Radio Signal Propagation

INTRODUCTION

This document is provided to explain and simplify many of the terms relating to antennas and RF (Radio Frequency) used when dealing with an RF installation system.

The following diagram depicts a typical radio system:

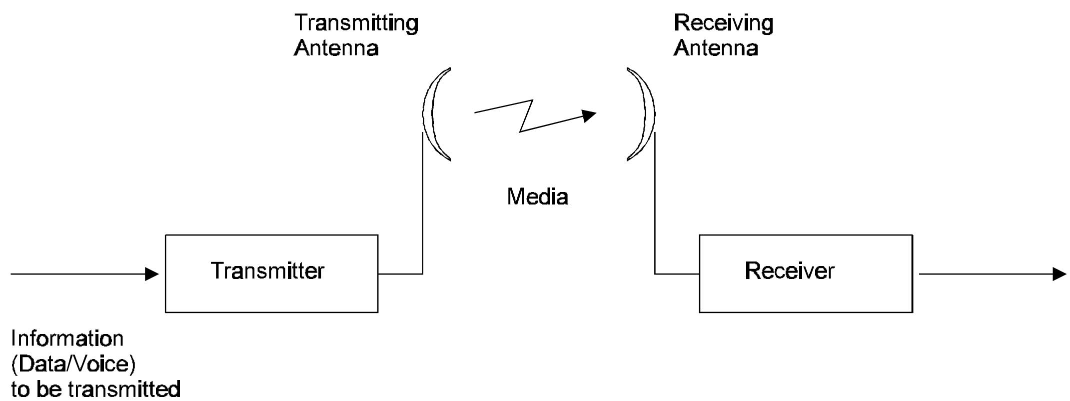

Figure 1: A Typical Radio System

A radio system transmits information to the transmitter. The information is transmitted through an antenna which converts the RF signal into an electromagnetic wave. The transmission medium for electromagnetic wave propagation is free space.

The electromagnetic wave is intercepted by the receiving antenna which converts it back to an RF signal. Ideally, this RF signal is the same as that originally generated by the transmitter. The original information is then demodulated back to its original form.

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RF Terms and Definitions

dB

The dB convention is an abbreviation for decibels. It is a mathematical expression showing the relationship between two values.

RF Power Level

RF power level at either transmitter output or receiver input is expressed in Watts. It can also be expressed in dBm. The relation between dBm and Watts can be expressed as follows:

$P_{dBm} = 10 \times \text{Log } Pmw$

For example: 1 Watt = 1000 mW; $P_{dBm} = 10 \times \text{Log } 1000 = 30$ dBm

100 mW; PdBm = 10 x Log 100 = 20 dBm

For link budget calculations, the dBm convention is more convenient than the Watts convention.

Attenuation

Attenuation (fading) of an RF signal is defined as follows:

Figure 2: Attenuation of an RF signal

Pin is the incident power level at the attenuator input
Pout is the output power level at the attenuator output

Attenuation is expressed in dB as follows:PdB = 10 x Log (Pout/Pin)

For example: If, due to attenuation, half the power is lost (Pout/Pin = 2), attenuation in dB is 10 x Log (2) = 3dB

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Path Loss

Path loss is the loss of power of an RF signal travelling (propagating) through space. It is expressed in dB. Path loss depends on:

- The distance between transmitting and receiving antennas.
- Line of sight clearance between the receiving and transmitting antennas.
- Antenna height.

Free Space Loss

Attenuation of the electromagnetic wave while propagating through space. This attenuation is calculated using the following formula:

Free space loss = 32.4 + 20xLog F(MHz) + 20xLog R(Km)

F is the RF frequency expressed in MHz.
R is the distance between the transmitting and receiving antennas.
At 2.4 Ghz, this formula is: 100+20xLog R(Km)

Antenna Characteristics

Isotropic Antenna

A hypothetical, lossless antenna having equal radiation intensity in all directions. Used as a zero dB gain reference in directivity calculation (gain).

