

RF Design Guidelines

Version 1.0
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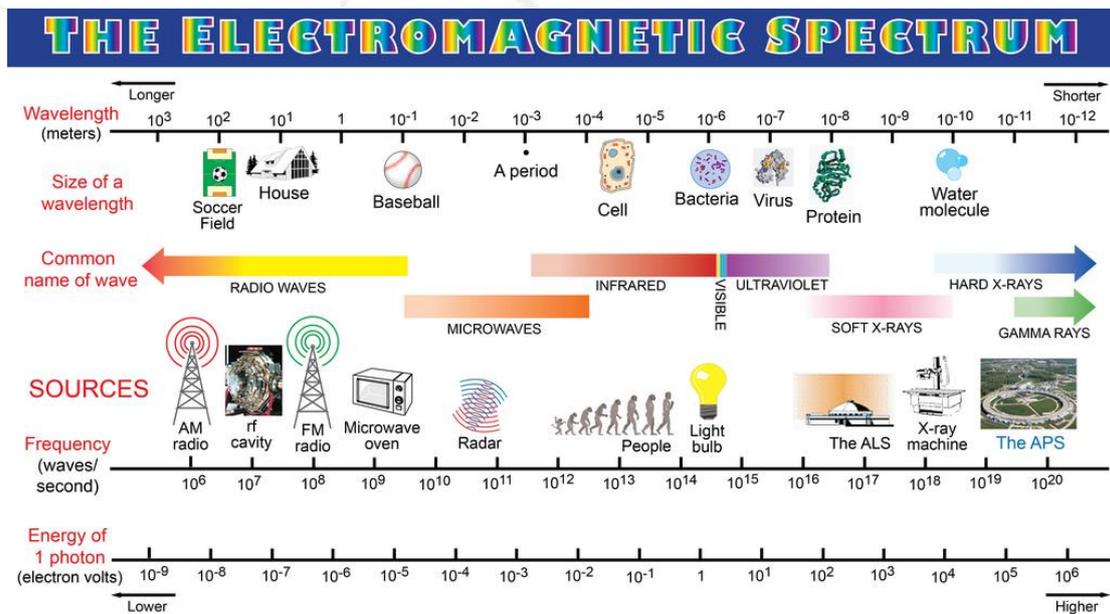
1. Introduction

In this document, a basic introduction to wireless system design is presented. The main concepts are explained briefly to assist the RF engineers to start designing wireless systems. Common propagation models are illustrated with some design considerations. At the end, the use of a software tool is described to facilitate the design.

1.1. EM spectrum

The electromagnetic spectrum is the entire range and scope (spectrum) of frequencies of electromagnetic radiation and their respective wavelengths and photon energies.

The electromagnetic spectrum extends from below the low frequencies used for modern radio communication to gamma radiation at the short-wavelength (high-frequency) end, thereby covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. Visible light lies toward the shorter end, with wavelengths from 400 to 700 nanometers.



1.2. Power Units: Watts, dB, dBm and dBi

If a receiver is very sensitive to RF signals, it may be able to pick up signals as small as 0.00000001 Watts.

A logarithm is the exponent to which the number 10 must be raised to reach a given value. If we are given the number 1000 and asked to find the logarithm (log), we find that $\log 1000 = 3$ because $10^3 = 1000$. Notice that our logarithm, 3, is the exponent. An important thing to note about logarithms is that the logarithm of a non-positive value does not exist. (Log (-100) and Log (0) are undefined)

However, the logarithms values themselves can be negative. (E.g. $\log (0.1) = -1$). Also, decibel is a relative measurement unit unlike the absolute measurement of milliwatts.

1.2.1. dBm

1 mW = 0 dBm

The m in dBm refers simply to the fact that the reference is 1 milliwatt (1 mW) and therefore a dBm measurement is a measurement of absolute power. The relationship between the decibels scale and the watt scale can be estimated using the following rules:

- +3 dB will double the watt value: (10 mW + 3dB \approx 20 mW)
- Likewise, -3 dB will halve the watt value: (100 mW - 3dB \approx 50 mW)
- +10 dB will increase the watt value by ten-fold: (10 mW + 10dB \approx 100 mW)
- Similarly, -10 dB will decrease the watt value to one tenth of that value: (300 mW - 10dB \approx 30 mW).

1.2.2. dBi

The unit of measurement dBi refers only to the gain of an antenna. The "i" stands for "isotropic", which means that the change in power is referenced against an isotropic radiator.

An isotropic radiator is a theoretical ideal transmitter that produces useful electromagnetic field output in all directions with equal intensity, and at 100-percent efficiency, in three-dimensional space. One example of an isotropic radiator is the sun.

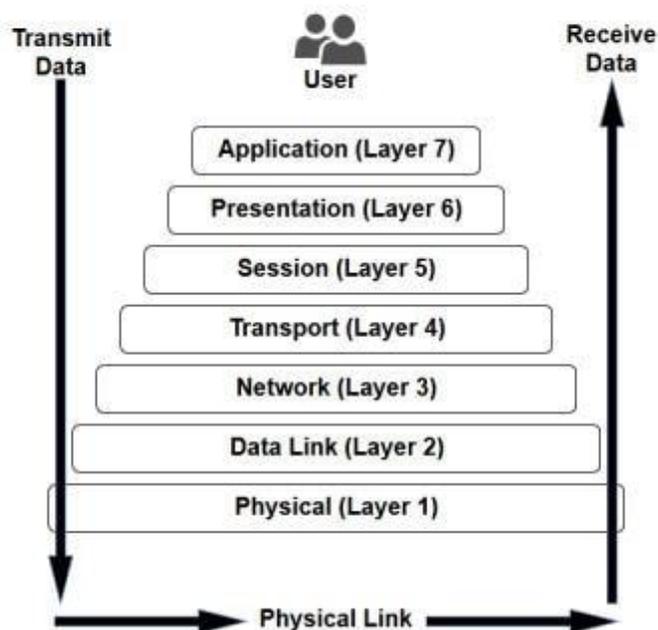
It also should be noted that dB, dBm and dBi can be added and subtracted without restrictions.

