MINT 709

CAPSTONE PROJECT
FINAL REPORT

PLANNING AND IMPLEMENTATION OF POINT TO POINT MICROWAVE COMMUNICATION LINK OVER A LONG DISTANCE USING S- BAND DISH ANTENNAS USING 2.4 GHz AND WLAN.

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Dr. Mike Macgregor
Please accept the accompanying Project Report entitled "Planning and implementation of point to point microwave communication link over a long distance using S-Band dish antennas using 2.4 GHz".

This report is an overview of the work that will be completed at the University of Alberta as a part of my capstone project to complete my Masters of Internetworking from this prestigious institution. During my last 2 years as a U of A student, I learnt a lot in the field of networking and besides from my technical field, I also got opportunity to get my hands on to Project Management course offered in our program. In this MINT 709 course of capstone project, I, with the support of my mentor and director of my program Mr. Mike Macgregor had planned and implemented point to point microwave long distance radio link using 2.4 GHz.

Through the implementation of this project I had been given opportunity to apply the concepts taught to us all MINT students in first semester under physical layer course (MINT 700) and under the guidance of team of brilliant professors led by Dr. Mike Macgregor, we learnt networking basics to advanced level of computer networks right from the first to last layer of OSI Model. I greatly feel that by providing me a chance to work in physical layer has certainly helped me to gain more knowledge of the foundations of my field of study and I strongly believe this project will prove beneficial to launch my career as a successful Network Engineer.

I would like to thank Dr. Mike Macgregor, Shahnawaz Mir, Chintha Tellambura, Ivan Fair and all other professors of MINT program for providing us their precious time and knowledge of this field.

Sincerely,
Sandeep Bhola

ACKNOWLEDGEMENT

The accomplishment of this project has been made possible by teamwork. I am grateful for helpful contribution from U of A Computer Science students who helped to give this project a practical implementation by coding the wireless sensors needed for the project and also I am grateful to the honorary director of MINT program, Mike Macgregor for his support and suggestions which helped us a lot to implement the theoretical knowledge on hardware and thus making this project a real success.

I want to acknowledge the knowledge that we gained from Chintha Tellambura and Ivan Fair who taught us MINT 700 and MINT 702 in the first year of MINT program. The in-depth knowledge gained from these courses really proved a big factor in implementing this project in the practical aspect.

I would also like to thank all faculty of MINT program for their amazing support and precious time that they dedicated to all MINT students. Their gentle criticisms and compliments really proved very helpful along the degree and helped us all in achieving a very good knowledge of the computer networks industry.

Special gratitude is reserved for the almighty for being the one who enabled us to keep going despite of many problems we encountered.

Sandeep Bhola

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1. INTRODUCTION

Microwave radio transmission is a way of transmitting signals in a duplex mode from point A to point B using the radio waves in the frequency range of 1- 30 GHz. The wavelength of these waves varies from 30 centimeters to 1 cm.
Microwave communication is still in demand because of the fact that we cannot lay fiber everywhere so microwave will still be a good choice for backhauling advanced cellular systems, LTE, HSPA and WIMAX. The first microwave link was deployed in 1950s and since then this industry has grown rapidly. Microwave links are often considered as less reliable than fiber optic links, but if the link design is done properly during the set up of the radio link, these links can provide reliability of the standards of fiber optics network in ideal conditions. Some factors impair radio links such as wind, rainfall, fading and obstacles in line of sight but the affect of these problems can be reduced to very small levels, thus providing reliability of more than 99.999%.
To use the limited electromagnetic spectrum widely, an international body was formed by the United Nations to control and allocate the parts of this EM spectrum, called International Telecommunications Union (ITU). ITU has two divisions, ITU-T (T) and ITU-(R). ITU-T handles telecommunication wing and ITU-R is responsible for radio links.
According to ITU nomenclature, microwave frequencies cover the super high frequency band (SHF), which is equivalent to S-, C-, X-, K- bands according to IEEE nomenclature. Commercial radio links use the frequency range 300 MHz to 90 GHz. The electromagnetic spectrum and microwave band nomenclature are shown figures below.

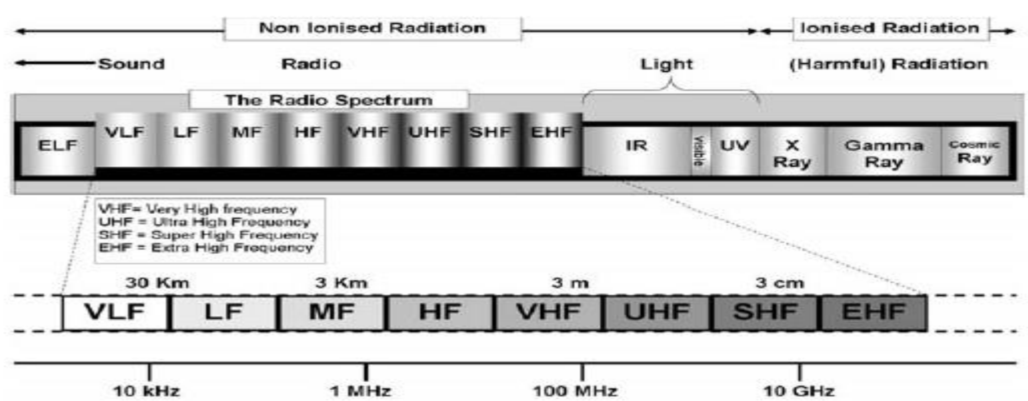

Fig1.1 Electromagnetic Spectrum

Old Bands		New Bands	
HF	3–30 MHz	A	0–250 MHz
VHF	30–300 MHz	B	250–500 MHz
UHF	300–3,000 MHz	C	500–1,000 MHz
L	1–2 GHz	D	1–2 GHz
S	2–3 GHz	E	2–3 GHz
S	3–4 GHz	F	3–4 GHz
C	4–8 GHz	G	4–6 GHz
SHF	3–30 GHz	H	6–8 GHz
X	8–12 GHz	I	8–10 GHz
J/Ku	12–18 GHz	J	10–20 GHz
K	18–26.5 GHz	K	20–40 GHz
Q/Ka	26.5–40 GHz		
U	40–60 GHz	L	40–60 GHz
O/E	60–90 GHz	M	60–100 GHz
EHF	30–300 GHz		

Fig1.2 Microwave Band Nomenclatures

ADVANTAGES OF USING MICROWAVE RADIO LINKS

I. Microwave links are relatively less expensive to set up as compared to other forms of transmission networks such as fiber optics, copper cables. Due to low fixed cost, microwave links reduce investment risk.
II. Microwave links can transmit large quantities of data by using a large number of data channels between transmitter and receiver with the help of repeaters at high frequencies.
III. Microwave links are more convenient to set up, as there is no need to dig roads as in the case of laying fiber.
IV. In event of natural disasters, radio links prove more resilient with shorter recovery times as compared to other networks.
V. Microwave links are ideal for rugged and difficult terrain rather than fiber because there is a high chance of breaking a fiber, and it can take a long time to fix such failures.
VI. Microwave links are reliable and offer the same bit error rate as fiber with the help of forward error control algorithms.
VII. Microwave links are more flexible than fiber networks.

DISADVANTAGES OF USING MICROWAVE RADIO LINKS

I. Line of sight considerations limit the number of radio paths available, as microwave signals will not pass through obstacles such as trees, mountains and buildings.

II. Microwave links are more susceptible to interference, such as from wind, rain, fading and other electronic equipment operating at the same frequency.
III. Microwave frequencies are not considered safe in public's opinion, even though they fall in non-ionizing category of electromagnetic spectrum and have no effect at all on human tissue.

2. BLOCK DIAGRAM OF RADIO SYSTEM

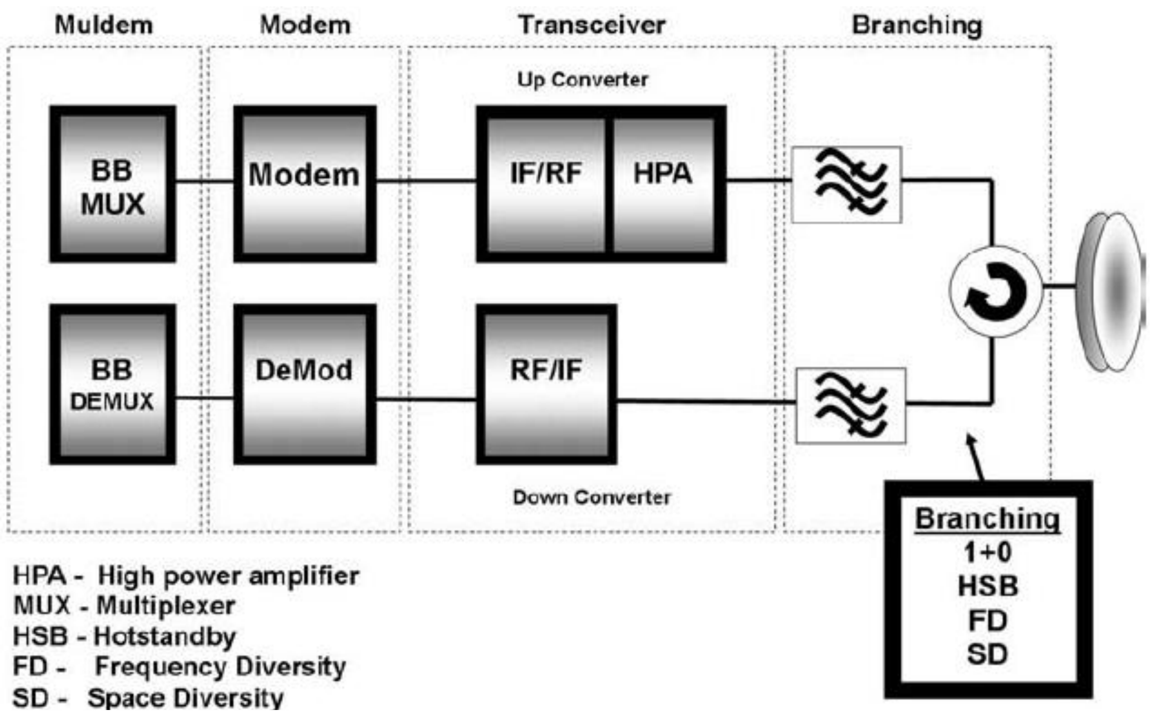

Fig 2.1 Basic Radio System

Fig. 2.1 shows the basic block diagram of a radio communication system. The input signal (analog or digital) along with signaling and control information is fed to the multiplexer. The output data stream from the multiplexer is fed to the modulator to make a more efficient bit stream with reduced bandwidth. The frequency of this bit stream is converted to IF frequency (Typically 70 MHz) because amplification is easier at this frequency. The IF is then unconverted to RF using a local oscillator. The RF signal is then fed to the high power amplifier before it is finally fed to the branching unit, which is connected to the antenna. The antenna transmits the signal and on the other end the receiving antenna receives it. These steps are followed in the reverse sequence to get back the original information.

For any radio communication link to work, we need four things: antennas, transmitter, receiver and the transmission lines. The transmitter generates the microwave signal of the desired power level at a desired frequency that carries the information from the source to destination. The other function of the transmitter is to modulate this microwave energy signal with the input signal, which is accomplished by varying certain characteristic of this energy with respect to transmitter's input.

The transmission line is responsible for carrying the signal from the transmitter to the transmitting antenna and from receiving antenna to the receiver. This could be coaxial cable or a waveguide.

The antennas are responsible for emitting and collecting signals at the transmitter and receiver side respectively. The antenna at the receiver side is pointed towards the transmitting station to receive the signal transmitted in free space. For this reason, the beam should be highly directional so we have to use highly directional antennas for our communication link.

