Out-Door antenna system design white paper

For the 2.4 GHz and 5.8 GHz Bands

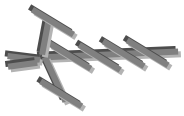
Spread Spectrum applications

This paper covers the fundamentals of antenna system engineering and can be used for planning a building-to-building connection. It should be possible to design a link after studying this white paper. It will help the planner to calculate the minimum antenna height, type of antenna and to select the correct cables for connecting antennas to the Zcomax equipment.

Antenna types

Omni-Directional

Directional Yagi enclosed in a fibreglass case.



Directional Yagi antennas
Horizontally polarized   Vertically polarized

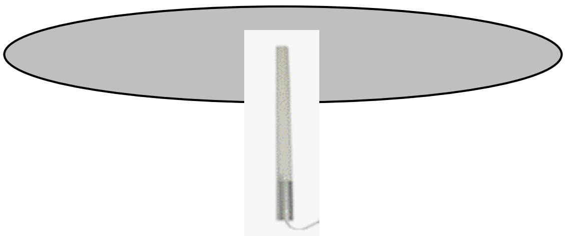
Directional Semi-Parabolic (Grid) antenna

Directional Patch Antenna (Also used in-doors)

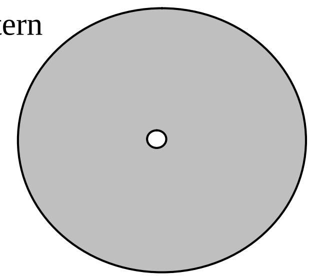
Antenna radiation patterns

An Omni directional antenna radiates the energy equally at 360 Degrees over the horizon. It is similar to a helicopter blade rotation pattern.

A directional on the other hand concentrates the energy pattern into one direction, very much like a light torch. The shape of the main lobe on a high gain directional antenna resembles a cigar shape.



Omni-Directional energy pattern



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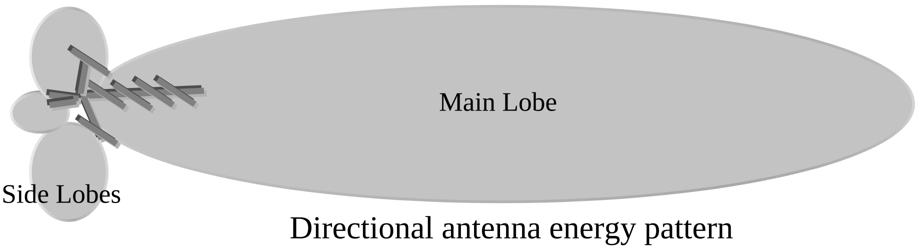


Directional antenna energy pattern

Antenna Gain

Antenna Gain is the measurement of the antenna's ability to focus the radio energy into a specific (preferred) direction. The antenna gain is measured in dBi, which is the ratio between the power radiated by an isotropic antenna connected to the same radio equipment (signal source).
An isotropic antenna radiates the signal evenly in all directions so its coverage has a sphere shape.
The manufacturers of antennas provide this information, which is used to determine the system's gain.
If the antenna gain is specified in dBd it can be converted to dBi by adding 2 to the dBd value so an antenna of 13 dBd=15 dBi.
The general rule is that the higher the gain number is, the longer and thinner the antenna radiation pattern (beam) becomes. All antenna specifications papers specify the angle of the beam that is then translated to "area coverage" by the system planner.

Antenna to antenna & Polarisation

Directional antennas need to be placed approximately facing one another. This is not an exact position as often reflections due to the earth's irregularities and nearby buildings can effect the position of the antenna by several degrees.
The most common polarisation is "vertical" as most omni-directional antennae have to be installed vertically. In areas with heavy interference a "horizontal" polarisation could be an advantage. Always check that both sites have the same polarisation. This is important as incorrect (opposite) polarisation will waste approx. 90% of the signal.

Free space loss

It stands for the attenuation radio waves experience when travelling through free space (without the effects of atmosphere). The free space loss figures for the 2.45 GHz frequencies are given on table T.1 and Table T.1.1

Radio line of sight – Fresnel zone

It is similar to "line of sight" but not the same. A good way to visualise this (although not entirely accurate) is: Remember the energy of a directional antenna looks like a cigar. The most of that energy is required to reach the receiving antenna. The way to calculate this is to know

the “Fresnel zone”. This is the diameter of the cigar at mid-distance. So the radio line of sight should allow at least 60% of the Fresnel zone to be visible by the receiver. Unfortunately this interacts with another parameter called “The earth’s curvature”. However these are the 2 parameters that dictate the minimum height above ground for the antenna.
For those technically minded the calculation is: Height=$D^2/8+43.3\sqrt{D/4F}$ or alternatively we can find the height by looking at the table T.1