1.3. Network Layers

The [International Standards Organization \(ISO\)](#) developed the Open Systems Interconnection (OSI) model. It divides network communication into seven layers. Layers 1-4 are considered the lower layers, and mostly concern themselves with moving data around. Layers 5-7, the upper layers, contain application-level data. Networks operate on one basic principle: "pass it on." Each layer takes care of a very specific job, and then passes the data onto the next layer.

In the OSI model, control is passed from one layer to the next, starting at the application layer (Layer 7) in one station, and proceeding to the bottom layer, over the channel to the next station and back up the hierarchy. The OSI model takes the task of inter-networking and divides that up into what is referred to as a *vertical stack* that consists of the following 7 layers.

The 7 Layers of OSI



Most of the functionality in the OSI model exists in all communications systems, although two or three OSI layers may be incorporated into one. OSI is also referred to as the OSI Reference Model or just the OSI Model.

1.3.1. Application (Layer 7)

OSI Model, Layer 7, supports [application](#) and end-user processes. Communication partners are identified, quality of service is identified, user authentication and privacy are considered, and any constraints on data [syntax](#) are identified. Everything at this layer is application-specific. This layer provides application services for file transfers, [e-mail](#), and other [network software](#) services. [Telnet](#) and [FTP](#) are applications that exist entirely in the application level. Tiered application architectures are part of this layer. Layer 7 Application examples include WWW browsers, NFS, SNMP, Telnet, HTTP, FTP

1.3.2. Presentation (Layer 6)

This layer provides independence from differences in data representation (e.g., [encryption](#)) by translating from application to network format, and vice versa. The presentation layer works to transform data into the form that the application layer can accept. This layer formats and encrypts data to be sent across a [network](#), providing freedom from compatibility problems. It is sometimes called the syntax layer. *Layer 6 Presentation examples include encryption, ASCII, EBCDIC, TIFF, GIF, PICT, JPEG, MPEG, MIDI.*

1.3.3. Session (Layer 5)

This layer establishes, manages and terminates connections between applications. The session layer sets up, coordinates, and terminates conversations, exchanges, and dialogues between the applications at each end. It deals with session and connection coordination. Layer 5 Session examples include NFS, RPC, SQL.

1.3.4. Transport (Layer 4)

OSI Model, Layer 4, provides transparent transfer of data between end systems, or [hosts](#), and is responsible for end-to-end error recovery and flow control. It ensures complete data transfer. Layer 4 Transport examples include SPX, TCP, UDP.

1.3.5. Network (Layer 3)

Layer 3 provides switching and routing technologies, creating logical paths, known as virtual circuits, for transmitting data from node to node. Routing and forwarding are functions of this layer, as well as addressing, internetworking, error handling, congestion control and packet sequencing. Examples are DDP, IP, IPX.

1.3.6. Data Link (Layer 2)

At OSI Model, Layer 2, data packets are encoded and decoded into bits. It furnishes transmission protocol knowledge and management and handles errors in the physical layer, flow control and frame synchronization. The data link layer is divided into two sub layers: The Media Access Control (MAC) layer and the Logical Link Control (LLC) layer. The MAC sub layer controls how a computer on the network gains access to the data and permission to transmit it. The LLC layer controls frame synchronization, flow control and error checking. Layer 2 Data Link examples include PPP, FDDI, ATM, IEEE 802.5/ 802.2, IEEE 802.3/802.2, HDLC, Frame Relay.

1.3.7. Physical (Layer 1)

OSI Model, Layer 1 conveys the bit stream - electrical impulse, light or radio signal — through the network at the electrical and mechanical level. It provides the hardware means of sending and receiving data on a carrier, including defining cables, cards and physical aspects. Ethernet, RS232, and ATM are protocols with physical layer components.

In this document, we will be focused on the physical and Data Link layers of wireless systems.

2. Wireless system components

2.1. Wireless transceivers

A transceiver is a combination transmitter/receiver in a single package. The term applies to wireless communications devices such as cellular telephones, cordless telephone sets, handheld two-way radios, and mobile two-way radios. Occasionally the term is used in reference to transmitter/receiver devices in cable or optical fiber systems.

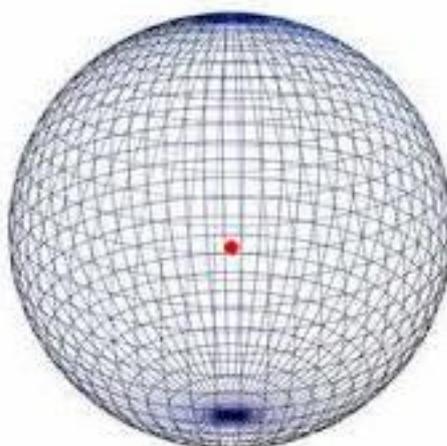
In a radio transceiver, the receiver is silenced while transmitting. An electronic switch allows the transmitter and receiver to be connected to the same antenna, and prevents the transmitter output from damaging the receiver. With a transceiver of this kind, it is impossible to receive signals while transmitting. This mode is called half duplex. Transmission and reception often, but not always, are done on the same.