The next important part in microwave communication is the microwave link between the transmitting station and the receiving station. We have to try to keep our link obstacle free as much as possible because microwaves are attenuated by trees, buildings and other tall structures. An important constraint is that we must fulfill the Fresnel zone criteria to meet link efficiency requirements.

Fresnel zones are used to calculate the reflections and diffraction loss between the transmitter and receiver antenna. These are denoted by F1, F2, and F3 etc. There are an infinite number of Fresnel zones but only first 3 have considerable effect on radio propagation.

The shape of the first Fresnel zone is cylindrical ellipse and size of the Fresnel zone is dependent on the frequency of the link and the total distance of the link. In our case we will be using 2.4 GHz frequency for our link.

When the signal is transmitted from transmitter, this radio signal can travel in several different ways to reach to reach the receiver. It can travel directly between the transmitter and receiver (main signal), it can get reflected off the ground or it can go left or right and be reflected by obstacle and then carry on to the distant receiver.

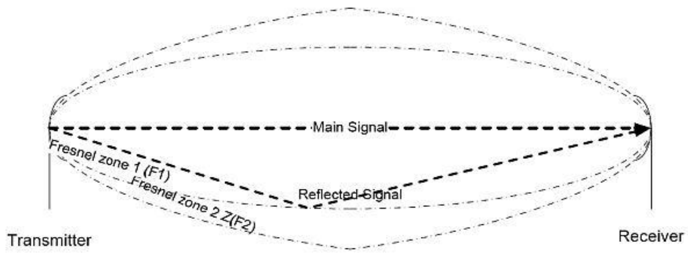

Fig 2.2: Fresnel zone clearance

The above figure shows that the radio signal reflection can happen at any random location in first and second Fresnel zones, before the signal reaches to the receiver.

Due to the reflection of the signal, 2 things that happen are mentioned below:

1. When the signal is reflected, its phase reverses and changes by 180 degrees in phase.
2. When the signal is reflected off the ground, it travels slightly more than the main signal to get to the reflection point and then to the receiver. Therefore the signal is shifted further in phase by the difference in the path length.

For the long distance links, this phase shift can be 180 degrees or more. Receiver receives both main and reflected signals and is not able to differentiate these signals because they are on the same frequency. Receiving antenna will add up these two signals, if the phase difference of these 2 signals is 360 degrees, then there is no issue but if the phase difference is 180 degrees between the main and reflected signals, these two signals will cancel out each other and the receiver will receive nothing.

For point to point microwave links the First Fresnel zone is important in determining the heights of the receiving antenna and second Fresnel zone is important for the signal strength.

The first Fresnel zone should be unobstructed for clear LOS requirements and for this reason the height of the transmitting and receiving antennas should be carefully calculated.

Second Fresnel zone has nothing to do with antenna heights but with received signal strength. So antennas should be mounted high enough to clear only 60 percent of the first Fresnel zone and the second Fresnel zone should be

obstructed by earth bulge or dominant obstacle. In our case we do not have any obstacle so the second Fresnel zone is obstructed by earth bulge.
The reason for obstructing second Fresnel zone is to attenuate 180 degrees out of phase signal so that it cannot reach the receiver to interfere and to cancel the main received signal.

So if we assume that there is an obstacle at distance d1 (kilometers) from the transmitting station and distance d2 (kilometers) from the receiving station and λ is the wavelength of the signal, in that case Fresnel radius F1 is given as

$$F1 = 17.3\ (d1d2/fD)^{1/2}$$

Where D is the total length of the link in kilometers, provided antennas are in far field region.
So the rule of thumb is that at least 60% of the first Fresnel zone should be clear of obstruction to neglect the effects of earth on the wave propagation.

The last important part in the link is the receiver, which recovers the original information through the process of demodulation. A good receiver must be sensitive enough to use the low-intensity received signal to reproduce the original information.

3. AIM OF THE PROJECT

The aim of this project is to predict the performance of a wireless communication link between two workstations using 2 S- band dish antennas at 2.4 GHz frequency by taking into consideration all the factors that are responsible for the deterioration of the signal from transmitter to the receiver such as diffraction, fading, k factor, fade margin, size of antennas, Fresnel zone and obstacles that might be present between the transmitter and receiver.
To establish a robust microwave radio link we need appropriate radio equipments to meet the design objectives. We also need to choose the frequency band of the link.

4. LINK PLANNING

Link planning is a very important part in the designing radio link. Thorough planning initially will avoid problem during the installation and deployment of the radio links. Link planning includes what types of services and what bandwidth we are expecting to be carrying over our radio link. Would it be voice circuits (300- 3400 Hz), data services or the video circuits (34 Mb/s)? These are the factors that make link planning important. Link planning also covers what level of quality is desirable for our radio link. By understanding the number of circuits needed and their associated bandwidths, the radio link designer can design the link efficiently. Link planning involves:

I. Understanding what capacity the customer is trying to achieve from this radio link.
II. Collecting the site information - using GPS (global positioning system), we can get the coordinates of the sites. This is a very critical step because we are dealing with narrow radio beams, and even a little inaccuracy would pose hindrance to radio beam clearance. In our application, it is not a very critical factor because UHF and VHF signals have a large Fresnel zone, resulting in less diffraction loss.
III. The next part of the planning process after knowing the initial capacity of the link is line-of-sight (LOS) requirements. If the LOS is not clear, the link will not work; it is very important to keep the LOS clear of obstacles. This could be achieved by mounting the antennas to the right height. If an obstacle is too high, it is advisable to move the location of the sites. Normally it is advisable to use a repeater every 50 km; our entire length between hops is 50 km so we won't need repeaters in our link.

5. RELIABILITY STANDARDS

It is very important the link should be free of errors all the time, but this is practically impossible, so some compromises must be made. Our radio link should meet the appropriate reliability standards. The ITU –R has specified outages in two groups: those that last over 10 seconds and those that last less than 10 seconds. For outages longer than 10 consecutive seconds or BER greater than 10^{-3}, the system is considered unavailable and the circuits could be rerouted using other transmission systems thus reducing long outages. Outages less than 10 seconds in duration are not rerouted; network improvement measures should be used in such cases to avoid degrading the quality of the link.

To avoid long outages we must consider the factors responsible for unavailability. Unavailability (outages more than 10 seconds) can be caused by any of the following factors or a combination of the following factors:

I. **Propagation**: Propagation failure can be caused by any of diffraction loss, rain and ducting. Diffraction loss occurs when the antennas are mounted at a height lower than desired. This results in attenuation as the signal travels close to the ground and encounters obstacles. Ducting is also responsible for outages more than 10 seconds: if the radio beam bends more than the curvature of the earth it can result in black-out fading which may last for several hours. Rain can also cause long outages, as we know that water droplets absorb microwave energy and therefore attenuate the signal. Thus, heavier rainfall results in more attenuation, which in turn results in flat fading. Using large antennas can reduce rain fading. Snow poses less attenuation to the signal but if it is wet snow, attenuation could be considerable, but less than rainfall in any case.

II. **Equipment failure**: Long outages can also occur due to equipment failure. The duration of these outages depends on the time it takes to repair the equipment.

III. **Other**: Other factors include natural disasters such as earthquakes, tower failure, or loss of power.

Short outages last for less than 10 seconds so there is not enough time for rerouting of circuits onto a different transmission medium. Performance measures have to be added to the radio link to make it reliable, Short outages can occur due to any of the following reasons:

I. **Multipath fading:** Multipath fading causes multiple paths to be established over the radio link. This causes flat fading. While planning the radio link, the amount of multipath fading must be predicted. It can be overcome to some extent by using adaptive equalization.

II. **Wind:** Strong wind can be responsible for outages as well. Strong winds tend to sway antennas, just because the antenna beam is narrow, a little drift can cause loss of signal. To overcome this condition towers should have adequate support.

III. **Background error in the equipment:** To match the BER of a fiber system, forward error control must be added to reduce the effect of receiver noise.

6. TRANSPORT TECHNOLOGY OPTIONS

Radio links are designed for the transmission of voice or data circuits from one point to the other and for that purpose various switching and multiplexing options are available such as Ethernet, SDH, ATM and PDH. PDH, SDH and ATM technologies have solved the purpose for switching and multiplexing but foreseeing the future growth of networks these technologies appeared to be costly so operators are trying to implement Ethernet technology in mobile networks as Ethernet has provided high bandwidths at low cost to the fixed networks. But point to point networks are still deploying PDH to transfer large amounts of data over digital equipments for transportation.

PDH (Plesiochronous Digital Hierarchy) allows the basic transfer rate of 2048 kilobits per second. Data rate is controlled by the clock in the data generating equipment. In case of voice transmission, normal rate breaks into 30 channels of 64 kilobits per second and 2 channels of 64 kilobits each are required for signaling and synchronization. In case of moving multiple data streams from one point to other, they are multiplexed in group of 4. Multiplexer at the transmitting side take first bit from stream #1 and then first bit from stream #2 and then stream # 3 and 4, assuming the data rate are same 2048 kilobits per seconds but in some case data rate of these streams will vary which will cause late arrival of bits in some streams, in that case receiving multiplexer will be notified by transmitting multiplexer that the bit is missing from the respective streams and thus helping the receiving multiplexer to reconstruct the original data stream. With the group of 4 streams data rate of 8.448 Megabits per seconds can be achieved.

With the advancement of wireless networks, need for higher data rate is also becoming increasingly important, so to keep these requirements in mind, telecommunication operators are switching from PDH to SDH.

7. MULTIPLEXING/DEMULTIPLEXING

Radio links can be deployed as TDM radio, Ethernet radio, Pseudo wire and Hybrid radio. In our case, we are going to use conventional TDM radio which will use TDM frames and in case of Ethernet frames they will be converted to the TDM frames which are done by encapsulating the Ethernet frames to the TDM frames and then mapping onto the TDM channel.

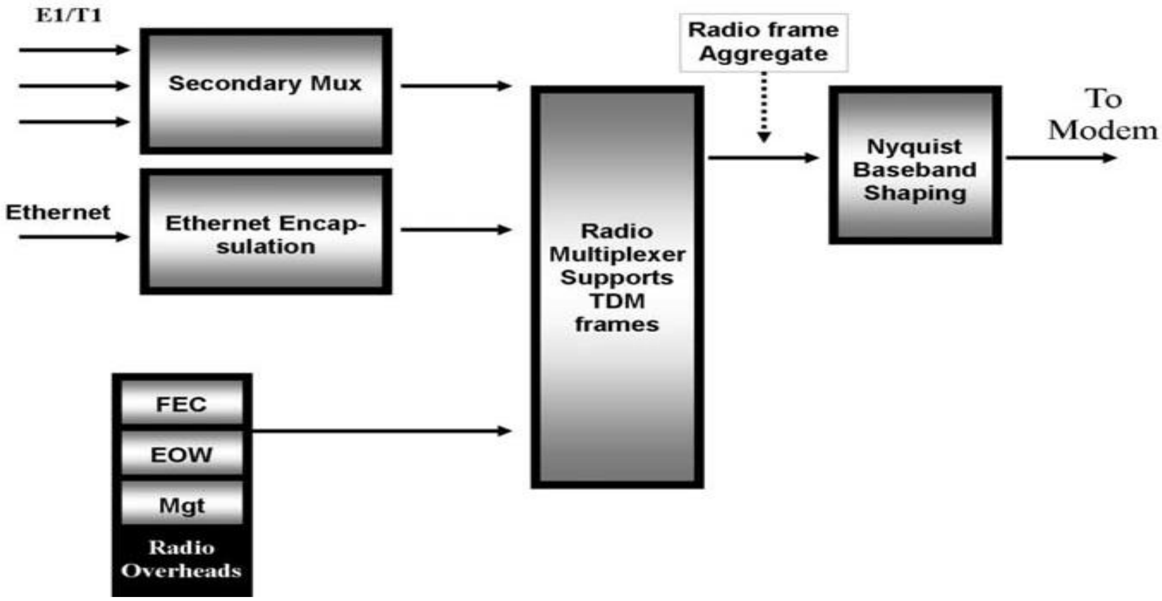

Fig 7.1: TDM radio

The process that is used to convert the analog signal to digital for transmission is known as PCM (Pulse Code Modulation). It uses line code (return-to-zero or non-return-to-zero) for digital data transport. To transmit the highest quality of voice signal, it is limited to the frequency of 300 Hz – 3400 Hz. PCM involves 4 steps:

I. **SAMPLING:** Sampling is done by mixing the analog signal with the periodic pulsed sampled signal. This periodic pulsed sampled signal follows the Nyquist Sampling Theorem, which states that the sampling frequency should be at least twice the highest frequency component in the signal in order to retrieve the original information. For that purpose the standard sampling frequency recommended by the ITU is 8 KHz.

