PROPAGATION FORMULAS

1.1 DBW FROM VOLTAGE OR POWER

$$\text{Power in dBW} = 10 \text{ Log} \left(\frac{(\text{Voltage in microvolts X } 10^{-6})^2}{50 \text{ ohms}} \right)$$

$$\text{Power in dBW} = 10 \text{ Log} \left(\frac{(\text{Voltage in volts})^2}{50 \text{ ohms}} \right)$$

Power in dBW = 10 Log (Power in watts)

Note: dBW = dBm - 30 dB

1.2 FREQUENCY TO WAVELENGTH

$$\text{Wavelength in Meters} = \frac{300}{f_{MHz}}$$

$$\text{Wavelength in Feet} = \frac{984}{f_{MHz}}$$

1.3 FREE SPACE LOSS

Half Wave Dipole (distance in miles) $dB = 32.28 + 20 \text{ LOG } f_{MHz} + 20 \text{ LOG } D_{mi}$

Isotropic radiator (distance in miles) $dB = 36.58 + 20 \text{ LOG } f_{MHz} + 20 \text{ LOG } D_{mi}$

Half Wave Dipoles (distance in Kilometers) $dB = 88.15 + 20 \text{ LOG } f_{GHz} + 20 \text{ LOG } D_{km}$

Isotropic radiator (distance in kilometers) $dB = 92.45 + 20 \text{ LOG } f_{GHz} + 20 \text{ LOG } D_{km}$

1.4 EARTH CURVATURE

	d in miles, h in feet	d in kilometers, h in meters
General	$h = \frac{d_1 d_2}{1.5K}$	$h = \frac{d_1 d_2}{12.75K}$
$K = \infty$	$h = 0$	$h = 0$
K = 4/3	$h = \frac{d_1 d_2}{2}$	$h = \frac{d_1 d_2}{17}$
K = 2/3	$h = d_1 d_2$	$h = \frac{d_1 d_2}{8.5}$
K = 1	$h = 0.67 d_1 d_2$	$h = \frac{d_1 d_2}{12.75}$

Where h = the change in vertical distance from a horizontal reference line, in feet/meters

d_1 = the distance from a point to one end of the path in miles/kilometers

d_2 = the distance from the same point to the other end of the path, in miles/kilometers

K = the equivalent earth radius factor

1.5 FRESNEL ZONE

Feet $F_1 = 72.1 \sqrt{\frac{d_1 d_2}{(f_{GHz})D}}$ d_1, d_2, D in miles

Meters $F_1 = 17.3 \sqrt{\frac{d_1 d_2}{(f_{GHz})D}}$ d_1, d_2, D in kilometers

Where: F_1 = first Fresnel zone radius in feet/meters

d_1 = distance from one end of path to reflection point

$d2 = D - d_1$

D = Total length of path

f = frequency in GHz

Note: These formulas provide the distance to the first Fresnel Zone. If "0.6" Fresnel is required then multiply by "0.6".

1.6 DISTANCE TO RADIO HORIZON

General $D = \sqrt{\frac{3Kh}{2}}$

K= 1 $D = \sqrt{1.5h}$

K = 4/3 $D = \sqrt{2h}$

Where: D = distance to the radio horizon in miles
K = the equivalent earth radius factor
h = height in feet

1.7 FIELD STRENGTH TO SENSITIVITY

$$u\text{V} = \frac{39.5 * (u\text{V} / \text{m})}{f_{\text{MHz}}}$$

$$F_{\text{dB}u\text{V} / \text{m}} = 20 \text{ Log } E_{(u\text{V} / \text{m})}$$

$$F_{\text{dB}u\text{V} / \text{m}} = 105 + 10 \text{ Log } P_{(\text{Watts})} + 20 \text{ Log}(f_{\text{MHz}})$$

$$F_{\text{dB}u\text{V} / \text{m}} = 75 + 10 \text{ Log } P_{(\text{milliWatts})} + 20 \text{ Log}(f_{\text{MHz}})$$

$$\frac{\text{dBW}}{\text{m}^2} = \text{dBm} - 70.65 + 20 \text{ Log}(f_{\text{MHz}})$$

Where F = field strength in dB microvolts per meter
P = power
f = frequency
Note: For 50 ohms, referenced to a dipole.