Some transceivers are designed to allow reception of signals during transmission periods. This mode is known as full duplex, and requires that the transmitter and receiver operate on substantially different frequencies (channels or sub-channels) so the transmitted signal does not interfere with reception. Cellular and cordless telephone sets use this mode. Satellite communications networks often employ full-duplex transceivers at the surface-based subscriber points. The transmitted signal (transceiver-to-satellite) is called the uplink, and the received signal (satellite-to-transceiver) is called the downlink.

Wireless transceivers parameters of interest are the output (transmitted) power (expressed in dBm), and receiver sensitivity which is the minimum threshold of power can be received by the transceiver at a certain

2.2. Antennas

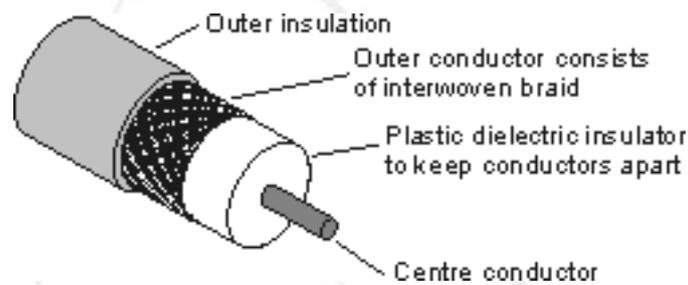
An Antenna is –usually- a passive device that converts guided RF signal into a radiated RF signal. The antenna works as a matching device between the line impedance (typically 50 or 75 ohms) and the free space -or air- impedance (377 ohm). An isotropic antenna is a theoretical point antenna that radiates power in uniformly in all directions. Its gain is 1 (or 0 dBi). Antennas gain is expressed in dBi: gain in dB with respect of the gain of isotropic antenna.



2.3. Feeders

Feeders or transmission lines are used to transfer RF signals from one point to another. They are used in many areas, one common example of an RF feeder is the coax or coaxial cable used to connect a television antenna to the television. These RF feeders need to have a number of properties if they are able to work well.

The loss that a feeder introduces between the antenna and receiver or transmitter is of the utmost importance. Any power that it loses will reduce the efficiency of the station. In order to reduce this low loss types of coax are almost always used at these frequencies. Loss is usually expressed by dB/m for a certain frequency. These coax cables are thicker than the standard types. Coax cable is the most widely used radio frequency feeder being used in many domestic and commercial applications. It consists of an inner conductor surrounded by an insulating dielectric and covered with an outer screen or braid. In turn there is a final insulation cover to act as protection. It carries current in both inner and outer conductors, but because they are equal and opposite all the fields are confined to within the cable and cannot radiate. As there are no fields outside the cable, nearby objects do not affect its properties and it can be used to carry RF energy through many locations with low risk of them being affected.



3. Wireless Design and System Design

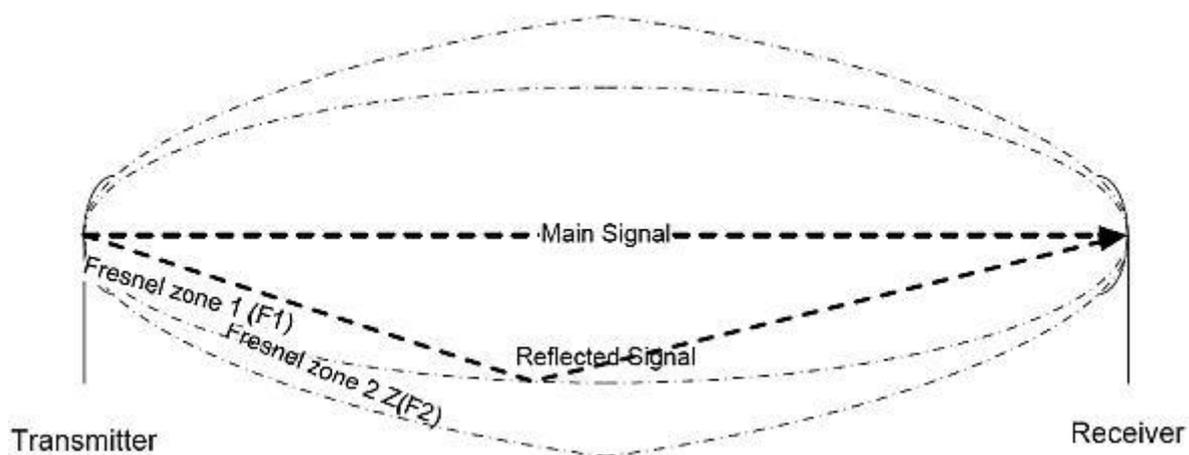
3.1. RF parameters

There are multiple parameters to consider when designing the wireless systems. Parameters related to power gain and losses are discussed later. In addition to these, the following parameters should be accounted for:

2. Wireless Protocol
The selection of the appropriate protocol depends on the application. The designer will need to trade-off between speed and transceiver sensitivity when selecting the protocol and hence your hardware.
3. Available bandwidth
You need to check how much bandwidth is required against what is actually available for your application.
4. Bit error rate (BER)
Most transceivers guarantee a certain BER for a certain sensitivity and throughput (speed). Some modems allow you to configure them to trade off among these parameters.

3.2. Fresnel zones

A Fresnel zone is a cylindrical ellipse drawn between transmitter and receiver. The size of the ellipse is determined by the frequency of operation and the distance between the two sites.



FIRST AND SECOND FRESNEL ZONES.

When a radio signal travels between transmitter and receiver, it can travel in several ways. It can go directly between transmitter and receiver (main signal). Signal can reflect off the ground and then carry on to the distant receiver (reflected signal). It can go left or right and be reflected back by a hill (another reflected signal).

