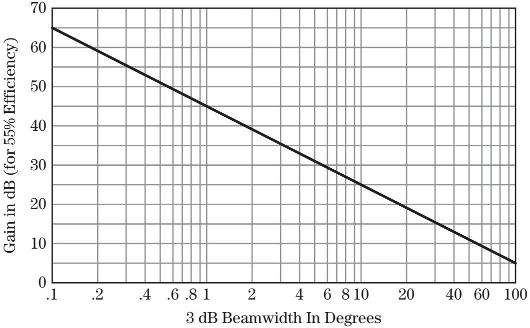
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

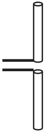
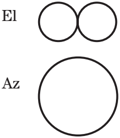
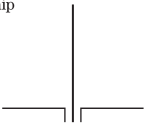
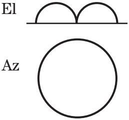
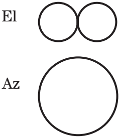
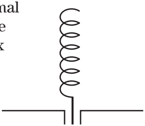
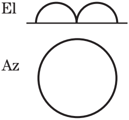
Peak gain vs. 3 dB beamwidth for 55% eff. dish

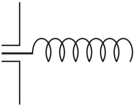
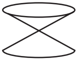
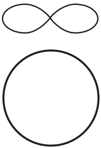
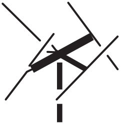
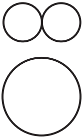
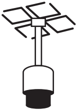
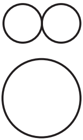


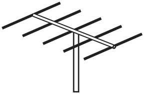
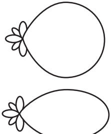
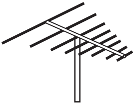
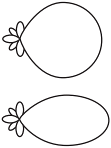
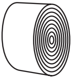
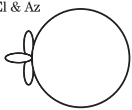
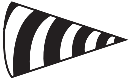
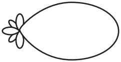
Antenna efficiency

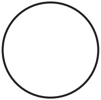
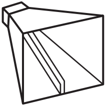
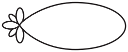
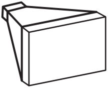
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

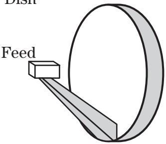
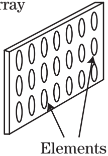
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: $80^\circ \times 360^\circ$ Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: $45^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: $45^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

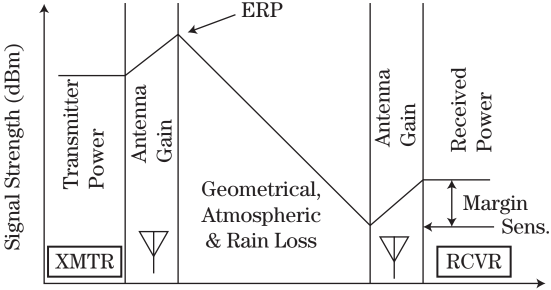
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El, Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El, Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El, Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El  Az 	Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El  Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El  Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss) Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

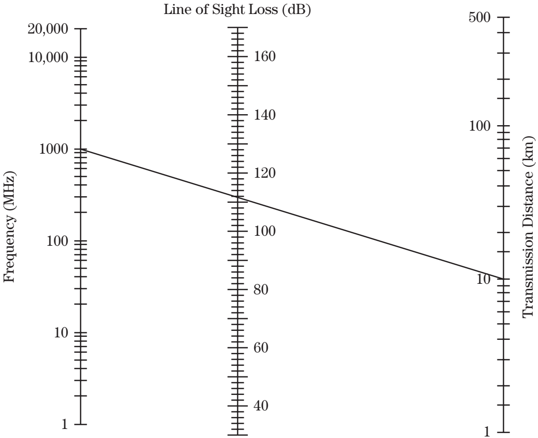
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

L(in dB) = 32.44 + 20 log(F) + 20 log(D)

F in MHz D in km

Line of Sight (Free Space) Nomograph

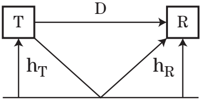


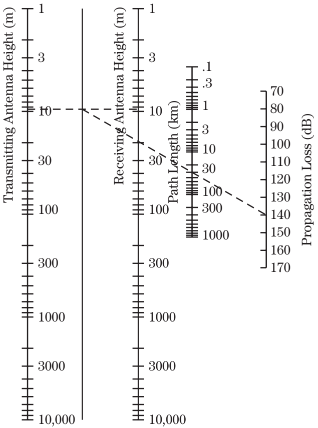
Two ray loss

$L = D^4/\left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

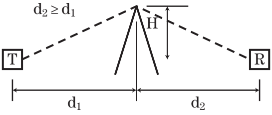
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



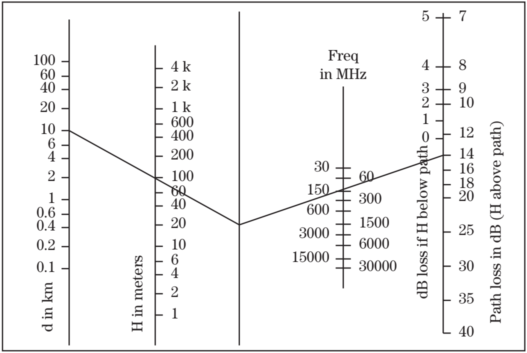


Knife edge diffraction geometry

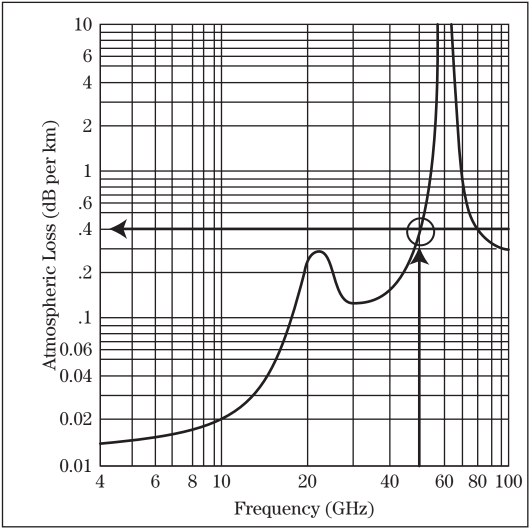


Calculate d = [sqrt 2 / (1 + (d_1/d_2)] d_1
or just use d = d_1 which reduces accuracy by ~ 1.5 dB

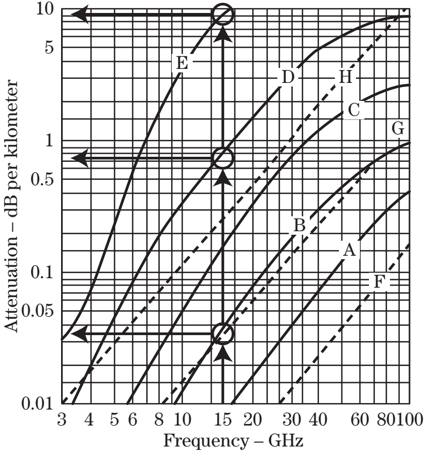
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



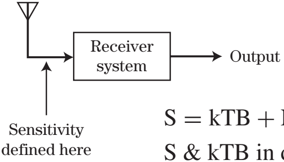
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

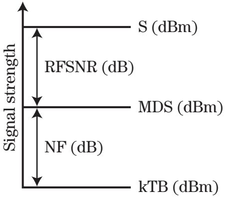


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

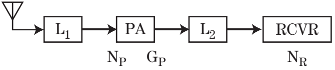


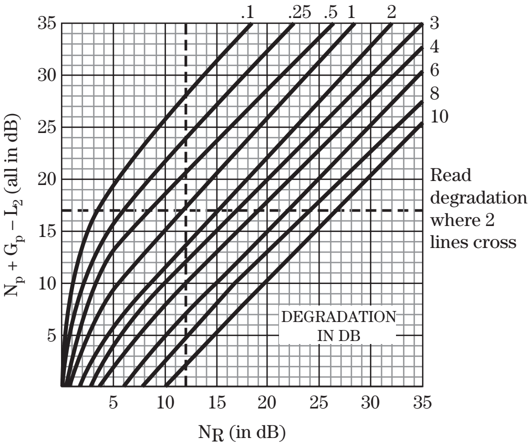
kTB(in dBm) $= -114 + 10 \log (\mathrm{BW}/1\ \mathrm{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$
$R_E = \text{anti-log}[20\ \log(R_E)/20]$

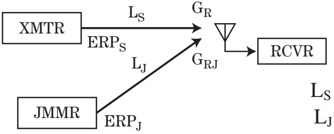
Effective range (Two-Ray Propagation)

$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$
$R_E = \text{anti-log}[40\ \log(R_E)/40]$

$R_E$in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20–33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

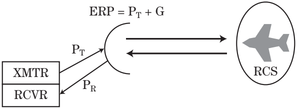
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

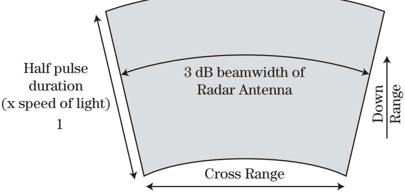
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

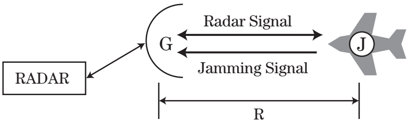


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

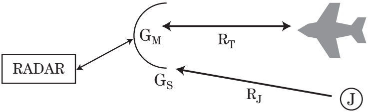
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J G_S R_T^4})/(\mathrm{ERP_S G_M R_J^2}\sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + \mathrm{G_S} - \mathrm{G_M} + 40\ \mathrm{Log}\,\mathrm{R_T} - 20 \log \mathrm{R_J} - 10\ \mathrm{Log\ RCS}$$

Burn through range

$$\mathrm{R_{BT}} = 4^{\mathrm{th}} \text{ root of } [(\mathrm{ERP_S\ G_M\ R_J^2}\sigma)/(4\pi \mathrm{ERP_J\ G_S})]$$

(In dB)

$$40\,\mathrm{Log}\,\mathrm{R_T} = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - \mathrm{G_S} + \mathrm{G_M} + 40\,\mathrm{Log}\,\mathrm{R_T} - 20\,\mathrm{Log}\,\mathrm{R_J} + 10\,\mathrm{Log\,RCS} + \mathrm{J/S(Required)}$$

$$\mathrm{R_{BT}} = \text{Anti-Log}\{[40\ \mathrm{Log\ R_T}]/40\}$$

Note about burn through range:
This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

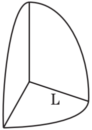
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

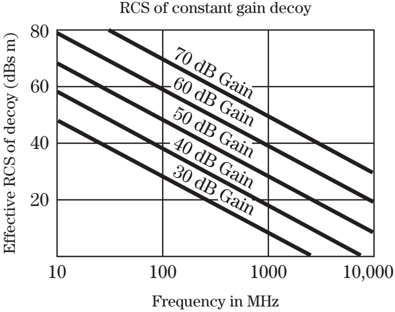
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

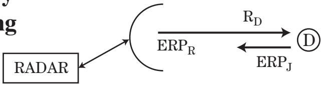


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F) L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, N(dB) = $20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

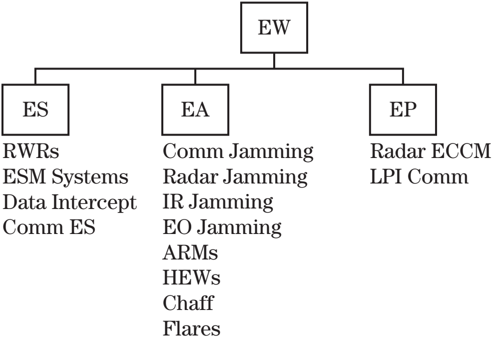
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



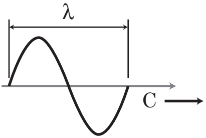
Frequency

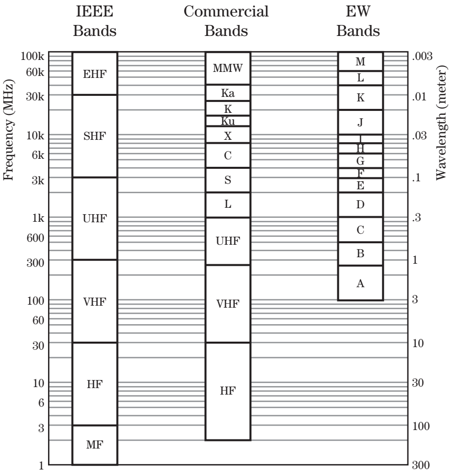
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

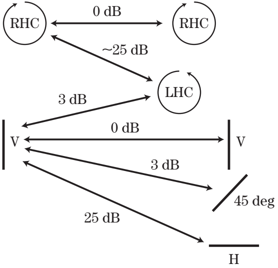
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

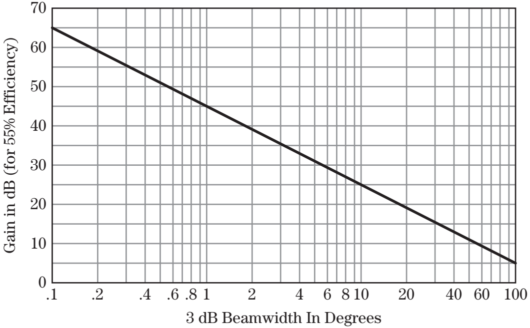
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

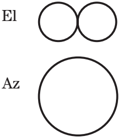
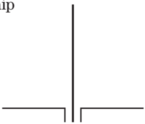
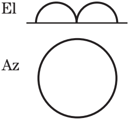
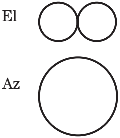
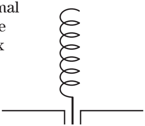
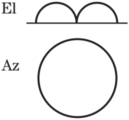
Peak gain vs. 3 dB beamwidth for 55% eff. dish

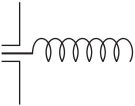
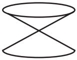
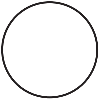
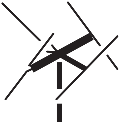
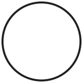
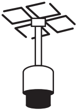
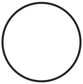


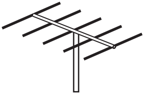
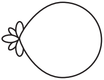
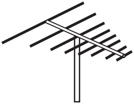
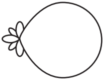
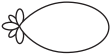
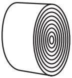
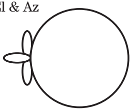
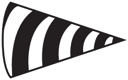
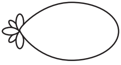
Antenna efficiency

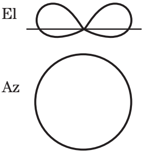
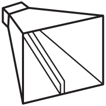
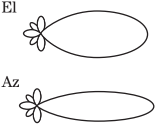
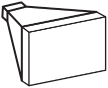
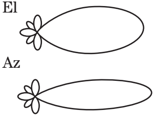
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

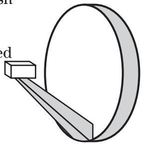
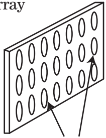
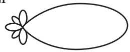
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ∼30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

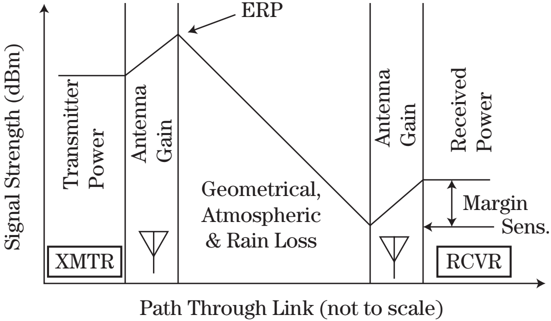
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El  Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El  Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 		Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 		Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 		Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

$P_R \text{ (in dB)} = P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

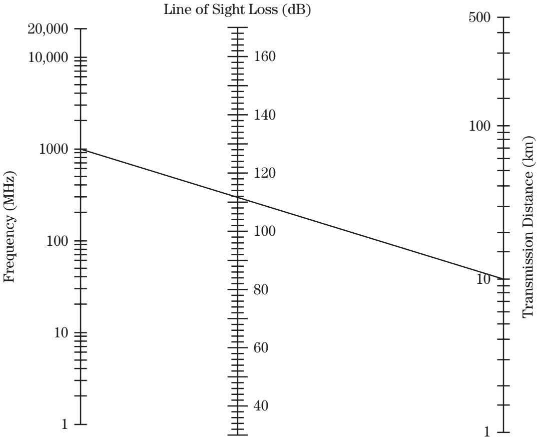
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

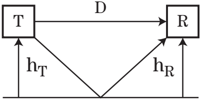


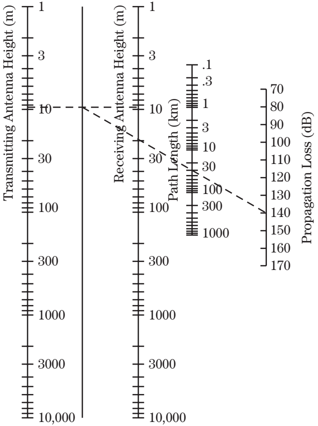
Two ray loss

$L = D^4/\left[h_T^2 h_R^2\right]$ L is ratio, D, h_T & h_R in meters

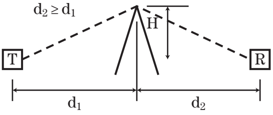
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



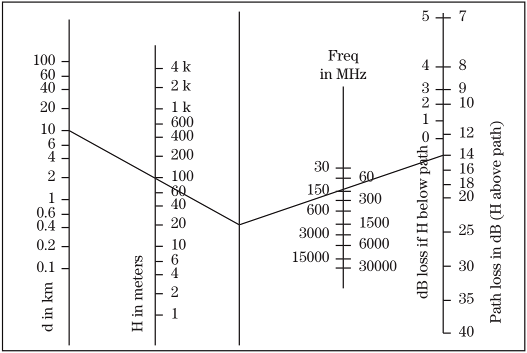


Knife edge diffraction geometry

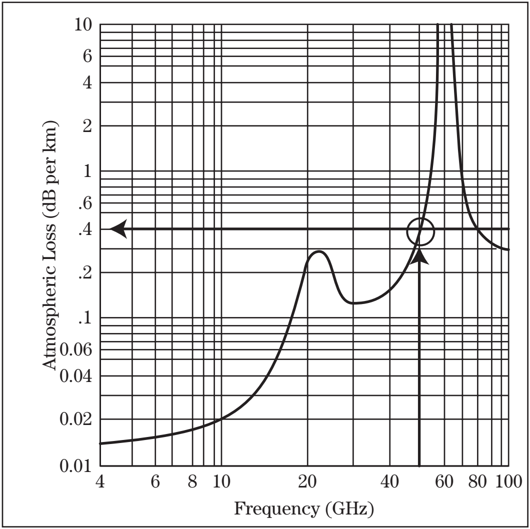


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)] \, d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

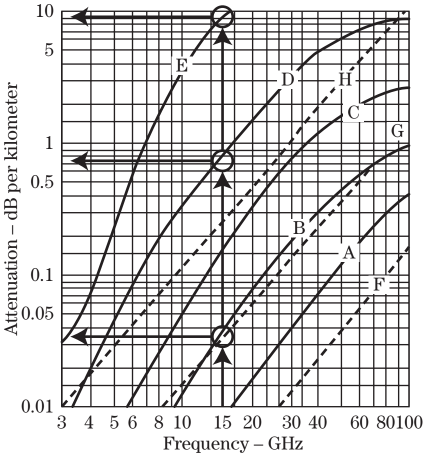
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



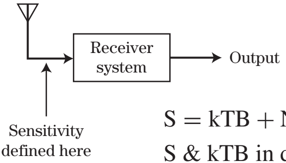
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

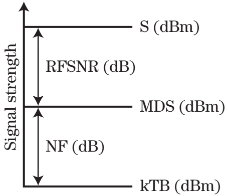


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

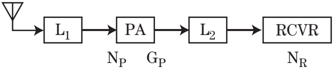


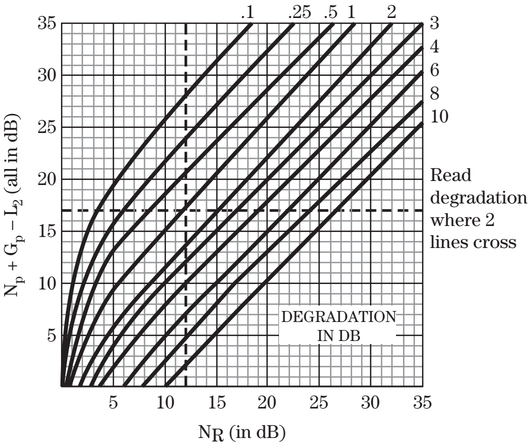
kTB(in dBm) $= -114 + 10 \log (\text{BW}/1 \text{ MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20 \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

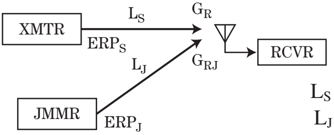
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

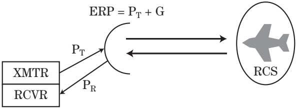
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

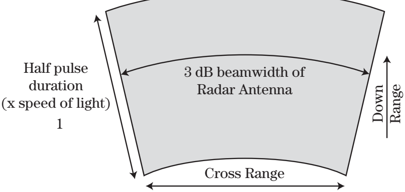
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$\text{(dB)}\, P_R = P_T + 2G - 103 - 20 \,\text{Log}\, F - 40 \,\text{Log}\, R + 10 \,\text{Log}\, \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

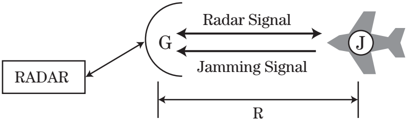


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

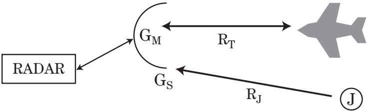
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40\ \mathrm{Log}\ R_T - 20 \log R_J - 10\ \mathrm{Log\ RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40\ \mathrm{Log}\ R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40\ \mathrm{Log}\ R_T - 20\ \mathrm{Log}\ R_J + 10\ \mathrm{Log\ RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40\ \mathrm{Log}\ R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

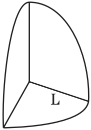
Start within radar resolution cell, capture tracking radar, move resolution cell away from target

Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

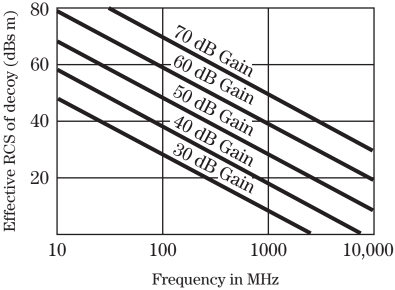


$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

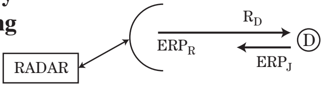
Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



RCS of primed decoy (fixed ERP) repeating radar signal



$$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10\log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

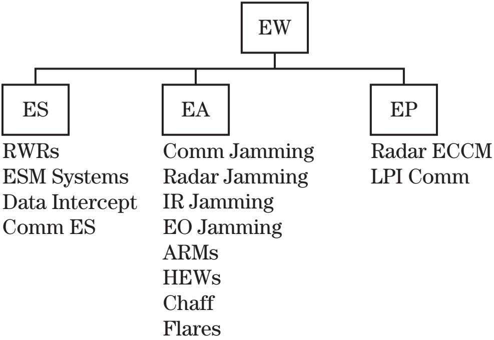
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



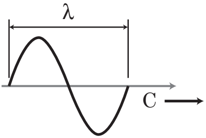
Frequency

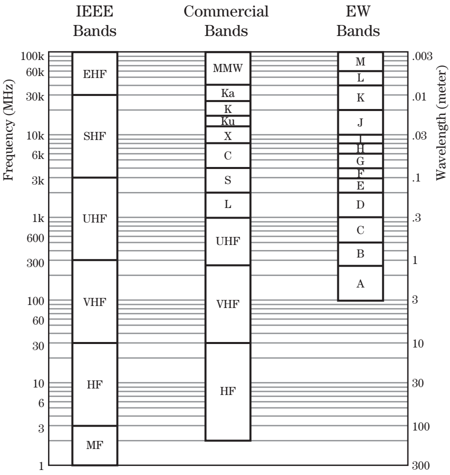
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

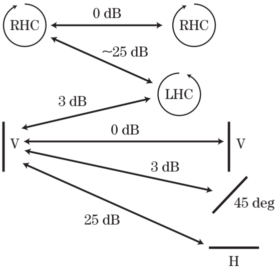
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

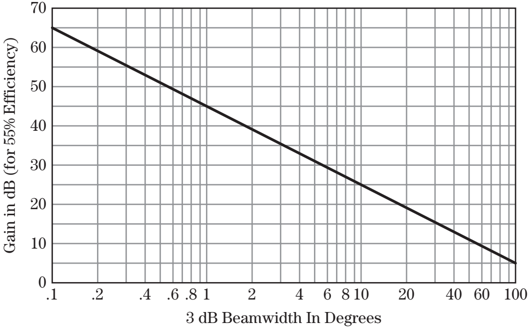
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

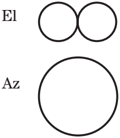
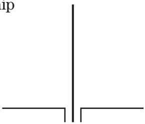
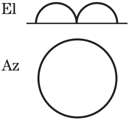
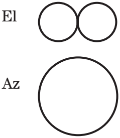
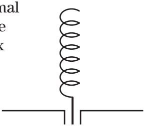
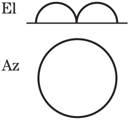
Peak gain vs. 3 dB beamwidth for 55% eff. dish

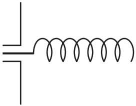
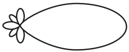
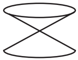
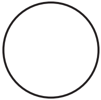
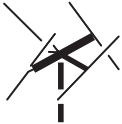
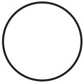
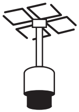
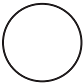


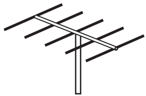
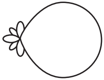
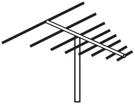
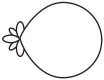
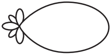
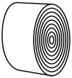
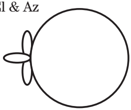
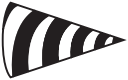
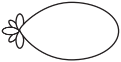
Antenna efficiency

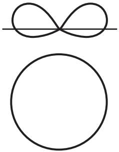
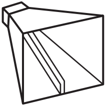
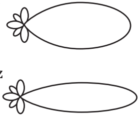
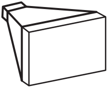
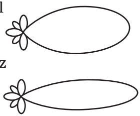
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

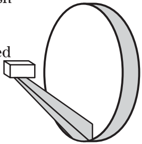
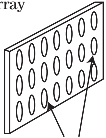
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

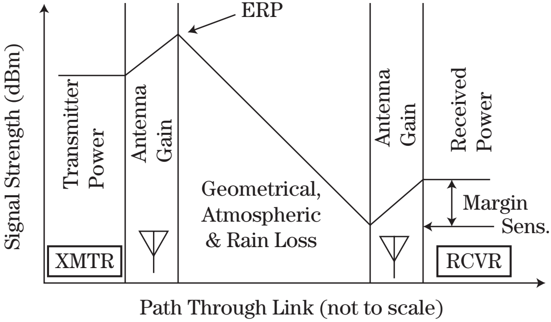
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El  Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El  Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El, Az 	Polarization: Circular Beamwidth: 50° × 360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El, Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El, Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss) Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

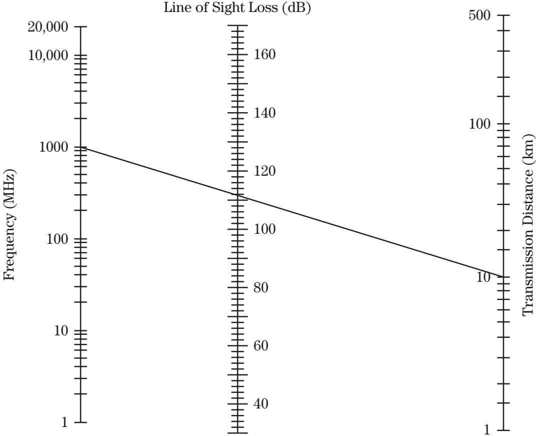
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

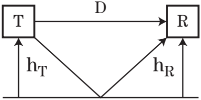


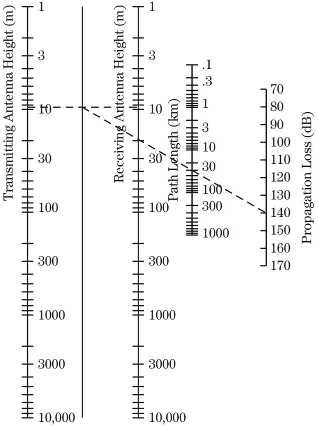
Two ray loss

$L = D^4 / \left[h_T^2 \, h_R^2 \right]$ L is ratio, D, h_T & h_R in meters

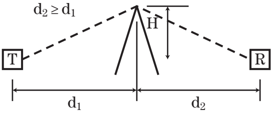
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