1.8 DOPPLER SHIFT

$$v_{(km/h)} = 1079 * \frac{\Delta f_{Hz}}{f_{MHz}} \qquad v_{(m/h)} = 670.6 * \frac{\Delta f_{Hz}}{f_{MHz}}$$

$$\Delta f_{Hz} = 0.009266 * v_{(km/h)} * f_{MHz} \qquad \Delta f_{Hz} = 0.00149 * v_{(m/h)} * f_{MHz}$$

Where v = velocity

1.9 NEAR FIELD / FAR FIELD BOUNDARY

Far Field Starts at: $\frac{983}{f_{MHz}} * 10^{\frac{G_{dBd}}{10}}$ (meters)

Far Field Starts at: $\frac{3226}{f_{MHz}} * 10^{\frac{G_{dBd}}{10}}$ (feet)

Where: G_{dBd} = Gain referenced to a dipole

1.10 NOISE POWER

$P_{N(Watts)} = kTB$

Where: k = Boltzman's constant = $1.38 * 10^{-23} \ \frac{J}{K}$

B = Bandwidth in Hz

T = 290 Kelvin

Noise power in dBm is $P_N = -143.9 + 10\text{Log}(B_{kHz})$

FORMULA REFERENCES:

1-1 Engineering Considerations for Microwave Communications Systems, Fourth Edition, GTE Lenkurt Inc., 1975

MICROVOLT TO dBW and dBm

Microvolt	dBW	dBm	Microvolt	dBW	dBm	Microvolt	dBW	dBm
0.10	-156.99	-126.99	**0.58**	-141.72	-111.72	**1.06**	-136.48	-106.48
0.11	-156.16	-126.16	**0.59**	-141.57	-111.57	**1.07**	-136.40	-106.40
0.12	-155.41	-125.41	**0.60**	-141.43	-111.43	**1.08**	-136.32	-106.32
0.13	-154.71	-124.71	**0.61**	-141.28	-111.28	**1.09**	-136.24	-106.24
0.14	-154.07	-124.07	**0.62**	-141.14	-111.14	**1.10**	-136.16	-106.16
0.15	-153.47	-123.47	**0.63**	-141.00	-111.00	**1.11**	-136.08	-106.08
0.16	-152.91	-122.91	**0.64**	-140.87	-110.87	**1.12**	-136.01	-106.01
0.17	-152.38	-122.38	**0.65**	-140.73	-110.73	**1.13**	-135.93	-105.93
0.18	-151.88	-121.88	**0.66**	-140.60	-110.60	**1.14**	-135.85	-105.85
0.19	-151.41	-121.41	**0.67**	-140.47	-110.47	**1.15**	-135.78	-105.78
0.20	-150.97	-120.97	**0.68**	-140.34	-110.34	**1.16**	-135.70	-105.70
0.21	-150.55	-120.55	**0.69**	-140.21	-110.21	**1.17**	-135.63	-105.63
0.22	-150.14	-120.14	**0.70**	-140.09	-110.09	**1.18**	-135.55	-105.55
0.23	-149.76	-119.76	**0.71**	-139.96	-109.96	**1.19**	-135.48	-105.48
0.24	-149.39	-119.39	**0.72**	-139.84	-109.84	**1.20**	-135.41	-105.41
0.25	-149.03	-119.03	**0.73**	-139.72	-109.72	**1.21**	-135.33	-105.33