Fresnel zone radius describes this reflection in relation to overall radio path length. In the above figure, the main and reflected signals and F_1 (first Fresnel zone) and F_2 (second Fresnel zone). The reflection can happen at any location between the transmitter and receiver. The figure shows the reflection happening at a random location, not the center of the path.

When a signal is reflected two things happen:

- The phase of the signal reverses and the signal changes in phase by 180° .
- Since the signal is being reflected and not going in a direct line, it travels slightly further to the reflection point and then on to the receiver. Therefore, the signal is shifted further in phase, by the difference in path length.

It means, over a long path, this can amount to 180° or more. This is important because the receive antenna cannot differentiate between a main and reflected signal. They are both on the same frequency. It receives both main and reflected signals. It also receives any other signals within its designed frequency range.

When an antenna receives a main signal and a reflected signal, the 2 signals will combine and add together at the antenna. If they are 360° shifted (in phase), there is no issue. However, if the signals are 180° apart (opposite phase), they will cancel and the receiver will receive nothing.

3.2.1. Fresnel Zone 1 (F1)

The first Fresnel zone radius is calculated so that the difference in path length between the main signal and a reflected signal from the F1 radius distance is 180° . A reflected signal shifted by 180° of path distance plus 180° from the actual reflection point totals 360° of phase shift. The 2 signals, main and reflected, arrive at the antenna 360° apart or in phase. They will add together and not affect receiver performance. This reflection phase shift can happen anywhere from the calculated Fresnel zone "tube", properly known as an ellipse.

3.2.2. Fresnel Zone 2 (F2)

The second Fresnel zone radius is calculated so that the path length difference between the main and reflected signals from the second Fresnel zone tube is 360° . This is critical, since a reflected signal has a 180° phase shift plus the path length difference of 360° equals a phase shift of 540° . 540° and 180° are the equivalent and the 2 signals will cancel, leaving no signal at the receiver. The second Fresnel Zone, F2, is the zone of reflection that is not wanted when designing a radio path.

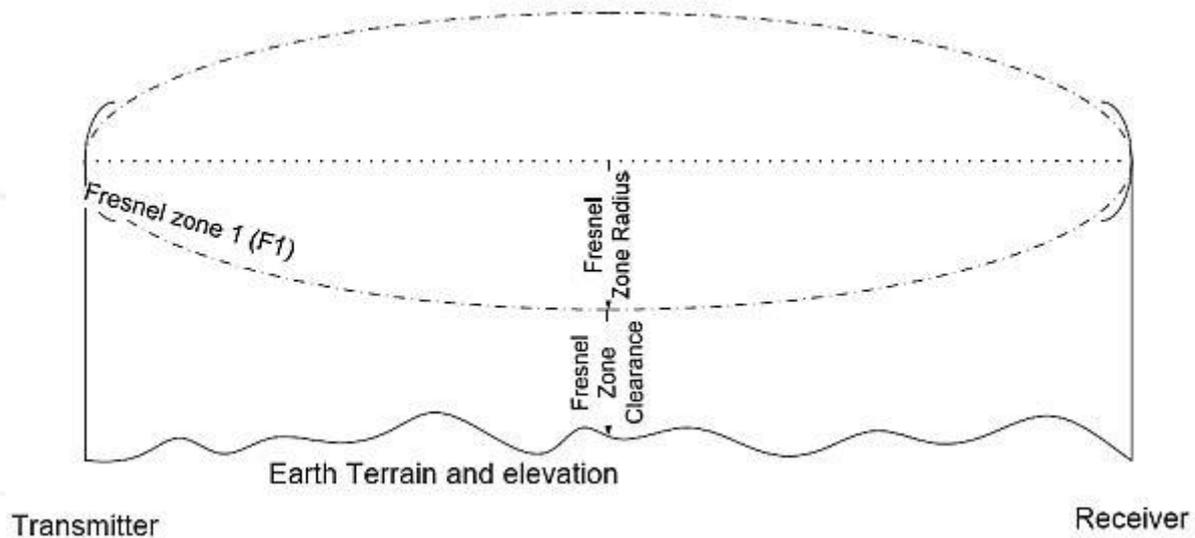
3.2.3. Fresnel Zone Effect

The net result is that even numbered Fresnel zones result in a 180° signal reflection. These are essential in radio propagation. Odd numbered Fresnel zones incur a 360° phase shift and have no effect. The rapid increase and decrease of signal is called Rayleigh fading. It is a direct result of Fresnel zone reflections.

3.2.4. Point to Point Radio links

Since the F2 zone is detrimental to receive signal level, antenna heights are often selected so that F1 is an unobstructed path and F2 is obstructed by a hill or the earth bulge along the path. Any 180° reflected signals along the F2 zone are attenuated by the hill or the earth and do not reach the receive antenna to interfere and cancel the main receive signal.

3.2.5. Fresnel Zone Radius and Earth Clearance



FRESNEL ZONE RADIUS AND EARTH CLEARANCE

The diameter of the Fresnel Zone (half the diameter is the radius) of the elliptical cylinder can be calculated. The important component of Fresnel Zone Radius is the clearance between the Fresnel zone cylinder and the surface of the earth. As shown in the figure, the Fresnel zone radius and Fresnel zone earth clearance are shown.

If the ratio of Fresnel zone earth clearance to Fresnel zone radius is greater than 60%, the radio path is considered "clear, line of sight" and incurs no diffraction loss.