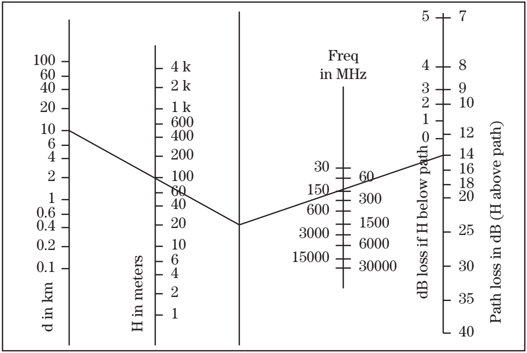


Knife edge diffraction geometry

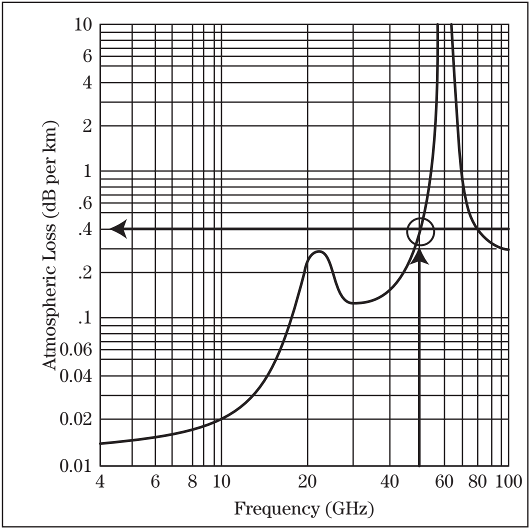


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\, d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

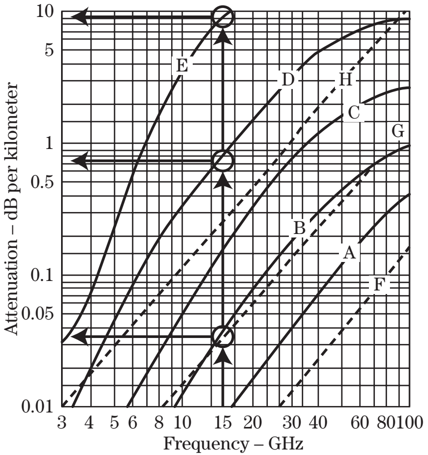
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



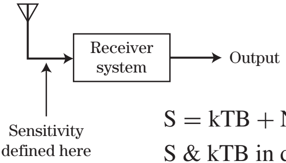
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

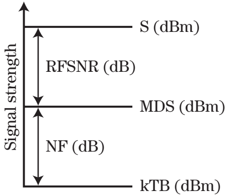


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

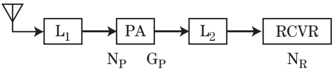
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

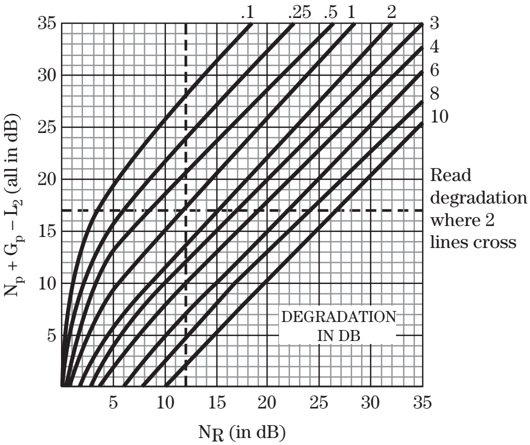


kTB(in dBm) $= -114 + 10 \log(\mathrm{BW}/1\ \mathrm{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB)
G_P = PA Gain (dB)
N_P = PA NF (dB)
N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

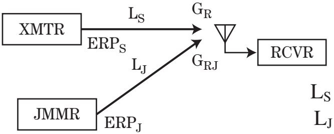
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

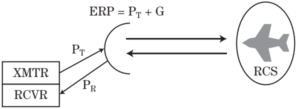
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

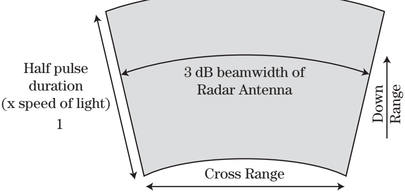
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20\,\text{Log}\,F - 40\,\text{Log}\,R + 10\,\text{Log}\,\sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

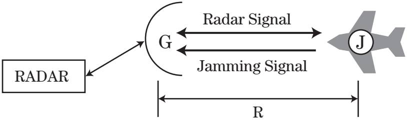


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

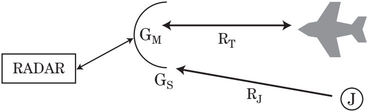
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- $0.925\ N\sigma_1$ with λ spacing
- $0.981\ N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

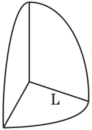
Start within radar resolution cell, capture tracking radar, move resolution cell away from target

Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

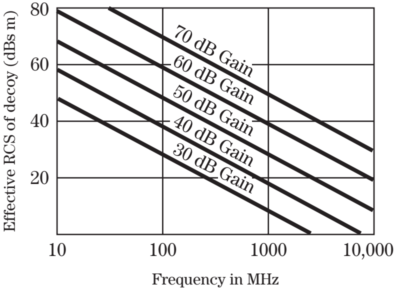


$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

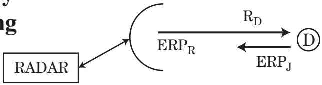
Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



RCS of primed decoy (fixed ERP) repeating radar signal



$$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10\log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in $^\circ$Kelvin

List of Abbreviations

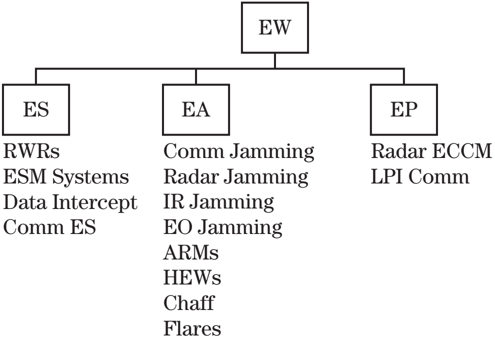
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



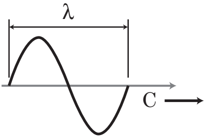
Frequency

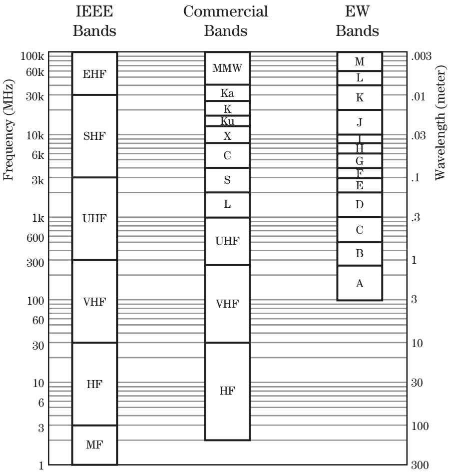
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

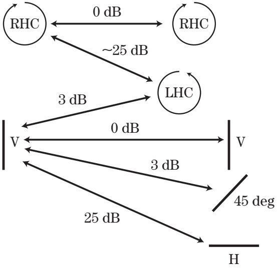
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

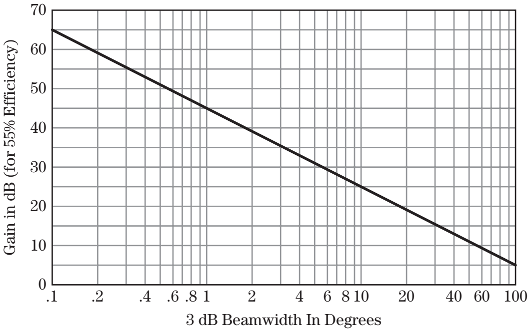
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

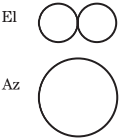
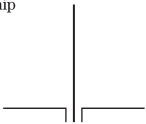
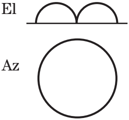
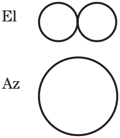
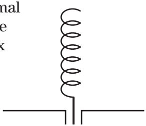
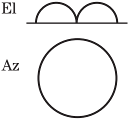
Peak gain vs. 3 dB beamwidth for 55% eff. dish

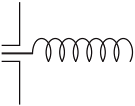
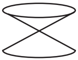
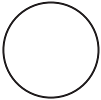
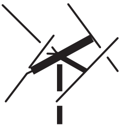
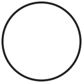
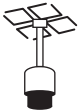
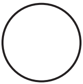


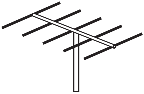
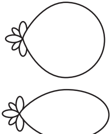
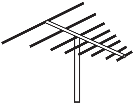
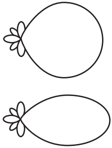
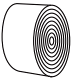
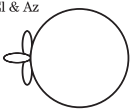
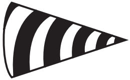
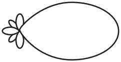
Antenna efficiency

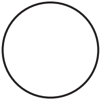
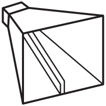
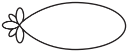
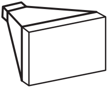
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

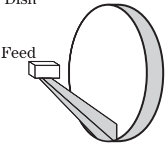
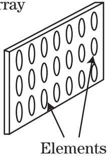
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ∼30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

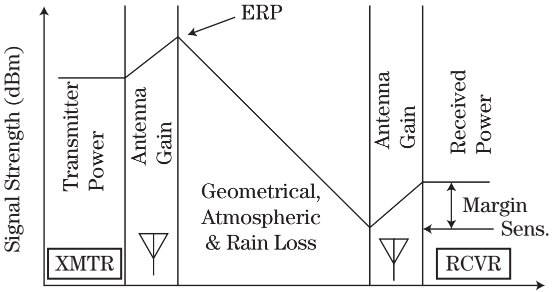
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El  Az 	Polarization: Circular Beamwidth: $50^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El  Az 	Polarization: Linear Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El  Az 	Polarization: Circular Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

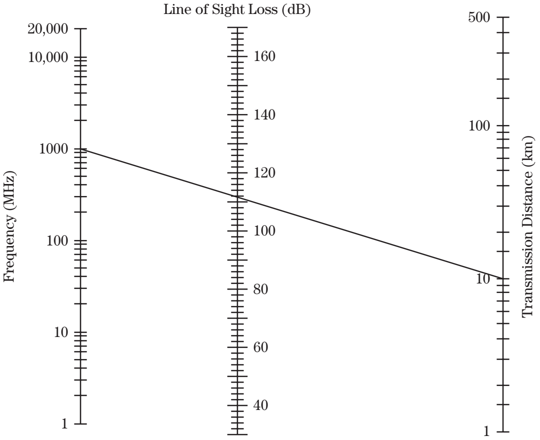
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

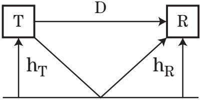


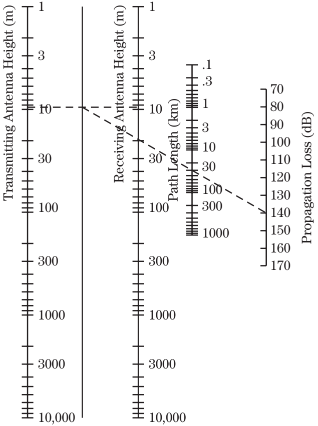
Two ray loss

$L = D^4 / \left[h_T^2 \, h_R^2 \right]$ L is ratio, D, h_T & h_R in meters

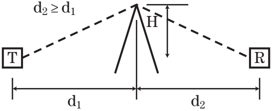
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



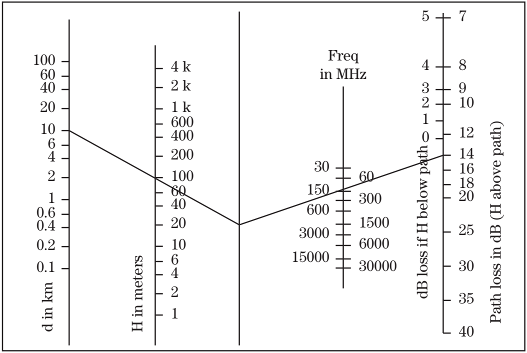


Knife edge diffraction geometry

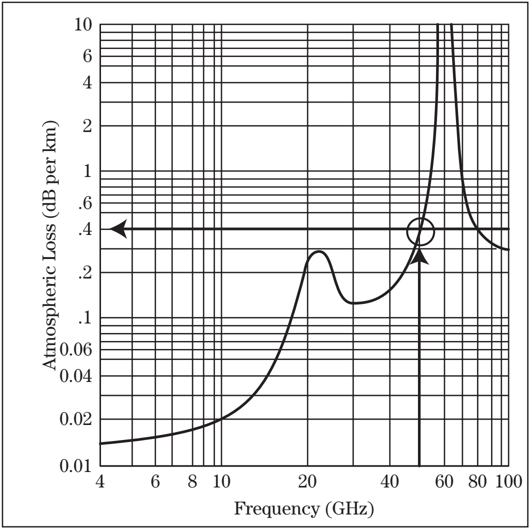


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

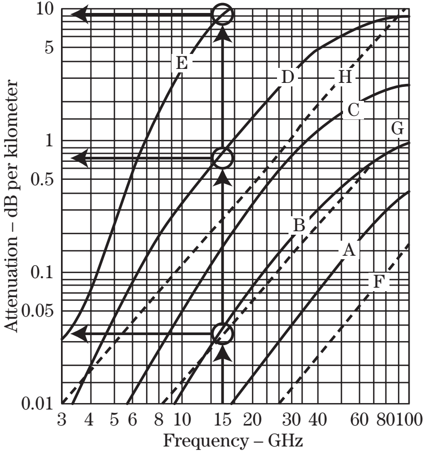
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



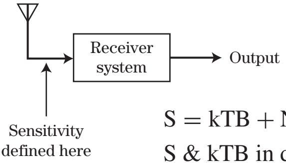
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

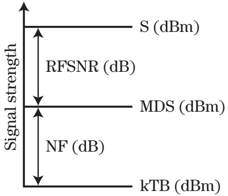


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

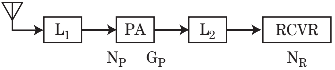


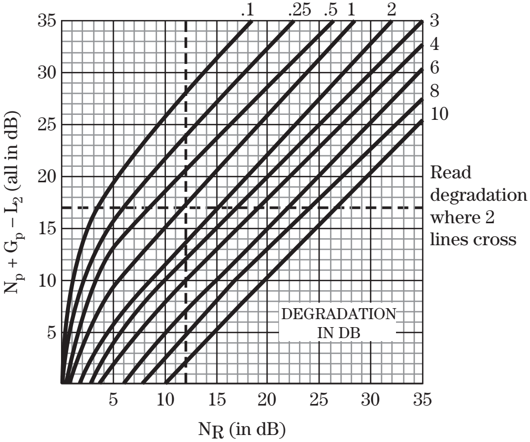
kTB(in dBm) $= -114 + 10 \log (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

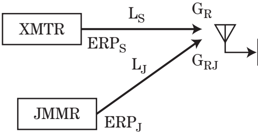
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

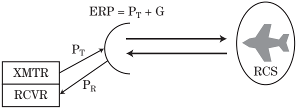
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

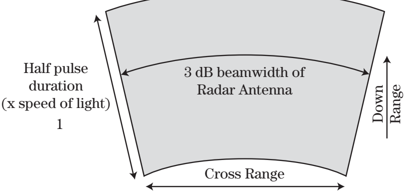
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20\,\text{Log}\,F - 40\,\text{Log}\,R + 10\,\text{Log}\,\sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

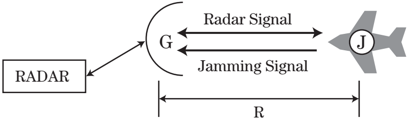


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

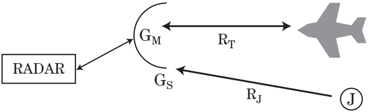
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\textbf{J/S} = (4\pi \text{ERP}_J G_S R_T^4)/(\text{ERP}_S G_M R_J^2 \sigma)$$

(In dB)

$$\textbf{J/S} = \text{ERP}_J - \text{ERP}_S + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$$R_{BT} = 4^{\text{th}} \text{ root of } [(\text{ERP}_S\ G_M\ R_J^2 \sigma)/(4\pi \text{ERP}_J\ G_S)]$$

(In dB)

$$40 \text{ Log } R_T = \text{ERP}_S - \text{ERP}_J - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + \text{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:
This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

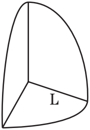
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

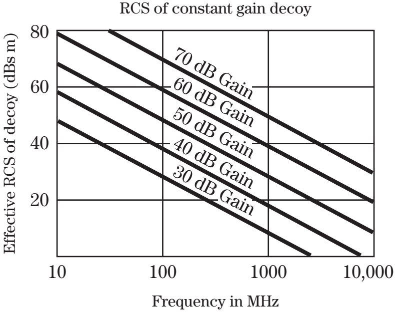
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

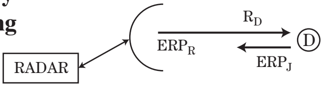


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

$N\ (dB) = 10 \log_{10}\ (N)$ Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30\ dB$

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

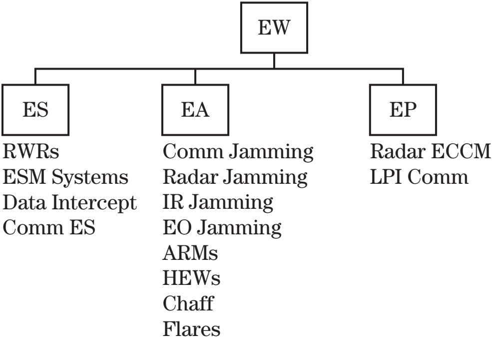
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



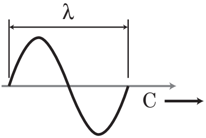
Frequency

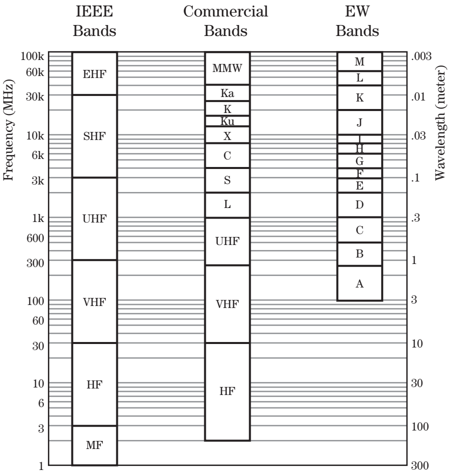
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

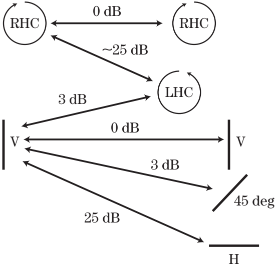
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

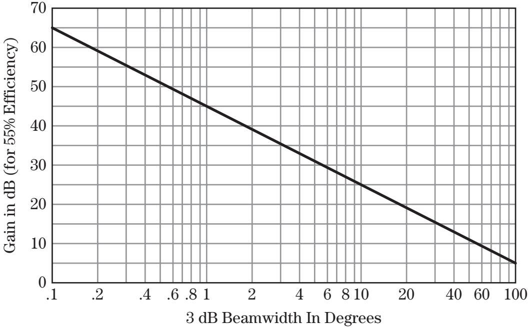
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

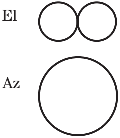
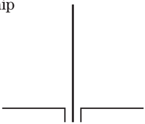
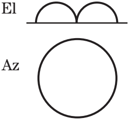
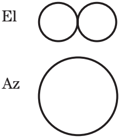
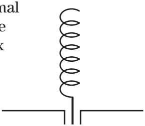
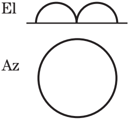
Peak gain vs. 3 dB beamwidth for 55% eff. dish

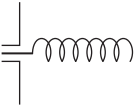
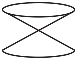
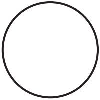
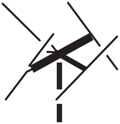
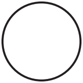
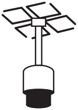
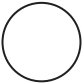


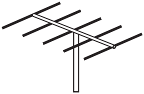
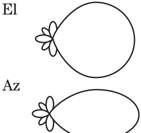
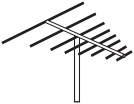
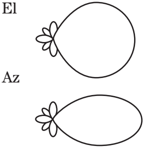
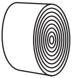
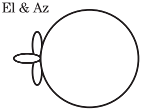
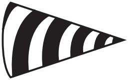
Antenna efficiency

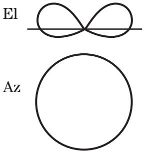
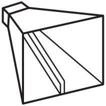
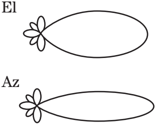
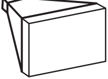
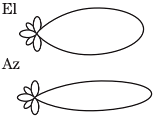
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

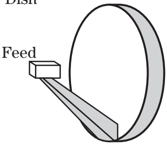
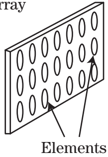
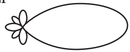
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

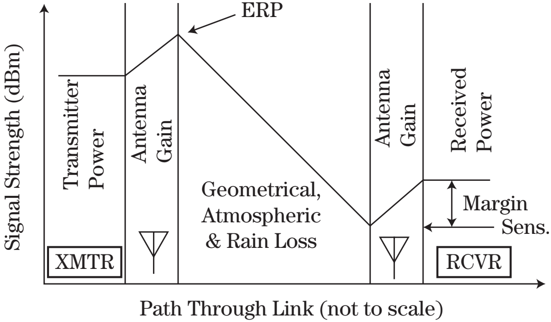
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 		Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 		Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 		Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 		Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral			Polarization: Circular Beamwidth: $50^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn			Polarization: Linear Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer			Polarization: Circular Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$	P_T & P_R in Watts G_T, G_R & L are ratios
P_R (in dB) $= P_T + G_T - L + G_R$	P_T & P_R in dBm G_T, G_R & L in dB L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

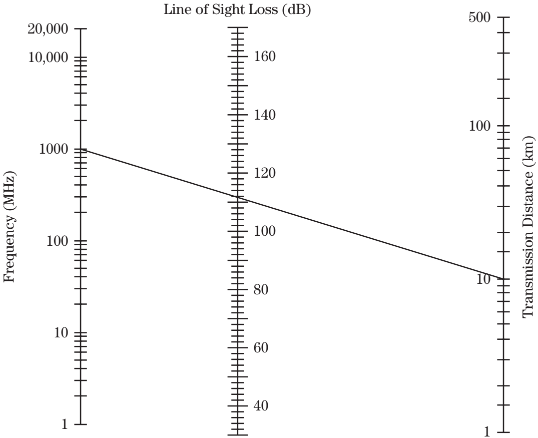
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph



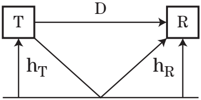
Two ray loss

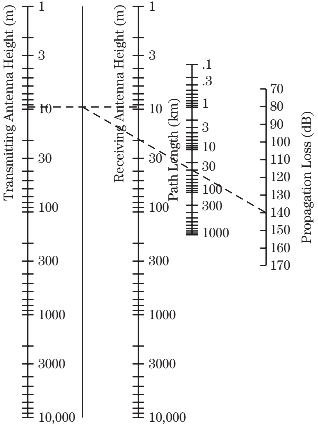
$$L = D^4 / \left[h_T^2\, h_R^2\right] \qquad \text{L is ratio, D, } h_T \text{ \& } h_R \text{ in meters}$$

$$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$$

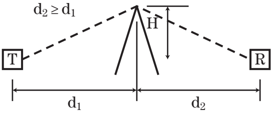
$$\text{D in km, } h_T \text{ \& } h_R \text{ in meters}$$

Two ray loss Nomograph



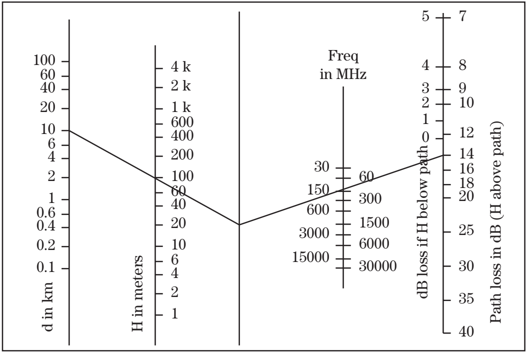


Knife edge diffraction geometry

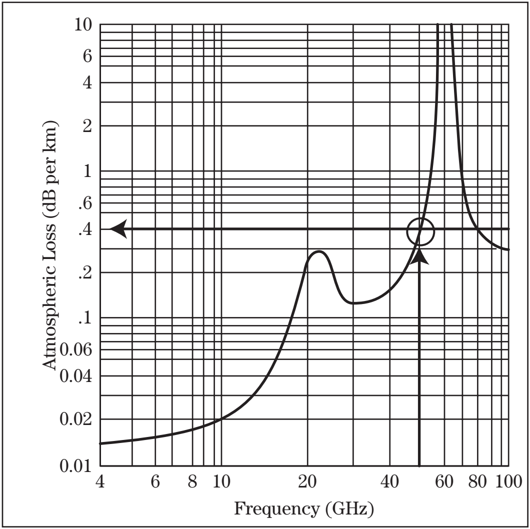


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

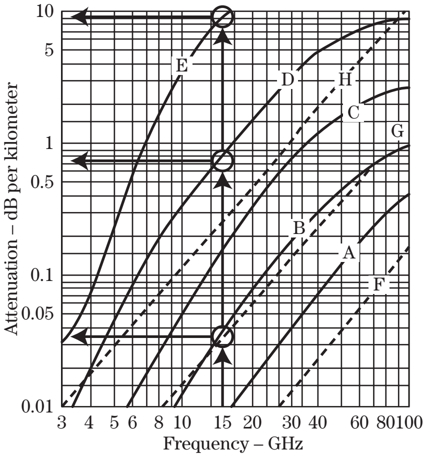
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



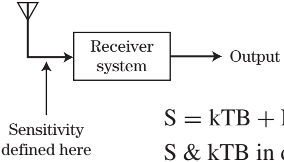
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

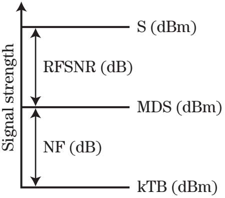


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

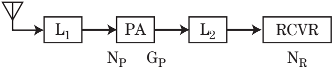


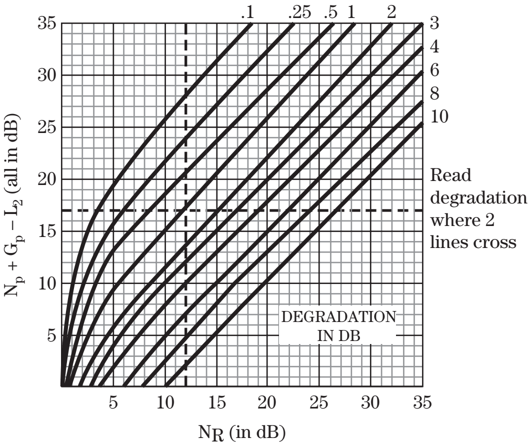
kTB(in dBm) $= -114 + 10\ \log\ (BW/1\ \text{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

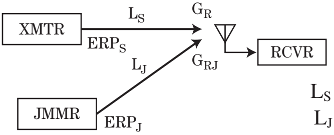
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

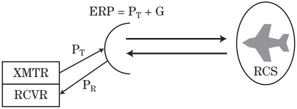
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

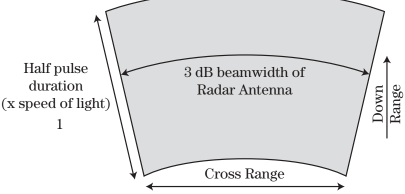
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \,\text{Log}\, F - 40 \,\text{Log}\, R + 10 \,\text{Log}\, \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

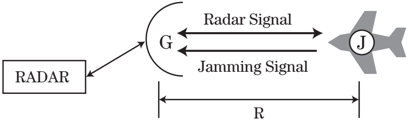


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

J/S $= (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) **J/S** $= ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

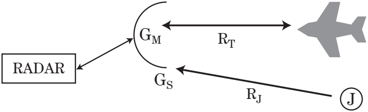
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40\ \mathrm{Log}\ R_T - 20 \log R_J - 10\ \mathrm{Log\ RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40\ \mathrm{Log}\ R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40\ \mathrm{Log}\ R_T - 20\ \mathrm{Log}\ R_J + 10\ \mathrm{Log\ RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40\ \mathrm{Log}\ R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- $0.925\ N\sigma_1$ with λ spacing
- $0.981\ N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

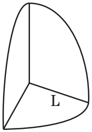
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

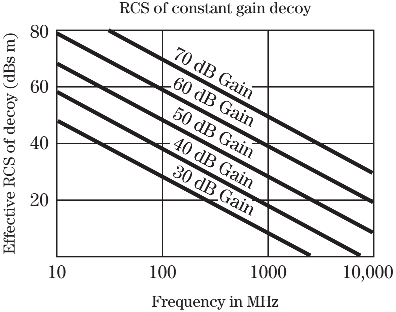
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

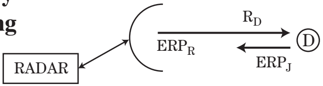


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) $= 10\log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

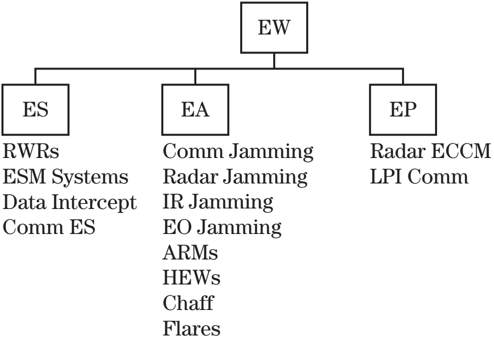
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



