Useful RF Relationships

Volts RMS, Power and dB Conversions

Volts RMS from V peak-peak:

$$V_{rms} = \frac{V_{p-p}}{2\sqrt{2}} = \frac{V_{pk}}{\sqrt{2}}$$

Power (Watts):

$$P_W = \frac{V_{rms}^2}{R_{ohms}}$$

Power (dBW "dB relative to 1 W"):

$$P_{dBW} = 10\log(P_W)$$

Power (dBm "dB relative to 1 mW"):

$$P_{dBm} = 10\log\left(\frac{P_W}{.001W}\right)$$

dBm to dBW:

$$P_{dBm} = P_{dBW} + 30$$

dBm to mW:

$$P_{mW} = 10^{\frac{P_{dBm}}{10}}$$

dBm to V_{rms}:

$$V_{rms} = \sqrt{10^{dBm/10} \cdot 0.001 \cdot R}$$

- R is usually 50 Ohms

Examples

P (W)	dBW	dBm	V (rms)	V (p-p)
4	6.02	36.02	14.1421	40.0000
2	3.01	33.01	10.0000	28.2843
1	0.00	30.00	7.0711	20.0000
0.1	-10.00	20.00	2.2361	6.3246
0.01	-20.00	10.00	0.7071	2.0000
0.001	-30.00	0.00	0.2236	0.6325
0.0001	-40.00	-10.00	0.0707	0.2000
1.00E-05	-50.00	-20.00	0.0224	0.0632
1.00E-06	-60.00	-30.00	0.0071	0.0200
1.00E-07	-70.00	-40.00	0.0022	0.0063
1.00E-08	-80.00	-50.00	0.0007	0.0020

- V (rms) computed using R=50 ohm

RF Path Loss

EIRP : Effective Isotropic Radiated Power : This is a normalized measure of power radiated out of an antenna at a transmitter, usually given in dBm or dBW. This accounts for any gain in the antenna.

Free-space Path Loss, L: The loss experienced between transmitting and receiving antennas over a line-of-sight path (i.e. no obstructions). Usually just called "path loss".

$$L = \left(\frac{4\pi d}{\lambda}\right)^2$$

$$L = \left(\frac{4\pi df}{c}\right)^2$$

where:

- $\lambda = \frac{c}{f}$
- $c =$ speed of light $(3 \cdot 10^8)$ m/s
- $f =$ frequency in Hz
- $d =$ distance in meters

In dB:

$$L_{dB} = 20\log(d) + 20\log(f) + 20\log\left(\frac{4\pi}{c}\right)$$

$$L_{dB} = 20\log(d) + 20\log(f) - 147.55$$

Computing Path Loss: Example

- Transmitter EIRP: +30 dBm
- Distance between antennas (d): 2 meters
- Freq: 10 GHz
- Receive antenna gain (G_r): 4dB (typical for a patch antenna)

Power at output of receive antenna:

$P_r = EIRP - L_{dB} + G_r$

$P_r = 30 - (20\log(2) + 20\log(10^9) - 147.55) + G_r$

$P_r = 30 - (6.02 + 200 - 147.55) + 4$

$P_r = 30 - 58.4 + 4$

$P_r = -24.4$ dBm

Takeaways:

- RF power loses 58.4 dB over just 2 meters!
- Power decreases with the square of the distance. This is the **Inverse Square Law**
- For every *doubling* of the distance you would only lose an additional 6 dB of power!
- This is why we can still communicate with the Voyager space probes!