3.3. Wireless Link and Network Availability

In wireless networks, it is difficult to collect availability information in real time due to the fact of limited bandwidth. However, statistical methods are utilized to estimate the availability of the network. A common method is based on the Received Signal Strength. By continuously monitoring the received signal strength from the neighboring nodes, an estimation of the wireless link availability to these nodes can be calculated based on a statistical model. One of the most common and conservative models is Rayleigh distribution.

The worst case of multipath fading is modeled as a Rayleigh distribution function which relates the fade margin to link availability. In the table below, it is shown the "nines standard" availability vs the required fade margin assuming Rayleigh distribution. Other values of availability can be extrapolated from the table.

FADE MARGIN VS AVAILABILITY

Availability (%)	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

Other empirical methods are used to calculate availability for a certain distance and fade margin. These methods classify paths by terrain and climate. One method relates the frequency, the fade margin and the link distance to the path "link" unavailability. It also accounts for climate of the area of interest. The formula for this method for flat coastal areas is:

$$Path\ Unavailability = 2 \times 10^{-7} \times f \times d^3 \times 10^{\frac{FM}{12}}$$

4. Link Budget Analysis

When designing a complete, i.e. end to end radio communications system, it is necessary to calculate the links budget. The link budget enables factors such as the required antennas gain levels, radio transmitter power levels, and receiver sensitivity figures to be determined. By assessing the link budget, it is possible to design the system so that it meets its requirements and performs correctly without being over designed at extra cost.

Link budgets are often used for satellite systems. In these situations it is crucial that the required signal levels are maintained to ensure that the received signal levels are sufficiently high above the noise level to ensure that signal to noise levels or bit error rates are within the required limits. However larger antennas, high transmitter power levels that required add considerably to the cost, so it is necessary to balance these to minimize the cost of the system while still maintaining performance.

In addition to satellite systems, link budgets are also used in many other radio communications systems. For example, link budget calculations are used for calculating the power levels required for cellular communications systems, and for investigating the base station coverage.

Link budget style calculations are also used within wireless survey tools. These wireless survey tools will not only look at the way radio signals propagate, but also the power levels, antennas and receiver sensitivity levels required to provide the required link quality.

As the name implies, a link budget is an accounting of all the gains and losses in a transmission system. The link budget looks at the elements that will determine the signal strength arriving at the receiver. The link budget may include the following items:

- Transmitter power.
- Antenna gains (receiver and transmitter).
- Antenna feeder losses (receiver and transmitter).
- Path losses.

Receiver sensitivity is necessary to know this to enable any pass fail criteria to be applied.

Where the losses may vary with time, e.g. fading, and allowance must be made within the link budget for this - often the worst case may be taken, or alternatively an acceptance of periods of increased bit error rate (for digital signals) or degraded signal to noise ratio for analogue systems. In essence the link budget will take the form of the equation below:

$$\text{Received power (dBm)} = \text{Transmitted power (dBm)} + \text{gains (dB)} - \text{losses (dB)}$$

The basic calculation to determine the link budget is quite straightforward. It is mainly a matter of accounting for all the different losses and gains between the transmitter and the receiver.

4.1. Link budget equation

In order to devise a link budget equation, it is necessary to investigate all the areas where gains and losses may occur between the transmitter and the receiver. Each link has to be analyzed on its own. A typical link budget equation for a radio communications system may look like the following:

$$PRx = PTx + GTX + GRx - LTx - LFs - Lp - LRx$$

Where:

- PR_x = received power (dBm)
- PT_x = transmitter output power (dBm)
- GT_x = transmitter antenna gain (dBi)
- GR_x = receiver antenna gain (dBi)
- LT_x = transmit feeder and associated losses (feeder, connectors, etc.) (dB)
- LF_s = free space loss or path loss (dB)
- L_p = miscellaneous signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)
- LR_x = receiver feeder and associated losses (feeder, connectors, etc.) (dB)

Note that for the sake of showing losses in the link budget equation is "minus" actual loss figures, e.g. LT_x or LF_s , etc. should be taken as the modulus "absolute value" of the loss.

4.1.1. Antenna gain and link budget

The basic link budget equation where no levels of antenna gain are included assumes that the power spreads out equally in all directions from the source. In other words the antenna is an isotropic source, radiating equally in all directions.

This assumption is good for theoretical calculations, but in reality all antennas radiate more in some directions than others. In addition to this it is often necessary to use antennas with gain to enable interference from other directions to be reduced at the receiver, and at the transmitter to focus the available transmitter power in the required direction.

In view of this, it is necessary to accommodate these gains into the link budget equation as they have been in the equation above because they will affect the signal levels - increasing them by levels of the antenna gain, assuming the gain is in the direction of the required link. When quoting gain levels for antennas it is necessary to ensure they are gains when compared to an isotropic source, i.e. the basic type of antenna assumed in the equation when no gain levels are incorporated. The gain figures relative to an isotropic source are quoted as dBi, i.e. dB relative to an isotropic source. Often gain levels given for an antenna may be the gain relative to a dipole where the figures may be quoted as dBd, i.e. dB relative to a dipole. However a dipole has gain relative to an isotropic source, so the dipole gain of 2.1 dBi needs to be accommodated if figures relative to a dipole are quoted for an antenna gain.

4.1.2. Effect of multipath propagation

For true free space propagation such as that encountered for satellites there will be no noticeable reflections and there will only be one major path. However for terrestrial systems, the signal may reach the receiver via a number of different paths as a result of reflections, etc. that will occur as a result of the objects around the path. Buildings, trees, objects around the office and home can all cause reflections that will result in the signal variations.

