DESIGN OF FREQUENCY MODULATION RADIO SERVICE FOR THE FEDERAL UNIVERSITY OF TECHNOLOGY AKURE COMMUNITY

BY

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EEE/91/2916

THE FEDERAL UNIVERSITY OF TECHNOLOGY,

AKURE

AUGUST, 2003.

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PONNLE, AKINLOLU ADEDIRAN (B. ENG., FUTA)
EEE/91/2916

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ONDO STATE,
NIGERIA.

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DEDICATION

This project is dedicated first to the glory of Almighty God, the author and finisher of my dream and faith and then to my ever courageous and loving mother, Evangelist (Mrs.) F.D. Ponnle whom God used to make my dream of being an Engineer become a reality.

CERTIFICATION

This is to certify that this work was carried out by Ponnle Akinlolu Adediran (EEE/91/2916) and approved as meeting the requirement for the award of Master of Engineering in Electrical and Electronics Engineering (Communication Option) of the Department of Electrical and Electronics Engineering, The Federal University of Technology, Akure.

Bisi Adeloye

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Supervisor & HOD, EEE.

31- 8 - 2003.

Date

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ABSTRACT

Communication is an important aspect of human life. As man continues in his daily life, the need to continually communicate, acquire and share information becomes more obvious. It then becomes important and necessary to be more information conscious not only in the content but as well as the speed of its transfer.

This work centers on the design of a broadcast Frequency Modulation Radio Service for the Federal University of Technology, Akure Community which could later be integrated into the community's existing communication network in order to reduce communication problems and improve information dissemination within the community. The whole work in general involved topographical study of FUTA Community, spot coordinates and height measurements, visual inspection and measurement of signal strength of some neighbouring FM stations. The results of these studies and measurements were used to recommend suitable transmitting location and antenna height; to develop appropriate model for field strength distribution prediction and evaluation of transmitting parameters such as radiated power, radiation pattern, polarisation, transmitter power, antenna gain and operating frequencies with a view to recommending appropriate broadcast equipment specifications.

Also, antenna design by hardware modeling and software simulation for the recommended radiation pattern was carried out. A model of a suitable broadband antenna system was tested at 1400 MHz using Antenna Lab System and Discovery Software Antenna Instruments 2.50. The designed antenna for the actual service band (VHF II band) and its array of 3 antennas was simulated on WIN-NEC Antenna Analysis 1.0 and radiation characteristics generated and examined.

A 3, 5 – element Log Periodic Dipole Antenna array orientated in West – East and South direction with equal amplitude and co – phased excitation on 30 metres free standing steel tower erected on Obanla Sports Complex ridge would produce satisfactory radiation pattern and horizontal polarisation. A minimum radiated power (EIRP) of 15W is adequate for the community.

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CHAPTER I
INTRODUCTION

More than 100 years ago, the world underwent drastic changes because of the Industrial Revolution. Nowadays, we are in the age of Information Revolution brought about by rapid development in Information Technology. Communication has entered our daily lives in many different ways that we easily overlook its multifarious facets. We have the GSM phones in our hand, radio and television sets in our living rooms and offices, newspapers and the Internet. Information available in these media is assembled by rapid communication from every corner of the globe.

Communication involves implicitly the transmission of information from one point to another through a succession of process. The process requires a communication system, which conveys the information from its source to a destination some distance away. The communication system comprises of:

- A transmitter which process the input signal to produce a transmitted signal suited to the characteristics of the transmission channel.
- A transmission channel which is the medium that bridges the distance from source to destination and
- A receiver, which operates on the output signal from the channel in preparation for delivery to the transducer of the destination.

Radio is the name given to the system of transmission and reception of information by the propagation of electromagnetic radiation as radio waves through space. Radio supports a very versatile telecommunications transmission technique. It is the only feasible transmission technique for some kinds of communication systems and for many others; it is often the most economical, Withers (1991). For example, communication with astronauts and space probes in deep space are only possible by radio.

International Telecommunications Union (ITU) defines radio communication as telecommunication by means of radio waves and radio communication service as services involving the transmission, emission and/or reception of radio waves for specific telecommunication purpose. Broadcasting service is a radio communication service in which transmissions are intended for direct reception by the general public. This service includes sound transmission, television transmission or other types of transmission, ITU-R, (1986).

Radio Service Planning and Design is about preparation for the establishment of a radio service for some targeted service area(s) with the goal of obtaining satisfactory reception of radio frequency signals within the targeted service area(s). For a broadcast purpose i.e. point to zone service, the work centers mainly on planning for the transmitter's coverage, channel capacity and operating frequency. For the transmitter's coverage, detailed information of the environment is needed from which transmitting parameters are determined. Transmitting parameters include location, effective radiated power, antenna type, gain and height, radiation pattern, polarisation and mode of modulation.

Specifying transmitting parameters requires a very good knowledge of radio wave propagation, modulation systems, transmitting and receiving equipment technology and the regulations on the use of radio wave spectrum formulated by national and international bodies, Causebrook (1992).

1.1 PROJECT MOTIVATION

Federal University of Technology, Akure (FUTA) community has been in existence for some time and currently, it is undergoing a rapid development. Quick information dissemination within the community especially those involving the majority of people, is very important. The condition of the community area is favourable for noise free service because it is well separated from the busy city of Akure which accommodates interference caused by many man made noise sources. FM is less susceptible to atmospherics, static, interference and fading when compared to AM. Though there are some communication networks within Akure community, nevertheless the installation of an FM broadcast radio station within FUTA community for informative, educative and commercial purpose becomes a necessity. The speed at which useful information are disseminated within a locality by the means of communication systems being used is one of the parameters that define the level of development of that locality. The prosperity and continued development of modern nations depends primarily not only on manufactured goods but as well as on origination and dissemination of information.

1.2 OBJECTIVES OF THE PROJECT

The objectives of this work are: -

- To recommend suitable transmitting location and antenna height.
- To evaluate transmitting parameters such as radiated power, radiation pattern, polarisation, antenna gain and operating frequencies for the desired service.
- Recommending appropriate transmitting (broadcast) equipment specifications.

1.3 METHODOLOGY

Topographical study of Akure and FUTA was carried out using topographical maps which were obtained from the Ministry of Works, Land and Transport, Akure and the Institution's Physical Planning Unit respectively. Geographical survey, visual inspection, spots coordinate and height measurements using GPS Receiver (Global Positioning by Satellite receiver) of the various target service areas of the community were also carried out. In order to allay fears of interference, relative signal strength (reception) of neighbouring FM stations was measured using a VHF/UHF field strength measuring equipment, UNAOHM, model EP742A. The results of these studies were used to develop a model for field strength prediction and determination of the planning objectives for the FM radio service.

In order to ensure satisfactory reception in the community with the parameters estimated, prediction of field strength distribution throughout the community was performed. This involved partitioning the community land area into zones and appropriate propagation model developed for each zone depending on the topography.

The second stage was the design of the antenna for the band of service in concern (VHF II). A QBASIC Program was written for this purpose.

The third stage is the Software Simulation of the designed antenna and radiation characteristics simulated and verified for the band of service concerned for agreement with hardware modeling results. The software simulation was facilitated by WIN – NEC, Antenna Analysis Software, Version 1.0 in Visual Basic.

1.4 EXPECTED CONTRIBUTION TO KNOWLEDGE

The project will provide fundamental specifications for planning and development of FM radio service in FUTA and similar locations.

1.5 ORGANISATION OF THESIS

The thesis is written to be comprehensive enough and is achieved by giving full description of operations, premises on which choices are based, mathematical analysis, photographs and extensive use of diagrams.

Chapter 1 introduces the work, motivation, objectives and contribution to knowledge

Chapter 2 gives a comprehensive literature review on history of radio communication, regulatory bodies (international and national), characteristics of broadcast radio service, frequency & transmission standards for VHF II band, mechanisms of radio wave propagation and ray path models developed for different land terrain as applicable to the community land area. Also, extensive review is given on transmission lines, antennas and matching techniques. The chapter is concluded with review of development, characteristics and design procedure of Log Periodic Dipole Antenna being the antenna modeled and simulated.

Chapter 3 is devoted to comprehensive description of the design process, operations and methods carried out in determining the transmitting parameters and antenna synthesis.

Chapter 4 provided the results of the field strength distribution prediction, the result of the antenna synthesis and the choice of suitable transmission line and transmitter power.

Some items and operations needed carrying out for the station's set up is outlined in Chapter 5 and the transmitting parameters for the community compiled in Chapter 6.

CHAPTER 2
LITERATURE REVIEW

2.1 BRIEF HISTORY OF RADIO COMMUNICATION

James Clerk Maxwell at London University first conceived the electromagnetic waves of radio in 1864. After constructing a brilliant new general theory of electromagnetism expressed in mathematical equations, he concluded that light consists of transverse waves of oscillatory electric and magnetic fields and he suggested that similar waves having quite different frequencies from that of light but traveling at the speed of light might be created or discovered.

In 1886 – 1888, Heinrich Hertz first used oscillatory radiating circuits to demonstrate the reality of electromagnetic waves other than light waves traveling in air at the speed of light and Gugliemo Marconi made practical applications of Hertz's work experimenting with various modifications of the design of Hertz's transmitter. Radio Communication was made possible by the invention of the triode tube and was greatly improved by the work done during World War II. It subsequently became even more widely used and refined through the invention of and use of the transistor, ICs and other semiconductor devices.

Radiotelegraphy, radio broadcasting, short wave radio, telephony and all other forms of radio communication in use up to 1935 used Amplitude Modulation (AM). After prolonged experimenting, Edwin H. Armstrong demonstrated in 1935 the advantages of using wide band Frequency Modulation (FM) over AM and persisted with public presentation until FM broadcasting started in 1939.

2.2 BRIEF HISTORY OF RADIO BROADCASTING IN NIGERIA

Radio broadcasting was introduced into Nigeria by the Colonial Administration in 1933 to provide a means of dissemination of information and entertainment to the people. Before the advent of portable transistor radios, radio broadcasting was through wired loudspeakers located at community receiving centers where large numbers of people gathered to listen to programmes.

The first radio stations were monitoring and re-broadcast stations for the British Broadcasting Corporation for the Empire Service. Gradually, local programmes were introduced and the stations later became full broadcasting houses under the Nigerian Broadcasting Service. Today, there are radio broadcasting stations owned by the Federal Government under the Federal Radio Corporation of Nigeria (FRCN) and some by state governments. Early radio stations established were mostly operating in the MW and the SW bands. FM operation was uncommon then.

The latter part of the last century (1990's) witnessed the springing up of many stereophonic FM stations owned by state governments and individuals due to the deregulation of the country's communications industry in 1992 by the then Military Government. Nowadays, the trend in terrestrial broadcast radio service is operation in the FM band.

The country will still witness establishment of more private FM radio stations in the next few decades though not without some problems of available spectrum management.

2.3 INTERNATIONAL TELECOMMUNICATION UNION (ITU)

ITU is a specialized agency of the United Nations saddled with the responsibility of allocating the entire radio frequency spectrum to various countries and services and coordinating their appropriate usage worldwide. The Union was set up in 1932. It incorporated a number of predecessor bodies most notably the International Telegraph Union and various consultative bodies, which had been used to foster international telecommunication, each dealing with particular aspects of the field. ITU membership has increased over the years and Nigeria is a member country.

The purposes of the Union are: -

- To maintain and extend international cooperation between all members of the Union for the improvement and rational use of telecommunications of all kinds, as well as to promote and to offer technical assistance to developing countries in the field of telecommunications.
- To promote the development of technical facilities and their most efficient operation with a view to improving the efficiency of telecommunications services, increasing their usefulness and making them, as far as possible, generally available to the public.
- To promote the use of telecommunication services with the objective of facilitating peaceful relations, Article 1 of Constitution, ITU (1990).

The Union fully recognises the sovereign right of each state to regulate its telecommunications.

In order to carry out its radio spectrum management functions, the Union:

- Effect allocation of the radio frequency spectrum, the allotment of radio frequencies and registration of radio frequency assignments and any associated orbital positions in the geostationary-satellite orbit in order to avoid harmful interference between radio stations of different countries.
- Coordinate efforts to eliminate harmful interference between radio stations of different countries and to improve the use made of the radio frequency spectrum and the geostationary-satellite orbit.
- Coordinate efforts to harmonise the development of telecommunication facilities, notably those using space techniques, with a view to full advantage being taken of their possibilities.
- Promote the adoption of measures for ensuring the safety of life through the cooperation of telecommunication services.
- Undertake studies, make regulations, adopt resolutions, formulate recommendations and opinions, and collect and publish information concerning telecommunication matters, Article 1 of Constitution, ITU (1990).

Various organs are established under the ITU to see to various aspects of its functions. The ITU controls the International Frequency Registration Board (IFRB), which keeps a record of frequencies allocated to different services. The Board is now re-designated as Radio Regulations Board (RRB) and their main task is to decide whether frequencies which countries assign to their transmitters (and which have been notified to the RRB) are in accordance with 'Radio Regulations' and will not cause harmful interference to other stations. If the RRB's finding is favourable, the frequency is recorded in the Master International Frequency Register and thus obtains protection.

The ITU also controls two International Consultative Committees, one for telegraph and telephone, CCITT and the other for radio, CCIR. The CCIR is now re-designated the Radio Communication Bureau (ITU-R) and CCITT as ITU-T. Plenary assemblies are held every few years, which draw up a list of subjects for study. Recommendations are then drawn up by study groups, which are submitted, to the next Plenary Assembly. If adopted, they are published.

ITU also organizes the World Radio Conference (WRC), which periodically reviews spectrum demands and utilization by both old and new radio communication services and devices. Their recommendations and demands are passed to the appropriate Study Group for further study and appropriate recommendations passed to the ITU-R.

2.4 FEDERAL MINISTRY OF COMMUNICATIONS

Policy on telecommunications in the country is the responsibility of the Federal Government of Nigeria through the Federal Ministry of Communications. The Ministry is empowered to: -

- Represent the country's membership and interest in ITU.
- Execute international agreements.
- Enforce rules and regulations as stipulated in the radio regulations.
- Assign frequency to operators of radio communication services in the country.

In order to carry out the above functions, the Federal Government set up two regulatory authorities, namely National Broadcasting Commission (NBC), Decree 38, (1992) and Nigeria Communications Commission (NCC), Decree 75, (1992).

2.5 NATIONAL BROADCASTING COMMISSION (NBC)

The Federal Military Government of Nigeria on August 24, 1992 promulgated Decree 38, which established the NBC as a government agency to regulate and control broadcasting in Nigeria. The main functions of the Commission include: -

- Receiving, processing and considering applications for the ownership of radio and television stations including cable TV services, direct satellite broadcast and any other medium of broadcasting.
- Allocating broadcast frequencies.
- Regulating and controlling the broadcast industry.
- Issuing, renewing of broadcast licenses and revoking licenses of defaulting stations, which do not operate in accordance with the broadcast code and in the public interest.
- Approving transmitting parameters, regulating transmitting (broadcast) equipments as well as monitoring emissions for harmful emission, interference and illegal broadcasting.
- Establishing, disseminating national broadcasting code and setting standards with regard to the contents and quality of materials for

broadcast. Supplement to Federal Republic of Nigeria Official Gazette Extraordinary, (1992).

2.6 RADIO SERVICES AND USES

2.6.1 CLASSIFICATION OF RF SPECTRUM

Carriers of wide range of frequencies are used in radio communication systems for different types of services. Table 2.1 gives classification and the propagation characteristics of the electromagnetic spectrum used for radio communication. It also gives the type of services involved.

2.6.2 USES OF RADIO

The first practical application of radio in the 1900's between ships and shore stations was followed quickly by overseas communication and communication between other widely separated fixed points. Subsequently, the applications have become widely diversified. Some of the important uses are: -

1.Public Safety: - Marine and aviation communication, police and fire protection, forestry conservation and highway traffic control.

2. Industrial: - Power utilities, pipelines, relay services, news system, agriculture and petroleum processing.

3. Land Transportation: - Rail roads, motor carriers, taxicabs and automobile emergency needs.

4. Broadcasting: - Television, FM broadcasting, AM broadcasting and short wave (SW) broadcasting.

5. Military and Space: - Radar, navigation, telemetry, missile tracking, satellite photographic survey and missile guidance.

6. Fixed Point to Point: - Long distance message and picture transmission.

7. Relaying: - Television, sound picture and public message relaying over long distance. Most recently as a major part of the relaying functions of radio, communication satellites have handled a great deal of overseas communications including several thousand narrow channel for telephone, teletype, wide channels for TV and other video transmission.

8. Telemetry: - Remote indication of water levels in reservoirs and rivers, performance of experimental aircraft, missiles, satellites and space probes.

9. Weather Reporting: - Early warning and location of hurricanes and other storms, trends of weather for industrial and public information.

2.6.3 CLASSIFICATION OF RADIO COMMUNICATION

Radio communication can be divided into three categories called point to point, point to zone and point to multipoint communication respectively.

In point to point communication, corresponding in particular to fixed service links, the characteristics and locations of the end of the path are entirely known. Fixed service links include radio relay links and satellite links. As this type of link involves relays, frequency reuse is standard which therefore leads to the possibility of interference.

In point to zone communication, only one of the ends (transmitter or base station) has a fixed location and known characteristics. The other end could be anywhere within the zone covered by the fixed station.

Point to multipoint communication appears both in radio broadcasting and fixed services. This is the case for example of a television transmitter serving a certain number of relay transmitters whose locations are well known.

2.6.4 CHARACTERISTICS OF POINT TO ZONE COMMUNICATION

The two major examples of point to zone communication are radio broadcasting (sound and vision) and mobile services (terrestrial, aeronautical or maritime). In general, one fixed station serves several stations either unilaterally (radio broadcasting) or bilaterally (mobile service). In this case, it is impossible to protect against interference by means of a shift in angle between the direction of the desired signal and the interfering signal.

The aim of services using point to zone communication is to obtain a complete coverage of a region, dividing it into contiguous zones (cells) if warranted, such that the radio station allocated to each zone provide adequate coverage of that zone and does not cause interference with others. In general, neighboring cells use different radio channels and possibly different polarizations.

In point to zone communication, one of the ends of each link is at an arbitrary location not specified in advance, and some of these locations are more favourable than others at the same distance. For example, for sound broadcasting, many of the receivers will be mobile and often at street level or inside buildings. Therefore a concept of percentage of locations for which given transmission characteristics apply is introduced. Statistics only consider locations for which the service in question is possible. Most are based on 50% of locations. The time percentages used to define quality are much closer to the middle of the distribution (10% to 90%) and are often limited to the median value (50%).

Point to zone communication are seldom line-of-sight though depending on the frequency band. They mainly use propagation by diffraction, either around the sphere of the earth for relatively low frequencies (hectometric and longer wavelengths) or around obstacles of different sizes and shapes for higher frequencies. Incidentally, major frequencies bands allocated to point to zone communications (radio broadcasting and mobile services) are in part of the radio spectrum where diffraction phenomena play a major role (metric and decimetric waves). Terrestrial area-coverage does not guarantee line-of-sight radio paths, since broadcast receivers are often inside buildings or in the radio shadow of buildings and other obstacles, Aboaba (1999).

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Table 2.1 Standard Classification Spectrum for Frequency used in Radio Communication.

Carrier Frequency	Free space Wavelength (m)	Class	Propagation Characteristic	Service
10 – 30 KHz	$3 \times 10^4 - 10^4$	Very Low Frequency (VLF)	At all times of day and year. Attenuation is low.	Long distance point-to-point communication.
30 – 300 KHz	$10^4 - 10^3$	Low Frequency (LF)	During daytime absorption exceeds that with VLF. During nighttime, propagation is similar to VLF.	Long distance point-to-point communication; Navigation.
300 – 3000 KHz	$10^3 - 10^2$	Medium Frequency (MF)	Daytime attenuation is high; Nighttime attenuation is low (ionospheric propagation).	Broadcasting; Ship to shore communication.
3 – 30 MHz	$10^2 - 10$	High Frequency (HF)	Ionospheric propagation.	National and International broadcast; point-to-point telephone and telegraph communication; Aviation.
30 – 300 MHz	10 - 1	Very High Frequency (VHF)	Tropospheric propagation (typical range equals line of sight).	Radar; Television; F.M. Broadcast; Short distance communication
300 – 3000 MHz	1 – 0.1	Ultra High Frequency (UHF)	Do	Facsimile; Television Relay; Air navigation.
3 – 30 GHz	0.1 – 0.01	Super High Frequency (SHF)	Do	Radar navigation; Radio Relay.

2.6.5 ITU WORLD REGIONS FOR FREQUENCY ALLOCATION

ITU Table of Frequency Allocation is contained in Radio Regulations and shows the frequency bands in different parts of the spectrum which have been allocated for each of the major radio services giving administrations the opportunity to assign frequencies with the propagation characteristics that suit each station best. For convenience sake, frequency bands are allocated to different services in different parts of the world. ITU divides the world into three Regions, 1, 2 and 3. The Regions are shown in Figure 2.1. Many frequency bands at LF, MF, VHF, UHF and some SHF bands are allocated to different services in the three regions. Nigeria and FUTA lie in Region 1.

Figure 2.1 The Three ITU Regions
(SOURCE: Radio Regulations RR8-2)

2.7 BROADCASTING IN THE VHF BAND II

The ITU international frequency allocations of primary status for broadcasting are shown in Table 2.2.

Table 2.2: - Broadcasting Service Allocations at VHF and UHF by ITU

	Region 1 (MHz)	Region 2 (MHz)	Region 3 (MHz)
Band I	47 -68	54 - 72	47 – 50 and 54 - 68
Band II	87.5 - 108	76 - 108	87 – 108
Band III	174 - 230	174 - 216	174 – 230
Band IV and V	470 - 960	470 – 608 and 614 - 890	470 - 960

RR8, ITU

The popular use of Band II is for sound broadcasting. With few exceptions, sound broadcasting systems at VHF use frequency modulation (FM) and most are designed to provide facilities of high audio frequency quality. Most stations transmit stereophonic signals. ITU-R gives the standards for maximum frequency deviation and the pre-emphasis characteristics for monophonic and various kinds of stereophonic sound broadcasting signals.

For Region 1, all planned emissions for Band II are for FM sound broadcasting, class of emission F3E, uniform nominal carrier spacing of 200KHz and pre-emphasis network time constant of 50μs, ITU, Geneva (1984). Five transmission systems are provided for as shown below: -

	Maximum frequency deviation
System 1: monophonic	+/- 75KHz
System 2: monophonic	+/- 50KHz
System 3: stereophonic, polar modulation system	+/- 50KHz
System 4: stereophonic, pilot-tone system	+/- 75KHz
System 5: stereophonic, pilot-tone system	+/- 50KHz

System 4 is adopted in the country.

2.7.1 MINIMUM USABLE FIELD STRENGTH/SERVICE RANGE OF A TRANSMITTER

ITU-R gives minimum usable field strengths estimated to be usable for various kinds of sound broadcast signal in the presence of man-made noise in various environments for use in frequency assignment planning. Weaker field strength may be satisfactorily receivable in an electrically quiet location, particularly if receiving antenna of high performance is used.

The Service Range of a transmitter is the distance between the transmitter and the points at which the field strength of the wanted signal at 50% of location during 50% of time, equals the ITU-R recommended median field strength measured in dB relative to 1μV/m. The recommended field strength for VHF band II FM sound broadcasting for different areas are shown in Table 2.3.

Table 2.3 Recommended Minimum Field Strength for VHF Band II FM Broadcasting.

Services	Rural Area dB (μV/m)	Urban Area dB (μV/m)	Large City dB (μV/m)
Monophonic	48	60	70
Stereophonic	54	66	74

ITU – R (1986)

2.7.2 POLARISATION

Polarisation refers to the orientation of the plane of the electric field vector of the wave with respect to the ground (earth's surface). If the plane of the E-vector is vertical with respect to the ground, the polarization is said to be vertical and if horizontal with respect to the ground, the polarisation is said to be horizontal. There is also circular polarisation in which the E-vector rotates about the axis of propagation as the wave travels. The rotation could be clockwise (right handed) or anti-clockwise (left handed) looking from the direction of propagation. The polarisation desired is realized by the type and orientation of the antenna used.

ITU-R has studied the advantages and disadvantages of using vertically or horizontally polarised waves for broadcasting at VHF and UHF. Many sound broadcasting receivers are hand-portable and many others are installed in vehicles.

For these receivers, it has been found that the transmission of a signal of mixed polarisation, typically circular or a slanted-linear polarisation, gives better performance at the receiver. The Geneva Agreement, 1984 gave each administration in Region 1 freedom to use the polarisation mode of its choice for sound broadcasting in VHF Band II. Horizontal, vertical and circular polarisations have certain advantages above 50 MHz, so there has never been complete standardization on any of them. However, horizontal systems are popular because in part they tend to reject man-made noise, much of which is vertically polarised. Vertical polarisation is best suited for service over a valley or a trough. Except for the VHF FM repeater systems, **horizontal polarisation is the standard VHF system almost everywhere.**

2.7.3 TECHNICAL CONSTRAINTS

Radio Regulations (RR) require the carrier frequencies of all sound broadcasting transmitters with mean power in excess of 50 W operating in Bands I and II to be maintained within 2 KHz of the nominal frequency, RR303 and RR Appendix 7, ITU, (1982). The regulation also require the worst spurious emission of any VHF transmitter (Bands I – III) having a mean output power greater than 25 W to be at least 60 dB below the output power level, up to a maximum of 1 mW RR304 and RR Appendix 8, ITU, (1982).

2.8 MODULATION CONCEPT AND BENEFITS

Modulation is defined as the process by which some characteristics of a voltage (usually sinusoidal voltage) is varied in accordance with the instantaneous value of some other voltage called the modulating voltage, Mithal & Mittal, (1992). The term 'carrier' is applied to the voltage whose characteristic is varied and 'carrier frequency' is the frequency of the carrier voltage being modulated. Modulation process may be classified as amplitude modulation, frequency modulation or phase modulation. In FM broadcasting, the frequency of the carrier is varied in accordance with the varying amplitude of the modulating signal. The carrier amplitude is kept constant.

Modulation helps to achieve the following:

- Efficient transmission: - Signal transmission over appreciable distance always involves a traveling electromagnetic wave with or without a guiding medium. Efficiency of any particular transmission method depends upon the frequency of the signal being transmitted. By exploiting frequency translation property of continuous wave modulation, message information can be impressed on a carrier whose frequency has been selected for the desired transmission method. Also in case of antenna length, efficient line-of-sight radio propagation requires antennas whose physical dimensions are at least 1/10 of the signal's wavelength.

