Application Note: Antenna Fundamentals

Discussion -

Decibel (dB)

The decibel is a power or voltage ratio: $dB = 10 \log P_2/P_1$ or $dB = 10 \log V_2/V_1$. We're concerned with power (the first formula).

If you take out your calculator and plug in 0.5 for (P_2/P_1) in the formula above, you get -3.01. In plain terms, this means that a 3 dB loss is equivalent to cutting the power in half.

Since dB is a ratio, it has no units and is a relative measure. Output power is commonly expressed in dBm. This replaces the P_1 term in the dB equation with 1 mW.

The units of antenna gain are usually expressed in dBi. The 'i' stands for isotropic, an ideal antenna with a spherical radiation pattern. Like anything "ideal", the isotropic antenna does not exist in the practical world. The correct units for a dipole antenna would be dBd ('d' for dipole), but we still often see dBi used for any kind of antenna gain.

FCC Limits

The FCC regulations for Point to Multi-Point allow only 36 dBm (4 watts) Effective Isotropic Radiated Power (EIRP). This is 30 dBm (1 watt) into a 6 dBi antenna. If you use a 10 dBi wireless antenna, you must limit your transmitter (or amplifier) to 26 dBm (10 + 26 = 36 dBm). For a 14 dBi panel wireless antenna, this allows a 22 dBm transmitter (or amplifier). Power is measured at the antenna connector, so **subtract any cable loss between the amplifier and the antenna**. Refer to the following table:

Power at Antenna (dBm/Watts)	Antenna Gain (dBi)	EIRP (dBm)	EIRP (watts)
30 dBm (1 W)	6	36	4
27 dBm (500 mW)	9	36	4
24 dBm (250 mW)	12	36	4
21 dBm (125 mW)	15	36	4
18 dBm (62 mW)	18	36	4
15 dBm (31 mW)	21	36	4
12 dBm (15 mW)	24	36	4

According to FCC regulations, 2.4 GHz Part 15.247 point-to-point transmitters may use a 30 dBm transmitter with a 6 dBi antenna. For a 3 dB increase in antenna gain, the transmitter power output must be reduced by 1 dB. Power is measured at the antenna connector, so **subtract any cable loss between the amplifier and the antenna**. Refer to the following table:

Power at antenna (dBm/watts)	Max Antenna Gain (dBi)	EIRP (dBm)	EIRP (watts)
30 dBm (1 W)	6	36	4
29	9	38	6.3
28	12	40	10
27 dBm (500 mW)	15	42	16
26	18	44	25
25	21	46	39.8
24 dBm (250 mW)	24	48	63
23	27	50	100
22	30	52	158

Cable

The antenna is only part of the equation. The cable between the transmitter and antenna always has some loss associated with it. The antenna extension cable typically supplied by Adalet Wireless (Belden 7806R) has a loss of 10.3 dB / 100 ft. (11.2 dB / 100m). Since this attenuation is linear, this means that every 29.1 ft. (26.9 m) of cable cuts the radiated power IN HALF!

Antennae

We sell two basic types – omnidirectional and Yagi. The "rubber duck" antenna supplied with Adalet Wireless' receivers, repeaters, modems and DIN-rail transmitters is an omnidirectional having a gain of +2 dBd. We offer an outside-mountable omnidirectional with a gain of +3 dBd. Our 4-element Yagi has a gain of +6 dBd.

Omnidirectional antennae have a radiation pattern that looks like a donut, with the hole centered on the antenna. Yagi antennae radiate a pattern somewhat like the beam of a flashlight. Refer to the radiation patterns on the following page.

Note that the "high gain" omni antenna has only 1 dBd more gain than the rubber duck. In fact, if we use 30' of cable between the receiver and the antenna, we've actually LOST 2 dBd! The Yagi has modestly better gain, but any extension cable longer than about 40' puts us at a loss.

Why not use higher-gain antennae? In some applications we can, but the trade-off for higher gain is a smaller beam angle. This means that the omni's donut gets flatter, and the Yagi's beam gets tighter (less like a flashlight, more like a laser beam). This makes aiming the antennae more critical and can complicate rather than simplify an installation.

Link Margin

Link margin is the difference between the power of the signal received at the remote end, and the receive sensitivity of the remote end. From this you can determine the viability of a link. Around 10dBm of margin is desirable for a reliable link.

Fresnel Zone

Pronounced "fruh-nel". This is the answer to the question "How high off the ground should the antenna be?" the answer is "At least _ the Fresnel distance." While line of sight is important, it may not always be adequate. Even though the path has clear line of sight, if obstructions (such as terrain, vegetation, buildings, etc.) penetrate the Fresnel zone, there will be signal attenuation.

Want to calculate it? Here you go: $F_N = \sqrt{\frac{N \times \lambda \times D_1 \times D_2}{D_1 + D_2}}$, N = 1, λ = 0.328m (915 MHz)