The multipath propagation will cause variations of the signal strength when compared to that calculated from the free space path loss. If the signals arrive in phase with the direct signal, then the reflected signals will tend to reinforce the direct signal. If they are out of phase, then they will tend to cancel the signal. If either the transmitter or receiver moves, then the signal strength will be seen to vary as the relative strengths and

phases of the different signals change. In order to allow for this in a link budget, a link margin "Fade Margin" is added into the equation to allow for this.

Link budget calculations are an essential step in the design of a radio communications system. The link budget calculation enables the losses and gains to be seen, and devising a link budget enables the apportionment of losses, gains and power levels to be made if changes need to be made to enable the radio communications system to meet its operational requirements. Only by performing a link budget analysis this is possible.

In general, the following steps are done to calculate the link budget:

1. Calculate EIRP (Equivalent Isotropic Radiated Power)
Transmitted power (PTx) + Transmitter Antenna gain (GTx) – Transmitter losses (LTx)
2. Calculate Receiver Gain (Rx)
Receiver Antenna gain (GRx) – Cable and line losses (LRx)
3. Calculate Path loss (LFs)
Using Free Space or empirical models
4. Calculate Received Power (PRx)
 $PRx = EIRP - LFs + Rx$
5. Calculate fade margin
Fade Margin (FM) = Received Power (PRx) – Receiver Sensitivity.

4.2. Free Space Model

The free space path loss formula or free space path loss equation is quite simple to use. It assumes line-of-sight between the two points, no atmospheric and no terrain effects on the propagated signal. Not only is the path loss proportional to the square of the distance between the transmitter and receiver, but the signal level is also proportional to the square of the frequency in use for other reasons explained in a section below.

$$\text{Free Space Path Loss (FSPL)} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi d f}{c}\right)^2$$

Where:

- **FSPL** is the Free space path loss
- **d** is the distance of the receiver from the transmitter (meters)
- **λ** is the signal wavelength (meters)
- **f** is the signal frequency (Hertz)
- **c** is the speed of light in a vacuum (meters per second). The speed of light is 2.998×10^8 meters per second, although for most practical purposes, this is taken to be 3×10^8 meters per second.

4.2.1. Decibel version of free space path loss equation

Most RF comparisons and measurements are performed in decibels. This gives an easy and consistent method to compare the signal levels present at various points. Accordingly it is very convenient to express the free space path loss formula, FSPL, in terms of decibels. It is easy to take the basic free space path loss equation and manipulate into a form that can be expressed in a logarithmic format.

$$FSPL(dB) = 20 \log(d) + 20 \log(f) + 32.44$$

Where:

- **d** is the distance of the receiver from the transmitter (km)
- **f** is the signal frequency (MHz)

4.3. Empirical models

4.3.1. Egli's Model

Egli is a greatly simplified model that assumes "gently rolling terrain with average hill heights of approximately 15 meters". Because of this assumption, no terrain elevation data between the transmitting and receiving facilities is needed. Instead, the free-space propagation loss is adjusted for the height of the transmitting and receiving antennas above ground.

As with many other propagation models, Egli is based on measured propagation paths and then reduced to mathematical model. In the case of Egli, the model consists of a single equation for the propagation loss as follows:

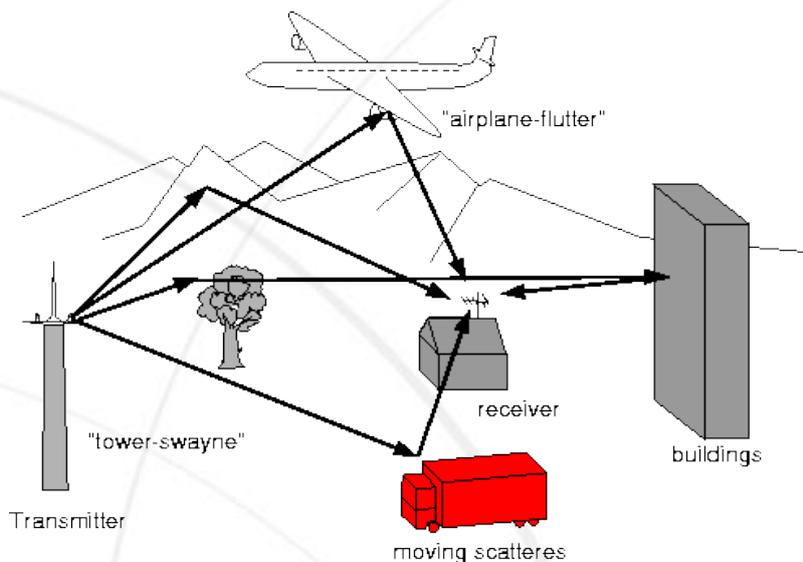
$$A(dB) = 40 \log\left(\frac{d}{1.61}\right) + 20 \log(f) - 20 \log\left(\frac{H_t \times H_r}{0.304^2}\right)$$

Where:

- **A** is the attenuation in dB (between dipoles)
- **d** is the path distance in km.
- **f** is the frequency in MHz
- **H_t** is the transmitter antenna height above ground level in meters.
- **H_r** is the receiver antenna height above ground level in meters.

4.3.2. Multipath Model

In an ideal world for wireless communication there would be no object in-between or around the transmitting and receiving antennas. With no objects between the antennas, an ideal line of sight can be achieved with a proper setup. However, in the real world there are trees, buildings, and even the Earth that make a perfect line of sight just about impossible. Wireless signals reflect off these objects on their way from the transmitting antenna to the receiving antenna, creating multiple paths for the signal to travel. This phenomenon is known as multipath Propagation.



The receiving antenna receives the transmitted waves via multiple signals due to reflecting off of objects; therefore the signal is picked up multiple times. In the figure above illustrated how the receiver can pick up multiple signals reflected from surrounding objects.