- Overcoming Hardware Limitation: - Hardware performance often depends upon frequencies involved. Modulation permits the designer to place a signal in some frequency range that avoids hardware limitations. A particular concern is the question of fractional bandwidth defined as the absolute bandwidth divided by the center frequency. Hardware costs and complications are minimized if the fractional bandwidth is kept very low. Since information rate is proportional to bandwidth (Hartley Shannon law), therefore, signals with large bandwidth should be modulated on high frequency carriers.
- Reduction of Noise and Interference: - A brute force method for combating noise and interference is to increase the signal power until it overwhelms the contaminants. This is often costly and may damage equipment. Fortunately, FM and certain other types of modulation have the valuable property of suppressing both noise and interference.
- Frequency Assignment: - Tuning a radio or TV to a particular station, one is selecting one of many signals being received at that time. Each station has a different assigned carrier frequency; therefore the desired signal can be separated from the others by filtering. Modulation allows for more than one station to broadcast in a given area otherwise, two or more broadcasting stations would create a hopeless jumble of interference.
- Multiplexing: - Multiplexing is the process of combining several signals for simultaneous transmission on one channel. Frequency Division Multiplexing (FDM) uses continuous wave (CW) modulation to put each signal on a different carrier frequency and a bank of filters separates the signals at the destinations. Time Division Multiplexing (TDM) uses pulse modulation to put samples of different signals in non-overlapping time slots. A switching circuit at the destination then separates the samples for signal reconstruction. Many

channels can be multiplexed in a single channel. Multiplexing thereby provide another way of increasing communication efficiency

2.9 ADVANTAGES OF FREQUENCY MODULATION

1. Use of FM provides an increase in the output signal to noise ratio. Since the transmitted amplitude is constant, thus the receiver can be fitted with an efficient amplitude limiter. This has the advantage of significantly improving immunity to noise and interference. Notable benefits are the use of pre-emphasis and de-emphasis. With emphasis, the highest modulating frequencies are critically boosted before transmission and corresponding attenuation after reception to reduce the effects of noise.
2. The dynamic range provided is much greater.
3. The FM transmitter is more efficient because class C amplifiers can be used throughout the r.f section.
4. Since the FM receiver does not respond to any amplitude variations, selective fading does not occur.
5. FM receiver has the ability to suppress the weaker of two signals simultaneously present at its antenna terminals ("capture effect").
6. Commercial FM broadcast began in 1940, decades after its AM counterpart. It was given better planning and other considerations. The following are the important ones:
   - Standard frequency allocation provides a guard band between commercial FM stations so that there is less adjacent-channel interference than in AM.
   - FM broadcast operate in the upper VHF and UHF frequency ranges at which there happens to be less noise than in the MF and HF ranges occupied by AM.
   - At FM broadcast frequencies (VHF & UHF), space wave is used for propagation so that the radius of operation is limited slightly to more than line-of-sight. It is thus possible to operate several independent FM broadcast transmitters on the same frequency with considerably less interference than would be possible with AM.

2.9.1 DISADVANTAGES OF FM

1. A much wider channel, typically 200KHz is needed.

2.Transmitting and receiving equipment particularly for modulation and demodulation are complex and costly.

3. Reception using conventional method is limited to line of sight. This reduces the area of reception of FM due to carrier frequency (i.e. VHF and UHF range) employed for its transmission. This is no doubt, a disadvantage for FM mobile communication over a wide area but forms an advantage for co-channel allocation.

2.10 RADIO WAVE PROPAGATION

Propagation of radio waves from the radiating antenna to the receiving antenna may take place in one of the following ways.

(i) Ground wave propagation

  (a) Surface wave propagation

  (b) Space wave propagation (tropospheric propagation)

(ii) Sky wave propagation (ionospheric propagation)

The ground wave is the radio wave, which results because of the presence of the ground. The surface wave is that part of the radio wave which travels along the surface of the earth. It is vertically polarized. The wave is supported at the lower edge by the ground. Such propagation takes place when the transmitting and receiving antennas are close to the surface of the earth. It is of importance only for medium and long wave signals.

2.10.1 SPACE WAVE PROPAGATION

The space wave is that part of the radio wave which travels from the transmitting antenna to the receiving antenna through the space, i.e. the earth's troposphere. It is normally used for frequencies above 30MHz, i.e. for television, FM broadcast etc. The space wave is constituted by two components namely (i) the direct wave and (ii) the ground reflected wave as shown in Figure 2.2.

The magnitudes of the space wave and the surface wave are both influenced by the following factors:

- Electrical properties of the ground.

- Frequency of the wave.
- Heights h_t and h_r respectively of the transmitting and receiving antennas.
- Curvature of the earth.
- The distance *d* between the transmitting and receiving antennas
- The variation of the refractive index of earth's atmosphere with height.

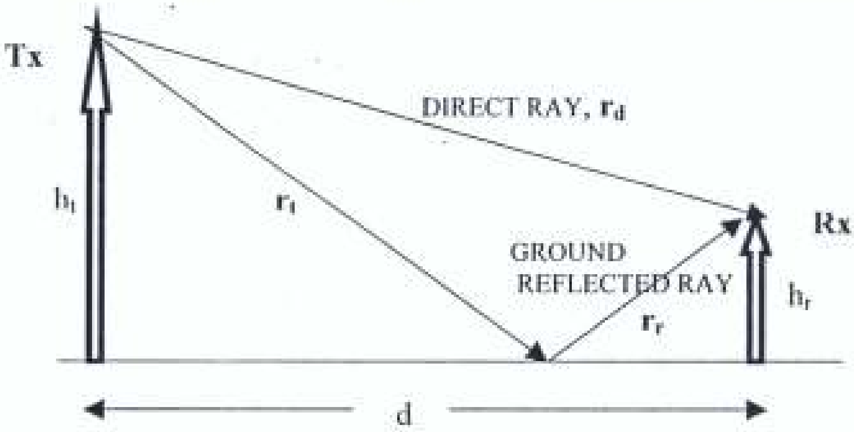


Figure 2.2 Direct and ground reflected components of the space wave.

The electrical properties of the ground influence (i) the rate of attenuation of the surface wave and (b) the reflection coefficient of the ground-reflected component of the space wave. The distance *d* between the antennas influences the amplitudes of both the surface wave and the space wave. The variation of the refractive index with height causes the path of propagation to be somewhat curved instead of straight, the curvature being in the same direction as the curvature of the earth.

2.10.2 THE TROPOSPHERE

The troposphere is the atmosphere region between the earth's surface and an altitude of about 15 km. It is lower at the poles and higher at the equator. It is a region where temperature generally decreases with height except in local regions of temperature inversion. The upper boundary of the troposphere is the tropopause above which there is general temperature inversion. The troposphere is the most important region of the atmosphere for radio propagation in the VHF and UHF bands.

Unlike free space, the troposphere is characterized by scattering, scintillation, reflection, refraction and diffraction of radio waves due to the variation of the radio meteorological parameters present in the atmosphere and physical structures, both natural and man – made, obstructing the paths of the radio waves, ITU-R, Rep 718, (1986).

2.10.3 RANGE OF SPACE WAVE PROPAGATION

In general the transmission of space wave is possible only up to or slightly beyond the line of sight distance.

Let d be the distance from the top of the antenna of height h to horizon as shown in Figure 2.3 (assuming a smooth earth). Let r be the radius of the earth.

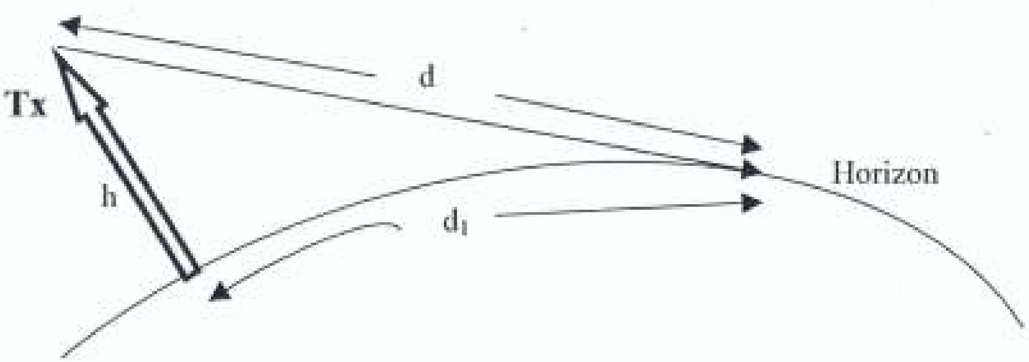


Fig. 2.3 Distance to the horizon.

Then, $d^2 + R^2 = (R+h)^2$ --(2.0)

$= R^2 + 2Rh + h^2$

or $d^2 = 2Rh + h^2$ --(2.1)

since $h^2 << 2Rh$

hence, $d = \sqrt{2Rh}$ --(2.2)

This distance d is almost the same distance as distance d_l along the earth's surface, since $h << d$. The service area increases on increasing the heights of the transmitting (and receiving) antennas.

2.10.4 EFFECT OF EARTH'S CURVATURE

The earth can be assumed flat up to a distance of $\frac{80}{\sqrt[3]{f}}$ where f is in MHz and the distance in kilometers, Smith Jnr, (1998). The curvature of the earth makes both the space wave and the surface wave diffract around the earth so as to reach a receiving point obscured by the curvature of the earth.

The curvature of earth produces two effects on the direct and ground reflected space waves:

(i) It reduces the difference in the path lengths between the direct and ground reflected waves by raising the point of reflection above that of a plane earth and as a result tends to reduce the strength of the received field.

(ii) It causes the reflection at the ground to take place from a spherical rather than a flat surface so that the reflected ray becomes divergent and consequently becomes weaker at the receiving point.

These two opposite effects produced by the earth's curvature almost neutralize each other. Consequently, the assumption of a plane earth yields results, which remain valid in spite of considerable curvature of earth.

2.10.5 REFLECTION OF GROUND WAVE BY EARTH SURFACE

When a plane electro-magnetic wave is incident on the surface of the earth, it gets reflected such that the angle of reflection equals the angle of incidence. The vector ratio of the strength of reflected wave to that of incident wave is called the 'Reflection Coefficient' or 'Reflectivity' and is indicated by $\mathbf{R} = \rho <\varphi$ where ρ is the modulus and φ is the phase angle of reflectivity. **R** depends on the following quantities:

(i) Dielectric constant of the earth,

(ii) Conductivity of the earth,

(iii) The frequency,

(iv) The plane of polarisation of the wave and

(v) The angle of incidence.

Typically, the reflected signal can be considered to consist of a specular component and a diffusely reflected component. The magnitude of the specularly reflected component may vary considerably with the angle of incidence if the polarisation is vertical. The magnitude is least at a certain angle, called the Brewster Angle which itself is a function of the frequency and the relative permittivity and conductivity of the reflecting surface. For angles of elevation greater than the Brewster angle, there is a phase reversal of the wave on reflection.

Horizontally polarised waves always undergo a phase reversal upon reflection. When the reflecting surface is vertical, like the side of a building, a signal, which is transmitted with horizontal polarisation effectively, becomes vertical polarization as far as the reflection is concerned. In these cases, horizontal polarisation generally results in weaker reflections and less multipath than vertical polarisation.

2.10.6 ELECTRICAL PROPERTIES OF THE EARTH

The electrical conductivity and dielectric constant of the earth depend almost entirely on the degree of humidity at the surface. It is widely different for different kinds of soil. It is also frequency dependent. Table 2.4 gives the values of the constants for a few typical soil types, seawater and fresh water.

Table 2.4: Electrical constants of the ground

Type of ground	Relative dielectric constant ε_r	Conductivity σ in S/m
Sea water	81	4.5
Sea water (Average Salinity)	75	5.0
Fresh water	80	0.01
Fresh water (20°C)	80	0.03
Wet Ground (100 MHz)	30	0.01
Rich soil and Low Hills	17	0.01
Forestation, clay soil and Medium Hills	13	0.005
Moderately dry soil (100 MHz)	15	0.002
Dry Ground	15	0.001
Sandy soil, rocky soil	10	0.002
Desert and Dry Rock	3	0.0001
Urban and Industrial Area	5	0.001

Reflectivity,

$$R = \frac{\sin\alpha - \sqrt{C}}{\sin\alpha + \sqrt{C}} \qquad \text{---(2.3)}$$

Where α = angle of incidence (with respect to ground).

For horizontal polarisation,

$$C_h = \eta - \cos^2\alpha \quad \text{--(2.4)}$$

And for vertical polarisation,

$$C_v = \frac{\eta - \cos^2\alpha}{\eta^2} \quad \text{--(2.5)}$$

$$\rho = \frac{\left|\sin\alpha - \sqrt{C}\right|}{\left|\sin\alpha + \sqrt{C}\right|} \quad \text{--(2.6)}$$

η (reflecting surface complex permittivity) $= \varepsilon_r - j\left(\frac{\sigma}{\omega\varepsilon_o}\right)$ ---------------(2.7)

where ε_0 = permittivity of free space (F/m),

σ = conductivity (S/m),

ε_r = relative permittivity and

ω = angular frequency (rad) of the wave.

2.10.7 FREE SPACE FIELD STRENGTH

For a transmitter of power T (W), feeding an antenna system of gain, g (relative to an isotrope) and efficiency, t (loss by components, transmission cables, etc), the Effective Isotropic Radiated Power,

$$EIRP(W) = gtT = P \quad \text{--(2.8)}$$

The power flux density, S at a distance, d from the antenna is

$$S = \frac{P}{4\pi d^2} \quad \text{--(2.9)}$$

This power flux density is equal to the amplitude of the Poynting Vector,

$$S = E \times H \quad \text{--(2.10)}$$

At great distances from the antenna, the vectors E, H, & S form a direct tri-rectangular trihedron and the scalar relation is obtained thus:

$$\frac{E}{H} = \sqrt{\frac{\mu_o}{\varepsilon_o}} \quad \text{--(2.11)}$$

$$= 120\pi \text{ ohms.}$$

Therefore, S (free space power density) $= \frac{E^2}{120\pi} = \frac{P}{4\pi d^2}$ ---------------(2.12)

From which the free space field strength,

$$E = \frac{\sqrt{30P}}{d} \quad \text{(V/m)} \qquad \text{--(2.13)}$$

Or $$E_{(mV/m)} = \frac{173\sqrt{P_{(KW)}}}{d_{(km)}} \qquad \text{--(2.14)}$$

The product $Ed = E_f$ is known as the cymomotive force (c.m.f.) and is generally expressed in volts.

For a 1 KW radiated power, the cymomotive force (cmf) is

173 volts for an isotropic antenna.

212 volts for a Hertzian dipole.

222 volts for a half-wave dipole antenna.

The expression in equation (2.13) is the field strength for a region, which is free of obstacles, and objects that absorb, refract or reflect radio energy. This only exists in outer space. Electric field strength E at a location differs markedly from the above expression for terrestrial propagation.

2.10.8 FIELD STRENGTH OF TROPOSPHERIC WAVE (Assuming open and smooth terrain. No obstruction by hills, trees and buildings)

In Figure 2.2, the direct ray and the ground reflected ray combine vectorially at the receiving antenna Rx. The resultant field E is given by:

$$E = E_o\left(1 + \rho D \exp j\left(\Phi + \frac{2\pi\Delta}{\lambda}\right)\right) \text{ V/m} \qquad \text{------------------------------(2.15)}$$

Where E_0 = free space field strength at the receiving antenna (V/m)

ρ = modulus of reflectivity

Φ = phase angle (argument) of reflectivity (rad)

D = divergence factor (spherical earth)

Δ = path difference between the direct ray and the reflected ray (m)

$= r_i + r_r - r_d$ ------------------------------------(2.16)

The ratio E/E_0 is termed as "Pattern Propagation Factor", F

$$\left|\frac{E}{E_o}\right| = \sqrt{1 + (\rho D)^2 + 2\rho D\cos\left(\Phi + \frac{2\pi\Delta}{\lambda}\right)} \qquad \text{------------------------------(2.17)}$$

$$E_o = \frac{E_f}{r_d} \text{ --(2.18)}$$

Where E_f = cymomotive force

$$= \sqrt{30P} \text{ --(2.19)}$$

P = Effective Isotropic Radiated Power

Particular case: If the earth is assumed to be flat (short distance) and reflectivity equal to –1 (very small grazing angle):

D = 1, ρ = 1 and Φ = π

Then,

$$\left|\frac{E}{E_o}\right| = 2\sin\left(\frac{\pi\Delta}{\lambda}\right) \text{ --(2.20)}$$

$$= 2\sin\left(\frac{2\pi h_t h_r}{\lambda d}\right) \text{ --(2.21)}$$

When d >> h_t or h_r, then

$$\sin\frac{2\pi h_t h_r}{\lambda d} \approx \frac{2\pi h_t h_r}{\lambda d} \text{ --(2.22)}$$

and $d \approx r_d$

so,

$$\left|\frac{E}{E_o}\right| = \frac{4\pi h_t h_r}{\lambda d} \text{ --(2.23)}$$

Since

$$E_o = \frac{E_f}{r_d}$$

Therefore,

$$E = \frac{4\pi E_f h_t h_r}{\lambda d^2} \text{ --(2.24)}$$

The above equation reveals that for propagation of VHF signals, the field strength increases (i) linearly with the height of the transmitting antenna, (ii) linearly with the height of the receiving antenna, (iii) linearly with the square root of the effective isotropic radiated power. The field strength varies inversely with wavelength and inversely with the square of the distance.

2.10.9 FADING OF SPACE WAVE SIGNALS

The condition in the troposphere keeps on changing with time, hence the amount of bending of refraction of wave changes from time to time. This influences the relative path length of the direct and the ground reflected components of space wave. Hence the field strength of the resultant space wave at the receiving point changes i.e. fading results.

2.10.10 FIELD STRENGTH BEYOND THE HORIZON

When the horizon or any other obstacle intercepts the direct and ground reflected waves, the signal may be propagated beyond it by diffraction. Since the source of re-radiation is at or near the surface, the radio wave suffers high attenuation in traveling beyond the obstacle and the attenuation increases rapidly with frequency. Thus while the field strength within the horizon distance decreases as the square of the distance, beyond the horizon, the field strength decreases at a much higher power. The exponent varies from the inverse fourth power at about 50 MHz to the inverse tenth power at about 500 MHz (Mithel & Mittal, 1992).

2.10.11 PROPAGATION BY DIFFRACTION

If an obstacle lies directly between a transmitter and a receiver, received power is only provided by re-radiation from the obstacle. The study of diffraction is very difficult especially for obstacles, which do not have a geometrically simple shape. Only two theoretical cases have been studied in detail: diffraction by a large radius sphere and diffraction by a ridge of low or negligible thickness. Practical problems are reduced to combinations of these two theoretical cases.

In the case of wave propagation near the earth's surface for long distance transmission, the major obstacle is the earth itself. The diffractions field behind a sharp ridge decreases when moving into the shadow of the ridge, following a function which approximates to the reciprocal of the distance to the geometric edge of the shadow, while for diffraction from a sphere, the function is exponential, giving a considerably faster decrease. The field strength due to diffraction is caused by radiation of currents induced by the incident field. In the case of a sharp ridge, the top of the ridge can be regarded as being in line of sight both to the transmitter and the receiver, while for a rounded top or sphere, currents are induced from element to element of that part of the ridge which is not in line – of –sight with either end of the path. Generally, diffraction processes result in transhorizon propagation, fading, attenuation and varied losses of radio waves.

2.10.11.1 Edge Diffraction

There may not be a line – of – sight between a transmitter and a receiver if a mountain or hill stands between them. It is relatively difficult to work out the fading due to such obstacle where its shape is often irregular and its conductivity unknown. The problem is simplified by treating the obstacle as a ridge of negligible thickness, as a simple cylindrical surface or as a succession of such obstacles.

2.10.11.2 Knife Edge Diffraction

There is a rigorous solution to the problem of diffraction from a semi – plane by Sommerfeld. Purely scalar approximate solution from optics gives results that are very close to the rigorous solution and is relatively simpler as it does not take polarization into account.

Consider a ridge of zero thickness at the summit, which is at height h (positive or negative) with respect to the straight line between the transmitter and the receiver as shown in Figure 2.4.

Let d be the total distance, d_1 and d_2 be the distances from the ridge to the transmitter and to the receiver respectively and λ the wavelength. If the angle of diffraction is assumed small and introducing a variable v, such that

$$v = h\sqrt{\left(\frac{2}{\lambda}\right)\left(\frac{d}{d_1 d_2}\right)} \quad \text{-- (2.25)}$$

The amplitude and phase of the field strength at the location of the receiver are given by the expression below:

$$\frac{E}{E_o} = \frac{1}{1+j}\int_v^\infty \exp\left(\frac{j\pi t^2}{2}\right)dt \quad \text{-------------------------------- (2.26)}$$

Where E_0 is the field strength without the ridge.

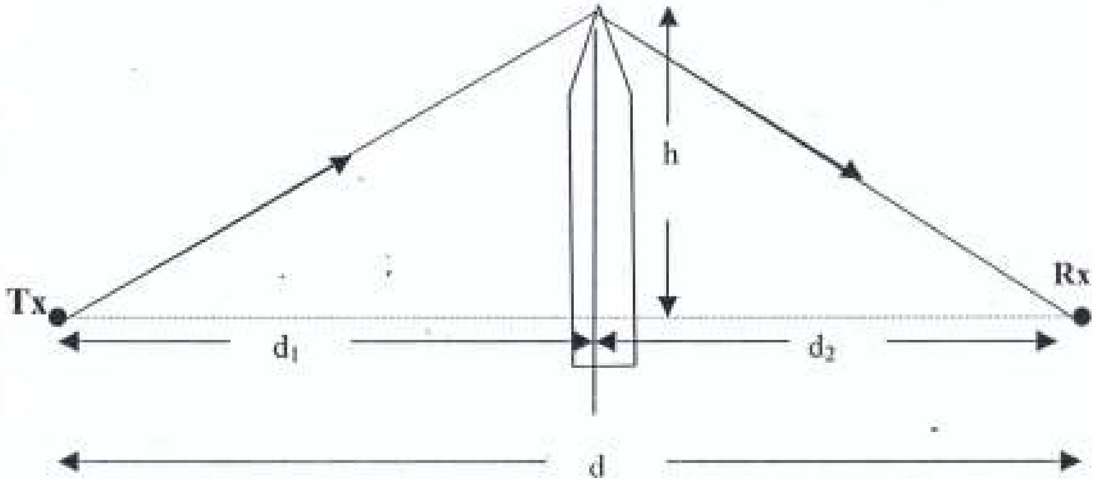


Figure 2.4 'Knife-edge' diffracting ridge.

Ratio of corresponding powers,

$$\frac{P}{P_o}=\frac{1}{2}\left[\left(\frac{1}{2}-\zeta(v)\right)^2+\left(\frac{1}{2}-\eta(v)\right)^2\right] \qquad \text{-------- (2.27)}$$

Where ζ(v) and η(v) for the Fresnel integrals:

$$\zeta(v)=\int_0^v \cos\left(\frac{\pi t^2}{2}\right)dt, \qquad \text{--------(2.28)}$$

$$\eta(v)=\int_0^v \sin\left(\pi t^2/2\right)dt, \qquad \text{--------(2.29)}$$

An approximation, which is valid for $v > -0.7$ is

$$10\log\left(\frac{P}{P_o}\right)=-6.9+20\log\left[\sqrt{(v-0.1)^2+1}-v+0.1\right] \qquad \text{-------- (2.30)}$$

2.10.11.3 Multiple Edge Diffraction

For multiple edge diffraction, the problem becomes more complicated because of the growing number of geometrical parameters to be taken into account. In the case of two thin ridges, there is a theoretical solution presented by Millington, which is a generalization to two dimensions of Fresnel Integrals used for a single ridge. The solution obtained is acceptable experimentally and is generally used as the standard to check empirical solutions.

Among empirical solutions, one method by Bullington (1947) was to replace all ridges by a single ridge seen from the ends of the path at the same angle of elevation as the outermost real edges. This method introduced major errors and is no longer used.

The method devised by Epstein and Peterson (1953) assumes that each ridge is illuminated by the transmitter or by the diffracted energy from the top of the preceding ridge. The diffraction fading from each of these ridges are then summed together.

The method by Deygout (1966) is based on the observation that in nearly all cases one of the ridges is predominant and is responsible for a large part of the loss and the other ridges take only a subsidiary role. The loss due to the predominant ridge only is first calculated and then the losses due to others are added.

These two methods give results, which do not differ by very much in practice. Generally Epstein's method is used for interference problems while Deygout's method for calculating communication effects.

2.10.12 EFFECT OF TREES AND FOREST

Forest tends to reduce the strength of the direct and the ground reflected wave (non-specular reflection and attenuation by dielectric loss and obstruction) if they pass through them from the transmitter to the receiver. As a matter of fact, trees attenuation are very difficult to predict accurately and it is costly, tedious (if not impossible) to obtain accurate information about them. The attenuation depends on the distance the signal must penetrate through the forest and it increases with frequency. In most cases, they are measured. Inside a forest, there is high probability that the signal will result from a complicated combination of many forms of propagation mechanisms such as multiple diffraction over trees tops, multiple diffraction round trees, many reflections and scattering by many trees and transmission through a combination of obstacles. These mechanisms will produce large location variations and time variations for example wind movement of trees. It does not seem possible to have a calculation technique, which will intrinsically integrate these different mechanisms, Causebrook, (1992).

The main contribution of the forest to the propagation will come from the part of the path, which is closest to the receiver. This is because transmitter antennas (in broadcasting) are always positioned higher than domestic receivers and thereby, in the rest of the path, the top of the volume is well clear of trees cluster. The transmitted energy loss (attenuation) through the forest with distance for a particular density distribution, Saxton & Lane, (1955) is given by:

$$A_T = x\int \rho(s)ds \qquad \text{-- (2.31)}$$

Where p(s) = likely density distribution of trees over a reasonable distance and

x = loss per unit distance through the trees.

The loss may depend on several factors such as frequency, polarization, types of trees, season, etc. Attenuation is of the order as shown in Table 2.5. At lower frequencies, the attenuation is lower for horizontal polarisation than for vertical polarisation.

Table 2.5 Attenuation From Trees And Forests

Frequency (MHz)	Attenuation (dB/m)
100	0.03
200	0.05
500	0.1
1000	0.2
2000	0.3
3000	0.4

ITU – R, Rep. 1145, (1990)

2.10.13 LAND PROFILE MODELS APPLIED FOR THE ZONES

In determination of field strength of tropospheric wave, equation (2.17) shows that it depends, among other factors, on the ray-path difference, Δ and modulus of reflectivity, ρ. As explained in Chapter Three, the community land area is divided into zones. Path difference varies from zone to zone depending on the terrain, antenna heights, distance etc.