Gain

Antenna gain is a measure of directivity. It is defined as the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna was radiated equally in all directions (isotropically). Antenna gain is expressed in dBi.

Radiation Pattern

The radiation pattern is a graphical representation in either polar or rectangular coordinates of the spatial energy distribution of an antenna.

Side Lobes

The radiation lobes in any direction other than that of the main lobe.

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Omni-directional Antenna

This antenna radiates and receives equally in all directions in azimuth. The following diagram shows the radiation pattern of an omni-directional antenna with its side lobes in polar form.

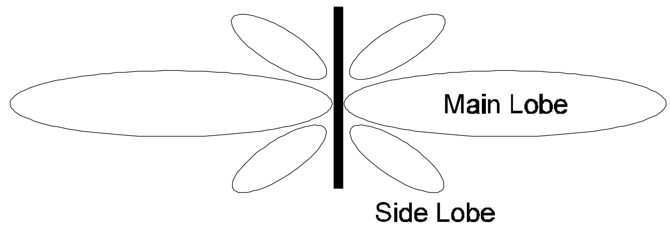

Figure 3: Side View

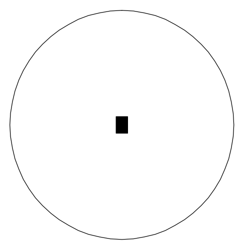

Figure 4: Top View

Directional Antenna

This antenna radiates and receives most of the signal power in one direction. The following diagram shows the radiation pattern of a directional antenna with its side lobes in polar form:

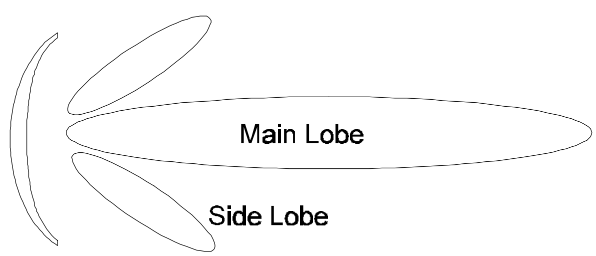

Figure 5: Radiation Pattern of Directional Antenna

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Antenna Beamwidth

The directiveness of a directional antenna. Defined as the angle between two half-power (-3 dB) points on either side of the main lobe of radiation.

System Characteristics

Receiver Sensitivity

The minimum RF signal power level required at the input of a receiver for certain performance (e.g. BER).

EIRP (Effective Isotropic Radiated Power)

The antenna transmitted power. Equal to the transmitted output power minus cable loss plus the transmitting antenna gain.

Pout	Output power of transmitted in dBm
Ct	Transmitter cable attenuation in dB
Gt	Transmitting antenna gain in dBi
Gr	Receiving antenna gain in dBi
Pl	Path loss in dB
Cr	Receiver cable attenuation is dB
Si	Received power level at receiver input in dBm
Ps	Receiver sensitivity is dBm

Si = Pout - Ct + Gt - Pl + Gr - Cr
EIRP = Pout - Ct + Gt

Example:

Link Parameters:

Frequency: 2.4 Ghz
P_{out} = 4 dBm (2.5 mW)
Tx and Rx cable length (Ct and Cr) = 10 m. cable type RG214 (0.6 dB/meter)
Tx and Rx antenna gain (Gt and Gr) = 18 dBi
Distance between sites = 3 Km
Receiver sensitivity (Ps) = -84 dBm

Link Budget Calculation

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$EIRP = P_{out} - Ct + Gt = 16$ dBm
$Pl = 32.4 + 20xLog F(MHz) + 20xLog R(Km) @ 110$ dB
$Si = EIRP - Pl + Gr - Cr = -82$ dBm

In conclusion, the received signal power is above the sensitivity threshold, so the link should work. The problem is that there is only a 2 dB difference between received signal power and sensitivity. Normally, a higher margin is desirable due to fluctuation in received power as a result of signal fading.