Multipath losses can be estimated if the distance between the transmitter and the repeater exceeds d_x :

$$d_x (\text{meter}) = \frac{4\pi h_t h_r}{\lambda}$$

And the loss to be multipath is:

$$\text{Loss (multipath)} = G_t G_r \frac{(h_t h_r)^2}{d^4}$$

5. Design Considerations

1. Choose your model

As shown in previous sections, each model is suitable for a certain terrain or deployment area. It is advised to start with the free space model since it is the easiest and most straight-forward approach. It will give the designer an idea if the requirements can be met given the input parameters. If everything looks good, the designer can apply other models to obtain a more accurate performance of the system.

2. Know your requirements and equipment

As stated before, knowledge of the requirements will determine the needed bandwidth, speed, BER which will all determine the most suitable equipment.

3. Impedance Matching

The industry standard is 50 or 75 ohm. Make sure the antenna port, cables, and transceivers' port match in impedance.

4. Minimize the line losses by using good quality RF feeders.

This is more critical for higher frequencies. The RF feeders' specifications provide you with losses per meter (or feet). The higher the frequency, so is the loss. Selecting high quality feeders may be cost efficient

6. Case Study

It is required to establish a wireless system in desert area with average hills heights of 10 meters. Can the system achieve a range of 5 km between the transmitter and the receiver, given:

- 1 Watt of transmitted power from the modems.
- Transmitter and Receiver Antennas gain is 3 dBi
- Cable losses in a transmitting of receiving station is 2 dB or less.
- Receiver Sensitivity= -110 dBm
- The antennas are allowed to be mounted 3 meters from the ground.

Step 1:

Parameter	Value
Tx Power	30 dBm
Antenna Gain	3 dBi
Cable and connector Losses	2 dB
Equivalent Isotropic Radiated Power	31 dBm

Step 2:

Parameter	Value
Antenna Gain	3 dBi
Cable and connector Losses	2 dB
Receiver Gain	1 dB
Receiver Sensitivity	-110 dBm

Step 3:

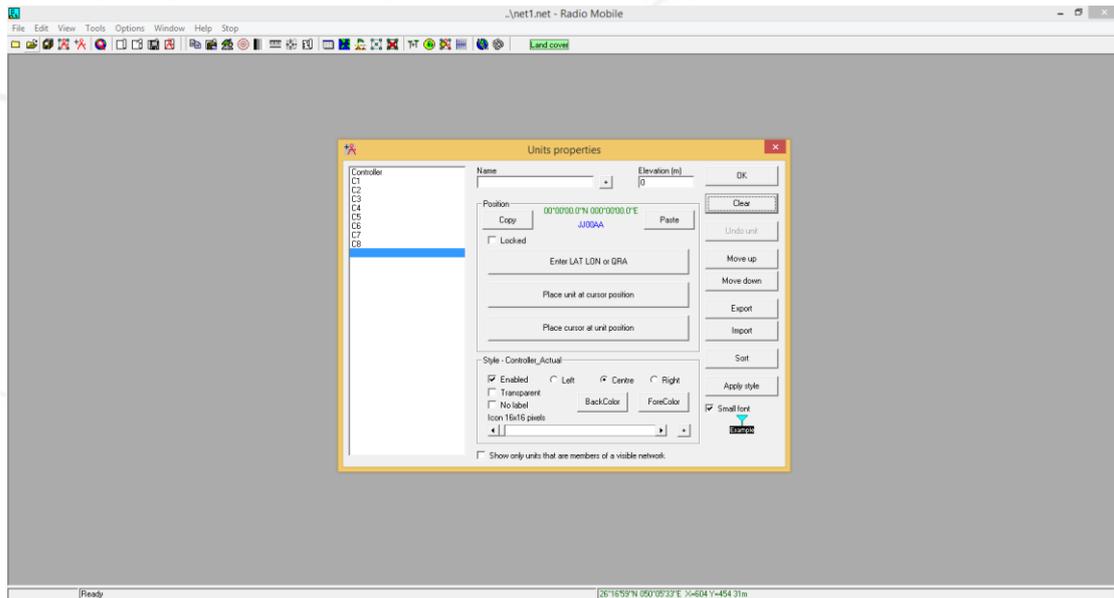
Model	Path Loss (dB)	Received Power (dBm)	Fade Margin (dB)
Free Path Loss	90.5	-78.5	31.5
MultiPath Model	128.9	-96.9	13.1
Egli's Model	141	-109	1

Overall, the system have enough budget to achieve the 5 km requirement. However, the performance is expected.