2.10.13.1 For a flat terrain, as drawn below in Figure 2.5

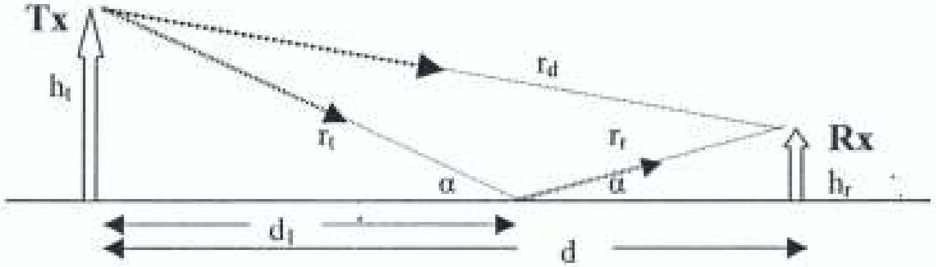


Figure 2.5 Ray path model for flat terrain

The letters are as indicated in the diagram.

Let $h_t + h_r = h_{tr1}$ and -- (2.32)

$h_t - h_r = h_{tr2}$, -- (2.33)

Then,

$$r_d = \sqrt{d^2 + (h_{tr2})^2}$$ -- (2.34)

$$r_t + r_r = \sqrt{d^2 + (h_{tr1})^2}$$ -- (2.35)

Path difference, $\Delta = r_t + r_r - r_d$.

Angle of incidence (wrt ground),

$$\alpha = \tan^{-1}\left(\frac{h_{tr1}}{d}\right)$$ -- (2.36)

$$d_1 = d\left(\frac{h_t}{h_{tr1}}\right)$$ -- (2.37)

This model is applicable to zones 2, 3, 4, 5, 9 and 11 (Chapter 3), though in form of Figure 2.6 shown below.

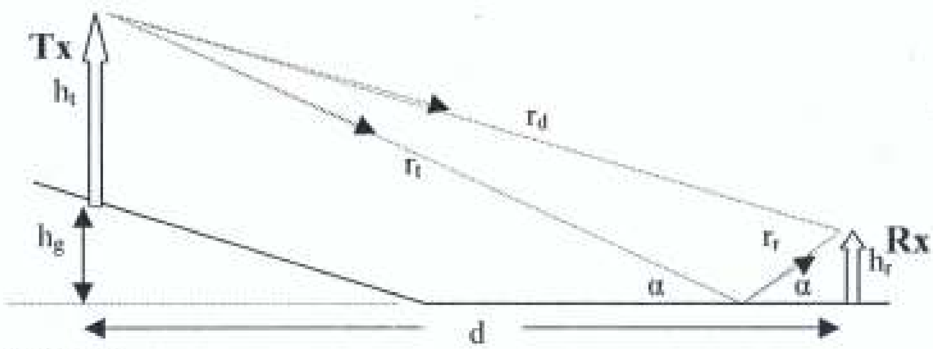


Figure 2.6

2.10.13.2 • For a ground that slopes down from the transmitter to the receiver as shown in Figure 2.7 below.

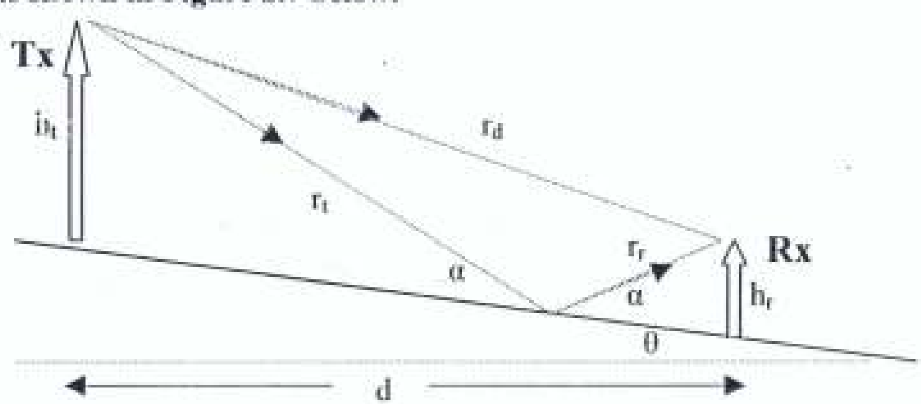


Figure 2.7 Ray path model for a slope

Let $h_{tr1} = h_t + h_r$ and

$h_{tr2} = h_t - h_r$,

Then (from geometrical analysis),

$$r_d = \sqrt{d^2 + (d\tan\theta + h_{tr2})^2} \quad \text{-- (2.38)}$$

$$r_i + r_r = \sqrt{(h_t + d\tan\theta + h_r(2\cos^2\theta - 1))^2 + (d - h_r\sin 2\theta)^2} \quad \text{------------- (2.39)}$$

Path difference, $\Delta = r_i + r_r - r_d$

$$\tan\alpha = \frac{h_{tr1}\cos\theta}{h_{tr2}\sin\theta + \dfrac{d}{\cos\theta}} \quad \text{-------------------------------- (2.40)}$$

This model is applicable to zones 1, 6, 7, 8(a), 8(b) and 10 (Chapter 3).

2.10.13.3 Forested zones

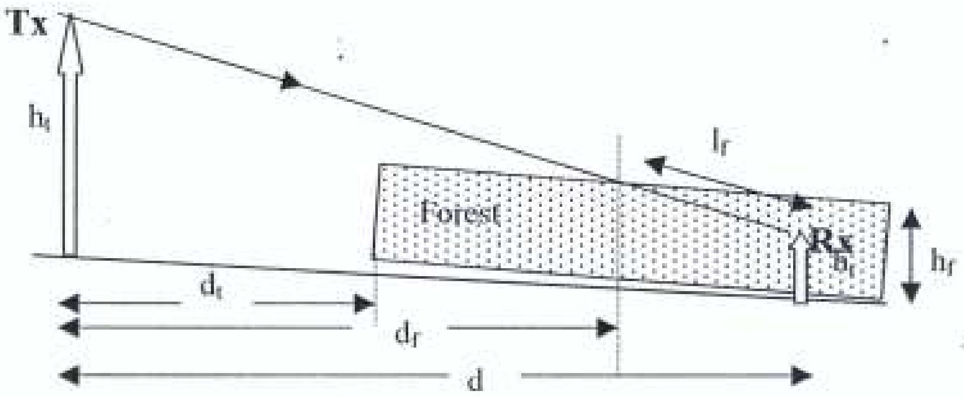


Figure 2.8 Forested zone model ($d_f > d_t$)

In Figure 2.8, assuming a uniform forest of height h_f lies in-between the transmitting antenna and the receiver, assuming a smooth ground and a low receiver height, analysis (by geometry) showed that irrespective of slope, for any distance d from the transmitting antenna, the direct ray (and also the ground reflected ray for low receiver height) enters the forest at distance d_f where

$$d_f = \frac{d(h_t - h_f)}{h_t - h_r} \quad \text{-- (2.41)}$$

h_t = transmitting antenna height above ground and

h_r = receiver height above ground.

If d_t = distance from transmitter at which the forest begins, then the length of forest that the rays pass through before getting to the receiver (if the receiver is within the forest) is l_f where

$$l_f \approx d - d_t \text{ for } d_f < d_t \quad \text{--} (2.42)$$

$$\approx d - d_f \text{ for } d_f > d_t \quad \text{--} (2.43)$$

If the forest stops at distance d_{tf} (from transmitter) before getting to the receiver location, then

$$l_f \approx d_{tf} - d_t \text{ for } d_f < d_t \quad \text{--} (2.44)$$

$$\approx d_{tf} - d_f \text{ for } d_f > d_t. \quad \text{--} (2.45)$$

Using equation (2.28) and assuming ρ(s) = 1 (uniform density).

Therefore, attenuation, $A_{T(dB)} = x_{(dB)} \times l_f$ where $x_{(dB)}$ = attenuation (dB) per unit distance.

$$A_T = 10^{\frac{A_{T(dB)}}{20}} \quad \text{--} (2.46)$$

Field strength at the receiver, $E = E_o F A_T$ ------------------------------ (2.47)

where F is the Pattern Propagation Factor as defined in equation (2.17). This model is applicable to zones 1,8(b) and 11 (Chapter 3).

2.10.13.4 Area Obstructed By Hill

For target service zone 12 (Obakekere Area behind Rock "M", Chapter 3), considering the land profile diagram of Figure 3.16, the whole scenario is modeled thus (Figure 2.9), assuming knife-edge diffraction by the mountaintop.

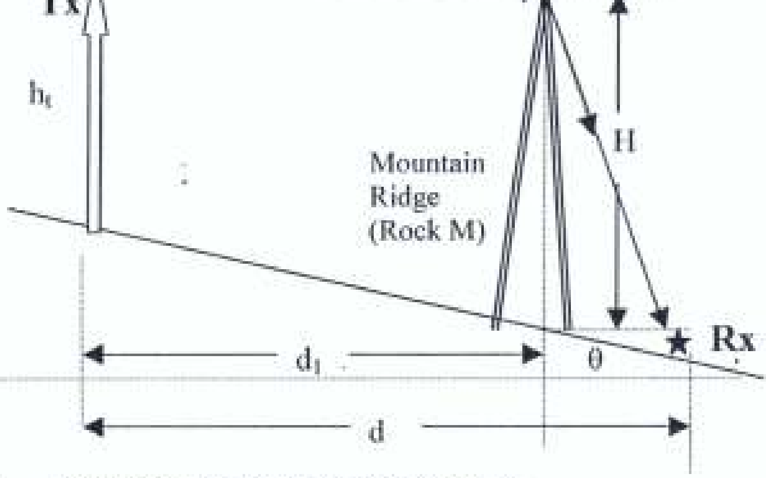


Figure. 2.9 Diffraction by Rock "M" in Zone 12.

The letters are as indicated in the diagram.

In this case, applying geometry and knife-edge diffraction techniques, the variable v then becomes:

$$v = \left[H - h_t\left(1 - \frac{d_1}{d}\right)\right]\sqrt{\left(\frac{2}{\lambda}\right)\left(\frac{d\cos\beta}{d_1(d - d_1)}\right)} \quad \text{-------------- (2.48)}$$

Where $\beta = \tan^{-1}\left(\frac{h_t}{d} + \tan\theta\right)$ -- (2.49)

From equation (2.27),

$$\log\left(\frac{E}{E_o}\right) = -0.345 + \log\left[\sqrt{(v - 0.1)^2 + 1} - v + 0.1\right] \quad \text{------------- (2.50)}$$

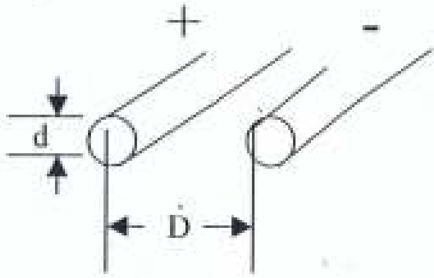
E_0 = field strength without the ridge

$$E_o = \frac{\cos\beta\sqrt{30P}}{d} \quad \text{---------------------------------- (2.51)}$$

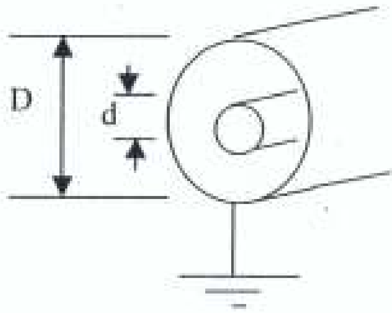
2.11 TRANSMISSION LINES (FEEDERS)

Transmission lines form essential links between transmitters and antennas or between antennas and receivers. They also provide branch feeds within antenna systems i.e. they distribute signals within antenna systems. Transmission lines may be symmetrical (balanced), coaxial or micro strip (unbalanced), or wave-guides. All transmission lines, other than wave guides support transverse electromagnetic wave (TEM) propagation where the lines of electric field and lines of magnetic field are at right angles to each other and both are at right angle to the direction of power flow.

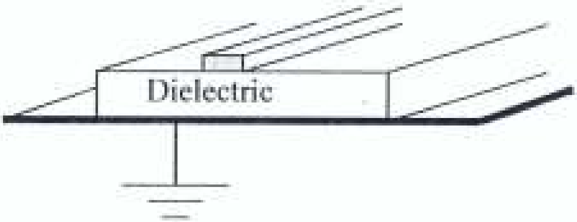
Most transmission lines for use below 1 GHz are coaxial, open-wire balanced lines are used for some HF antenna systems, micro strip and strip lines are sometimes used above 1 GHz in low-power applications. Some are illustrated in Figure 2.10.



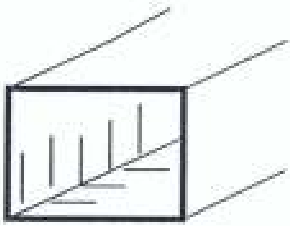
(a) symmetrical (balanced)



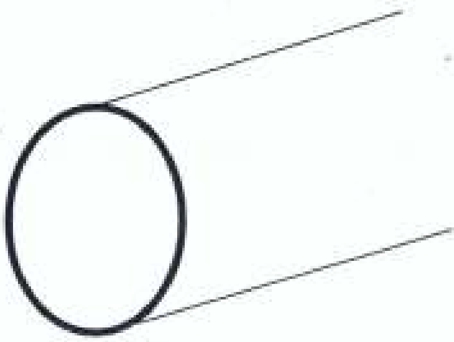
(b) Coaxial (unbalanced)



c) Micro strip (unbalanced)



(d) Rectangular wave guide



(e) Circular wave guide

Figure 2.10 Some common Transmission Lines

2.11.1 CHARACTERISTIC IMPEDANCE

The characteristic impedance, Z_0 of a coaxial feeder or any other TEM line that is carrying power in only one direction is the ratio of voltage to current at any point on the line. The Z_0 depends on the shape of the line, the ratio of its dimensions and the nature and amount of any dielectric material between its conductors.

The characteristic impedance of coaxial and balanced lines, where air or dielectric material completely fills the space between the conductors, are given by,

$$Z_0\,(\text{coaxial}) = \frac{138\log_{10}\left(\frac{D}{d}\right)}{\sqrt{\varepsilon_r}} \quad \text{---(2.52)}$$

$$Z_0\,(\text{balanced}) = \frac{120\cosh^{-1}\left(\frac{D}{d}\right)}{\sqrt{\varepsilon_r}} \quad \text{------------------------------(2.53)}$$

$$= \frac{276\log_{10}\left(\frac{2D}{d}\right)}{\sqrt{\varepsilon_r}} \quad \text{if } D >> d \quad \text{-------------------(2.54)}$$

where ε_r is the relative permittivity of the dielectric material.

Balanced open- wire feeders are commonly found in HF antenna installations. The characteristic impedance of these feeders is usually in the region of 200 to 600 Ω. Most installations for frequencies below 1 GHz use coaxial feeders. These usually have Z_0 of 50 Ω but feeders manufactured for 60 Ω and 75 Ω are available. The upper usable frequency for any coaxial feeder is reached when the wavelength in the feeder becomes less than about 2.2 times the inside diameter, D of the outer conductor. Above this frequency, the energy inside the feeder starts to break up into wave guide-type modes.

2.11.2 VELOCITY OF PROPAGATION

Signals would propagate along a perfect air-spaced line with the velocity of light but in practice the presence of dielectrics other than air reduces the velocity. The time required for a signal of a given frequency to travel down a length of practical transmission line is longer than the time required for the same signal to travel the same distance in free space. Because of this propagation delay, a wavelength of a given wave exists in a physically shorter distance on a given transmission line than in free space. This delay is expressed in terms of speed of light (as % or ratio) and is referred to as velocity factor (VF). The velocity factor is related to the dielectric constant ε_r by

$$VF = \frac{1}{\sqrt{\varepsilon_r}} \text{ --(2.55)}$$

The wavelength of energy in the line λ_L is proportional to the velocity factor and is given by

$$\lambda_{L(m)} = \frac{300 \times VF}{f_{(MHz)}} \text{ ---(2.56)}$$

Whenever reference is made to a line as being " half-wavelength" or "quarter-wavelength" long ($\lambda/2$ or $\lambda/4$), the electrical length of the line is meant.

2.11.3 LOSSES, DETERIORATION, VOLTAGE AND POWER RATINGS

The power handling capability and loss characteristics of feeders is largely dependent on the nature of the dielectric material between its conductors and the diameter of the conductors. Attenuation increases with frequency as the ohmic losses increase due to the diminishing skin depth (skin effect) of currents in the conductors. The attenuation per unit length is proportional to $\sqrt{frequency}$. Also, losses decrease as cable diameter increases.

Peak power and voltage handling are largely determined by the diameters of the conductors. At low frequencies, the mean power rating is the same as the peak power rating, but at higher frequencies, the mean power handling capability is less because it is limited by the ability of the feeder to dissipate heat. The power rating is inversely proportional to $\sqrt{frequency}$. The power rating depends on the ambient temperature and on the ability of heat to get away from its surface. It also depends on the voltage standing wave ratio (VSWR) within the feeder and on the nature of the modulation. If a cable were loss less, only the breakdown voltage would limit the power handling capability.

However, in practical coaxial cables for example, the copper and dielectric losses, rather than breakdown voltage, limit the maximum power that can be accommodated. Excessive RF operating voltage can cause noise generation, dielectric damage and eventual breakdown (flashover) between the conductors. If feeder ratings quoted by manufacturers do not include any factor of safety, then it is suggested that theoretical figures for peak voltage and mean power should be multiplied by 2.0 and 1.5 respectively when choosing a particular feeder, Manton, (1992).

2.11.4 MEAN POWER AND PEAK VOLTAGE FOR DIFFERENT FORMS OF MODULATION

Mean power and peak voltage are important parameters when specifying size (or type) of feeders to be used. Their relationships to the unmodulated carrier power P_t for the two popular forms of modulation for sound transmission are: -

1. Frequency modulation: -

   Mean Power $= P_t$

   Peak RF voltage $= \sqrt{2P_tZ_o}$ -----------------------------(2.57)

2. Amplitude Modulation: -

   Mean Power $= \left(1+\frac{m^2}{2}\right)P_t$ -----------------------------(2.58)

   Peak RF voltage $= (1+m)\sqrt{2P_tZ_o}$ -------------------(2.59)

   where m is the modulation index.

2.11.5 FEEDER UNIFORMITY

Long feeders carrying wideband-modulated signals such as FM, TV or pulse signals, must have reasonably constant characteristic impedances along their lengths. If the feeders are not uniform, the modulation information may be marred by multiple reflections. To minimise this form of distortion, the input voltage reflection coefficient of the feeder, when terminated by a load equal to its average Z_o should not exceed 5% at any frequency within the modulated bandwidth, Manton, (1992).

2.11.6 FEEDER TERMINATIONS

If a uniform feeder is terminated by an impedance, which is not equal to its characteristic impedance, Z_o, some power will be reflected back towards the transmitter. This gives rise to standing waves (interaction of forward and reflected waves) of voltage and current with consequent high voltages and currents at λ/2 intervals. The voltage maxima are separated from the current maxima by λ/4. The load which terminates a feeder is generally in most cases a complex quantity which may be expressed in terms of an impedance Z = R + jX or an admittance Y = G + jB.

The conditions in the feeder may be expressed in terms of a complex voltage reflection coefficient ρ_v, in terms of a scalar voltage standing wave ratio or in terms of an equivalent scalar return loss. The voltage reflection coefficient is the ratio of the reflected voltage to the incident voltage at a given point on a transmission line. It is also the ratio of the reflected current to incident current. The relationship between the line Zo and the actual load at the terminated end of the line determines the reflection coefficient.

$$\rho_v = \frac{\frac{Z}{Z_o} - 1}{\frac{Z}{Z_o} + 1} \qquad \text{-----------(2.60)}$$

or

$$\rho_v = \frac{1 - YZ_o}{1 + YZ_o} \qquad \text{-----------(2.61)}$$

The amplitude of ρ_v is often quoted as a %.

$$\text{Return loss} = -20\log|\rho_v| \qquad \text{-----------(2.62)}$$

Voltage standing wave ratio (VSWR) or simply SWR is defined as the ratio of the maximum voltage to the minimum voltage existing on the line due to interaction of incident and reflected voltages along the line.

$$SWR = \frac{E_{max}}{E_{min}} = \frac{I_{max}}{I_{min}} \qquad \text{-----------(2.63)}$$

The SWR is an index of many of the properties of a mismatched line. It can be measured with fairly simple equipment, so it is a convenient quantity to use in making calculations on line performance. The SWR is related to the magnitude of the complex reflection coefficient by

$$SWR = \frac{1 + |\rho_v|}{1 - |\rho_v|} \qquad \text{-----------(2.64)}$$

and conversely

$$|\rho_v| = \frac{SWR - 1}{SWR + 1} \qquad \text{-----------(2.65)}$$

The reflection coefficient may also be expressed in terms of forward and reflected power, quantities that can be easily measured using directional RF wattmeter and in most cases indicated on the transmitting equipment.

$$|\rho_v| = \sqrt{\frac{P_r}{P_f}} \qquad \text{-----(2.66)}$$

where P_r = power in the reflected wave

P_f = power in the forward wave.

Therefore from equation 2., SWR is related to P_r and P_f by

$$SWR = \frac{1+\sqrt{\frac{P_r}{P_f}}}{1-\sqrt{\frac{P_r}{P_f}}} \qquad \text{-----(2.67)}$$

2.11.7 LINE VOLTAGES AND CURRENTS

The maximum voltage developed on a line operating with standing waves,

$$E_{max}\,(rms) = \sqrt{P \times Z_o \times SWR} \qquad \text{-----(2.68)}$$

where E_{max} = voltage maximum along the line in the presence of standing waves.

P = Power delivered by the source to the line input (W).

Z_o = characteristic impedance of the line (ohms) and

SWR = SWR at the load.

$$E_{min} = \frac{E_{max}}{SWR} \qquad \text{-----(2.69)}$$

By using Ohm's law, the maximum current developed

$$I_{max}\,(rms) = \frac{I_{max}}{Z_o} \qquad \text{-----(2.70)}$$

Minimum current

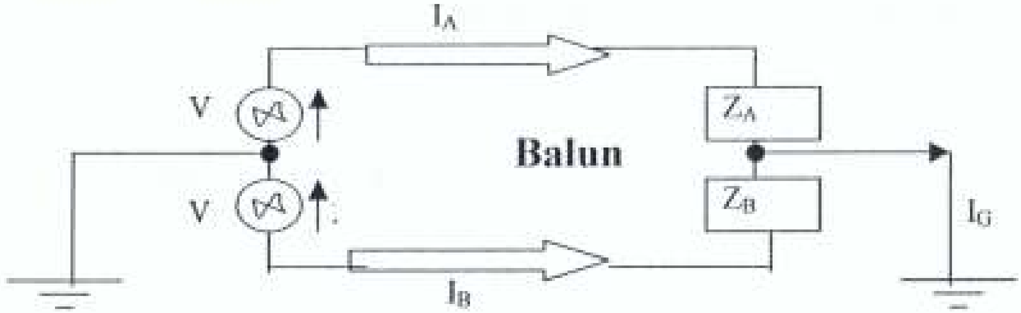
$$I_{min}\,(rms) = \frac{I_{max}}{SWR} \qquad \text{-----(2.71)}$$

2.11.8 ADDITIONAL POWER LOSS DUE TO SWR

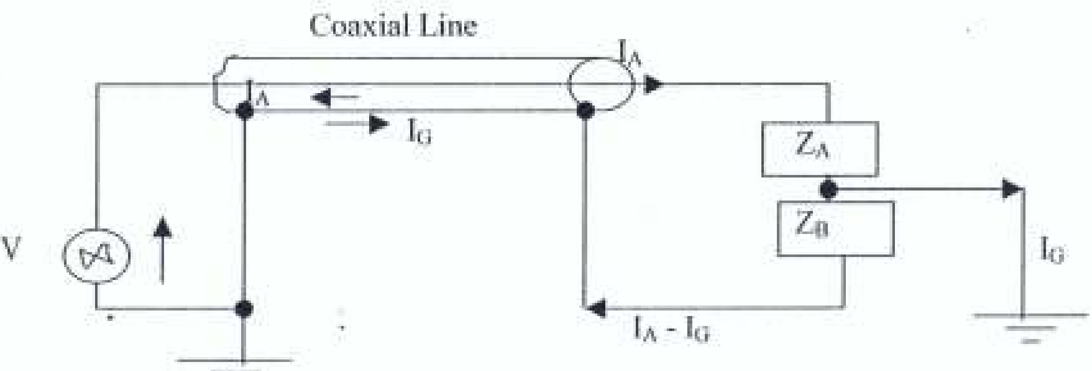
The power lost in a given line is least when the line is terminated in a resistance equal to its Z_0, and that is called the matched - line loss. There is however an additional loss that increases with increase in SWR. This is because the effective values of both current and voltage become greater on lines with standing waves. The increase in effective current raises the ohmic losses (I^2R) in the conductors, and the increase in effective voltage increases the losses in the dielectric (E^2/R).

2.11.9 BALANCED AND UNBALANCED SYSTEMS

For proper termination, a balanced transmission line must be terminated by a balanced load. Similarly, an unbalanced transmission line must be terminated by an unbalanced load. If these conditions are not met, currents flowing through the two conductors of the transmission line will be unequal; current will flow to the ground. In the case of a coaxial system, current will flow on the outside of the outer conductor. These conditions are illustrated in Figure 2.11.



(a) If Z_A is not equal to Z_B, the I_A is not equal to I_B and I_G is not equal to zero



(b) If Z_B is not equal to zero, then I_G is not equal to zero

Figure 2.11 Balanced and unbalanced system

Many practical radiating elements have balanced feed points and most antenna feeders are coaxial (they are far more convenient and safer to use) therefore it is necessary to introduce a suitably transforming arrangement at the joining point. This is known as a 'balun' (balanced-unbalanced).

2.11.10 COAXIAL CABLES

Coaxial cable is available in flexible and semi flexible varieties. The fundamental design is the same in all types. Power handling capability and cable size are directly proportional. Larger dielectric thickness and larger conductor sizes can handle higher voltages and currents. Losses generally decrease as cable diameter increases.Some coaxial cables have stranded wire centre conductors while others use a solid copper conductor. The outer conductor (shield) may be a single layer of copper braid, a double layer of braid, a solid aluminum (hard line), aluminum foil or a combination of these.

The commonly used cables and some of their properties are listed in Table 2.6. Figure 2.12 is a graph of the attenuation characteristics versus frequency for the most popular lines.