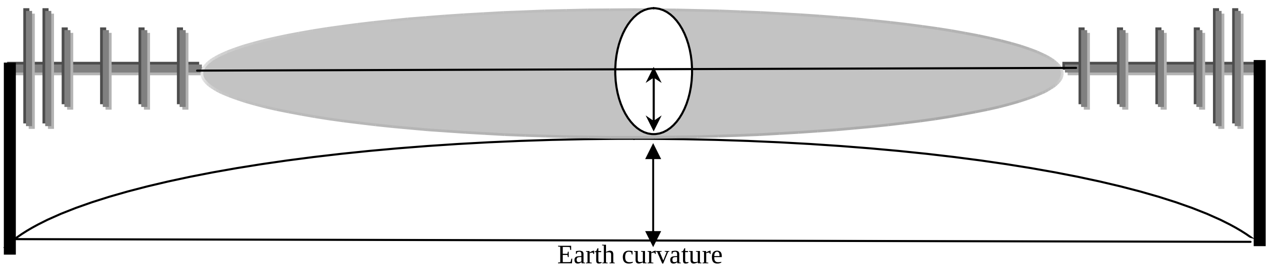


Diagram D.1

Optimum antenna height / Free space loss

These antenna heights are the minimum for 2.4 Gigahertz, smooth earth curvature and 60 % of the 1st Fresnel zone. (At 5.8GHz the height can be reduced by 15%). If there are obstructions like buildings, trees, hills etc then the height of the obstruction must be added to the antenna height figures. The antenna height figures are cumulative. So if the height of the one site is lowered the height of the other site must be raised by an equal amount.