II. **QUANTIZING:** Sampling gives us analog pulses from the continuous analog wave and now these pulses contain the original information. Quantization is the process of getting digital value from these analog values. The number of digital values depends on the number of bits that are used to represent each sample. More the number of digital values we have less will be the size of the quantization levels and less will be the quantization noise. The number of quantization level is 2^n, where n is the number of bits. 8-bit PCM will give 64 kilobits per second. Quantization noise is tending to degrade the quality of signal by degrading the signal to noise ratio. Thus for this regard, non-uniform quantization was introduced, known as **Companding**.

III. **COMPANDING:** Companding term stands for compressing and expanding. It is done before the quantization takes place and it is done by compressing the larger values of the analog signal at the source and then expanding it to normal at the receiving end. Companding improves the SNR ratio and 8- bit PCM with companding reconstructs the signal very close to the original signal. A-law companding is used in Europe and µ-law is used in North America and Japan.

IV. **CODING:** Analog signal is sampled first and then digitized into linear PCM code with larger number of bits per sample and then this linear PCM code is compressed to smaller number of bits per sample using µ-law companding. The 8bit to 12bit companding is popular these days. The 12 bit linear PCM code is encoded to 8 bit compressed code and on the receiver side this 8 bit compressed code is decoded back to 12 bit code using µ-law companding with µ= 255.

Sign bit 1 = + 0 = –	3-Bit segment identifier	4-Bit quantization interval A B C D
	000 to 111	0000 to 1111

Fig 7.2: 8-bit compressed µ255 code format

	Encoded PCM	Transmit	Transmission media	Receive	Decoded PCM	
Segment	12-Bit linear code	8-Bit compressed code		8-Bit compressed code	12-Bit recovered code	Segment
0	s0000000ABCD	s000ABCD		s000ABCD	s0000000ABCD	0
1	s0000001ABCD	s001ABCD		s001ABCD	s0000001ABCD	1
2	s000001ABCDX	s010ABCD		s010ABCD	s000001ABCD1	2
3	s00001ABCDXX	s011ABCD		s011ABCD	s00001ABCD10	3
4	s0001ABCDXXX	s100ABCD		s100ABCD	s0001ABCD100	4
5	s001ABCDXXXX	s101ABCD		s101ABCD	s001ABCD1000	5
6	s01ABCDXXXXX	s110ABCD		s110ABCD	s01ABCD10000	6
7	s1ABCDXXXXXX	s111ABCD		s111ABCD	s1ABCD100000	7

Fig 7.3: µ255 Encoding and Decoding Table

V. **TIME MULTIPLEXING:** Time division multiplexing deals with the digital signals only, it is because of this reason analog signal is converted into digital signals. The final step is to multiplex these signals into a framed signal. Because the sampling rate is 8000 samples/second, therefore the time interval between samples is 125 µs. North American hierarchy has 24 channels in a sample, whereas European counterpart has 32 channels. With sampling rate of 8000 samples per second and 8 bit time slot it gives the standard rate of 64 kbps which is known as T0 and E0. With 24 and 32 channels respectively, rate becomes 1.544 Mbps (T1) and 2048 kbps (E1) after including the framing bit and signaling information. The multiplexer is required to multiplex these 24 or 32 voice channels into framed E1 or T1 signal. In case a higher data rate is required external secondary multiplexers are required to get the rates of E3 (34 Mbps) in case of TV signals.

8. MODULATION/DEMODULATION

Modem is short word for modulation/ demodulation. Two types of modulation used for digital radio links are direct modulation and indirect modulation. In direct modulation, there is no IF carrier and the Baseband signal is directly applied to the modulator to convert it to the RF frequency whereas in Indirect modulation, it is first converted to the IF frequency before it is fed to the modulator to convert to the RF frequency.

In case of our link we will use digital modulation for the data transmission. To decide which modulation scheme should be employed for data transmission, it depends on 2 factors:

I. **POWER EFFICIENCY:** It is defined as signal energy per bit to noise power spectral density (E_b/N_0). It is the ability of the modulation technique to preserve the fidelity of the digital message against the noise, which is done by increasing the signal power.

II. **BANDWIDTH EFFICIENCY:** Bandwidth efficiency is expressed as the ability to accommodate data with in the limited bandwidth. It is given as $\eta_B = R/B$ where R is the data rate in bits per second and the B is the bandwidth occupied by the modulated RF signal. The unit of bandwidth efficiency is bps/Hz.

So deciding what type of modulation is required for the data transmission depends on compromise between these two parameters. If we add the error control bits in our data, it’s going to increase the bandwidth occupancy but at the same time the actual power required for receiver will be reduced for a desired BER.

The two most commonly used modulation schemes with microwave equipments are Multilevel- FSK and n- QAM. FSK is more cost efficient and robust and in FSK there is no need for the IF frequency, thus signal can be modulated onto RF carrier directly which results in less complex circuitry. Because FSK has been widely used in remotely metering applications, we will be using FSK as well.

BFSK also know as FSK can provide the maximum bit rate of 1200 bps.

Let’s go through some of the formulas required to calculate the bandwidth and capacity of the link.

According to Shannon capacity theorem, the capacity of the link is given as

$C= B \log_2 (1 + S/N)$ where B is in hertz, C is in bps and S/N has no units.

In case of M-ary Encoding, M is the digit that depicts the number of levels of the binary variables. The number of bits that are required to produce M number of levels or combinations is given by

$N= \log_2 M$

Therefore 4 possible combinations will require 2 bits.

According to Nyquist, the minimum bandwidth required to propagate the signal is given as:

$R=2B$

R is the bit rate in bps

B is the ideal Nyquist bandwidth in Hz.

If more than two levels are used then bandwidth (Hz) can be calculated as:

$R= B\log_2 (M)$

M is the number of levels and is given by 2^N where N is equal to number of bits.

R is the bit rate in bps.

BFSK uses two carrier frequencies, one for binary 1(Mark) and the other binary 0 (Space) as shown in fig 10.1. With the help of these frequencies, binary information is sent over the link. The minimum bandwidth of the FSK is given by Carson rule as

$B= (f_m – f_s)* 2R$ where f_s and f_m are space frequency and mark frequency and R is the input bit rate in bps and the bandwidth is in Hz.

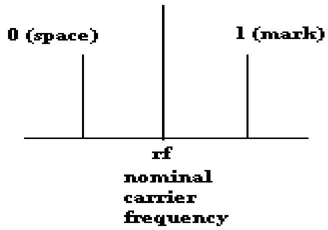

Fig 8.1: FSK Frequencies

The NRZ code is applied to the FSK modulator and the center frequency is chosen halfway between mark and space frequency and as the binary input changes from 1 to 0, output deviates from space to mark frequencies on VCO.
Demodulation techniques that are used to demodulate the signal to get the original information can be either envelope demodulator or coherent FSK modulator.
FSK input signal is applied simultaneously to the two band pass filters through the power splitter and these filters passes only the mark and only the space frequency to their respective envelope detectors and these envelope detectors indicates the power in each passband and comparator responds to the largest of the two powers and that's how non coherent demodulation works.

9. ATMOSPHERIC EFFECTS

When the radio links are designed, it is the task of the link planner to predict the outage period that link will face when deployed. Microwave signal when travels in vacuum, it will follow the straight line where as in real world microwave signal is subjected to travel in atmosphere, so under different atmospheric conditions it will behave differently and follow different path trajectories.
Microwave signals travels as an electromagnetic wavefront in the troposphere. Density decreases with altitude that means the upper portion of the wavefront travels fasters than the lower part of the wavefront.
Different atmospheric factors that effect the propagation of microwave signal can be understood but before that we need to know these terms:

I. **REFRACTIVE INDEX:** Refractive index is the ratio of the speed of EM wave in free space to the speed with which it will travel in finite medium, it is given as $n = c_0/c$ where c_0 is the speed of light in free space and c is speed of wave in a finite medium. Because the refractive index of the air is very close to unity, which applies EM waves travels almost with the speed of light. Atmospheric attenuation due to rain and oxygen absorption is significant if we are dealing with links over 10 GHz but we are dealing with 2.4 GHz so we don't need to bother about these atmospheric attenuations.

II. **RADIO REFRACTIVITY:** The refractive index of the atmosphere in which the EM wave transverses is slightly over unity. So a new term is designed by the link designers to get more convenient values, called Radio Refractivity. It is denoted by N and is given as $N= (n-1) *10^6$ where n is the refractive index of the air with value 1.000315, when we put this value in the above relation we get N= 315 N-units. For microwave links below 100 GHz, this radio refractivity can be given as $N= 77.6 P/T + 3.732*10^5 e/T^2$ where P is atmospheric pressure in mbars and T is absolute temperature in Kelvin and e is the partial pressure in mbars. This refractivity decreases exponentially with altitude and is given as $N (h) =N_0 \exp (-h/h_0)$ where N_0 is 315 units and h_0 is 7.35 km.

