JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY (JIT)
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

MICROWAVE LINK DESIGN BETWEEN JIMMA MAIN CAMPUS AND AGARO BRANCH

By

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A thesis submitted to the school of graduate studies of Jimma University in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering (Communication)

Advisor

Dr.-ing. Tofik Jemal

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DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been acknowledged.

All examiners' comments are duly incorporated.

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Signature

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Date of Submission: _________________

This thesis has been submitted for examination with my approval as a university advisor.

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ABSTRACT

Microwaves are widely used for point to point communications, because their small wavelength allows conveniently-sized antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna. This allows nearby microwave equipment to use the same frequencies without interfering with each other. Microwave links provide the bulk of the interconnectivity between sites in telecommunications networks, especially mobile voice and data networks, because they are rapidly deployable, relatively small and require fewer infrastructures out by than technologies such as optical fiber transmission.

The aim of the thesis was to provide microwave radio link operating at microwave frequencies Jimma main and Agaro campuses, with the minimum objective reliability 99.999%. The designed link depends on Geo context-profiler for path profile analysis, Feko suite 5.5 for rectangular waveguide design and link budget calculator. In the analysis there are some parameters, which are significant in design of microwave link establishment: free space loss calculation, path profile analysis, fades margin, frequency planning, attenuation, rain fading predictions, reflection point calculation, tower heights, Signal to Noise Ratio, Fresnel zone and link budget calculation. Fresnel zone clearance was considered at least at 60% of the first Fresnel zone. To achieve the performance of the link antennas are placed on a tower at sufficient to provide clear line of sight between the transmitter and receiver sites.

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ABBREVIATIONS

GHz	Giga Hertz
MHz	Mega Hertz
PTP	Point to Point
LOS	Line Of Sight
LO	Local Oscillation
Km/s	kilometer/s
RF	Radio Frequency
IF	Intermediate Frequency
IDU	Indoor Unit
ODU	Outdoor Unit
RSL	Receiver Signal Level
FSL	Free Space Loss
m/s	meter/s
C/N	Carrier to Noise ratio
ICT	Information Center Technology
ATG	Average Tree Growth
BPF	Bandwidth Pass Filter

ATS	Automatic Transfer Switch
ATPC	Automatic Transmit Power Control
Mbps	Mega bit per second
QAM	Quadrature Amplitude Modulation
Erfc	Error function
SNR	Signal to Noise Ration
RF	Radio Frequency
dBm	decibel in mil
EIRP	Effective Isotropic Radiated Power
ITU	International Telecommunication Union
ETSI	European Telecommunication Standard Institute
BER	Bit Error Rate
FCC	Federal Communications Commission
XPD	Cross-Polar Discrimination
VSWR	Voltage Standing Wave Ratio
VCO	Voltage Controlled Oscillator
TWT	Travelling Wave Tube
RRC	Root Raised Cosine
FIR	Finite Impulse Radio
AWGN	Additive white Gaussian Noise

CHAPTER ONE
INTRODUCTION

1.1. Background

Microwaves describes the contemporary current signals between 300 MHz to 300GHz frequency ranges, microwaves have a resultant wavelength among 1m and 1mm respectively. Microwave communication is a cost-effective, can be rapidly installed, can cross complicated terrains, and efficient means to connect two or more wireless points together over a variety of terrains and space, where continuous runs of cable or fiber type transmission lines would not be practical or even possible.

The point to point microwave communication describes that transmission take place among two and provides dedicated point to point connectivity using directional antennas. PTP links typically require clear line of sight between the transmitting antennas and uses a beam of radio waves in the microwave frequency to transmit audio and data between two locations.

In order to design point to point microwave link system, there are several technical choices that we considered for instances the microwave LOS link, the link budget, free space path loss on the link analysis. Performance of short hop length Microwave links is mostly affected by rain that can cause an outage of energy.

A microwave link fundamentally consists of a transmitter and a receiver. The transmitter and receiver are each connected to an antenna. This is typically a parabolic dish or horn antenna connected to the transmitter and also typically to the receiver. The receiver always needs to be typically with the range of kilometers of the transmitter, but the distance is very much dependent on the path contour between the transmitter and receiver.

There are five sections in this thesis. First section is an introduction of microwave communication; succeeding section; Over review of microwave link, fundamental parameters of the link. The last three sections relate the methodology, design steps requirements, results and analysis, conclusion, and future works.

1.2. Objectives

General objective

The aim of the thesis is to design point to point microwave link access between Jimma main to Agaro branch campuses. The planning of a link must take into account cost, equipment availability, and Line of sight propagation availability. A microwave radio communications link is to identify it as an economic and practical means of bridging awkward terrain, in planning of link was to design the radio path in such a way that losses of visibility rare events. A Microwave link design methods; frequency planning, link budget, Rain fading, fade margin, outages and availability calculations.

Specific objective

- To analysis and find out; sites location, path profile analysis, tower heights, rain fading, and reflection point substantiation, clearance verification
- To plan the frequencies of the link depending on the hop length, rain fading
- To design root raised cosine filter for the transmitter and receiver pulse shaping filter
- To design horn antenna at 8.5GHz and 10.7GHz frequencies
- To list the equipments products specifications

1.3. Microwave communication systems

1.3.1. Transmitter

In a microwave link the transmitter produces a microwave signal that carries the information to be communicated. Main functions of transmitter are as follows:

- Generate proper LO within the RF band.
- Use the local oscillation signal from the local oscillator to convert the adjusted IF signal from the adjuster to the required frequency in transmitting.
- Achieve amplification of linear RF
- In the branching system, the local carrier is combined with other carriers together and sent to the antenna.

Indoor Unit: An Indoor Unit is typically mounted in an indoor location or weatherproof shelter connected via a coaxial cable or waveguide to the ODU. IDU performs the functions of service access, service scheduling, multiplexing and modulation and demodulation.

Microwave Outdoor Unit: The term ODU is used in Split-Mount Microwave systems where an Indoor Unit is typically mounted in an indoor location or weatherproof shelter connected via a coaxial cable or waveguides to the ODU which is mounted on the top of a tower either directly connected to a microwave antenna or connected to it through a wave guide [1].

Generally, Microwave ODUs designed for full duplex operation, with separate signals for transmit and receive. On the airside interface this corresponds to a "pair" of frequencies, one for transmit, the other for receive.

ODU Power and data signals: The ODU receives its power and the data signals from the IDU through a single waveguide. ODU parameters are configured and monitored through the IDU. The power, transmit signal, receive signal and some command/control telemetry signals are all combined. This use of a single cable is to reduce cost and time of installation. The most common is 1+0 which has a single ODU, generally connected directly to the microwave antenna. 1+0 means "unprotected" in that there is no resilience or backup equipment or path.

1.3.2. Transmission lines

The second integral part of a microwave link is a transmission line. This line carries the signal from the transmitter to the antenna and, at the receiving end of the link, from the antenna to the receiver. Feeder system consists of the feeder connecting branching system to antennas and the waveguide components. In microwave communication, channels share the same set of an antenna and feeder system. The branching system consists of circulator, branching filter, terminator and connection waveguide.

Currently, elliptical waveguide is commonly used, which has lower loss in certain length and is suitable for long feeders. Now, elliptical waveguide is widely used in frequency band ranging from 4 GHz to 15 GHz as the feeder for it makes the layout and installation of the feeders easier.

1.3.3. Antenna

The third part of the microwave system is the antennas. The antenna is used to directionally radiate the microwave power emitted by the transmitter ODU and transmit the microwave power received to the receiver. ODU is used to convert IF and RF signals, process and amplify the RF signals. At the receiver site, an antenna pointed toward the transmitting station collects the signal energy and feeds it into the transmission line for processing by the receiver [2]

- **Horn antenna**

Horn antennas are used for receiving and transmitting RF signals. Horn antennas are simply elongated structure of rectangular waveguide. The waveguide structure is open out or flared, launching the signal towards to the receiving antenna. Since horn antenna used in very high frequency their applications is in microwave and radar communications. As shown in the figure1.3 below when A is the height and B is the width of the flared waveguide.

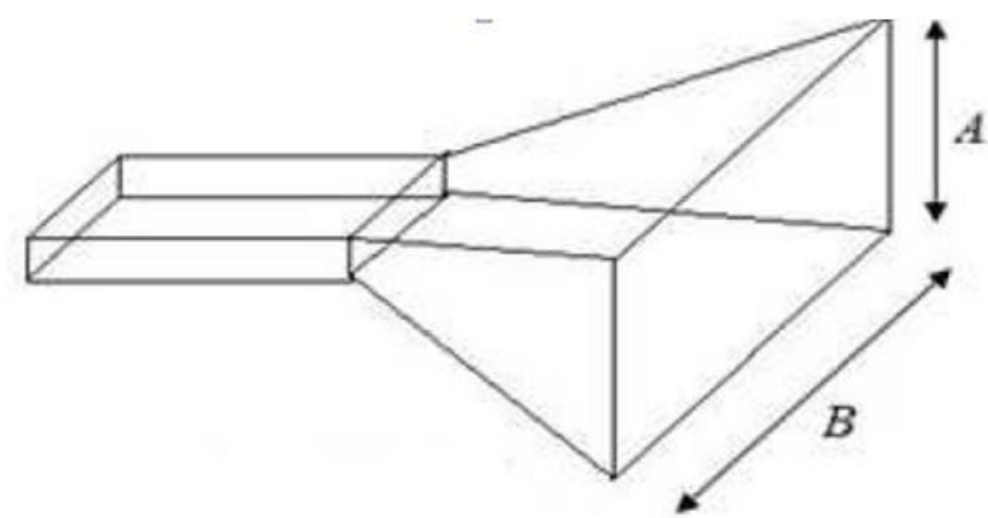

Figure 1.3: rectangular horn

Antenna gain: Gain is a major parameter of the antenna. When the size of the antenna is certain, the antenna gain directly reflects the efficiency of the antenna. The gain is the ratio of the input power of isotropic antenna to the input power of the surface antenna when the surface antenna and isotropic antenna produce the same electric field at the same place.

Polarization: Signals transmitted in any frequency band have a property termed polarization. Hence polarization describes the orientation of the electrical field radiated from the antenna.

Hop length: Between the link's antennas lies another vital element of the microwave link the path taken by the signal through the earth's atmosphere. A clear path is critical to the microwave link's success. Since microwaves travel in essentially straight lines, man-made obstacles that might block the signal must either be overcome by tall antenna structures or avoided altogether. Natural obstacles also exist. Flat terrain and water bodies can create undesirable reflections.

1.3.4. Receiver

At the end of the link is the final component, the receiver. Here, information from the microwave signal is extracted and made available in its original form. To accomplish this, the receiver must demodulate the signal to separate the information from the microwave energy that carries it. The receiver must be capable of detecting very small amounts of microwave energy, because the signal loses much of its strength on its journey [3].

1.3.5. Microwave repeaters

The microwave beam is transmitted along a straight line and it is incapable of diffraction when it encounters obstacles. Therefore, there should be no obstacles in the line-of-sight range between two communication points. Otherwise, a microwave repeater station should be added at the obstacle point or other suitable place to communicate the two communication points.

Microwave repeater station can be classified into two types: passive repeater station and active repeater station.

Active Repeaters

Active repeater site contains two complete microwave radio terminals, antennas, waveguides or coax cables, and other components. It requires an enclosure for the equipment, power plant, an antenna-mounting structure of some kind, and so on. Types of active repeaters are: IF, Baseband, and RF repeaters (appendix A).

- **RF to RF repeater:** Depending on the path profile and site selection analysis due to the mountain obstructions repeater is selected. With RF-to-RF repeaters, the received microwave signal is not down-converted to IF or base band; it is simply mixed with a local oscillator frequency in a nonlinear mixer. The output of the mixer is tuned to the difference between the incoming RF and the local oscillator frequency.

Passive Repeaters

They are also employed when the cost as compared with an active repeater is too high. A passive repeater is not only less expensive to build than an active repeater, but the operation cost is also substantially reduced. Passive repeaters have a major advantage over active repeaters from the ecology standpoint since it is not necessary to provide access roads and power line rights of way to the repeater site [4].

1.3.6. Automatic transfer switch

ATS must have the ability to be switched on and off to different sources that is the main power source. As well as transferring the load to the backup generator, an ATS may also command the backup generator to start, based on the voltage monitored on the primary supply. The transfer switch isolates the backup generator from the electric utility when the generator is on and providing temporary power.

The generator supplies power to the home's electric load, but are not connected to the electric utility lines. It is necessary to isolate the generator from the distribution system to protect the generator from overload in powering loads in the house and for safety, as utility workers expect the lines to be dead.

1.3.7. Automatic Transmit Power Control

ATPC is an electronic process for controlling the radio frequency transmission power at the transmitting site in dependence upon the received power level at the opposite site. This ensures that an increased transmission power or the maximum value of this power is only transmitted at times when the conditions for the microwave propagation can lead to problems.

Lightning protection: The potential for lightning damage to radio equipment should always be considered when planning a wireless link. The lightning protection that will be used must contain the appropriate conductive paths for lightning currents and be able to disperse atmospheric discharge in order to prevent surge current to enter the equipments and sustain safety in the facility.

1.4. Statement of the problem

Recently, the main focus of the computer center is shifted to the newly built campus-wide network of the university. From the conception to the implementation of the network infrastructure, the computer center has been eagerly participating in every activity. In fact, the network project was under the direct supervision of the computer center since the beginning. Apart from these activities the computer center is highly involved in developing specifications for purchase orders of computers and accessories and maintenance of equipments.

The strategic plan of the university states that the future academic and administrative tasks of the university highly depend on the effective utilization of ICT infrastructures and services campus-wise and broadly.

1.5. Scope and limitations of the study

The links from main campus to site A of transmitting terminals, and site B to the receiving terminals were intended to connect by optical fiber. Repeater at Yebu is 13.8 km from site A and 19 km distances from site B. The design is limited to by the geocontex-profiler for path profile analysis and determination of tower heights,Feko suite 5.5 for antenna feed design. The path round walk is conducted to verify the line of sight clearance, assess the reflective potential surfaces; such as flat terrain, and water bodies and manmade obstructions. The type of soil would not be taken into consideration because of the inavailability of measuring instruments.

CHAPTER TWO
OVER REVIEW OF MICROWAVE LINK

2.1. Microwave Link

Generally a microwave link means a beam of radio wave in microwave frequency range enabling a transmitter and receiver to communicate. Different forms of microwave link applications are available in modern communication system. Broadcasters use microwave links to send programs from the studio to the transmitter location, which might be miles away. Microwave link is the backbone in latest telecommunication system which makes our life easier. Most of the telecommunication companies communicate between their switching centers through this link although recently it is done by fiber optic cables as well. Many government and private organization use this technology to link up their corporate offices for easy and fast access to the main server. One of the reasons for the adaptability of microwave links is because they are broadband; meaning they can transfer large amount of information at high speeds. Another important quality of microwave links is that they require no equipment or facilities between the two terminal points. Often a repeater station is installed if the clear LOS in not available.

Installing a microwave link is often faster and less costly than a wired connection. Finally, they can be used anywhere as long as the distance to be spanned is within the operating range of the equipment and there is clear path between the locations. Microwave link is seldom interrupted by rain, fog, and snow; though in harsh weather conditions, it can be disrupted at some instants [5].

2.2. Emergence of Microwave Communication

With the 21st century, it can be said that the world has closer means. In this age we can talk, chat, meet, and greet people and our friends from every part and corner of the world within a click. The click can be over the cell phone for having a talk or over the keyboard or mouse of a computer to have an online chat with our near and dear ones. It is possible only because of the technology called microwave communication. Internet usage in modern life is very essential job and with it even the remotest of areas are connected.

Security systems are also advancing with the help of Microwave link. Satellite communication, data communication, bio-medical engineering and cellular networks are the main domains for Microwave communication. Due to following advantages microwave communication is emerging day by day [11].

- Large bandwidth
- Line of sight propagation
- Antenna size reduction
- Can accommodate large number of channels
- Less Power requirement especially in case of repeaters
- Environmentally Stable

2.3. Fundamental Parameters in microwave Link

2.3.1. Line of Sight

For any point-to-point radio communication; the general setup requires Microwave antennas to be placed in a high position so that there are no obstacles in between. This direct link is usually referred as LOS. It is very important to find out a visible path between sites before establishing those links. Moreover only seeing a visible path does not always confirm that LOS will give a sufficient level of signal, it should satisfy other parameter such as the terrain for wave propagation. Figure 2.1 shows a LOS where one microwave antenna has a direct link to another antenna placed at far end.

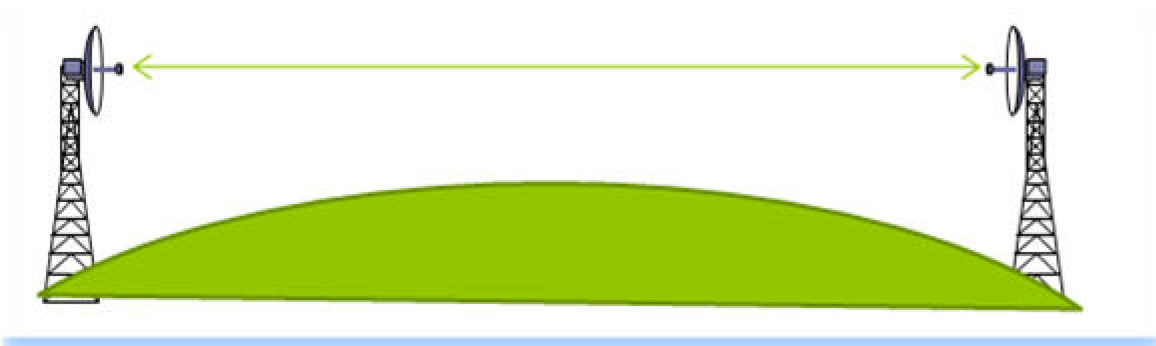

Figure 2.3: Atypical line of sight microwave link

2.3.2. Free Space Loss

Signal power is diminished by geometric spreading of the wave front. The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes. The FSL calculations only look at the loss of the path only and do not contain any factors relating to the transmitter power, antenna gains or receiver sensitivity level. These factors are normally addressed when designing a link budget and are used within radio and wireless survey tools.

$$FSL = 92.4 + 20 \log f + 20 \log D$$

Where f=frequency in GHz, D =distance is given in km, FSL=free-space loss dB

2.3.3. Fresnel Zone

The First Fresnel Zone is an ellipsoid-shaped volume around the line of sight path between transmitter and receiver. The Fresnel Zone is important to the integrity of the RF link because it defines a volume around the LOS that must be clear of any obstacle for the maximum power to reach the receiving antenna.

Objects in the Fresnel Zone as trees, hilltops and buildings can considerably attenuate the received signal, even when there is an unobstructed line between the Transmitter and receiver. For a line of sight; the main beam has to be clear at least 60% of the first Fresnel Zone was considered.

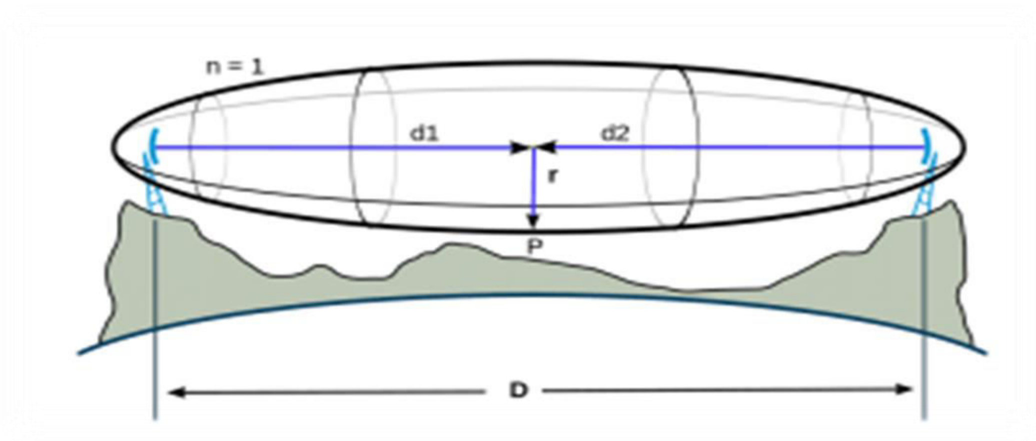

Figure 2.4: first Fresnel Zone of microwave link

The radius of the first Fresnel Zone at a given point between the transmitter and the receiver can be calculated as:

$$r=17.3\times\sqrt{\frac{d1\times d2}{f\times D}}$$

Where r is the radius of the Zone in meters, d1and d2 are distances from the obstacle to the link end points in meters and D is the hop distance in km and f is the frequency in GHz.