7. Radio Mobile Software

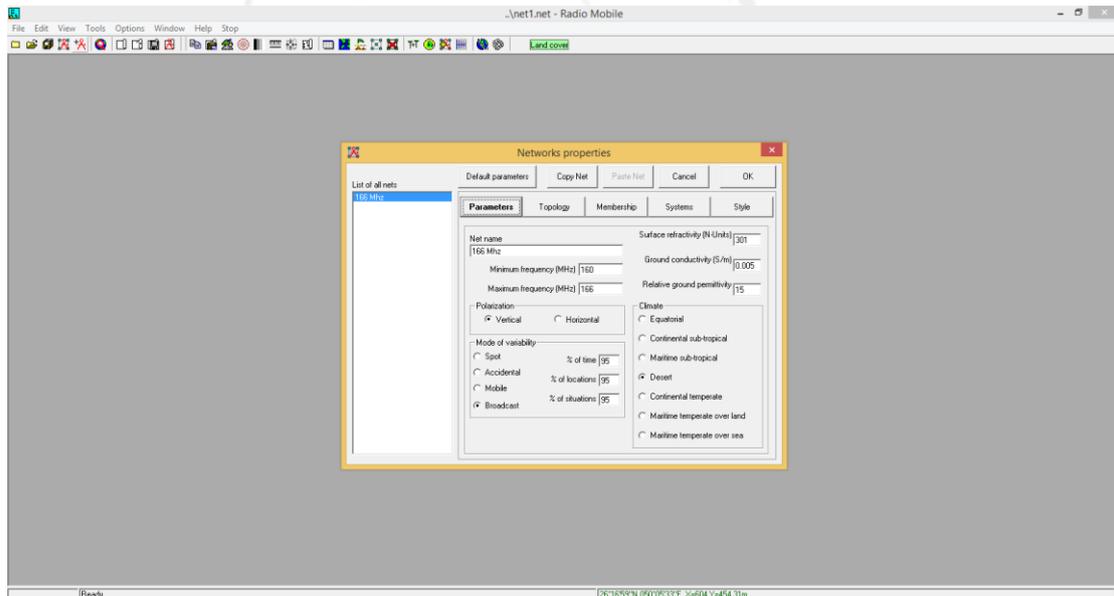
The RF design can be analyzed using software tools. The user can set the parameters in the software, and it will compute for the user the link budgets, and their fade margins. In this section, we will go through one example of using this tool.

1. After Opening the software >> go to >> File >> Units Properties



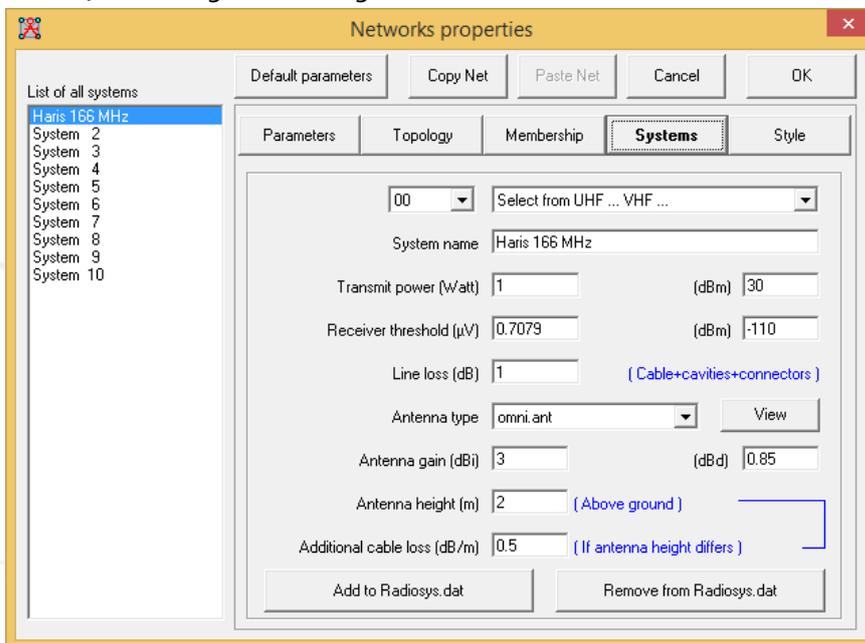
Enter the units "stations" names and coordinates.

2. Go to >> File >> Network Properties

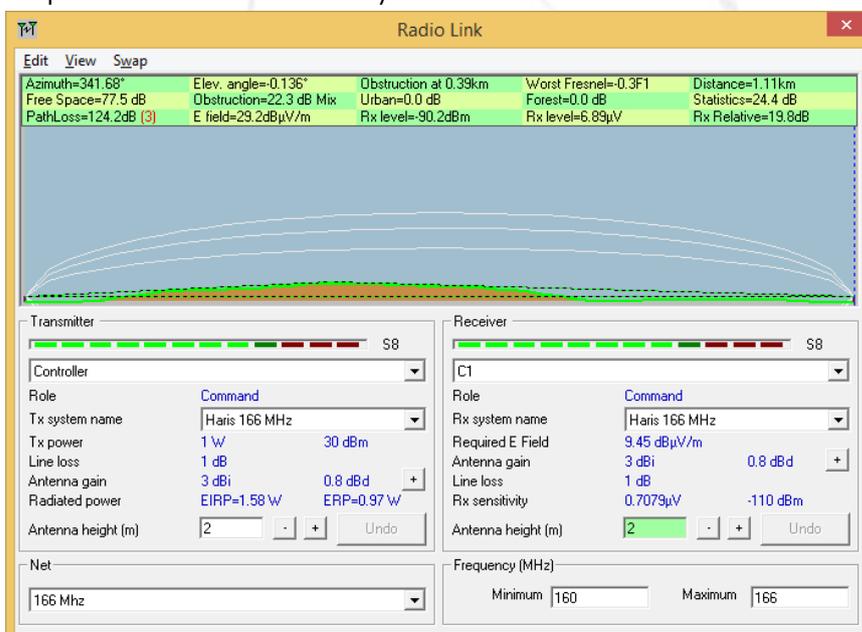


Enter the Network Max and Min frequency, the climate of the area. Leave the rest as is.

- Go to Systems tab >> enter the system properties: name, Tx Power, Receiver threshold "sensitivity", Losses, antenna gain and height.



- Go to Membership Tab and tick all the units to be included in the analysis. And then press OK.
- Go to >> Tools >> Radio Link, an interactive window will appear where you can change the units from drop-down lists to see the analysis of the link between the two units.



There you can see, the Rx Relative which is the Fade Margin, the determining metric of the performance of the wireless link. You may choose to change the antenna height to enhance the fade margin by pressing "+" button next to the Antenna height field (m).