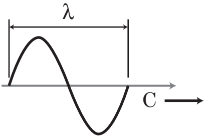
Frequency

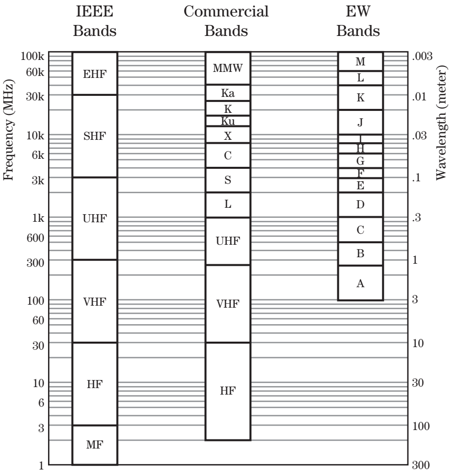
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

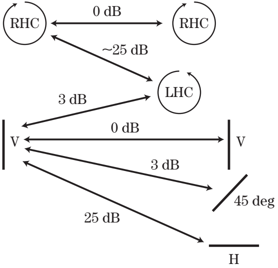
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

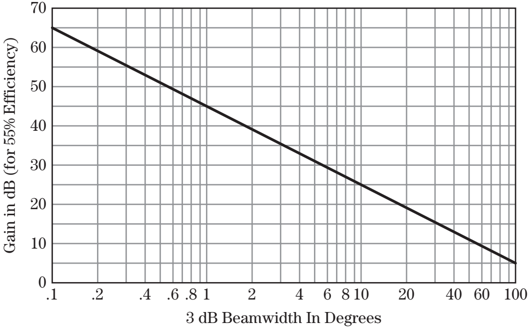
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

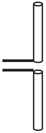
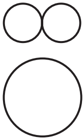
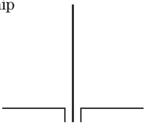
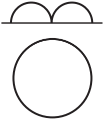
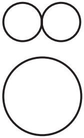
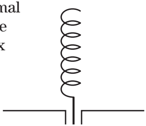
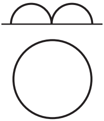
Peak gain vs. 3 dB beamwidth for 55% eff. dish

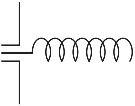
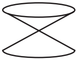
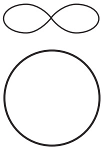
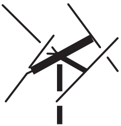
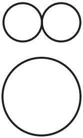
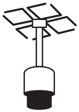
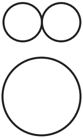


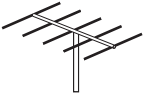
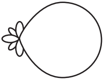
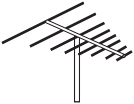
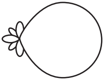
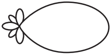
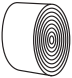
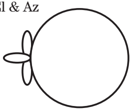
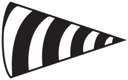
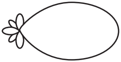
Antenna efficiency

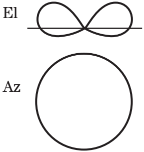
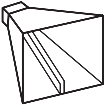
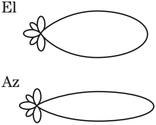
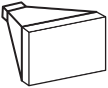
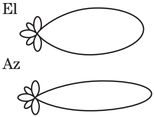
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

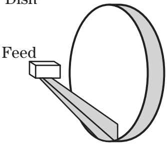
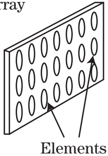
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 	El Az 	Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 	El Az 	Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 	El Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 	El Az 	Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

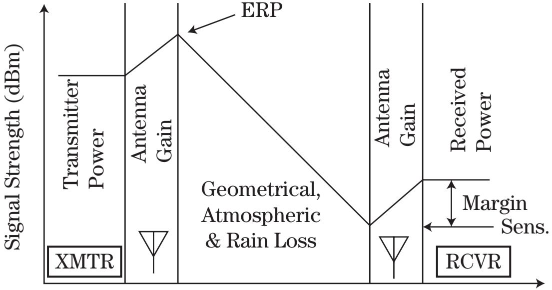
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El  Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El  Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral			Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn			Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer			Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

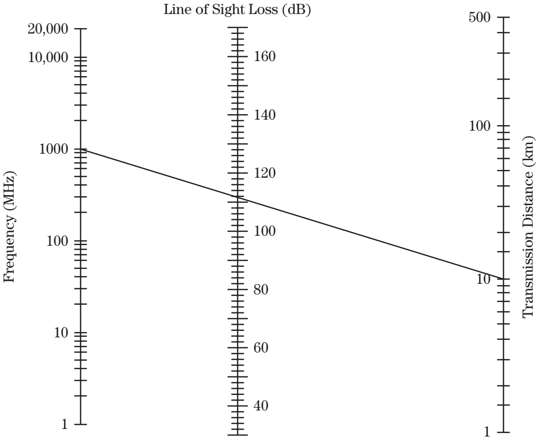
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

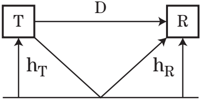


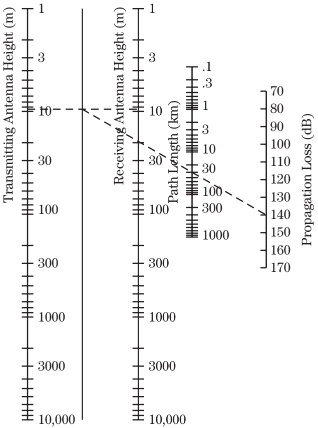
Two ray loss

$L = D^4/\left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

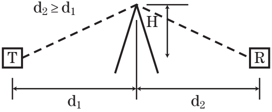
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



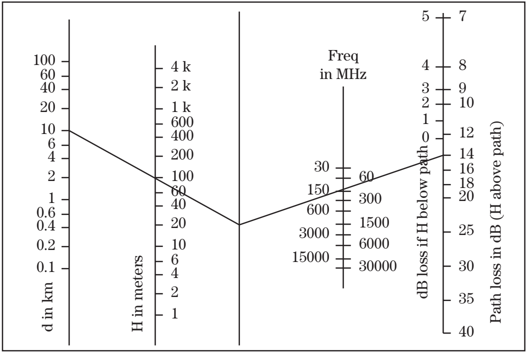


Knife edge diffraction geometry

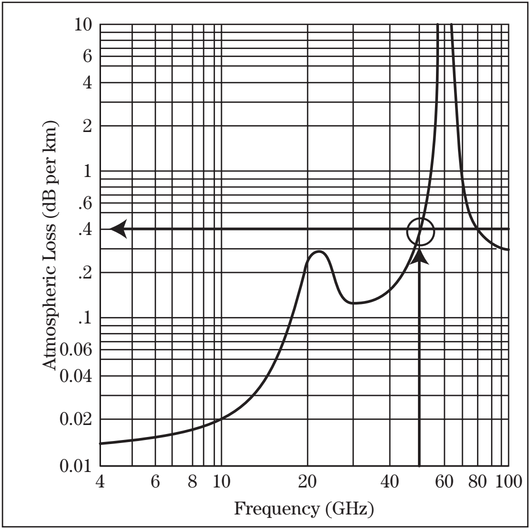


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

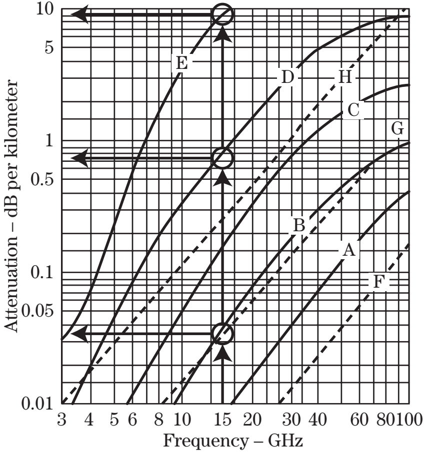
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



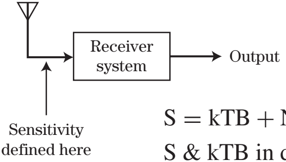
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

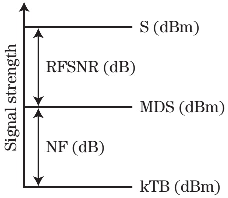


S = kTB + NF + RFSNR

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

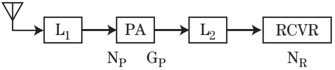


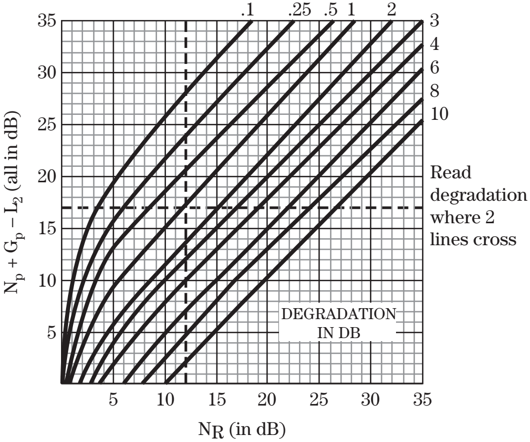
kTB(in dBm) = −114 + 10 log (BW/1 MHz)

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

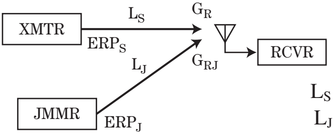
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

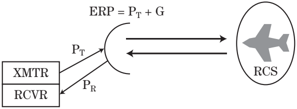
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

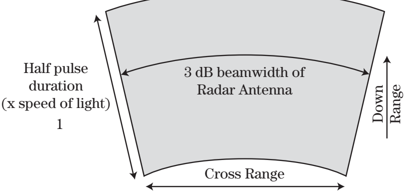
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$\text{(dB)}\, P_R = P_T + 2G - 103 - 20 \,\text{Log}\, F - 40 \,\text{Log}\, R + 10 \,\text{Log}\, \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

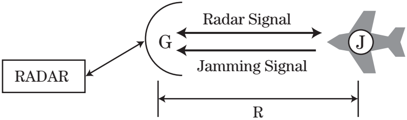


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

J/S $= (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) **J/S** $= ERP_J - ERP_S + 71 + 20 \text{ Log R} - 10 \text{ Log } \sigma$

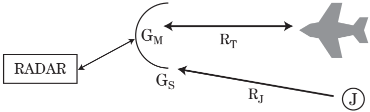
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log R}]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$$R_{BT} = 4^{th} \text{ root of } [(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$$

(In dB)

$$40 \text{ Log } R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + \text{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:
This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- $0.925\ N\sigma_1$ with λ spacing
- $0.981\ N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

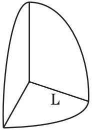
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

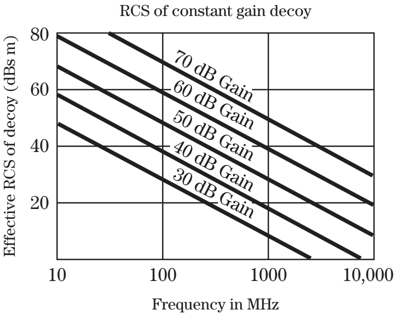
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

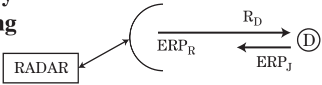


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B(dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

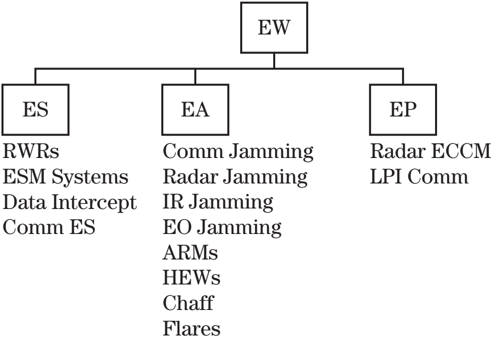
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



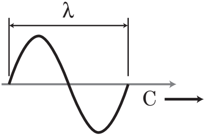
Frequency

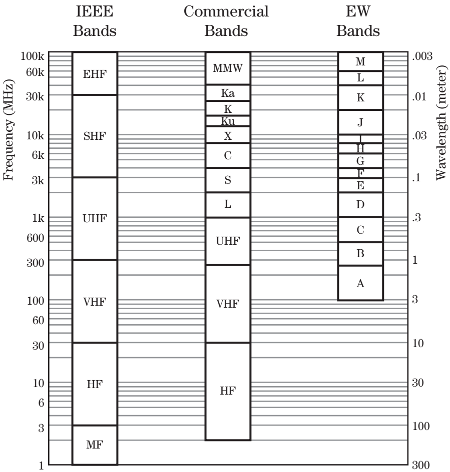
$\lambda = c/F$

λ in meters

$c = 3 \times 10^8$ m/sec

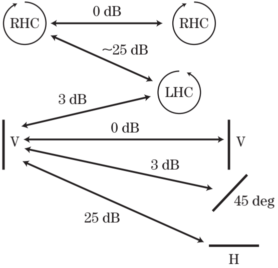
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

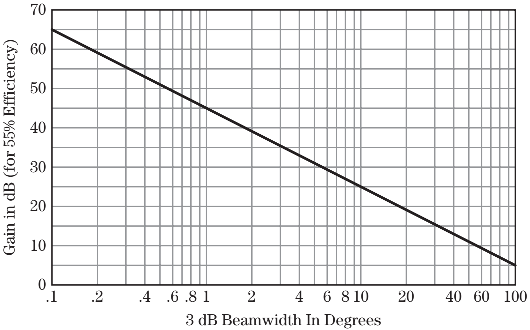
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

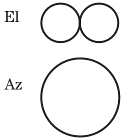
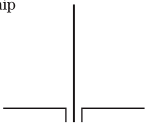
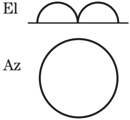
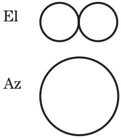
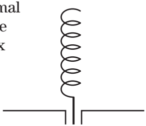
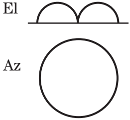
Peak gain vs. 3 dB beamwidth for 55% eff. dish

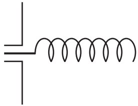
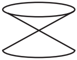
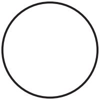
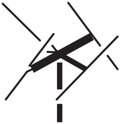
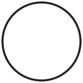
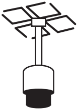
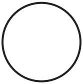


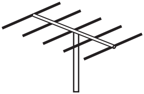
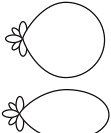
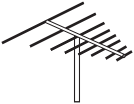
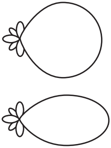
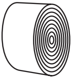
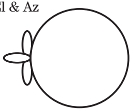
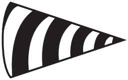
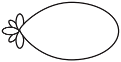
Antenna efficiency

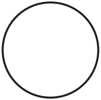
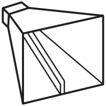
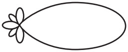
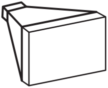
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

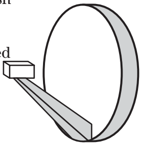
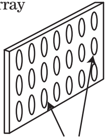
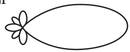
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

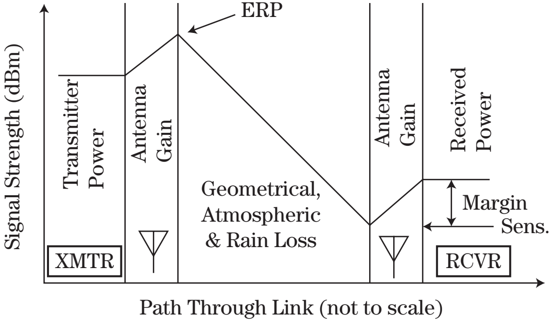
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El, Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El, Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral		El  Az 	Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn		El  Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer		El  Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish Feed 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  Elements	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss) Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

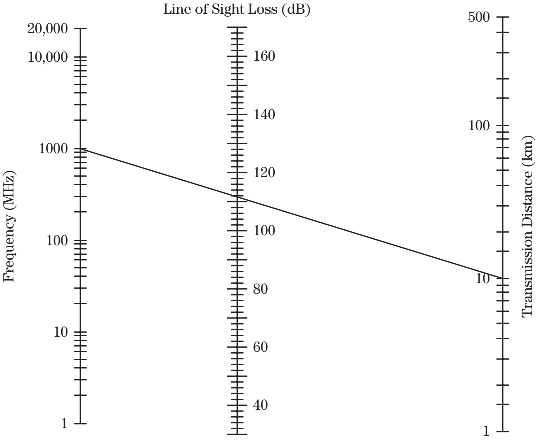
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20 \log(F) + 20 \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph



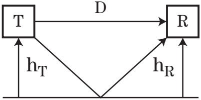
Two ray loss

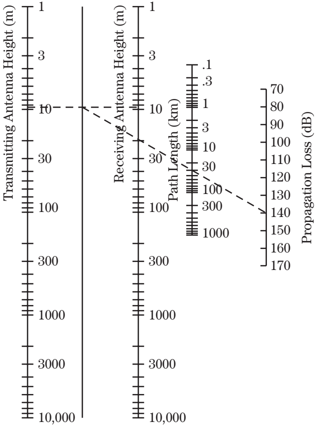
$L = D^4/\left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$

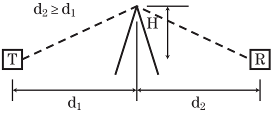
D in km, h_T & h_R in meters

Two ray loss Nomograph



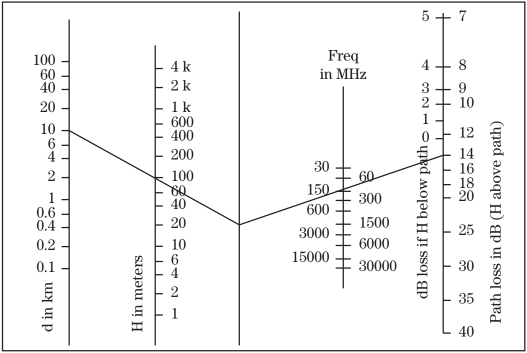


Knife edge diffraction geometry

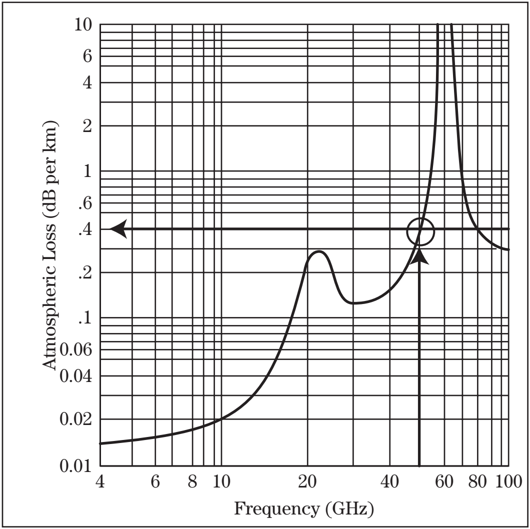


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)] \, d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

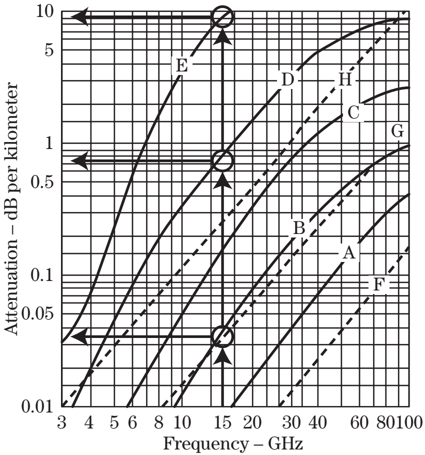
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



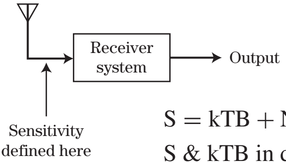
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

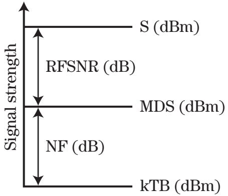


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

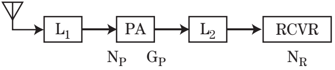


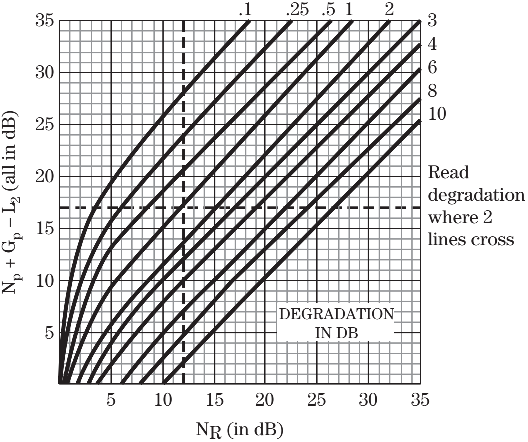
kTB(in dBm) $= -114 + 10 \log (\text{BW}/1 \text{ MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB)

G_P = PA Gain (dB)

N_P = PA NF (dB)

N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

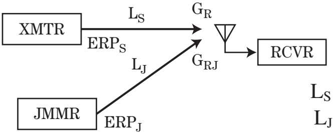
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

$R_E$in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

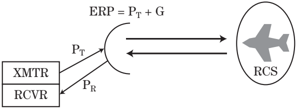
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

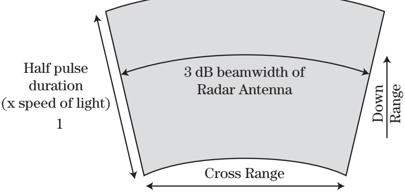
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

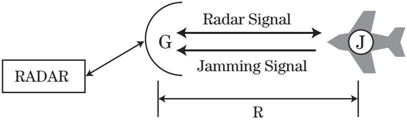


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

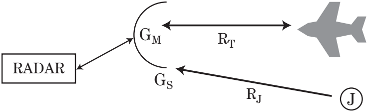
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



J/S $= (4\pi \mathrm{ERP_J G_S R_T^4})/(\mathrm{ERP_S G_M R_J^2}\sigma)$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + \mathrm{G_S} - \mathrm{G_M} + 40\ \mathrm{Log}\ \mathrm{R_T} - 20\log \mathrm{R_J} - 10\ \mathrm{Log\ RCS}$$

Burn through range

$\mathrm{R_{BT}} = 4^{\text{th}}$ root of $[(\mathrm{ERP_S\ G_M\ R_J^2}\sigma)/(4\pi \mathrm{ERP_J\ G_S})]$

(In dB)

$$40\,\mathrm{Log}\,\mathrm{R_T} = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - \mathrm{G_S} + \mathrm{G_M} + 40\,\mathrm{Log}\,\mathrm{R_T} - 20\,\mathrm{Log}\,\mathrm{R_J} + 10\,\mathrm{Log\,RCS} + \mathrm{J/S(Required)}$$

$$\mathrm{R_{BT}} = \text{Anti-Log}\{[40\ \mathrm{Log}\ \mathrm{R_T}]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

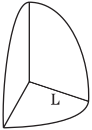
Start within radar resolution cell, capture tracking radar, move resolution cell away from target

Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

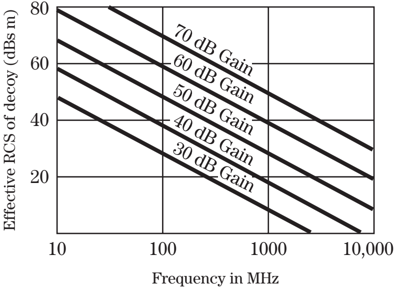


$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

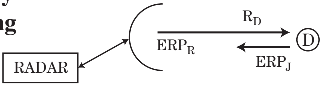
Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

$N\,(dB) = 10\log_{10}(N)$ Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\,(dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10\,\text{Log}(\text{number not in dB})$
$A(dB) \pm 20\,\text{Log}(\text{number not in dB})$
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30\text{ dB}$

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

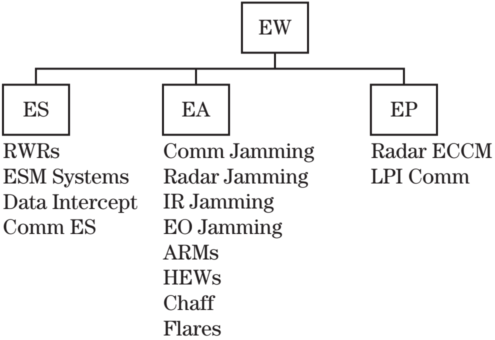
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



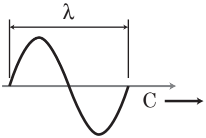
Frequency

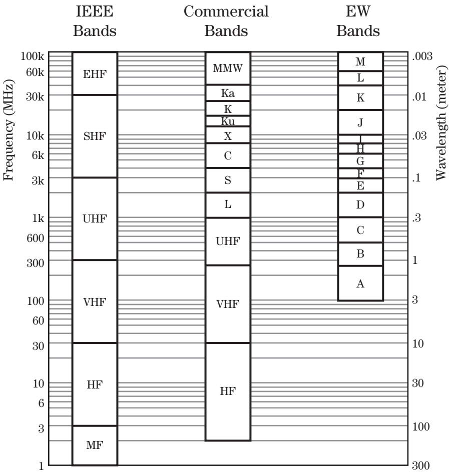
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

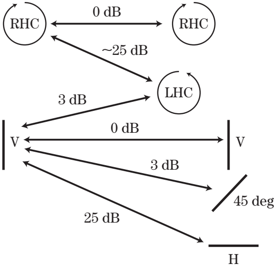
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

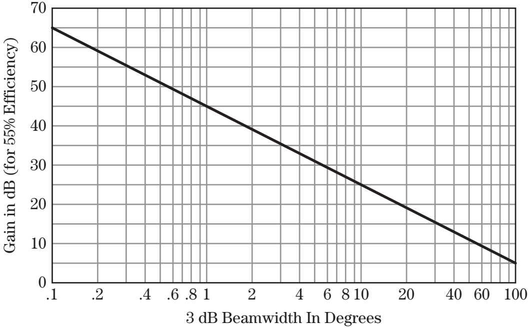
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

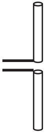
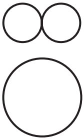
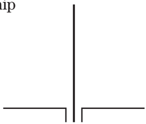
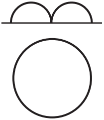
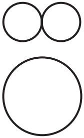
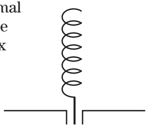
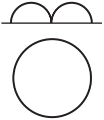
Peak gain vs. 3 dB beamwidth for 55% eff. dish

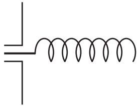
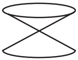
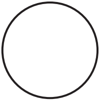
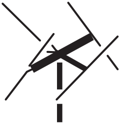
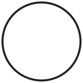
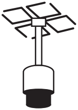
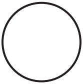


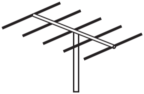
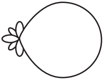
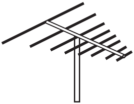
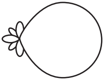
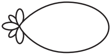
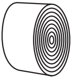
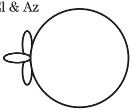
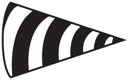
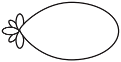
Antenna efficiency

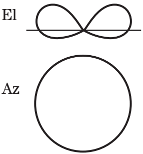
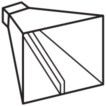
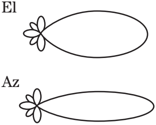
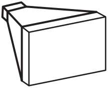
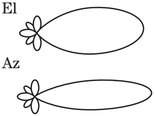
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

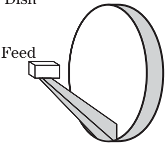
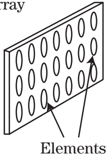
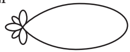
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole		El, Az 	Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip		El, Az 	Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop		El, Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix		El, Az 	Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

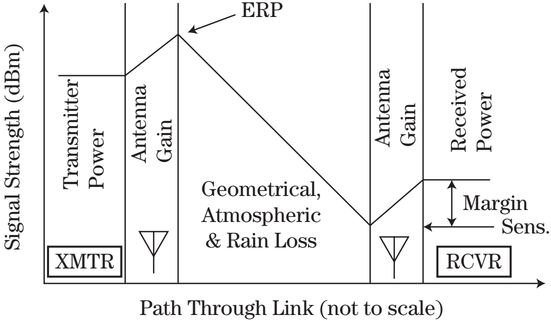
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El  Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El  Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 		Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 		Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 		Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss) Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

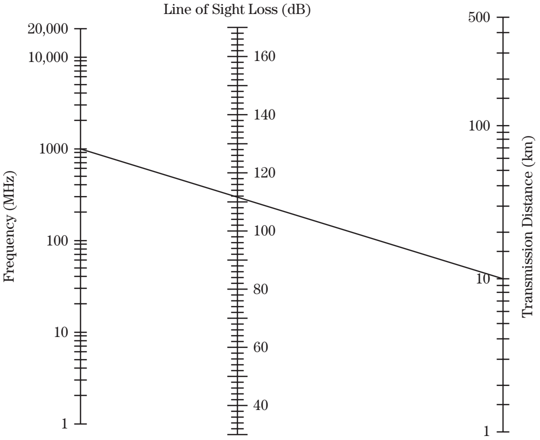
Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

L(in dB) = 32.44 + 20 log(F) + 20 log(D)
F in MHz D in km

Line of Sight (Free Space) Nomograph



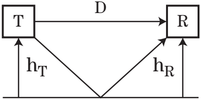
Two ray loss

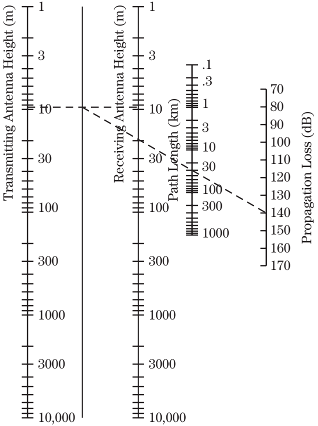
$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$