Table 2.6: Characteristics Of Commonly Used Transmission Lines

Type of line (Belden No)	Z_0 (ohms)	Velocity Factor (%)	Capacitance (pF per foot)	Outer Diameter (inches)	Dielectric Material	Max. RMS Operating Voltage
RG-6 (1152A)	75.0	75	16.5	0.266	Foam PE	300
RG-8X (9258)	50.0	78	26.0	0.242	Foam PE	300
RG-8 (8237)	52.0	66	29.5	0.405	PE	3700
RG-8 (8214)	50.0	78	26.0	0.405	Foam PE	600
RG-8A (9251)	52.0	66	29.5	0.405	PE	3700
RG-9 (8242)	51.0	66	30.0	0.420	PE	3700
RG-9A	51.0	66	30.0	0.420	PE	3700
RG-9B	50.0	66	30.8	0.420	PE	3700
RG-11 (8238)	75.0	66	20.5	0.405	PE	3700
RG-11 (8213)	75.0	78	17.4	0.405	Foam PE	600
RG-11A (8261)	75.0	66	20.5	0.405	PE	3700
RG-12	75.0	66	20.6	0.475	PE	3700
RG-12A	75.0	66	20.6	0.475	PE	3700
RG-17	52.0	66	29.5	0.870	PE	11000
RG-17A	52.0	66	29.5	0.870	PE	11000

RG-55	53.5	66	28.5	0.216	PE	1900
RG-55A	50.0	66	30.8	0.216	PE	1900
RG-55B	53.5	66	28.5	0.216	PE	1900
RG-58 (8240)	53.5	66	28.5	0.195	PE	1400
RG-58A (8259)	50.0	66	30.8	0.195	PE	1400
RG-58A (8219)	50.0	78	26.0	0.195	Foam PE	300
RG-58B	53.5	66	28.5	0.195	PE	1400
RG-58C (8262)	50.0	66	30.8	0.195	PE	1400
RG-59 (8241)	75.0	66	20.5	0.242	PE	1700
RG-59 (8212)	75.0	79	16.9	0.242	Foam PE	300
RG-59B (8263)	75.0	66	20.5	0.242	PE	1700
RG-62 (8254)	93.0	86	13.5	0.242	Air-spaced PE	750
RG-62	95.0	79	13.4	0.242	Foam PE	300
RG-62A (9228)	93.0	86	13.5	0.242	Air-spaced PE	750
RG-62B (8255)	93.0	86	13.5	0.242	Air-spaced PE	750
RG-133A	95.0	66	16.2	0.405	PE	4000
RG-141	50.0	70	29.0	0.190	PTFE	1400
RG-141A (83241)	50.0	70	29.0	0.190	PTFE	1400
RG-142 (84142)	50.0	70	29.0	0.206	PTFE	1400
RG-142A	50.0	70	29.0	0.206	PTFE	1400
RG-142B (83242	50.0	70	29.0	0.195	PTFE	1400
RG-174 (8216)	50.0	66	30.8	0.100	PE	1100
RG-213 (8267)	50.0	66	30.8	0.405	PE	3700
RG-214* (8268)	50.0	66	30.8	0.425	PE	3700
RG-215	50.0	66	30.8	0.475	PE	3700
RG-216 (9850)	75.0	66	20.5	0.425	PE	3700
RG-218 (ex RG-17)	52.0	66	29.5	0.870	PE	11000
RG-223* (9273)	50.0	66	30.8	0.212	PE	1700
9913 (Belden) *	50.0	89	24.0	0.405	Air-spaced PE	600
9914 (Belden) *	50.0	78	26.0	0.405	Foam PE	600

Aluminum Jacket, Foam Dielectric

1/2 inch	50.0	81	25.0	0.500		2500
3/4 inch	50.0	81	25.0	0.750		4000
7/8 inch	50.0	81	25.0	0.875		4500
1/2 inch	75.0	81	16.7	0.500		2500
3/4 inch	75.0	81	16.7	0.750		3500
7/8 inch	75.0	81	16.7	0.875		4000
Open wire	-	97	-	-		-
75-U transmitting twin lead	75.0	67	19.0	-		-
300-U twin lead	300.0	82	5.8	-		-
300-U tubular	300.0	80	4.6	-		-

Open Wire Line, "Window" Type (# 18 conductors)

1/2 inch	300.0	95	-	-		-
1 inch	450.0	95	-	-		-

* Double shield

Dielectric Designation	Name	Temperature Limits
PE	Polyethylene	-650 to +800 C
Foam PE	Foamed polyethylene	-650 to +800 C
PTFE	Polytetrafluoroethylene	-2500 to +2500 C (Teflon)

(SOURCE: ARRL Antenna Book (American Radio Relay League), 1997).

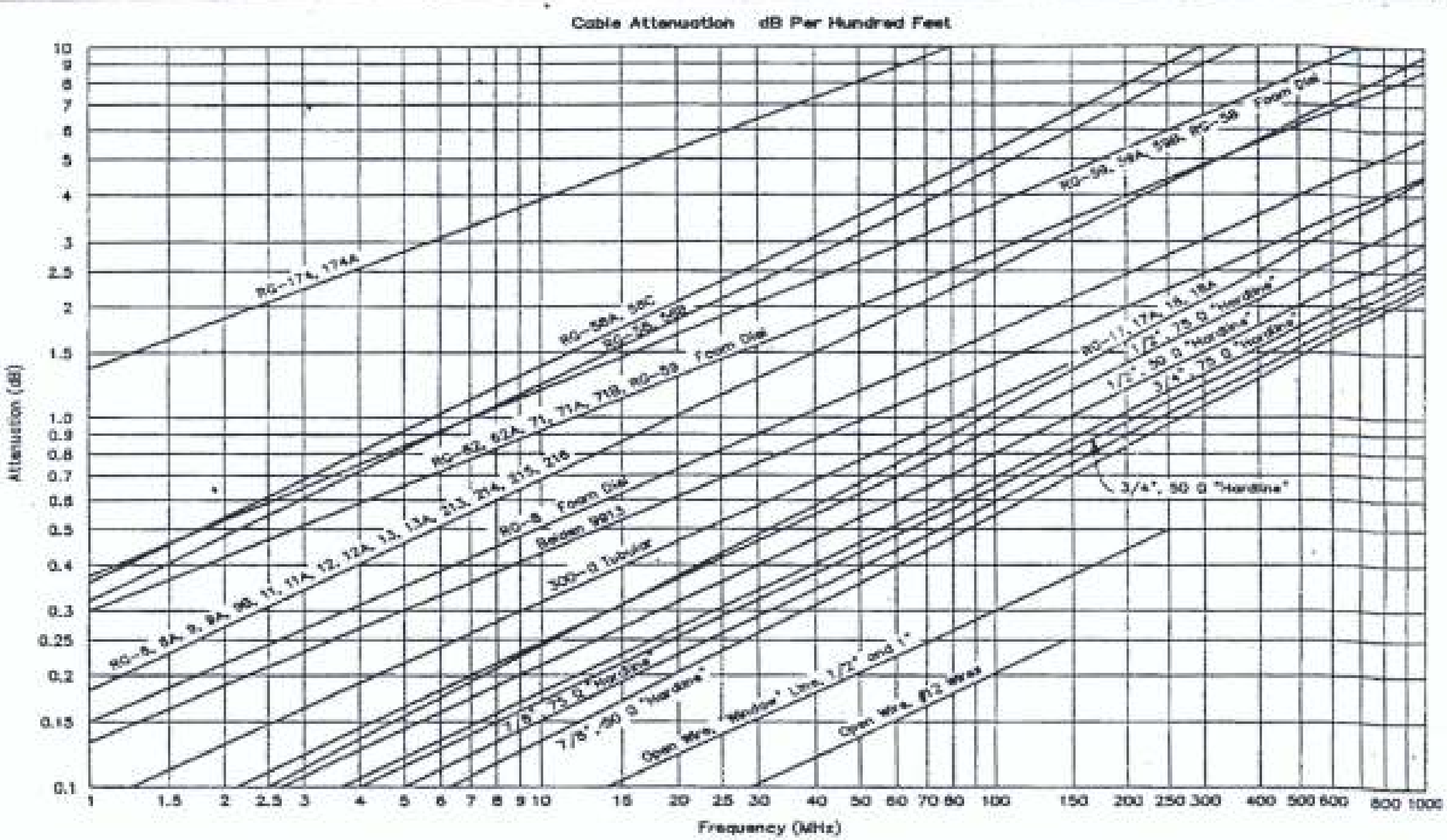


Figure 2.12 Nominal matched-line attenuation in decibels per 100 feet of various common transmission lines. Cables grouped together have approximately the same attenuation. (SOURCE: ARRL Antenna Book, 1997).

2.11.11 DIRECTIONAL COUPLERS

A directional coupler is a transmission line or wave-guide component for sampling waves traveling in one direction. In general, it has four ports. Two ports are used to connect the coupler into the line. The other two ports form auxiliary outputs. When these auxiliary outputs are correctly terminated by resistive loads, a fraction of the energy traveling in one direction in the line is diverted into one load and the same fraction of the energy traveling in the opposite direction is diverted into the other load.

2.11.12 HYBRIDS

Hybrids are special forms of directional couplers in which the input power divides equally between the load and the coupled forward wave output. Depending on the construction, a hybrid can be 'quadrature' where the power from a single output is split equally between two outputs, which are 90^0 out of phase. Alternatively, a hybrid may be 'sum and difference (0^0 - 180^0)', whereby power is split equally between two outputs which may be co-phased or 180^0 out of phase, depending on which input port is used.

Hybrids have the following uses in transmission and receiving systems.

1. To split power from a single source equally between two loads. The advantages of using a hybrid for this purpose are: -
   (a) Equal impedance loads, which are fed in phase quadrature, present a perfect match at the hybrid input, regardless of their impedance, all reflected power being delivered to the load.
   (b) A fault on one load will only have a small effect on the power delivered to the other load – in the limit.
2. To combine power from two sources at the same frequency, while keeping the sources isolated from each other provided the intended load and the balancing load are matched to the system.
3. To form part of a channel combiner or channel splitter.

In all cases, due attention has to be paid to the relative phases of the hybrid outputs.

2.11.13 MATCHING THE LINE TO THE TRANSMITTER

Transmitters are able to deliver their rated output power – at their rated level of distortion – only when operated into loads for which they were designed. If the impedance at the input of the transmission line connected to the transmitter differs appreciably from the load resistance into which the transmitter output is designed to operate, an impedance-matching network must be inserted between the transmitter and the line. A device that transforms the impedance at the input end of a transmission line (whatever it may be), to the 50 Ω need to keep the transmitter loaded properly is often referred to as antenna tuner or Transmatch "Transmitter Matching" network. The antenna tuner does not alter the SWR on the transmission line going to the antenna. It only ensures that the transmitter is properly loaded for which it was designed.

Modern transmitters often employ protection circuitry to reduce the output power automatically if the SWR rises to more than about 2: 1. Protective circuits are needed because the active devices for example solid state devices can instantly get destroyed trying to deliver power into the wrong load impedance. Some modern solid-state transmitters often include built-in antenna tuner (at extra cost) to match impedances when the SWR is not 1: 1. Figure 2.13 shows essentials of a coupling system between transmitter and a transmission line.

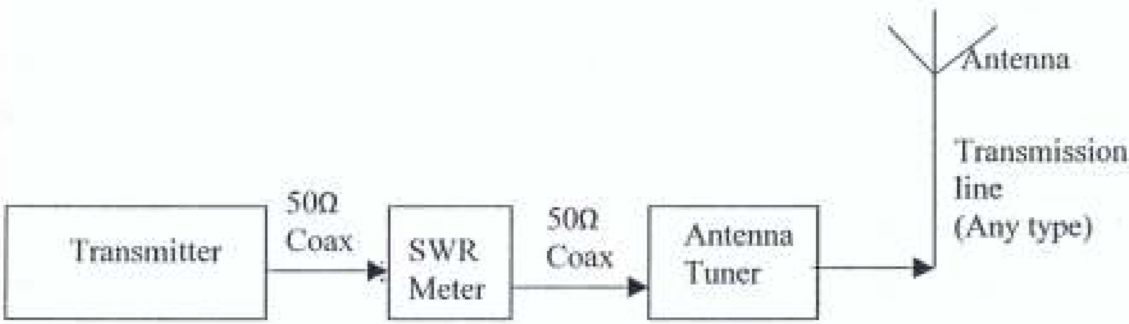


Figure 2.13 Essentials of a coupling system between transmitter and transmission line

2.12 ANTENNA

The Institute of Electrical and Electronic Engineers defines the Antenna as "a means for radiating or receiving radio waves". Radio transmitting antennas radiate the radio frequency energy generated in the transmitter and passed to the antenna through the transmission line. In this capacity, it acts as an impedance matching device to match the impedance of the transmission line to that of free space. Another function of the antenna is to direct the radiated energy into desired directions and suppress radiation in unwanted directions. A non-directional or omni directional radiator radiates uniformly in all directions and is known as isotropic radiator or a unipole.

2.12.1 RADIATING ELEMENT

Every radio antenna system consists of a basic radiating element or group of radiating elements, arranged to give the required gain, radiation pattern and polarisation. The simplest type of radiating element is formed when the end of a balanced transmission line is opened out at right angles as shown in Figure 2.14.

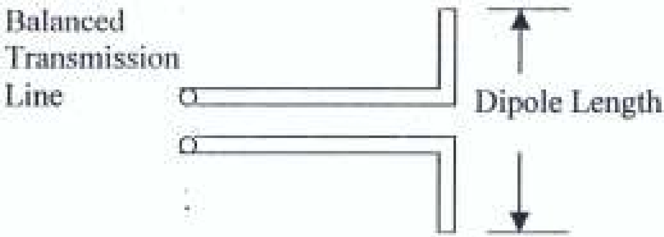


Figure 2.14 Forming a radiating element from a balanced transmission line.

It then forms a dipole whose impedance varies with the length of the dipole (in wavelengths). The most useful lengths for dipoles in practice are those, which are close to multiples of a half-wavelength, where the input reactance is low. When a dipole is about a half-wavelength long, its resistance is about 70 Ω, regardless of its cross section though its bandwidth depends on the elements length/diameter ratio. There are other forms of radiating elements, which in many cases are variants of the dipole.

The folded half-wave dipole has an input resistance of about 280 Ω and has a built- in reactance compensation. Any symmetrical dipole radiator can be converted to an unbalanced monopole radiator by using one half of the antenna fed against a ground plane, which is inserted in its plane of symmetry. The input series reactance and resistance of the monopole is then each equal to half of the corresponding dipole.

There are also other variety of hybrid arrangement of dipoles and slots and loops as radiators. Some are the skeleton slots, wire-loop radiators, metal strip radiators, monostrip radiators (for antenna miniaturisation), etc.

2.12.2 MUTUAL COUPLING

When two or more radiating elements are very close to one another (spaced less than a wavelength apart), there is strong mutual coupling between them. High current from one radiating element (the driven element) are induced into the other, resulting in changes to the input impedance of the driven element. Mutual coupling can be beneficial as in the Yagi-Uda array or constitute a nuisance in some other cases, Manton, (1997).

2.12.3 RADIATION PATTERN

Radiation pattern refers to the way the transmitting antenna radiates power around it. It is a graphical representation of the radiation of the antenna as a function of direction. An antenna may radiate power equally in all directions around it, or radiate more in some directions and less in other directions. Horizontal radiation pattern refers to the far-field radiation intensity distribution round the transmitting antenna in the horizontal plane. It is also called azimuth radiation pattern. Radiation pattern determination is essential both for technical and economic reasons.

- It ensures that signals of suitable strength reach the desired areas.
- Power is not wasted to areas that are not desired.
- It reduces or eliminates interference of the transmitting signal with signals of other stations in area not desired.

When the radiation is expressed as field strength (V/m), the radiation pattern is a field strength pattern. If the radiation is expressed in terms of power per unit solid angle, the resulting pattern is a power-pattern. A power pattern is proportional to the square of the field strength pattern. No practical antenna is capable of radiating the same amplitude of field strength to a given distance in all directions of azimuth (horizontal) and elevation (vertical) simultaneously i.e. completely isotropic. The concept of isotropic antenna is used as a standard against which to measure the performance of all other practical antennas.

The location of the transmitting site with respect to the whole service areas dictates the horizontal radiation power. The type of antenna, height of the transmitting antenna with respect to the ground, terrain and the coverage area dictates the radiation pattern in the vertical plane. If the antenna is located at the center of the coverage area, then the antenna horizontal radiation pattern can be omni directional. This is most desirable, but in a case where the terrain and other physical features and factors favour or restrict the choice of the site to a location not at the center of the coverage area, then the radiation pattern has to be modified from being omni directional. For horizontal pattern, a plot is usually made showing relative intensities of radiated power or field strength (usually in dB) in all directions (usually in degrees) round the antenna. The maximum intensity is taken as reference.

The shape of the radiation pattern of a half wave dipole when measured in the plane of the dipole is well known (figure 8 pattern). The radiation pattern of the same dipole when measured in a plane normal to the dipole is a uniform circle. The 3 - dimensional radiation pattern of the half-wave dipole is illustrated in Figure 2. 15

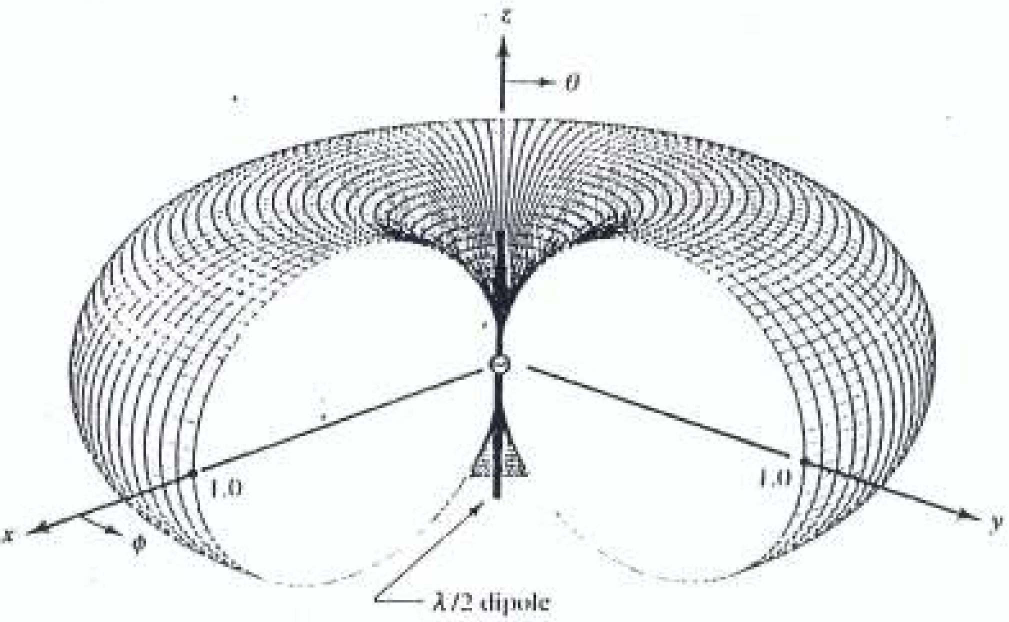


Figure 2.15 Three-dimensional pattern of a λ/2 dipole. (SOURCE: C.A. Balanis, "Antenna Theory: A Review" Proc. IEEE, Vol. 80, No 1. Jan. 1992)

A one-wavelength dipole has a radiation pattern similar to that of a half wave dipole but the lobe of radiation is narrow. If a dipole is placed with its plane parallel to the ground, it gives horizontal polarisation. But if the dipole is positioned with its plane normal with respect to the ground, it gives vertical polarisation.

A very wide range of radiation patterns can be synthesized in both horizontal and vertical planes and of different polarisations by suitably arranging dipoles or other radiating elements in the appropriate planes and then feeding them with suitable amplitudes and phases of currents.

2.12.4 ANTENNA GAIN

The gain of an antenna is directly related to its directivity. The narrower the beam into which power is directed, the higher the gain. In definition of antenna gain, comparison is made with a standard or reference antenna. An isotropic is the fundamental antenna standard, the gain Gi being quoted in dBi but other reference antennas are also found to be convenient for use as standards in some circumstances. If the reference antenna is a half-wavelength dipole, the gain Gd then is quoted in dBd. The power gain is defined as the ratio of power, which must be fed to the reference antenna to the power, which must be fed to the actual antenna in order to produce equal field strengths, at a distant point. When no direction is stated, it is implied that the gain relates to the direction of maximum radiation.

The particular reference antennas are:

A Hertzian dipole in free space.

A half-wave dipole in free space.

A Hertzian dipole near a perfectly conducting ground plane.

A short vertical monopole on a perfectly conducting ground plane.

A quarter-wave monopole on a perfectly conducting ground plane.

The maximum gains of these standard antennas are compared in Table 2.7.

Table 2.7 The directivity of typical reference antennas.

Reference antenna	g_t	$G = 10 \log g_t$ (dB)
Isotropic in free space	1.0	0
Hertzian dipole in free space	1.5	1.75
Half-wave dipole in free space	1.65	2.15
Hertzian dipole near a perfectly conducting ground plane, or a short vertical monopole on the ground plane	3.0	4.8
Quarter-wave monopole on perfectly conducting ground plane	3.3	5.2

The strength of the signal produced by some of these standard antennas in the direction of their maximum gain is also used as a standard of comparison for defining the strength of the signal radiated in a specified direction by a real transmitting antenna. Thus:

- The signal strength from a real antenna radiating real power relative to that of an isotropic antenna is called the equivalent isotropically radiated power (EIRP) of the source, typically expressed in dBW. In other words, the equivalent isotropic radiated power (EIRP) of a transmitter-antenna system is equal to the power, which would have to be fed into the terminals of an isotropic source in order to produce the same field strength as the actual transmitter-antenna system at a distant point.
- Signal strength related to that of a half-wave dipole is called the effective radiated power (ERP).
- Signal strength related to that of a short vertical monopole is called the effective monopole radiated power (EMRP).

2.12.5 ANTENNA ARRAY

An array is an assembly of radiating elements in an electrical and geometrical configuration. In most cases, the elements are identical. This is not necessary but is convenient, simpler and more practical. The individual elements of an array may be of any form (wires, apertures, etc.).

The total field of an array is determined by the vector addition of the fields radiated by the individual elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively in the desired directions and interfere destructively in the remaining space. Theoretically this can be accomplished but practically it is only approached.

In an array of identical elements, the shape of the overall pattern of the antenna depends on: -

- The geometrical configuration of the overall array (linear, rectangular, circular or spherical).
- The relative displacement between the elements.
- The excitation amplitude of the individual elements.
- The excitation phase of the individual elements.
- The relative pattern of the individual elements.

2.12.5.1 Array Factor

The far-zone field of a uniform multi-element array of identical elements is equal to the product of the field of a single element, at a selected reference point (usually the origin) and a factor, which is widely referred to as array factor i.e.,

E (total) = [E (single element at reference point)] x [array factor].

This is referred to as Pattern Multiplication. Each array has its own array factor. The array factor in general is a function of the number of elements, their geometrical arrangement, their relative current magnitudes their relative phases and their spacings. Pattern Multiplication is also valid for arrays of identical elements but having no identical magnitudes, phases and/or spacings between them. The array factor does not depend on the directional characteristics of the radiating elements themselves.

In order to synthesize the total pattern of an array, it is not only required to select the proper radiating elements but the geometry (positioning) and excitation of the individual elements.

2.12.6 ANTENNA MATCHING

The output impedance of the transmitter and the input impedance of the antenna should both be matched to the impedance of the transmission line (feeder) primarily to maximise power transfer. For a well-matched antenna, there will be a low standing wave ratio on the feeder. This then make it possible to use a smaller feeder for a given power (voltages and currents on the line are minimised) provided that its attenuation is not too high and provided that the feeder rating can cope with fault conditions.

Matching the antenna impedance to that of the feeder becomes very critical if the bandwidth of modulation is wide, modulation changes rapidly and there is long length of feeder between the transmitter and the antenna, Manton, (1992). Any signal that is reflected by the antenna travels back to the transmitter.

2.12.6.1 Some Matching Techniques

The overall performance of an antenna system is not completely dependent on the antenna alone but rather on the characteristics of the transmission line-antenna combination. In practice, the characteristic impedance of transmission line is usually real but that of antenna element is complex. Therefore there has to be efficient coupling between the antenna and the transmission line.

2.12.6.1.1 Stub Matching

Matching at a given frequency is accomplished by placing a shunt or open - circuited shunt stub a distance, *s* from the transmission line-antenna element. The connection is shown in Figure 2.16.

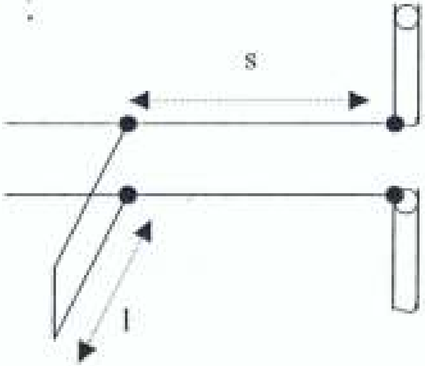


Figure 2.16 Stub matching.

The length, *s* is controlled so as to make the real part of the antenna-element impedance equal to the line characteristic impedance. The length, *l* of the shunt line is varied until the susceptance of the stub is equal in magnitude but opposite in phase to the line input susceptance at the point of the transmission line-shunt element connection.

2.12.6.1.2 Quarter Wavelength Transformer

Another technique is the use of a λ/4 transformer. If the antenna impedance is real, the trânsformer is connected directly to the load but if the antenna impedance is complex, the transformer is placed a distance s_o away from the antenna as shown in Figure 2.17.

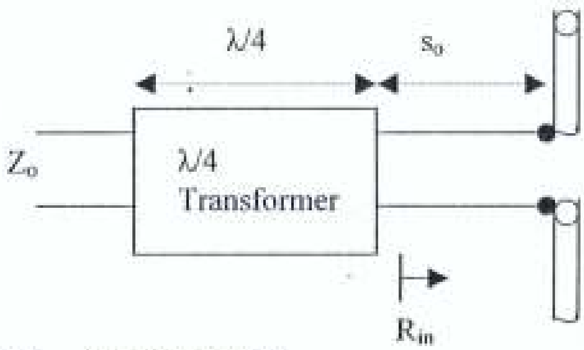


Figure 2.17 λ/4 transformer.

The distance s_o is chosen so that the input impedance toward the load at s_o is real and designated as R_{in}. For matching, the transformer characteristic impedance, Z_1 should be

$$Z_1 = \sqrt{R_{in} Z_o} \, Z_1 \qquad \text{--(2.72)}$$

Where Z_o is the characteristic impedance (real) of the input transmission line. The transformer is usually another transmission line with the desired characteristic impedance. This technique is most suitable in micro strip transmission lines.