2.3.4. Earth bulge

Earth bulge describes the effect of physical earth curvature along a direct path between two points on the earth's surface. The earth surface appears to bulge upwards in the path, with the peak of the bulge occurring at mid-path as shown below figure. This assumes that the earth's surface is flat, with no topological variation along the path between the two points. In radio path profiling, the effects of physical Earth bulge must be added to the terrain profile.

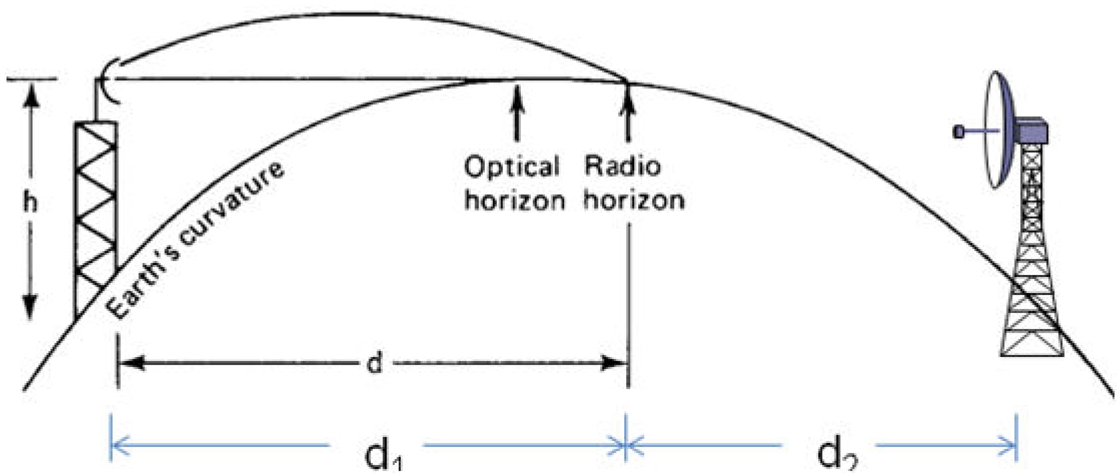

Figure 2.5: Earth bulge and Curvature

Effective Earth Bulge: Effective earth bulge represents the effects of atmospheric refraction, or K, combined with physical earth bulge.

$$h=\frac{d1\times d2}{12.75\times k}$$

where h=distance in ms and d1,d2 in kms

The K-Curve: A numerical figure that considers the non-ideal condition of the atmosphere refraction that causes the ray beam to be bent toward the earth or away from the earth .

K=$\frac{EffectiveEarthRadius}{TrueEarthRadius}=\frac{re}{r0}$, where, r_0=6370 km

Effective Earth radius

$$re=\frac{r0}{1-0.04665e^{0.005577Ns}}$$

Where

N_S = Surface Refractivity (300)

r_0 = True earth radius (6370km)

r_e = Effective earth radius

K –curve *conditions*:

- When K=1, there is no refractive effect, and the signal path is a straight line.
- When K < 1, the microwave beam is bent away from the Earth (sub-standard conditions)
- When K =4/3 , the fictitious earth radius appears to the microwave beams to be longer than the true earth radius (Standard Condition)
- When K > 4/3, this condition results in an effective flattening of the equivalent earth's curvature (Super-standard Condition)
- When K= ∞, This condition results to zero curvature (as if the earth is flat) and the microwave beam follows the curvature of the earth.

CHAPTER THREE
METHODOLOGY

3.1. Design methods

The process is iterative and goes through many redesign phases before the required quality and availability are achieved. As shown fig.3.1 below, a preliminary fade margin is a result of the loss/attenuation calculations and is used for preliminary fade predictions in the fading calculation. If interference is present in the frequency-planning calculation, then the threshold degradation is included in the fade margin. The updated fade margin would become the effective fade margin used in the fading predictions that would form the necessary input to the quality and availability calculations [6].

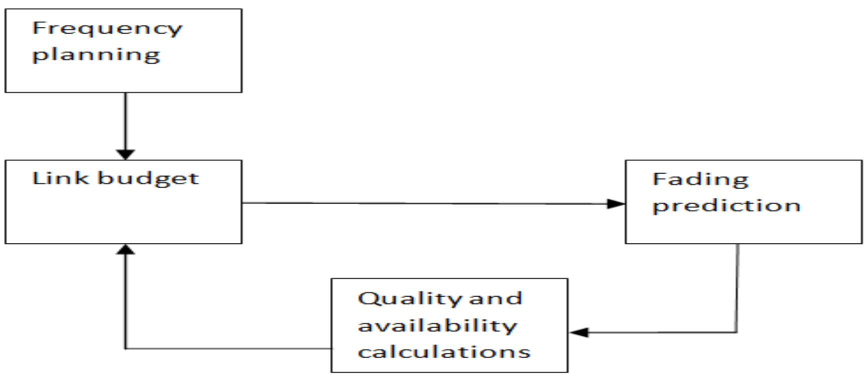

Figure 3.1: Microwave link design development

3.1.1. Frequency planning

Microwave links of short distances are generally allocated with higher frequencies and it is good to have short distances in these cases. While for long hop distances or so we use lower frequencies. Since Microwave frequencies have short wavelengths, they generally require a LOS propagation path [7].

3.1.2. Link Budget

The performance of any communication link depends on the quality of the equipment being used. Link budget is a way of quantifying the link performance. The received power in the figure 3.2 below is determined by three factors: transmit power, transmitting antenna gain, and receiving antenna gain.

If the power, minus the free space loss of the link path, is greater than the minimum received signal level of the receiving radio, then the link is possible.

The difference between the minimum received signal level and the actual received power is the link margin. The link margin must be positive, and should be maximized.

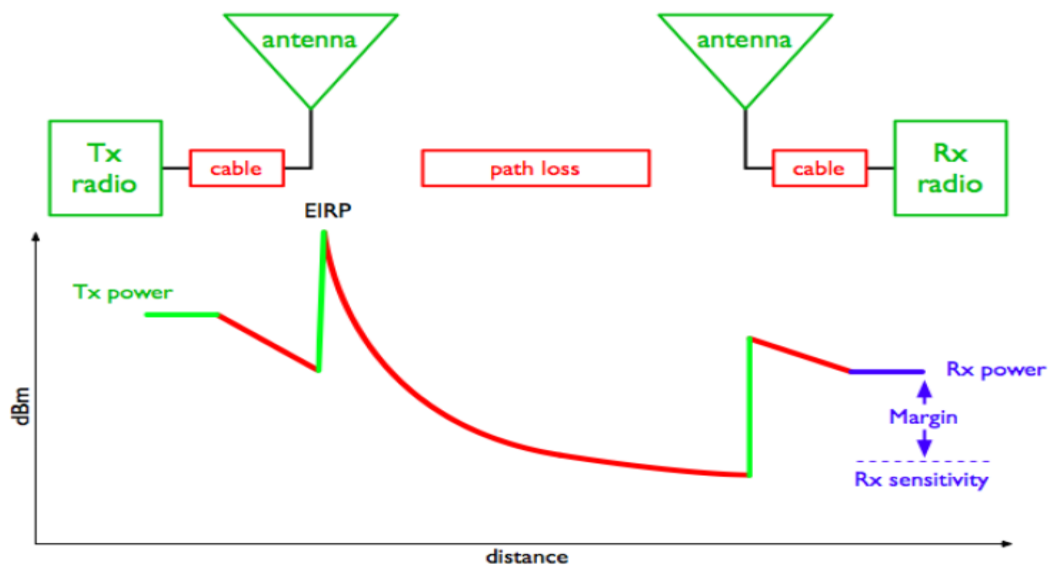

Figure 3.2: Power in a link system

3.1.3. Rain Fading:

Rain attenuation is one of the series issues in microwave links. Rain attenuation increases with increase Hop length and the frequency. Frequency spectrum above 10 GHz is affected by rain attenuation. Information that has to be transmitted has to be within one channel bandwidth, irrespective of the data rate.

Jimma is a weather condition of precipitation 59%, humidity 63%, temperature 23degree centigrade, wind 3km/hr and light thunderstorm and rain.

3.1.4. Gas Absorption

A major difference in propagation through the real atmosphere versus free space is that there is air present. The two absorption peaks present in the frequency range of commercial radio links are located around 23 GHz, water molecules and 60 GHz, oxygen molecules.

3.1.5. Vapor Density

This variable reflects the humidity of the atmosphere in which the link is deployed. An average value of 7.5 is the default, though the table below reflects some other typical conditions from which to choose.

Table 3.1: Vapor density at different temperature

Vapor Density	Surface Temperature	Surface Relative Humidity
0	7	0.000
3	11	0.300
7.5	15	0.584
10	19	0.612
13	23	0.631
15	27	0.581
17	31	0.530
21	35	0.529

3.1.6. Loss caused by Knife-edge Obstacles

Loss caused by the knife-edge obstacles is additional loss. When the peak of obstacles just falls down on the link between the transmitting and receiving points where the height of obstacle is almost equal to radius of the Fresnel zone is 6dB losses and where the peak of obstacles surpasses the link between two points, the loss may rapidly increases up to 20dB.

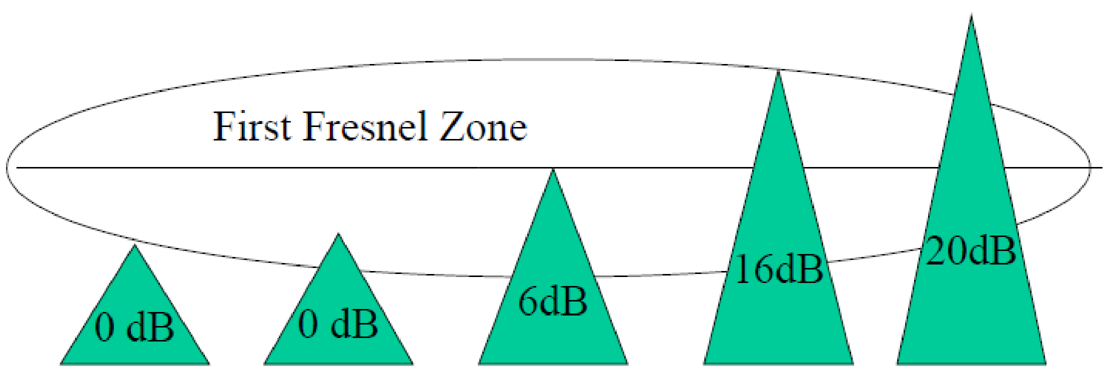

Figure 3.3: knife edge losses

3.1.7. Ground Reflection

Due to different terrain conditions, different relay sections have different influence on microwaves. Major influences are reflections, diffraction and ground scattering. For ground scattering has little on the main waves, it can be ignored. The influence of reflection is that the ground can reflect some of the signals from the antenna to the receiving antenna .i.e. water surface and smooth ground have strong influence of reflection, which interference the direct waves. Changing the antenna heights can move the location of the reflection point. The formulas for getting the reflection point:

$X = \frac{h1}{D^2}$, $Y = \frac{h2}{D^2}$

Where h1=first antenna height, h2=second antenna height, D=distance of the first site to the second site

$$\eta = \frac{1}{1 + \sqrt{\frac{Y}{X}}}$$

Where d1=η D, d2=D-d1, η =reflection point, D1 and d2 are distance of the site from the reflection point.

3.1.8. Fade Margins

Determining sufficient fade margin is the most important step in microwave link design. If the margin is too small, the link will be unstable – as a result, sufficient availability of the link or quality of the provided services cannot be guaranteed [8]. Equation considers the non-ideal and less predictable characteristics of radio wave propagation.

Fade margin using Barnett-Vienna Equation;

FM = 30 log D + 10 log (6ABf) – 10 log (1 –R) – 70

Where RSL=Receiver Sensitivity Level, FM=Fade Margin, 30 log D = multi-path effect,
10 log (6ABf) = terrain sensitivity as shown table 3.1 below, 10 log (1 –R) = reliability objectiveness.

Table 3.2: A and B values

A values	Land formation	B values	Climatic conditions
4	smooth terrain, over water, or flat desert	0.5	Hot humid areas
1	Average terrain	0.25	average inland areas, normal temperature areas or sub-arctic areas
0.25	mountains, very rough, very dry terrain	0.125	Mountainous or very dry but non reflective areas

CHAPTER FOUR
MICROWAVE LINK DESIGN PROCESSES

4.0. Design procedure

To reach the stage where a radio link can be deployed and brought into service, several steps must be successfully completed, often in an iterative process, leading to final link design.

The LOS distance between the campuses is 32.8km and by road 46km as shown in the Fig.4.0 below indicate the sites distance between Jimma and Agaro by the road and LOS.

Figure 4.0: a) distance by road b) distance by direct path

4.1. Site selection

Selection of a suitable microwave radio site encompasses a number of issues. The following factors should be considered: Geographical location, for possible line of sight path obstruction, the possibility of future building construction along the path, the relationship of the site to any commercial, military or private airport within several kilometers.

4.1.1. Site A

Site A is located at Jimma University, main campus 110m from main distributor. Its exact location is at 07°41’03.9”N latitude and 036°51’11.6”Elongitude. It has an elevation of 1769 meters above sea level as shown figure 4.2 below. Any vehicle via two-way lane of a distance can reach the site 10 meters from the main road. Actually, the proposed site was near to the ICT center and power lines.

Figure 4.1: Site A location

As described previous from the main ICT to the site A I have decided to connect by fiber optics due to its less losses and capable of high speed data transfer.

4.1.2. Repeater site

Repeater is located at Yebu town, 13.8kilometers from site A. Its exact location is at 07°44’42.4”N Latitude and 036°44’39.4”E longitude, and at an elevation of 2098 meters above sea level, and 100 and 400meters from small and main roads respectively as shown figure 4.3. The site is 200 meters away from the commercial power line.

Actually, the selected site was mountainous and surrounded by corns and tree fields. There is no airport within site and a round, no high structures that may cause potential obstruction of signal.

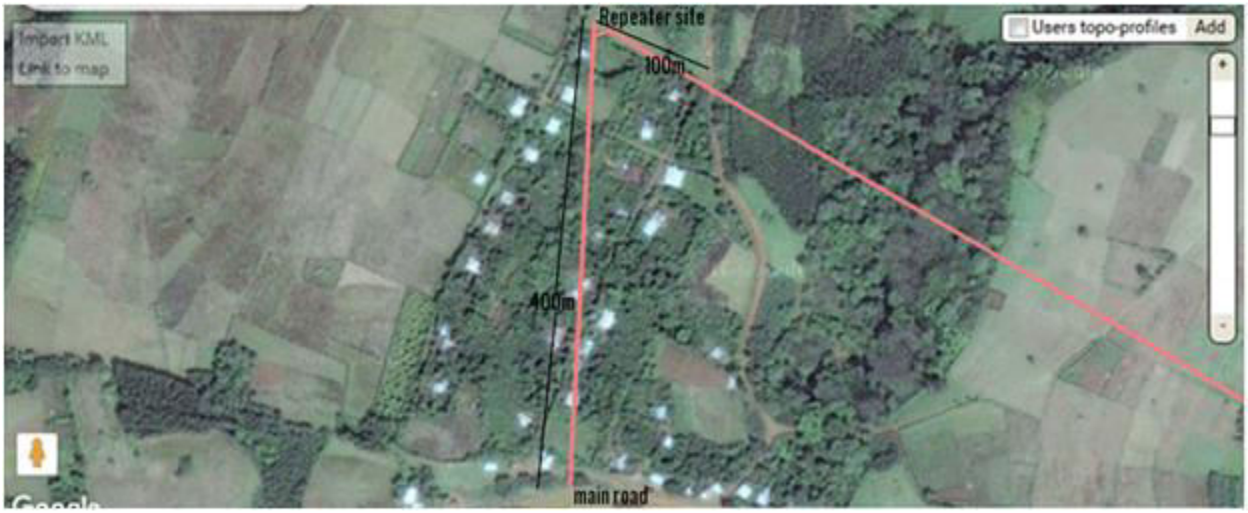

Figure 4.2: Repeater site

4.1.3. SITE B

Site B is located at Agaro town, campus under constructions. Its exact location is at 07°51’23.8”N Latitude and 036°36’50.6”E Longitude and 19 kilometers long from repeater site. It has an elevation of 1628 meters above sea level as shown in figure 4.4. A vehicle can reach the site, and 400meters from the main road. The site is 200 meters away from the commercial power line. Actually, the selected location is mountainous and future building construction could not reach.

Figure 4.3: Site B

4.2. Path profile analysis

The path profile used to determine the height of the towers at of the link, and ensure free of obstructions, such as hills, trees, and not subject to the propagation losses from the radio phenomena. Elevation profile is generated from the geo-context profiler for that particular LOS path between sites. Both site A to repeater site and site B path profiles were analyzed.