III. **REFRACTIVITY GRADIENT:** Refractivity is the function of altitude and it decreases exponentially with the altitude and therefore refractivity gradient is given as $G = dN/dh$ where N is the radio refractivity. In radio links, waves travel as wavefront and we know that the refractivity decreases with altitude, so the upper part of the wavefront in normal atmospheric conditions will travel faster than the bottom part of the wavefront, therefore causing the beam bend downwards. This is called refraction under normal atmospheric conditions. This is shown in fig 11.1 below. For a small period of time, let us say, this $n1<<<n2$, in this case the beam will bend strongly downwards to the ground and thus causing the wave to die before it reaches to the receiving antenna. This phenomenon is called Ducting

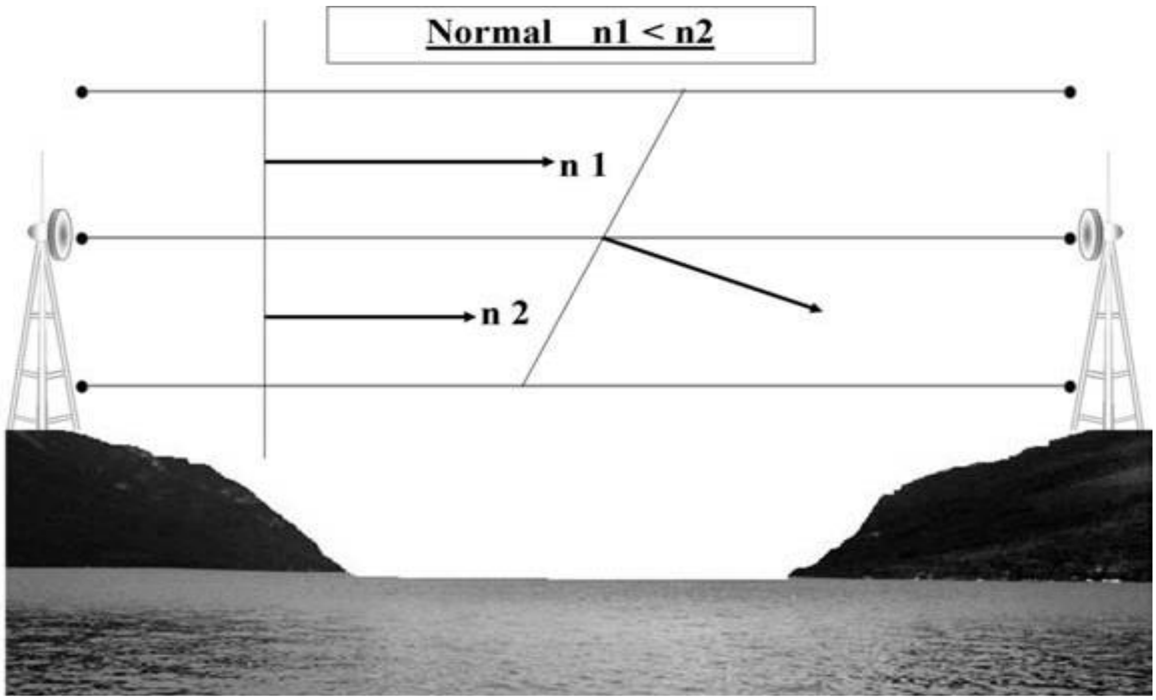

Fig 9.1: Refraction under normal atmospheric conditions.

IV. **EFFECTIVE EARTH RADIUS (k factor):** It is clear from the above point that the radio wave doesn't travel in a straight line due to phenomenon called Refraction. The amount of bending that radio wave experiences during any point in the trajectory is dependent on the gradient of refractivity at that particular point. This is the reason the radio beam travels in an arc of radius r. This radius is inversely proportional to the average refractive index gradient, given by the **1/r = dn/dh**. Similarly the surface over which radio wave propagates is not flat either, it's approximated to be an arc of radius 6,371 km. So the relative distance for the clearance of the wave is dependant on the distance between these two curves. Radio link designers have found the solution to simplify the matters by considering one of these 2 arcs as a straight line, so we assume that our radio wave travels in a straight line relative to the earth effective radius. This effective radius is the actual radius of the earth multiplied with the earth radius factor and is denoted by 'k'. This earth radius factor is dependant on the refractivity gradient and value of k is varies geographically. The effective earth radius dependency on refractive index gradient is given as k= 1/ (1 + a dn/dh) where 'a' is the actual radius that is 6,371 km. This equation when solved further gives the final relation k= 157/ (157 + G) where G is the refractivity gradient.

V. **ANOMALOUS PROPAGATION ('k' factor):** Below is the table shown for different values of the k factor for different value of refractivity gradient. Experiments have shown that the refractivity gradient can vary from positive to negative steeply and these experiments have concluded that 50% of the time the refractivity gradient values at -39 N-units/km which corresponds to the k factor value of 4/3. The refractivity gradient of positive value represents the diffraction loss and refractive index more negative than -100 N-units/km results in multipath fade and if this gradient becomes more negative than -157 N-units/km it results in black out conditions known as fading.

Earth radius factor k	Refractive Gradient G
k= 1	G= 0
k= 4/3	G= -39
k= infinity	G= -157
k< 1	G> 0

Table 9.1: Comparison of k factor versus refractivity gradient

VI. **PHYSICAL ATMOSPHERIC CONDITIONS:** Physical atmospheric conditions are responsible for negative values of the refractivity gradient. We know that the radio refractivity is dependent on the physical conditions of atmosphere (Pressure, humidity and temperature). It is given as $N= 77.6\ P/T + 3.732*10^5\ e/T^2$ now if we want to have positive gradient, strong negative temperature gradient or positive humidity gradient or both is required. That means cool moist air can cause positive gradient. For negative gradients, strong positive temperature gradients and negative pressure gradients are required that will give strong negative refractive gradients in excess of -100 N-units/km and these gradients can go as low as -157 N-units/km which will result in ducting. Surface heating and advection are responsible for negative gradients and evaporation can lead to formation of ducts. A duct can be formed over moist ground or water surface due to negative gradients. These ducts can be 20 m deep, this depth depends on altitude and the lower altitudes get deeper ducts.

10. FREE SPACE LOSS

Radio waves when propagate through the atmosphere, they are affected by the various factors. Link planners define a reference position where the propagation of waves is unaffected by the earth. The loss between the transmitting and receiving antenna unaffected by earth is known as Free Space Loss.

Let's assume that power transmitted by the transmitting antenna is given by P_t and this antenna is a point source and the power received by the receiving antenna at the distance, d is given by P_r. The ratio of power transmitted to power received is given as, $P_t/P_r= (4\pi d/ \lambda)^2$ where $\lambda= c/f$, where c is the velocity of the light and f is the frequency used by the antenna.

Therefore if we assume the two antennas as isotropic antennas, FSL in decibels is given as:

$FSL= 10\log (P_t/P_r)$ decibels

$FSL= 96.6+ 20\log d$ (miles) $+20 \log f$ (GHz)

In practical world scenarios, in addition to FSL loss atmospheric attenuation loss is need to be added along with FSL to calculate nominal received signal over a fixed hop in unfaded conditions.

11. LINK BUDGET AND FADE MARGIN

To determine the performance of a link, the planner should calculate the time period for which the received microwave signal power at the receiver is below the threshold value relative to the total time period. Fade margin is the difference between this nominal signal power and the receiver threshold value. This fade margin should be adequate for the radio links to work efficiently. Adding various gains and losses over the path from the transmitter output to the input of the receiver, is called the Power budget.

The threshold value of the receiver is the minimum value of signal that is required for the demodulator to work at a specific BER. Acceptable BER for audio applications is 10^{-3} and for data applications its 10^{-6} or better. Radio links under unfaded conditions operate under 10^{-13} which is almost same as fiber systems. So radio receivers are designed to operate between 10^{-3} and 10^{-9} BER, although the range between 10^{-3} and 10^{-9} is often as less as 2 db.

The receiver threshold value is dependant on the S/N ratio and the thermal noise (P_n) and the bandwidth of the receiver. The receiver threshold value is provided by the manufacturer with the receiver hardware.

Under unfaded conditions the link budget is given as:
$P_{RX} = P_{TX} - L_{TX} - FL_{TX} + A_{TX} - FSL + A_{RX} - FL_{RX} - L_{RX}$

Where P_{RX} is the nominal received power level in dBm, FSL is the free space loss in dB, P_{TX} is the transmitter output in dBm and $FL_{TX, RX}$ is the feeder loss of the cable in decibels and $A_{TX, RX}$ are transmitter and receiver antenna gains in dBi, and $L_{TX, RX}$ are branching losses.

The difference between the nominal received power at receiver and receiver threshold is for safety of the radio links against the fading and for this reason it is known as fade margin. Usually fade margin of 40 dB is set for the analog links and 15 dB fade margin is good in between hops for digital links.

12. FADING/FRESNEL ZONE

Radio signal when propagates over the surface of earth, it experiences various signal fluctuations due to various reasons and these fluctuations causes the radio signal to vary around the nominal received level. This is known as Fading. Radio links are subjected to various types of fading when they are deployed in practical world. Fading can be either refractive fading, diffraction fading or the multipath fading. Rain attenuation can also cause fading in systems that operates over 10 GHz.

The three types of fading that are of our interest are:

1. **ATMOSPHERIC ABSORPTION AND RAIN ATTENUATION:** The two factors that cause attenuation of radio signals in the atmosphere are water and oxygen and both these factors absorb microwave energy, but for links below 10 GHz rain attenuation is considered insignificant. Even though the rain scatters the signal but for point to point links, scattering is negligible. But if we deal with higher frequencies such as 23 GHz and 38 GHz then in that cases we have to consider the effects of rain attenuation as higher the frequency, higher

the absorption. This absorption of radio signals by oxygen and water limits the distance between hops. The path attenuation in decibels for links over 10 GHz is given by $A_{dB} = \gamma_a d + \gamma_R d$ where γ_a and γ_R are the specific attenuations from the atmospheric gases and rain given by ITU.

2. **DIFFRACTION FADING:** There are times when the refractivity gradients are positive for some k values, in those cases the lower wavefront of the radio beam travels unusually close to the ground that is actually received by the receiving antenna. Just because it traveled closer than usual to ground, depending upon terrain types or obstacles in between, it might be possible that the radio beam is hindered by the obstacles and it does not reach the receiving antenna. So to avoid such scenario of diffraction loss, radio link designers have to think through this by mounting their antennas at adequate heights to have a clear line of sight. So we need to understand Fresnel zone requirements in order to find the adequate height of the antennas that will be required for our radio link operating at 2.4GHz.

FRESNEL ZONE: As radio link designers, we need to minimize the diffraction losses as much as we can due to loss of visibility or due to obstructions in the line of sight or due to atmospheric k values variations. But our main goal is to keep these diffraction losses as minimum as possible so that our link is efficient at all times. If the other end is visible from one end, that doesn't necessarily mean that there will not be any obstruction losses because of the bending of radio waves. So for this reason, **Fresnel zone** is used to calculate amount of clearance that is required for free space propagation conditions.
As a radio link designer, first and second Fresnel zone are important to consider while designing the radio link.

So if we assume that there is an obstacle at distance d1 (kilometers) from the transmitting station and distance d2 (kilometers) from the receiving station and λ is the wavelength of the signal, in that case Fresnel radius F1 is given as

$$F1 = 17.3\,(d1d2/fD)^{1/2}$$

Where D is the total length of the link in kilometers, provided antennas are in far field region.

So the rule of thumb is that at least 60% of the first Fresnel zone should be clear of obstruction to neglect the effects of earth on the wave propagation.
So when radio links are designed, they are designed in such a way that only first Fresnel zone is unobstructed and second Fresnel zone is obstructed by a tall obstacle such as trees or hill or by earth bulge along the path of the link. This helps in reducing the height of antennas as well.

When the signal is transmitted from transmitter, this radio signal can travel in several different ways to reach to reach the receiver. It can travel directly between the transmitter and receiver (main signal), it can get reflected off the ground or it can go left or right and be reflected by any obstacle and then carry on to the distant receiver.

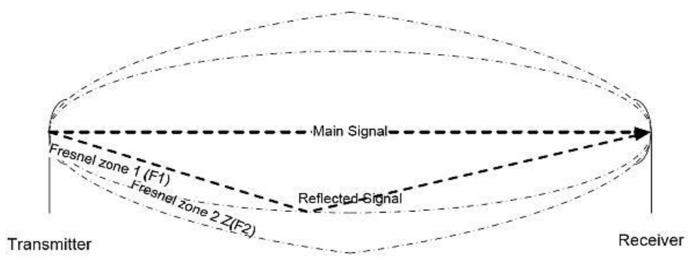

Fig 12.2.1: Fresnel zone clearance

The above figure shows that the radio signal reflection can happen at any random location in first and second Fresnel zones, before the signal reaches to the receiver.
Due to the reflection of the signal, 2 things happen:

1. When the signal is reflected, its phase reverses and changes by 180 degrees in phase.
2. When the signal is reflected off the ground, it travels slightly more than the main signal to get to the reflection point and then to the receiver. Therefore the signal is shifted further in phase by the difference in the path length.