2.12.6.1.3 T – Match

In this technique, the dipole of length, l and radius, a, is connected to the transmission line by another dipole of length, l' ($l' < l$) and radius a'. The smaller dipole is tapped to the larger one at distances $l'/2$ from the center and the two are separated by a small distance s. The transmission line is connected to the smaller dipole at its center. The T-match connection is shown in Figure 2.18

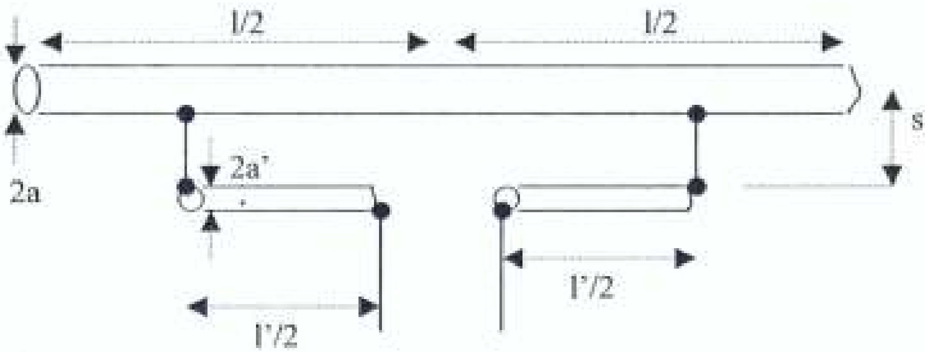


Figure 2.18 T – Match

The T-match is a symmetrical and balanced system; therefore it is well suited for use with parallel conductor transmission lines.

2.12.6.1.4 Gamma Match

The gamma match is equivalent to half of the T-match but requires a capacitor in series with the gamma rod. It is a convenient method of connecting dipole or other antennas (Yagi-Uda, log-periodic, etc) to coaxial cables, which are, unbalanced transmission lines and obtain a match. The arrangement is shown in Figure 2.19.

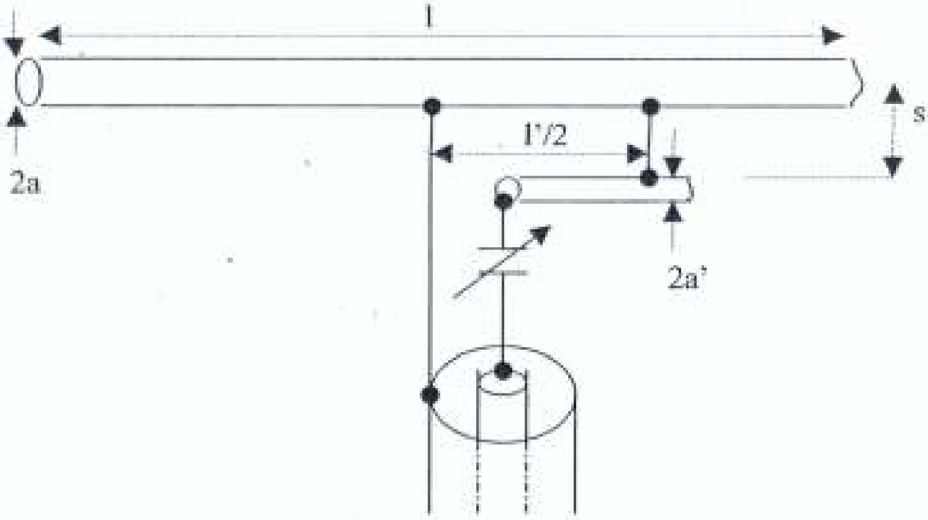


Figure 2.19. Gamma match

2.12.6.1.5 Baluns And Transformers

As mentioned earlier in 2.11.9, baluns are devices used to balance inherently unbalanced systems. Also they can provide not only balancing but step up or step down impedance transformations. They are then referred to as balun-impedance transformers. Employing ferrite cores in their construction can increase their bandwidth.

2.12.7 THE LOG PERIODIC ANTENNA

The log periodic antenna was invented by D. E Isbell at University of Illinois in 1958. It is a system of driven elements designed to be operated over a wide range of frequencies. It exhibits constant characteristics (radiation resistance, VSWR and pattern characteristics) over its designed bandwidth. It has similar directivity as the Yagi-Uda array but they are achievable and maintained over a wider bandwidth than Yagi-Uda. In Yagi-Uda antenna, only one element is energized directly, the other elements operate in parasitic mode but in log-periodic antenna, all the elements are energized (they are connected). The feed is at an end of the antenna where we have the element of the shortest length. Different elements of the antenna are active at different frequencies of operation within its designed frequency range.

There are several varieties of log-periodic antenna such as the zigzag, planar, trapezoidal, slot, V and the dipole. The dipole type is referred to as the log-periodic – dipole antenna often abbreviated as LPDA. The LPDA consist of several dipole elements, which are of different lengths and different relative spacings. A distributive type of feeder system is used to excite the individual dipole elements. Each element is excited with a phase shift of 180^0 by alternating element connections. The geometrical dimensions of Yagi-Uda array element do not follow any set pattern but that of LPDAs do. The element lengths, relative spacings, diameters and gap spacing of dipole centers of the LPDA increase logarithmically in dimensions beginning from the array feed point and greater for each element than for the previous element in the array. It is this design feature of the LPDA, which gives it wide bandwidth advantage over Yagi-Uda array.

The LPDA, within its bandwidth is frequency independent. Its electrical properties vary periodically with the logarithm of the frequency, hence the name log-periodic. For example, the input impedance of the LPDA varies periodically with the logarithm of the frequency. Other parameters such as directivity, beam width etc has similar variations. This periodicity may seem not to ensure broadband operation, but if the variations within one cycle are sufficiently small and acceptable for the corresponding bandwidth of the cycle, then broadband operation is ensured. The total bandwidth is determined by the number of repetitive cycles. Yagi-Uda array is often designed for single frequency operation.

The 180^0 phase excitation makes the radiated fields from the dipoles of the LPDA to be in phase in a direction towards the array apex. The radiated wave of a single LPDA is linearly polarized and is horizontal if the plane of the antenna is parallel to the ground. Patterns of larger directivities or different shapes can be achieved by "arraying" and "phasing" multiple log-periodic dipole arrays. The schematic of the LPDA is shown in Figure 2.20

2.12.8 LOG PERIODIC DIPOLE ANTENNA DESIGN

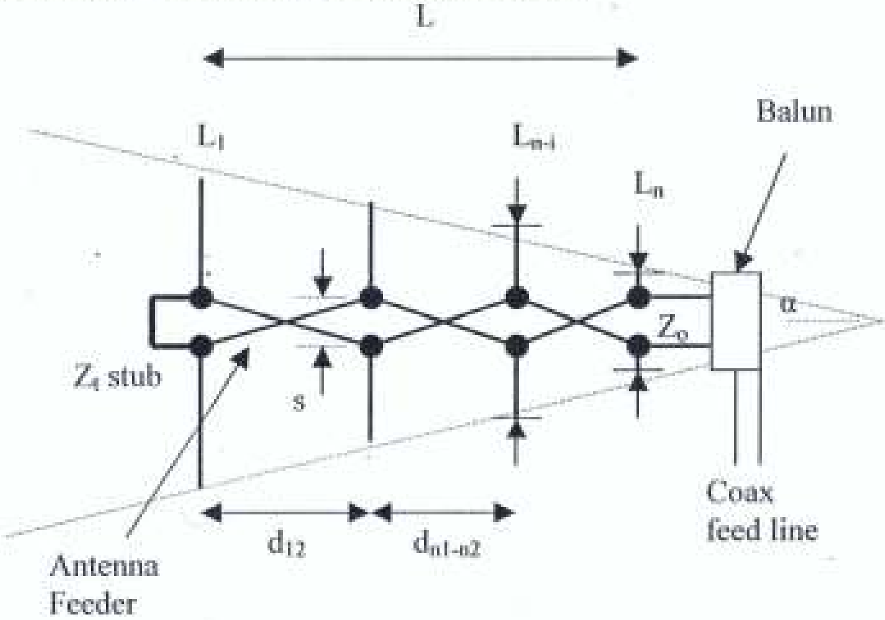


Figure 2.20 LPDA Schematic

Design parameters (geometric constants) used to determine the elements lengths and element spacings are:

$$\tau = \frac{l_n}{l_{n-1}} \tau \qquad \text{------------(2.73)}$$

$$= \frac{d_{n,n-1}}{d_{n-2,n-1}} \qquad \text{------------(2.74)}$$

$$\sigma = \frac{d_{n,n-1}}{2l_{n-1}} \qquad \text{------------(2.75)}$$

where l = element length

d = element spacing

τ = design constant ($\iota < 1.0$)

σ = relative spacing constant

s = feeder spacing

L = boom length

Z_o = characteristic impedance of antenna feeder

α = half the apex angle

The element dimensions is such that

$$l_2 = \tau l_1 \qquad \text{------------(2.76)}$$

$$l_3 = \tau l_2 = \tau^2 l_1$$

.

.

$l_n = l_1\tau^{n-1}$ --(2.77)

where l_1 = longest element

l_n = shortest element

Also, $d_{23} = \tau d_{12}$ --(2.78)

$d_{34} = \tau d_{23} = \tau^2 d_{12}$

.

.

$d_{n-1,n} = \tau^{n-2} d_{12}$ --(2.79)

where d_{12} = spacing between elements 1 and 2.

An active region bandwidth, B_{ar} exists for the LPDA in which within the frequency range, the radiated fields from the dipoles are in phase and in direction towards the apex. The phase relationship existing amongst the dipoles is such that the phase delay in the transmission line combines with the 180° switch (by the alternate interconnection of transmission lines) gives a total of 360°.

For a design-frequency coverage of bandwidth B, there exists an associated bandwidth of the active region, B_s in such a way that

$B_s = B \times B_{ar}$ --(2.80)

Where $B = \dfrac{f_n}{f_1}$ --(2.81)

f_1 = lowest frequency (MHz)

f_n = highest frequency (MHz).

B_{ar} varies with τ and α. The gain of LPDA is directly related to its directivity and is determined by the design parameter τ and relative element spacing constant σ. Figure 2.21 shows the relationship between these parameters.

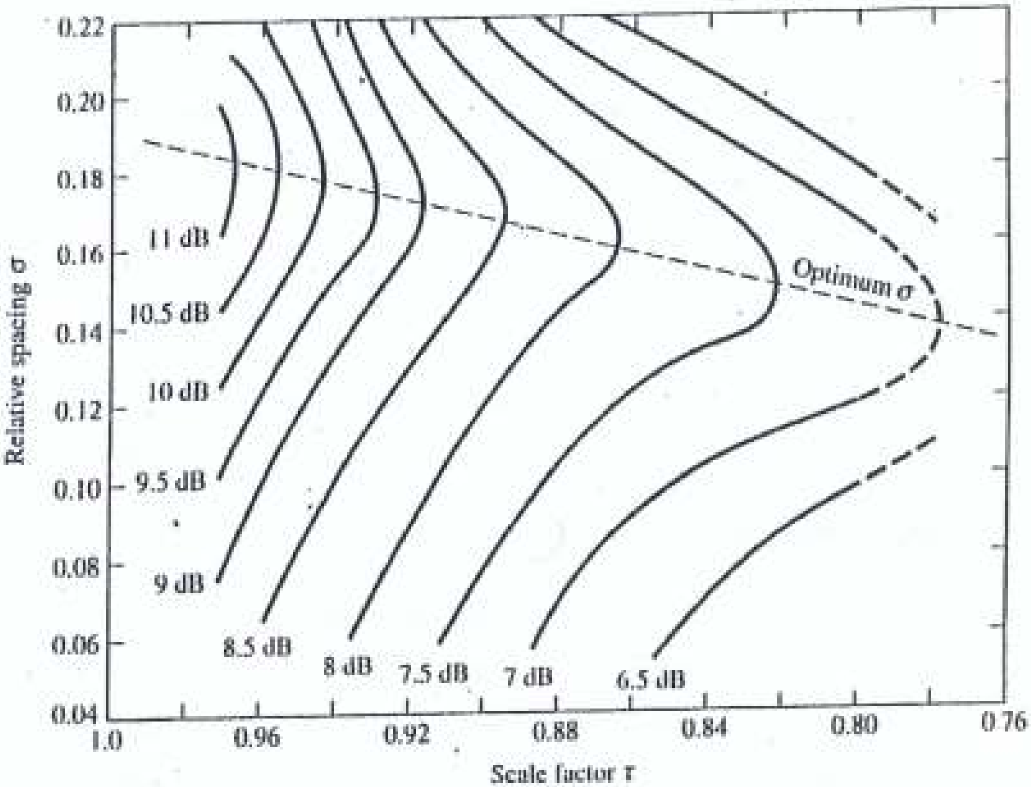


Figure 2.21 Computed contours of constant directivity versus σ and τ for Log - Periodic dipole arrays. (SOURCE: R. L. Carrel, " Analysis and Design of the Log-Periodic Dipole Antenna", Ph. D. Dissertation, Elect. Eng. Dept., University of Illinois, 1961, University Microfilms, Inc., Ann Arbor Michigan. The work was followed by Buston, P.C. and Thompson, G.T. (1976).

For each value of τ in the range $0.8 \le \tau \le 1.0$, there exist an optimum value for σ, called σ_{opt}, for which gain is maximum. An increase in τ means more elements and optimum σ means a long boom.

Equation 2.82 gives the relationship between α, σ and τ.

$$\sigma = \left(\frac{1-\tau}{4}\right)\cot\alpha \quad \text{---(2.82)}$$

and $\sigma_{opt} = 0.234\tau - 0.051$ ---(2.83)

The input resistance of the LPDA depends primarily on Z_o, the characteristic impedance of the antenna ;feeder (though exhibit periodic characteristic with frequency). An approximation (to within 10%) is

$$R_n = \frac{Z_o}{\sqrt{1 + \dfrac{Z_o}{4\sigma' Z_{av}}}} \quad \text{--(2.84)}$$

where R_o = mean radiation resistance of the LPDA input impedance

Z_o = characteristic impedance of antenna feeder

Z_{av} = average characteristic impedance of a dipole

$$= 120\left(\log_e \frac{l_n}{d_{iamn}} - 2.25\right) \quad \text{--------------------------(2.85)}$$

l_n/d_{iamn} = length to diameter ratio of *nth* element.

σ' = mean spacing factor

$$= \frac{\sigma}{\sqrt{\tau}} \quad \text{--(2.86)}$$

The LPDA are constructed with progressively increasing element diameters from the front to the back of the array to minimize SWR variations but if all elements are of the same diameter, the SWR performance may not be noticeably degraded.

The antenna feeder termination, Z_t is a short circuit at a distance of $\lambda_{max}/8$ or less behind element no. 1, the longest element. Z_t may be eliminated without significant effect on the results. The design equations and procedure for the LPDA are contained in Appendix A.

2.12.9 FEED ARRANGEMENT

In the LPDA, a balanced feeder is required for each element and adjacent elements are fed with an 180° phase shift by alternating element connections. If the input feed line is a balanced line, then the method of feeding is very simple. The antenna feeder is the line, which connects each adjacent element. The feed line is the line between the antenna and the transmitter.

If a coaxial cable is used as the feed line (as is often in VHF and UHF installations), a practical method of achieving the 180° phase reversal between adjacent elements is shown in Figure 2.22 In this technique, element halves (tubing) are supported by feeder conductors of tubing that are closely spaced. The antenna feeder can even serve as the boom. The coaxial cable is brought to the feeder at the end with the longest element through the hollow part of one of the feeder line pipes. The outside conductor of the coax is connected to the conductor at the feed; the coax inner conductor is extended and is connected to the other pipe of the feeder line as shown in the figure. This arrangement provides a built-in broadband balun resulting in a balanced overall system.

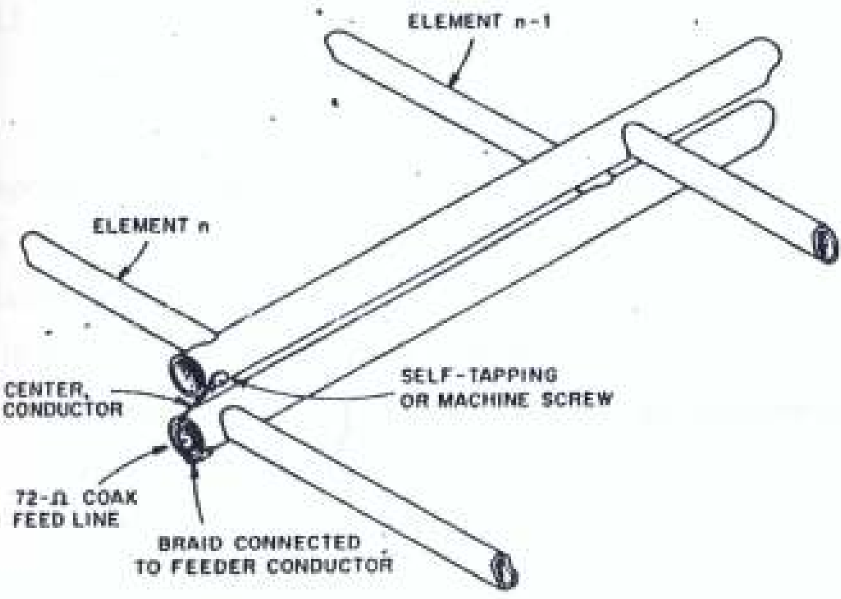


Figure 2.22 A method of feeding the LPDA for VHF and UHF designs.

CHAPTER THREE
PLANNING PROCESS

3.1 TOPOGRAPHICAL STUDY OF THE AREA (FUTA COMMUNITY) TO BE COVERED.

Area topographical study is a very important aspect of radio service planning especially broadcasting and point to multipoint. The purpose of the study is to be able to identify the requirements of the area to be covered needed for the determination of the transmitting parameters.

The process of the study is described below:

- Administrative map of Ondo State and the Topographical Map (scale 1 : 100,000) of Akure Local Government Area was obtained from Ministry of Works, Land and Transport, Akure. From another topographical map (scale 1 : 50,000) of part of Akure Local Government Area, the Community's topographical map was extracted.
- Survey maps of the community showing the land boundaries, dimensions, form contours and some physical features existing were obtained from the Physical Planning Unit of the Institution.
- The maps from the Physical Planning Unit were not comprehensive enough (the contours shown are form contours). Form contours are contours shown with broken lines. They may have numbers or no number attached to them. They are not as a result of accurate ground surveys but are determined by studying aerial photographs taken in the field and are mere estimates or approximations. Therefore, coordinates (Latitude & Longitude) and heights (Altitude) measurement of some spots (using the maps from the Physical Planning Unit as guide) within the community were taken with the help of a navigational instrument called "GPS" Receiver, (Global Positioning System) Receiver. GPS is a network of earth-orbiting satellites used for precise position finding in surveying and navigation, (Appendix G). All the heights and the coordinates used in this work were as indicated by the GPS receiver complemented by the topographical map from the Ministry of Works, Land & Transport, Akure.

- Apart from spot height measurements, visit to some areas within the community was made and photographs taken in order to get a clearer idea about existing features and also to gain information about suitable transmitting site.
- The GPS measurements and results of the topographical study were combined with the topographical maps from both Ministry of Works and Physical Planning Unit to get the community's boundary and detailed land contours.

Representative topographical map of the community and environs is shown in Figure 3.1.

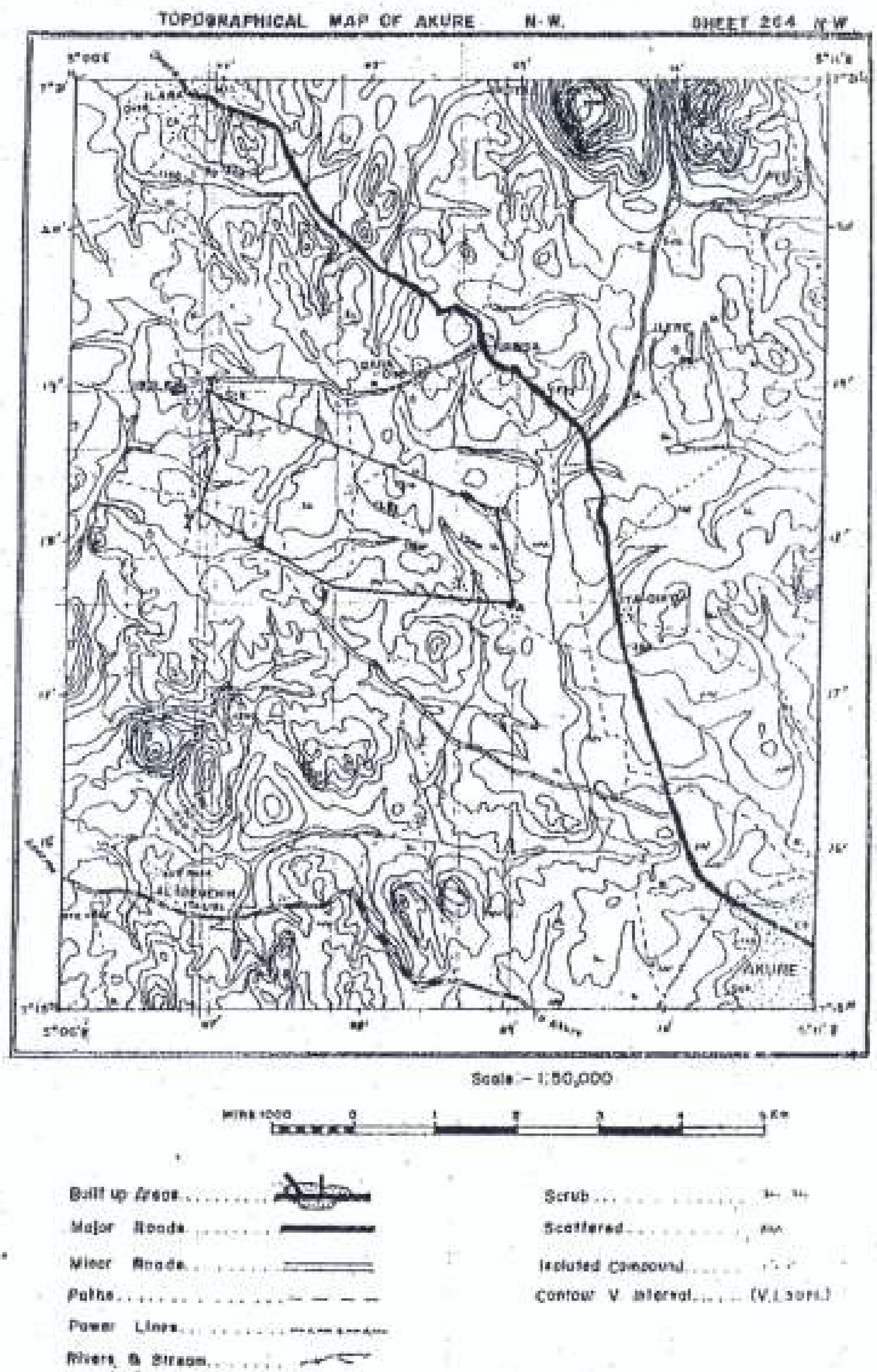


Figure 3.1 Topographical map of North West of Akure South LGA where FUTA Community is located. (SOURCE: Ministry of Works, Land and Transport, Akure. Note: FUTA boundary coordinates and lines were drawn on the map after the detailed topographical study).

3.1.1 COORDINATES AND SPOT HEIGHT MEASUREMENTS

Letters of the alphabets on the map in Figure 3.2 indicates spots whose heights and coordinates were measured using GPS receiver. The height (altitude) and the coordinates (latitude and longitude) of the spots were tabulated in Table 3.1. The values shown are the average values of several readings of the GPS receiver. The altitude is the height of the spot above sea level with an error of few meters. GPS Receiver used is GPS 38 by Garmin Corporation.

Table 3.1: - Spot height measurements

Location	Mean Geographical coordinate (degrees)	Mean measured Altitude (metres)
(A) At Obakekere South Gate	7.29321 N 5.14962 E	360
(S) At Obakekere Hostel	7.29434 N 5.14875 E	360
(L) At Obakekere staff quarters.	7.29707 N 5.14565 E	362
(T) At Agric Research/Feed mill area.	7.30140 N 5.14472 E	375
(U) At Obanla Female Hostel	7.30313 N 5.14195 E	379
(V) At Obanla hostel open ground (front)/SUB	7.30483 N 5.14074 E	380
(B) At Obanla North Gate	7.30653 N 5.14017 E	379
(C1) At Obanla sports area edge beside the north gate road/proposed CEC building site	7.30497 N 5.13875 E	385
(C2) At Obanla Sports Complex field	7.30515 N 5.13733 E	390
(D) At the Senate Junction	7.30341 N 5.13873 E	380

(E) At the Sports Complex ridge	7.30521 N 5.13626 E	395 (edge) 400 (peak)
(W) At the bore hole/tank area	7.30564 N 5.13570 E	402
(F) At Obanla staff quarters junction	7.30541 N 5.13268 E	382
(I1) Top of Rock "IA".	7.30443 N 5.13343 E	385
(I2) Top of Rock "IB"	7.30387 N 5.13390 E	383
(G) At Obanla staff quarters old gen. House	7.30362 N 5.13277 E	380
(H) At the culvert of stream B2 at Obanla staff quarters	7.30316 N 5.12953 E	375
(J) At Obanla Chancellors' quarters	7.30312 N 5.12756 E	378
(X) At Agric Building area	7.30208 N 5.13522 E	380
(K) At the Auditorium stream	7.30095 N 5.13706 E	376
(β) At Engineering building area	7.30309 N 5.13630 E	382
(P) Beside the stream 'c' at the Chancellors' area	7.30641 N 5.12308 E	360
(M) Top of the elongated rock "M" between Obanla and Obakekere	7.29831 N 5.14025 E	394

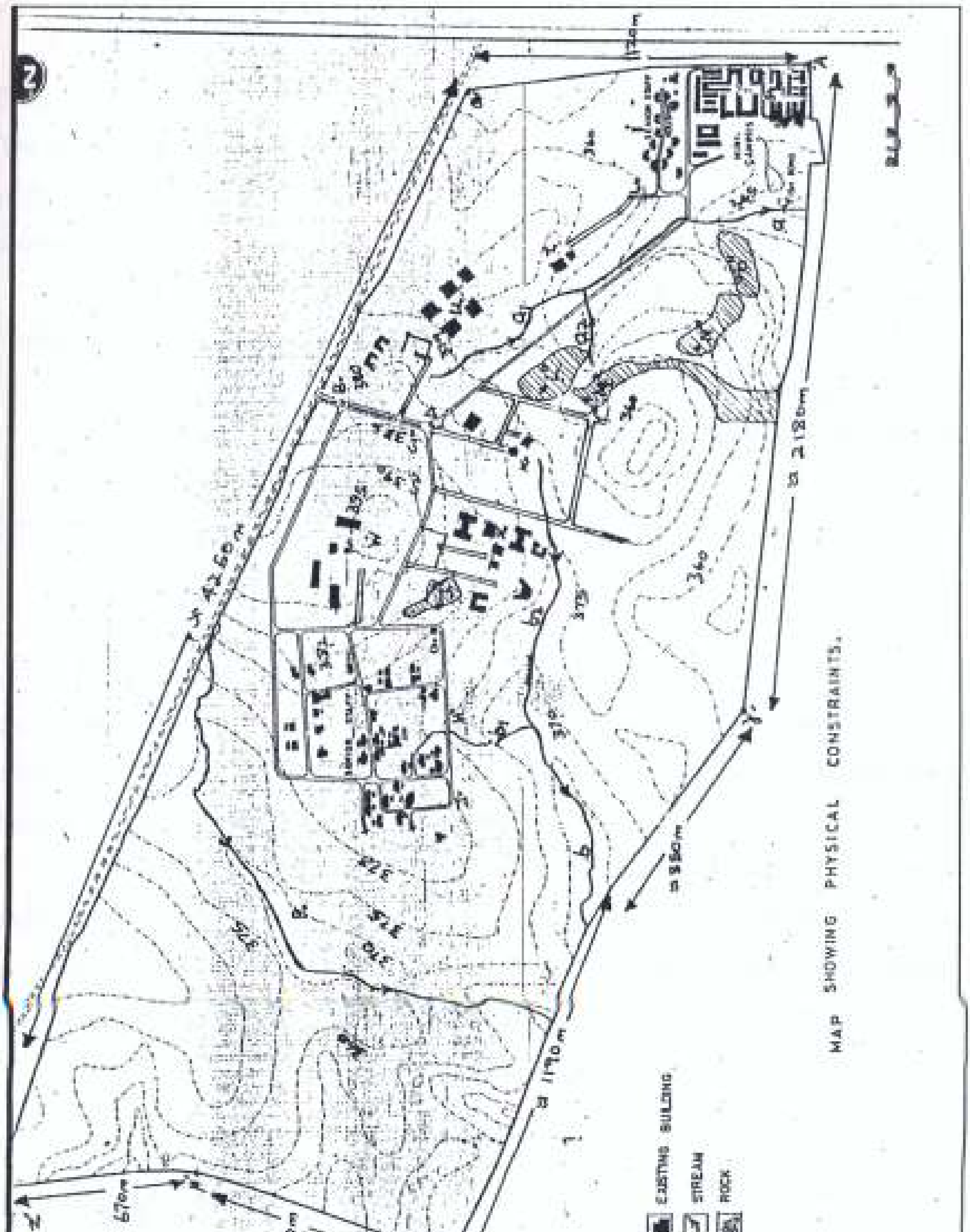


Figure 3.2 Diagrammatic land area and dimensions of FUTA Community. (SOURCE: Physical Planning Unit, Federal University of Technology, Akure. Note: Contour numbers (in metres), dimensions, measured spots identification letters and features labeling were added after the detailed topographical study.