Site A to repeater site

Path profile was considered by 107meters and 92 centimeters from each following obstruction where considerations took place. Computation for table 4.1 below;

- Earth Curvature (Eb) = $\frac{d1d2}{12.75k}$ where k = $\frac{4}{3}$, tree height + ATG=15.24 meters
- First Fresnel Zone (F1) = 17.3 x $\sqrt{\frac{d1d2}{freqxtotaldistance}}$, f=10.7GHz, D=13.8 km
- Total Extended Height = elevation + earth curvature + F1 + Tree Height plus ATG

Table 4.1: Path profile from site A to repeater

obstacle	Differences of d1s' (km)	Dist. From Tx.d1(km)	Dist. from - Rx.d2 (km)	elevation (m)	Earth curvature (eb) (m)	first fresnel clearance F1(m)	tree height +ATG(m)	total extended height (m)
1	0	0	13.8	1768.79236	0	0	15.24	1784.03236
2	0.10792	0.10792	13.6920799	1760.11243	0.086920625	1.730615356	15.24	1777.169963
3	0.10792	0.2158402	13.5841598	1753.3988	0.172471045	2.437795266	15.24	1771.24907
4	0.10792	0.3237603	13.4762397	1751.30896	0.256651259	2.973793662	15.24	1769.779405
5	0.10792	0.4316804	13.3683196	1747.69873	0.339461268	3.420064103	15.24	1766.698256
6	0.10792	0.5396005	13.2603995	1744.36584	0.420901071	3.808282412	15.24	1763.835028
7	0.10792	0.6475206	13.1524794	1742.13306	0.500970668	4.154753678	15.24	1762.028781
8	0.10792	0.7554407	13.0445593	1739.54321	0.579670088	4.469197809	15.24	1759.832081
9	0.10792	0.8633608	12.9366392	1738.71277	0.656999274	4.757968653	15.24	1759.367736
10	0.10792	0.9712809	12.8287191	1741.79041	0.732958225	5.02549382	15.24	1762.788857
11	0.10792	1.0792011	12.720799	1744.42957	0.807547034	5.275007058	15.24	1765.75212
12	0.10792	1.1871212	12.6128788	1744.99927	0.880765609	5.508956031	15.24	1766.628989
13	0.10792	1.2950413	12.5049587	1748.23499	0.952613972	5.729247782	15.24	1770.156847
14	0.10792	1.4029614	12.3970386	1746.67126	1.023092135	5.93740269	15.24	1768.871759
15	0.10792	1.5108815	12.2891185	1741.32886	1.092200086	6.134656287	15.24	1763.795714
16	0.10792	1.618802	12.1811984	1736.96472	1.159937838	6.322029087	15.24	1759.686689
17	0.10792	1.726722	12.0732783	1737.26025	1.226305378	6.500375551	15.24	1760.226935
18	0.10792	1.834642	11.9653582	1739.71533	1.291302718	6.67041976	15.24	1762.917055
19	0.10792	1.942562	11.8574381	1736.85083	1.354929846	6.832781555	15.24	1760.278541
20	0.10792	2.050482	11.749518	1735.91699	1.417186775	6.987996474	15.24	1759.562175
21	0.10792	2.158402	11.6415979	1737.7948	1.478073491	7.136530823	15.24	1761.649404
22	0.10792	2.266322	11.5336778	1734.62891	1.537590008	7.278793622	15.24	1758.68529
23	0.10792	2.374242	11.4257577	1734.42627	1.595736314	7.41514582	15.24	1758.677152
24	0.10792	2.482162	11.3178376	1739.57874	1.652512419	7.545907857	15.24	1764.017156
25	0.10792	2.590083	11.2099175	1748.84094	1.707918313	7.671365576	15.24	1773.460226
26	0.10792	2.698003	11.1019974	1760.62097	1.761954006	7.791775222	15.24	1785.414701
27	0.10792	2.805923	10.9940773	1757.66357	1.814619489	7.907367387	15.24	1782.625561
28	0.10792	2.913843	10.8861572	1743.99072	1.86591477	8.01835044	15.24	1769.114988
29	0.10792	3.021763	10.7782371	1760.6814	1.915839842	8.124913238	15.24	1785.96215
30	0.10792	3.129683	10.670317	1747.10071	1.964394712	8.227227562	15.24	1772.53233
31	0.10792	3.237603	10.5623969	1760.6814	2.011579371	8.325450029	15.24	1786.258426
32	0.10792	3.345523	10.4544767	1769.55786	2.05739383	8.41972386	15.24	1795.274979
33	0.10792	3.453443	10.3465566	1773.26709	2.101838078	8.510180267	15.24	1799.119108
34	0.10792	3.561363	10.2386365	1776.13818	2.144912125	8.596939766	15.24	1802.120035
35	0.10792	3.669284	10.1307164	1778.12793	2.186615962	8.680113196	15.24	1804.234659
36	0.10792	3.777204	10.0227963	1779.74146	2.226949597	8.759802721	15.24	1805.968207
37	0.10792	3.885124	9.91487621	1790.62512	2.265913026	8.836102595	15.24	1816.967138

38	0.10792	3.993044	9.80695611	1790.59314	2.303506246	8.9090999	15.24	1817.045746
39	0.10792	4.100964	9.69903601	1782.854	2.33972926	8.978875193	15.24	1809.412608
40	0.10792	4.208884	9.5911159	1774.12256	2.374582071	9.045503042	15.24	1800.782644
41	0.10792	4.316804	9.48319579	1777.9574	2.408064677	9.109052506	15.24	1804.714515
42	0.10792	4.424724	9.37527569	1793.49207	2.440177074	9.169587583	15.24	1820.34183
43	0.10792	4.532644	9.26735558	1798.82275	2.470919268	9.227167614	15.24	1825.760841
44	0.10792	4.640565	9.15943548	1798.09973	2.500291254	9.281847583	15.24	1825.12187
45	0.10792	4.748485	9.05151537	1797.01379	2.528293036	9.333678468	15.24	1824.115765
46	0.10792	4.856405	8.94359527	1806.61902	2.55492461	9.382707477	15.24	1833.796651
47	0.10792	4.964325	8.83567516	1814.59961	2.580185981	9.428978325	15.24	1841.848774
48	0.10792	5.072245	8.72775506	1818.29456	2.604077144	9.472531423	15.24	1845.611164
49	0.10792	5.180165	8.61983495	1817.65918	2.626598103	9.513404106	15.24	1845.039182
50	0.10792	5.288085	8.51191485	1821.17761	2.647748854	9.551630775	15.24	1848.616992
51	0.10792	5.396005	8.40399474	1827.04553	2.667529401	9.587243088	15.24	1854.540305
52	0.10792	5.503925	8.29607464	1831.90796	2.685939741	9.620270073	15.24	1859.454169
53	0.10792	5.611846	8.18815453	1835.97791	2.702979877	9.650738279	15.24	1863.571623
54	0.10792	5.719765	8.08023443	1843.35754	2.718649805	9.678671864	15.24	1870.994866
55	0.10792	5.827686	7.97231432	1858.45984	2.732949529	9.704092721	15.24	1886.136881
56	0.10792	5.935606	7.86439422	1869.41968	2.745879046	9.727020547	15.24	1897.132577
57	0.10792	6.043526	7.75647411	1871.12219	2.757438359	9.747472939	15.24	1898.867104
58	0.10792	6.151446	7.64855401	1859.70093	2.767627464	9.765465445	15.24	1887.474021
59	0.10792	6.259366	7.5406339	1850.63403	2.776446365	9.781011644	15.24	1878.431491
60	0.10792	6.367286	7.4327138	1858.73083	2.783895059	9.794123182	15.24	1886.548853
61	0.10792	6.475206	7.32479369	1868.84583	2.789973548	9.804809829	15.24	1896.680609
62	0.10792	6.583126	7.21687359	1869.1355	2.794681831	9.813079506	15.24	1896.983259
63	0.10792	6.691046	7.10895348	1860.62158	2.798019908	9.81893832	15.24	1888.47854
64	0.10792	6.798967	7.00103338	1845.25659	2.79998778	9.822390585	15.24	1873.11897
65	0.10792	6.906887	6.89311327	1831.80762	2.800585445	9.823438838	15.24	1859.671641
66	0.10792	7.014807	6.78519317	1844.39709	2.799812905	9.822083849	15.24	1872.258991
67	0.10792	7.122727	6.6772731	1871.28516	2.79767016	9.818324625	15.24	1899.141151
68	0.10792	7.230647	6.569353	1891.39075	2.794157209	9.8121584	15.24	1919.237063
69	0.10792	7.338567	6.461433	1900.20337	2.789274058	9.803580642	15.24	1928.036224
70	0.10792	7.446487	6.353513	1910.94995	2.783020703	9.79258501	15.24	1938.765557
71	0.10792	7.554407	6.245593	1920.78357	2.775397146	9.779163346	15.24	1948.57813
72	0.10792	7.662327	6.137673	1929.01721	2.766403385	9.763305648	15.24	1956.786921
73	0.107921	7.770248	6.029752	1934.76233	2.756039319	9.74499984	15.24	1962.503368
74	0.10792	7.878168	5.921832	1929.28235	2.744305139	9.724232438	15.24	1956.990886
75	0.10792	7.986088	5.813912	1914.48914	2.731200756	9.700987473	15.24	1942.161324
76	0.10792	8.094008	5.705992	1909.56494	2.71672617	9.675247089	15.24	1937.196915
77	0.10792	8.201928	5.598072	1910.52307	2.700881381	9.64699131	15.24	1938.110944
78	0.10792	8.309848	5.490152	1910.23132	2.683666389	9.616197962	15.24	1937.771188

79	0.10792	8.417768	5.382232	1918.84094	2.665081194	9.582842585	15.24	1946.328866
80	0.10792	8.525688	5.274312	1929.63269	2.645125796	9.546898322	15.24	1957.064715
81	0.10792	8.633608	5.166392	1939.75427	2.623800194	9.508335815	15.24	1967.126408
82	0.10792	8.741529	5.058471	1948.97827	2.601104173	9.467122674	15.24	1976.286498
83	0.10792	8.849449	4.950551	1951.36243	2.577038153	9.42322489	15.24	1978.60269
84	0.10792	8.957369	4.842631	1957.60547	2.551601929	9.376604384	15.24	1984.773675
85	0.10792	9.065289	4.734711	1968.62366	2.524795503	9.327220327	15.24	1995.715673
86	0.10792	9.173209	4.626791	1978.23816	2.496618873	9.275028577	15.24	2005.249807
87	0.10792	9.281129	4.518871	1968.87817	2.46707204	9.219981454	15.24	1995.805227
88	0.10792	9.389049	4.410951	1947.65259	2.436155004	9.162027491	15.24	1974.49077
89	0.10792	9.496969	4.303031	1943.11536	2.403867765	9.101111157	15.24	1969.860335
90	0.10792	9.604889	4.195111	1949.6167	2.370210323	9.037172549	15.24	1976.264082
91	0.10792	9.71281	4.0871905	1961.32458	2.335182513	8.97014672	15.24	1987.869914
92	0.10792	9.82073	3.97927	1975.79565	2.298784486	8.899964218	15.24	2002.234403
93	0.10792	9.92865	3.87135	1996.81702	2.261016422	8.82655009	15.24	2023.144583
94	0.10792	10.03657	3.76343	2008.7644	2.221878155	8.749822669	15.24	2034.976105
95	0.10792	10.14449	3.65551	2009.62573	2.181369685	8.669693985	15.24	2035.716796
96	0.10792	10.25241	3.54759	2011.61462	2.139491011	8.586068814	15.24	2037.580184
97	0.10792	10.36033	3.43967	2018.21912	2.096242135	8.498843945	15.24	2044.054202
98	0.10792	10.46825	3.33175	2023.68018	2.051623055	8.407907346	15.24	2049.379706
99	0.10792	10.57617	3.22383	2029.31055	2.005633772	8.313137212	15.24	2054.869318
100	0.10792	10.68409	3.11591	2037.18835	1.958274287	8.21440086	15.24	2062.60103*
101	0.10792	10.79201	3.00799	2032.44812	1.909544598	8.111553458	15.24	2057.709218
102	0.10792	10.89993	2.90007	2024.44568	1.859444706	8.004436541	15.24	2049.54956
103	0.10792	11.00785	2.79215	2031.89514	1.80797461	7.892876282	15.24	2056.835992
104	0.10792	11.115771	2.684229	2036.73901	1.755133816	7.776680359	15.24	2061.510828**
105	0.10792	11.223691	2.576309	2032.60071	1.700923302	7.6556399	15.24	2057.197271
106	0.10792	11.331611	2.468389	2017.91284	1.645342585	7.529520169	15.24	2042.327705
107	0.10792	11.439531	2.360469	2000.27209	1.588391665	7.398061401	15.24	2024.498548
108	0.10792	11.547451	2.252549	2001.63184	1.530070541	7.260973615	15.24	2025.66288
109	0.10792	11.655371	2.144629	2017.64514	1.470379215	7.117931582	15.24	2041.473452
110	0.107919	11.76329	2.03671	2023.57703	1.409318257	6.968570063	15.24	2047.194915
111	0.107922	11.871212	1.928788	2024.66541	1.346885368	6.812467591	15.24	2048.064758
112	0.10792	11.979132	1.820868	2027.20557	1.283083419	6.649156855	15.24	2050.377807
113	0.10792	12.087052	1.712948	2035.26917	1.217911268	6.478089681	15.24	2058.205166
114	0.10792	12.194972	1.605028	2040.9165	1.151368913	6.29863412	15.24	2063.606507
115	0.10792	12.302892	1.497108	2038.08252	1.083456355	6.110051101	15.24	2060.516027
116	0.10792	12.410812	1.389188	2042.39429	1.014173594	5.911467158	15.24	2064.559928
117	0.10792	12.518732	1.281268	2046.85059	0.94352063	5.701837448	15.24	2068.735944
118	0.10792	12.626652	1.173348	2033.60425	0.871497463	5.479894474	15.24	2055.19564
119	0.107918	12.73457	1.06543	2037.77856	0.798105466	5.244079588	15.24	2059.06075

120	0.10792	12.84249	0.95751	2054.71094	0.723341918	4.992418092	15.24	2075.666698
121	0.107923	12.950413	0.849587	2040.00903	0.647206031	4.722374332	15.24	2060.618614
122	0.10792	13.058333	0.741667	2030.22461	0.569702039	4.430604851	15.24	2050.464916
123	0.10792	13.166253	0.633747	2039.14404	0.490827844	4.112479323	15.24	2058.98735
124	0.10792	13.274173	0.525827	2062.198	0.410583445	3.761316239	15.24	2081.609898
125	0.10792	13.382093	0.417907	2082.58545	0.328968843	3.366793777	15.24	2101.521212
126	0.10792	13.490013	0.309987	2083.9624	0.245984039	2.911337777	15.24	2102.359724***
127	0.10792	13.597933	0.202067	2075.56079	0.161629031	2.359928344	15.24	2093.322348
128	0.10792	13.705853	0.094147	2084.0918	0.07590382	1.617226871	15.24	2101.024928
***	***	13.8	0	2098.000	0	0	15.24	2113.240

Repeater site to Site B

Path profile is considered by 148meters and 59 centimeters from each obstruction considered in the analysis above the same formulas have been done as shown in table 4.2 below.

Table 4.2: Path profile from repeater to Site B

obstacle	Differences of d1s' in (km)	Dist. From Tx.d1(km)	Dist. from Rx.-2 (km)	elevation (m)	Earth curva-ture (eb)(m)	first Fresnel clearanceF1(m)	tree height + ATG (m)	total extended height (m)
	0	0	19	2097.93579	0	0	15.24	2113.17579
2	0.148594	0.148594	18.851406	2087.58398	0.16477681	1.142519542	15.24	2104.131281
3	0.148595	0.297189	18.702811	2067.35718	0.32695704	1.614184394	15.24	2084.538319
4	0.148594	0.445783	18.554217	2061.24121	0.4865385	1.975022593	15.24	2078.942772
5	0.148595	0.594378	18.405622	2045.07288	0.64352334	2.278315894	15.24	2063.234715
6	0.148594	0.742972	18.257028	2051.16797	0.79790945	2.544724269	15.24	2069.750602
7	0.148594	0.891566	18.108434	2069.78491	0.94969789	2.784852376	15.24	2088.759462
8	0.148594	1.04016	17.95984	2050.77197	1.09888866	3.005007486	15.24	2070.115869
9	0.148595	1.188755	17.811245	2038.9939	1.24548274	3.209303614	15.24	2058.688683
10	0.148595	1.33735	17.66265	2059.65332	1.38947912	3.400597821	15.24	2079.683397
11	0.148594	1.485944	17.514056	2065.13647	1.53087685	3.580976255	15.24	2085.488328
12	0.148594	1.634538	17.365462	2064.71216	1.66967691	3.752013473	15.24	2085.373849
13	0.148595	1.783133	17.216867	2082.33423	1.80588022	3.91493328	15.24	2103.295042*
14	0.148594	1.931727	17.068273	2073.80054	1.93948493	4.070711189	15.24	2095.050733**
15	0.148593	2.08032	16.91968	2049.9812	2.0704911	4.220101607	15.24	2071.511794
16	0.148596	2.228916	16.771084	2049.18262	2.1989022	4.363864561	15.24	2070.985384
17	0.148594	2.37751	16.62249	2045.19385	2.32471389	4.502439232	15.24	2067.261001
18	0.1486	2.52611	16.47389	2028.79773	2.44793284	4.636322189	15.24	2051.121985
19	0.14859	2.6747	16.3253	2014.97839	2.56854588	4.765910143	15.24	2037.55285

20	0.14859	2.82329	16.17671	2025.81189	2.68656139	4.891544007	15.24	2048.629995
21	0.148598	2.971888	16.028112	2028.77124	2.80198551	5.013520497	15.24	2051.826746
22	0.148594	3.120482	15.879518	2013.70105	2.91480883	5.13210087	15.24	2036.98796
23	0.1485948	3.2690768	15.730923	2037.17676	3.02503506	5.247515676	15.24	2060.689309***
24	0.1485942	3.417671	15.582329	2026.1853	3.13266317	5.359968593	15.24	2049.917935
25	0.148595	3.566266	15.433734	2004.76294	3.23769417	5.469642901	15.24	2028.710277
26	0.148594	3.71486	15.28514	1991.22314	3.34012678	5.576702703	15.24	2015.379974
27	0.148594	3.863454	15.136546	1994.92993	3.43996172	5.981549802	15.24	2019.591443
28	0.1485949	4.0120489	14.987951	1987.72302	3.53719957	6.354245937	15.24	2012.854468
29	0.1485941	4.160643	14.839357	1967.90613	3.63183923	6.700158563	15.24	1993.478126
30	0.148595	4.309238	14.690762	1976.28271	3.72388176	7.023245594	15.24	2002.269842
31	0.148594	4.457832	14.542168	1975.04395	3.81332599	7.326528169	15.24	2001.423799
32	0.148594	4.606426	14.393574	1961.73706	3.90017256	7.612373138	15.24	1988.489606
33	0.148595	4.755021	14.244979	1955.75842	3.98442202	7.882677693	15.24	1982.865523
34	0.148594	4.903615	14.096385	1955.83228	4.06607323	8.138990945	15.24	1983.27734
35	0.1485947	5.0522097	13.94779	1945.97729	4.14512714	8.382595846	15.24	1973.745018
36	0.1485943	5.200804	13.799196	1919.55408	4.22158316	8.614570674	15.24	1947.630231
37	0.148594	5.349398	13.650602	1891.83948	4.29544136	8.835831623	15.24	1920.210751
38	0.148595	5.497993	13.502007	1876.3656	4.36670235	9.047164456	15.24	1905.019467
39	0.148594	5.646587	13.353413	1859.29834	4.43536519	9.24925042	15.24	1888.222955
40	0.148594	5.795181	13.204819	1855.06238	4.50143036	9.44268265	15.24	1884.246491
41	0.148595	5.943776	13.056224	1862.0802	4.56489829	9.48975131	15.24	1891.37485
42	0.148594	6.09237	12.90763	1856.81458	4.6257681	9.536319083	15.24	1886.216662
43	0.148595	6.240965	12.759035	1854.28247	4.68404064	9.582394016	15.24	1883.788905
44	0.148594	6.389559	12.610441	1851.31274	4.73971511	9.627983046	15.24	1880.920442
45	0.148595	6.538154	12.461846	1847.04834	4.79279225	9.805613579	15.24	1876.886746
46	0.148594	6.686748	12.313252	1861.91174	4.84327136	9.975980106	15.24	1891.970995
47	0.148594	6.835342	12.164658	1855.35864	4.89115281	10.13945317	15.24	1885.629249
48	0.148595	6.983937	12.016063	1834.98547	4.93643688	10.29635902	15.24	1865.45827
49	0.148594	7.132531	11.867469	1843.92871	4.97912297	10.44699448	15.24	1874.594828
50	0.148595	7.281126	11.718874	1835.69299	5.01921166	10.5916265	15.24	1866.543831
51	0.148594	7.42972	11.57028	1806.24377	5.0567024	10.73049763	15.24	1837.270974
52	0.148594	7.578314	11.421686	1784.43872	5.09159547	10.8638296	15.24	1815.634146
53	0.148595	7.726909	11.273091	1788.1698	5.12389108	10.9918234	15.24	1819.525514
54	0.148594	7.875503	11.124497	1804.17932	5.15358879	11.11466331	15.24	1835.687573
55	0.148595	8.024098	10.975902	1823.0708	5.18068902	11.23251894	15.24	1854.724009
56	0.148594	8.172692	10.827308	1824.3667	5.20519138	11.34554537	15.24	1856.157436
57	0.148594	8.321286	10.678714	1809.20813	5.22709608	11.45388525	15.24	1841.129111
58	0.148594	8.46988	10.53012	1811.12427	5.24640311	11.55767097	15.24	1843.168342
59	0.148595	8.618475	10.381525	1813.3468	5.26311257	11.65702357	15.24	1845.506938
60	0.1485947	8.7670697	10.23293	1802.81921	5.2772243	11.68118261	15.24	1835.017621