0.26	-148.69	-118.69	**0.74**	-139.61	-109.61	**1.22**	-135.26	-105.26
0.27	-148.36	-118.36	**0.75**	-139.49	-109.49	**1.23**	-135.19	-105.19
0.28	-148.05	-118.05	**0.76**	-139.37	-109.37	**1.24**	-135.12	-105.12
0.29	-147.74	-117.74	**0.77**	-139.26	-109.26	**1.25**	-135.05	-105.05
0.30	-147.45	-117.45	**0.78**	-139.15	-109.15	**1.26**	-134.98	-104.98
0.31	-147.16	-117.16	**0.79**	-139.04	-109.04	**1.27**	-134.91	-104.91
0.32	-146.89	-116.89	**0.80**	-138.93	-108.93	**1.28**	-134.85	-104.85
0.33	-146.62	-116.62	**0.81**	-138.82	-108.82	**1.29**	-134.78	-104.78
0.34	-146.36	-116.36	**0.82**	-138.71	-108.71	**1.30**	-134.71	-104.71
0.35	**-146.11**	**-116.11**	**0.83**	-138.61	-108.61	**1.31**	-134.64	-104.64
0.36	-145.86	-115.86	**0.84**	-138.50	-108.50	**1.32**	-134.58	-104.58
0.37	-145.63	-115.63	**0.85**	-138.40	-108.40	**1.33**	-134.51	-104.51
0.38	-145.39	-115.39	**0.86**	-138.30	-108.30	**1.34**	-134.45	-104.45
0.39	-145.17	-115.17	**0.87**	-138.20	-108.20	**1.35**	-134.38	-104.38
0.40	-144.95	-114.95	**0.88**	-138.10	-108.10	**1.36**	-134.32	-104.32
0.41	-144.73	-114.73	**0.89**	-138.00	-108.00	**1.37**	-134.26	-104.26
0.42	-144.52	-114.52	**0.90**	-137.90	-107.90	**1.38**	-134.19	-104.19
0.43	-144.32	-114.32	**0.91**	-137.81	-107.81	**1.39**	-134.13	-104.13
0.44	-144.12	-114.12	**0.92**	-137.71	-107.71	**1.40**	-134.07	-104.07
0.45	-143.93	-113.93	**0.93**	-137.62	-107.62	**1.41**	-134.01	-104.01
0.46	-143.73	-113.73	**0.94**	-137.53	-107.53	**1.42**	-133.94	-103.94
0.47	-143.55	-113.55	**0.95**	-137.44	-107.44	**1.43**	-133.88	-103.88
0.48	-143.36	-113.36	**0.96**	-137.34	-107.34	**1.44**	-133.82	-103.82
0.49	-143.19	-113.19	**0.97**	-137.25	-107.25	**1.45**	-133.76	-103.76
0.50	**-143.01**	**-113.01**	**0.98**	-137.17	-107.17	**1.46**	-133.70	-103.70
0.51	-142.84	-112.84	**0.99**	-137.08	-107.08	**1.47**	-133.64	-103.64
0.52	-142.67	-112.67	**1.00**	-136.99	-106.99	**1.48**	-133.58	-103.58
0.53	-142.50	-112.50	**1.01**	-136.90	-106.90	**1.49**	-133.53	-103.53