3.1.2 FUTA COMMUNITY

FUTA Community is situated at the northwestern part of Akure, the Ondo State capital. It lies within 5^0 07'E, 5^0 09'E longitude and 7^0 17'N, 7^0 19'N latitude. The community land area is about 576.128 hectares and is situated at an average level of 380m (1250 ft) above sea level. The land area (diagrammatic) of the community is shown in Fig. 3.2. The numbers on the contour lines are in metres.

The community land area is divided into two major areas namely Obanla and Obakekere. They are further sub-divided into the following:

1) Academic area comprising the present and future academic areas.
2) Residential area comprising the staff quarters, the students' hostels and the chancellors' quarters.
3) Administrative area.
4) Communal area and sports complex.
5) University farms.

People are concentrated in the present academic area, the residential areas and the administrative area. The whole community population, being an educational institution, varies throughout the year. Also there are concentrations of people living immediately outside the campus at Obakekere.

As at the time of this work, the community can be categorized as both urban and rural. It is rural in terms of population and the percentage of land area covered by buildings, roads and other man - made structures. It is urban in terms of development. The few buildings within the whole area are scattered. Much of the land area is covered with forest and shrubs, though for most period of the year, they are cultivated.

3.1.3 TERRAIN

The community land profile ranges from about 340 metres above sea level to about 400 metres. There are lowlands and uplands though the height difference between them is not much. The lowlands are the Obakekere area and the Chancellors' quarters around the western stream (stream 'c' in Fig. 3.2). The uplands are the Obanla area most especially the present academic area, administrative area and the sports complex area. Other areas such as the feed mill, Obanla hostel area, Obanla staff quarters and future academic areas are of intermediate range. The highest spot in the community is the borehole site at the top of the Obanla Sports Complex ridge.

Three major streams flow within the community. Two have their source within the community and the third only passes through. For this work, the streams are labeled 'a', 'b' and 'c' (Fig. 3.2).

There are few scattered rocks within the community and the major ones are five (Fig. 3.2). For this work, they are labeled as rock "I", "L", "M", "N" and "O". They are of few metres in height but the most prominent, highest and elongated of them all is the rock labeled "M". The terrain study showed some areas that are fairly flat (Obakekere hostel area, Obanla hostel area and the Obanla staff quarters) while others are of gentle slope.

The community is within the rain forest belt; therefore the vegetation is of forest type. Most of the trees are of medium height due to all – around – the – year cultivation and human activities. The soil is of the forested, rich, clayey-loamy and moderately dry type (Jan. 2003). Uncultivated part of the community, which is presently covered with thick forest, is the area beyond stream 'c' at the western side. The forest area of the community is shown in Fig. 3.3.

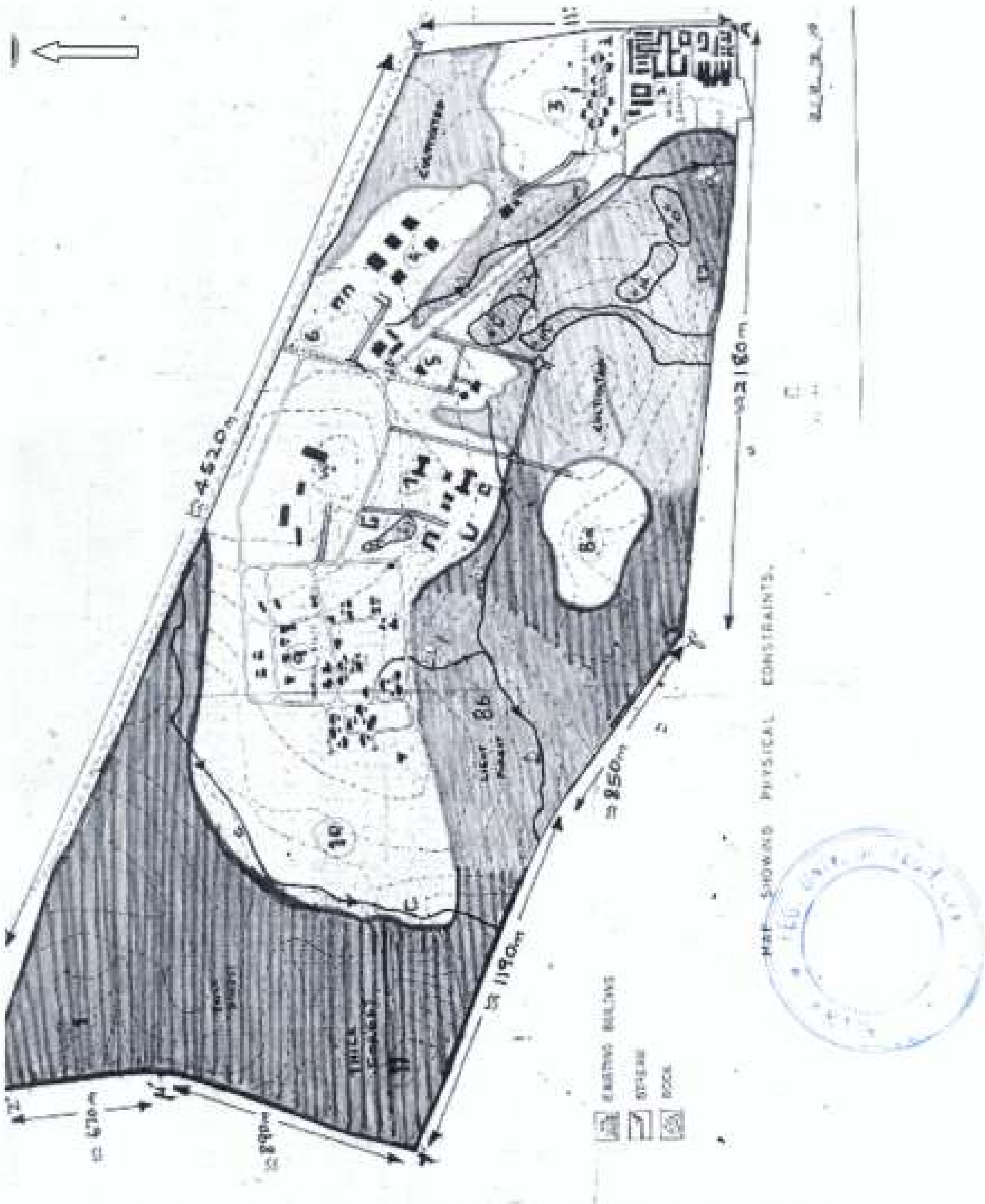


Figure 3.3 Forested areas of the Community. (Note: The forested regions shown are as found out from the detailed topographical study (Nov. 2002 - Jan. 2003) and are super imposed on the map (Figure 3.2) from the Institution's Physical Planning Unit. The numbers in circles indicate the target zones (see text)).

3.2 LOCATION OF TRANSMITTER AND ANTENNA HEIGHT

The transmitting site and height were selected to give the following benefits: -

(i) Required coverage.

(ii) Minimum shadow effect caused by hills, trees and tall buildings.

(iii) Wanted field strength for the target service zones in the community.

Factors considered are: -

- The transmitting site should be a relatively quiet place for most period of the year (in terms of human activities).
- It is advantageous though not compulsory if the site is located on the highest point in the community.
- The transmitting antenna height (mast height) should be of such value as to provide (if possible) line-of-sight propagation to many target service areas (zones) i.e. clearance off buildings, trees and hilltops in order to minimize diffraction and shadow zones.
- The location selected must have enabling environment for operation in terms of development, accessibility, availability of power and other basic infrastructures. Also, erection of mast in such a location should not cause damage to the environment or pose a danger to the vicinity.

The result of the coverage area study (survey, spot height measurement and topography) were combined and used to select a location and mast height that optimally met the aforementioned considerations.

The transmitting antenna location selected is **the top of the ridge at the Obanla Sports Complex.** The spot coordinate is 7.30521 N & 5.13626 E. The suitability of this location is due to the following desirable features:

- It is the highest spot throughout the whole community that is on ground.
- It is not close to where people concentrate throughout the year.
- It is relatively quiet for most period of the year. The sports complex is occasionally used.
- Existing Building: - the Sports Complex building, which is very close to the ridge, can house the transmitting equipment.
- Power Supply: - the Sports Complex building has a functional electric power supply already.

- Water Supply: - the location is very close to the community's Obanla water borehole.
- Erection of mast on the ridge can cause no environmental damage and ecological imbalance.
- Accessibility: - the location is easily accessible from every part of the community. It is close to most users of the service.

Photographs of the location are shown in Plate 3A and Plate 3B. Some views from the spot are shown in Plate 3C, 3D and 3E.

Transmitting antenna height: - The transmitting height selected having considered the factors mentioned earlier is 30 metres of mast height (line-of-sight propagation to many zones and clearance off many trees and buildings especially those around the Obanla area). Fresnel first ellipsoid minor radius, r_e for a distance of 2060m from the antenna spot (Obakekere edge, zone 2 land profile diagram of Fig. 3.6) and representative frequency of 100MHz,

$$r_e = \frac{1}{2}\sqrt{\lambda d} \qquad \text{-----} \quad (3.0)$$

where d is the transmit-antenna to the receive-antenna distance (m) and λ is the wavelength (m).

$$\lambda = \frac{c}{f} \qquad \text{-----} \quad (3.1)$$

$$= \frac{3\times10^8}{100\times10^6}$$

$$= 3\text{m}$$

Substituting for λ,

$$r_e = \frac{1}{2}\sqrt{3\times2060}$$

$$= 39.3\text{m}.$$

The top of the ridge is about 8m above the immediate surroundings. So the effective antenna height (as seen from a receiving location) varies from location to location due to varying terrain altitudes. Heights of some buildings (and their altitude above sea level) around the Obanla area close to the transmitting location are shown in Table 3.2.

Table 3.2: - Height of some buildings around the Obanla Area close to the proposed transmitting location.

	Building	Average Height (as measured by GPS receiver) (metres)	Altitude above sea level (metres).
1	School of Engineering	13	382
2	School of Agriculture	14	380
3	School of Sciences	14	380
4	Uncompleted Library	13	385
5	Senate Building	18	382
6	Student Union	9	380

3.3 SIGNAL STRENGTH TESTS OF SOME NEIGHBOURING FM STATIONS

Signal strength measurements of some neighbouring FM stations were carried out within the community using a Professional Synthesized TV Field Strength Meter UNAOHM model EP742A. The equipment can be used to measure field strength for band I, II, III, IV and V covering the entire VHF/UHF spectrum. The equipment is shown in Plate 3I. An ordinary rod antenna (the common type in portable radio receivers) as specified by the manual for VHF band II measurements, at a height of 1.5 metres above ground level was connected to the 75Ω RF input of the equipment through a 75Ω coaxial cable and then tuned to the operating frequencies of the stations. The received field strength level in dB/μV was displayed on its CRT tube. Also, received signal spectrum was observed. The results for the stations tested are shown below in Table 3.3. They are values for the antenna orientation giving maximum reception.

Table 3.3: - Signal strength tests of some neighbouring FM stations (Jan, 2003)

Station	Operating frequency (MHz)	Signal strength dB (μV/m) indicated by the equipment	Remarks
Ekiti FM Station	91.5	-	No signal or signal strength too negligible for the equipment detection irrespective of antenna orientation.
OSRC FM Station, Akure.	96.5	70	Strong. Carrier frequency not exactly at 96.5MHz but a bit higher. Interfering (spurious) signals of the station observed at some other frequencies throughout the whole FM band but reduced in strength.
Edo Broadcasting Service, Benin.	95.7	-	Signal over-ridden by interfering (spurious) OSRC signal.
Independent Radio, Benin.	92.3	10	Weak
Positive FM, Akure (NTA)	102.5	100	Very strong.
NTA Channel 11, Akure	108.5	15	NTA 11 sub harmonic. FM sound & AM vision interference.

3.4 EFFECTIVE ISOTROPIC RADIATED POWER

The minimum effective isotropic radiated power required for the whole community must be of a value that would provide adequate signal strength even to the remotest target service area of the community. Since sensitivity varies from receiver to receiver and there are (assumed) hundreds of receivers to be considered (direct broadcasting), therefore a universally accepted minimum field strength value for stereophonic transmission (ITU-R recommendation) would be chosen from which the minimum EIRP to produce the field strength at the service range will be determined.

3.4.1 CHOICE OF MINIMUM FIELD STRENGTH

FUTA community is categorized to be both urban and rural. It is urban in terms of development and rural in terms of population (Section 3.1.2). Therefore from Table 2.3, a median value between that of rural and urban will be chosen.

For stereophonic transmission, urban = 66dB (μV/m).

Rural = 54dB (μV/m).

Therefore, chosen minimum field strength for the community,

$$\text{Minimum Field Intensity (MFI)} = \frac{66 + 54}{2}$$

$$= 60 \text{ dB } (\mu\text{V/m}).$$

Field strength of 60 dB (μV/m) is expected at a point within the community that is farthest from the transmitting antenna.

3.4.2 TARGET SERVICE ZONES

In order to determine the minimum EIRP, the farthest area (zone) from the transmitter location must be known. Also, the antenna height as seen by a receiver in the zone must be known. Therefore towards this, the whole community land area was divided into target service areas or zones. The zones are listed in Table 3.4 and their land profile diagram (land cross sectional diagram from topographical study) shown in Figures 3.5 to 3.16. The lines of cross-section from the transmitter location (point W) to the respective zones are shown in Figure 3.4.

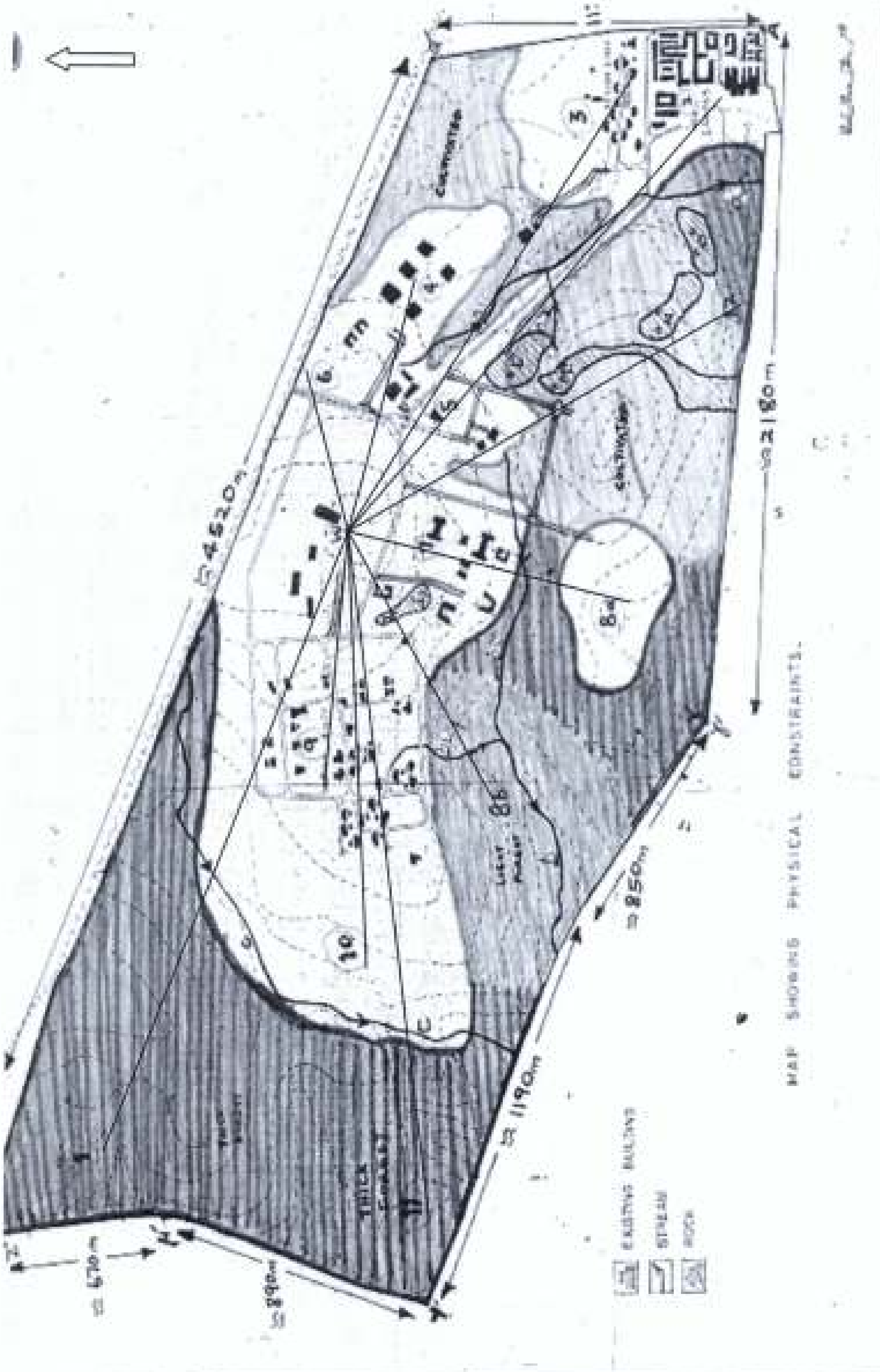


Figure 3.4 Map of Figure 3.3 showing line of cross – section between the transmitting location and the target zones as indicated in the Land Profile Diagrams.

Table 3.4: - Zones For Analysis

Area	Target service zone	Zone Number	Horizontal distance from transmitting location (metres).
Obanla	North West End/Ibule Edge	1	1520 - 2500
	Obanla Hostel Area	4	460 – 800
	Admin. Area	5	460 – 610
	North Gate	6	400 – 460
	Present Academic Area	7	230 – 620
	Future Academic Areas	8 (a) and (b)	(a) 760 – 1060, (b) 610 - 1370
	Obanla Staff Quarters	9	300 – 1000
	Chancellors' Quarters/School Farm.	10	1260 – 1420
	South West End	11	1680 – 2400
Obakekere	Obakekere Hostel Area	2	1520 - 2060
	Obakekere Staff Quarters	3	1380 – 1680
	*Fish pond/Farm Area at Obakekere Behind Rock "M".	12	1120 - 1520

* - propagation influenced by diffraction mainly by Rock "M".

3.4.3 LAND PROFILE DIAGRAMS

Figures 3.5 – 3.16 show the land cross-section between the proposed transmitting location and each of the zones. The figures are the land profile of the straight lines running from the transmitter location to the zones in Figure 3.4. The arrows beneath the grid lines indicate the beginning of the zones from the transmitter.

ZONE 1 **NORTH WEST END/IBULE EDGE**

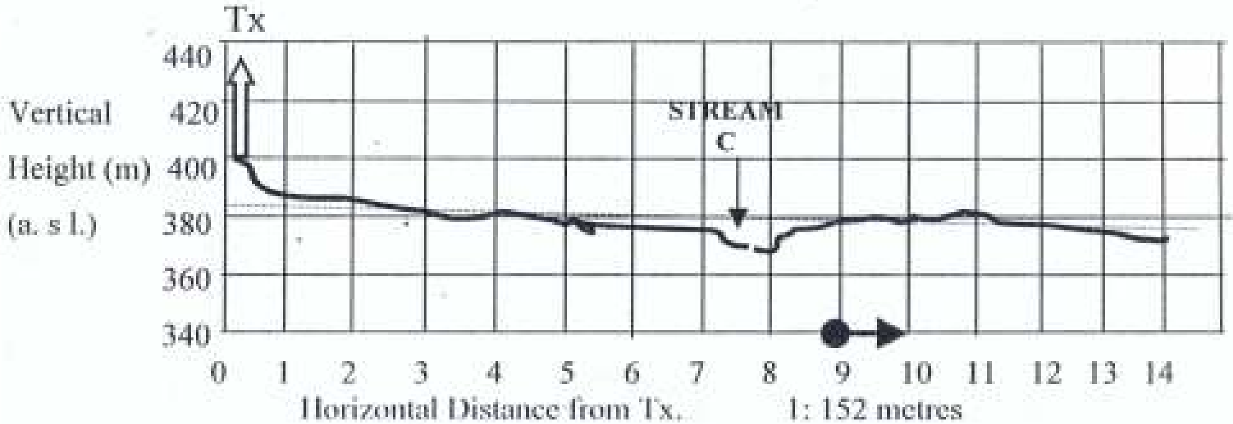


Figure 3.5 Land profile of North West End / Ibule Edge. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 2 **OBAKEKERE HOSTEL AREA**

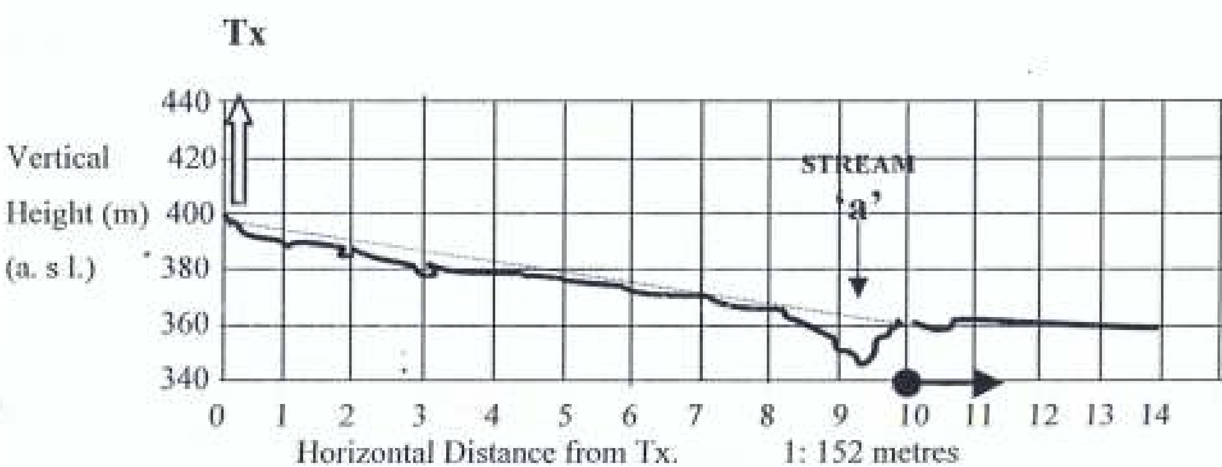


Figure 3.6 Land profile of Obakekere Hostel Area. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 3 **OBAKEKERE STAFF QUARTERS**

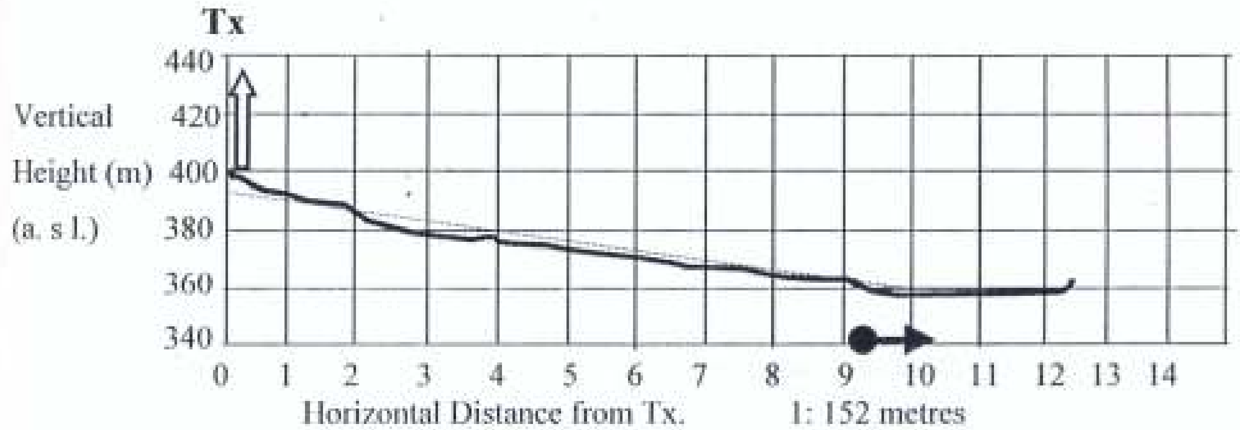


Figure 3.7 Land profile of Obakekere Staff Quarters. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 4 **OBANLA HOSTEL AREA**

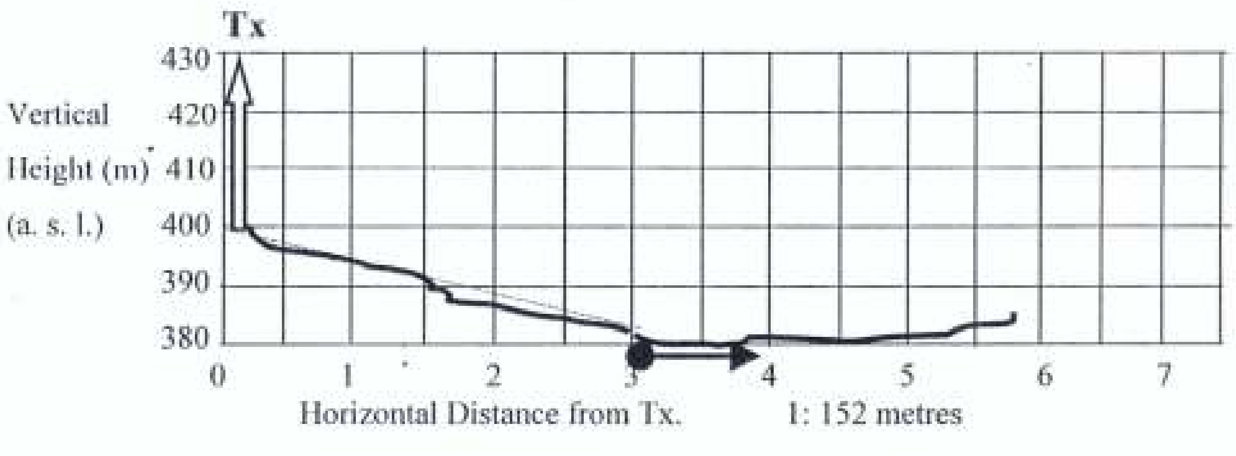


Figure 3.8 Land profile of Obanla Hostel Area. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

LAND PROFILE (contd.)