For the long distance links, this phase shift can be 180 degrees or more. Receiver receives both main and reflected signals and is not able to differentiate these signals because they are on the same frequency. Receiving antenna will add up these two signals, if the phase difference of these 2 signals is 360 degrees, then there is no issue but if the phase difference is 180 degrees between the main and reflected signals, these two signals will cancel out each other and the receiver will receive nothing.

FIRST FRESNEL ZONE: The first Fresnel zone radius is calculated so that the difference in the path length of the main signal and the signal that is reflected off the ground is 180 degrees and another 180 degrees is from the reflection. This results in the phase shift of 360 degrees but in phase. Therefore both these signals will combine and add up at the receiver. Thus it will not affect the receiver performance.

SECOND FRESNEL ZONE: The second Fresnel zone is calculated so that the path length difference of the main signal and reflected signal from the second Fresnel zone tube is 360 degrees and additional 180 degrees shift is because of reflection. So the total phase shift is 540 (360 +180) degrees which is equivalent to 180 degrees out of phase. When these 2 signals combine at the receiver, they cancel out each other and receiver will receive nothing. So the important part is to attenuate this out of phase signal so that it cannot combine with the main signal, so radio link designers obstruct the second Fresnel zone and this also helps to reduce the height of antennas.

NOTE: Only odd number Fresnel zones will have no affect on receiver’s performance and even number Fresnel zones will always attenuate the signals at the receiver and thus degrades the performance of the radio link.

Below is the figure showing clearance of first Fresnel zone.

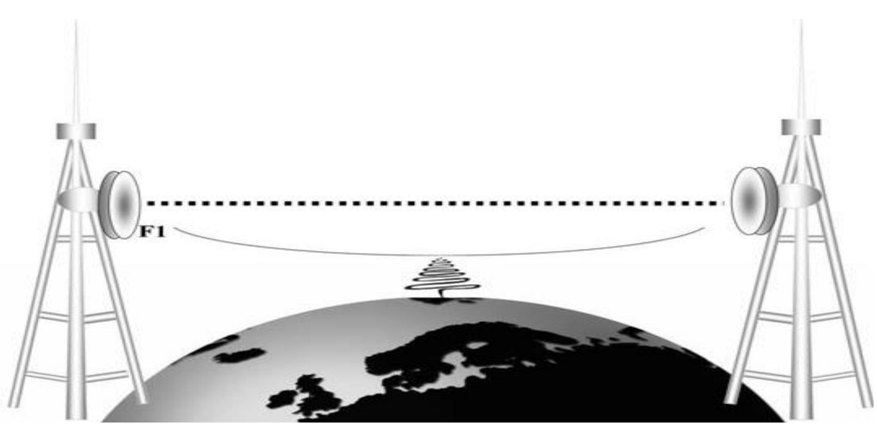

Fig 12.1: First Fresnel zone clearance: Knife edge

The fig shown above has a pointed obstacle but Fresnel zone is cleared by 60 percent so there will not be obstruction losses but if the clearance is less than 60 percent in that case there will be obstruction losses due to diffraction and these losses will depend on the type of obstacles and their reflection coefficients.
Because we have a big obstacle in our path, so knife edge method will be used here and grazing LOS diffraction loss of 6 dB is used for more paths.

MINIMUM k VALUES: As we know that diffraction losses occur when the refractivity gradient is positive and in order to avoid the risk of beam clearance due to abnormal k conditions, so we need to pick the right value of k factor because the clearance of beam over the obstacle depends on k factor.
Normally k value of 4/3 is used for very high frequencies because radio waves are believed to travel in a straight line when the radius of earth is multiplied with factor 4/3. So we will be using this value as well.

3. **REFRACTIVE FADING:** As we know that when the refractivity gradient has value more than -100 N-units/km it results in the multipath fading and when this value becomes even more negative such as -157 N-units/km it results in the Ducting. This strong negative refractive gradient results in the bending of the radio downwards. This signal might get reflected back from the ground and might reach the receiving stations following different path. This causes Multipath fading. This multipath fading is main fading in links that operate below 10 GHz. We will be using 2.4 GHz for our link so it is important to consider the Multipath fading. This multipath signal either results from the elevated duct or from the ground reflected signal as shown in fig 12.2 below. In case of ground duct, signal bend downwards so strongly that it never reaches the receiving station. This type of ducting results in black out conditions.

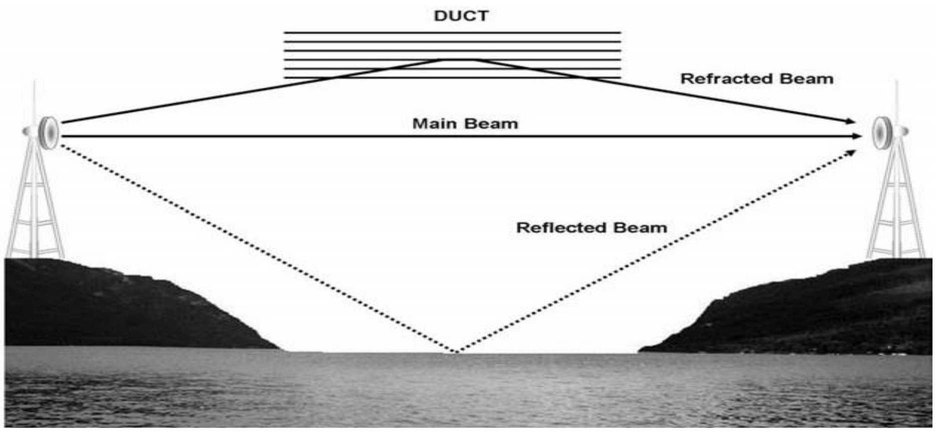

Fig 12.2: Refractive fading due to elevated duct

13. FRESNEL ZONE CODING

The C++ coding that is used to calculate the suggested first Fresnel zone clearance is tested in Code::blocks 12.11 environment assuming that there is no obstacle present in the link such as in our scenario.
Fresnel zone radius is longest at center point because of its elliptical shape. So we are calculating Fresnel zone clearance radius at center point that is required for clear LOS requirements.

```
#include <iostream>
#include <math.h>
#include <string>
#include <sstream>
using namespace std;

int main ()
{
  string mystr;
  double d1=0;
  double d2=0;
  double freq=0;

  cout << "Enter distance in meters from transmitter to point P or center point: ";
  getline (cin,mystr);
  stringstream(mystr) >> d1;
```

```
  cout << "Enter distance in meters from receiver to point P or center point: ";
  getline (cin,mystr);
  stringstream(mystr) >> d2;

  cout << "Enter frequency in GHz: ";
  getline (cin,mystr);
  stringstream(mystr) >> freq;
  cout << "Minimum First Fresnel zone clearance in metres: " <<
sqrt(d1*d2/(d1+d2))*0.2121 << endl;

  return 0;
}
```

The screenshots of the output of the above code are shown below:

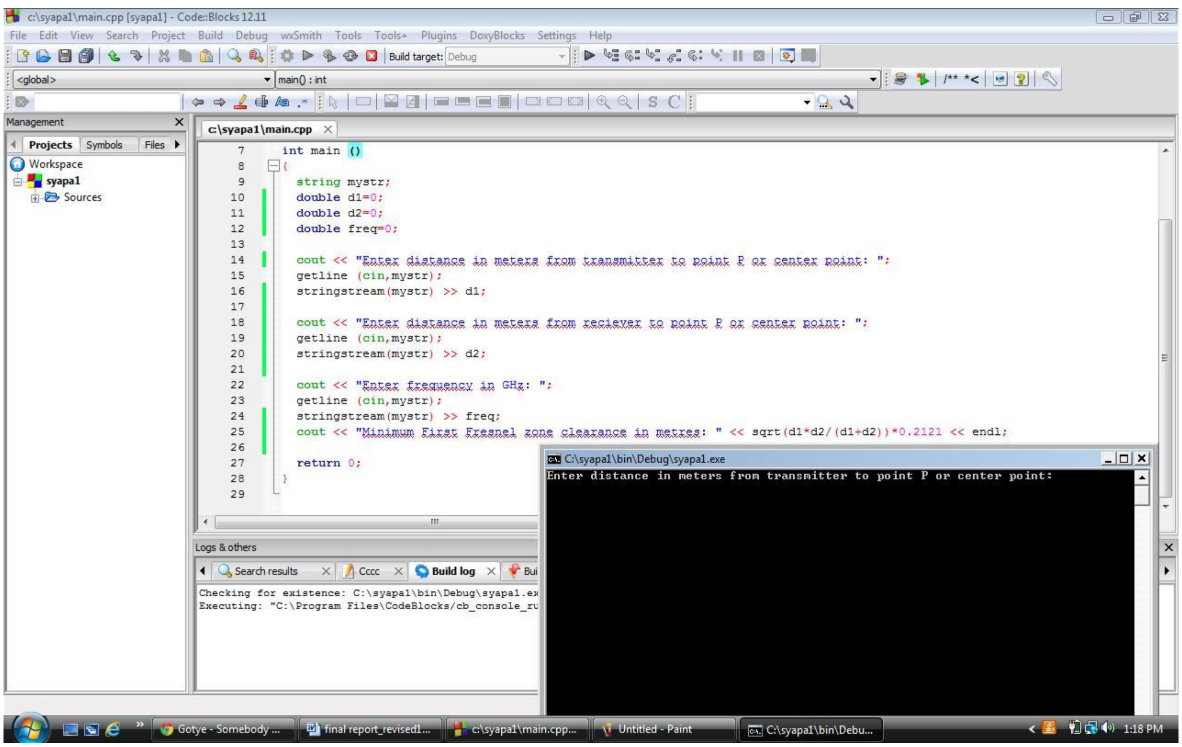

Fig 13.1: Screenshot of the code output

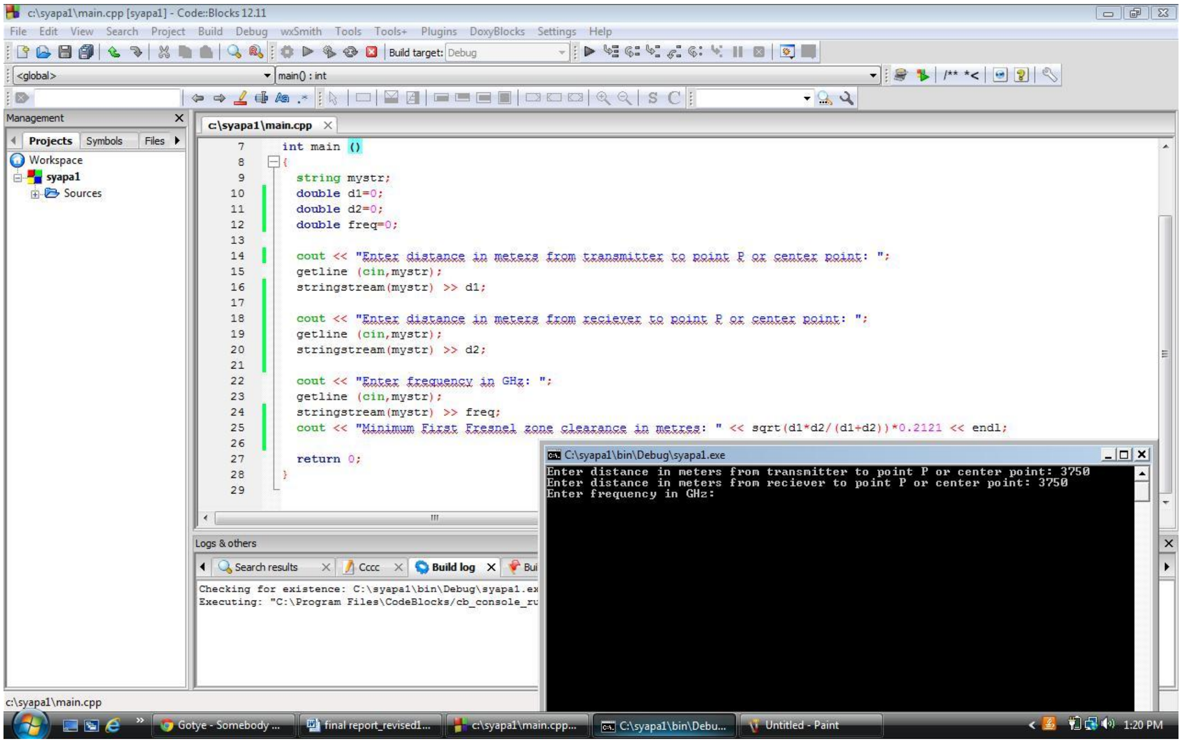

Fig 13.2: Screenshot of code output

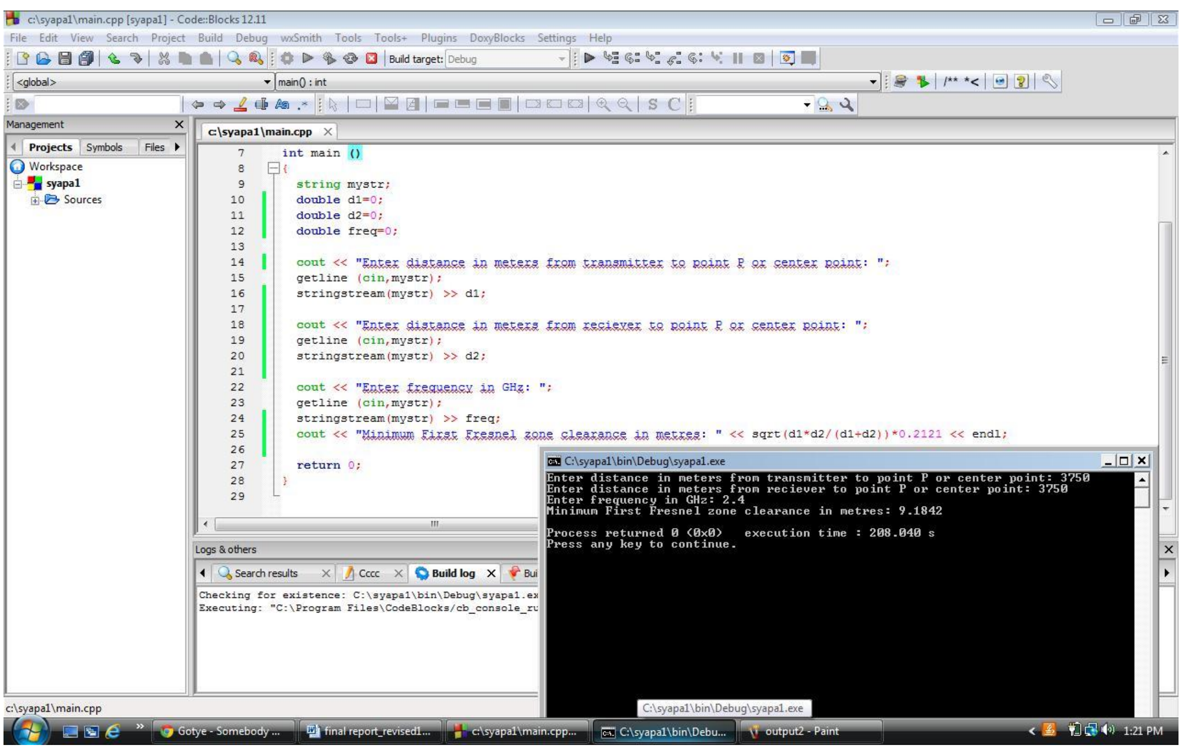

Figure 13.3: Screenshot of code output

14. ANTENNA CONSIDERATIONS

Radio link designers really have to choose antenna very carefully according to the demands of the links. The factors that must be considered are antenna gain, beamwidth, interference rejection and height of antenna above the ground. These factors play very significant role in successful link design. Antenna is a vital component in the communication system that converts the electrical energy generated in the transmitter of the radio system into focused wavefront and on the receiver side it converts this wavefront to the corresponding electrical signal. Antenna works on a principle that a varying current produces varying magnetic field and this varying magnetic field in turn produces varying electric field. Both these varying fields interact with each other and if the length of the conductor is sufficient, it will radiate and produce maximum oscillation for that particular frequency. The simplest antenna is the dipole antenna which is conducting element just one half the wavelength. This is closest real antenna which radiates power equally in all directions.

In microwave radio system links, the type of antenna that we are interested in is directional antenna that radiates more power at the front of antenna. Some of the factors that are important for the radio link designers are as follows:

1. **GAIN:** Antenna is a passive device so it cannot amplify the signal but it can make shape the signal to be stronger in one direction as compared to the other. So in our case it is important because for microwave links we need highly directional antennas. The gain of the antenna is expressed as the ratio of power density of the isotropic radiator and power density in a particular direction of interest. Gain of the microwave antenna is expressed in dBi and is given as
   $dBi = 10 \log_{10} P/P_{di}$
   Where P is the power density in considered direction and P_{di} is the power density of the isotropic radiator. For microwave antennas the gain is given as
   $G\ (dBi) = 10 \log \eta\ (4\pi A_a/\lambda^2)$ where η is the efficiency of the antenna aperture, A_a is the area of the antenna aperture and λ is the wavelength of the signal. If we assume that the antenna is parabolic antenna with efficiency of 55%, gain of the antenna can be estimated by
   $G\ (dBi) = 17.8+20 \log (d*f)$
   where d is diameter of antenna in meters and f is the frequency in GHz.

2. **SIDELOBES:** Microwave antennas are intended to radiate energy in one considered direction but it is not practically 100% achievable so some of the energy is radiated in other directions as well as at the back of antenna which results in lobes. So the purpose of directional antenna is to maximize the energy in the main lobe by minimizing the energy in the side lobes. The diagram below shows the main lobe along with side lobes and back lobes.

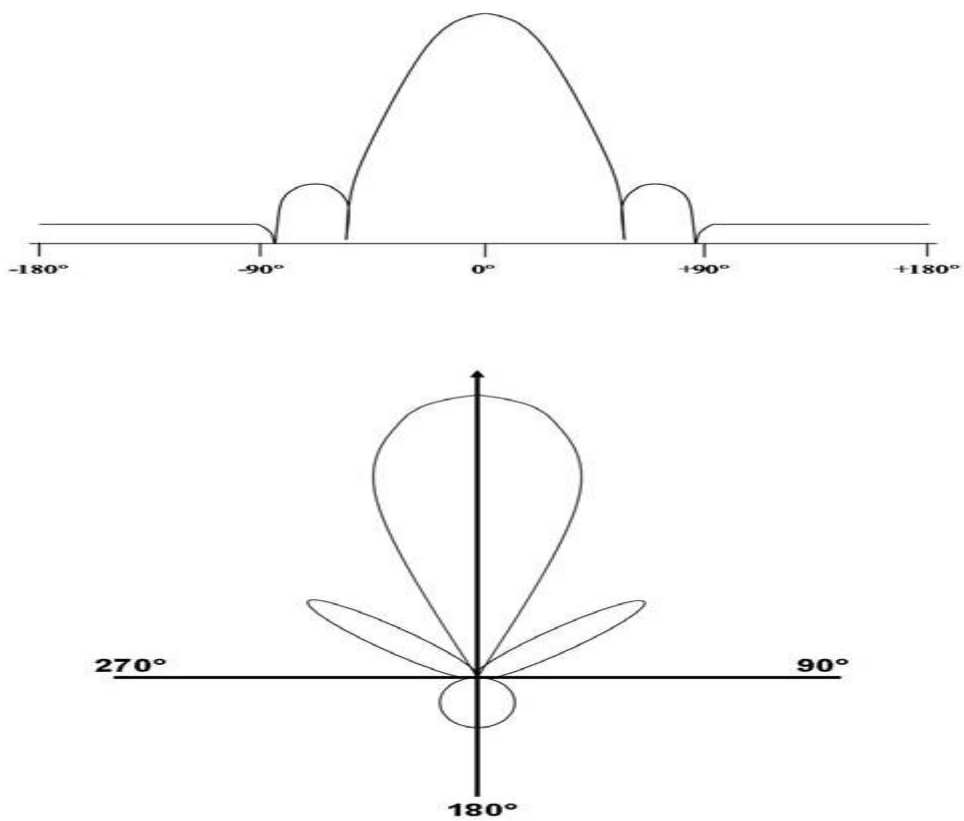

Fig 14.1: Antenna pattern

3. **FRONT TO BACK RATIO:** As we know that some of the energy is radiated at the back of the directional antennas too, so Front to back ratio is also an important consideration for antenna selection. Front to back ratio is the ratio of the antenna gain in the forward desired direction to the gain in the opposite direction. Higher the front to back ratio, better the antenna is. Ratio as high as 70 dB may be required for certain links.

4. **BEAMWIDTH:** For the radio beam to travel more distance, main lobe of antenna pattern has to be narrow and this width of main lobe at half power intensity is called beamwidth. To achieve narrow beamwidth, antenna with higher gain should be used. If the size of the reflector in increased, it decreases the beamwidth and it also improves in reducing the interference of the signals. Microwave antennas are available in market with the beamwidth of less than 1 degree.

5. **POLARIZATION:** To avoid cross polarization attenuation, it is advisable to set up radio links to transmit and receive on same polarization.

6. **VOLTAGE STANDING WAVE RATIO (VSWR):** In general, there is a mismatch between the feeder and antenna, due to which a small portion of power is reflected back to the transmitter and there too is a mismatch that results in reflecting back of this power, resulting in standing wave. It is given as the ratio of V (max) to V (min) and this ratio is always greater than 1. In general, VSWR of 1.2 is considered good. Reflection coefficient is the ratio of the reflected and incident waves and in terms of VSWR it can be given as
   ρ = VSWR-1/VSWR+1. This mismatch that results in standing waves can be expressed in terms of reflection loss in decibels, that can be given as $RL_{dB} = 20 \log(1/\rho)$ where ρ is the reflection coefficient. For microwave link reflection loss should be 20 dB or more.

7. **NEAR FIELD & FAR FIELD:** Experiments to understand the antenna pattern have all been done in far field and thus the concept of gain, FSL are all defined for the far field region. So far field distance is given by:
   Far field distance = $2D^2/\lambda$ where D is the antenna diameter in meters and λ is the wavelength of the signal.

So what is the far field distance for a 60cm dish at 2.4 GHz frequency?
We can put D= .60 meter and $\lambda = c/f$ where c is the speed of light and f is the frequency in GHz.
Therefore, λ= 0.125 meters

Therefore, far field distance for a 60 cm dish = 2*0.60*0.60/0.125
Far field distance = 5.76 meter.

Two antennas must be at least 5.76 meters apart to apply rules of free space propagation.

The types of antennas we will be using are S band dish antennas. It works on the principle that the horn feed is placed on focal point so that reflected signals off the reflector are in phase. Most of the microwave antennas are parabolic reflectors antennas.
And to feed the electrical signal from the transmitter module to the antenna, we will be using coaxial cables. And the characteristic impedance of the coaxial cables for RF applications is 50 Ohms.

