

# Appendix 1

## ABOUT ANTENNAS

The 2 antennas in a wireless system are extremely important to the reliable performance of the system. The transmitter antenna radiates a magnetic field that must couple to the receiver antenna with sufficient strength to create a power level above the minimum threshold of the receiver. The gain of the antennas, the polarization of the elements, the height above ground or other objects, and the lack of obstructions between the two antennas play an important role in achieving satisfactory performance. Appendix 2 defines the simple math required to achieve a reliable installation of the antennas.

## UNDERSTANDING ANTENNAS

Antennas have a gain that is usually referenced to an isotropic source or a dipole. The gain is referenced to the ratio of the power level out of the antenna of interest to one of the above reference antennas. Gain referenced to an isotropic source is expressed in dBi while gain referenced to a dipole is commonly expressed in dB. All antennas in this document have their gain expressed in dBi.

Antennas have perfect reciprocity. They have the same characteristics whether used as a transmitting or receiving antenna. The gain is identical for both applications.

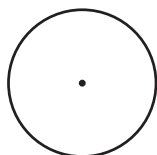
Gain is expressed as the ratio of the antenna power out (transmitting) or in (receiving) to the reference antenna power out or in. Assume a reference antenna is used to receive a signal from a transmitter. Then the antenna of interest is used. The gain of the antenna of interest is:

$$\text{Gain} = 10\text{Log}(P2/P1) \text{ dBi}$$

P2 = Power out of antenna of interest  
P1 = Power out of reference antenna

A power ratio of 2 yields    Gain = 10Log(2)    Log 2 = .30    Gain = 3dBi  
A power ratio of 10 yields    Gain = 10Log(10)    Log 10 = 1    Gain = 10dBi

## HOW ANTENNAS GET THEIR GAIN (Reference Isotropic Source)



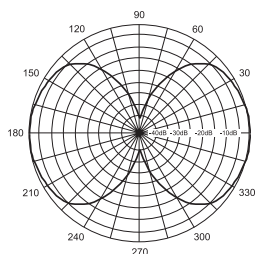
Isotropic Source  
Perfect Solid Sphere

An isotropic source antenna radiates a signal in a perfect sphere. At a given distance from the antenna, the signal level is the same at any point on the sphere. There is no isotropic antenna. It is a mathematical element only.

Gain in an antenna is achieved by shaping the magnetic field to reduce the field in some areas and increase it in others.

The simplest antenna is a vertical wire 1/4 wavelength long with a metallic plane under the bottom. It has a gain of 2.1dBi.

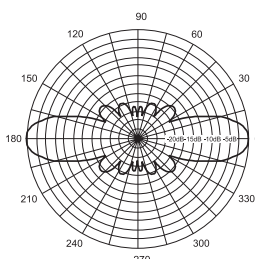
### VERTICAL PATTERN



This image is the vertical beam pattern of a 2.1dBi gain vertical antenna. The radiation angle has been changed by the design so it radiates more in a horizontal direction with a reduction of radiation vertically. It has a doughnut shaped pattern horizontally which gives it the name "omnidirectional antenna".



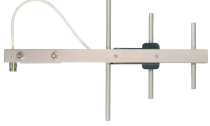
### VERTICAL PATTERN



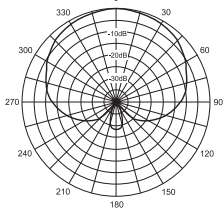
This image is the vertical beam pattern of a 6dBi gain vertical antenna. The radiation angle is much narrower than the 2.1dBi gain antenna. The narrow radiation angle puts more power out in a horizontal direction and less vertically. A longer mechanical length creates the greater gain by modifying the radiation pattern. It has a doughnut shaped pattern horizontally.



## YAGI ANTENNAS

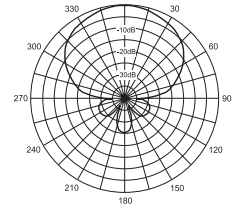


HORIZONTAL PATTERN

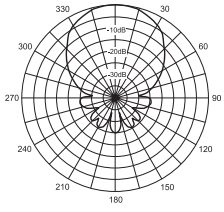


Yagi antennas have a greater gain capability than a simple vertical antenna. This is possible due to the ability to reduce radiation in a vertical as well as horizontal direction and direct more energy in a single direction. The horizontal beam pattern shows the reduction in energy to the rear and sides of the antenna. The vertical beam pattern shows the reduction in energy to the top and bottom as well as the rear of the antenna. This 3 element yagi has a gain of 8dBi.

VERTICAL PATTERN

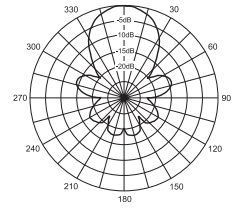


HORIZONTAL PATTERN



This 10 element yagi has a gain of 14dBi. Note the narrower beam width in the horizontal and vertical planes. The higher gain is achieved by narrowing the energy into this narrower beam in the horizontal and vertical planes.