Signal Fading

Fading of the RF signal is caused by several factors:

- Multipath

  The transmitted signal arrives at the receiver from different directions, with different path lengths, attenuation and delays. The summed signal at the receiver may result in an attenuated signal.

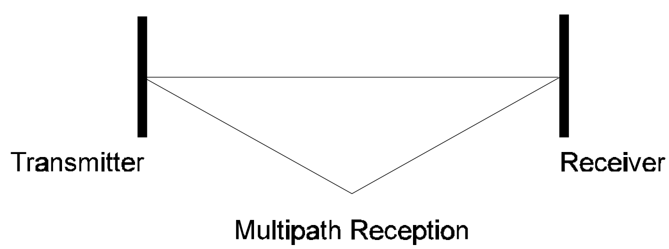

Figure 6: Multipath Reception

- **Bad Line of Sight**

  An optical line of sight exists if an imaginary straight line can connect the antennas on either side of the link.

  Radio wave clear line of sight exists if a certain area around the optical line of sight (Fresnel zone) is clear of obstacles. A bad line of sight exists if the first Fresnel zone is obscured.

- **Link Budget Calculations**
- **Weather conditions (Rain, wind, etc.)**

  At high rain intensity (150 mm/hr), the fading of an RF signal at 2.4 Ghz may reach a maximum of 0.02 dB/Km.

  Wind may cause fading due to antenna motion.

- **Interference**

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Interference may be caused by another system on the same frequency range, external noise, or some other co-located system.

The Line of Sight Concept

An optical line of sight exists if an imaginary straight line can be drawn connecting the antennas on either side of the link.

Clear Line of Sight

A clear line of sight exists when no physical objects obstruct viewing one antenna from the location of the other antenna.

A radio wave clear line of sight exists if a defined area around the optical line of sight (Fresnel Zone) is clear of obstacles.

Fresnel Zone

The Fresnel zone is the area of a circle around the line of sight.
The Fresnel Zone is defined as follows:

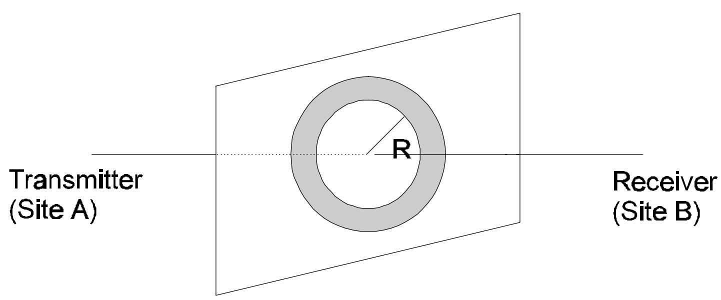

Figure 7: Fresnel Zone

$R_1 = \frac{1}{2} \sqrt{(\lambda x D)}$

R: radius of the first fresnel zone

λ: wavelength

D: distance between sites

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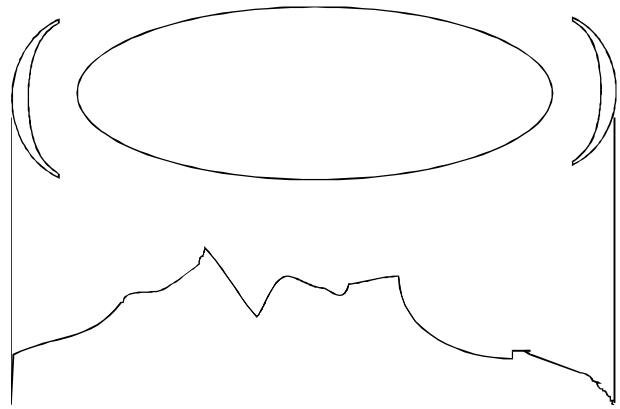

Figure 8: Fresnel Zone Clear of Obstacles

When at least 80% of the first Fresnel Zone is clear of obstacles, propagation loss is equivalent to that of free space.

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