15. FREQUENCY PLAN AND CHANNEL SPACING

After deciding what type of antennas we will be using and all other parameters, the next big step is to decide what frequency we will be using for our microwave link and how we can minimize the effects of interference to keep our link in a good state. Microwave links have been categorized in four groups as follows:

1. **Less than 3 GHz:** Microwave links that uses 2.4 GHz ISM band falls under this group and we will be using 2.4 GHz as well and with this frequency hop length of 100 km can be achieved. This band requires less stringent LOS requirements.
2. **3- 11 GHz:** This group also has ISM band with frequency of 5.8 GHz that can be used for hop length of up to 50 km. This frequency band often faces more multi path fading and also requires full LOS requirements.
3. **13 -38 GHz:** This group is for shorter distance hops (5 km). It also has 24 GHz unlicensed frequency in it.
4. **60- 90 GHz:** This group is also used for the shorter distance hops, up to few kilometers.

We will be using 2.4 GHz frequency because we don’t have to take permission from government to operate in this frequency (ISM band). This frequency is good for hop length of up to 100 km and rules for LOS are not that stringent and path loss is less as well.

Let us take 4 channels 2.4GHz transmitter system example. It has 14 channels but 11 out of 14 are used. Each channel needs to be properly spaced to avoid the inter channel interference so adjacent channel are spaced 5 MHz apart and 25 MHz of channel separation is required.

16. BIT ERROR RATE REQUIREMENTS

BER is the bit error rate. It is the ratio of number of error bits transmitted to the total number of bits. BER for voice traffic should be 10^{-6} or better and for data traffic it should be 10^{-9} or better. The BER rate highly depends upon the interference of the signals at the receiver input. We will be dealing with digital receivers so we have to take consideration of interference on digital receiver. Digital receivers are very robust and perform well in unfaded conditions but as soon fading comes into play, the received signal power approaches the receiver threshold value. As soon as it gets below to the threshold value it becomes difficult for the receiver to demodulate and signal quality decreases. There is negligible effect on BER as long as it stays well over the threshold value.

Interference is given in terms of ratio of wanted signal to unwanted signal. It is given by C/I. Normally digital radio links designed have fade margin of more than 15 dB between fixed hops. Every equipment manufacturer gives C/I value for its receiver and there is minimum C/I_{min} above which the BER remains constant and below which the performance of the system becomes unacceptable. Thus minimum value of C/I depends on the type of modulation scheme used in the communication system. So for the system to perform well

$C/I = C/I_{min}$ + Fade Margin.

Receiver threshold curve is shown below which indicates that BER is constant even though signal attenuation increases and when this attenuation reaches receiver threshold value, BER increases steeply. This effect is called Threshold Effect.

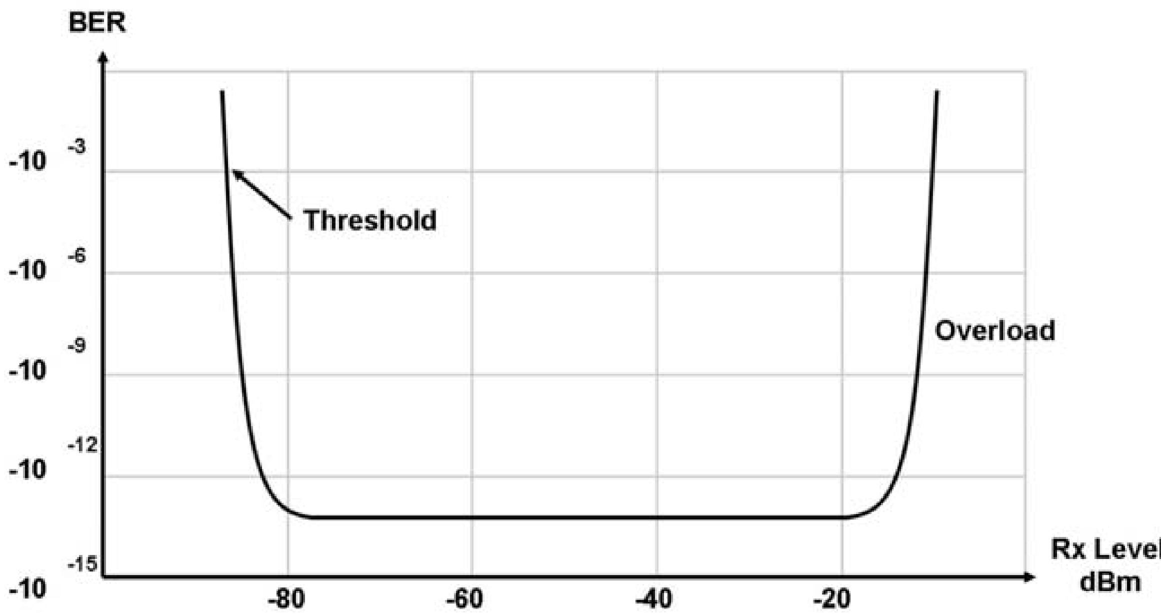

Fig 16.1: Receiver threshold curve

17. LINK DESIGN/PRACTICAL SCENARIOS

We are dealing with 2.4 GHz frequency band and for this frequency band so the LOS requirements are not very stringent because of large Fresnel zones at these frequencies.

Some of the factors to be considered are:

1. Attenuation due to trees varied on the use of frequency for the radio link. For 2.4 GHz links we can consider trees as an obstacle and by using Fresnel calculation we can bypass these obstacles. Typically tree losses depend upon the thickness of the tree and on the number of leaves it has on it and moisture on the leaves. Radio link designers always prefer to not to point RF waves to the trees by elevating the antennas. Typically for 2.4 GHz links, trees offer 0.5 dB/meter attenuation which can be avoided by appropriate Fresnel zone calculation.
2. Climatic attenuation due to rain, fog and snow are considered for links over 10 GHz and these have very less effect on 2.4 GHz links, so can be ignored. Generally, rain and snow attenuation varies from 0.001 to 0.01 dB/ kilometer. We will not be considering these losses in our radio link.

3. Feeder cable losses are also important to consider and these losses depend on the type of cable we use and length of the cable. Depending on the type of cable, these losses vary from 0.222 - 0.812 dB/km. These feeder cables are fed with high power using amplifier, keeping the 24 dBm radiated power constraint in mind.
4. We are assuming that we are going to mount antennas at the same height irrespective of the location of obstacle if any.

Scenario 1: **Let us find the adequate height of antenna and first Fresnel zone radius and the earth curvature for the given length of the path. Consider we have a link of length 30 miles operating at 2.4 GHz and in our path we have an obstacle of 20 feet high. This obstacle is in the middle of the transmitting and receiving antenna. Most of the digital microwave radio links have a fade margin of more than 15 dB. High fade margin is better so our link should yield fade margin of more than 15 dB or we need to use antennas with even more gain, high gains can be achieved by increasing the diameter of the antennas.**
G (dBi) = 17.8+20 log (d*f)
Where d is diameter of the antenna in meters and f is the frequency in GHz.

NOTE: So if we double the diameter of the antenna, gain is increased by 6 dB.

Scenario 1: step 1 is to calculate the Fresnel zone radius using formula, $F1 = 36.03 (D/f)^{1/2}$ where D is the link length in miles and F1 first Fresnel zone radius given in feet and f is the frequency in GHz so from the given values F1 is equal to 127.38 feet

This Fresnel radius is calculated at the mid point of the path (15 miles from transmitting and receiving station).

The earth curvature can be calculated as
$H= 1000*D^2/8\ E_r$ where E_r is the effective radius of the earth, which is actual radius of the earth multiplied with the k factor. In our link we will be using median k value of 4/3 which gives effective radius of 8504 km.
D is the total length of link in kilometers.
By putting D= 48.28 km (30 miles) and E_r= 8504 we

Therefore the earth curvature is 112.4 feet.

We know that if we want to have free space propagation we need to have 60 percent first Fresnel zone clearance.

NOTE: That means suggested clearance of Fresnel zone is given as 0.6*F1 that comes out to be 0.6*127.38= 76.428 feet.

So if we have obstacle of 20 feet in our path and we need to have clear line of sight for that purpose we need our transmitting and receiving antennas at a specific height, so that radio signals can propagate over this obstacle.

NOTE: This height can be calculated by adding the height of the obstacle to the suggested radius of the Fresnel zone clearance and the earth curvature which comes out to be 76.28+ 20+ 112.4 = 208.68 feet.

So now if we have to find the size of antennas and free space loss and fade margin. Let assume TX output is 25 dBm and the receiver threshold is -100 dBm and path length is 30 miles and the link is operating on 2.4 GHz frequency and atmospheric attenuation is .4 dB (0.02 dB/km) and branch losses for transmitter and receiver are 1.5 and 3.5 dB and the gain for transmitter and receiver antennas is 24 dBi. All of this information is provided by the manufacturer with the equipments. So the first step is to calculate the free space loss, which is given by

FSL= 92.4 + 20 log f (GHz) + 20 log d (km) dB
This comes out to be 133.67 dB

Next step is to find the EIRP (Effective isotropic radiated power), this is the actual power radiated by the transmitter and is given by:

EIRP= transmitter output + gain of the antenna – transmitter branch loss

This comes out to be 47.5 dB

The next step is to find the fade margin and to find the fade margin we need to find the nominal received power and the nominal received power is given by:

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain – Atmospheric attenuation

NOTE: This comes out to be -65.679 dB
Receiver should be sensitive to receive this signal if nominal received power is more than threshold value.
This value is more than receiver threshold value, so the receiver is sensitive enough to receive this signal and demodulate back to the original information.

FADE MARGIN = nominal received value- threshold value
Therefore, fade margin = -65.679 – (-100) = 34.320 dB

For links that operate at 2.4 GHz, desirable fade margin is 35-40 dB so to increase our fade margin by over 6 dB we need to increase the diameter of the antenna to twice the size that we used now to get fade margin of 40 dB.

NOTE: If we have an obstacle of a height that it starts blocking the 60 % suggested clear Fresnel zone, in that case the height of the antennas should be increased to meet the LOS requirements to get the first Fresnel zone clear of obstacles.

SCENARIO 2: Assume there is no obstacle and path is free of trees, in this scenario height of obstacle will be 0 feet and the length of the path is 30 km. Gain of the transmitting and receiving antenna is 24 dBi and atmosphere attenuation 0.4dB and transmitter and receiver branching losses are 1 dB and 2 dB. The output of the transmitter is 25 dBm and receiver threshold is -100 dBm

First Fresnel zone measured at the centre of the path is calculated as
$F1= 56.758(1/f\ (d1*d2)/\ (d1+d2))^{1/2}$ where d1 and d2 are distances to the transmitter from the center point of the path in kilometers and f is the frequency in GHz.
So the first Fresnel zone is 100.33 Feet

So the suggested first Fresnel zone clearance is given by .60*F1 that comes out to be 60.200 Feet

Earth curvature given by **$H= 1000*D^2/8\ E_r$** where D is the total length in kilometers and E_r is the effective radius using k=4/3
NOTE: EARTH CURVATURE= 13.22 meters
NOTE: EARTH CURVATURE= 13.22*3.280= 43.39 feet

NOTE: The height of the transmitting and receiving antenna will be given by = First suggested Fresnel zone + dominant obstacle +Earth curvature that come out to be 103.59 Feet.

FREE SPACE LOSS IS GIVEN BY
FSL= 92.4 + 20 log f (GHz) + 20 log d (km) dB
FSL= 129.54 dB

So the effective isotropic radiated power is given by:
EIRP= transmitter output + gain of the antenna – transmitter branch loss
Therefore, EIRP= 25+24-1
EIRP= 48 dB

To calculate Fade margin, we need nominal received power measured at BER 10^{-6} that is given by

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain- atmospheric attenuation

Nominal received power = 47 – 129.54 -1.5 + 24 -0.4
Nominal received power -60.44 dB

Therefore Fade margin= Nominal received power – Receiver threshold value
Fade Margin= -60.44-(-100)
Fade Margin= 39.56 dB

Normally radio system are designed with fade margins of 35-40 dB so this scenario will work fine but as a precaution, antenna with high gain can be used for this case, and to increase gain we need to increase the diameter of the antenna.