ZONE 5 **ADMIN. AREA**

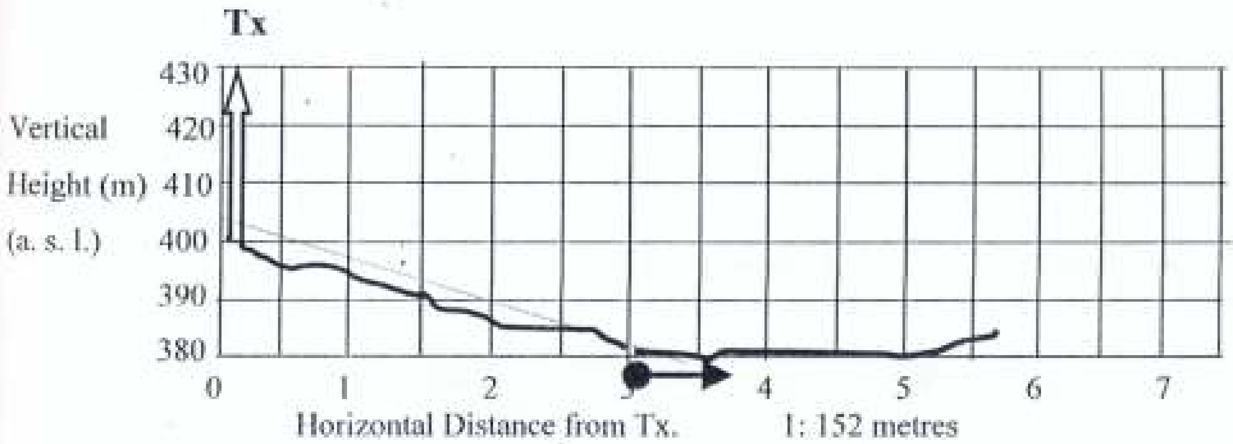


Figure 3.9 Land profile of Admin. Area. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 6 **NORTH GATE**

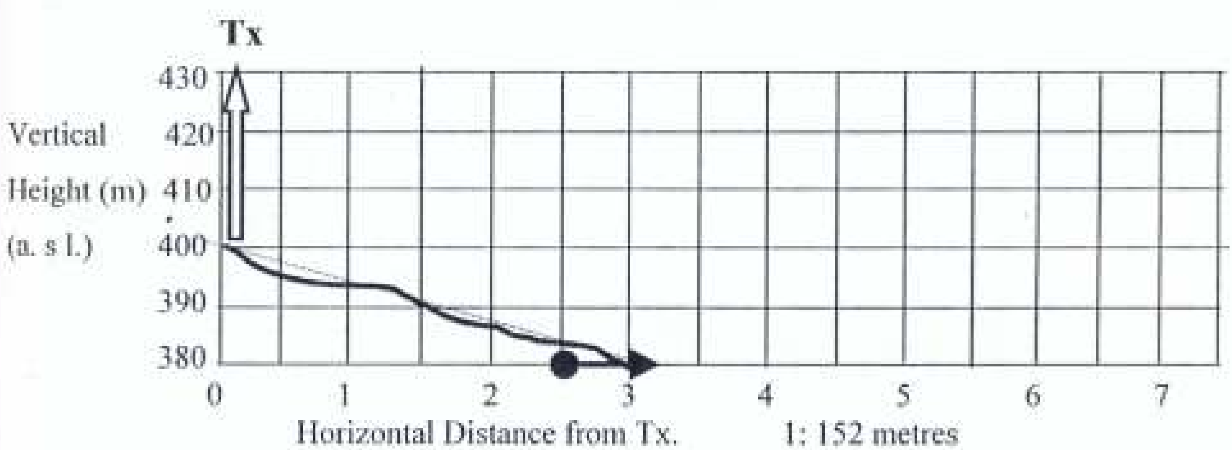


Figure 3.10 Land profile of North Gate Area. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONES 7 & 8 (a) **PRESENT & FUTURE ACADEMIC AREA**

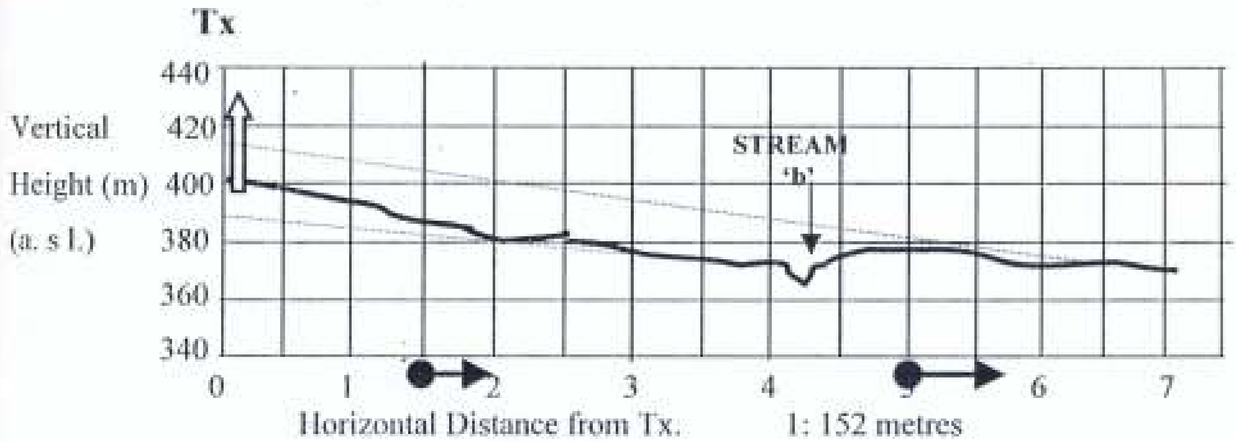


Figure 3.11 Land profile of Present and First Future Academic Area. The arrows beneath the grid lines indicate the beginning of the zones from the transmitter.

ZONE 8 (b) **FUTURE ACADEMIC AREA**

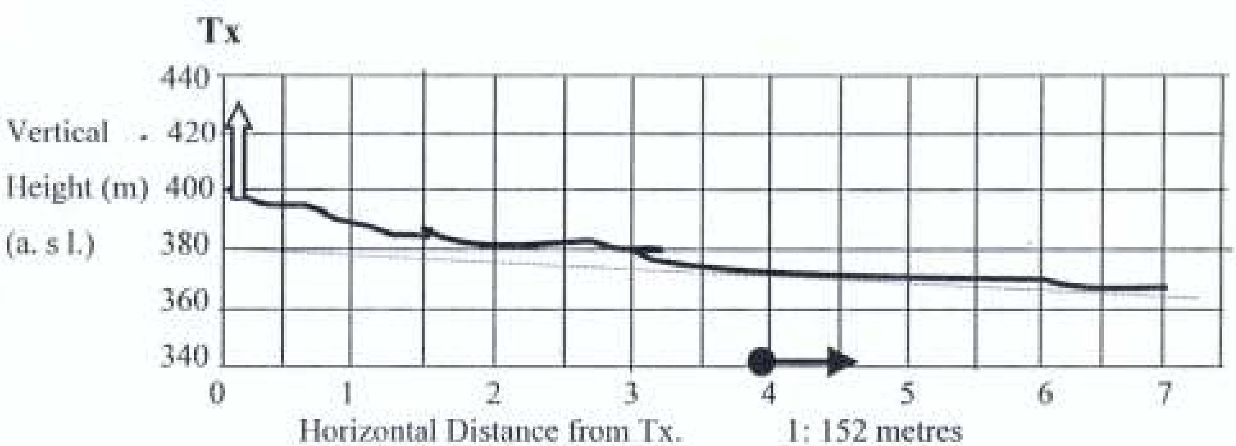


Figure 3.12 Land profile of Second Future Academic Area. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 9 OBANLA STAFF QUARTERS

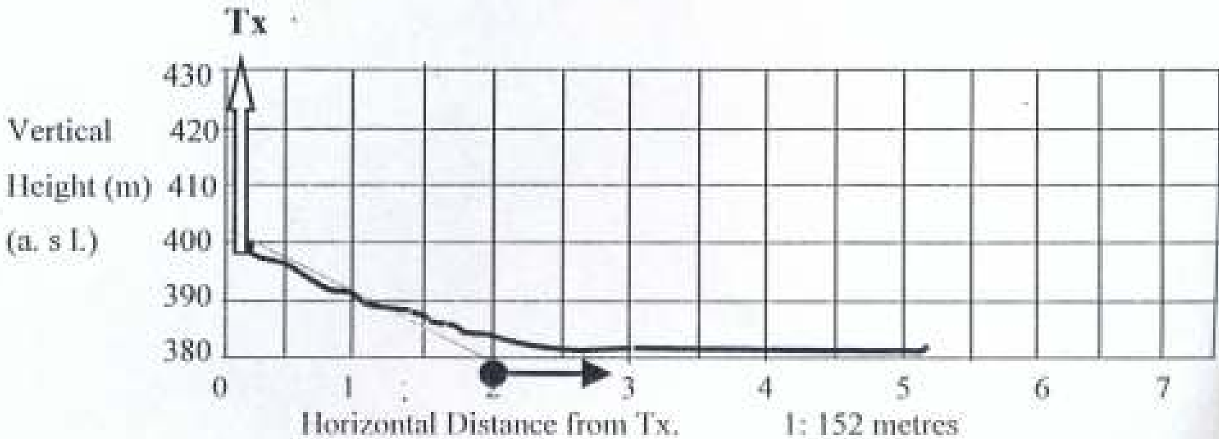


Figure 3.13 Land profile of Obanla Staff Quarters. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 10 CHANCELLORS' QUARTERS

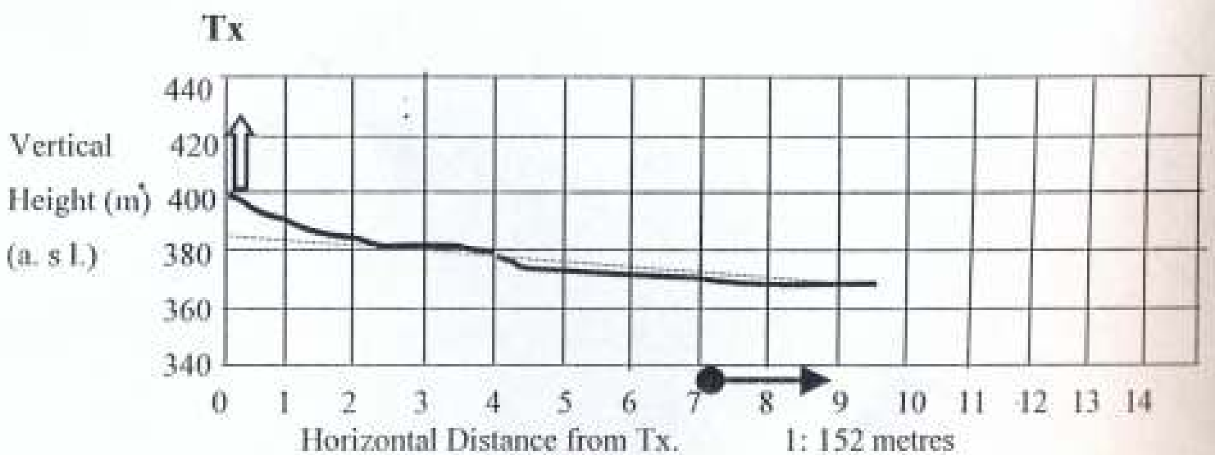


Figure 3.14 Land profile of Chancellors' Quarters. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 11 **SOUTH WEST END**

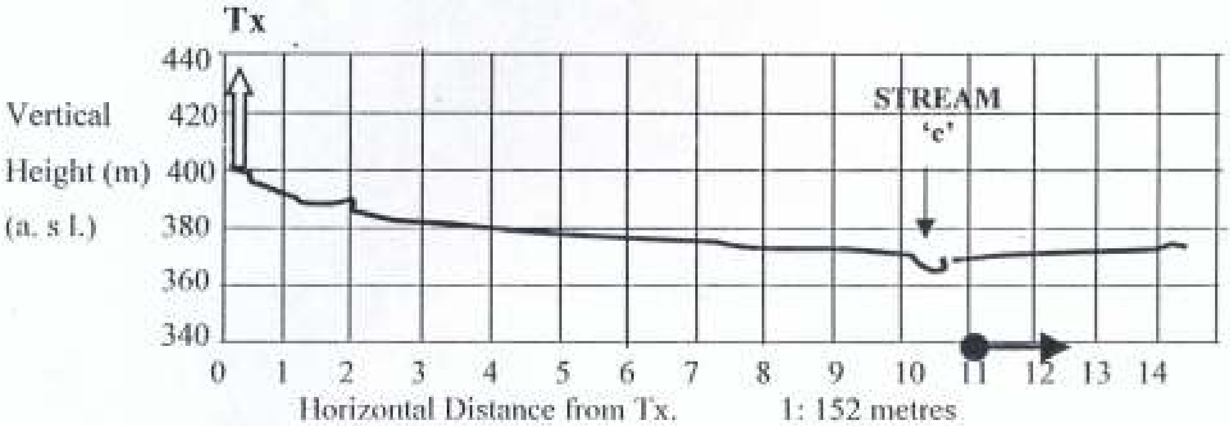


Figure 3.15 Land profile of South West End. The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

ZONE 12 **OBAKEKERE AREA BEHIND ROCK "M"**

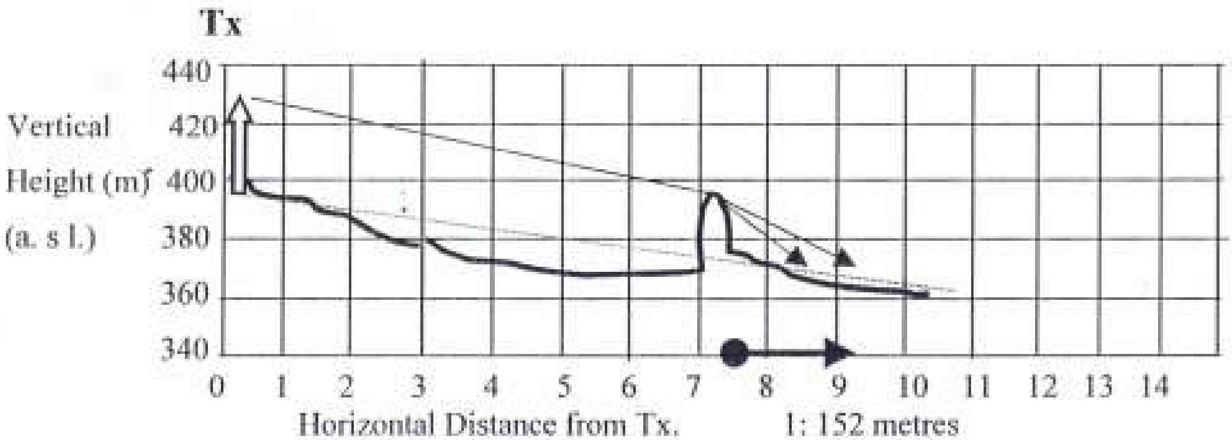


Figure 3.16 Land profile of Obakekere Area behind Rock "M". The arrow beneath the grid lines indicates the beginning of the zone from the transmitter.

3.4.4 PROPAGATION CURVES

ITU-R has prepared set of curves established for radio broadcasting, mobile land service and the mobile aeronautical service planning. Some curves are for tropical service planning while some for the temperate region. The curves give either the field strength (radio broadcasting) or the basic transmission loss (mobile service) as a function of distance for certain antenna heights, frequencies and for various time and locations percentages.

To reduce the number of curves, the heights selected are only those considered representative of real situations.

- 10 m for television receiving antenna.
- 1.5m and 3m for land mobile and land based vehicle antenna.
- 15m for a base station antenna in a mobile aeronautical service.
- 1524m, 7620m, 18300m (5000 feet, 25000 feet and 60000 feet) for a flying station in a mobile aeronautical service.

In general, these set of curves give values corresponding to average conditions over long distances (tens of km) and high transmitting power (usually 1kW EIRP) and calculations are completed using empirical formulas or correction tables to take account of different circumstances e.g. locations, population, density of buildings, terrain, surface irregularity etc., Bothias, (1987).

3.4.5 MINIMUM EIRP DETERMINATION

Considering Figure 3.2 and Figure 3.5 (Zone 1), the farthest distance from the transmitter location is 2500m (i.e. d = 2500m). Average altitude of the area = 370m above sea level (a.s.l.).

Recommended antenna height = 30m.

Altitude of antenna mast location = 400m a.s.l.

Therefore, effective antenna height (as seen from the zone), $h_t = 30 + (400 - 370)$

$= 60$m.

Receiver height assumed, h_r = 1.5m,

Representative frequency adopted, f = 100 MHz which gives a wavelength, λ of 3 metres.

Substituting these figures into equation (2.24) i.e. $$E = \frac{4\pi E_f h_t h_r}{\lambda d^2}$$

from which

$$E_f = \frac{E\lambda d^2}{4\pi h_t h_r} \quad \text{-- (3.2)}$$

For Minimum Field Intensity (MFI) of 60dB (μV/m).

$$E = 10^{(60/20)}$$
$$= 1000\ \mu V/m$$
$$= 1 mV/m$$

therefore,

$$E_f = \frac{1\times10^{-3}\times2500^2\times3}{4\times\pi\times60\times1.5}$$
$$= 16.579V$$

from equation (2.19).

$$P = \frac{E_f^{\ 2}}{30} \quad \text{-- (3.3)}$$
$$= \frac{16.579^2}{30}$$
$$= 9.16\ W.$$

Let the minimum recommended EIRP = 15W and the maximum EIRP (to take care of attenuation by physical features, forests, future development and to minimize interference) = 50W.

3.4.6 SERVICE RANGE AT MAXIMUM EIRP

From Section 2.10.4, flat earth assumption range,

$$d_e = \frac{80}{\sqrt[3]{f}} \quad \text{--(3.4)}$$

where f is in MHz and the distance in kilometers.

For a frequency of 100 MHz,

$$d_e = \frac{80}{\sqrt[3]{100}}$$
$$= 17.2\ km.$$

From equation 2.19 and 2.24,

$$d = \sqrt{\frac{4\pi h_t h_r \sqrt{30p}}{E\lambda}} \quad \text{--(3.5)}$$

From the topographical map of Figure 3.1, the surrounding area of the community is at an average height of 360m above sea level.

Altitude of antenna mast location = 400m a.s.l.

Therefore, effective antenna height, h_t = 30 + (400 – 360)

= 70m.

Also, the surrounding area is both rural and urban, therefore, for Minimum Field Intensity (MFI) of 60dB (μV/m), receiver height of 1.5m, frequency of 100MHz and maximum EIRP of 50W (assuming a smooth terrain),

$$d_m = \sqrt{\frac{4 \times \pi \times 70 \times 1.5 \times \sqrt{30 \times 50}}{3 \times 1 \times 10^{-3}}}$$

= 4127.26m

= 4.127 km from the transmitter location.

A circle of radius 4.127 km centered on the transmitter location is drawn on the topographical map to indicate the service range at maximum EIRP of 50W. This is shown in Figure 3.17.

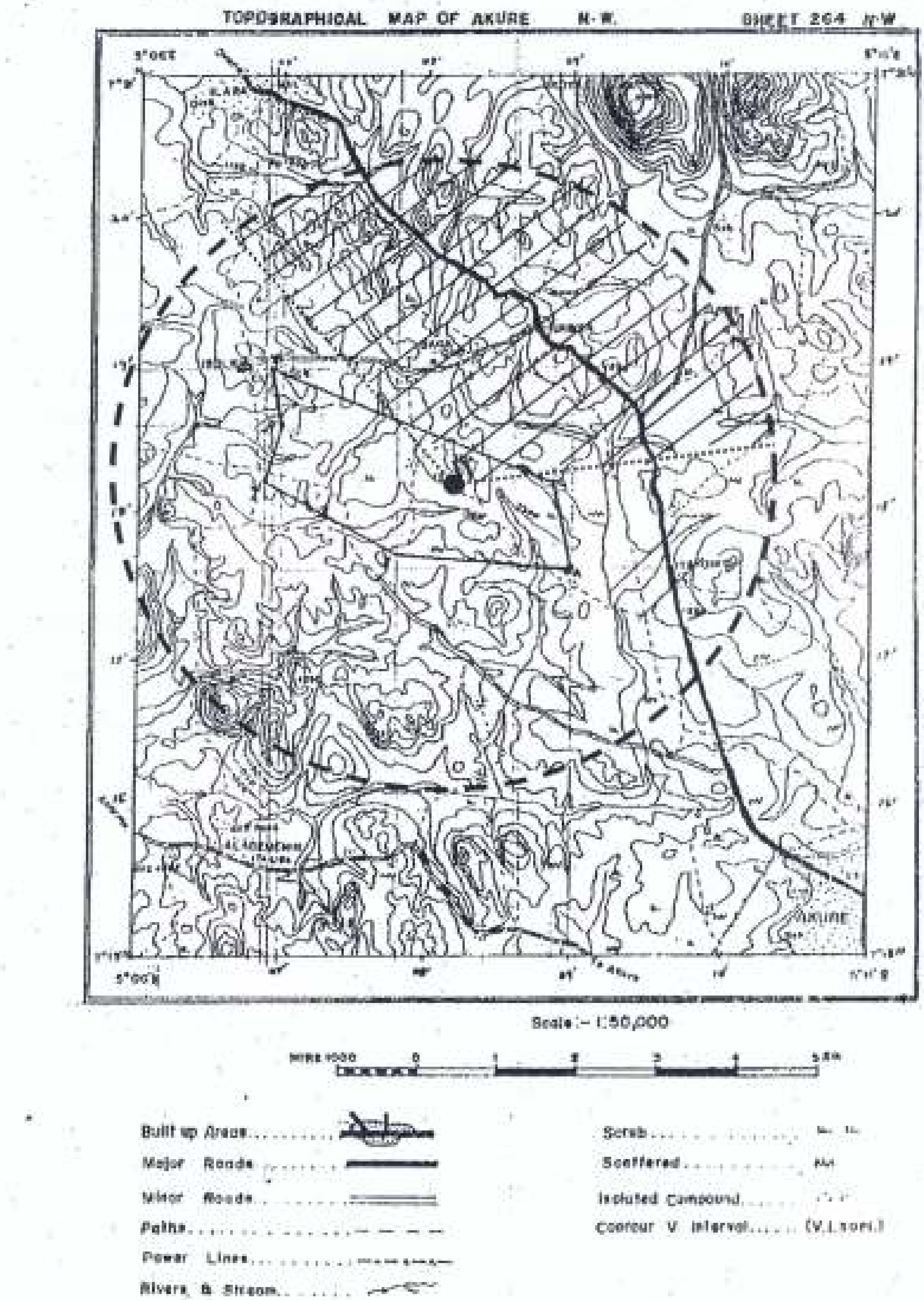


Figure 3.17 Service range at maximum EIRP of 50W. The shaded region is of little or no intensity (see Figure 3.18 on radiation pattern). Point W is the transmitter location.

3.5 FIELD STRENGTH DISTRIBUTION

Having computed the minimum and maximum EIRP based on equations (2.19) and (2.24), the next step is to determine the field strength distribution within the community. This exercise is to ensure that there will be satisfactory reception in all the service target zones, and appropriate measures recommended for areas of insufficient reception. The topography varies from zone to zone.

There are two methods in determining the field strength distribution. One is by installing temporary equipment, varying the transmitter power and measuring the fields so produced. This method is very costly both in time and money. The other method is by prediction. Methods of making reasonably accurate predictions inevitably involve enormous amount of long, repetitive and awkward computations and much data handling since many receivers are assumed and it is important to ensure a high probability of good service. This method was adopted.

In the prediction exercise:

- Calculations performed for each target zone are based on smooth and flat earth model and then terrain taken into consideration since the whole land area is of few kilometres. The calculations are for a number of locations within the zones and for two levels of receiver heights. The height chosen for the receiver, which is representative of the heights of most domestic receivers above ground level including that in vehicles are 1.5m and 3m. Broadcast receivers are often at street levels or inside buildings.
- Tropospheric propagation (space waves: line-of-sight and ground reflection) is assumed within the community and diffraction techniques applied to areas obstructed by hills. Since space waves propagation are straight therefore geometrical (optical) method of calculation is adopted and a frequency of 100 MHz as the operating frequency.
- The curvature of the earth is neglected since the whole land stretch is of few kilometers (5km).
- Predictions carried out for every zone is assumed for an open field i.e. reception in the open. No attempt is made predicting field strength inside buildings. Electromagnetic waves inside buildings are attenuated by scattering and reflection. Absorption plays insignificant role except at very high frequencies, Smith Jnr, (1998).