0.54	-142.34	-112.34	**1.02**	-136.82	-106.82	**1.50**	-133.47	-103.47
0.55	-142.18	-112.18	**1.03**	-136.73	-106.73	**1.51**	-133.41	-103.41
0.56	-142.03	-112.03	**1.04**	-136.65	-106.65	**1.52**	-133.35	-103.35
0.57	-141.87	-111.87	**1.05**	-136.57	-106.57	**1.53**	-133.30	-103.30
1.54	-133.24	-103.24	**2.01**	-130.93	-100.93	**2.48**	-129.10	-99.10
1.55	-133.18	-103.18	**2.02**	-130.88	-100.88	**2.49**	-129.07	-99.07
1.56	-133.13	-103.13	**2.03**	-130.84	-100.84	**2.50**	-129.03	-99.03
1.57	-133.07	-103.07	**2.04**	-130.80	-100.80	**2.51**	-129.00	-99.00
1.58	-133.02	-103.02	**2.05**	-130.75	-100.75	**2.52**	-128.96	-98.96
1.59	-132.96	-102.96	**2.06**	-130.71	-100.71	**2.53**	-128.93	-98.93
1.60	-132.91	-102.91	**2.07**	-130.67	-100.67	**2.54**	-128.89	-98.89
1.61	-132.85	-102.85	**2.08**	-130.63	-100.63	**2.55**	-128.86	-98.86
1.62	-132.80	-102.80	**2.09**	-130.59	-100.59	**2.56**	-128.82	-98.82
1.63	-132.75	-102.75	**2.10**	-130.55	-100.55	**2.57**	-128.79	-98.79
1.64	-132.69	-102.69	**2.11**	-130.50	-100.50	**2.58**	-128.76	-98.76
1.65	-132.64	-102.64	**2.12**	-130.46	-100.46	**2.59**	-128.72	-98.72
1.66	-132.59	-102.59	**2.13**	-130.42	-100.42	**2.60**	-128.69	-98.69
1.67	-132.54	-102.54	**2.14**	-130.38	-100.38	**2.61**	-128.66	-98.66
1.68	-132.48	-102.48	**2.15**	-130.34	-100.34	**2.62**	-128.62	-98.62
1.69	-132.43	-102.43	**2.16**	-130.30	-100.30	**2.63**	-128.59	-98.59
1.70	-132.38	-102.38	**2.17**	-130.26	-100.26	**2.64**	-128.56	-98.56
1.71	-132.33	-102.33	**2.18**	-130.22	-100.22	**2.65**	-128.52	-98.52
1.72	-132.28	-102.28	**2.19**	-130.18	-100.18	**2.66**	-128.49	-98.49
1.73	-132.23	-102.23	**2.20**	-130.14	-100.14	**2.67**	-128.46	-98.46
1.74	-132.18	-102.18	**2.21**	-130.10	-100.10	**2.68**	-128.43	-98.43
1.75	-132.13	-102.13	**2.22**	-130.06	-100.06	**2.69**	-128.39	-98.39
1.76	-132.08	-102.08	**2.23**	-130.02	-100.02	**2.70**	-128.36	-98.36
1.77	-132.03	-102.03	**2.24**	-129.98	-99.98	**2.71**	-128.33	-98.33
1.78	-131.98	-101.98	**2.25**	-129.95	-99.95	**2.72**	-128.30	-98.30
1.79	-131.93	-101.93	**2.26**	-129.91	-99.91	**2.73**	-128.27	-98.27
1.80	-131.88	-101.88	**2.27**	-129.87	-99.87	**2.74**	-128.23	-98.23
1.81	-131.84	-101.84	**2.28**	-129.83	-99.83	**2.75**	-128.20	-98.20
1.82	-131.79	-101.79	**2.29**	-129.79	-99.79	**2.76**	-128.17	-98.17
1.83	-131.74	-101.74	**2.30**	-129.76	-99.76	**2.77**	-128.14	-98.14
1.84	-131.69	-101.69	**2.31**	-129.72	-99.72	**2.78**	-128.11	-98.11
1.85	-131.65	-101.65	**2.32**	-129.68	-99.68	**2.79**	-128.08	-98.08
1.86	-131.60	-101.60	**2.33**	-129.64	-99.64	**2.80**	-128.05	-98.05
1.87	-131.55	-101.55	**2.34**	-129.61	-99.61	**2.81**	-128.02	-98.02
1.88	-131.51	-101.51	**2.35**	-129.57	-99.57	**2.82**	-127.98	-97.98
1.89	-131.46	-101.46	**2.36**	-129.53	-99.53	**2.83**	-127.95	-97.95
1.90	-131.41	-101.41	**2.37**	-129.49	-99.49	**2.84**	-127.92	-97.92
1.91	-131.37	-101.37	**2.38**	-129.46	-99.46	**2.85**	-127.89	-97.89
1.92	-131.32	-101.32	**2.39**	-129.42	-99.42	**2.86**	-127.86	-97.86
1.93	-131.28	-101.28	**2.40**	-129.39	-99.39	**2.87**	-127.83	-97.83
1.94	-131.23	-101.23	**2.41**	-129.35	-99.35	**2.88**	-127.80	-97.80
1.95	-131.19	-101.19	**2.42**	-129.31	-99.31	**2.89**	-127.77	-97.77
1.96	-131.14	-101.14	**2.43**	-129.28	-99.28	**2.90**	-127.74	-97.74
1.97	-131.10	-101.10	**2.44**	-129.24	-99.24	**2.91**	-127.71	-97.71
1.98	-131.06	-101.06	**2.45**	-129.21	-99.21	**2.92**	-127.68	-97.68
1.99	-131.01	-101.01	**2.46**	-129.17	-99.17	**2.93**	-127.65	-97.65
2.00	-130.97	-100.97	**2.47**	-129.14	-99.14	**2.94**	-127.62	-97.62