SCENARIO 3:

In this case let us say, we have a dominant obstacle of 50 feet and distance of the link is 38 miles (61.15 km) and the obstacle is 14 miles from the transmitting station and 24 miles from the receiving station. Gain of the transmitting and receiving antenna is 35 dBi each and transmitter and receiver branching losses are 2 dB and 4 dB and receiver threshold is -90 dBm and atmosphere attenuation is .69 dB.

First Fresnel zone measured at the point of the obstacle in the path is calculated as

$F1= 56.758(1/f\ (d1*d2)/\ (d1+d2))^{1/2}$ where d1 and d2 are distances to the obstacle from transmitter and receiver in kilometers and f is the frequency in GHz.

So the first Fresnel zone is 138.20 Feet

So the suggested first Fresnel zone clearance is given by .60*F1 that comes out to be 82.92 Feet

Earth curvature given by **$H= 1000*D^2/8\ E_r$** where D is the total length in kilometers and E_r is the effective radius using k=4/3

NOTE: EARTH CURVATURE= 54.97 meters

NOTE: EARTH CURVATURE= 54.97*3.280= 180.311 feet

NOTE: The height of the transmitting and receiving antenna will be given by = First suggested Fresnel zone + dominant obstacle +Earth curvature that come out to be 313.234 Feet.

FREE SPACE LOSS IS GIVEN BY
FSL= 92.4 + 20 log f (GHz) + 20 log d (km) dB
FSL= 135.73 dB

So the effective isotropic radiated power is given by:
EIRP= transmitter output + gain of the antenna – transmitter branch loss
Therefore, EIRP= 25+35-2
EIRP= 58 dB

To calculate Fade margin, we need nominal received power measured at BER 10^{-6} that is given by

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain- atmospheric attenuation

Nominal received power = 58 – 135.73 -4 + 35-.69
Nominal received power -47.42 dB

Therefore Fade margin= Nominal received power – Receiver threshold value
Fade Margin= -47.42-(-90)
Fade Margin= 42.58 dB

NOTE: All these measurements should be taken in far field region that is the distance of separation between two antennas should be greater than $2D^2 / \lambda$ where D is the diameter of the antenna in meters.

SCENARIO 4:

Assume we have 60cm dishes that give 21 dBi gain each, that the maximum height of each antenna is 10m, and that there are no obstacles between the two endpoints. Transmit power is 15 dBm and receiver sensitivity is -80 dBm. Find the maximum link length for two or three values of fade margin.

Fresnel zone radius is elliptical in shape so it has the longest radius at the centre point. In this scenario there is no obstacle in between transmitting and receiving antenna so, we will be calculating Fresnel zone at center point of the link.

From the above given parameters, we need to find the total distance of the link. Let us assume this total distance of the link is 'D'.

Given parameters:
Diameter of dish= 60 cm
Gain of antenna= 21dBi
Transmit power= 15 dBm

Receiver sensitivity= -80 dBm
Height of antenna= 10 m
Antenna efficiency= 55% (calculated from the given gain and diameter of antenna)

Height of the antenna= Obstacle height + Earth curvature + 60% of First Fresnel zone

Height of the antenna is 10 Meters (given)
Earth's curvature (meters), $H= 1000*D^2/8\ E_r$
First Fresnel zone (meters) = $8.657(D/f)^{1/2}$ meters
Effective earth radius, $E_r = 8504$ km
K factor= 4/3
Frequency = 2.4 GHz

Height of the antenna (meters) = 0 (obstacle height in our case) + $1000*D^2/08\ E_r$ (meters) + 60% of $8.657(D/f)^{1/2}$ (meters)

10 (Height of antenna in meters) = 0 (obstacle height in our case) + $1000*D^2/8*8504$ + 60% of $8.657(D/2.4)^{1/2}$

$1000*D^2/8*8504$ + 60% of $8.657(D/2.4)^{1/2} = 10$

From the above relation, D in kilometers can be calculated and value of D comes out to be 7.5 Km

So the total length of the link is 7.5 Kilometers.

Free space loss in dB is given by:

FSL= 92.4 + 20 log f (GHz) + 20 log d (km) dB
FSL= 92.4 + 20 log 2.4 (GHz) + 20 log 7.5 (km) dB
FSL= 92.4 + 7.60 + 17.50
FSL= 117.5 dB

EIRP= Transmitter output + Gain of the antenna – Transmitter branch loss

EIRP= 15 + 21 – 1 (assumed transmitter branching loss)

EIRP= 35 dB

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain- atmospheric attenuation

Nominal received power = 35 dB –117.5 dB – 1 dB (assumed) +21 dBi - 0.75 dB (assume 0.1 dB per kilometer)

Nominal received power = 35 dB –117.5 dB – 1 dB +21 dBi - 0.75 dB

Nominal received power = -63.25 dB

Fade margin= Nominal received power – Receiver threshold value
Fade margin= -63.25 – (-80)

Fade margin= 16.75 dB

Fade margin of more than 15 dB between 2 hops is generally considered sufficient. However by changing the dimensions of the antenna we can improve the fade margin further. In our case, 60 cm dishes will do fine job.

HOW TO IMPROVE FADE MARGIN TO MORE THAN 20 dB FOR BETTER QUALITY?

Fade margin can be increased if EIRP is increased and EIRP depends on gain of the antenna. We need to increase the gain of antenna to increase the fade margin.
Microwave antennas usually have the efficiencies in the range between 50 and 60% and these efficiencies can be achieved by illuminating the face of the reflector.

The gain of the antenna is given by G (dBi) = 10 log $\eta\ (4\pi A_a/\lambda^2)$
η is the efficiency of the antenna aperture
A_a is the area of the antenna aperture
λ is the wavelength of the signal.

If efficiency is assumed to be 55%, the above formula can be given as

G (dBi) = 17.8+20 log (d.f) where'd' is the diameter of the dish in meters and 'f' is the frequency in GHz.

So to increase the gain we can either illuminate the entire parabolic face of the reflector but this would result in a very poor front to back ratio, so it is advisable to reduce the illumination area to have good front to back ratio.

FADE MARGIN OF OVER 20 dB

The other option to increase the gain is by selecting antenna with higher diameter. So if we increase the diameter of the dish from 60 cm to 90 cm, gain of the antenna will increase from 21 dBi to 24.5 dBi which would further improve the fade margin from 16.75 dB to 23.75 dB.

G (dBi) = 17.8+20 log (d.f)
By putting d=.90 meters and f= 2.4 GHz, G (dBi) = 24.5 dBi

EIRP= Transmitter output + Gain of the antenna – Transmitter branch loss
EIRP= 15 + 24.5 – 1 (assumed transmitter branching loss)

EIRP= 38.5 dB

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain- atmospheric attenuation

Nominal received power = 38.5 dB –117.5 dB – 1 dB (assumed) +24.5 dBi - 0.75 dB (assume 0.1 dB per kilometer)

Nominal received power = 38.5 dB –117.5 dB – 1 dB +24.5 dBi - 0.75 dB

Nominal received power = -56.25 dB

Fade margin= Nominal received power – Receiver threshold value
Fade margin= -56.25 – (-80)

Fade margin= 23.75 dB

FADE MARGIN OVER 25 dB
The other option to increase the gain is by selecting antenna with higher diameter. So if we increase the diameter of the dish from 60 cm to 120 cm, gain of the antenna will increase from 21 dBi to 27 dBi which would further improve the fade margin from 16.75 dB to 28.75 dB.

G (dBi) = 17.8+20 log (d.f)
By putting d=1.20 meters and f= 2.4 GHz, G (dBi) = 27 dBi

EIRP= Transmitter output + Gain of the antenna – Transmitter branch loss
EIRP= 15 + 27 – 1 (assumed transmitter branching loss)

EIRP= 41 dB

Nominal received power = EIRP –FSL – Receiver branch loss +receiver antenna gain- atmospheric attenuation

Nominal received power = 41 dB –117.5 dB – 1 dB (assumed) +27 dBi - 0.75 dB (assume 0.1 dB per kilometer)

Nominal received power = 41 dB –117.5 dB – 1 dB +27 dBi - 0.75 dB

Nominal received power = -51.25 dB

Fade margin= Nominal received power – Receiver threshold value
Fade margin= -51.25 – (-80)

Fade margin= 28.75 dB

18. CONCLUSIONS

The starting point of the link design is to decide what we expect from our link. This detailed planning should be implemented then to design radio link. Choice of equipments is also vital as we don't want our link establishment to exceed project cost, for that proper microwave equipments are required to be used. As we know microwave signal can fade from various climatic factors and terrain type so a thorough understanding of how microwave signal propagates and types of fading it is subjected to also give link designer valuable knowledge to design link. After this detailed planning is the selection of frequency band we will be using, in our case we are using ISM band so we don't have to take permission from government and after this, we need to consider other aspects such as what should be height of antennas, fade margin. To find the height of antennas we need to consider two values of effective earth radius, median k value and k (min) value. Once all these factors have been calculated we can test our link on field.

19. MICROWAVE RADIATION SAFETY

People still have this perception about microwaves that these are dangerous waves just like the way x- rays and gamma rays but it's not true. Microwaves fall under non ionized portion of EM spectrum as shown in fig 1.1. These waves don't have enough energy to ionize atoms and change the composition of the DNA. But the heating effect of microwave can affect humans adversely so it is advisable for microwave engineers to never look directly into horn feed antenna as our eyes have low blood circulation and thus cannot dissipate heat effectively like the other parts of body. So for these reasons limit has been set by FCC of 1 mW/cm^2. In case of microwave links we generally use directional antennas, but the output power is still in watts and this signal strength keep decreasing with distance, so after few miters of distance these microwaves are harmless to the humans. Microwaves are thus safe to use for communication purposes.

20. REFERENCES

1. Microwave radio transmission guide, 2nd edition By Trevor Manning.
2. http://www.ieeeghn.org/wiki/index.php/Microwave_Link_Networks
3. http://en.wikipedia.org/wiki/Plesiochronous_digital_hierarchy
4. http://www.ad-net.com.tw/index.php?id=419
5. http://www.omega.com/prodinfo/wirelesssensors.html
6. Digital signal processing: Fundamentals and Applications By Li Tan
7. http://labprograms.files.wordpress.com/2009/09/digital-companding.pdf
8. http://www.scnt01426.pwp.blueyonder.co.uk/Articles/Modulation/FSK.html
9. http://www.scribd.com/doc/68499700/5/FSK-Bit-Rate-Baud-and-Bandwidth

10. http://www.sqa.org.uk/e-learning/NetTechDC01DCD/page_19.htm
11. http://radiomobile.pe1mew.nl/?Calculations:Propagation_calculation:Fresnel_zones
12. http://webcache.googleusercontent.com/search?q=cache:NewmJ0F7iyMJ:www.extronics.com/media/100578/318642_08%2520extronics%2520rf%2520calculator%2520final.xls+antenna+height+to+clear+obstruction&cd=2&hl=en&ct=clnk&gl=ca
13. http://www.4gon.co.uk/solutions/technical_fresnel_zones.php
14. http://www.cisco.com/en/US/docs/wireless/technology/channel/deployment/guide/Channel.html
15. http://www.cplusplus.com/doc/tutorial/basic_io/

THANKS