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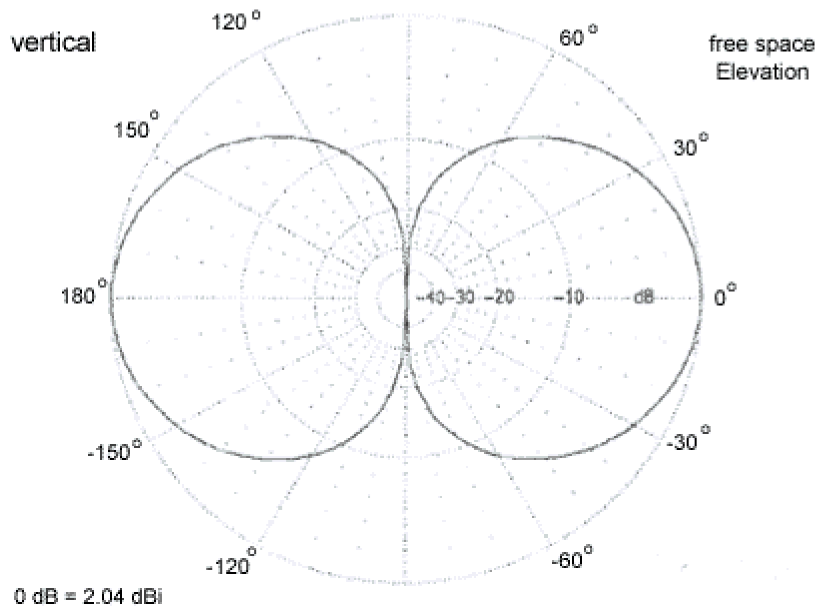
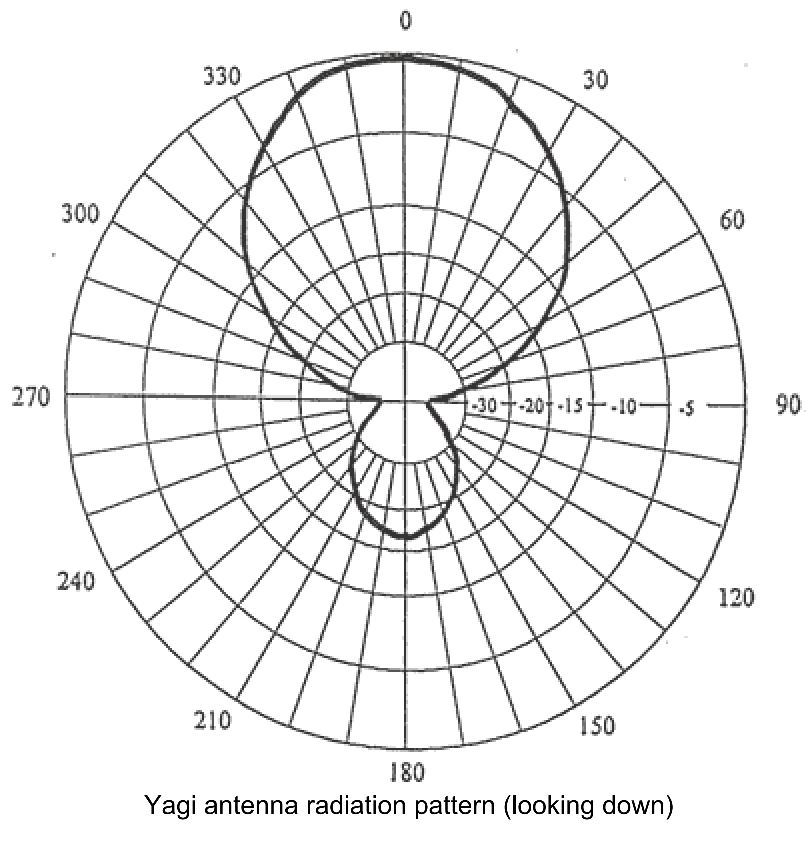
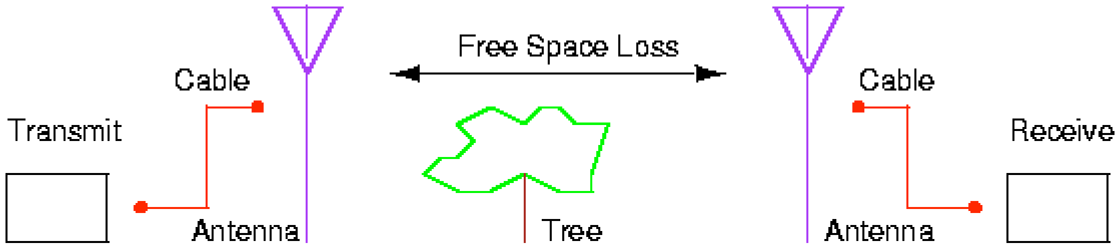


Omnidirectional antenna radiation pattern – cross section



Yagi antenna radiation pattern (looking down)

Putting it all together -



Free space loss for various distances:

FSL (isotropic) = 20Log_{10}(Frequency in MHz) + 20Log_{10} (Distance in Miles) + 36.6

Distance (mi)	Path Loss (dB)
0.25	83.79
0.5	89.81
1	95.83
2	101.85
3	105.37
4	107.87
5	109.81
10	115.83
20	121.85
40	127.87

Free space loss is not really a "loss" at all. It describes the reduction in received signal strength due to the expansion of the electromagnetic field. Note that there is about 6 dB between 0.5 mi and 1 mi, another 6 dB between 1 mi and 2 mi, another 6 dB between 2 mi and 4 mi, and so on. Remember that 3 dB is the same as cutting the power in half. This means that it takes FOUR TIMES the power to go TWICE the distance.

If we express the drawing above as a mathematical equation, we get:

$P_{RX} = P_{TX} + G_{TX\_CABLE} + G_{TX\ ANT} + G_{FREE\ SPACE} + G_{RX\ ANT} + G_{RX\ CABLE}$

Let's assume a 1W transmitter, 30' of antenna cable on the transmitter to a 4-element Yagi, 1 mile transmit distance, and a "rubber duck" antenna on the receiver, which has a sensitivity of -100 dBm. Plugging in the numbers, we get:

P_{RX} = 30 dBm + (-3 dBm) + 6 dBi + (-96 dB) + 2 dBi + 0 = (-61 dBm)

This gives us a link margin of 39 dBm (-100 – (-61)), and should be a reliable system. For simplicity, we've omitted the losses due to the connections between the radios, cables and antennae. These are typically 0.5-1 dBm per connections but are usually (as in this case) negligible.