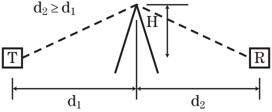
D in km, h_T & h_R in meters

Two ray loss Nomograph



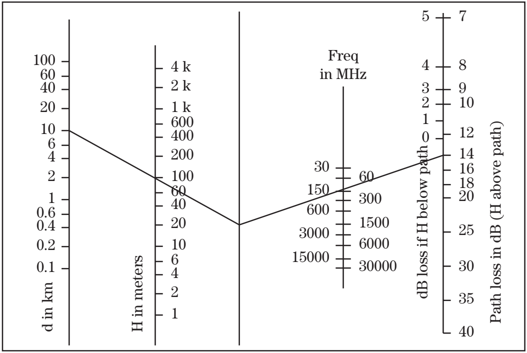


Knife edge diffraction geometry

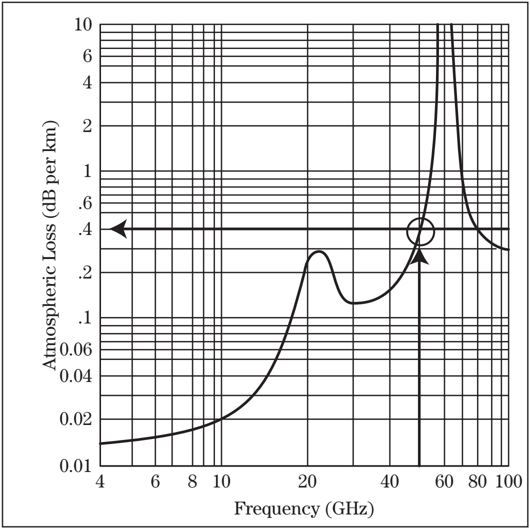


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

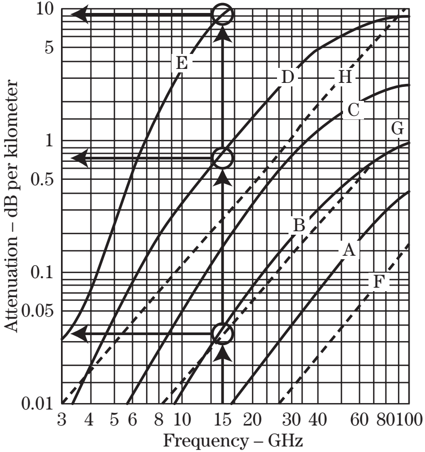
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



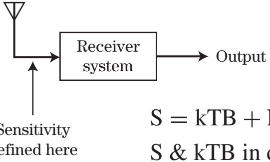
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

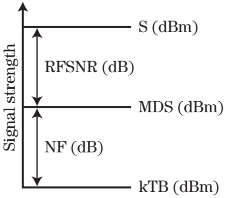


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

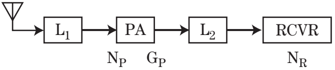


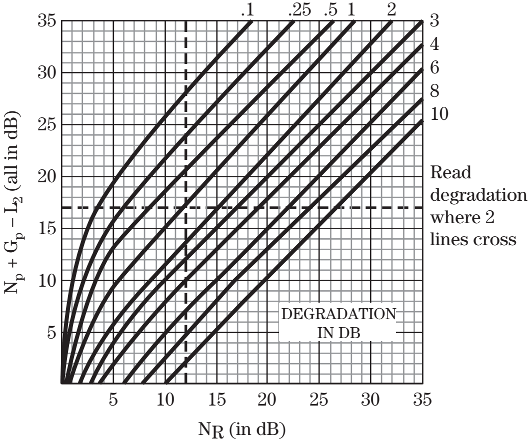
kTB(in dBm) = $-114 + 10 \log(\text{BW}/1\ \text{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

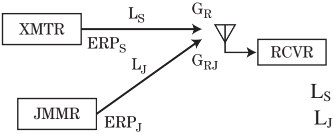
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

$R_E$in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

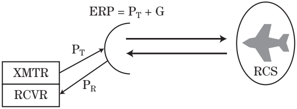
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

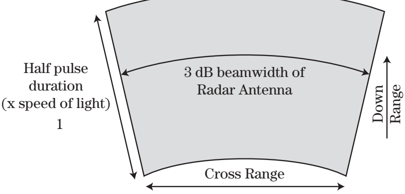
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

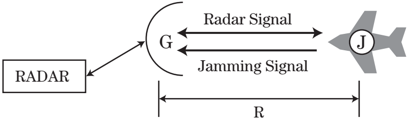


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

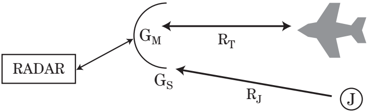
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



J/S $= (4\pi ERP_J G_S R_T^4)/(ERP_S G_M R_J^2 \sigma)$

(In dB)

$$\mathbf{J/S} = ERP_J - ERP_S + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(ERP_S\ G_M\ R_J^2 \sigma)/(4\pi ERP_J\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = ERP_S - ERP_J - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

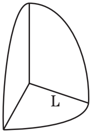
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

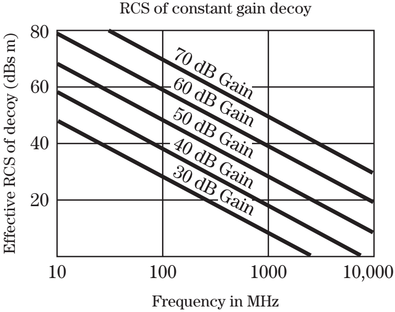
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

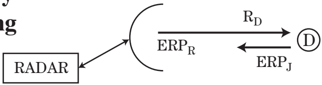


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F) L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) – B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

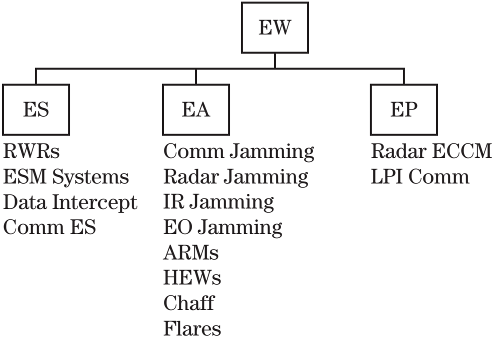
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



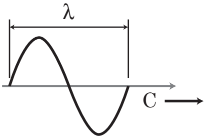
Frequency

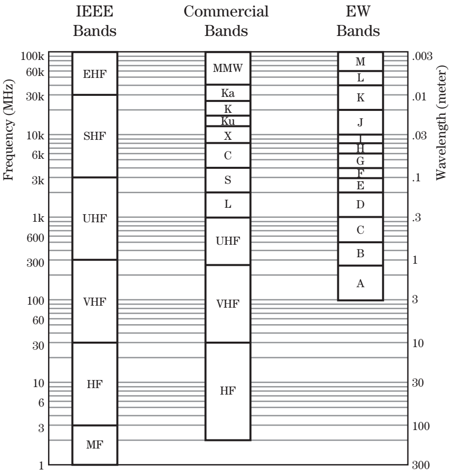
$$\lambda = c/F$$

λ in meters

$c = 3 \times 10^8$ m/sec

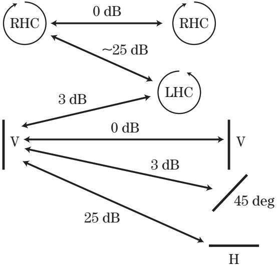
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

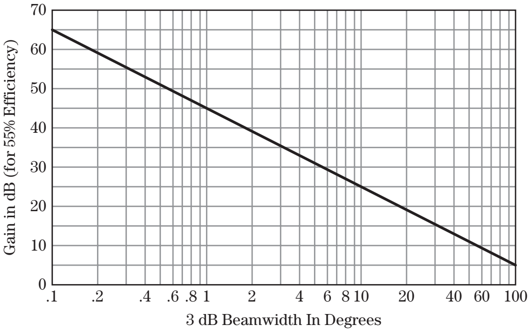
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

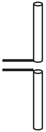
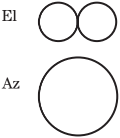
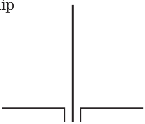
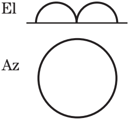
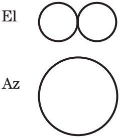
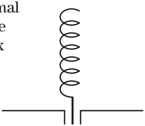
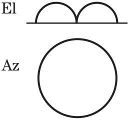
Peak gain vs. 3 dB beamwidth for 55% eff. dish

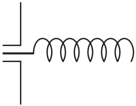
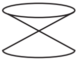
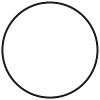
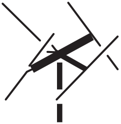
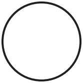
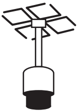
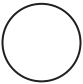


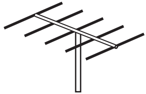
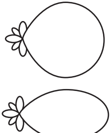
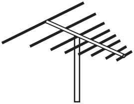
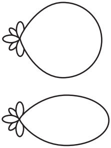
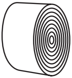
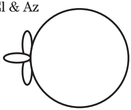
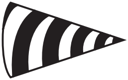
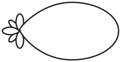
Antenna efficiency

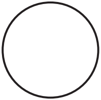
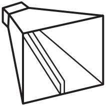
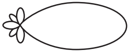
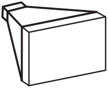
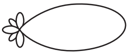
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

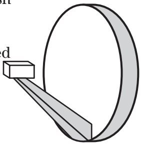
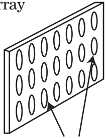
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

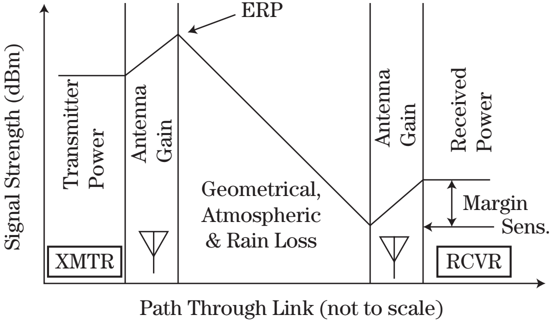
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral		El  Az 	Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn		El  Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer		El  Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish Feed 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  Elements	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

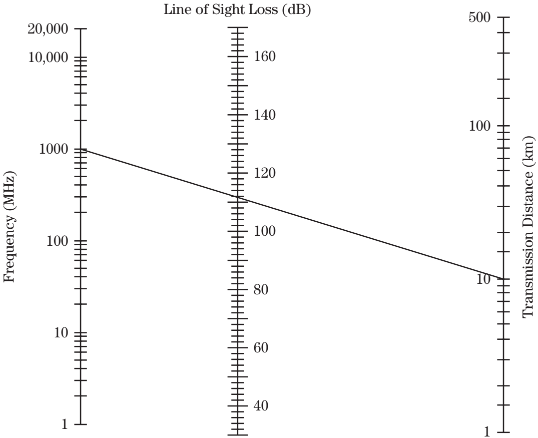
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

L(in dB) = 32.44 + 20 log(F) + 20 log(D)

F in MHz D in km

Line of Sight (Free Space) Nomograph



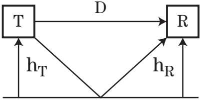
Two ray loss

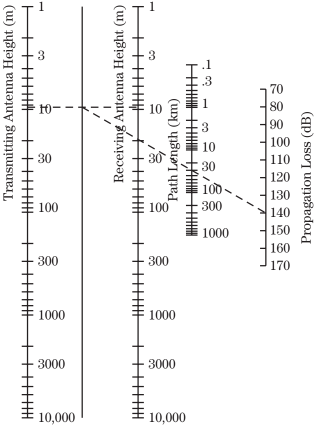
$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$

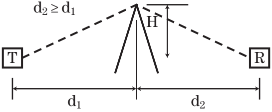
D in km, h_T & h_R in meters

Two ray loss Nomograph



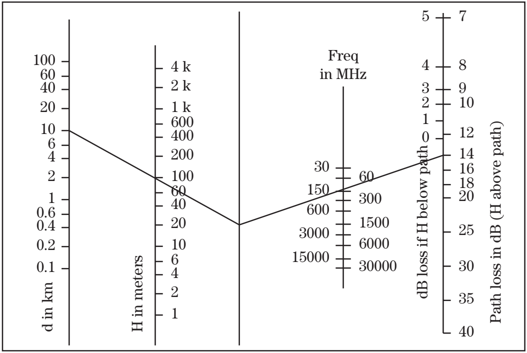


Knife edge diffraction geometry

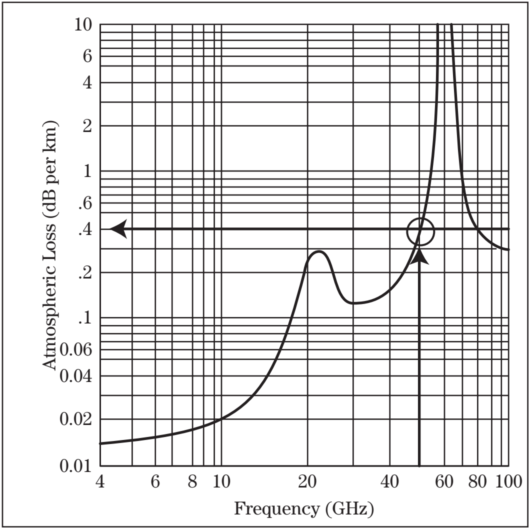


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

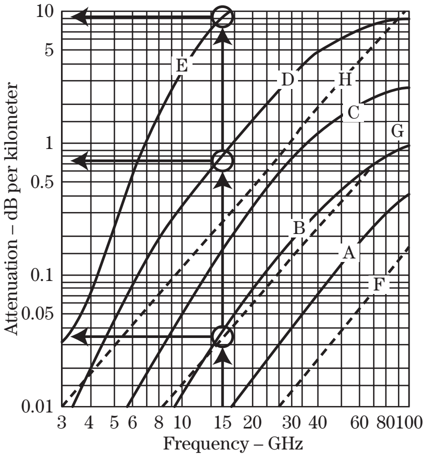
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



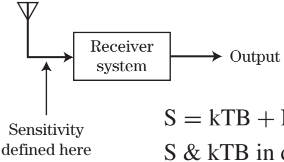
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

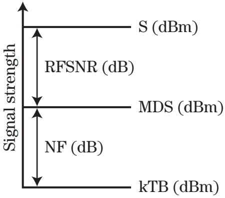


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

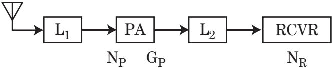


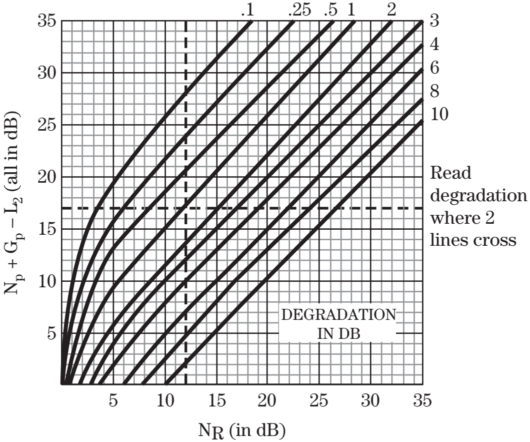
kTB(in dBm) $= -114 + 10 \log (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

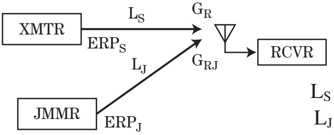
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

$R_E$in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

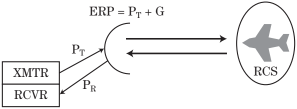
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

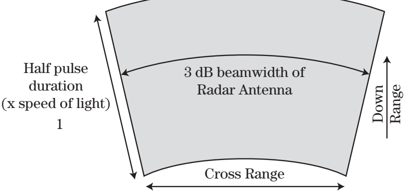
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$\text{(dB)}\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

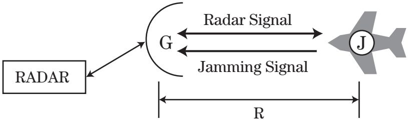


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

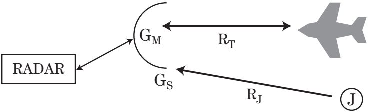
Burn through range

$$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log } RCS + J/S \text{ (Rqd)}$

$$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$$

Remote Jamming



$$\mathbf{J/S} = (4\pi ERP_J G_S R_T^4)/(ERP_S G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = ERP_J - ERP_S + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(ERP_S\ G_M\ R_J^2 \sigma)/(4\pi ERP_J\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = ERP_S - ERP_J - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

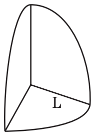
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

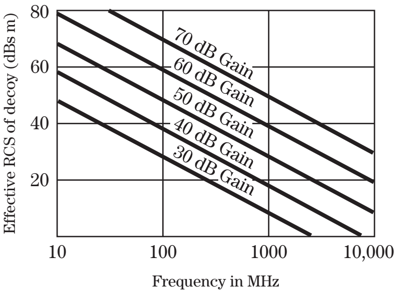
$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$



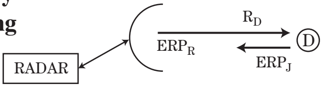
Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$
ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in $^\circ$Kelvin

List of Abbreviations

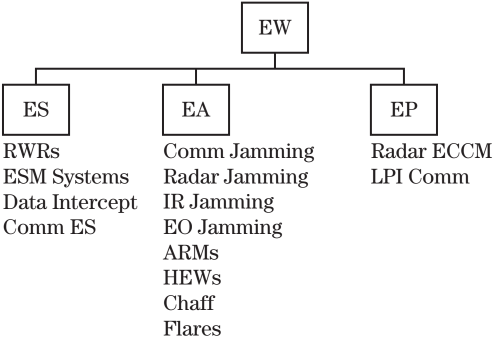
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



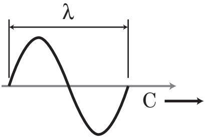
Frequency

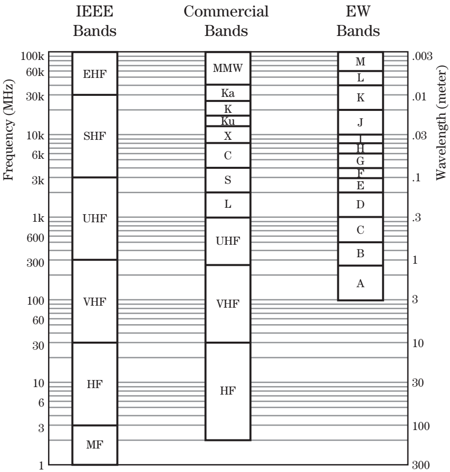
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

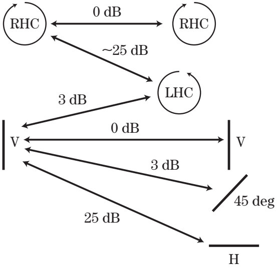
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

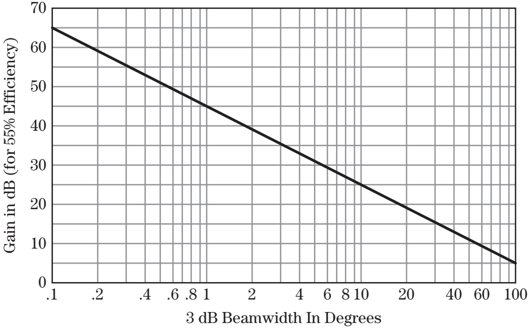
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

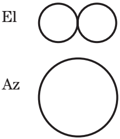
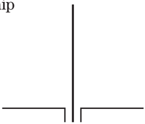
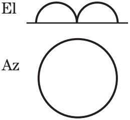
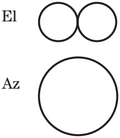
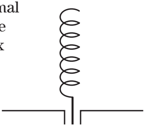
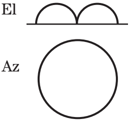
Peak gain vs. 3 dB beamwidth for 55% eff. dish

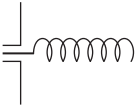
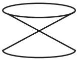
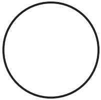
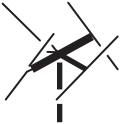
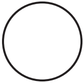
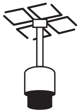
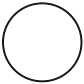


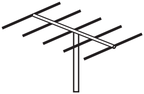
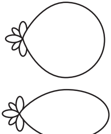
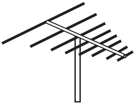
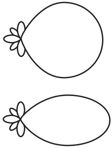
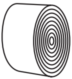
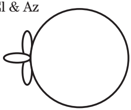
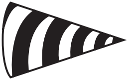
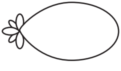
Antenna efficiency

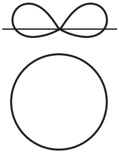
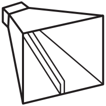
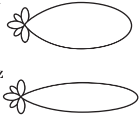
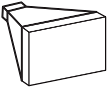
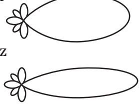
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

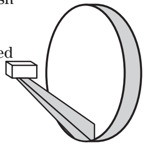
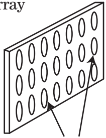
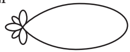
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

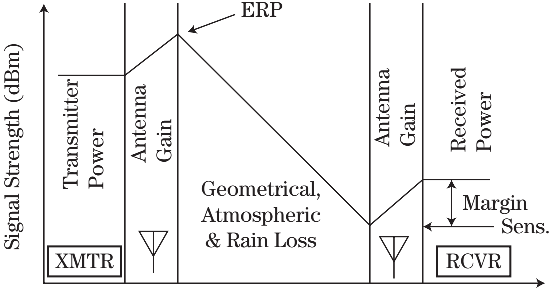
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El Az 	Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

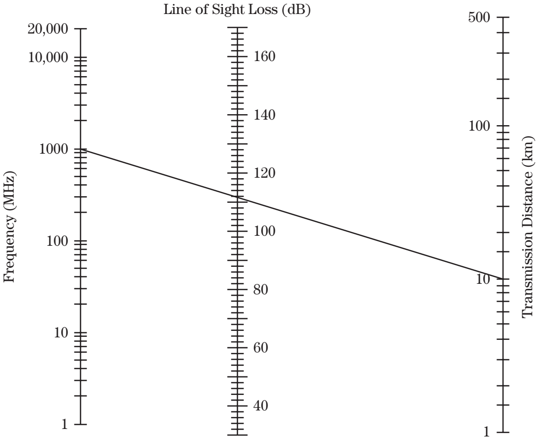
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

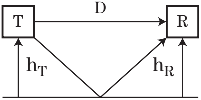


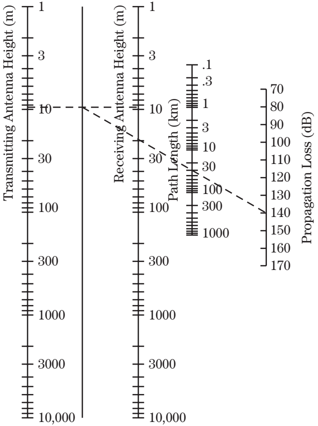
Two ray loss

$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

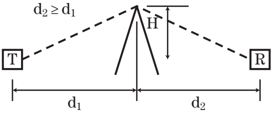
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$ D in km, h_T & h_R in meters

Two ray loss Nomograph



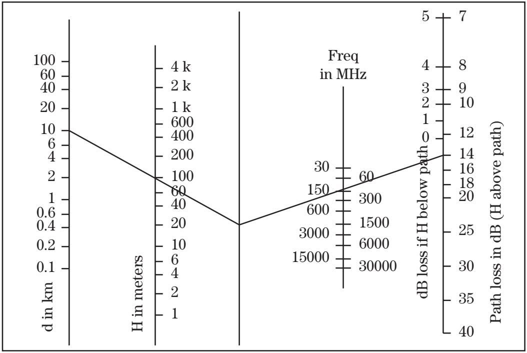


Knife edge diffraction geometry

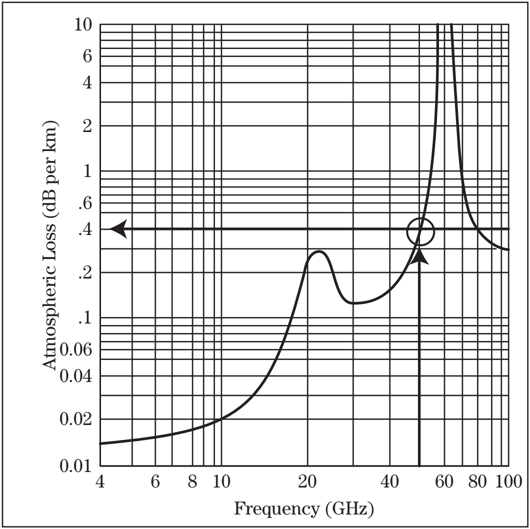


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

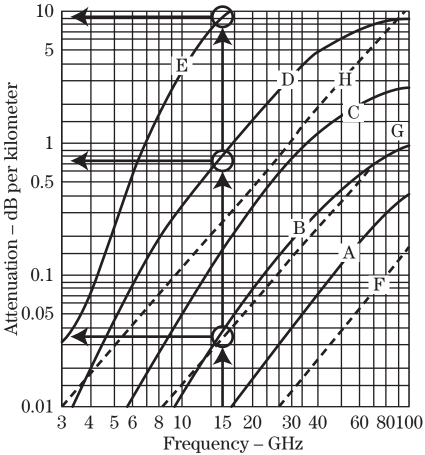
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



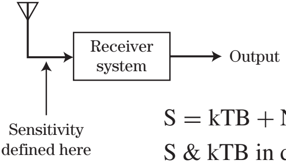
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

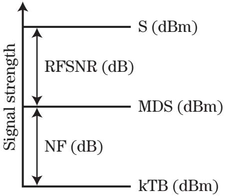


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

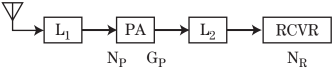


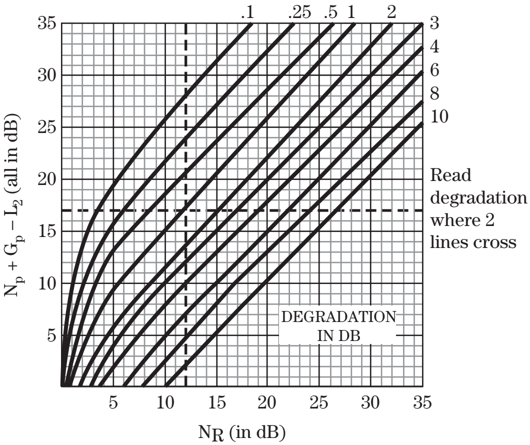
kTB(in dBm) $= -114 + 10 \log (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

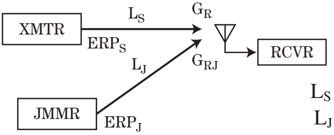
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

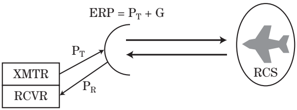
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

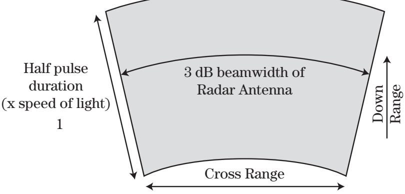
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20\,\text{Log}\,F - 40\,\text{Log}\,R + 10\,\text{Log}\,\sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

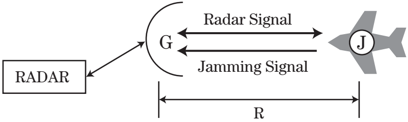


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

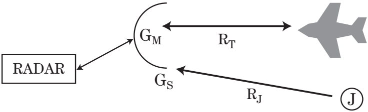
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2\sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\,\lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

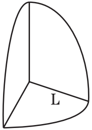
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

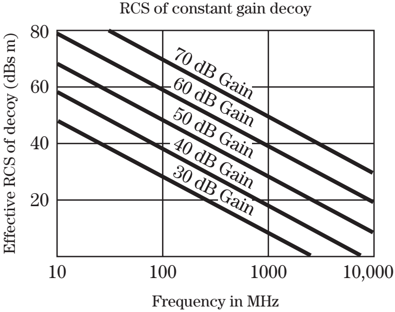
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

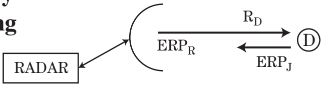


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$\text{RCS(dBsm)} = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, N(dB) = $20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

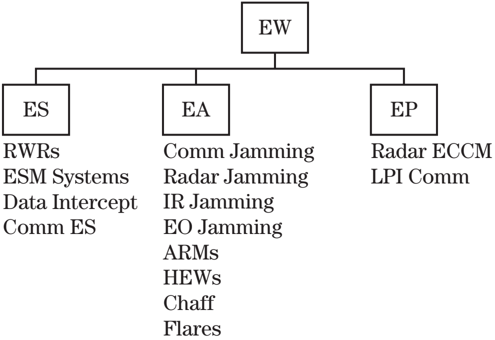
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



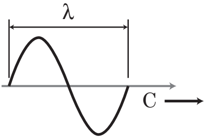
Frequency

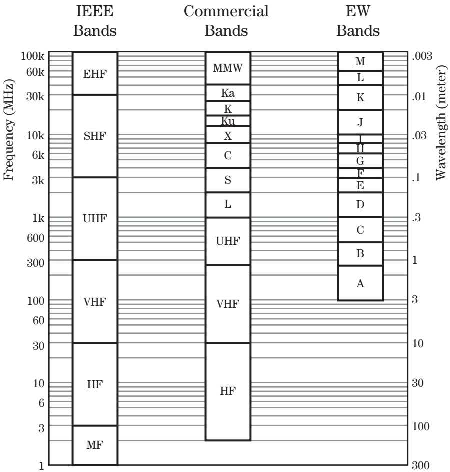
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