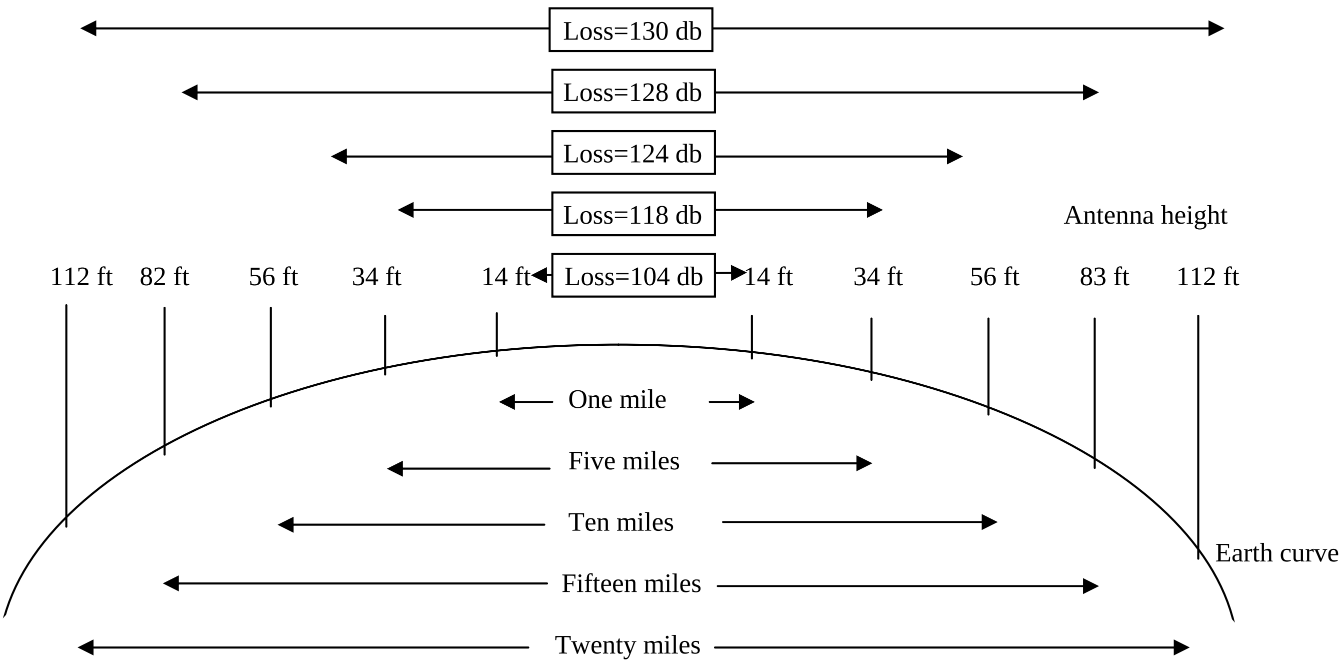


Table T.1

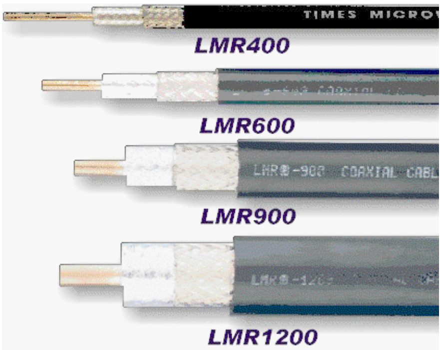
Distance in Kilometres	Free Space Loss at 2.45GHz	Free Space Loss at 5.8GHz in dB
0.5	94.2	101.7
1.0	100.2	107.7
1.5	103.7	111.3
1.8	105.3	112.8
2.0	106.2	113.8
2.2	107.1	114.6
2.5	108.2	115.7
2.8	109.2	116.7
3.0	109.8	117.3
3.3	110.6	118.1
3.5	111.1	118.6
3.8	111.8	119.3
4.0	112.3	119.8
4.3	112.9	120.4
4.5	113.3	120.8
4.8	113.8	121.4
5.0	114.2	121.7
5.5	115.0	122.5
6.0	115.8	123.3
6.5	116.5	124.0
7.0	117.1	124.6
7.5	117.7	125.2
8.0	118.3	125.8
8.5	118.8	126.3
9.0	119.3	126.8
10	120.2	127.7
12	121.8	129.3
14	123.2	130.7
16	124.3	131.8

Table T.1.1

Antenna Cables

Cable loss is an important parameter in external antenna installations and must be taken into account for proper path analysis and fade margin calculations.
Any 50-Ohm coaxial cable can be used whose loss in dB per 100 feet at the correct frequency is low enough (3 to 12 dB) so as not to contribute significantly to the total link loss.

- Cable loss is proportional to the frequencies used. – See Table T2.
- Loss is almost always relative to cable diameter. Lower loss cable = Thicker cable.
- The more flexible cable types experience more cable loss.
- Always waterproof connectors used outdoors with amalgamated tape.



Comparison of RF power loss for various cables

Cable Type	915 MHz (L-Band Cable Loss at	2.4 GHz (S-band) Cable Loss at	5.5 to 5.8GHz - B & C Band Cable Loss at
RG 214	8 dB/100 ft	13.9dB/100 ft	Not suitable
Belden 9913	4.2 dB/100 ft	7.7 dB/100 ft	14.1 dB/100 ft
Times LMR 195		18.1 dB/100 ft	28.3 dB/100 ft
Times LMR 240		12.9 dB/100 ft	20.4 dB/100 ft
Times LMR 400		6.8 dB/100 ft	10.8dB/100 ft
Times LMR 600		4.4 dB/100 ft	7.3 dB/100 ft
CableWave Low-Loss ½' Foam FLC 12-50J	2.25 dB/100 ft	6.0 dB/100 ft	10.1 dB/100 ft
Andrew 7/8' Heliax LDF5-50A And VXL5-50	1.25 dB/100 ft	2.25 dB/100 ft	Not suitable

Table T.2

A good antenna installation needs professionally made cables that should be able to withstand all the weather conditions for long periods.

Fade margin

We are almost to the point that we can calculate the signal strength at the receiving end. There is one more parameter that we need to take into account "The fade margin". If you remember earlier we discussed the "free space loss". However in real life we do have an atmosphere that has or may have a negative impact on the signal strength. So if the signal fades further and becomes weaker due to atmospheric conditions we should have allowed enough margins (Fade Margin) to compensate for the losses. The fade margin should be anything from 3 to 10 dB for a reliable operation. The bigger this figure is, the better the link reliability becomes.

Path analysis

We are ready to calculate the path analysis. This is like an accountant's calculation. We add all the losses then we add all the gains and subtract the one from the other. The resulted figure is the "Fade Margin".

Herewith a practical example.

A company going through expansion rented another building about a mile away where it plans to relocate the accounts department. The requirement is for the accounts department to have full access to the company's LAN. They are considering a wireless link between the two buildings. There are no obstructions and they have a good line of sight between the two buildings.

We know from the table T.1 that the antenna height should be at least 14 feet at both sites. This is not a problem as the buildings are taller than the antenna minimum height. It means that either a short pole (one meter or two) or even the antenna positioned inside a window would meet the height requirement.
If we use 15 dBi Yagi antennae and 2.4GHz units at both ends what would be the path analysis?

System Gain		System losses	
Transmit signal of the bridge	13 dB	Transmit antenna cable	5 dB
Transmit antenna (external)	15 dB	Receive antenna cable	5 dB
Receive antenna (external)	15 dB	Free space loss	104 dB
Receive sensitivity of the bridge	83 dB		
Total Gain	**126 dB**	**Total losses**	**114 db**
Subtract total losses	-114 dB		
Fade margin	**12 dB**		

This is a very comfortable "Fade margin" figure. The reliability of this link will be very high. In cases where the Fade margin figure would not give us the required margin we can try to alter the parameters we are in control, Like the antenna gain, the quality or the length of the antenna cable or improve the signal strength by deploying signal amplifiers.

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