61	0.1485943	8.915664	10.084336	1776.78149	5.28873832	11.70507335	15.24	1809.015306
62	0.148594	9.064258	9.935742	1769.92908	5.29765464	11.7288769	15.24	1802.195609
63	0.148595	9.212853	9.787147	1774.48975	5.30397333	11.75205609	15.24	1806.785776
64	0.148594	9.361447	9.638553	1778.57739	5.3076943	11.84287225	15.24	1810.967959
65	0.148595	9.510042	9.489958	1771.87891	5.3088176	11.92956797	15.24	1804.357292
66	0.148594	9.658636	9.341364	1752.45679	5.30734321	11.95060892	15.24	1784.954739
67	0.1485945	9.8072305	9.1927695	1752.01697	5.30327114	11.97140249	15.24	1784.531641
68	0.1485945	9.955825	9.044175	1761.50928	5.29660139	11.99194005	15.24	1794.037819
69	0.148595	10.10442	8.89558	1757.27234	5.28733391	12.01223317	15.24	1789.811906
70	0.14859	10.25301	8.74699	1746.12781	5.27546917	12.09095027	15.24	1778.734227
71	0.1486	10.40161	8.59839	1718.07727	5.26100585	12.16579525	15.24	1750.744072
72	0.14859	10.5502	8.4498	1679.28394	5.24394588	12.23684017	15.24	1712.004722
73	0.148597	10.698797	8.301203	1664.46997	5.2242874	12.30415051	15.24	1697.238409
74	0.148593	10.84739	8.15261	1676.54199	5.20203178	12.36778655	15.24	1709.351811
75	0.1486	10.99599	8.00401	1690.69824	5.17717729	12.42780581	15.24	1723.543225
76	0.14859	11.14458	7.85542	1679.69043	5.14972686	12.44225183	15.24	1712.522408
77	0.148594	11.293174	7.706826	1684.18799	5.11967806	12.45647522	15.24	1717.004142
78	0.148595	11.441769	7.558231	1706.07312	5.08703136	12.47047795	15.24	1738.870629
79	0.148594	11.590363	7.409637	1715.64368	5.05178721	12.48426007	15.24	1748.419724
80	0.148595	11.738958	7.261042	1720.68567	5.01394512	12.49782187	15.24	1753.437436
81	0.148592	11.88755	7.11245	1705.50037	4.97350618	12.51116522	15.24	1738.225038
82	0.148597	12.036147	6.963853	1691.28357	4.93046814	12.5242901	15.24	1723.978328
83	0.148594	12.184741	6.815259	1695.99463	4.88483328	12.53719676	15.24	1728.656659
84	0.148594	12.333335	6.666665	1694.01123	4.83660075	12.54988702	15.24	1726.637718
85	0.148595	12.48193	6.51807	1684.66467	4.7857702	12.56236084	15.24	1717.252804
86	0.148594	12.630524	6.369476	1673.15332	4.73234232	12.5746184	15.24	1705.700281
87	0.148595	12.779119	6.220881	1652.13208	4.67631639	12.5866615	15.24	1684.635058
88	0.148594	12.927713	6.072287	1633.22559	4.61769315	12.63269438	15.24	1665.715973
89	0.148594	13.076307	5.923693	1650.71436	4.55647225	12.64367041	15.24	1683.154498
90	0.148595	13.224902	5.775098	1671.63562	4.49265324	12.65443548	15.24	1704.022709
91	0.148594	13.373496	5.626504	1678.96448	4.42623698	12.66498944	15.24	1711.295704
92	0.148594	13.52209	5.47791	1666.18811	4.35722306	12.6753324	15.24	1698.460666
93	0.148595	13.670685	5.329315	1668.95361	4.28561098	12.68546584	15.24	1701.16469
94	0.148594	13.819279	5.180721	1672.19507	4.2114017	12.69538954	15.24	1704.34186
95	0.148595	13.967874	5.032126	1655.48828	4.13459423	12.70510449	15.24	1687.56798
96	0.148594	14.116468	4.883532	1672.34705	4.0551896	12.71461066	15.24	1704.356846
97	0.148592	14.26506	4.73494	1682.02917	3.97318842	12.75055949	15.24	1713.992923
98	0.1486	14.41366	4.58634	1679.45325	3.88858502	12.78320744	15.24	1711.36504
99	0.148591	14.562251	4.437749	1668.38318	3.80138911	12.81257932	15.24	1700.237147
100	0.148595	14.710846	4.289154	1657.7229	3.71159317	12.83869783	15.24	1689.513191
101	0.148594	14.85944	4.14056	1666.72644	3.61920017	12.86158294	15.24	1698.447224

102	0.1486	15.00804	3.99196	1674.98022	3.52420561	12.86680097	15.24	1706.611231
103	0.14859	15.15663	3.84337	1672.22546	3.42661983	12.87181824	15.24	1703.763902
104	0.14859	15.30522	3.69478	1665.62793	3.32643651	12.87663512	15.24	1697.071001
105	0.148598	15.453818	3.546182	1648.36633	3.22365007	12.88125156	15.24	1679.711235
106	0.148594	15.602412	3.397588	1616.75122	3.11826869	12.88566792	15.24	1647.995157
107	0.148595	15.751007	3.248993	1596.96155	3.01028891	12.88988577	15.24	1628.101723
108	0.148593	15.8996	3.1004	1627.66748	2.89971293	12.8939013	15.24	1658.701095
109	0.148595	16.048195	2.951805	1635.02527	2.78653778	12.89771859	15.24	1665.949525
110	0.148595	16.19679	2.80321	1632.52283	2.67076492	12.90133666	15.24	1663.334929
111	0.148594	16.345384	2.654616	1643.60376	2.55239517	12.90475548	15.24	1674.30091
112	0.148595	16.493979	2.506021	1632.69397	2.43142693	12.9079753	15.24	1663.273372
113	0.148591	16.64257	2.35743	1631.15491	2.30786434	12.91099636	15.24	1661.613768
114	0.148597	16.791167	2.208833	1640.21936	2.18169905	12.91381862	15.24	1670.554878
115	0.148593	16.93976	2.06024	1650.5614	2.05293948	12.91644231	15.24	1680.770783
116	0.148596	17.088356	1.911644	1648.03943	1.9215796	12.91886761	15.24	1678.119876
117	0.148594	17.23695	1.76305	1634.83533	1.78762381	12.9210945	15.24	1664.784045
118	0.148595	17.385545	1.614455	1611.3219	1.65106941	12.92312315	15.24	1641.136092
119	0.148594	17.534139	1.465861	1612.70947	1.51191827	12.9249537	15.24	1642.386345
120	0.148595	17.682734	1.317266	1629.99084	1.37016849	12.92658614	15.24	1659.527599
121	0.148594	17.831328	1.168672	1639.22144	1.22582199	12.92802058	15.24	1668.615278
122	0.148592	17.97992	1.02008	1634.30896	1.07887981	12.93177971	15.24	1663.559619
123	0.1486	18.12852	0.87148	1632.71021	0.92933192	12.9323746	15.24	1661.811912
124	0.14859	18.27711	0.72289	1619.31543	0.77719647	12.92980571	15.24	1648.262432
125	0.1486	18.42571	0.57429	1619.01904	0.622453	12.92407112	15.24	1647.805567
126	0.14859	18.5743	0.4257	1636.08496	0.46512232	12.91516669	15.24	1664.70525
127	0.14859	18.72289	0.27711	1639.1322	0.30519412	12.91244459	15.24	1667.589841
128	0.1486	18.87149	0.12851	1634.48438	0.14265736	12.90952344	15.24	1662.776556
***	***	0	19	0	0	0	0	0

4.2.1. Tower heights calculations

Microwave tower is a structure built to enhance wireless communication, for them to work. They have to go long path using interconnecting pattern and can be located anywhere. Most of them are located close to where power supply areas.

The tower used must possess the following:

- The capability of the tower to hold loads such as antennas and cables prior to constructions;
- The type of soil wherein the tower is raised must be considered for any ground movement to prevent the tower from swaying.
- The height of the tower must be enough in order to avoid obstructions [9].

Tower heights calculation of the Site A to repeater site

As shown in Fig.4.4, the sites A, peak obstruction height, and repeater site are at Elevations of 1769, 2037 and 2098meters above sea level respectively.

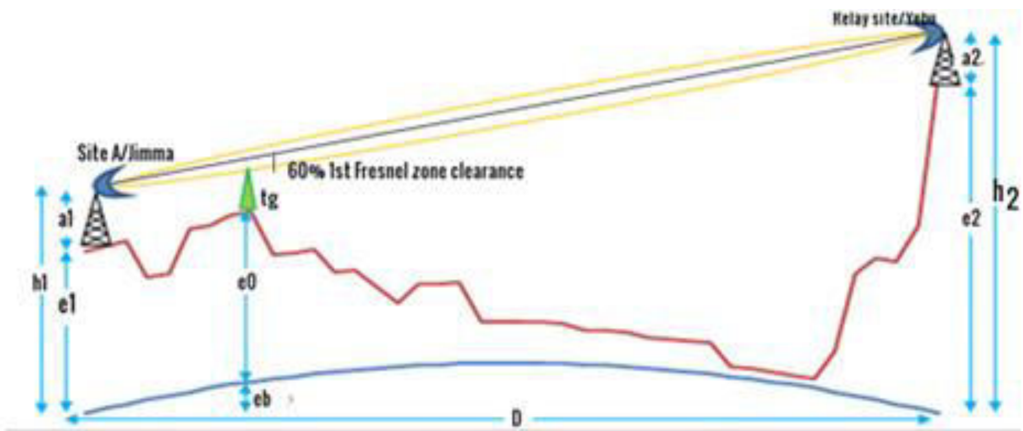

Figure 4.4: Tower heights calculation of Site A and Repeater

Values from the tables above; e_1 =1769m, D=13.8km, e_0=2037.2 m, d_1=10.68 km, e_2=2098m, d_2=3.116km, F=10.7GHz, k=4/3, TG=15.24m

$$E_b = \frac{d1*d2}{12.75*k} = \frac{10.684\times3.1159}{12.75\times4/3}=1.958\text{m}$$

$$F_1 = 17.3\sqrt{\frac{d1 \text{ x } d2}{f(d1+d2)}} = 17.3\sqrt{\frac{10.68409 \text{ x } 3.1159}{10.7 \text{ x } 13.8}} =8.214\text{m}$$

$H=0.6\times F_1= 0.6\times 8.214 =4.928$ m

H_{01} = Eb + TG + e_0 =1.958m +15.24m+2037.2m= 2054.4 m

$h_1=a_1+e_1= a_1+1769m$, $h2=a_2+e_2= a_2+2098m$

Assuming $a_1= a_2= a$

$$H=[d1\left(\frac{h2-h1}{D}\right)] - H0 + h1=[10.684\left(\frac{a+2098m-a+1769m}{13.8}\right)] - 2054.4m + a + 1769m$$

$$4.928m=\left[10.684\left(\frac{329}{13.8}\right)\right] - 2054.4m + a + 1769m \rightarrow a=35.6\ m=a_1=a_2\approx 40m$$

Where

E_b=Earth bulge, F_1=First Fresnel zone,

H=the first Fresnel zone at 60% clearance, TG=Tree growth

e_0=elevation of the obstruction, e_1=elevation of the site A

e_2=elevation of the repeater site, a_1=the first tower heights

a_2=the second tower heights, h_1= the height site A and elevation

h_2= the height of repeater site and elevation, H_{01}=first peak obstruction height

Second Obstruction: 2036.74 meters

d1 = 11.11577km; d2 = 2.68423km

$$E_b = \frac{d1*d2}{12.75*k} = \frac{11.11577\times2.68423}{12.75\times4/3}=1.755m$$

$$F_1 = 17.3\sqrt{\frac{d1\ x\ d2}{f(d1+d2)}}$$

$$F_1 = 17.3\sqrt{\frac{11.11577\ x\ 2.68423}{10.7\ x\ 13.8}} =7.8m$$

F_{C1} = 0.6 F_1=0.6*7.777=4.666m

H_{02} = Eb + TG + Elevation of obstruction =1.755+15.24+2036.74=2053.74m

$H_{02} < H_{01}$=2054.4m; H_{02} is inconsiderable.

Third Obstruction: 2083.96 meters

d1 = 13.49 km; d2 = 0.31 km

$$E_b = \frac{d1\times d2}{12.75\times k} = \frac{13.49\times0.31}{12.75\times4/3}=0.246m$$

$$F_1 = 17.3\sqrt{\frac{d1\ x\ d2}{f(d1+d2)}}$$

$F_1 = 17.3\sqrt{\frac{13.49 \times 0.31}{10.7 \times 13.8}}$ =2.9114m,

$F_{C1} = 0.6\, F_1$=0.6×2.9114=1.75m

H_{03} = Eb + TG + Elevation of obstruction =0.246+15.24+2083.96=2099.45m

$H_{03} < h_2$=2113.24m; H_{03} is inconsiderable.

4.2.2. Antenna orientation calculation

C= $absolute(longitude\ site\ A - longitude\ repeater/R)$

C=036°51'11.6"−036°44'39.4" must be positive

C= 0°6'32.2" = 0.108944°

$$\tan\frac{y-x}{2} = cot\frac{C}{2}\left(\frac{sin\frac{Latitude\ R - Latitude A}{2}}{cos\frac{Latitude\ R + Latitude\ A}{2}}\right)$$

$$\tan\frac{y-x}{2} = cot\frac{C}{2}\left(\frac{sin(\frac{07°44'42.4" - 07°41'03.9"}{2})}{cos(\frac{07°44'42.4" + 07°41'03.9"}{2})}\right)$$

$\tan\frac{y-x}{2}$ = 05°37'19.12" = 5.6219779 → $\frac{y-x}{2}$ =79.914°

$$\tan\frac{y+x}{2} = \cot\frac{C}{2}\left(\frac{\cos(\frac{Latitude\ R - Latitude\ A}{2})}{\sin(\frac{Latitude\ R + Latitude\ A}{2})}\right)$$

$$\tan\frac{y+x}{2} = \cot\frac{C}{2}\left(\frac{\cos(\frac{07°44'42.4" - 07°41'03.9"}{2})}{\sin(\frac{07°44'42.4 + 07°41'03.9}{2})}\right)$$

$\tan\frac{y+x}{2}$ =7835.4184776 → $\frac{y+x}{2}$ = 89.9926876°

X= $\frac{y+x}{2} - \frac{y-x}{2}$ = 89.9926876 − 79.9140944 =10.07859° → 10°4'42.9";

Y= $\frac{y+x}{2} + \frac{y-x}{2}$ = 89.9926876 + 79.914094 =169.90678° → 169° 54'24.4"

Site A: N $(90° - 10°4'42.9" = 79°55'17.07")E$ or N(79.9214)E

Site R: S $(169°\ 54'24.4" - 90° = 79°54'24.4"$79.906782°) W or

S (79.906782°) W

Where **C** = difference of the longitudinal coordinates of the sites in a hop

X = the computed coordinate of the first site

Y = the computed coordinate of the second site

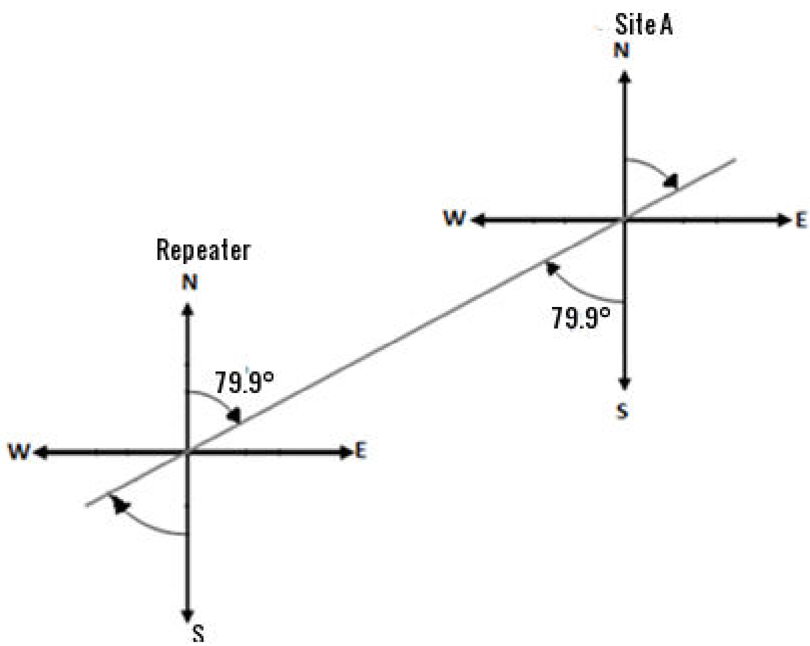

Figure 4.5: The first hop antenna orientation

4.2.3. Tower heights calculation of the repeater with site B

Repeater site, peak obstruction height, and Site B are at elevations 2098, 2082, and 1628meters above sea level respectively. As shown in the figure 4.6 below, the first Fresnel zone, Earth bulge, and antenna heights were calculated.

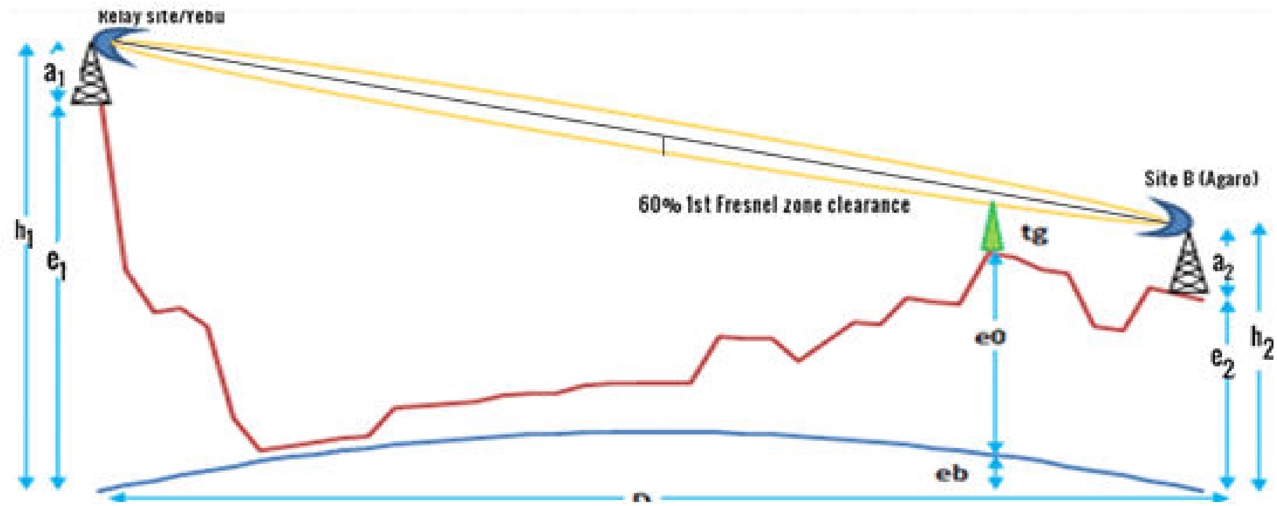

Figure 4.6: Tower heights calculation of Repeater site and Site B

Values from the tables above; e1=2098m, D=19km, e_0=2082.33 m, d1=1.78km, e_2=1628m, d_2=17.22km, F=8.5GHz

$$E_b = \frac{d1*d2}{12.75*k} = \frac{1.78\times17.22}{12.75\times4/3} = 1.803m$$

$$F_1 = 17.3\sqrt{\frac{d1\times d2}{f\times D}} = 17.3\sqrt{\frac{1.78\times17.22}{8.5\times19}} = 7.54\text{ m}$$

$H=0.6\times F_1= 0.6\times 7.54$ m =4.522 m

H_{01} = Eb + TG + e_0 =1.803m +15.24m+2082.33m= 2099.37 m

$h_1=a_1+e_1= a_1+2098m$, $h_2=a_2+e_2= a_2+1628m$

Assuming $a_1= a_2= a$

$$H=[d1\left(\frac{h2-h1}{D}\right)]-H_{01}+h1=[1.78\left(\frac{a+1628m-a+2098m}{19}\right)]-2099.37m+a+2098m$$

$$4.522m=[1.78\left(\frac{-470}{19}\right)]-2099.37m+a+2098m \rightarrow a=49.92\text{ m}=a_1=a_2\approx 50m$$

PATH CLEARANCE: at frequency = 8. 5 GHz

Second Obstruction: 2073.8 meters

d1 = 1.931727 km;   d2 = 17.068273

$E_b = \frac{d1*d2}{12.75*k} = \frac{1.931727\times17.068273}{12.75\times4/3}$=1.9396m

$F_1 = 17.3\sqrt{\frac{d1 \text{ x } d2}{f(d1+d2)}}$

$F_1 = 17.3\sqrt{\frac{1.931727 \text{ x } 17.068273}{8.5 \text{ x } 19}}$ =7.817m

F_{C1} = 0.6 F_1=0.6*7.817=4.69m

H_{02} = Eb + TG + Elevation of obstruction =1.9396+15.24+2073.8=2090.98m

H_{02}< H_{01}=2100.1m; H_{02} is inconsiderable.