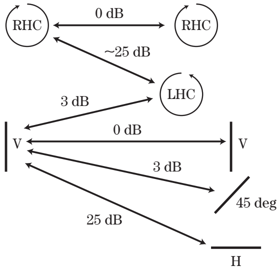
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

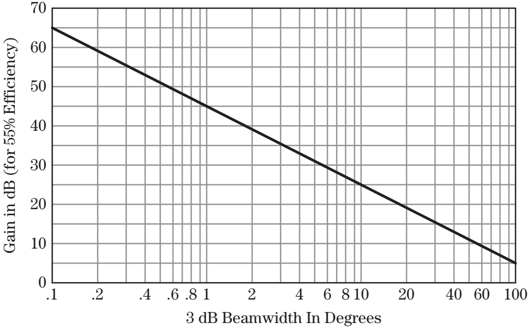
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

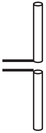
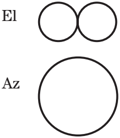
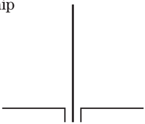
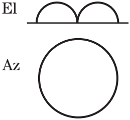
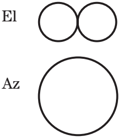
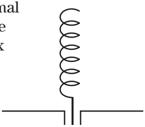
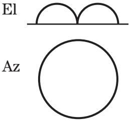
Peak gain vs. 3 dB beamwidth for 55% eff. dish

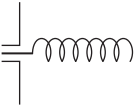
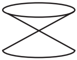
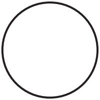
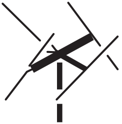
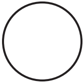
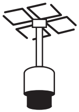
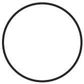


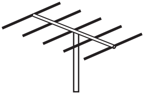
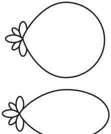
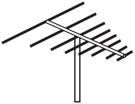
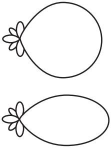
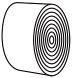
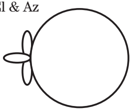
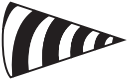
Antenna efficiency

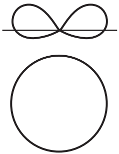
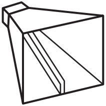
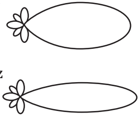
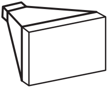
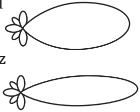
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

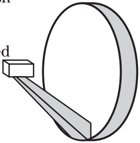
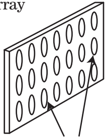
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

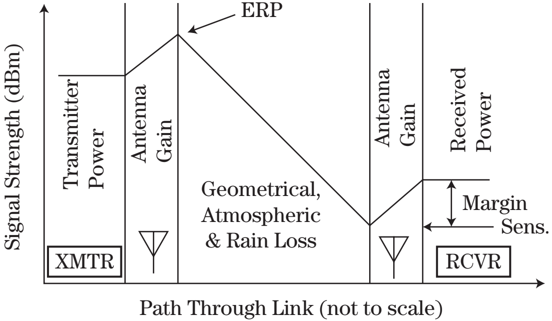
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El, Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El, Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral		El Az 	Polarization: Circular Beamwidth: $50^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn		El Az 	Polarization: Linear Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer		El Az 	Polarization: Circular Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish Feed 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  Elements	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

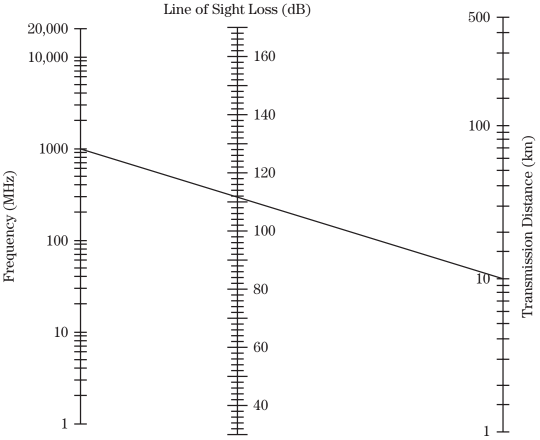
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

L(in dB) = 32.44 + 20 log(F) + 20 log(D)

F in MHz D in km

Line of Sight (Free Space) Nomograph

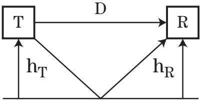


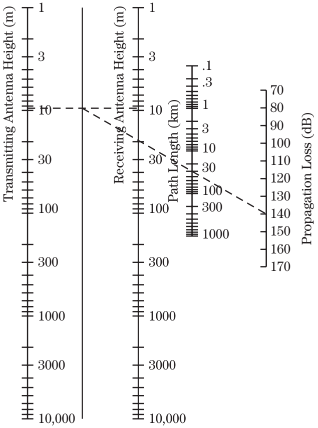
Two ray loss

$L = D^4 / \left[h_T^2 \, h_R^2 \right]$ L is ratio, D, h_T & h_R in meters

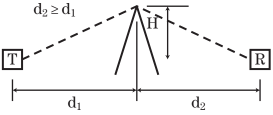
$L(\text{in dB}) = 120 + 40 \log(D) - 20 \log(h_T) - 20 \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



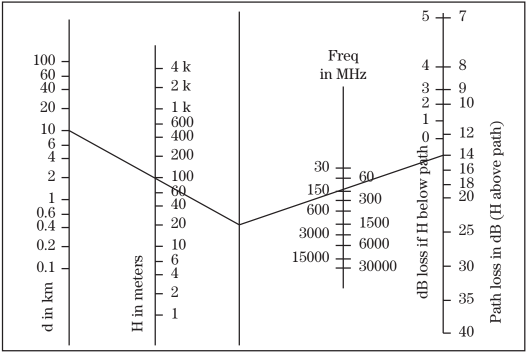


Knife edge diffraction geometry

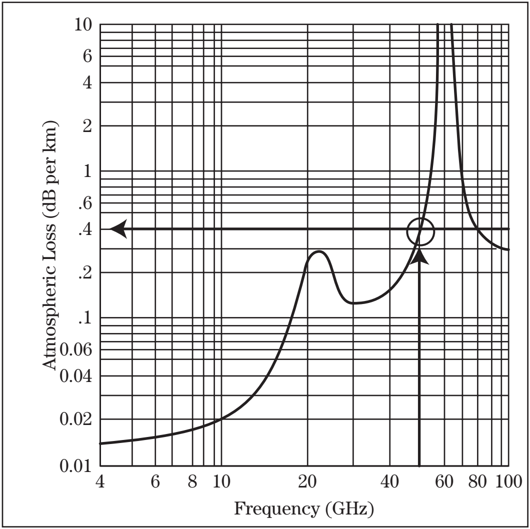


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

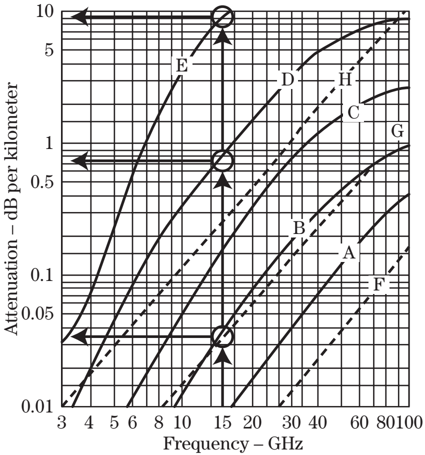
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



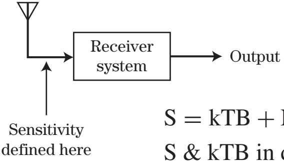
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

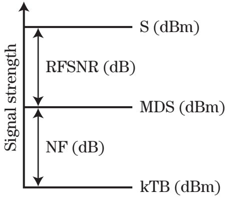


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

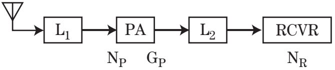
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

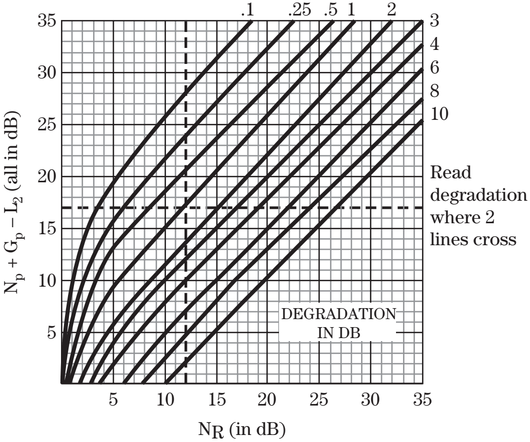


kTB(in dBm) $= -114 + 10 \log (BW/1\ \text{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20 \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

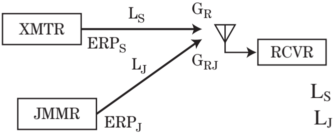
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

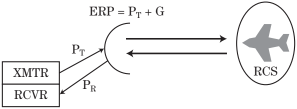
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

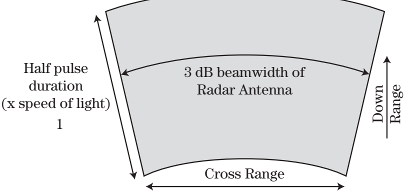
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

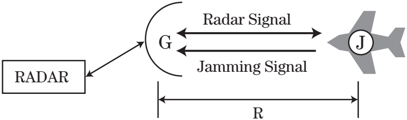


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} R^2)/(\mathrm{ERP_S}\sigma)$$

(In dB) $\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + 20 \,\mathrm{Log}\, R - 10 \,\mathrm{Log}\, \sigma$

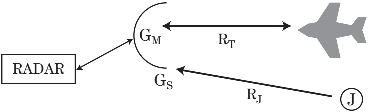
Burn through range

$R_{BT} = \mathrm{sqrt}[(\mathrm{ERP_S}\sigma)/(4\pi \mathrm{ERP_J})]$

(In dB) $20 \,\mathrm{Log}\, R_{BT} = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 + 10 \,\mathrm{Log}\, \mathrm{RCS} + \mathrm{J/S}\ (\mathrm{Rqd})$

$R_{BT} = \text{Anti-Log}\ \{[20 \,\mathrm{Log}\, R]/20\}$

Remote Jamming



$$\textbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\textbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40\ \mathrm{Log}\ R_T - 20 \log R_J - 10\ \mathrm{Log\ RCS}$$

Burn through range

$R_{BT} = 4^{\text{th}}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40\ \mathrm{Log}\ R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40\ \mathrm{Log}\ R_T - 20\ \mathrm{Log}\ R_J + 10\ \mathrm{Log\ RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40\ \mathrm{Log}\ R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

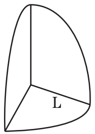
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

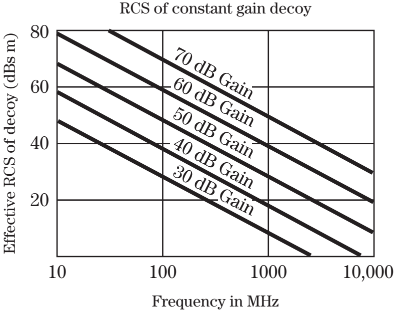
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

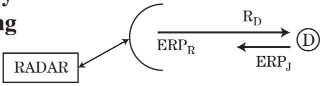


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

$N\ (dB) = 10\log_{10}(N)$ Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) – B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

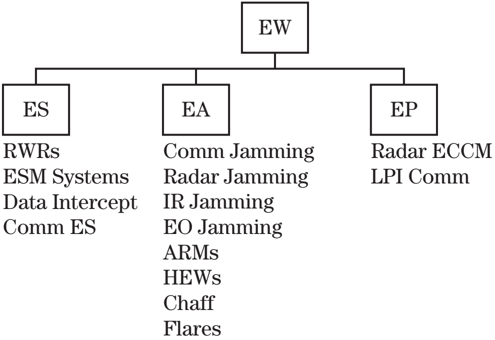
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



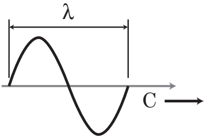
Frequency

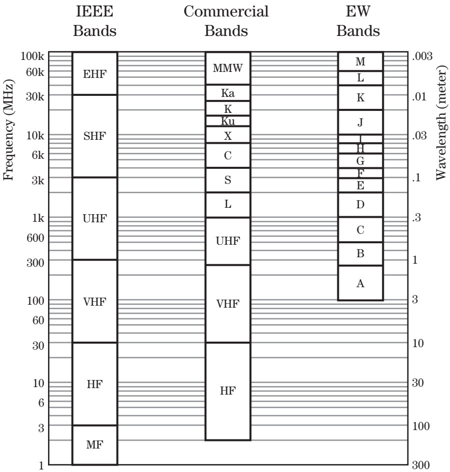
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

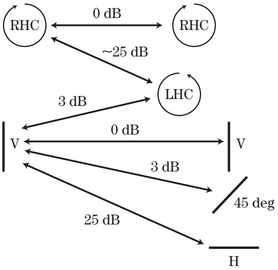
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

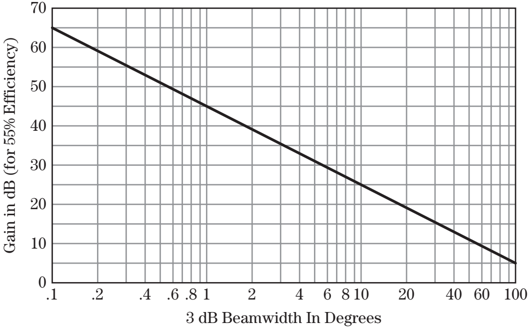
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

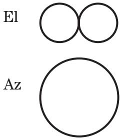
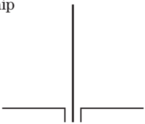
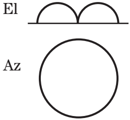
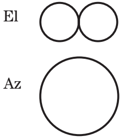
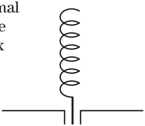
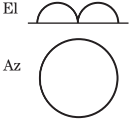
Peak gain vs. 3 dB beamwidth for 55% eff. dish

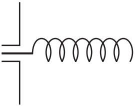
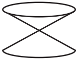
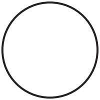
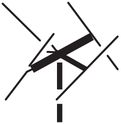
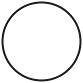
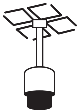
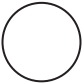


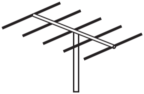
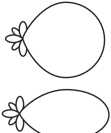
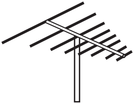
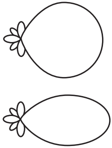
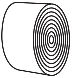
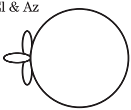
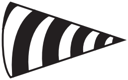
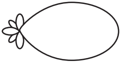
Antenna efficiency

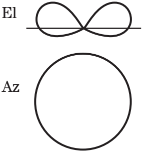
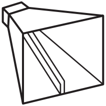
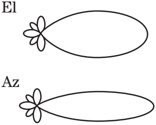
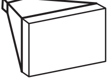
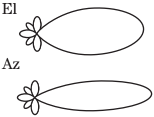
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

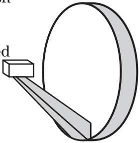
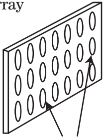
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

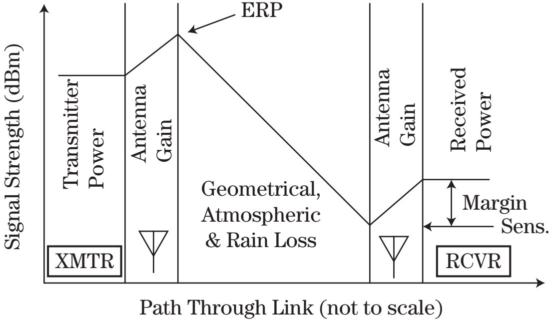
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 		Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 		Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 		Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

$P_R \text{ (in dB)} = P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss) Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

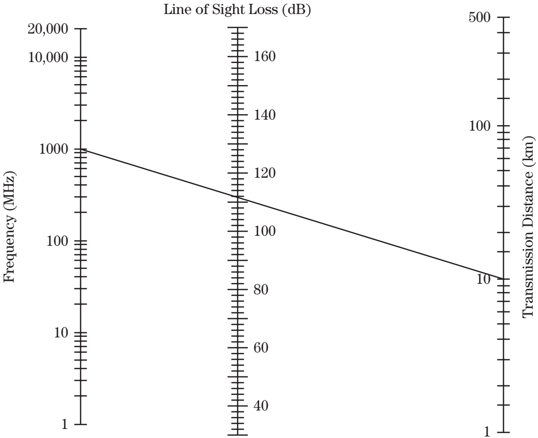
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

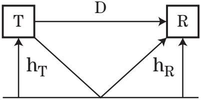


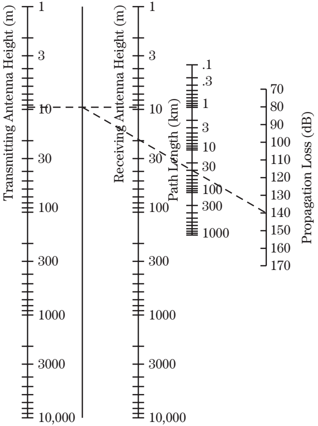
Two ray loss

$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

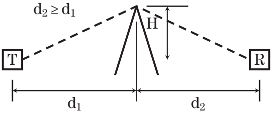
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



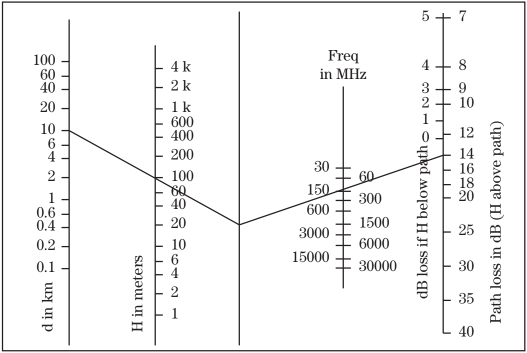


Knife edge diffraction geometry

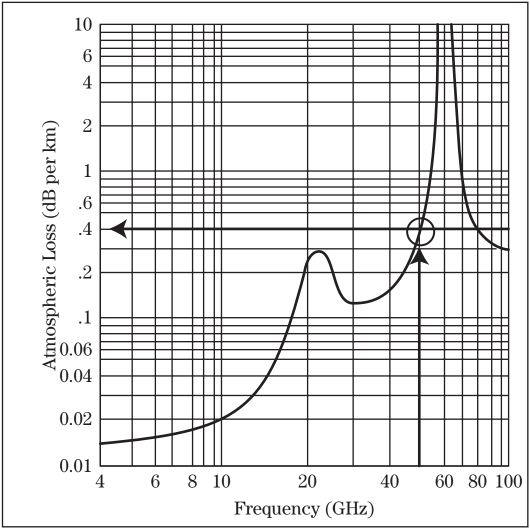


Calculate d = [sqrt 2 / (1 + (d_1/d_2)] d_1
or just use d = d_1 which reduces accuracy by ~ 1.5 dB

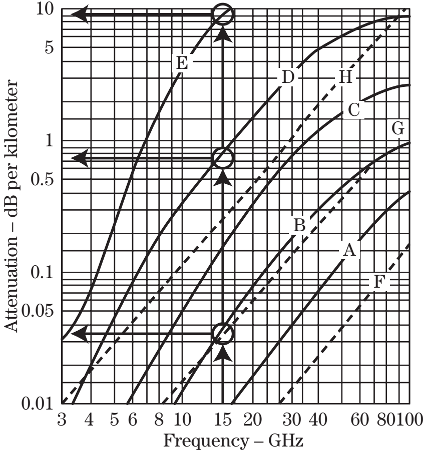
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



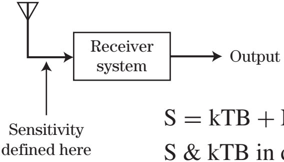
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

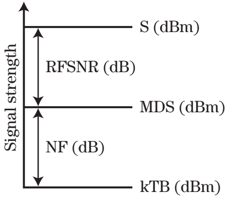


S = kTB + NF + RFSNR

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

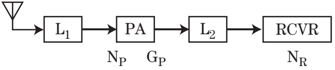
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

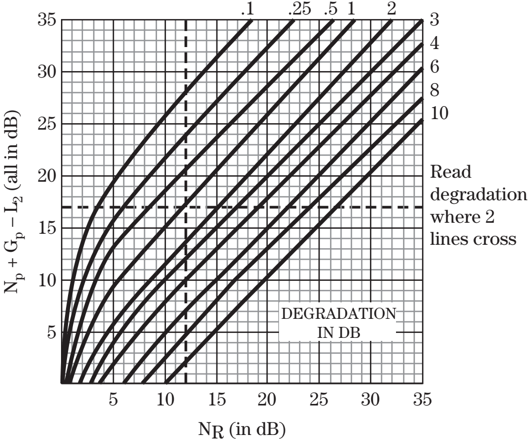


kTB(in dBm) = −114 + 10 log (BW/1 MHz)

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

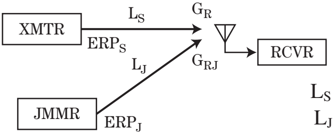
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20–33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

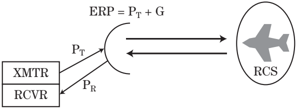
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

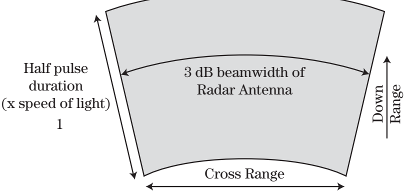
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20\,\text{Log}\,F - 40\,\text{Log}\,R + 10\,\text{Log}\,\sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

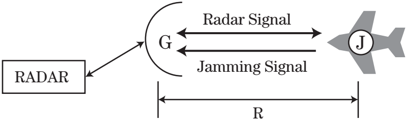


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

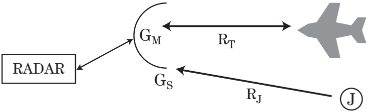
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \,\mathrm{Log}\, R_T - 20 \log R_J - 10 \,\mathrm{Log\, RCS}$$

Burn through range

$$R_{BT} = 4^{th} \text{ root of } [(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$$

(In dB)

$$40 \,\mathrm{Log}\, R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \,\mathrm{Log}\, R_T - 20 \,\mathrm{Log}\, R_J + 10 \,\mathrm{Log\, RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40 \,\mathrm{Log}\, R_T]/40\}$$

Note about burn through range:
This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

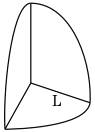
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

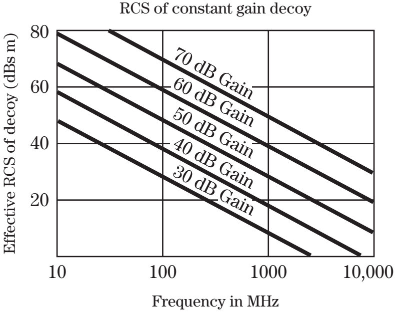
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

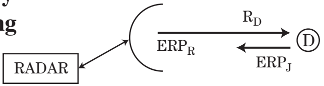


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F) L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

$N\ (dB) = 10\log_{10}(N)$ Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10\ \text{Log}(\text{number not in dB})$
$A(dB) \pm 20\ \text{Log}(\text{number not in dB})$
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30\ dB$

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

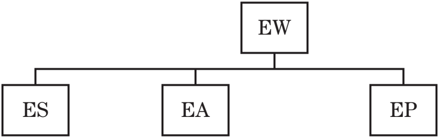
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



ES	EA	EP
RWRs	Comm Jamming	Radar ECCM
ESM Systems	Radar Jamming	LPI Comm
Data Intercept	IR Jamming	
Comm ES	EO Jamming	
	ARMs	
	HEWs	
	Chaff	
	Flares	

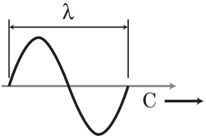
Frequency

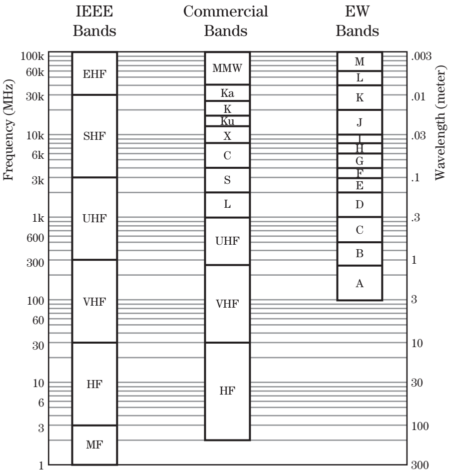
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

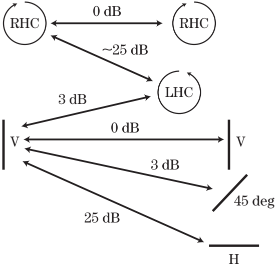
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

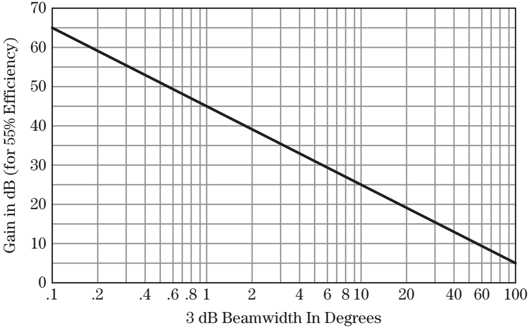
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

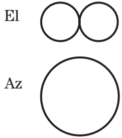
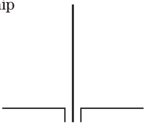
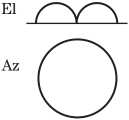
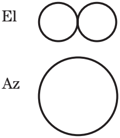
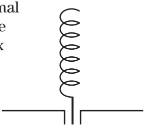
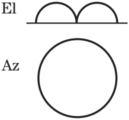
Peak gain vs. 3 dB beamwidth for 55% eff. dish

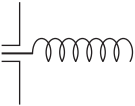
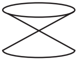
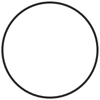
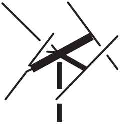
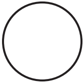
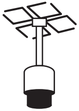
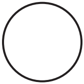


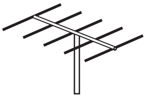
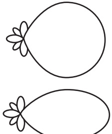
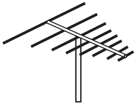
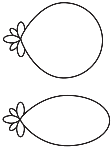
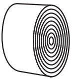
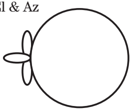
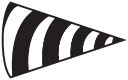
Antenna efficiency

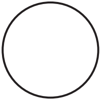
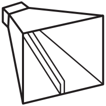
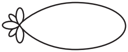
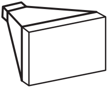
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

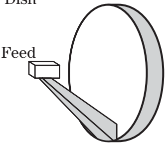
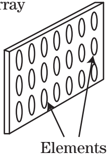
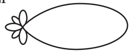
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ∼30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

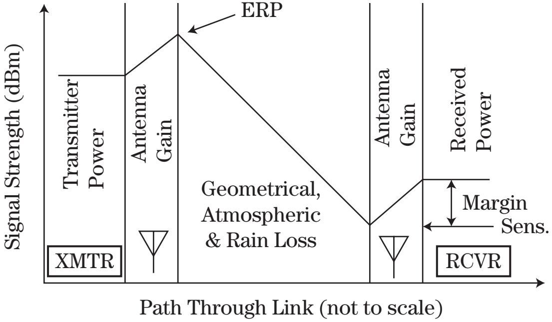
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El  Az 	Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El  Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El  Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

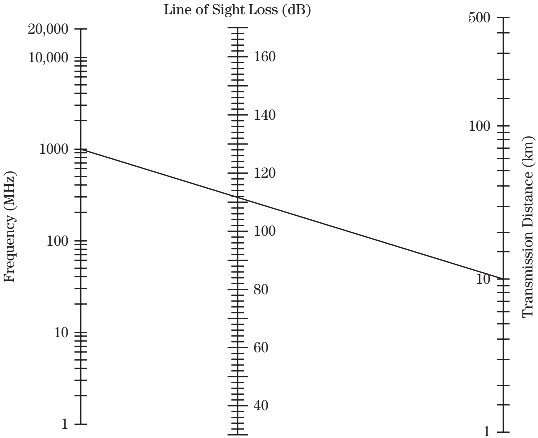
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

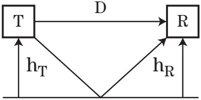


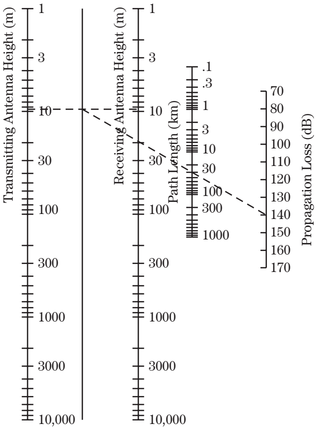
Two ray loss

$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

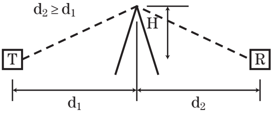
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