VERTICAL PATTERN



The insensitivity of the yagi to signals from the rear makes it a good choice for reducing interference from the back direction. The difference in gain for the 2 directions is labeled the front to back ratio.

This antenna has a front to back ratio of 20dB to 30dB, depending on the polarization used.

## POLARIZATION

A vertical omnidirectional antenna has vertical polarization. Any antenna sending or receiving signals to/from it must have the same polarization. For the magnetic field around an antenna to be received by another antenna, the magnetic field must be at a right angle to the receiving antenna. Since the magnetic field is at a right angle to the transmitting antenna, the 2 antennas must be parallel to each other. A yagi must have its elements parallel to another yagi or an omnidirectional antenna. When antenna elements are cross polarized, the signal at the receiving antenna can approach zero.

Yagi antennas must be aligned pointing at each other and with the same polarization. Yagi antennas must be aligned pointing at omnidirectional antennas and must have the same polarization.

Omnidirectional antennas on steep hillsides must be tilted to make the elements parallel and the elements should be in the same plane. Treat them as a single element yagi and point them at each other.

Antennas can provide a wide choice of gain to insure reliable operation. The cable that connects the antennas to the receiver and transmitter has a loss in RF energy. The resultant system gain is the antenna gain - the coaxial cable loss.

See Appendix 2 for details on determining required antenna gains and cable losses.

## Appendix 2

The RF system must insure adequate signal strength is available at the receiver. Assume a minimum of 20dB safety margin in signal strength is required at the receiver.

The antennas must have a clear line of sight to each other and the Fresnel Zone must be clear. (See chart below)

The system gain is :

TX output + TX antenna gain - TX cable loss + RX antenna gain - RX cable loss + Abs Value RX sensitivity

Available signal at the RX is System Gain - Space Loss. For a 20 dB safety margin, the system gain must be 20 dB greater than the Space Loss

### 915MHz System Gain Calculation

TX Power Out = 20dbm (100mW)

TX antenna gain = \_\_\_\_\_ (see chart below)

TX cable loss = \_\_\_\_\_ (see chart below)

RX antenna gain = \_\_\_\_\_ (see chart below)

RX cable loss = \_\_\_\_\_ (see chart below)

Abs Value RX Sensitivity = 110dBm

### 2.4GHz System Gain Calculation

TX Power Out = 17dbm (50mW)

TX antenna gain = \_\_\_\_\_ (see chart below)

TX cable loss = \_\_\_\_\_ (see chart below)

RX antenna gain = \_\_\_\_\_ (see chart below)

RX cable loss = \_\_\_\_\_ (see chart below)

Abs Value RX Sensitivity = 105dBm

Example: 8 mile range and 8dBi gain yagi antennas on the TX and RX with 50ft of WBC400 coax at each antenna

TX Power = 20dBm

TX antenna gain = 8dBi

TX cable loss = 2dB

RX antenna gain = 8dBi

RX cable loss = 2dB

RX sensitivity = 110dBm

System gain = 20 + 8 - 2 + 8 - 2 + 110 = 142dB

System gain - Space Loss = 142dB - 114dB = 28dB safety margin. A very viable system.

## FCC regulations limit the maximum radiated power for these products to 36dBm

**Transmitter power plus antenna gain minus cable losses must not exceed 36dBm**

COAXIAL CABLE LOSS DATA		
Cable Type	dB Loss / ft 915MHz	dB Loss/ft 2.4GHz
WBC195	0.111	0.186
WBC400	0.039	0.066
WBC600	0.025	0.043
Cable Loss = Feet X dB/Ft = _____ dB		
(Connector loss is insignificant)		

SPACE LOSS DATA		
Distance Miles	Space Loss 915MHz - dB	Space Loss 2.4GHz - dB
0.25	84	92
0.5	90	98
1	96	104
2	102	110
4	108	116
8	114	122
16	120	128
32	126	

### ANTENNA SELECTION DATA

Model	Type	Gain
900MHz Band		
4008	Vertical Indoor	2.1dBi
4023	Vertical Outdoor	2.1dBi
4275	Omnidirectional	6dBi
4241	Omnidirectional	8.5dBi
4009	Yagi	8dBi
4078	Yagi	11dBi
4079	Yagi	12dBi
4025	Yagi	14dBi
4152	Dual Stacked Yagi	17dBi
2.4GHz Band		
4007	Vertical Indoor	2dBi
4023	Vertical Outdoor	2.1dBi
4063	Yagi	14dBi

The diameter of the Fresnel zone is a function of the frequency and the distance between the antennas.

#### Fresnel Zone Table

Distance between antennas	900 MHz Fresnel Zone diameter	2.4 GHz Fresnel Zone diameter
1000 ft (300 m)	16 ft (7 m)	11 ft (5.4 m)
1 Mile ( 1.6 km)	32 ft (12 m)	21 ft (8.4 m)
5 Miles (8 km)	68 ft (23 m)	43 ft (15.2 m)
10 Miles (16 km)	95 ft (31 m)	59 ft (20 m)
20 Miles (32 km)	138 ft (42 m)	87 ft (27 m)