Third Obstruction: 2037.18 meters

d1 = 3.27km;   d2 = 15.73km

$E_b = \frac{d1*d2}{12.75*k} = \frac{3.27\times15.73}{12.75\times4/3}$=3.026m

$F_1 = 17.3\sqrt{\frac{d1 \text{ x} d2}{f(d1+d2)}} = 17.3\sqrt{\frac{3.27\text{x } 15.73}{8.5 \text{ x } 19}}$ =9.76m

F_{C3} = 0.6 F_1=0.6*9.76=5.86m

H_{03} = Eb + TG + Elevation of obstruction =3.026+15.24+2037.18=2055.45m

H_{03} < H_{01}=2099.37m; H_{03} is inconsiderable

4.2.4. The second hop antenna orientation calculation

C= $absolute(longitudeR - longitudeB$

C=036°44'39.4" − 036°36'50.6=0°7'48.8" =0.130222

$$\tan\frac{y-x}{2} = cot\,\frac{C}{2}\left(\frac{sin(\frac{LatitudeB-LatitudeR}{2})}{cos(\frac{LatitudeB+LatitudeR}{2})}\right)$$

$$\tan\frac{y-x}{2} = cot\frac{C}{2}\left(\frac{sin(\frac{07°51'23.8"-07°44'42.4"}{2})}{cos(\frac{07°51'23.8"+07°44'42.4"}{2})}\right)$$

$\tan\frac{y-x}{2}$ =0.864227358 → $\frac{y-x}{2} = 40.83447°$

$$\tan\frac{y+x}{2} = \cot\frac{C}{2}\left(\frac{\cos(\frac{\text{Latitude B}-\text{Latitude R}}{2})}{\sin(\frac{\text{Latitude B}+\text{Latitude R}}{2})}\right)$$

$$\tan\frac{y+x}{2} = \cot\frac{C}{2}\left(\frac{\cos(\frac{07°51'23.8"-07°44'42.4"}{2})}{\sin(\frac{07°51'23.8"+07°44'42.4"}{2})}\right)$$

$\tan\frac{y+x}{2}$ =6483.216898 → $\frac{y+x}{2} = 89.991162°$

X= $\frac{y+x}{2} - \frac{y-x}{2} = 89.991162° - 40.83447° = 49.156692446° \rightarrow 49°9'24.09"$;

Y= $\frac{y+x}{2} + \frac{y-x}{2} = 89.99116° + 40.83447°$ =130.8256° → 130°49'32.16"

Site R: N ($90° - 49°9'24.09" = 40°50'35.9"$)Eor N (40.84°)E

Site B: S ($130°49'32.16" - 90° = 40°49'32.28"$ Wor S (40.83°))W

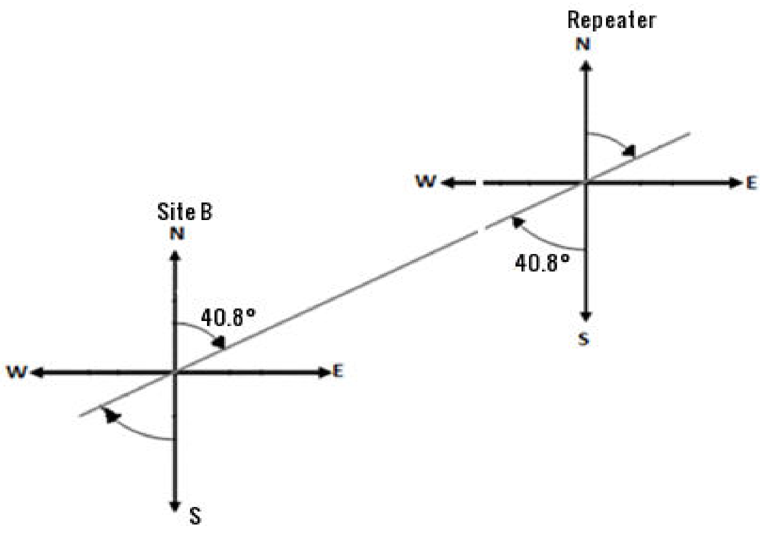

Figure 4.7: The second hop antenna orientation

4.2.5. Path feasibility study

A path profile is a graphical representation of the path traveled by the radio waves between the two ends of a link. It determines the location and height of the antenna at each end of the link, and it ensures that the link is free of obstructions, such as hills, and not subject to propagation losses from radio phenomena, such as multipath reflections. As shown in the Fig.4.8 below the path profile of Site A to repeater site was shown that obtained from geo context profiler.

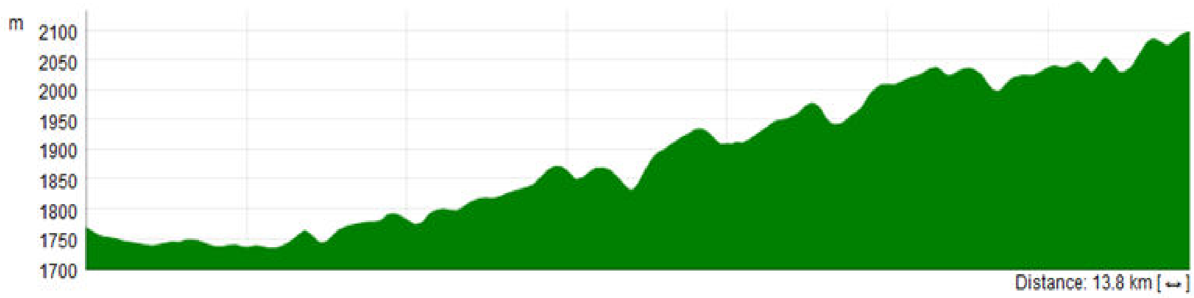

Figure 4.8: Path representation graph of site A to repeater

The second graphical representation of path profile was longer hop length than that of the first hop length relatively. As shown in figure below path representation of Repeater site to site B.

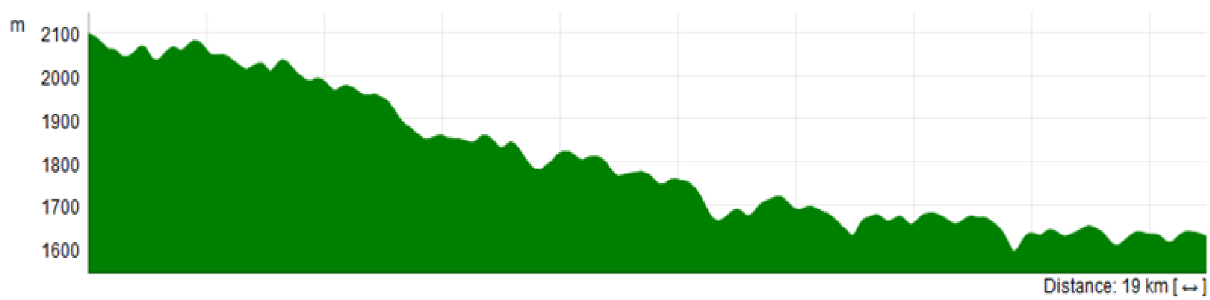

Figure 4.9: Path representation graph of repeater site to site B

CHAPTER FIVE
ANALYSIS AND RESULTS

5.1. Site A to Repeater site

As shown in the figure below, there are design steps to achieve the required transmission capacity and link availability in microwave link design procedures.

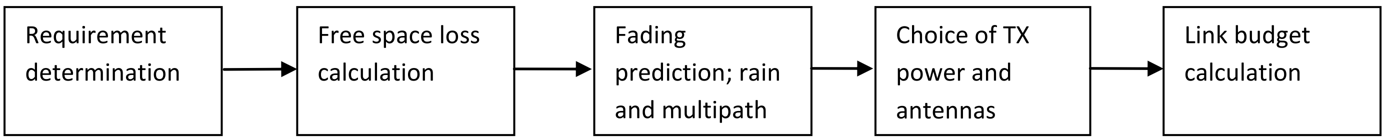

Figure 5.1: Design flowchart

Step 1-Requirement Determination

Transmission requirements:

Maximum data rates > 155 Mbps

Minimum required availability: 99.999%

Ray parameters:

10.7GHz

Modulation 16 QAM; BW=28MHz; Ps (BER 10^{-6}) =-80.8 dBm

Tx/Rx spacing 490MHz, TX power=26 dBm

Step 2-Free space loss calculation

FSL = 92.4 + 20 log $f_{(GHz)}$ + 20 log $D_{(km)}$ =92.4 + 20 log 10.7 + 20 log 13.8=135.8 dB

Step 3-Rain attenuation

Table 5.1: rain attenuation of 8-11GHz frequency bands

Frequency(GHz)	k_h	α_h	k_v	α_v
8	0.0046	1.328	0.0040	1.313
8.5	0.0057	1.316	0.0050	1.303
9	0.0069	1.304	0.0061	1.294
10	0.01	1.260	0.01	1.220
10.7	0.017	1.227	0.017	1.178
11	0.02	1.210	0.02	1.160

For 99.999% availability in rain zone J the rain rate is $R_{0.001}$=55 mm/hr

For f=10.7 GHz k_h=0.017; α_h=1.227; k_v =0.017; α_v=1.178

Vertical polarization:

$\gamma R0.01 = kv .R^{\alpha v}{}_{0.001} = 0.017 * (55)^{1.178} = 1.9024 dB/km$

Horizontal polarization:

$\gamma R0.01 = k_h .R^{\alpha h}{}_{0.001} = 0.017 \cdot *(55)^{1.227} = 2.32$ dB/km

Step 4 –link budget: The link budget is a calculation involving the gain and loss factors associated with the antennas, transmitters, transmission lines and propagation environment, to determine the maximum distance at which a transmitter and receiver can successfully operate.

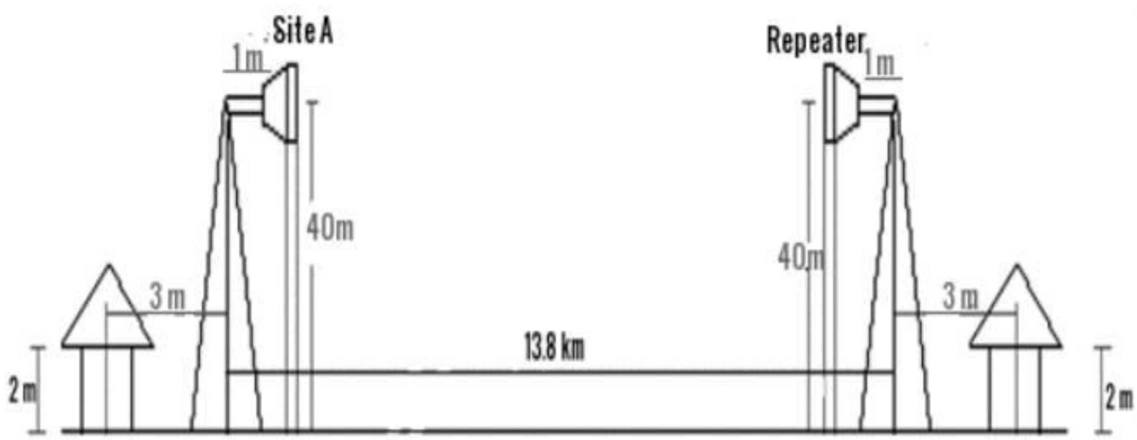

Figure 5.2: Link budget of Site A to Repeater

5.1.1. Site A Link Budget

Transmitter Gain: The diameter of the antenna 1.8m, and the gain,

$G = 17.8 + 20 \log (f_{GHz}) + 20 \log (d_m) = 17.8 + 20 \log 10.7 + 20 \log (1.8) = 43.5$ dB

Wave Guide Loss

Elliptical waveguide type (WR90), maximum length 60m (197ft), and loss of 9.74dB/100m at 10.7GHz.

$L_{WG\ (TX)}$ =40 m+3m-2 m +1 m+5 m → 47m=47 m $(\frac{9.74dB}{100m})$ = 4.58 dB

Branching loss

Branching loss (Lb_{Tx}=2 dB), that is, the total filter and circulator loss when transmitters and receivers are coupled to a single unit.

Radome loss

Radome loss (Lr_{Tx}=0.5dB)

5.1.2. Repeater site Link budget

$G_R = 17.8 + 20 \log (f_{GHz}) + 20 \log (d_m) = 17.8 + 20 \log (10.7) + 20 \log (1.8) = 43.5$dB

Wave Guide Loss

$L_{WG(R)}$ =40m+3m-2m +1 m+5m → 47 m =47 m $(\frac{9.74dB}{100m})$ =4.58 dB

Branching loss

The branching system consists of circulator, branching filter, terminator and connection waveguide, and branching loss (Lb_R =2 dB taken from specification).

Radome loss

Radome loss (Lr_R=0.5dB)

Miscellaneous losses

Miscellaneous Loss (L_{misc}=2dB), e.g. antenna misalignment, TX variation loss

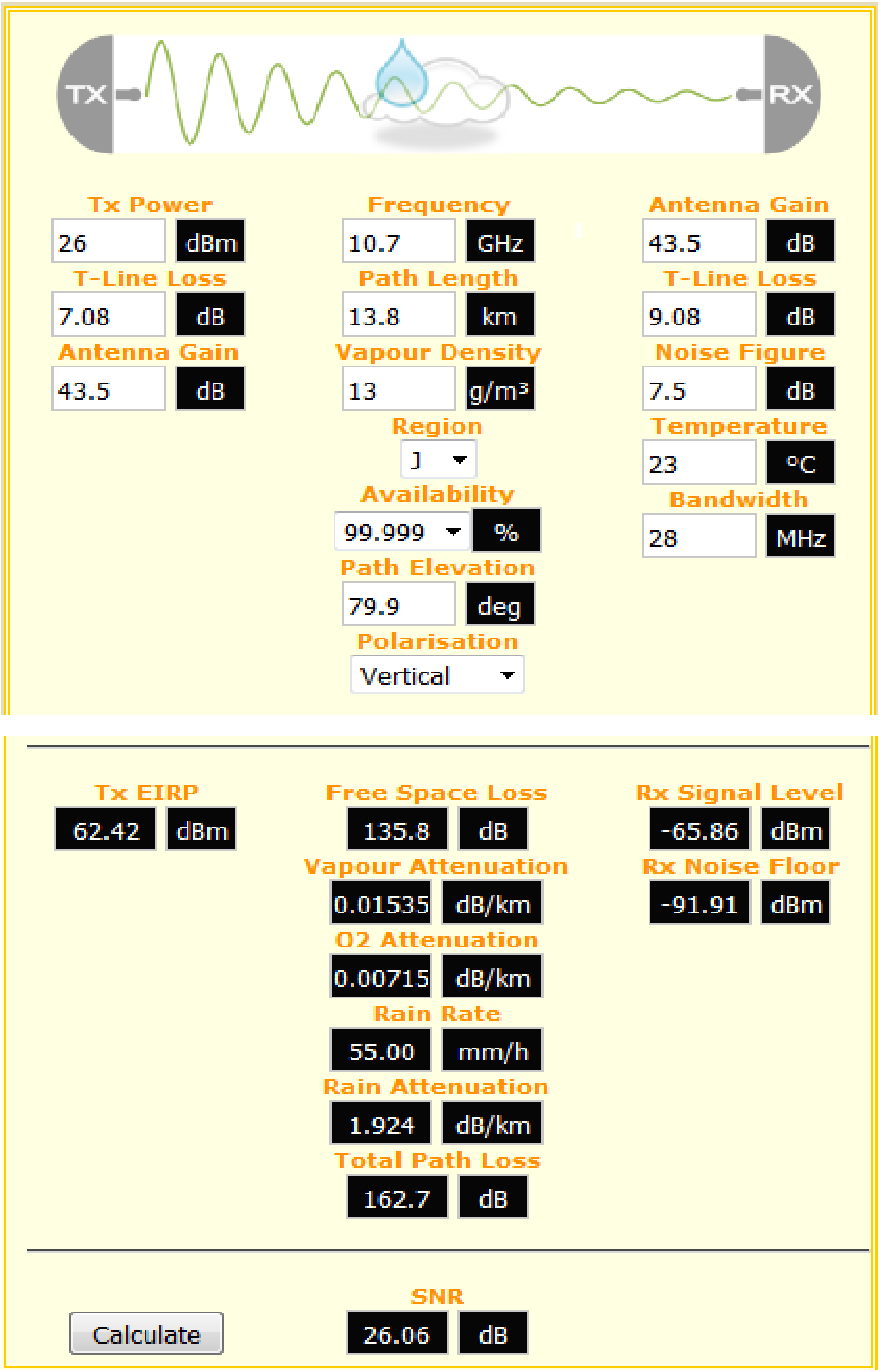

Figure 5.3: Link budget calculators

5.2. Repeater site to site B

Step 1-requirement determination

Link parameters:

Link distance: 19 km

First antenna height above sea level: 2098 m

Second antenna height above sea level: 1628 m

Transmission requirements:

Data rates: >155Mbps

Minimum required availability: 99.999%

Ray parameters:

8.5GHz

Modulation 16QAM; BW=28MHz; Ps (BER 10^{-6}) =-80.6dBm

Tx/Rx spacing 490MHz

TX power=28 dBm (Appendix B)

Step 2-Free space loss calculation

FSL = 92.4 + 20 log $f_{(GHz)}$ + 20 log $D_{(km)}$ =92.4 + 20 log 8.5 + 20 log 19=136.6 dB

Step 3-Rain attenuation

For f=8.5 GHz k_h=0.0057; α_h=1.316; k_v=0.0050; α_v=1.303

Vertical polarization:

$\gamma R0.001 = kv \cdot R^{\alpha v}_{0.001} = 0.005 * (55)^{1.303} = 0.926$ dB/km

Horizontal polarization:

$\gamma R0.001 = k_h \cdot R^{\alpha h}_{0.001} = 0.0057 *(55)^{1.316} = 1.112$ dB/km

Step 4 –link budget

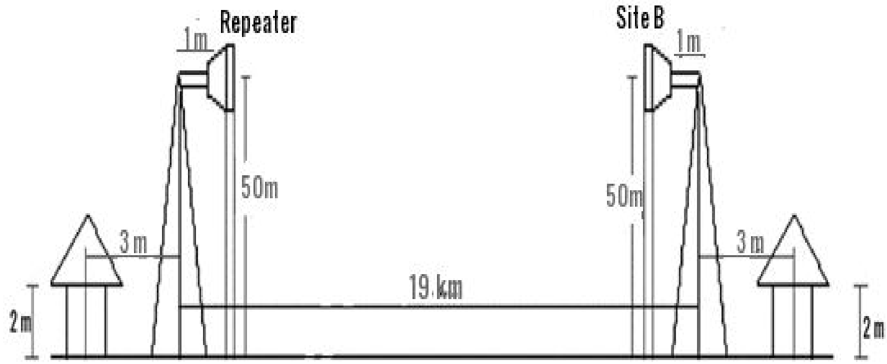

Figure 5.4: Link budget of Repeater site to Site B

5.2.2. Repeater site

Antenna gain

The diameter of reflector antenna 1.8m, and the gain,

$G = 17.8 + 20 \log (f_{GHz}) + 20 \log (d_m) = 17.8 + 20 \log 8.5 + 20 \log (1.8) = 41.5$ dB

Wave Guide Loss

$L_{WG(R)} = 50m - 2m + 3m + 1m + 5m = 57m$ and 5.84dB/100m loss,

$L_{WG(R)} = 187ft\ (\frac{1.78dB}{100ft}) = 57m\ (\frac{5.84dB}{100m}) = 3.33dB$

Branching loss

Branching loss (Lb_R=2 dB), that is, the total filter and circulator loss when transmitters and receivers are coupled to a single unit.