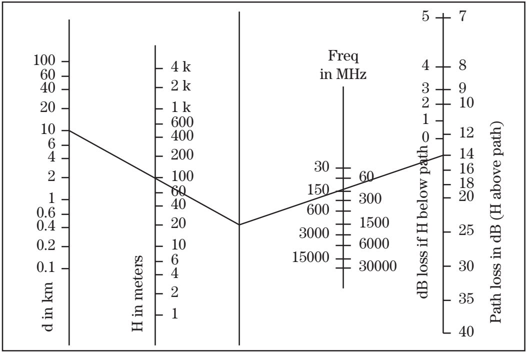


Knife edge diffraction geometry

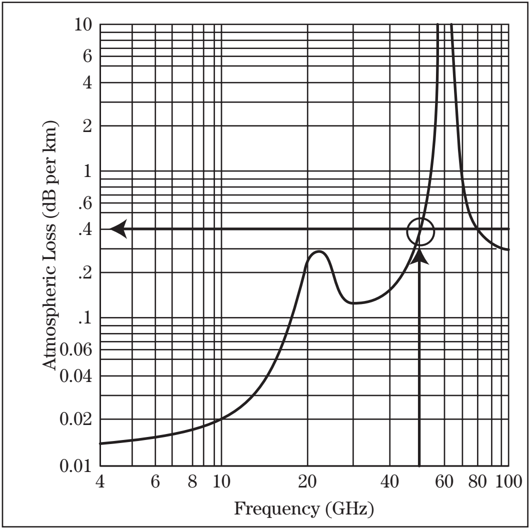


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

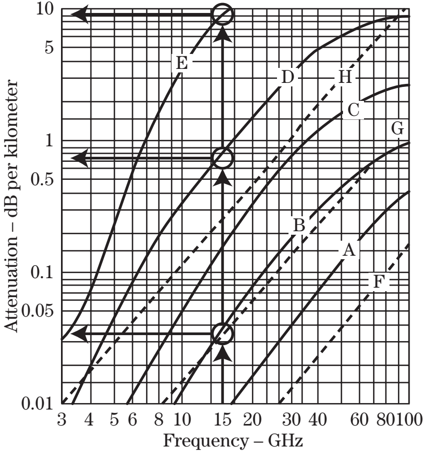
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



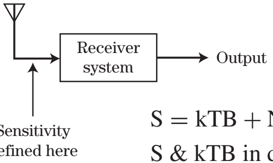
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

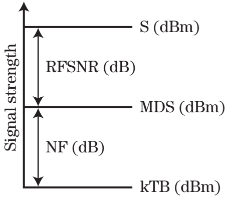


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

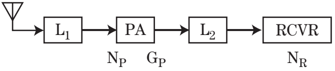
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

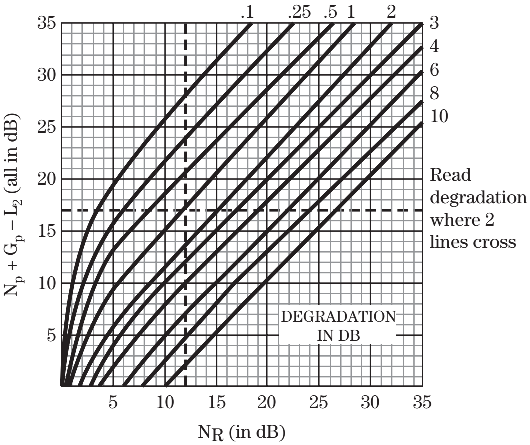


kTB(in dBm) $= -114 + 10\ \log\ (\mathrm{BW}/1\ \mathrm{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

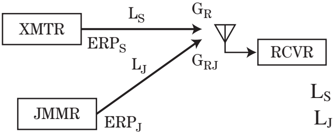
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

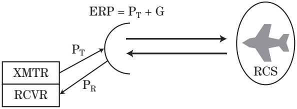
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

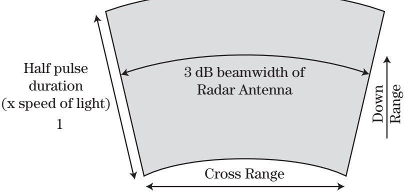
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \text{ Log } F - 40 \text{ Log } R + 10 \text{ Log } \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

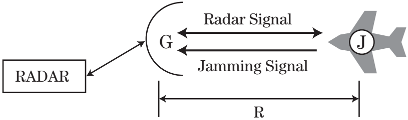


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20\,Log\,R - 10\,Log\,\sigma$

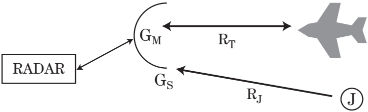
Burn through range

$$R_{BT} = sqrt[(ERP_S \sigma)/(4\pi ERP_J)]$$

(In dB) $20\,Log\,R_{BT} = ERP_S - ERP_J - 71 + 10\,Log\,RCS + J/S\ (Rqd)$

$$R_{BT} = Anti\text{-}Log\ \{[20\,Log\,R]/20\}$$

Remote Jamming



$$\mathbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

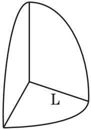
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

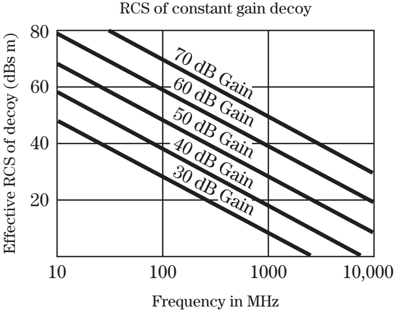
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

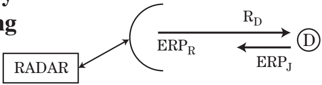


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, N(dB) = $20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

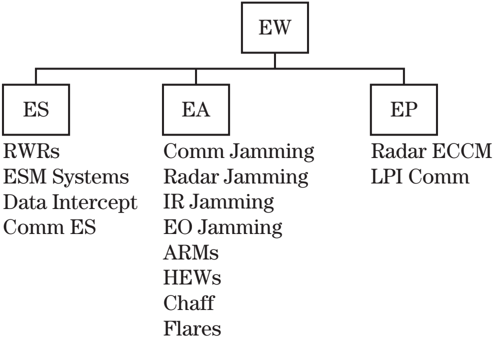
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



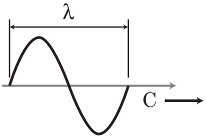
Frequency

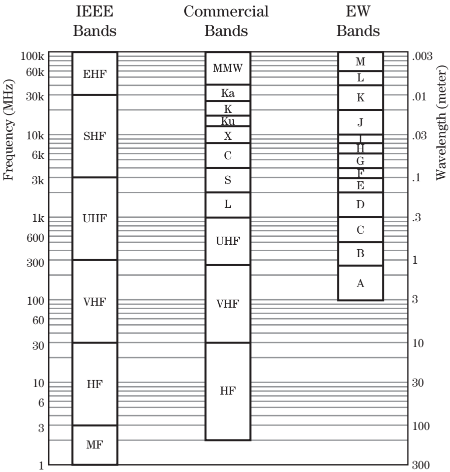
$$\lambda = c/F$$

λ in meters

$c = 3 \times 10^8$ m/sec

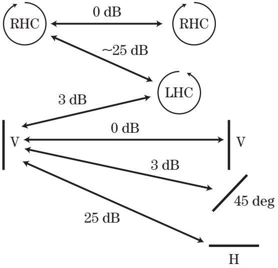
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

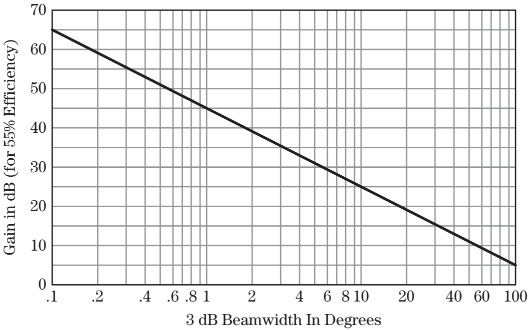
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

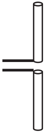
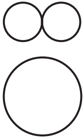
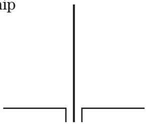
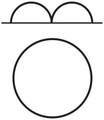
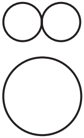
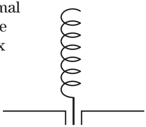
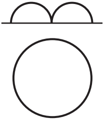
Peak gain vs. 3 dB beamwidth for 55% eff. dish

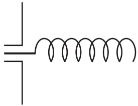
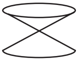
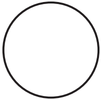
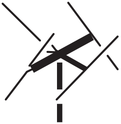
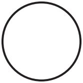
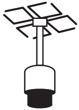
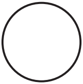


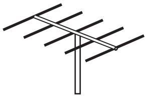
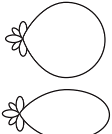
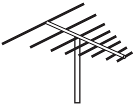
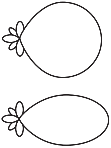
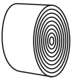
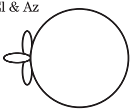
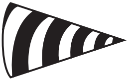
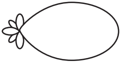
Antenna efficiency

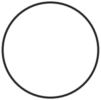
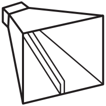
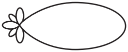
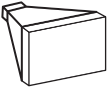
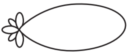
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

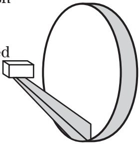
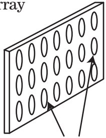
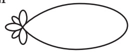
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type	Pattern	Typical Specifications
Dipole 	El Az 	Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 	El Az 	Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 	El Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 	El Az 	Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

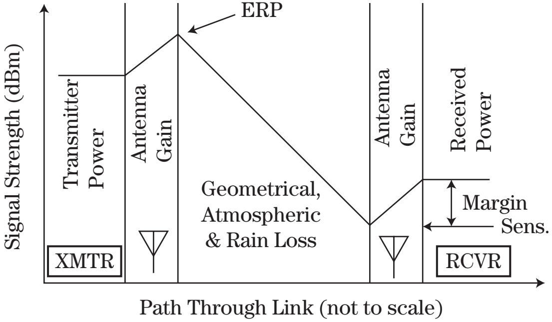
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El  Az 	Polarization: Circular Beamwidth: 50° × 360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El  Az 	Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El  Az 	Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^{\circ}$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array 	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ P_T & P_R in Watts
G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ P_T & P_R in dBm
G_T, G_R & L in dB
L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:
$FZ = (h_T \times h_R \times F)/24,000$
FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)
Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

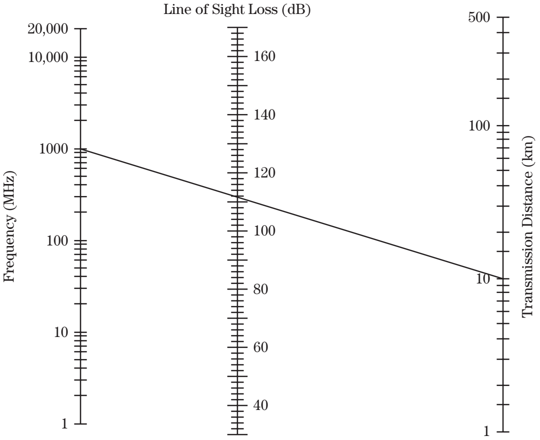
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

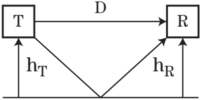


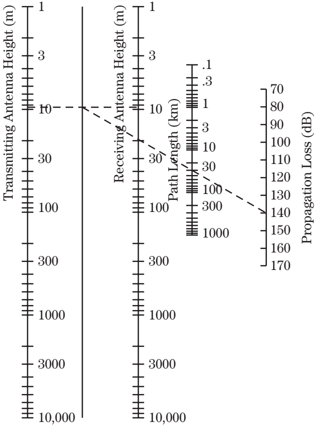
Two ray loss

$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

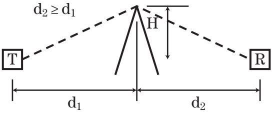
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



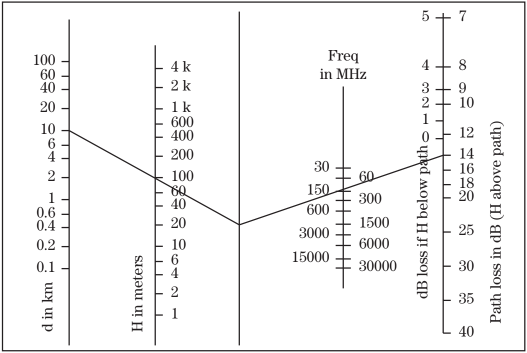


Knife edge diffraction geometry

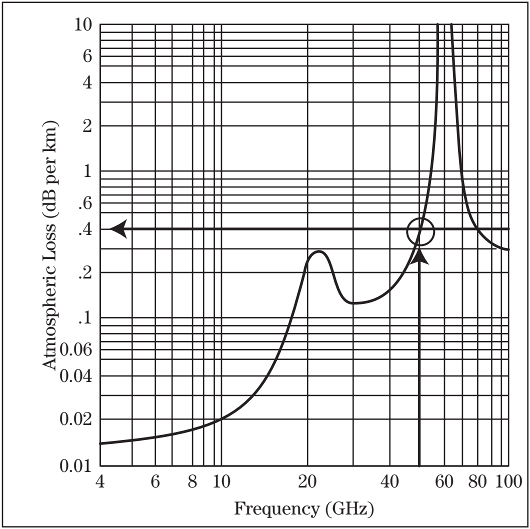


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)] \, d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

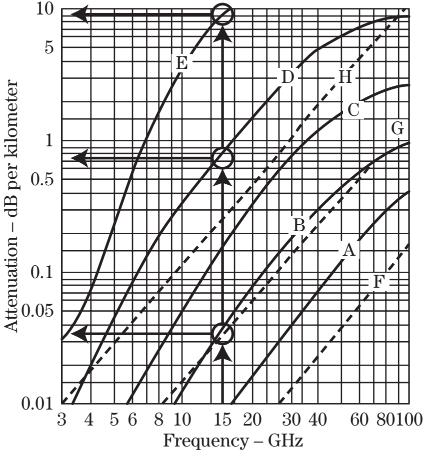
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



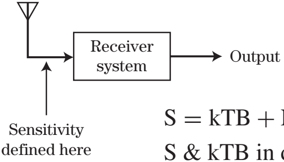
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

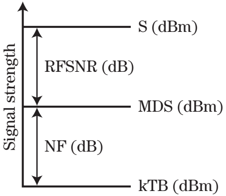


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

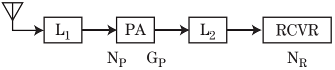
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

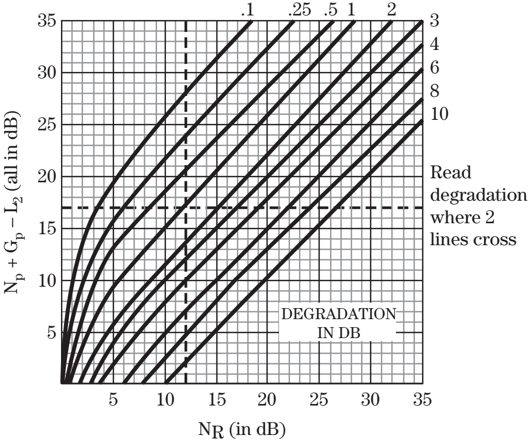


kTB(in dBm) $= -114 + 10 \log(\text{BW}/1\ \text{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

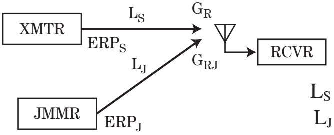
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

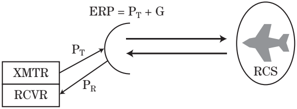
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

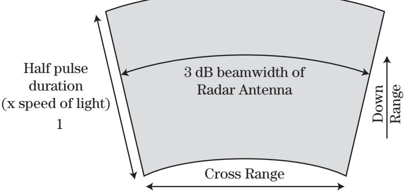
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \text{ Log } F - 40 \text{ Log } R + 10 \text{ Log } \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

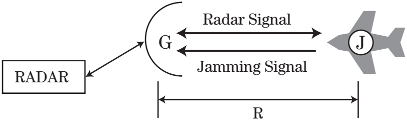


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

J/S $= (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) **J/S** $= ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

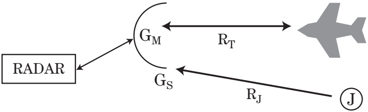
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\textbf{J/S} = (4\pi \mathrm{ERP_J} G_S R_T^4)/(\mathrm{ERP_S} G_M R_J^2 \sigma)$$

(In dB)

$$\textbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(\mathrm{ERP_S}\ G_M\ R_J^2 \sigma)/(4\pi \mathrm{ERP_J}\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + \mathrm{J/S(Required)}$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- $0.925\ N\sigma_1$ with λ spacing
- $0.981\ N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

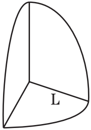
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

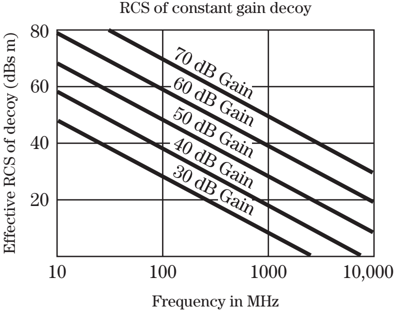
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

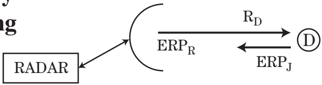


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10\log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

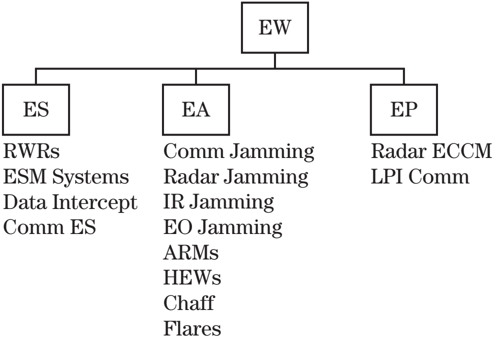
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

- ES Receiving hostile signals to support EA
- EA Actions to interfere with enemy radar or comm
- EP Features of radars or communication systems that reduce the effectiveness of enemy EW



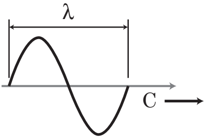
Frequency

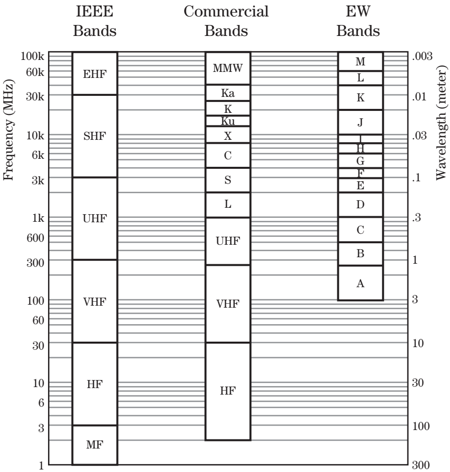
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

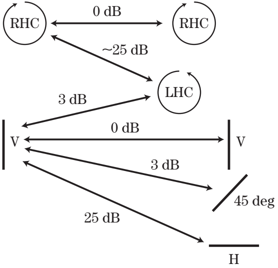
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

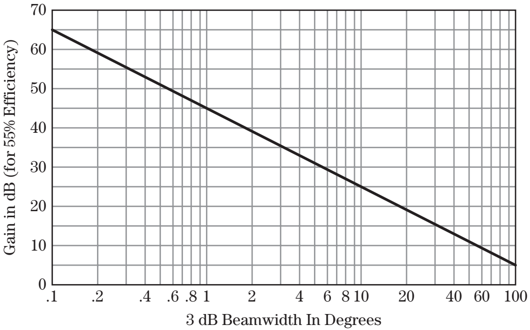
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

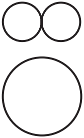
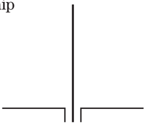
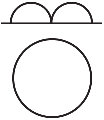
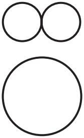
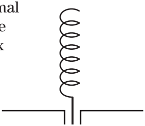
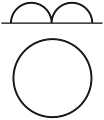
Peak gain vs. 3 dB beamwidth for 55% eff. dish

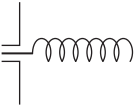
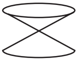
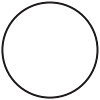
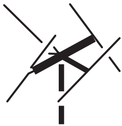
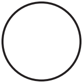
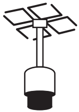
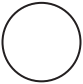


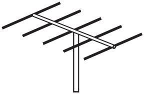
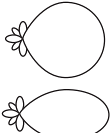
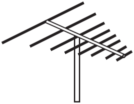
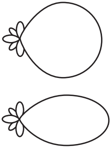
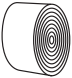
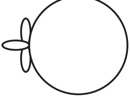
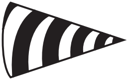
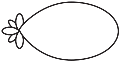
Antenna efficiency

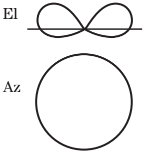
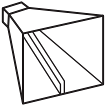
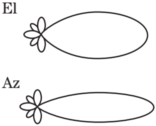
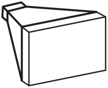
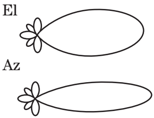
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

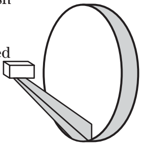
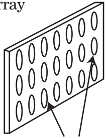
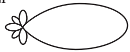
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole		El, Az 	Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip		El, Az 	Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop		El, Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix		El, Az 	Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

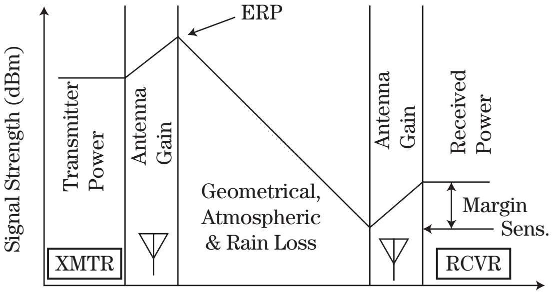
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral			Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn			Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer			Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

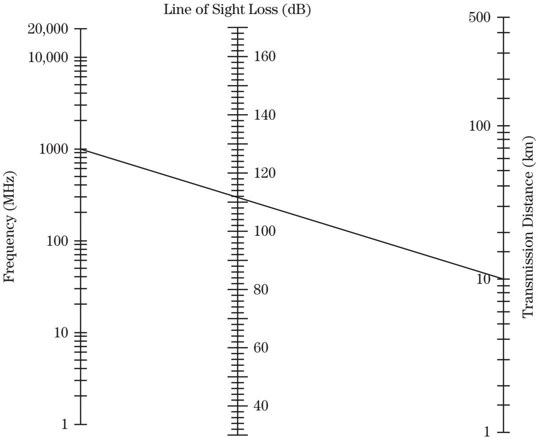
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph



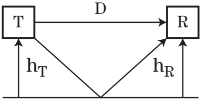
Two ray loss

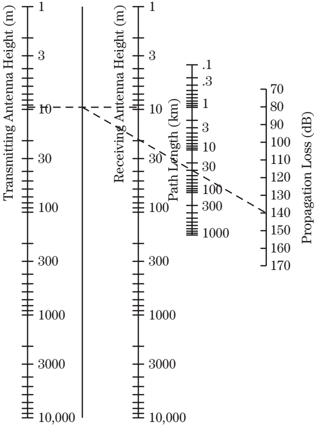
$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$

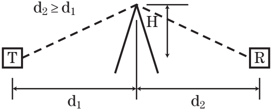
D in km, h_T & h_R in meters

Two ray loss Nomograph



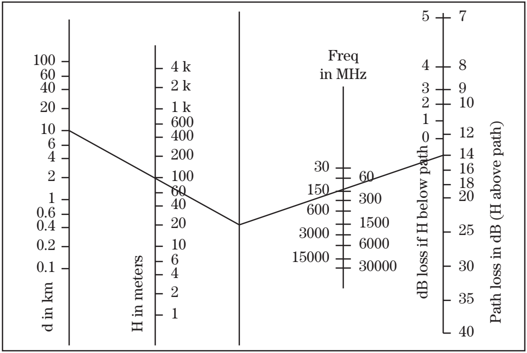


Knife edge diffraction geometry

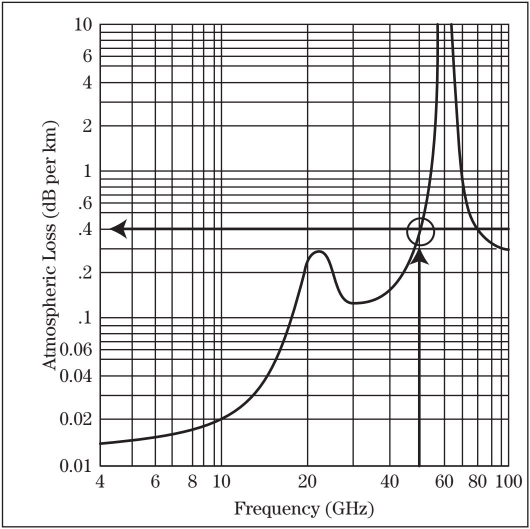


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

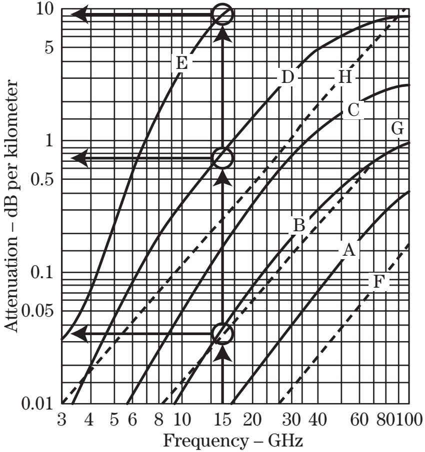
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



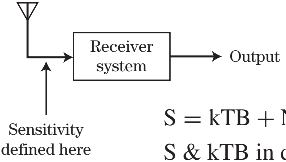
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

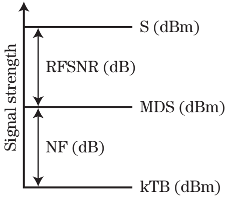


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

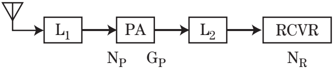


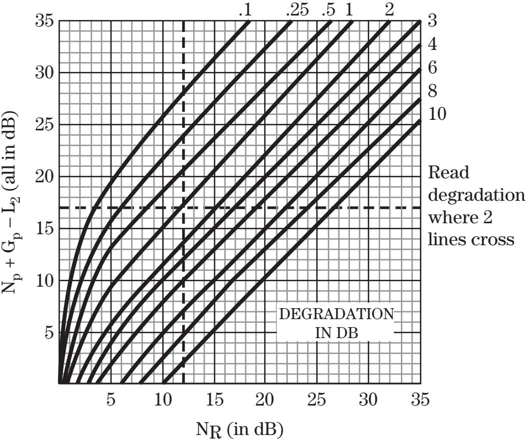
kTB(in dBm) $= -114 + 10 \log(\text{BW}/1\ \text{MHz})$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB) G_P = PA Gain (dB)

N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

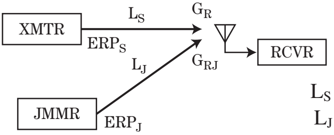
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$$

If RCV ant has 360° coverage

$$J/S = ERP_J - ERP_S - L_J + L_S$$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

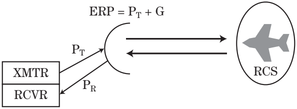
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

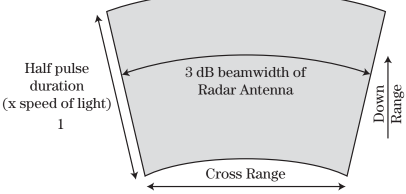
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\mathrm{dB})\, P_R = P_T + 2G - 103 - 20 \,\mathrm{Log}\, F - 40 \,\mathrm{Log}\, R + 10 \,\mathrm{Log}\, \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

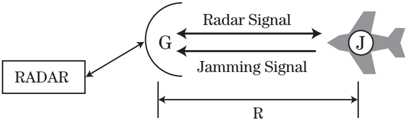


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20\,\text{Log}\,R - 10\,\text{Log}\,\sigma$

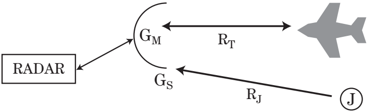
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20\,\text{Log}\,R_{BT} = ERP_S - ERP_J - 71 + 10\,\text{Log}\,RCS + J/S\,(\text{Rqd})$

$R_{BT} = \text{Anti-Log}\,\{[20\,\text{Log}\,R]/20\}$

Remote Jamming



J/S $= (4\pi ERP_J G_S R_T^4)/(ERP_S G_M R_J^2 \sigma)$

(In dB)

$$\textbf{J/S} = ERP_J - ERP_S + 71 + G_S - G_M + 40 \text{ Log } R_T - 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(ERP_S\ G_M\ R_J^2\sigma)/(4\pi ERP_J\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = ERP_S - ERP_J - 71 - G_S + G_M + 40 \text{ Log } R_T - 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$

$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

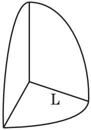
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

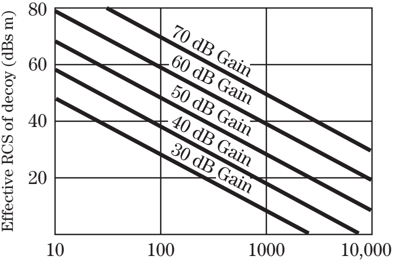
$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$