Radome loss

Radome loss (Lr_R=0.5dB)

5.2.3. Site B Link budget

Gain

G_{Rx} = 17.8 + 20 log (f_{GHz}) + 20 log (d_m) = 17.8 + 20 log (8.5) + 20 log (1.8) = 41.5dB

Wave Guide Loss

$L_{WG\ (Rx)} = 50m - 2m + 3m + 1m + 5m$=57 m → 57 m ($\frac{5.84\text{dB}}{100\text{m}}$) = 3.33dB

Branching loss

Branching loss (Lb_{Rx} =2 dB), that is, the total filter and circulator loss when transmitters and receivers are coupled to a single unit.

Radome loss

Radome loss (Lr_{Rx} =0.5dB)

Miscellaneous losses

Miscellaneous Losses (L_{misc}=2dB), e.g antenna misalignment, TX variation loss,

Figure 5.5: Link budget calculators

5.3. Reflection Point Calculation

The formulas for getting the reflection point

$X=\frac{h1}{D^2}$, $Y=\frac{h2}{D^2}$

$\eta=\frac{1}{1+\sqrt{\frac{Y}{X}}}$

Where $d1=\eta D$, η=reflection point, D and d1 are distance of the site from the reflection point.

h1=40m, h2=40m, D=13.8 km

$X=\frac{h1}{D^2}=\frac{40}{13.8^2}=0.21\frac{m}{km^2}$

$Y=\frac{h2}{D^2}=\frac{40}{13.8^2}=0.21\ \frac{m}{km^2}$

$\eta=\frac{1}{1+\sqrt{\frac{y}{x}}}=\frac{1}{1+\sqrt{\frac{0.21004}{0.21004}}}=0.5$

D1=0.5*13.8=6.9 km→ $d_2=D-d_1$=13.8 km -6.9 km=6.9 km

h1=50m, h2=50m, D=19 km

$x=\frac{h1}{D^2}=\frac{50}{19^2}=0.1385\frac{m}{km^2}$

$y=\frac{h2}{D^2}=\frac{50}{19^2}=0.1385\ \frac{m}{km^2}$

$\eta=\frac{1}{1+\sqrt{\frac{y}{x}}}=\frac{1}{1+\sqrt{\frac{0.1385}{0.1385}}}=0.5$,

$d1=\eta D$, $d_2=D-d_1$→ D1=0.5*19=9.5 km, d_2=19-9.5=9.5km

5.4. Results

5.4.1. Clearance verification of site A, repeater and site B

The path profile, hop length, the frequency planned, and tower height calculations above we have got the following result and Fresnel zone clearance as shown in Fig.5.6 below from the Site A to Repeater site.

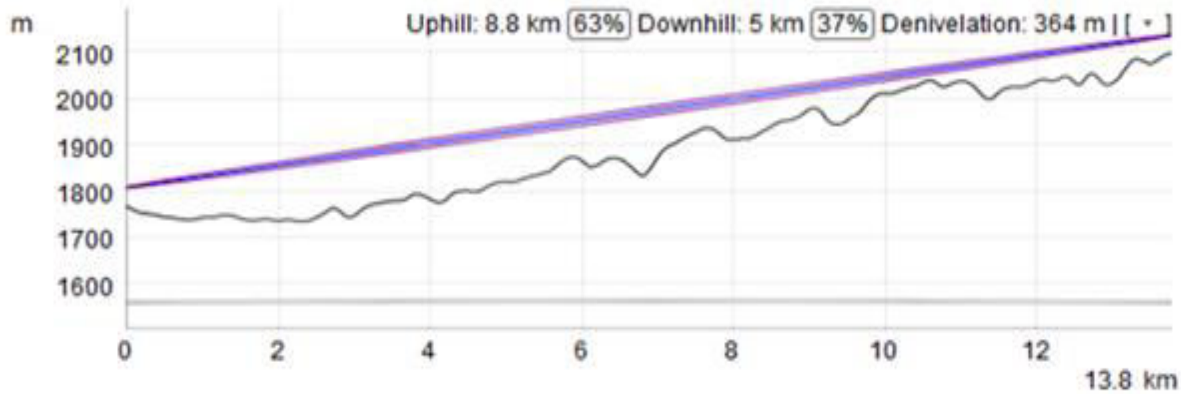

Figure 5.6: Clearance verification of site A to repeater

The second result was from longer hop length than that of the first hop length relatively. As shown in figure 5.7 below clearance verification of repeater site to site B.

Figure 5.7: Clearance verification of repeater site to site B

5.4.2.Transmitter

The voice or data channels are combined by a multiplexing. This signal is frequency modulated to an IF in the indoor unit and by elliptical wave guide to the outdoor unit and then up converted to the RF for transmission through the atmosphere.

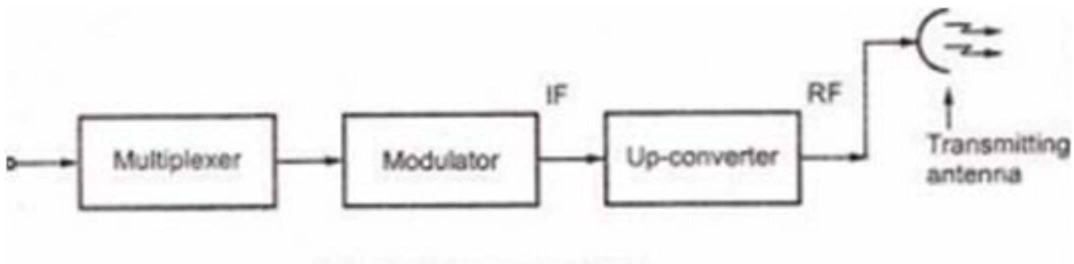

Figure 5.8: Transmitter's blocks diagram

Table 5.4: Transmitter products and specifications

Model	Product type	Specifications
SN74CBTLV 3257		**1 Features** • 5-Ω Switch Connection Between Two Ports • Rail-to-Rail Switching on Data I/O Ports • I_{off} Supports Partial-Power-Down Mode Operation • Latch-Up Performance Exceeds 100 mA Per JESD 78, Class II • ESD Protection Exceeds JESD 22 - 2000-V Human-Body Model (A114-A) - 200-V Machine Model (A115-A) **2 Applications** • Internet of Things • Wireless Headphones • Television Set • 4-Bit Bus Multiplexing and Demultiplexing
SSM0812		**Features** • RF output/carrier input .... 8 to 12 GHz • Modulation bandwidth .... DC to 500 MHz (Q) • Linear RF input .... Up to +5 dBm • IF input power .... +10 to +13 dBm • Sideband suppression .... 25 dB • Carrier rejection .... 35 dB • IF options: Single sideband .... A, B and C (internal hybrid) Multioctave IFs .... Q (separate inputs)

<table>
<tr>
<td>222040-2</td>
<td>
</td>
<td>Characteristics
Type Numbers
Super Premium Waveguide, Standard Jacket — EWP90S
Premium Waveguide, Standard Jacket — EWP90
Standard Waveguide, Standard Jacket — EW90
Premium Waveguide, Fire Retardant, Non-Halogenated Jacket — 35409-16*
Premium Waveguide Type CATVP — 222040-2
Electrical
Max. Frequency Range, GHz — 8.3-11.7
eTE11 Mode Cutoff Frequency, GHz — 6.50
Group Delay at 11.2 GHz, ns/100 ft (ns/100 m) — 125 (410)
Peak Power Rating at 11.2 GHz, kW
with 190 series connectors — 44.9
with 290 series connectors — 30.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ODU features and specificatons
• 4-42GHz frequency bands available
• Fully synthesized design
• 3.5-56MHz RF channel bandwidths
• Supports QPSK and 16 to 1024 QAM. Some ODUs may support 2048QAM
• Standard and high power options
• High MTBF, greater than 92.000 hours
• Software controlled ODU functions
• Designed to meet FCC, ETSI and CE safety and emission standards
• Supports popular ITU-R standards and frequency recommendations
• Software configurable microcontroller for ODU monitor and control settings</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>UHX6-102</td>
<td></td>
<td>General Specifications
Antenna Type — UHX - Ultra High Performance Parabolic Shielded Antenna, du
Diameter, nominal — 1.8 m | 6 ft
Packing — Standard pack
Radome Color — White
Radome Material — Enhanced
Reflector Construction — One-piece reflector
Antenna Input — UBR100
Antenna Color — Gray</td>
</tr>
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5.4.3. Root raised cosine filter

The specification of impulse response of root raised cosine filter is shown in the figures below. In order to achieve these requirements, a FIR filter using Kaiser Window is chosen to design the filter. The characteristics of the filter indicate that the filter is non-distorting.

As shown in the Fig.5.9 the impulse response is highest at 400nseconds and zeros at 300nseconds and 500nseconds.before 300 and after 500ns it approaches to zero.

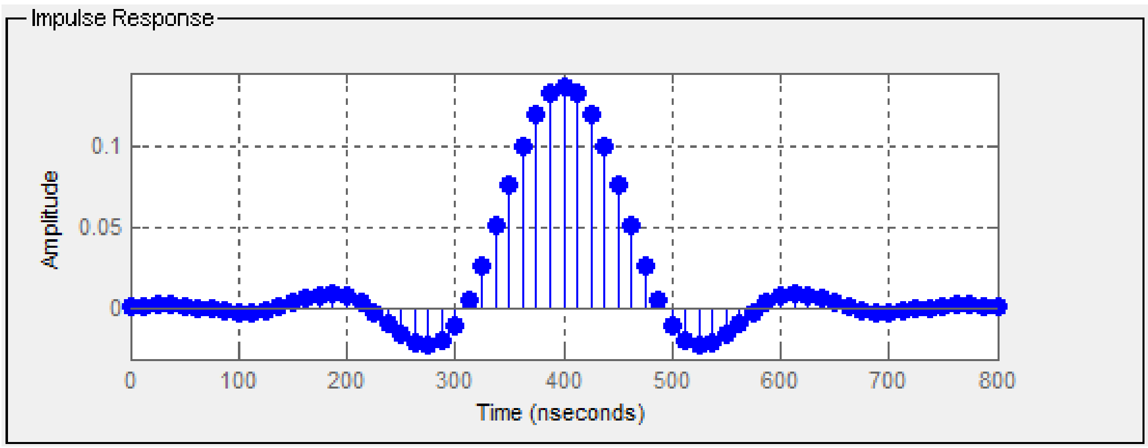

Figure 5.9: Impulse response of RRC

5.4.4.RF repeater

In order to overcome the problems of line-of-sight and power amplification of weak signals, microwave systems use repeaters depending on non-line of sight and interferences. The repeater is placed in line-of-sight of the transmitting and receiving stations. The data signals are received, mixed with local oscillator, and re-transmitted to the receiver.

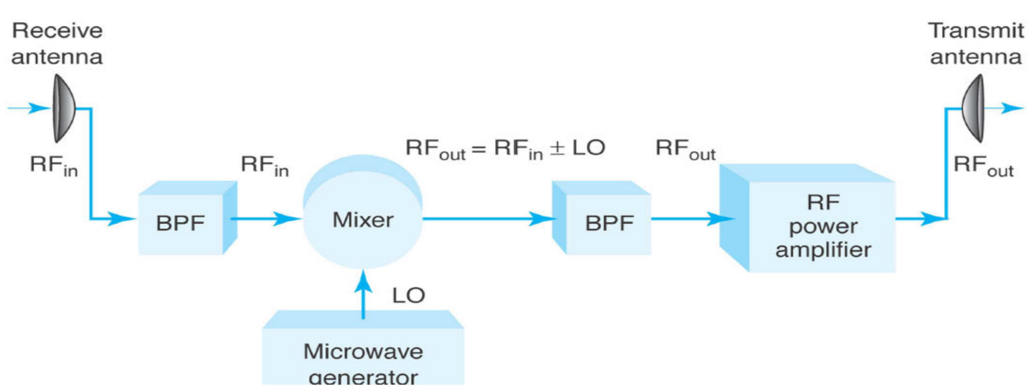

Figure 5.10: RF repeater block diagram

Table 5.5: RF repeater products and specifications

Model	Product types	Specifications
19558		**Specifications:** Passband: 10.7 - 11.7 GHz Passband Loss: 0.2 dB Typ Passband VSWR: 1.25:1 Max Rejection: 80 dB Typ / 70 dB Min from 12.75 - 14.50 GHz Flanges: WR75 Cover Dimensions: 3.25" x 1.5" x 1.5" (82 mm x 38 mm x 38 mm) Finish: White Lacquer
SM1807		SM1807 Microwave Mixer LO=+7 dBm 2-20 Ghz **Electrical Specifications:** RF Frequency: 2.0 – 20.0 Ghz LO Frequency: 2.0 – 20.0 Ghz IF Frequency: DC – 2.0 Ghz LO Drive: +7 dBm Typ Conversion Loss: 7.0 4-20 Ghz dB Max 12.0 2-20 Ghz dB Max Isolation L-R: 25 dB Min Isolation L-I:: 20 dB Min Input 1 dB compression: 0 dBm Typ
PB1049CB		Designed for converter applications for suppressing LO leakage and transmitter signals Passband 8.55 to 9.35 GHz Passband Insertion loss 0.7 dB typical Passband Return loss 20 dB min Rejection: DC to 5.15 GHz 90 dB min 7.9 to 8.4 GHz 20 dB min 10 to 20 GHz 80 DB min Converter SMA Female (alternatives available)

<table>
<tr>
<td>PE15A407</td>
<td>
</td>
<td>X-band high gain power amplifiers/specifications
<table>
<tr><td>Frequency, Min</td><td>8.5 GHz</td></tr>
<tr><td>Frequency, Max</td><td>11 GHz</td></tr>
<tr><td>Gain, Min</td><td>30 dB</td></tr>
<tr><td>Gain Flatness</td><td>1.25 dB</td></tr>
<tr><td>1dB Compression Point, Min</td><td>3 Watts</td></tr>
<tr><td>3rd Intercept Point, Typ</td><td>45 dB</td></tr>
<tr><td>3rd Intercept Point, Min</td><td>44 dB</td></tr>
<tr><td>Voltage, DC Typ</td><td>12 Volts</td></tr>
<tr><td>Current, DC Typ</td><td>5,000 mA</td></tr>
</table></td>
</tr>
</table>

5.4.5. Receiver

The reverse process of the transmitter occurs at the receiver. In this part the products: down converter, demodulator and demultplexer are introduced in table 5.3 above.

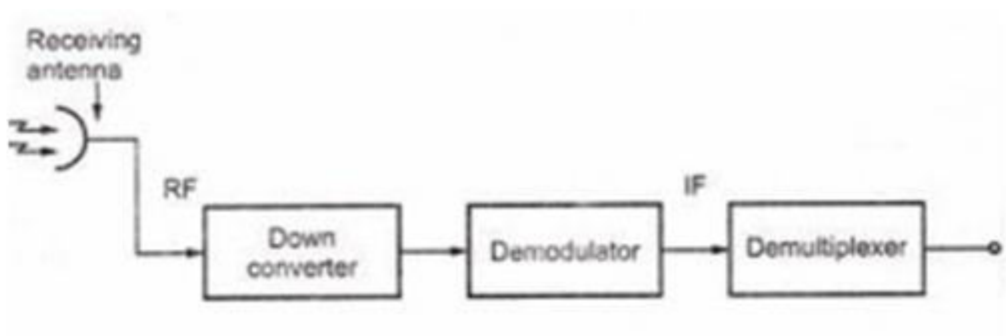

Figure 5.11: Receiver's block diagram

Table 5.6: Receiver products and specifications

Model	Product types	Specifications
HSX6-82		**High Performance Antennas** - Super High Cross Polarization Discrimination – Dual Polarized Diameter, nominal 1.8 m | 6 ft Polarization Dual **Electrical Specifications** Beamwidth, Horizontal 1.4 ° Beamwidth, Vertical 1.4 ° Cross Polarization Discrimination (XPD) 40 dB Electrical Compliance ETSI Class 3 Front-to-Back Ratio 67 dB Gain, Low Band 41.3 dBi Gain, Mid Band 41.4 dBi Gain, Top Band 41.7 dBi Operating Frequency Band 8.200 – 8.500 GHz Radiation Pattern Envelope Reference (RPE) 1222B | 1224B Return Loss 30.7 dB VSWR 1.06
35409-24		EWP77-71W,HELIAX®premium Elliptical Waveguide,7.125-8.5GHz,black non halogenated,fire retardant polyolefin jacket

5.4.6. Horn antenna simulation and design

The basis for this given design was to implement standard gain horn, directivity, electric and magnetic waves in near and far field propagations using Feko suite 5.5(CAD feko simulation). The horn antenna we designed for the link was subjected to the following constraints:

- Operating frequency at 8.5GHz and10.7GHz, Maintain gain of 20 dB over the frequency
- Dimensions of rectangular waveguide (in mm): width x height x length → 42 x 35 x 75 respectively as shown below.

At 10.7GHz flared out waveguide design

The following results and plots show the electric field radiation representations in dB that was modeled at 10.7GHz frequency using POSTFEKO with respect to theta angle graph. The magnitude of electric far field has different as it faces different theta angles. It decreases starting from the transmitter at zero degree and increases after 120 degrees up to 180 degrees.

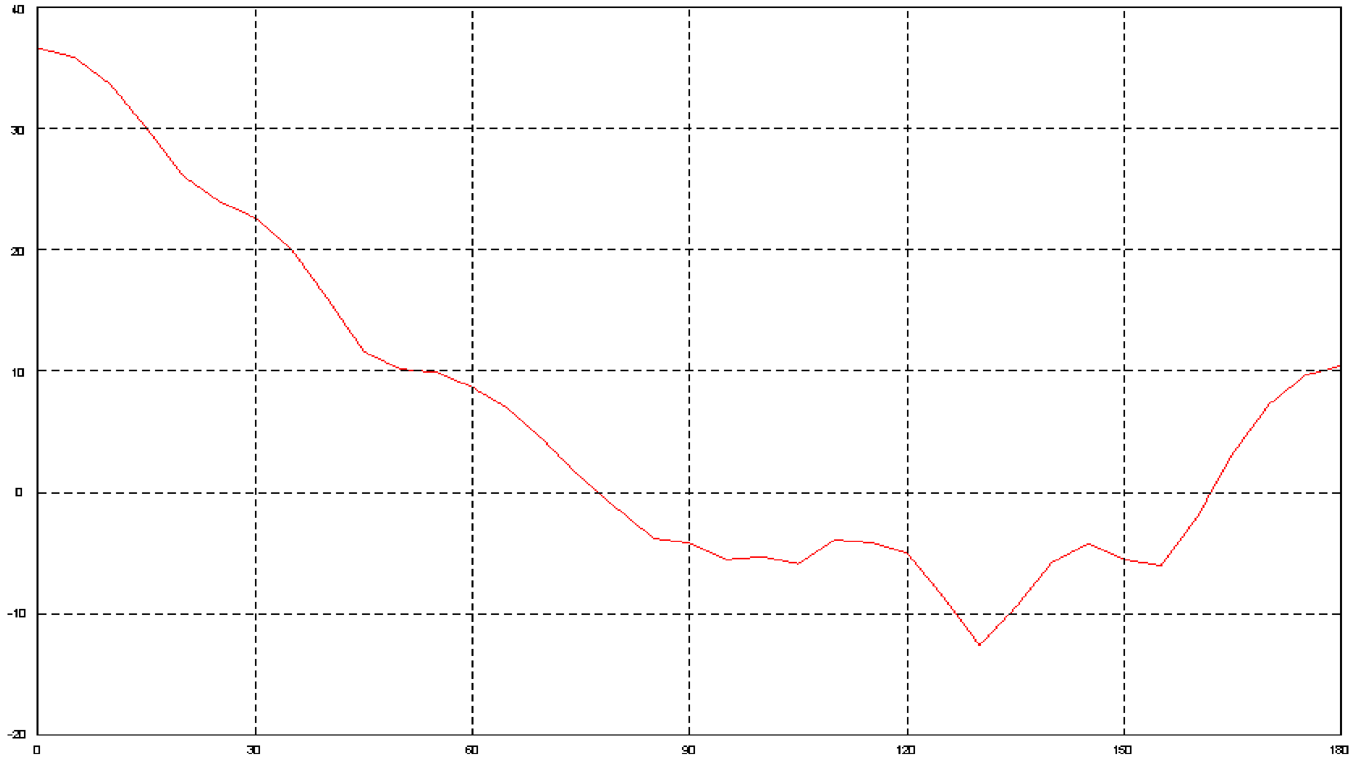

Figure 5.12: Electric far fields with respect to different angles

As shown Fig.5.13 below the mesh of flared out wave guide and electric field density with respect to the colors starting from the center, on top left numerical values. The right figure is the gain of far field at 10.7GHz frequency. Vertically at zero degree the gain is greater than elsewhere.