Active decoys

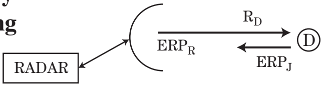
RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



Frequency in MHz

RCS of primed decoy (fixed ERP) repeating radar signal



$$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10\log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20\log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

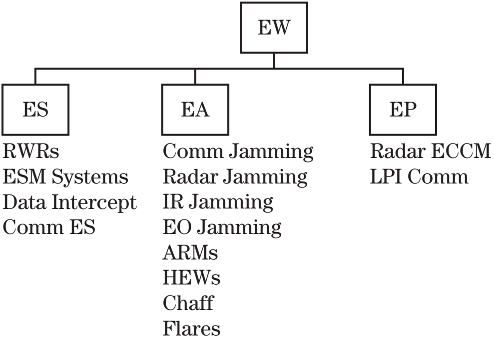
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



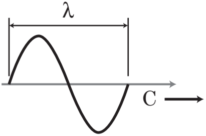
Frequency

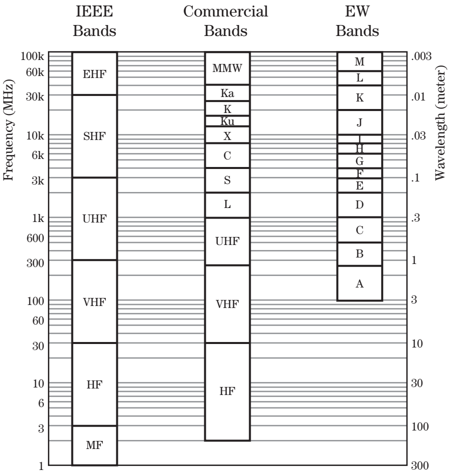
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

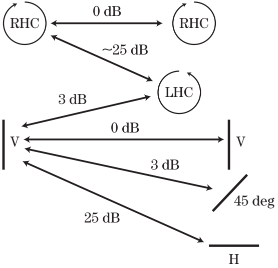
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

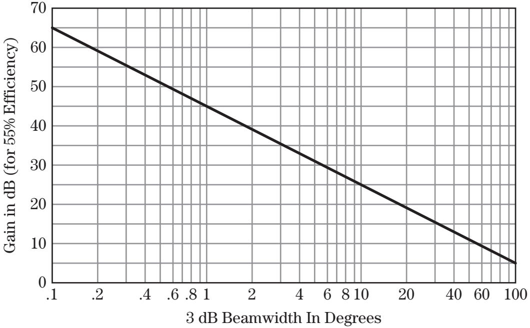
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

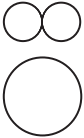
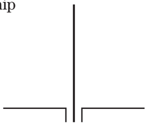
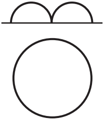
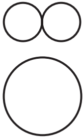
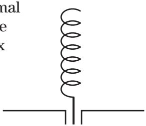
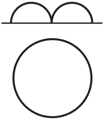
Peak gain vs. 3 dB beamwidth for 55% eff. dish

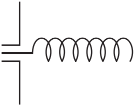
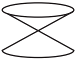
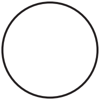
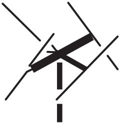
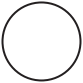
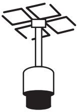
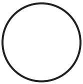


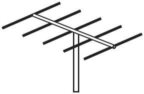
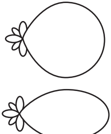
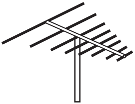
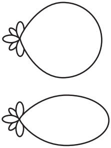
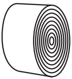
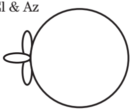
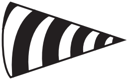
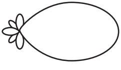
Antenna efficiency

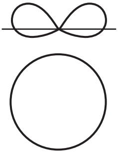
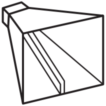
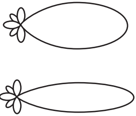
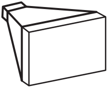
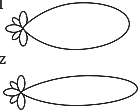
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

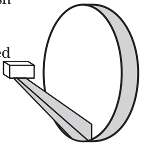
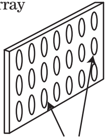
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ∼30%

Antenna Type	Pattern	Typical Specifications
Dipole 		Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip 		Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop 		Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix 		Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

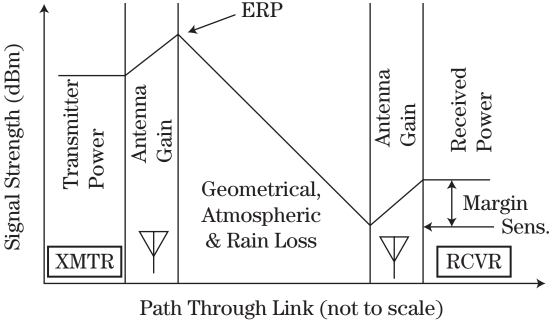
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
4 Arm Conical Spiral 	El Az 	Polarization: Circular Beamwidth: $50^\circ \times 360^\circ$ Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn 	El Az 	Polarization: Linear Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer 	El Az 	Polarization: Circular Beamwidth: $40^\circ \times 40^\circ$ Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish Feed 	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  Elements	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

$P_R \text{ (in dB)} = P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

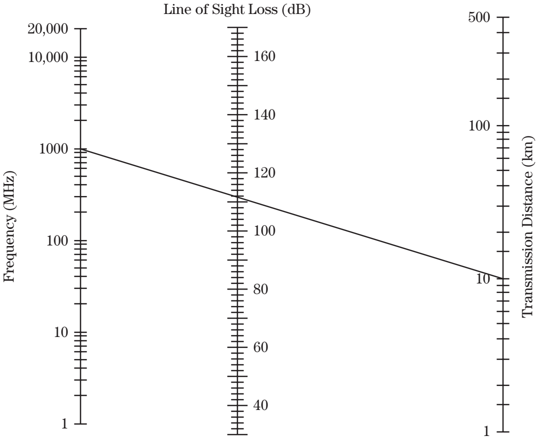
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

L(in dB) $= 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph



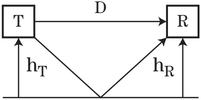
Two ray loss

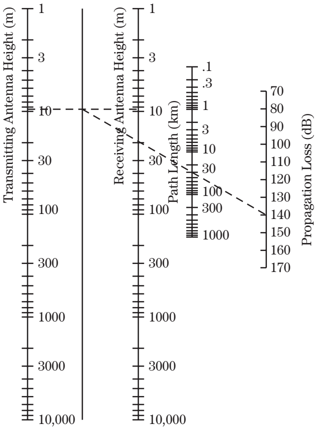
$L = D^4 / [h_T^2\, h_R^2]$ L is ratio, D, h_T & h_R in meters

$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$

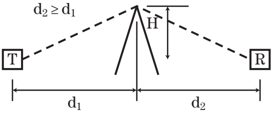
D in km, h_T & h_R in meters

Two ray loss Nomograph



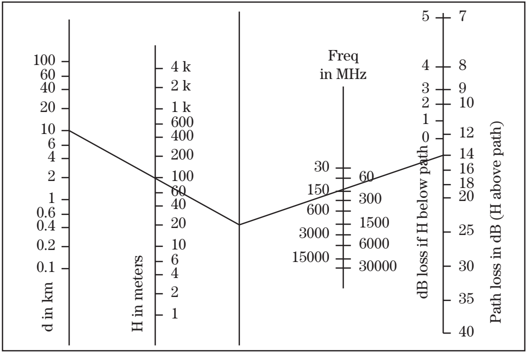


Knife edge diffraction geometry

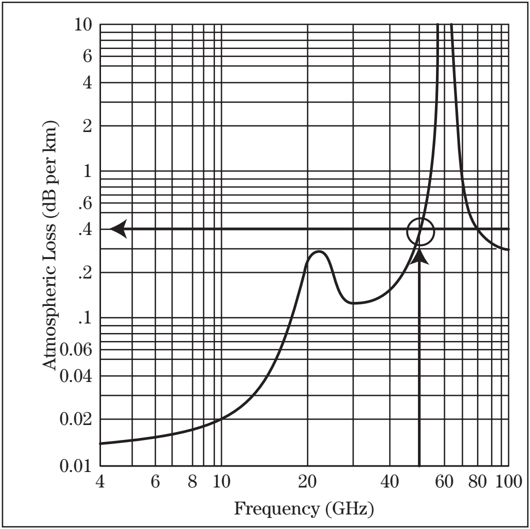


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

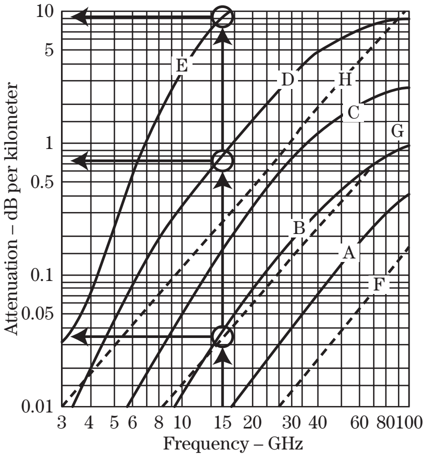
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



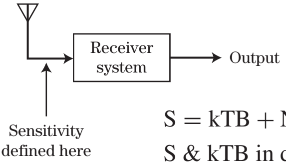
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m³	Visibility greater than 600 meters
	G	0.32 gm/m³	Visibility about 120 meters
	H	2.3 gm/m³	Visibility about 30 meters

Receiver Sensitivity

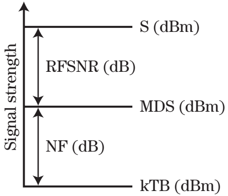


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

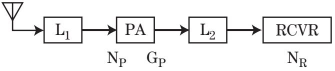


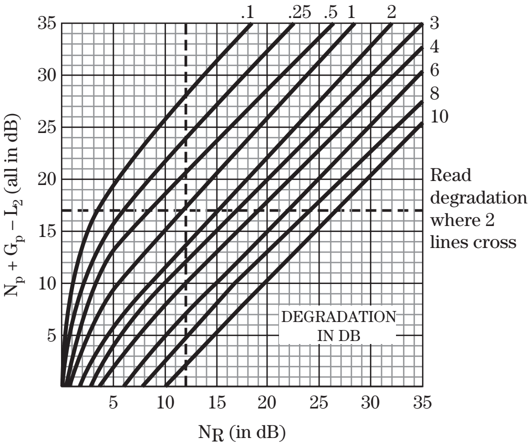
kTB(in dBm) $= -114 + 10\ \log\ (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$

With Preamp: $NF = L_1 + N_P + Deg$ All in dB





$L_1 \& L_2$ = Losses (dB)

N_P = PA NF (dB)

G_P = PA Gain (dB)

N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. "SQR" is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

Effective range (Two-Ray Propagation)

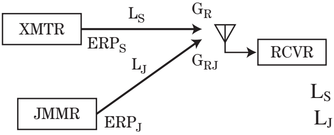
$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range

Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S ~ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S ~ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

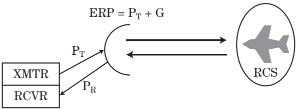
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

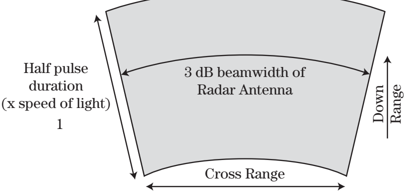
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

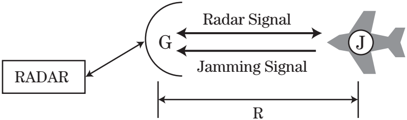


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

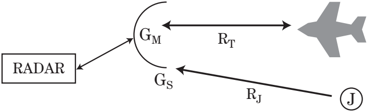
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



J/S $= (4\pi \mathrm{ERP_J G_S R_T^4})/(\mathrm{ERP_S G_M R_J^2} \sigma)$

(In dB)

$$\mathbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + \mathrm{G_S} - \mathrm{G_M} + 40\ \mathrm{Log}\ \mathrm{R_T} - 20 \log \mathrm{R_J} - 10\ \mathrm{Log\ RCS}$$

Burn through range

$\mathrm{R_{BT}} = 4^{\mathrm{th}}$ root of $[(\mathrm{ERP_S\ G_M\ R_J^2}\sigma)/(4\pi \mathrm{ERP_J\ G_S})]$

(In dB)

$$40\ \mathrm{Log}\ \mathrm{R_T} = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - \mathrm{G_S} + \mathrm{G_M} + 40\ \mathrm{Log}\ \mathrm{R_T} - 20\ \mathrm{Log}\ \mathrm{R_J} + 10\ \mathrm{Log\ RCS} + \mathrm{J/S(Required)}$$

$$\mathrm{R_{BT}} = \text{Anti-Log}\{[40\ \mathrm{Log}\ \mathrm{R_T}]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

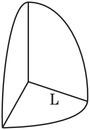
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

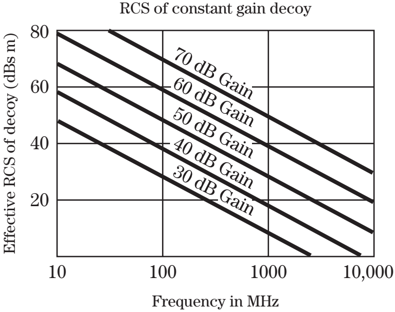
RCS of passive corner reflector decoy

$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$

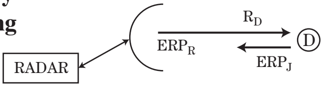


Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

$A(dB) \pm B\ (dB) = C(dB)$
$A(dBm) \pm B(dB) = C(dBm)$
$A(dBm) - B(dBm) = C(dB)$
$A(dB) \pm 10$ Log(number not in dB)
$A(dB) \pm 20$ Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

$N(dBm) = N(dBW) + 30$ dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

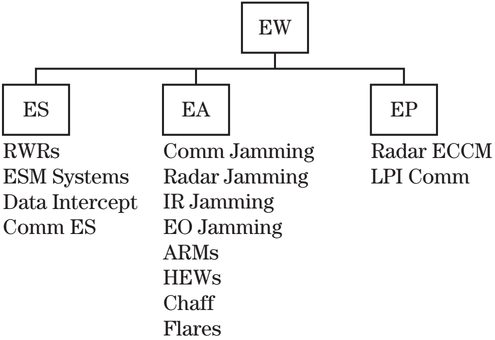
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



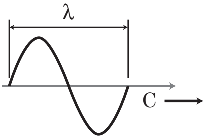
Frequency

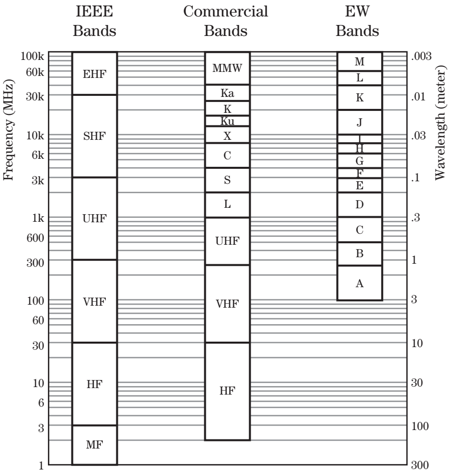
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

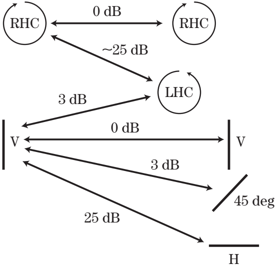
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

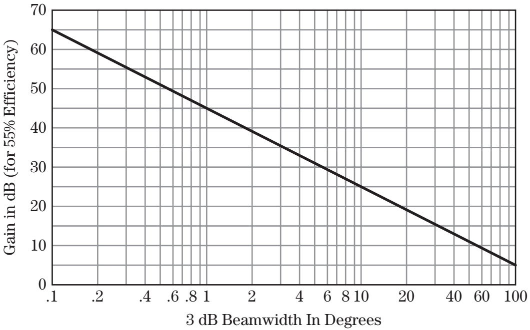
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

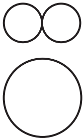
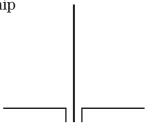
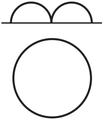
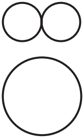
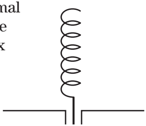
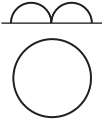
Peak gain vs. 3 dB beamwidth for 55% eff. dish

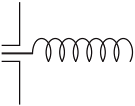
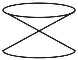
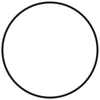
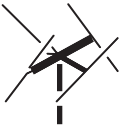
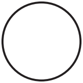
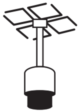
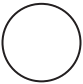


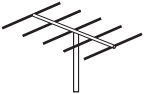
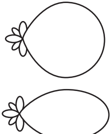
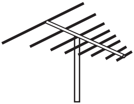
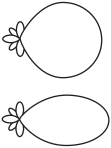
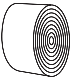
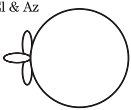
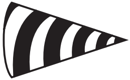
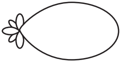
Antenna efficiency

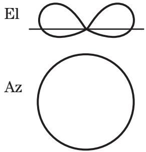
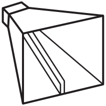
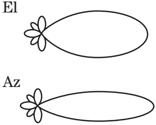
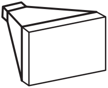
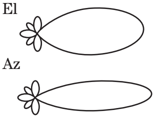
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

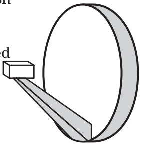
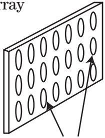
10% frequency range dish can have 55%
2–18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole		El, Az 	Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip		El, Az 	Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop		El, Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix		El, Az 	Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

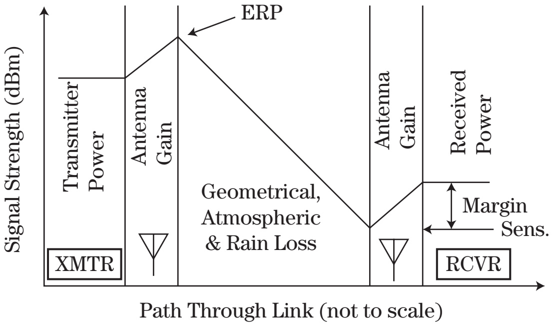
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: $50^\circ \times 50^\circ$ Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to $100^\circ \times 360^\circ$ Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: $80^\circ \times 360^\circ$ Gain: -1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El, Az 	Polarization: Horizontal Beamwidth: 90° × 50° Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El, Az 	Polarization: Vertical or Horizontal Beamwidth: 80° × 60° Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: 60° × 60° Gain: −15 dB (min freq) +3 dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: 60° × 60° Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral			Polarization: Circular Beamwidth: 50°×360° Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn			Polarization: Linear Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer			Polarization: Circular Beamwidth: 40° × 40° Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to ×30° Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24,000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)
Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

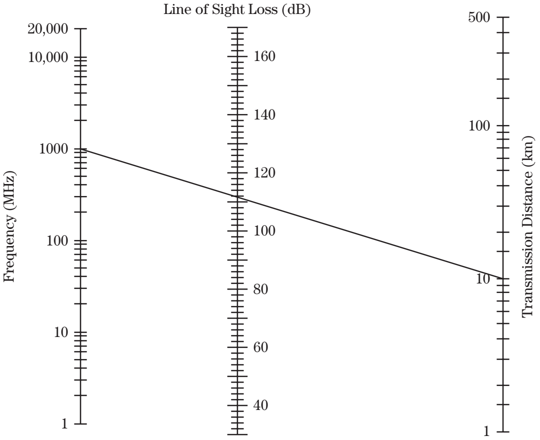
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

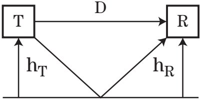


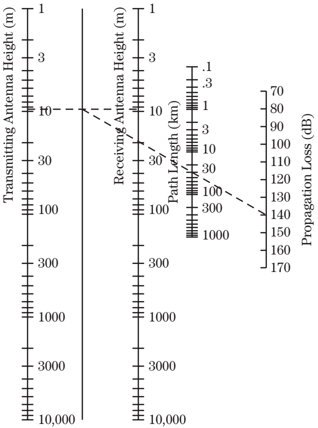
Two ray loss

$L = D^4 / \left[h_T^2 \, h_R^2 \right]$ L is ratio, D, h_T & h_R in meters

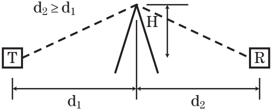
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



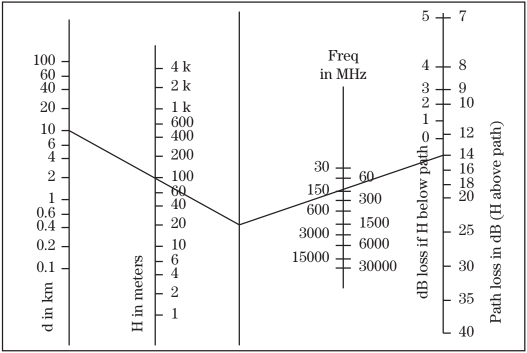


Knife edge diffraction geometry

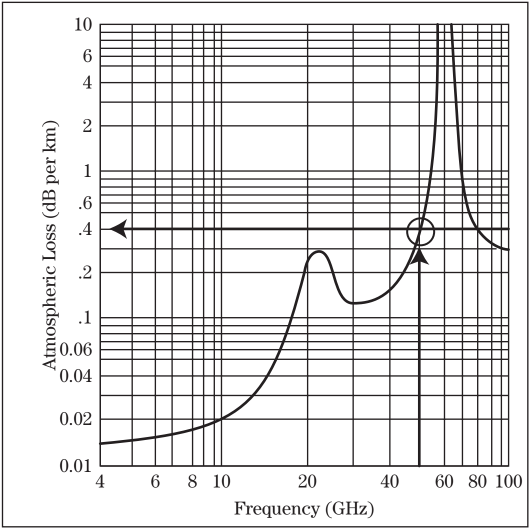


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\ d_1$
or just use $d = d_1$ which reduces accuracy by ~ 1.5 dB

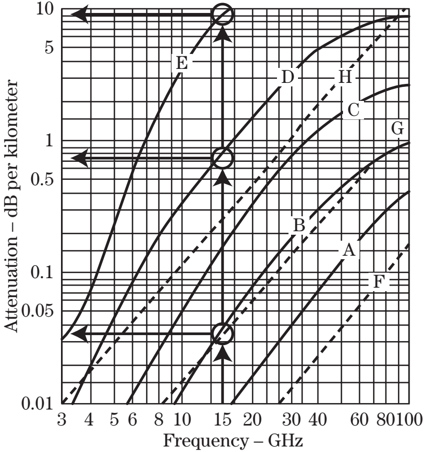
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



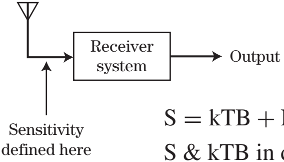
Rain & Fog attenuation



RAIN	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

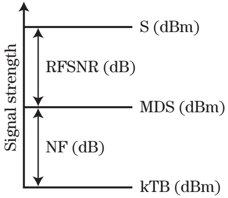


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

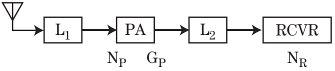
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR

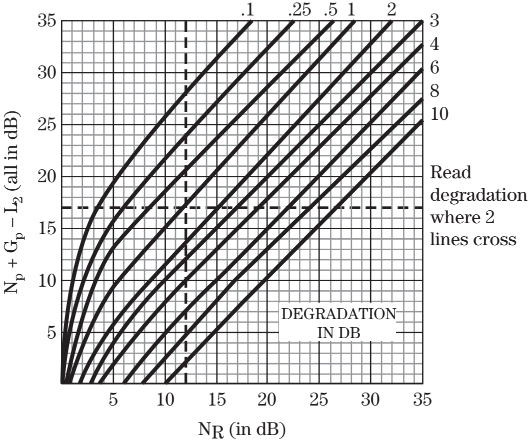


kTB(in dBm) $= -114 + 10\ \log\ (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB





L_1&L_2 = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20 \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

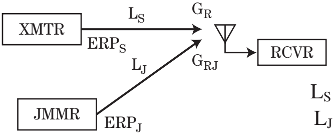
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

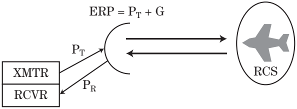
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

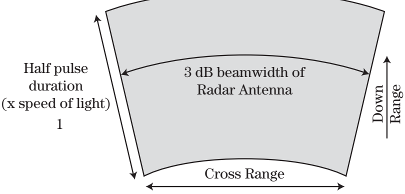
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\,P_R = P_T + 2G - 103 - 20\,\text{Log}\,F - 40\,\text{Log}\,R + 10\,\text{Log}\,\sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

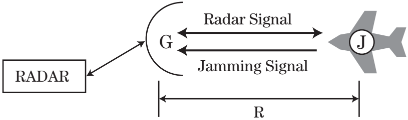


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20 \text{ Log } R - 10 \text{ Log } \sigma$

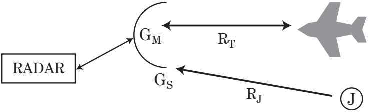
Burn through range

$R_{BT} = \text{sqrt}[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20 \text{ Log } R_{BT} = ERP_S - ERP_J - 71 + 10 \text{ Log RCS} + J/S \text{ (Rqd)}$

$R_{BT} = \text{Anti-Log } \{[20 \text{ Log } R]/20\}$

Remote Jamming



$$\textbf{J/S} = (4\pi \mathrm{ERP_J G_S R_T^4})/(\mathrm{ERP_S G_M R_J^2}\sigma)$$

(In dB)

$$\textbf{J/S} = \mathrm{ERP_J} - \mathrm{ERP_S} + 71 + \mathrm{G_S} - \mathrm{G_M} + 40\ \mathrm{Log}\ \mathrm{R_T} - 20 \log \mathrm{R_J} - 10\ \mathrm{Log\ RCS}$$

Burn through range

$\mathrm{R_{BT}} = 4^{\mathrm{th}}$ root of $[(\mathrm{ERP_S\ G_M\ R_J^2}\sigma)/(4\pi \mathrm{ERP_J\ G_S})]$

(In dB)

$$40\ \mathrm{Log}\ \mathrm{R_T} = \mathrm{ERP_S} - \mathrm{ERP_J} - 71 - \mathrm{G_S} + \mathrm{G_M} + 40\ \mathrm{Log}\ \mathrm{R_T} - 20\ \mathrm{Log}\ \mathrm{R_J} + 10\ \mathrm{Log\ RCS} + \mathrm{J/S(Required)}$$

$$\mathrm{R_{BT}} = \text{Anti-Log}\{[40\ \mathrm{Log}\ \mathrm{R_T}]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

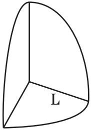
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

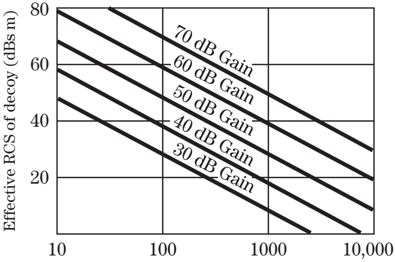
$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$



Active decoys

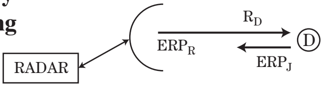
RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



Frequency in MHz

RCS of primed decoy (fixed ERP) repeating radar signal



$\mathrm{RCS(dBsm)} = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

$N\ (dB) = 10 \log_{10}(N)$ Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$
\begin{aligned}
N(\text{not in dB}) &= 10^{[N(dB)/10]} \\
&= \text{AntiLog}[N(dB)/10]
\end{aligned}
$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

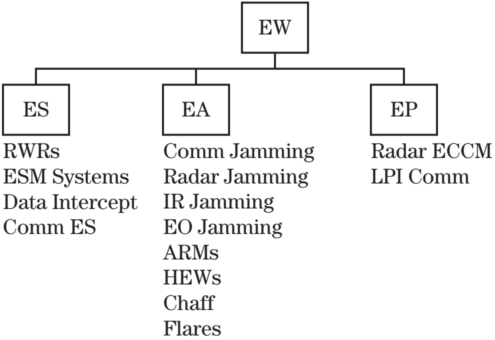
EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor

EW Definitions

EW is the art and science of denying an enemy the benefits of the electromagnetic spectrum while preserving them for friendly forces.