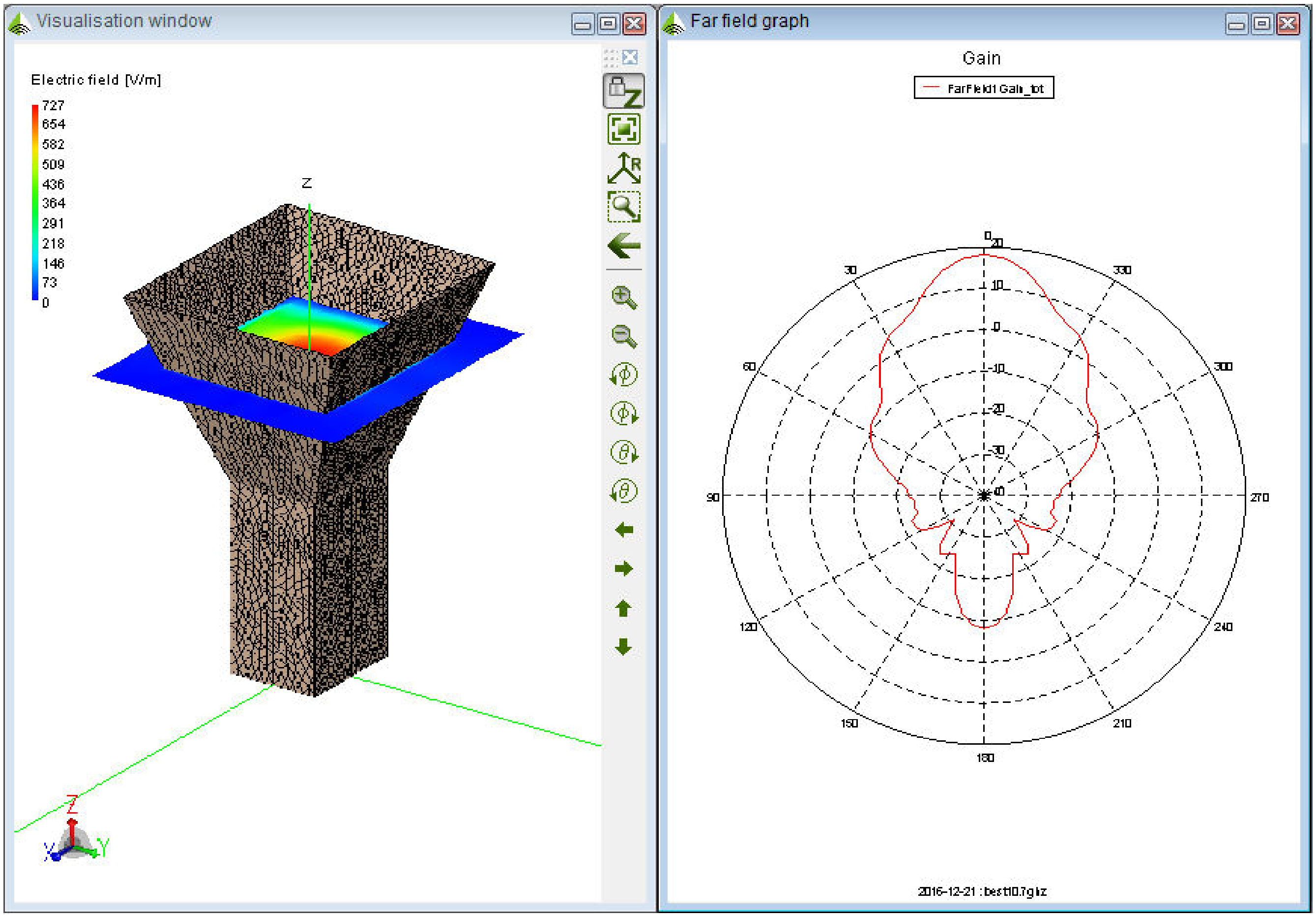

Figure 5.13: waveguide model and gain in polar plane at 10.7GHz

At 8.5GHz flare out waveguide design

From the graph of Fig.5.14 below as angles increases right and the electric field decreases. 3.84 mesh size of flared out wave guide and electric field density with respect to the colors starting from the center to the edges, on top left numerical values. The right figure is the gain at 8.5GHz frequency. The waveguide is vertically polarized, at zero degree the gain is greater actually less than at 10.7GHz frequency.

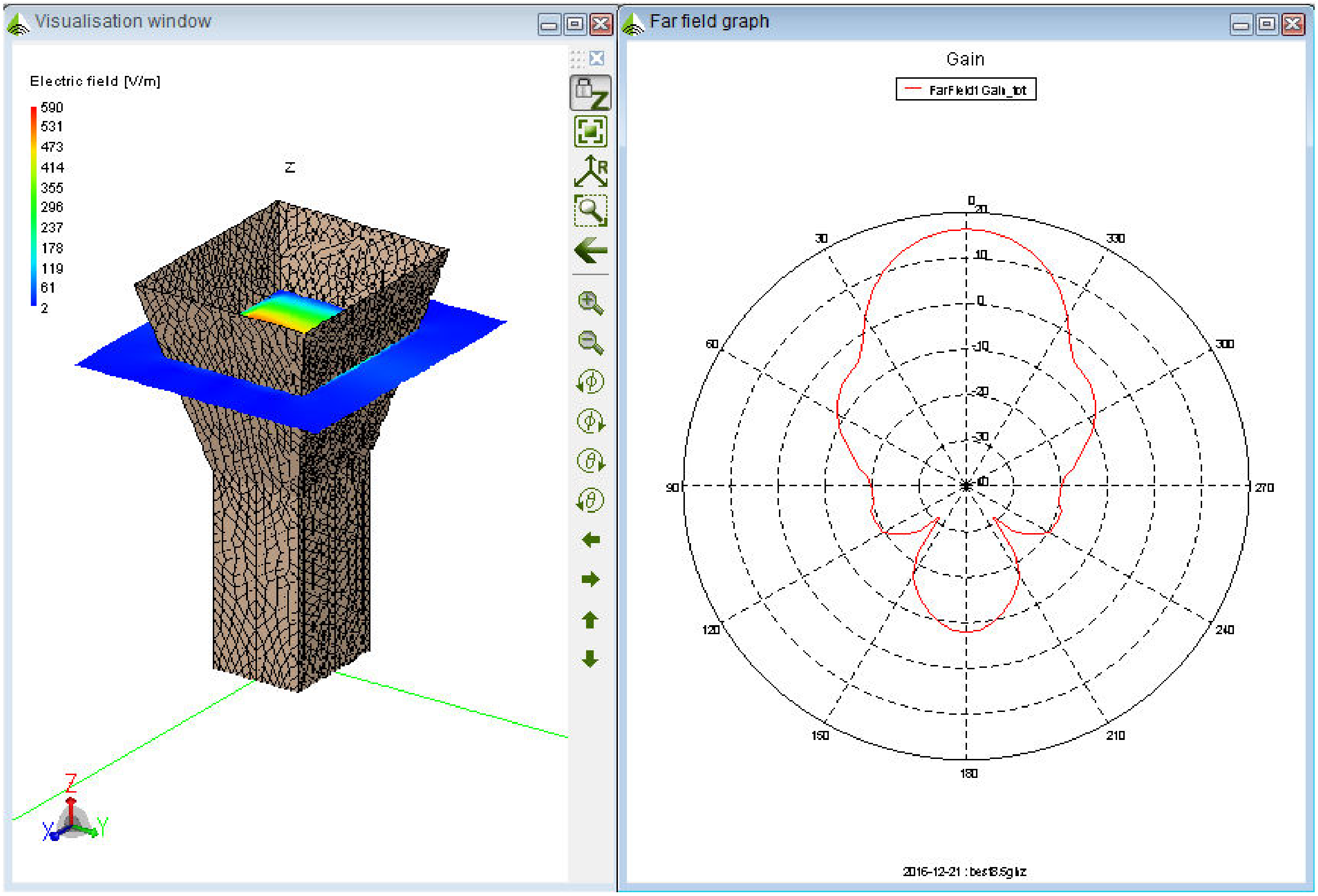

Figure 5.14: waveguide model and gain in polar plane at 8.5 GHz

6. Conclusion

In this thesis, the designed point to point microwave link communication between Jimma Main Campus and Agaro branch by means of geo-context profiler for path profile data's, feko suite 5.5 for flared out waveguide feeder design and mat lab/simulink for filter deign. Microwave link works on LOS and is not the same as optical line of sight; as a result it requires more clearance than optical line of sight to accommodate the characteristics of microwave signals; such as line of sight, Fresnel zone clearance, and free space loss considerations. The path profile for the two hop lengths were analyzed; The path profile for Site A to repeater is intended to use 107meters and 92 centimeters from each obstructions within the path, and 148meters and 59 centimeters for Repeater Site to Site B . The tower height calculations, angle of elevations and azimuth, Link budget calculations, signal to noise ratio calculations, reflection point calculations were also conducted.

The designed rectangular horn antennas have directional radiation pattern, ability to achieve high gain and directivity, slowly varying input impedance. The horn antenna we designed was subject to the following constraints: Operating frequency at 8.5GHz and 10.7 GHz. Reflection points that account for response signal fading are devised for different antenna heights, choosing high elevation of repeater site that is line of sight with both transmitter and receiver.

6.1. Future works

The designed microwave link in this thesis is depended on the transmission of only data and audio, video is not included. Therefore, further research could focus on video transmission and reception as with data and audio in wireless communication system of the link. Within the path of multipath/rain fading, Doppler shift, phase error, etc. was not considered that can be added to the channel, in order to closely simulate real life systems.

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APPENDIX A

A DEFINITION OF TERMS

Antenna- A device for receiving and transmitting electromagnetic signal

Antenna Feed- is the mechanism by which signal energy is radiated toward the parabolic reflector for transmission

Attenuation- Reduction of signal's voltage level as it travels down a line, measured in decibels

Azimuth- in directional radio transmission, the azimuth is the direction in degrees (bearing) that an antenna is transmitting to its far-end counterpart.

Bandwidth-refers to the range of frequencies the antenna will radiate effectively

Ducting- surface and elevated ducts are formed in a manner similar to conditions of super refraction and substandard refraction

Directivity- Antenna directivity means that maximum antenna gain compared with its gain that is averaged in all direction.

Elevation- is a perpendicular distance or vertical height of an objective above sea level

Fade Margin- is a "fudge factor" included in the system gain equation that considers the non-ideal and less predictable characteristics of radio wave, such as multi-path propagation, and terrain sensitivity

Fading- is the variation of the strength of a received radio carrier signal due to atmospheric changes or ground and water reflections in the propagation path.

Free Space- the space that does not interfere with the normal radiation and propagation of values

Free Space Loss- is the loss incurred by an electromagnetic wave as it propagate in a straight line through a vacuum with no absorption or reflection of energy from nearby objects

Fresnel Zones- Radio frequency line of sight is defined by Fresnel Zones which are ellipse shaped areas between any two radios

Gain- an increase in signal strength when transmitted from one point to another, often expressed in decibel, ratio of the output current, voltage or power of an amplifier

Ionosphere- the upper portion of the atmosphere which absorbs large quantities of radiant energy from the sun becoming heated and ionized

Interference- the mutual action of two or more waves at the same frequency, as of sound and light, in reinforcing or neutralizing each other according to their relative phases on meeting static, unwanted signal producing a distortion of sounds or images and preventing good reception

Latitude- the location of the point north or south of the equator measured in degrees, minutes and seconds of an arc

Longitude-the location of the point east or west of the prime meridian measured in degrees, minutes and seconds of an arc

Microwave- an electromagnetic wave in the radio frequency spectrum above 890MHZ

Noise- any condition that interferes with the desired signal to the detected signal by the control

Noise Factor (F) and Noise Figure (NF)- are the figures of merit used to indicate how much the signal-to-noise ratio deteriorate as a signal passes through a circuit or series of circuit

Parabolic Antenna- A highly directional used at a distance from 40-20 miles to achieve maximum transfer between the transmitter and receiver

Percent Reliability- provides means of translating system reliability by relating to system outage time

Reflection- the return of signal as it strikes a conductive medium such as metal surface or earth's surface

Refraction- is the change of direction of a ray as it passes obliquely from one medium to another with different velocities of propagation

Reliability- probability that is functioning the time it will be needed

Radome- used to protect microwave antennas against accumulation of ice, snow, and dirt and to reduce wind loading.

If Repeaters- are active repeater that the received RF carrier is down converted to an IF frequency, amplified, reshaped, up-converted to an RF frequency, and then retransmitted. The signal is never demodulated below IF.

Baseband Repeater- the RF carrier is down-converted to an IF frequency, amplified, filtered, and then further demodulated to base band.

Cross-polar discrimination (XPD)-In transmit mode, XPD is the proportion of signal that is transmitted in the orthogonal polarization to that which is required.

Voltage Standing Wave Ratio- is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna.

Front-to-Back (F/B) ratio- the ratio of power gain between the front and back of a directional antenna, or the ratio of signal strength transmitted in a forward direction to that transmitted in a backward direction.

Voltage-controlled oscillator- is an electronic oscillator whose oscillation frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency.

Local Oscillator-an oscillator whose output heterodynes with the incoming radio signal to produce sum and difference tones

A magic tee or hybrid tee- is a hybrid or 3 dB couple used in microwave systems. It is an alternative to the rat-race coupler. In contrast to the rat-race, the three-dimensional structure of the magic tee makes it less readily constructed in planar technologies such as micro strip.

Direct Current /DC - the electric current flows in a constant direction, distinguishing it from alternating current.

X- band- is a segment of the microwave radio region of the electromagnetic spectrum. In some cases, such as in communication engineering, the frequency range of the X band is rather indefinitely set at approximately 7.0 to 11.2 GHz.

A **light-emitting diode /LED-** two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated.

Terrestrial Microwave-is a communications system that uses a beam of radio waves in the microwave frequency range to transmit information between two fixed locations on the earth.

Denivelation- is the difference in level (depth) between two parts of a cave system, usually the highest and lowest known point. Depth is the distance between the cave entrance and the lowest known point reached

Carrier-to-Noise power ratio requirement

The C/N required at the input to the receiver to bit error rate. For M-QAM systems; the system bit error probability is given by:

$$Pe= \frac{2(\sqrt{M-1})}{\sqrt{M}\ \log2\ M} \text{erfc}\sqrt{\frac{3}{2(M-1)}(\frac{C}{N})}$$

Thus, for a 16-QAM

$$Pe= \frac{2(\sqrt{16-1})}{\sqrt{16}\ \log2\ 16} \text{erfc}\sqrt{\frac{3}{2(16-1)}(\frac{C}{N})}$$

$$\frac{22.5389}{79.467} \text{erfc}\sqrt{\frac{3}{2(16-1)}(\frac{C}{N})}=10^{-6}$$

$$1-\text{erf}\sqrt{\frac{3}{254}(\frac{C}{N})}=\frac{10-6}{0.2836} \rightarrow \text{erf}\sqrt{\frac{3}{254}(\frac{C}{N})}=0.9999965$$

$$\sqrt{\frac{3}{254}(\frac{C}{N})}=3.28 \rightarrow \frac{3}{254}(\frac{C}{N})=10.7584, \left(\frac{C}{N}\right) = 29.6 \text{ dB}$$

Receiver Input Noise Power

The total noise power at the input of a receiver is given by:

$N = K^* T0 ^*L^*F ^* B_{n},$

N (dBm) = -114 dBm/MHz + 10 log Bn (MHz) + 10 log LF, since KT0 = -114 dBm/MHz

Where: Ts, Bn, F and L are system temperature, noise bandwidth, receiver noise figure and loss representing losses between antenna and receiver.

i. The overall noise figure of a typical receiver for the 10.7 GHz band is 7.5dB

The total noise power N at the receiver input:

N =−114+10 log28 (MHz) +7.5=−99.53dBm

The required received carrier power for a minimum objective is given by:

$C_{min}= N + \frac{C}{N}$

The receiver threshold at $P_e= 10^{-6}$

C_{min}= -99.45+31.5 = -68.03dBm

System gain (Gs)

Gs=Pt-Cmin =21-(-68.03) = 89.03dB

ii. The overall noise figure of a typical receiver for the 8.5 GHz band is 8.39.

The total noise power N at the receiver input:

N =−114+10 log28 (MHz) +8.39=−91.14dBm

The required received carrier power for a minimum objective is given by:

C_{min}= N + $\frac{C}{N}$

The receiver threshold at $P_e = 10^{-6}$

C_{min}=-91.14+31.5 = -59.64dBm

System gain (Gs): Gs=Pt-Cmin =24-(-59.64) = 83.64dB

Configurations used for calculations of tower heights

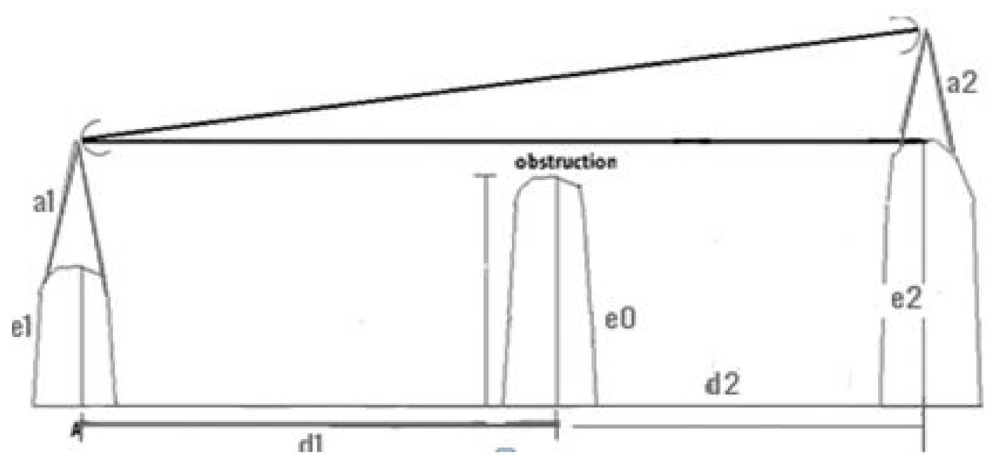

Figure A-1: Peak obstruction with antenna heights

First tower height = a1+e1+eb, Second tower height=a2+e2+eb

Peak obstructions heights=e0+eb+TG

Where: e1, $e_{0,}$ e2elevations at three different points, eb earth bulge, and TG tree growth

The following similar triangle configuration was used for calculations

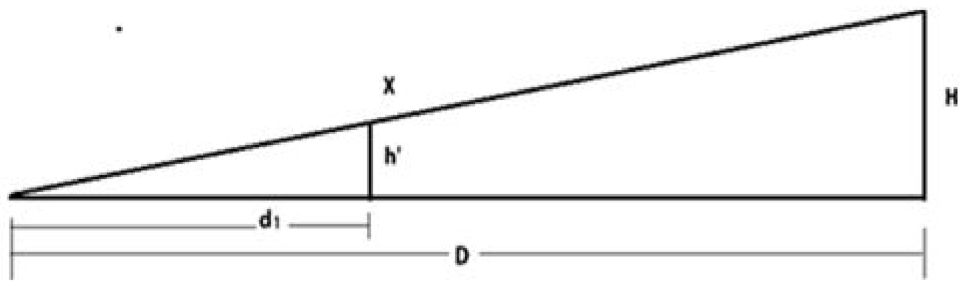

Figure A-2: triangle configuration was used for calculations

X =$\sqrt{D^2 + H^2}$, H= $h_2 - h_1$

$\frac{h'}{H} = \frac{d_1}{D}$ →h'= $\frac{d_1}{D} \times H = \frac{d_1}{D} \times (h_2 - h_1)$

$$H_{60\%} = 0.6 \times FFZ \rightarrow H_{60\%} = \frac{d_1}{D} \times (h_2 - h_1) - H_0 + h_1$$

h_2=First antenna height,$H_0 = Highest\ obstruction\ height$

$h_1 = \text{Secondantennaheight}$, H=the difference between antenna heights

FFZ=First Fresnel zone, D= hop length

APPENDIX B

USEFUL TABLES AND FIGURES

Table B-1: Radio configuration

	Frequency (GHz)	L6	U6	7	8	11	13	15	18	23	26	28	32	38
	Standard	ETSI / FCC	ETSI	ETSI	ETSI	ETSI / FCC	ETSI	ETSI	ETSI / FCC	ETSI / FCC	ETSI / FCC	ETSI	ETSI	ETSI / FCC
	Frequency Range (GHz)	5.925 ~ 6.425	6.425 ~ 7.100	7.125 ~ 7.9	7.725 ~ 8.5	10.7 ~ 11.7	12.75 ~ 13.25	14.4 ~ 15.35	17.7 ~ 19.7	21.2 ~ 23.6	24.25 ~ 26.5	27.5 ~ 29.5	31.8 ~ 33.4	37.0 ~ 40.0
FCC	T/R Spacing (MHz)	252.04				490 500			1560	1200	800			700
FCC	Channel Bandwidth (MHz)	10 30				10 30 40			10 20 30 40 50	10 20 30 40 50	10 20 40			10 50
ETSI	T/R Spacing (MHz)	252.04	340	154 161 168 196 245	119 126 208 266 311.32	490 530	266	420 490 728	1008 1010	1008 1232	1008	1008	812	1260
ETSI	Channel Bandwidth (MHz)	29.65	7 14 30 40 60	7 14 28	7 14 28 29.65	40	7 14 28	7 14 28 56	7 13.75 27.5 55	7 14 28 56	7 14 28 56	7 14 28 56	7 14 28 56	7 14 28 56
	RF Channel Selection	Via Web GUI												
	System Configuration	1+ 0, 1+1 HSB and 2+0												
	ATPC Range (dB)	Transmit Power Control – Adaptive, lower power limit varies with RF band down to 1dBm minimum.												

Table B-2: maximum transmit power of 6-38GHz frequency

Modulation	Maximum Transmit Power – ETSI (dBm)								Maximum Transmit Power – FCC (dBm)				
	Frequency (GHz)								Frequency (GHz)				
	6, 7, 8	11	13, 15	18	23, 26	28	32	38	L6	11	18	23, 26	38
QPSK	30.0	28.0	26.0	26.0	25.0	25.0	23.0	23.0	22.0	19.0	23.0	23.0	20.0
8PSK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	22.0	19.0	22.0	22.0	19.0
16 QAM	28.0	26.0	23.0	22.0	22.0	22.0	21.0	20.0	22.0	19.0	22.0	22.0	19.0
32 QAM	28.0	26.0	23.0	22.0	22.0	20.0	19.0	20.0	22.0	19.0	22.0	22.0	19.0
64 QAM	24.0	21.0	18.0	17.0	17.0	17.0	16.0	16.0	22.0	19.0	17.0	17.0	15.0
128 QAM	24.0	21.0	18.0	17.0	17.0	17.0	16.0	16.0	22.0	19.0	17.0	17.0	15.0
256 QAM	22.0	19.0	16.0	15.0	15.0	15.0	14.0	14.0	22.0	19.0	15.0	15.0	13.0

Table B-3: Receive sensitivity of frequency bands 6-38GHz

Receive Sensitivity									
BER = 1e-6	Modulation	Frequency (GHz)							
		6, 7, 8	11	13, 15	18	23, 26	28	32	38
Receive Sensitivity @ 56/60 MHz channel (dBm)	256 QAM-H	N/A	N/A	-63.7	N/A	-63.2	-62.7	-62.2	-61.2
	256 QAM-L	N/A	N/A	-65.6	N/A	-65.1	-64.6	-64.1	-63.1
	128 QAM	N/A	N/A	-68.3	N/A	-67.8	-67.3	-66.8	-65.8
	64 QAM	N/A	N/A	-71.3	N/A	-70.8	-70.3	-69.8	-68.8
	32 QAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	16 QAM	N/A	N/A	-77.7	N/A	-77.2	-76.7	-76.2	-75.2
	8PSK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	QPSK	N/A	N/A	-83.5	N/A	-83.0	-82.5	-82.0	-81.0
Receive Sensitivity @ 55 MHz channel (dBm)	256 QAM-H	N/A	N/A	N/A	-63.8	N/A	N/A	N/A	N/A
	256 QAM-L	N/A	N/A	N/A	-65.7	N/A	N/A	N/A	N/A
	128 QAM	N/A	N/A	N/A	-68.4	N/A	N/A	N/A	N/A
	64 QAM	N/A	N/A	N/A	-71.4	N/A	N/A	N/A	N/A
	32 QAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	16 QAM	N/A	N/A	N/A	-77.8	N/A	N/A	N/A	N/A
	8PSK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	QPSK	N/A	N/A	N/A	-83.6	N/A	N/A	N/A	N/A
Receive Sensitivity @ 50 MHz channel (dBm)	256 QAM	N/A	N/A	N/A	-65.8	-65.3	N/A	N/A	-62.3
	128 QAM	N/A	N/A	N/A	-69.0	-68.5	N/A	N/A	-65.5
	64 QAM	N/A	N/A	N/A	-72.0	-71.5	N/A	N/A	-68.5
	32 QAM	N/A	N/A	N/A	-74.3	-73.8	N/A	N/A	-70.8
	16 QAM	N/A	N/A	N/A	-76.3	-75.8	N/A	N/A	-72.8
	8PSK	N/A	N/A	N/A	-79.6	-79.1	N/A	N/A	-76.1
	QPSK	N/A	N/A	N/A	-84.2	-83.7	N/A	N/A	-80.7
Receive Sensitivity @ 40 MHz channel (dBm)	256 QAM	N/A	-67.3	N/A	-67.3	-66.8	N/A	N/A	N/A
	128 QAM	-69.5	-70.0	N/A	-70.0	-69.5	N/A	N/A	N/A
	64 QAM	-71.9	-72.4	N/A	-72.4	-71.9	N/A	N/A	N/A
	32 QAM	N/A	-74.5	N/A	-74.5	-74.0	N/A	N/A	N/A
	16 QAM	N/A	N/A	N/A	-79.4	-78.9	N/A	N/A	N/A
	8PSK	N/A	N/A	N/A	-81.6	-81.1	N/A	N/A	N/A
	QPSK	N/A	N/A	N/A	-85.2	-84.7	N/A	N/A	N/A
Receive Sensitivity @ 30 MHz channel (dBm)	256 QAM	-68.0	-68.5	N/A	-68.5	-68.0	N/A	N/A	N/A
	128 QAM	-70.7	-71.2	N/A	-71.2	-70.7	N/A	N/A	N/A
	64 QAM	-73.0	-74.2	N/A	-74.2	-73.7	N/A	N/A	N/A
	32 QAM	N/A	-76.8	N/A	-76.8	-76.3	N/A	N/A	N/A
	16 QAM	N/A	N/A	N/A	-80.6	-80.1	N/A	N/A	N/A
	8PSK	N/A	N/A	N/A	-82.8	-82.3	N/A	N/A	N/A
	QPSK	N/A	N/A	N/A	-86.4	-85.9	N/A	N/A	N/A
Receive Sensitivity @ 28/29.65[3] MHz channel (dBm)	256 QAM	-68.2	N/A	-68.7	N/A	-68.2	-67.7	-67.2	-66.2
	128 QAM	-70.9	N/A	-71.4	N/A	-70.9	-70.4	-69.9	-68.9
	64 QAM	-73.9	N/A	-74.4	N/A	-73.9	-73.4	-72.9	-71.9
	32 QAM	-76.4	N/A	-76.9	N/A	-76.4	-75.9	-75.4	-74.4
	16 QAM	-80.3	N/A	-80.8	N/A	-80.3	-79.8	-79.3	-78.3
	8PSK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	QPSK	-86.1	N/A	-86.6	N/A	-86.1	-85.6	-85.1	-84.1

Table B-4: Radome losses

Radome Type	Diameter ft (m)	Attenuation, dB							Add to Antenna VSWR		
		2 GHz	6 GHz	8 GHz	11 GHz	13 GHz	15 GHz	18 GHz	2 GHz	6 GHz	11 GHz and above
Standard Antenna Radomes											
Standard	2 (0.6)	0.1	0.4	0.6	1.0	1.2	1.5	2.7	0.02	0.03	0.05
Standard	4 (1.2)	0.1	0.4	0.7	1.2	1.5	2.0	2.9	0.02	0.03	0.05
Standard	6 (1.8)	0.1	0.5	0.9	1.4	1.7	2.1	2.9	0.02	0.03	0.03
Standard	8 (2.4)	0.1	0.6	1.0	1.5	1.8	2.2	–	0.02	0.03	0.03
Standard	10 (3.0)	0.2	0.9	1.3	1.8	2.1	2.5	–	0.02	0.03	0.03
Standard	12 (3.7)	0.2	1.0	1.3	1.9	2.2	2.6	–	0.02	0.03	0.03
Extra Strength	10 (3.0)	0.3	1.2	1.5	2.0	2.2	2.6	–	0.02	0.03	0.03
Extra Strength	12 (3.7)	0.03	1.4	1.7	2.0	2.3	2.6	–	0.02	0.03	0.03

Table B-5: X-Band Solid State Power Amplifier specification

• Frequency Range:	9.0 to 10 GHz
• Output Power:	40W CW (+46 dBm)
• Power Gain:	46 dB nominal
• Dynamic Range:	30 dB
• Phase Stability	± 2.0° Peak to Peak
• Duty Cycle:	up to 100% DF
• Input VSWR:	<1.8:1
• Output Load VSWR	1.5:1
• Load VSWR Protection:	Internal Circulator
• Input RF Overdrive	+10 dB Max
• Output Fwd. & Rev. Monitoring:	± 0.5 dB typical
• Harmonics:	
2Fo:	<-60dBc
3Fo:	<-80dBc
• DC Voltage Input:	+36 VDC to +45 VDC
• DC Power Consumption:	225W max
• RF to DC Efficiency:	>18 % typical
• Operating Temperature:	0°C to +55°C baseplate
• Operating Humidity:	0 to 95% non-condensing
• Operating Shock & Vibration:	Per Mil-Std-810F
• Operating Altitude:	10,000 Ft.
• Control Interface:	RS-485
• RF Connectors:	
RF Input Port:	SMA Female
RF Output:	WG-90 (Bottom Surface)
• DC & Interface Connectors:	*Mighty Mouse* Series 80
• Size:	4.00" x 4.00" x 3.33"
• Weight:	2.5 lbs.

Table B-6: Waveguide (EU77) losses

Frequency GHz	Attenuation(1) dB/100m (dB/100ft)	Group velocity %	Av. Power(2) kW
7.1	6,65 (2.03)	71.0	2.88
7.2	6,56 (2.00)	72.0	2.92
7.3	6,48 (1.97)	72.9	2.96
7.4	6,40 (1.95)	73.7	2.99
7.5	6,33 (1.93)	74.5	3.03
7.6	6,27 (1.91)	75.3	3.06
7.7	6,21 (1.89)	76.0	3.09
7.8	6,15 (1.87)	76.8	3.12
7.9	6,10 (1.86)	77.4	3.14
8.0	6,05 (1.84)	78.1	3.17
8.1	6,00 (1.83)	78.7	3.20
8.2	5,96 (1.82)	79.3	3.22
8.3	5,91 (1.80)	79.8	3.24
8.4	5,87 (1.79)	80.4	3.26
8.5	5,84 (1.78)	80.9	3.28

Table B-7: Waveguide (EU-90-FR) losses

Frequency GHz	Attenuation(1) dB/100m (dB/100ft)	Group velocity %	Av. Power(2) kW
10.2	10,08 (3.07)	75.0	1.58
10.3	10,01 (3.05)	75.5	1.59
10.4	9,94 (3.03)	76.1	1.60
10.5	9,87 (3.01)	76.6	1.61
10.6	9,81 (2.99)	77.1	1.62
10.7	9,74 (2.97)	77.6	1.63
10.8	9,68 (2.95)	78.1	1.64
10.9	9,63 (2.93)	78.5	1.65
11.0	9,57 (2.92)	79.0	1.66
11.1	9,52 (2.90)	79.4	1.67
11.2	9,47 (2.89)	79.8	1.68
11.3	9,43 (2.87)	80.2	1.69
11.4	9,38 (2.86)	80.6	1.70
11.5	9,34 (2.85)	81.0	1.70
11.6	9,30 (2.83)	81.3	1.71
11.7	9,26 (2.82)	81.7	1.72

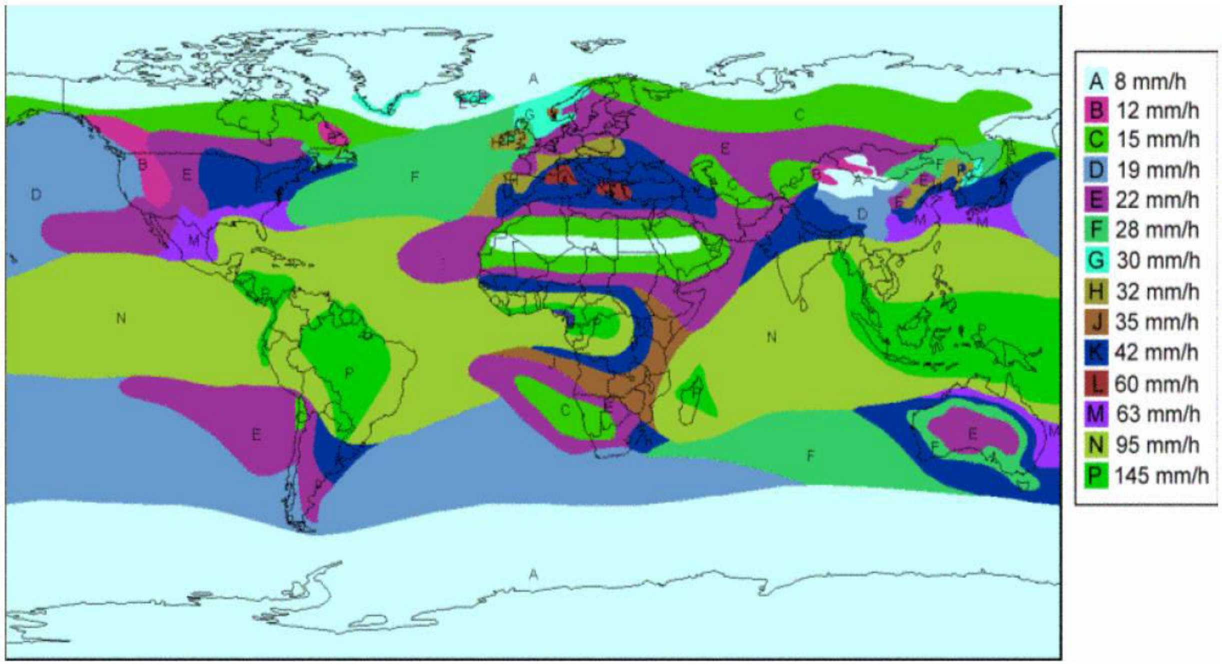

Figure B-5: Rain zone map

Table B-8: Rain rate R (mm/h)

Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	15	2	4	5	12	14
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	42	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

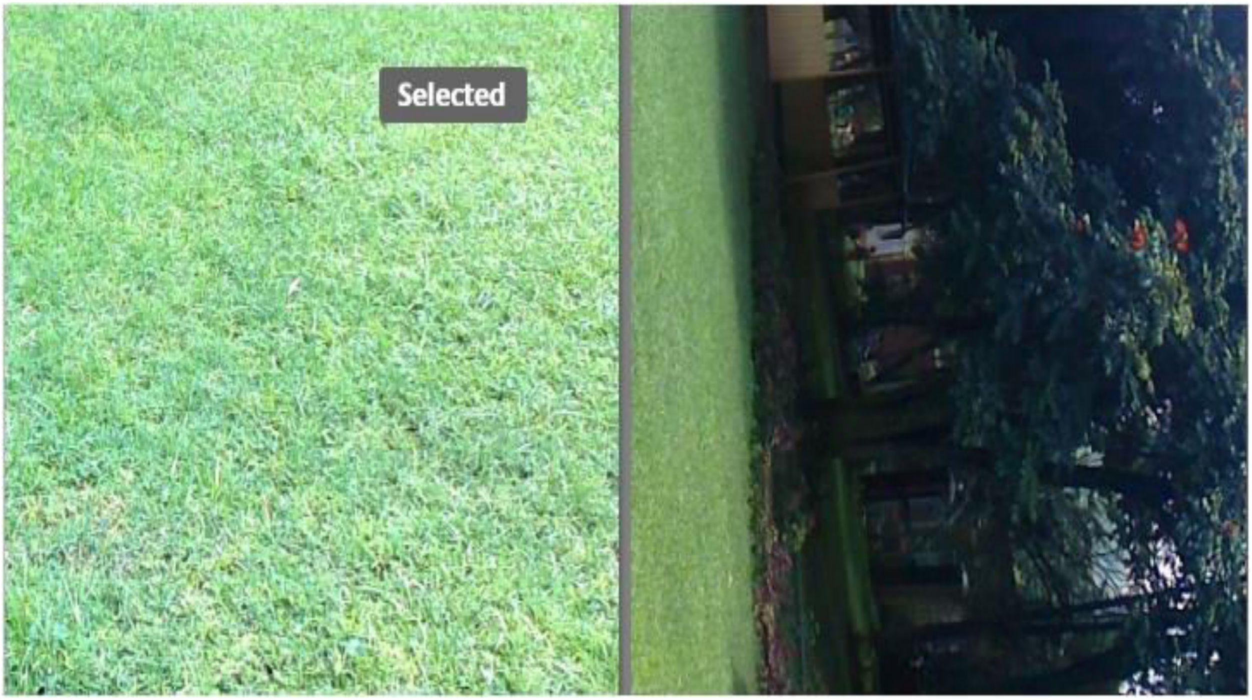

Figure B-6: Selected area of site A

Figure B-7: Selected area of repeater

Figure B-8: Selected area of site B