EW Subareas

ES Receiving hostile signals to support EA
EA Actions to interfere with enemy radar or comm
EP Features of radars or communication systems that reduce the effectiveness of enemy EW



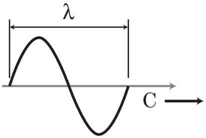
Frequency

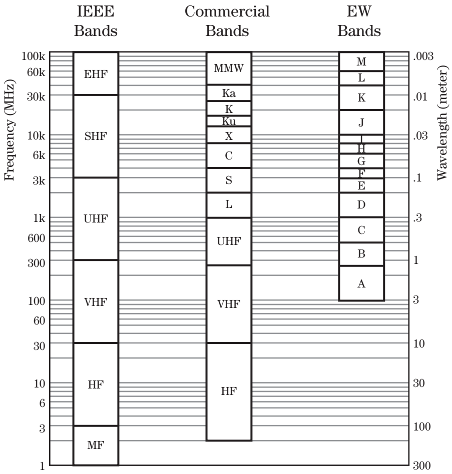
$\boldsymbol{\lambda = c/F}$

λ in meters

$c = 3 \times 10^8$ m/sec

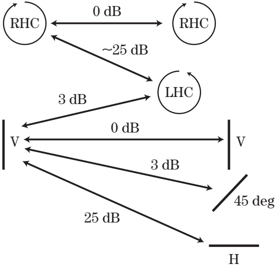
F in Hz





Antennas

Polarization loss



Polarization loss is in addition to antenna gain

No loss for matched polarization

Loss of 3 dB from any linear polarization to any circular polarization

Gain of non-symetrical 55% efficient Parabolic Dish

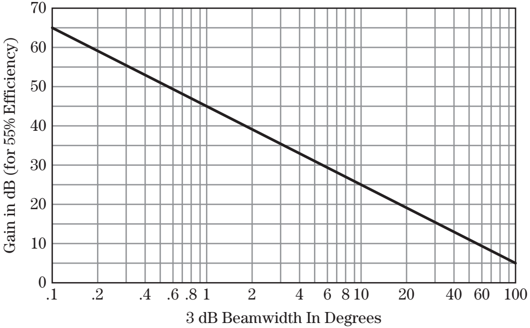
$$\text{Gain (not in dB)} = \frac{29,000}{\theta_1 \times \theta_2}$$

Gain of non-symetrical 60% efficient Horn Antenna

$$\text{Gain (not in dB)} = \frac{31,000}{\theta_1 \times \theta_2}$$

θ_1 & θ_2 are orthogonal 3 dB beamwidths in degrees.

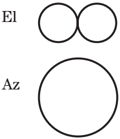
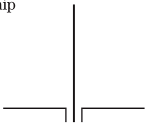
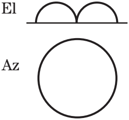
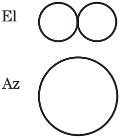
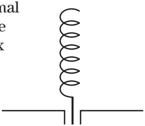
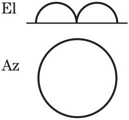
Peak gain vs. 3 dB beamwidth for 55% eff. dish

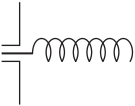
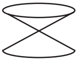
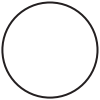
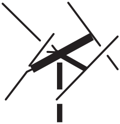
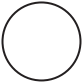
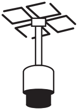
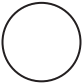


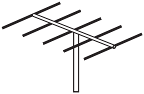
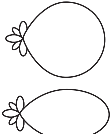
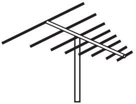
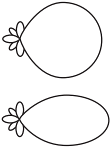
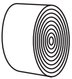
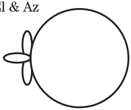
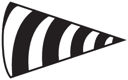
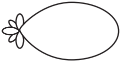
Antenna efficiency

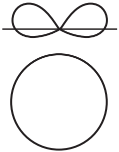
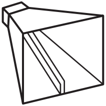
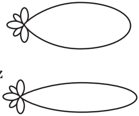
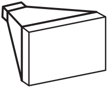
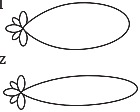
This is approximately the % of total input/output power to/from an antenna which is transmitted/received within the 3 dB beamwidth

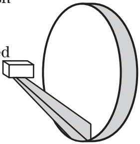
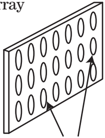
10% frequency range dish can have 55%
2−18 GHz dish efficiency is ~30%

Antenna Type		Pattern	Typical Specifications
Dipole			Polarization: Aligned with element orientation Beamwidth: 80° × 360° Gain: 2 dB Bandwidth: 10% Frequency Range: zero through μw
Whip			Polarization: Vertical Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF
Loop			Polarization: Horizontal Beamwidth: 80° × 360° Gain: −2 dB Bandwidth: 10% Frequency Range: HF through UHF
Normal Mode Helix			Polarization: Horizontal Beamwidth: 45° × 360° Gain: 0 dB Bandwidth: 10% Frequency Range: HF through UHF

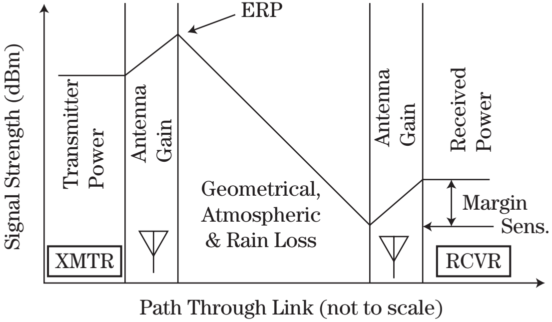
Antenna Type	Pattern	Typical Specifications
Axial Mode Helix 	Az & El 	Polarization: Circular Beamwidth: 50° × 50° Gain: 10 dB Bandwidth: 70% Frequency Range: UHF through low μw
Biconical 	El  Az 	Polarization: Vertical Beamwidth: 20° to 100° × 360° Gain: 0 to 4 dB Bandwidth: 4 to 1 Frequency Range: UHF through mmw
Lindenblad 	El  Az 	Polarization: Circular Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw
Swastika 	El  Az 	Polarization: Horizontal Beamwidth: 80° × 360° Gain: −1 dB Bandwidth: 2 to 1 Frequency Range: UHF through μw

Antenna Type	Pattern	Typical Specifications
Yagi 	El Az 	Polarization: Horizontal Beamwidth: $90^\circ \times 50^\circ$ Gain: 5 to 15 dB Bandwidth: 5% Frequency Range: VHF through UHF
Log Periodic 	El Az 	Polarization: Vertical or Horizontal Beamwidth: $80^\circ \times 60^\circ$ Gain: 6 to 8 dB Bandwidth: 10 to 1 Frequency Range: HF through μw
Cavity Backed Spiral 	El & Az 	Polarization: R & L Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: -15 dB (min freq) $+3$ dB (max freq) Bandwidth: 9 to 1 Frequency Range: μw
Conical Spiral 	El & Az 	Polarization: Circular Beamwidth: $60^\circ \times 60^\circ$ Gain: 5 to 8 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw

Antenna Type		Pattern	Typical Specifications
4 Arm Conical Spiral		El Az 	Polarization: Circular Beamwidth: $50^{\circ} \times 360^{\circ}$ Gain: 0 dB Bandwidth: 4 to 1 Frequency Range: UHF through μw
Horn		El Az 	Polarization: Linear Beamwidth: $40^{\circ} \times 40^{\circ}$ Gain: 5 to 10 dB Bandwidth: 4 to 1 Frequency Range: VHF through mmw
Horn with Polarizer		El Az 	Polarization: Circular Beamwidth: $40^{\circ} \times 40^{\circ}$ Gain: 5 to 10 dB Bandwidth: 3 to 1 Frequency Range: μw

Antenna Type	Pattern	Typical Specifications
Parabolic Dish  Feed	El & Az 	Polarization: Depends on Feed Beamwidth: 0.5 to $\times 30^\circ$ Gain: 10 to 55 dB Bandwidth: Depends on Feed Frequency Range: UHF to μw
Phased Array  Elements	El  Az 	Polarization: Depends on Elements Beamwidth: 0.5 to 30° Gain: 10 to 40 dB Bandwidth: Depends on Elements Frequency Range: VHF to μw

Radio Propagation



$P_R = [P_T G_T \times G_R]/L$ — P_T & P_R in Watts; G_T, G_R & L are ratios

P_R (in dB) $= P_T + G_T - L + G_R$ — P_T & P_R in dBm; G_T, G_R & L in dB; L is propagation loss

Fresnel zone distance

Fresnel zone distance is calculated from:

$FZ = (h_T \times h_R \times F)/24{,}000$

FZ in km, h_T & h_R in meters, F in MHz

Propagation loss models

Three propagation Loss models commonly used in EW: Line of Sight, Two Ray, Knife Edge Diffraction. All are losses between isotropic (0 dB gain) transmit and Receive antennas. Atmospheric & rain loss is often ignored Below 10 GHz

Selection of propagation model

<table>
<tr><td rowspan="3">Clear Propagation Path</td><td rowspan="2">Low frequency, wide beams, close to ground</td><td>Link longer than Fresnal Zone</td><td>Use two ray mode</td></tr>
<tr><td>Link shorter than Fresnal Zone</td><td rowspan="3">Use line of sight mode</td></tr>
<tr><td colspan="2">High frequency, narrow beams, far from ground</td></tr>
<tr><td>Propagation path obstructed by lerrain</td><td colspan="2">Additional loss from knife-edge diraction</td></tr>
</table>

Line of Sight (also called free space or spreading loss)

Function of frequency and range

2 Ray (cancellation by reflection from ground or water. Function of range and heights of antennas, not frequency

Knife edge refraction (loss from terrain ridges between transmitter and receiver) In addition to line of sight loss

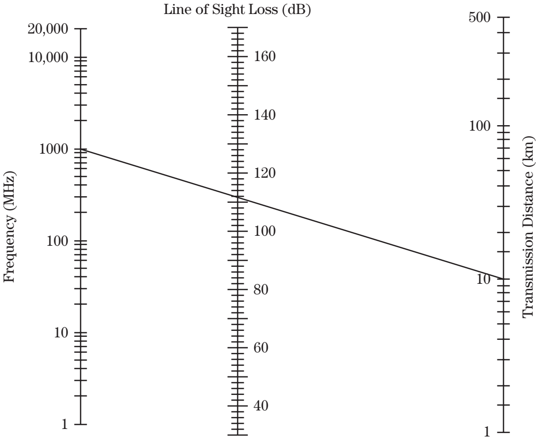
Line of sight loss

$L = [(4\pi)^2 D^2]/\lambda^2$ L is ratio, D & λ in meters

$L(\text{in dB}) = 32.44 + 20\ \log(F) + 20\ \log(D)$

F in MHz D in km

Line of Sight (Free Space) Nomograph

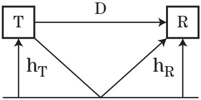


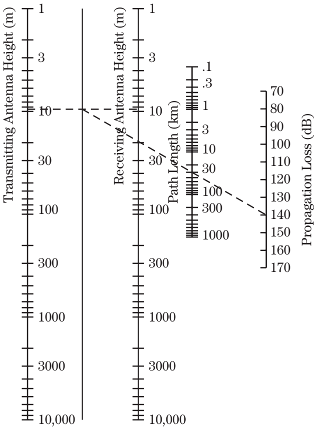
Two ray loss

$L = D^4 / \left[h_T^2\, h_R^2\right]$ L is ratio, D, h_T & h_R in meters

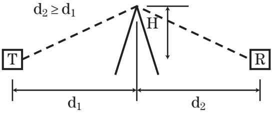
$L(\text{in dB}) = 120 + 40\log(D) - 20\log(h_T) - 20\ \log(h_R)$
D in km, h_T & h_R in meters

Two ray loss Nomograph



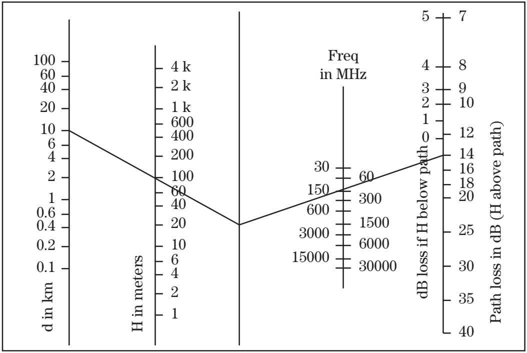


Knife edge diffraction geometry

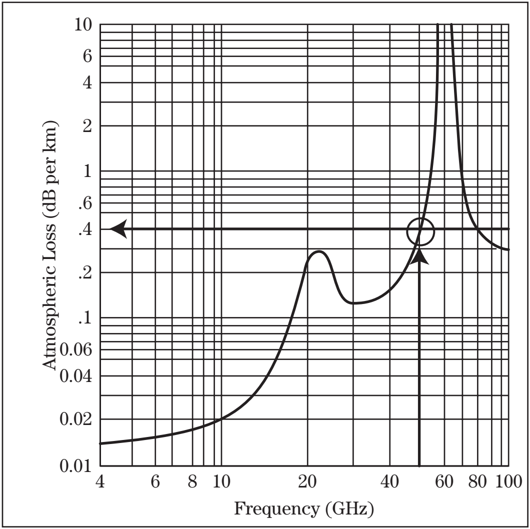


Calculate $d = [\text{sqrt } 2 / (1 + (d_1/d_2)]\, d_1$
or just use $d = d_1$ which reduces accuracy by $\sim$ 1.5 dB

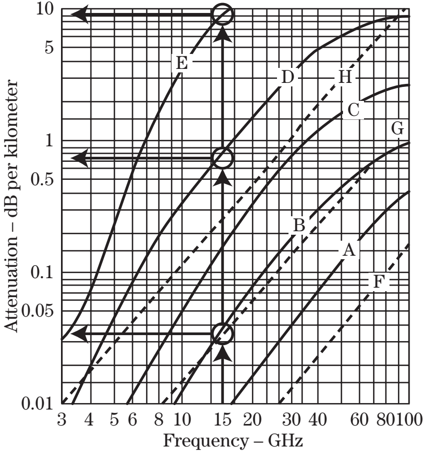
Knife edge diffraction nomograph



Atmospheric attenuation at sea level



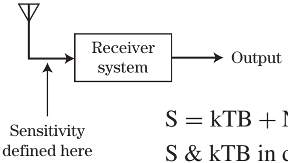
Rain & Fog attenuation



RAIN				
	B	1.0 mm/hr	.04 in/hr	Light Rain
	C	4.0 mm/hr	.16 in/hr	Moderate Rain
	D	16 mm/hr	.64 in/hr	Heavy Rain
	E	100 mm/hr	4.0 in/hr	Very Heavy Rain

FOG			
	F	0.032 gm/m^3	Visibility greater than 600 meters
	G	0.32 gm/m^3	Visibility about 120 meters
	H	2.3 gm/m^3	Visibility about 30 meters

Receiver Sensitivity

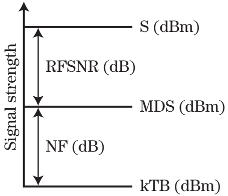


$$S = kTB + NF + RFSNR$$

S & kTB in dBm, NF & RFSNR in dB

Sensitivity is the minimum signal level out of antenna at which the receiver can provide adequate output SNR

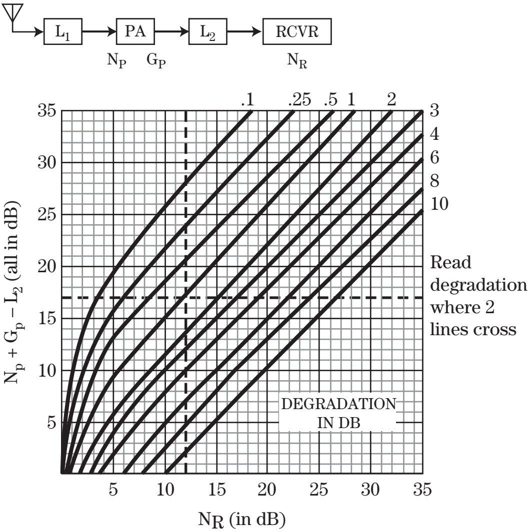
Minimum discernable signal (MDS) is signal level for 0 dB RFSNR



kTB(in dBm) $= -114 + 10 \log (BW/1\ MHz)$

System noise figure

w/o Preamp: $NF = L_1 + N_R$
With Preamp: $NF = L_1 + N_P + Deg$ All in dB



L_1&L_2 = Losses (dB) G_P = PA Gain (dB)
N_P = PA NF (dB) N_R = Rcvr NF(dB)

Signal to Noise Ratio Required

Type of Signal	RFSNR	Output SNR
Pulse Signal –Expert Operator	8 dB	8 dB
Pulse Signal – Computer Analysis	15 dB	15 dB
Television Broadcast	40 dB	40 dB
AM Signal	10 to 15 dB	10 to 15 dB
FM Signal	4 or 12 dB	15 to 40 dB
Digital Signal	≅ 12 dB	SQR

FM signal

4 dB for FM improvement with PLL Discriminator
12 dB for FM improvement with tuned Discriminator
FM improvement above RF SNR:
$IF_{FM} = 5 + 20\ \log(\beta)$
Output SNR = RFSNR + IF_{FM}

Digital signal

RFSNR depends on required bit error rate Output SNR is determined by digitization. “SQR” is The signal to Quantization error ratio

Effective range (Line of Sight Propagation)

$$20\ \log(R_E) = P_T + G_T - 32.44 - 20\ \log(F) + G_R - S$$
$$R_E = \text{anti-log}[20\ \log(R_E)/20]$$

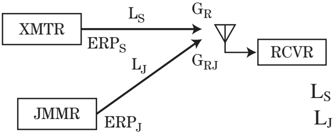
Effective range (Two-Ray Propagation)

$$40\ \log(R_E) = P_T + G_T - 120 + 20\ \log(h_T) + 20\ \log(h_R) + G_R - S$$
$$R_E = \text{anti-log}[40\ \log(R_E)/40]$$

R_E in km, P_T & S in dBm, G_T & G_R in dB, h_T & h_R in meters,

KED impact on effective range
Because the range impacts the location of the transmitter and/or receiver relative to the ridge line, it is normally best to calculate the KED loss after the geometry is defined, then make the appropriate recalculation of range after addition of the KED loss.

Communication Jamming



ERP_J = ERP of JMMR
ERP_S = ERP of XMTR
L_S = XMTR to RCVR loss
L_J = JMMR to RCVR loss
G_R = Gain of Rcv Ant to XMTR
G_{RJ} = Gain of Rcv Ant to JMMR

General case

$J/S = ERP_J - ERP_S - L_J + L_S + G_{RJ} - G_R$

If RCV ant has 360° coverage

$J/S = ERP_J - ERP_S - L_J + L_S$

Loss in signal or jam link can be from any of the propagation models on pages 15–19.

Jamming effectiveness

Note that the above equations and those presented later for RADAR jamming assume that all jamming power is within the target receiver bandwidth and that the jamming signal will have the same processing gain as the desired signal. Resulting J/S calculations must be adjusted for both of these factors when they apply.

Required J/S & Jamming duty cycle

Against analog modulations: J/S $\sim$ 10 dB and 100% duty cycle are required to assure complete interruption of the target link.

Against digital modulations: J/S $\sim$ 0 dB
Duty cycle = 20−33% over info period (for example over the period of a syllable of voice communication)
This will cause sufficient bit errors to stop communication.
Both of these J/S ratios are after any reductions for receiver processing gain and jamming inefficiency.

Communication EP (LPI Comm)

Anti jamming (A/J) advantage

The amount of total jamming power required relative to that required for a conventional non-LPI signal with the same Information bandwidth.

Frequency hopping

Requires digital modulation Slow hop is bits/hop

Fast hop is hops/bit

A/J advantage = hopping range/Information Bandwidth

Chirp

Requires digital modulation

Sweep at very high rate

A/J advantage = sweep range/Information Bandwidth

Long sweep with many bits per sweep

- Pseudo-random sweep synchronization &/or non-linear sweep

Sweep per bit with uni or bi directional sweep on each bit

- Detected in compressive filters

Direct sequence spread spectrum

Requires digital modulation

Secondary modulation with high rate pseudo-random code

A/J advantage = spreading code rate/information code rate

Jamming LPI Communications

Slow frequency hopping
Follower jammer driven by digital RCVR with FFT
Partial band jamming

Fast frequency hopping
Partial band jamming

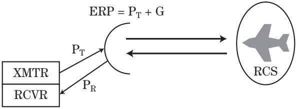
Chirp (long sweep)
Partial band jamming

Chirp (sweep/bit)
Match sweep waveform for one or for zero for all bits

Direct sequence spread spectrum
CW Jamming or Pulse Jamming
Adequate J/S to overcome A/J advantage and achieve 0 dB J/S after despreading

Partial band jamming
Spreads jamming power over the number of channels for which 0 dB J/S can be achieved. In general, this provides optimum hopper or chirp jamming performance.

Radar Characteristics



Radar range equation (matched filter)

$$\frac{P_P \tau G_T \sigma A_R}{(4\pi)^2 R^4 k T_s L} = 20$$

Radar return power equation

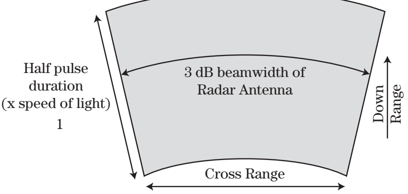
$$P_R = P_T G^2 \lambda^2 \sigma / (4\pi)^3 R^4$$

P_T P_R & P_P in Watts
G & L are ratios
R in meters
τ in sec T_S in °K
σ & A_R in sq meters
λ in meters

$$(\text{dB})\, P_R = P_T + 2G - 103 - 20 \operatorname{Log} F - 40 \operatorname{Log} R + 10 \operatorname{Log} \sigma$$

P_T & P_R in dBm , G in dB, F in MHz. R in km, σ in sq meters

Radar resolution cell

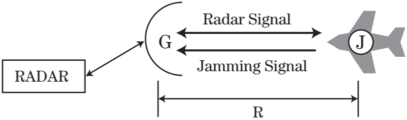


Radar Jamming

For non-dB forms: J/S , G, G_M, G_S are ratios
ERP_J & ERP_S in watts
R, R_T & R_J in meters, σ in m^2

For dB forms: J/S in dB G, G_M, G_S in dBi ERP_J & ERP_S in dBm R, R_T & R_J in km, σ in m^2

Self protection jamming



Note that G is G_M

$\mathbf{J/S} = (4\pi ERP_J R^2)/(ERP_S \sigma)$

(In dB) $\mathbf{J/S} = ERP_J - ERP_S + 71 + 20\,Log\,R - 10\,Log\,\sigma$

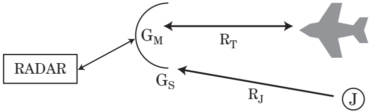
Burn through range

$R_{BT} = sqrt[(ERP_S \sigma)/(4\pi ERP_J)]$

(In dB) $20\,Log\,R_{BT} = ERP_S - ERP_J - 71 + 10\,Log\,RCS + J/S\,(Rqd)$

$R_{BT} = Anti\text{-}Log\,\{[20\,Log\,R]/20\}$

Remote Jamming



$$\mathbf{J/S} = (4\pi ERP_J G_S R_T^4)/(ERP_S G_M R_J^2 \sigma)$$

(In dB)

$$\mathbf{J/S} = ERP_J - ERP_S + 71 + G_S - G_M + 40 \text{ Log } R_T$$
$$- \; 20 \log R_J - 10 \text{ Log RCS}$$

Burn through range

$R_{BT} = 4^{th}$ root of $[(ERP_S\ G_M\ R_J^2 \sigma)/(4\pi ERP_J\ G_S)]$

(In dB)

$$40 \text{ Log } R_T = ERP_S - ERP_J - 71 - G_S + G_M + 40 \text{ Log } R_T$$
$$- 20 \text{ Log } R_J + 10 \text{ Log RCS} + J/S(\text{Required})$$
$$R_{BT} = \text{Anti-Log}\{[40 \text{ Log } R_T]/40\}$$

Note about burn through range:

This is actually the range at which the radar can reacquire the target, but it is common to calculate with the minimum J/S for which jamming can be assumed to be effective.

Radar EP

Ultralow side lobes: Reduces J/S & increases burnthrough range in sidelobe jamming

Sidelobe cancellation: Reduces CW sidelobe jamming

Sidelobe blanking: Cancels pulse sidelobe jamming

Anti-crosspol: Reduces cross polarized (Condon) lobes

Pulse compression: Reduces J/S by the compression factor unless jammer has compression modulation

Monopulse radar: Counters multi-pulse angle deception

Pulse doppler radar: Detects non-coherent jamming, detects chaff, requires coherent jamming

Dicke-Fix: counters AGC jamming

Burn-through modes: Increase power or duty cycle to increase burn-through range.

Frequency agility: Requires jamming energy to be spread to cover transmission frequencies

PRF Jitter: requires longer cover pulses

Home on jam mode: Makes self protection jamming Impractical, endangers stand-off jammers

Expendable Countermeasures

RCS of chaff

RCS of one (average) dipole

$\sigma_1 = 0.15\ \lambda^2$

0.46 λ to 0.48 λ dipole length

Dipoles randomly oriented

RCS of all (N) dipoles in chaff cloud or in radar resolution cell if cloud is larger

- 0.925 $N\sigma_1$ with λ spacing
- 0.981 $N\sigma_1$ with 2λ spacing
- $N\sigma_1$ with wide spacing

Flares

Older flares are much hotter than heat source targeted by heat seeking missiles. Slope of IR energy vs. wavelength varies with temp. so 2 color sensor can discriminate against flare. 2-color or low temp. flares match energy slope of target.

Expendable decoys

Protect Ships and Aircraft

Generate more RCS than target

Start within radar resolution cell, capture tracking radar, move resolution cell away from target

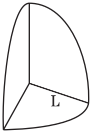
Towed decoys

Towed within radar resolution cell at acquisition range but beyond burst radius of missile warhead.

Decoys

RCS of passive corner reflector decoy

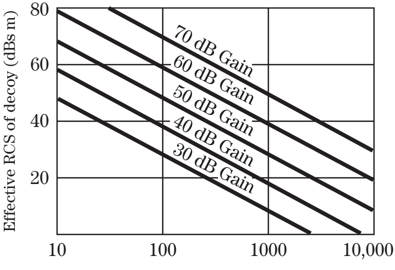
$$\sigma = \frac{15.59\,L^4}{\lambda^2}$$



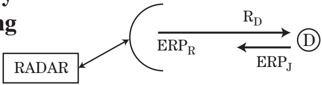
Active decoys

RCS(dBsm) = 39 + Gain − 20 log(F)   L & λ in meters, F in MHz

RCS of constant gain decoy



RCS of primed decoy (fixed ERP) repeating radar signal



$RCS(dBsm) = 71 + ERP_J - ERP_R + 20\log(R_D)$

ERP (both) in dBm, R_D in km

Decibels (dB)

N (dB) = $10 \log_{10}$ (N) Where N is a ratio
Special case for voltage ratio, $N(dB) = 20 \log_{10}(N)$

$$N(\text{not in dB}) = 10^{[N(dB)/10]}$$
$$= \text{AntiLog}[N(dB)/10]$$

A(dB) ± B (dB) = C(dB)
A(dBm) ± B(dB) = C(dBm)
A(dBm) – B(dBm) = C(dB)
A(dB) ± 10 Log(number not in dB)
A(dB) ± 20 Log(number not in dB)
when square of number goes into eqn

dBm	dB value of Pwr/1 mW	Signal Strength
dBW	dB value of Pwr/1 watt	Signal Strength
dBsm	dB value of area/1 sm	RCS & Ant. Area
dBi	dB value of ant gain/ isotropic	Antenna Gain

N(dBm) = N(dBW) + 30 dB

Graph & Nomograph Instructions

Peak gain vs 3 dB beamwidth (p7):
draw up from 3 dB beamwidth to 55% efficiency line, then left to peak gain. Note that dish antenna can have values to the left of this line but not to the right.

Line of sight loss (p 15):
Draw line from distance in km to frequency in MHz. Read loss in dB at center scale.

Two ray loss (p16):
Draw line from transmit antenna Height to receiving antenna height (both in meters). Draw Line from dividing line through distance in km. Read Loss in dB at right scale

Knife edge diffraction loss (p17):
Draw line from d in km On left scale through H in meters to index line. (note that H can be above or below knife Edge). Draw line from index crossing through frequency in MHz to right scale. Read KED loss (above LOS loss) in dB at right scale If H is above knife edge use left side; if H is below knife edge use right side.

Graph & Nomograph Instructions

Atmospheric loss (p18):
Draw vertical line up from Frequency to curve, then left to loss per km.

Rain & Fog loss (p 19):
identify appropriate curve from Table. Draw line from frequency up to curve, then left to Attenuation per km.

Receiver system NF (p21):
Draw vertical line from N_R Draw horizontal line from $G_P + N_P - L_2$. lines cross on applicable degradation value curve.

Active decoy RCS (p33):
Draw up from frequency to Gain line, then left to Decoy RCS

List of Symbols

P_T	Transmitter power in dBm
P_R	Received Power in dBm
G_T	Transmitting Antenna gain in dB
G_R	Receiving Antenna gain in dB
G_M	Antenna main beam peak gain
G_S	Antenna average side lobe gain
L	Propagation loss (from any model)
F	Frequency in MHz
D	Link distance in km
d	distance input to KED nomograph
d_1	distance from XMTR to knife edge
d_2	distance from knife edge to RCVR
h_T	height of transmit antenna in meters
h_R	height of receiving antenna in meters
FZ	Fresnel zone distance in km
S	Sensitivity in dBm
λ	Wavelength in meters
c	Speed of light (3×10^8 m/sec)
R	Range
R_E	Effective range
R_J	Range to jammer
R_T	Range to target
σ	Radar cross section
τ	Pulse width
k	Boltzman's constant
T_S	System temperature in °Kelvin

List of Abbreviations

EW	Electronic Warfare
ES	Electronic Support
EP	Electronic Protection
ARM	Anti-radiation missile
HEW	High energy weapons
LPI	Low probability of intercept
RWR	Radar Warning Receiver
LOS	Line of sight Loss
KED	Knife Edge Diffraction Loss
XMTR	Transmitter
RCVR	Receiver
kTB	Thermal noise in receiver in dBm
RFSNR	Predetection signal to noise ratio
SNR	Output signal to noise ratio
BW	Receiver effective bandwidth
PA	Preamplifier
LHC	Left hand circular (polarization
RHC	Right hand circular (polarization)
ERP	Effective radiated power
RCS	Radar cross section
PRF	Pulse repeitition frequency
MDS	Minimum discernable signal
NF	Noise figure
PLL	Phase locked loop
IF_{FM}	FM improvement factor