- No emphasis is placed on the refraction of the waves in the atmosphere in traveling from the transmitter to the receivers since the transmitting distances are short and most radio receivers within buildings and those outside in the open are very close to the ground.
- Surface wave is neglected in the analysis since the operation is in the VHF band II having wavelength small compared to the specified transmitting antenna height. The surface wave will only be the main component of the ground wave around the base of the transmitting antenna and quickly attenuated by ground losses after covering few distances from the antenna, Mittel and Mittal, (1992).
- The ground electrical constants are assumed uniform throughout the entire land area since the soil is predominantly of one type.
- The results of the prediction exercise may be a little far from the exact if measurements were made since buildings are neglected and the ground assumed smooth and electrically uniform. Diffraction of the direct rays by tree tops and roof tops of some buildings close to the transmitting antenna and non-clearance of the Fresnel ellipsoid zones by obstacles for a given receiver location will affect reception, Bothias, (1987). Effect of forests is only considered where the forest lies in-between the transmitter and the receiver line-of-sight. The main contribution of the forest to the propagation will come from the part of the path, which is closest to the receiver. The forest is assumed uniform and of constant height with distance. The transmitted energy loss rate through them (attenuation rate) was assumed constant with distance for the chosen frequency.

With all these above assumptions, nevertheless, the analysis provided a picture of relative field strength distribution for the zones.

3.6 RADIATION PATTERN

In determining the horizontal radiation pattern for the proposed station, the location of the transmitting antenna with respect to the land boundaries was considered. The horizontal radiation pattern should follow the shape of the community land area in relation to the antenna location. Considering the community map and recommended antenna location (point W on the map in Fig. 3.2 and 3.3), there should be maximum radiation in the Northwest – Southeast direction, fairly high radiation towards the South and very little or no radiation towards the North.

Therefore, horizontal radiation pattern of a **cardiod** with a little decrease of -3dB (normalized) opposite that of the main null is recommended. This is shown in Figure 3.18.

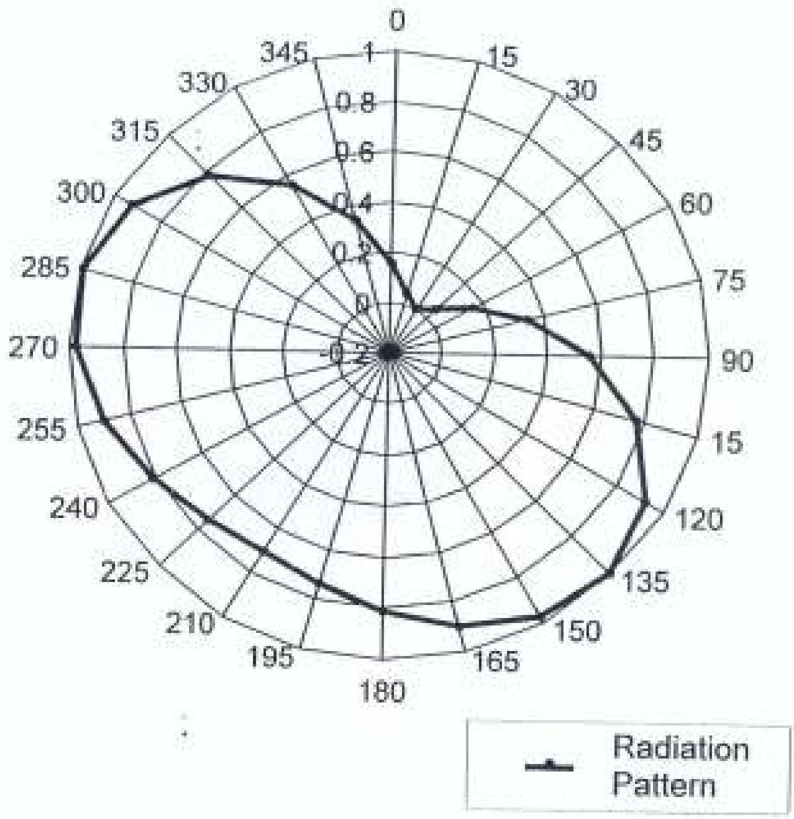


Fig. 3.18 Recommended Horizontal Radiation Pattern

3.7 POLARISATION

Since horizontal polarisation is the most common everywhere for VHF II FM Broadcast Service (Section 2.7.2) and the community is not in a trough, therefore recommended polarisation is horizontal.

3.8 THE ANTENNA SYNTHESIS

The procedure for the antenna synthesis and design to give the recommended pattern were in three parts.

1. Hardware Modeling of a representative antenna producing the pattern at a 'scaled – up' frequency for laboratory measurement purposes. Hardware accessories, operations, measurements and results for the hardware modeling was facilitated by 'Antenna Lab System' and the Discovery Software, Antenna Instruments Version 2.50. (Appendix D).
2. Having determined the type and orientation of the required antenna (or array) from the hardware modeling, then the design of such antenna for the band of service in concern (VHF band II).
3. Software Simulation of the designed antenna and radiation characteristics verified for the band of service in concern for agreement with the hardware modeling results. The Software Simulation was facilitated by WIN-NEC Software, Antenna Analysis Version 1.0 in Visual Basic. (Appendix E).

3.8.1 PROCEDURE

Considerations: -

1. Considering the recommended pattern (Figure 3.18) and the 'figure-eight' radiation pattern of a dipole for horizontal polarization (Figure 2.15 and Section 2.12.3), it is obvious that,

(i) The recommended pattern cannot be produced by a single dipole antenna but array of antennas.

(ii) The pattern cannot be produced by array of ordinary horizontal dipoles using method of array pattern multiplication (Section 2.12.5).

Hence, the pattern is only realizable by special dipole antennas having unidirectional properties and giving horizontal polarization e.g. Yagi-Uda, Log-Periodic, orientated in different directions and 'excited' so as to give a resultant pattern close to the recommended pattern.

2. The first consideration limits the choice between array of Yagi-Uda and Log-Periodic. Yagi-Uda has unidirectional properties but for a narrow bandwidth. Log-Periodic has constant unidirectional properties over a wide bandwidth (Section

2.12.7). Yagi-Uda is resonant only for a particular design frequency and will give the desired pattern only at that particular transmitting frequency.

3.8.2 THE HARDWARE MODELING

Log-periodic was chosen for its wide bandwidth since for the proposed station, operating frequency assignment is much later by the authority concerned, therefore it was reasoned out of foresight to design an antenna that is usable throughout the entire VHF II band without having to change its dimensions or arrangement irrespective of the final operating frequency. This calls for a broadband antenna.

Frequencies available on the Discovery Software for hardware modeling ranges from 1200 MHz to 1800 MHz. The antenna accessories supplied has already made log-periodic antennas designed for base frequency of 1400 MHz giving constant characteristics to the frequency of 1800 MHz. The method of feed of the LPDA is of that explained in Section 2.12.9.

3.8.3 EXPERIMENTAL SET UP

The 'Antenna Lab System' set up is illustrated in Figure 3.19, and shown in Plate 3J. The distance between the transmitter (Generator Tower, 57-200) and receiver (Receiver Tower, AMS506R) is 1.5m. This ensures 'plane wave' reception of the signals at the receiving antenna.

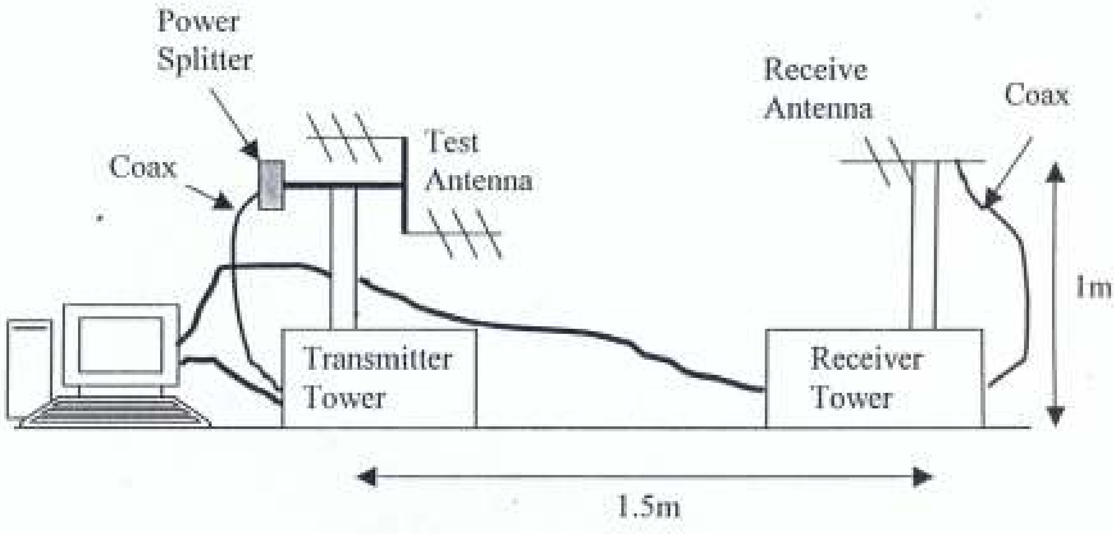


Figure 3.19 The Antenna Hardware Modeling Set Up.

Three (3) Log-Periodics of 5 elements were mounted on the Generator Tower orientated in three directions West, East and South with respect to the Laboratory, forming a bay array of log-periodics and equally fed from a splitter also mounted on the Generator Tower (Plate 3J). The transmitter was connected through a coax already supplied. The LPDA dimensions are illustrated in Figure 3.20 and shown in Plate 3K. Each element (and boom) diameter is 3mm. The LPDA Array arrangement is shown in Plate 3L.

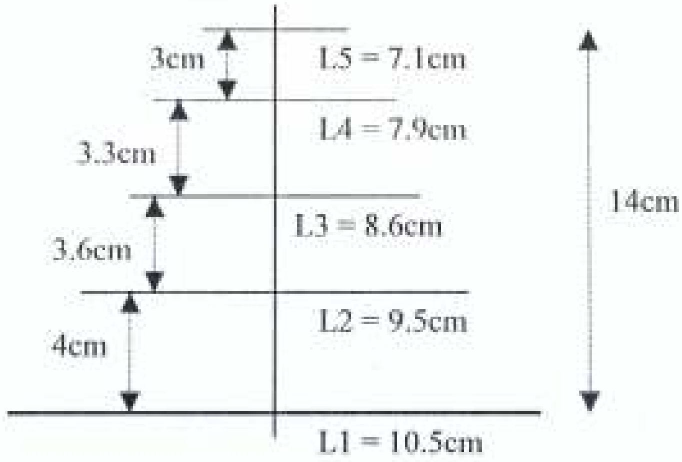


Figure 3.20 The tested 5 – element LPDA dimensions.

Using the Discovery Software, different transmitting frequencies from 1200 MHz to 1800 MHz were tested; the antenna motor energized from the computer for a complete revolution and the receiver/computer generates data of signal strength received by the receiver. The Software produced the polar plot of the received signal for the 360^0 revolution, which represents the polar plot of the radiation pattern of the array. The receiving antenna used is a horizontal dipole with a reflector element mounted on the Receiver Tower. The reflector element was included in order to prevent reception of signals at the side of the dipole opposite the side facing the transmitter. This side without the reflector will as well receive signals from the transmitter that bounce off the walls of the laboratory arriving at the backside.

3.8.4 ANTENNA DESIGN AND SIMULATION

Having ascertained the use of LPDA, LPDA for operation in the VHF II Band was designed using the Design Equations and Procedures in Appendix A (C. A. Balanis, "Antenna Theory, Analysis and Design", 1997 and The ARRL Antenna

Book, 1997). In order to facilitate quick design for different directivities and comparing dimensions, a program was written in QBASIC for the design procedure, Appendix B.

Using the program and Figure 2.21, higher directivities imply longer dimensions. Longer dimensions imply increased weight, material and cost. A design was arrived at giving fairly high directivity of each LPDA and of bearable dimension. This designed antenna was then simulated by the WIN-NEC Software, Antenna Analysis V1.0 and radiation characteristics examined. The simulation was for **T6061 aluminum alloy** dipole elements. Aluminum was chosen for its ductility, malleability and lightweight, (Appendix C). Also, array composed of 3 of the designed LPDA in different arrangements and orientation was simulated using the WIN – NEC software and radiation patterns examined over the entire VHF II band.

PLATE 3A THE OBANLA SPORTS COMPLEX RIDGE (THE PROPOSED TRANSMITTING ANTENNA LOCATION).

PLATE 3B THE OBANLA SPORTS COMPLEX AND THE RIDGE

PLATE 3C VIEW OF THE SPORTS GROUND FROM THE TOP OF THE RIDGE. OBANLA HOSTEL (ZONE 4) IN THE DISTANCE.

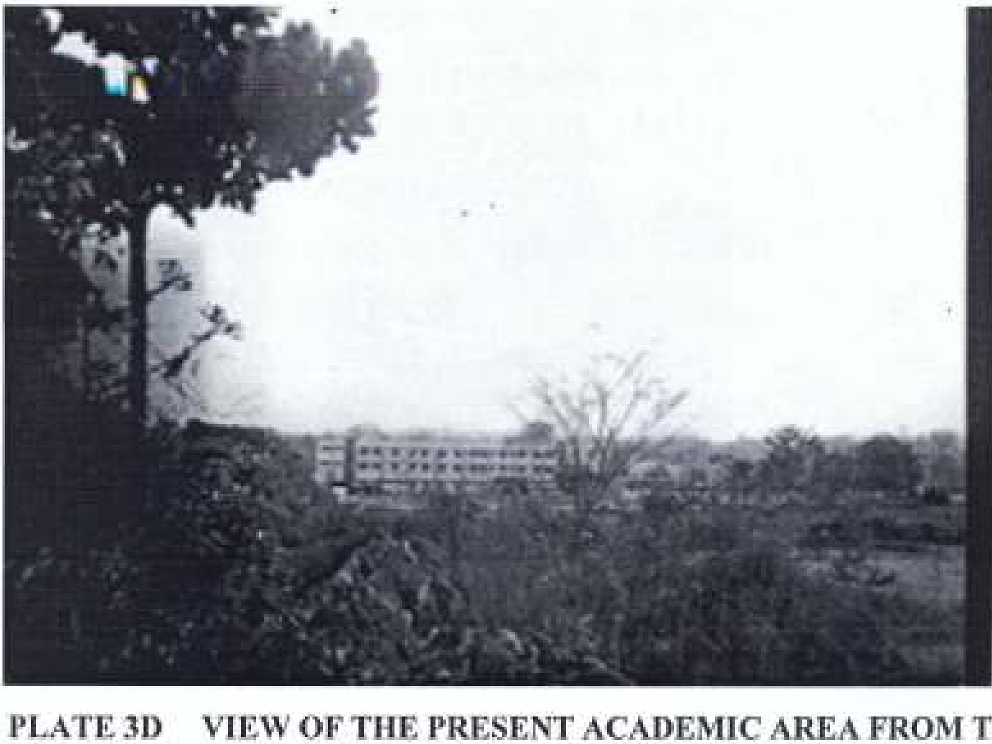


PLATE 3D VIEW OF THE PRESENT ACADEMIC AREA FROM THE TOP OF THE RIDGE. ENGINEERING BUILDING IN THE DISTANCE.

PLATE 3E VIEW OF OBANLA STAFF QUARTERS (ZONE 9) FROM THE TOP OF THE RIDGE

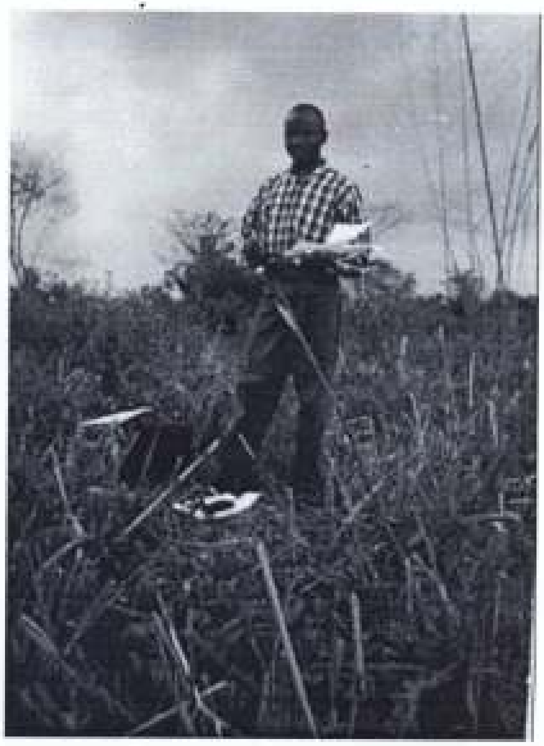


PLATE 3F TAKING MEASUREMENTS WITH THE GPS RECEIVER ON THE TOP OF THE RIDGE

PLATE 3G   TAKING MEASUREMENTS WITH THE GPS RECEIVER IN OBAKEKERE STAFF QUARTERS (ZONE 3). THE RECEIVER IS ON THE WHITE PAPER ON THE GROUND.

PLATE 3H   ON THE TOP OF THE ELONGATED ROCK "M" TAKING MEASUREMENTS (SEE TEXT AND FIGURE 3.2).

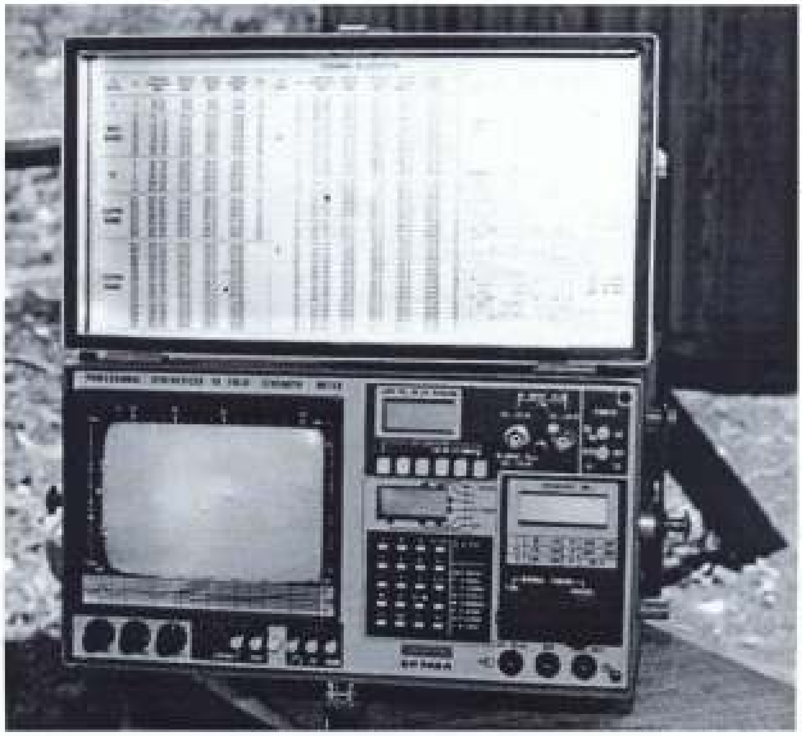


PLATE 3I THE PROFESSIONAL TV FIELD STRENGTH METER UNAOHM, MODEL EP742A.

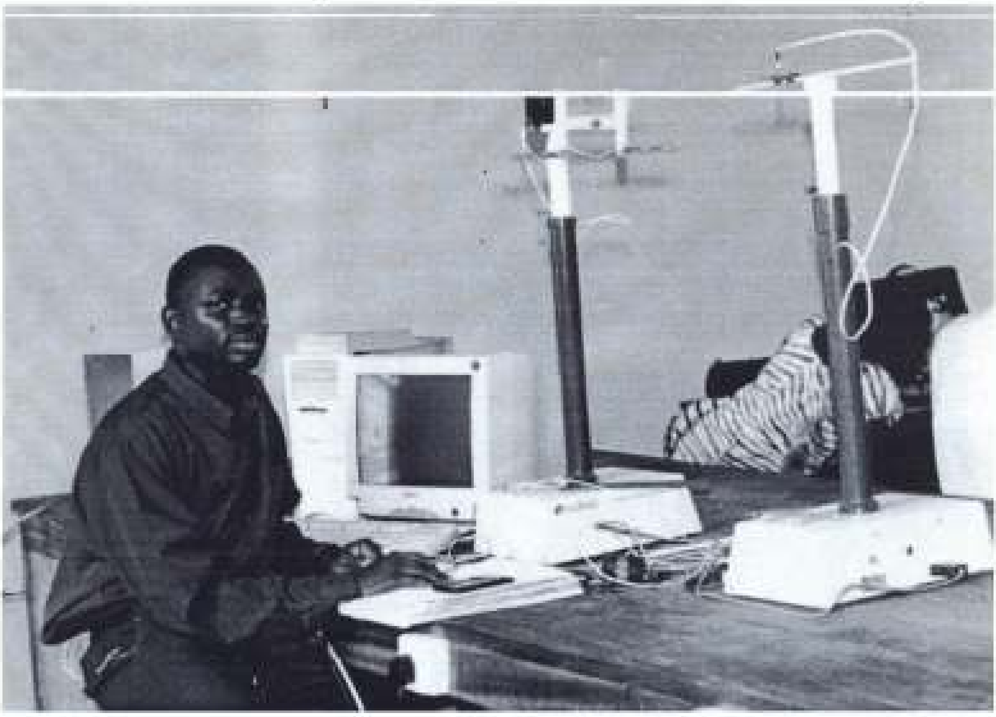


PLATE 3J SETTING UP THE 'ANTENNALAB' SYSTEM FOR THE HARDWARE MODELLING (THE TWO POLES ARE THE GENERATOR TOWER AND THE RECEIVER TOWER)

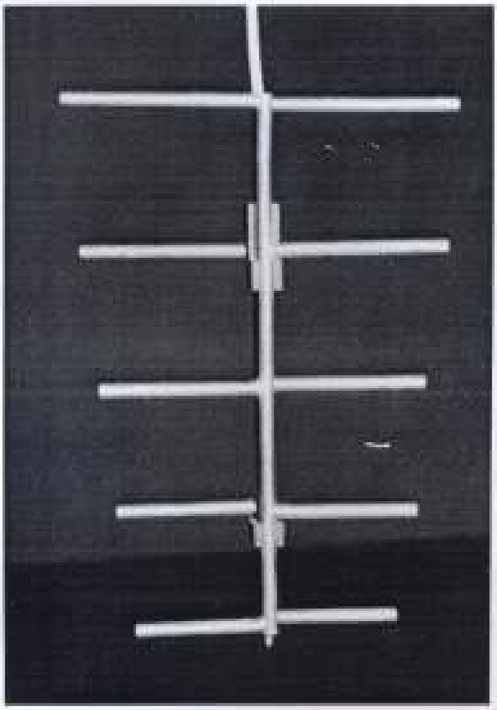


PLATE 3K THE TESTED (MODEL) 5 – ELEMENT LOG-PERIODIC DIPOLE ANTENNA

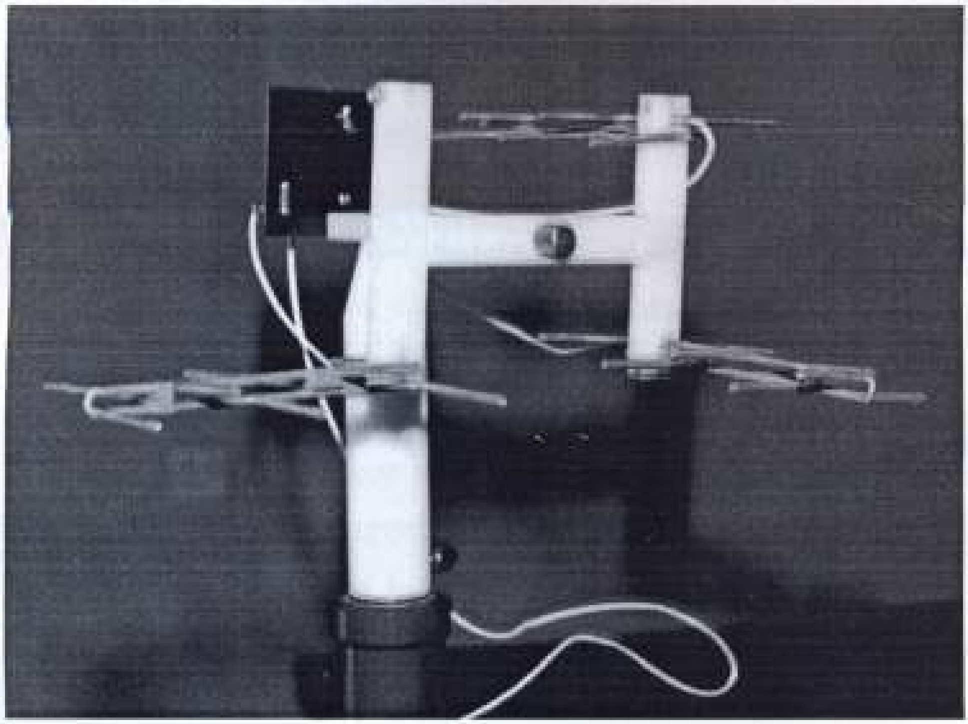


PLATE 3L THE 3, 5-ELEMENT LOG-PERIODIC DIPOLE ANTENNA ARRAY THAT GAVE THE RECOMMENDED PATTERN (PLATE 4A)

CHAPTER FOUR

PREDICTED FIELD STRENGTH RESULT, ANTENNA DESIGN AND TRANSMISSION LINE

4.1 PREDICTED FIELD STRENGTH RESULTS

The results of the predicted field strength for the zones are presented in Tables 4.1 to 4.13 and their graphs in Figures 4.2 to 4.14. The figures show the graph of field strength dB (uV/m) versus horizontal distance (metres) from the proposed transmitting location. Computation was performed for two receiver heights of 1.5m and 3m above ground (representative of receivers located within ground floors and first floors of storey buildings) and for EIRP of 15W and 50W. The predicted field strengths for all the zones is for horizontal polarisation and soil constants of $\epsilon_r = 15$ & $\sigma = 0.005$ S/m (taking the average between rich soil, forestation and clay soil, Table 2.4 and Section 3.1.3) except for the diffraction region of Zone 12. Attenuation by the forest at 100 MHz is taken to be 0.03 dB/m (Table 2.5).

4.1.1 Definition of some symbols as used for the computation:

If the zone area is of gentle slope, and the line of slope is *projected to meet a vertical line drawn through the transmitter location as shown in Figure 4.1,*

Then,

(i) h_{tt} = transmitter height (h_t) plus the vertical distance between the top of the ridge (transmitter location) and the point of intersection of the line of slope and the vertical line drawn through the transmitter spot (h_g).

(ii) h_f = average height of forest (defined in 2.10.13.3 and Figure 2.8).

(iii) $\ddot{d}_T$ = horizontal distance from transmitter location to where forest begins (defined in 2.10.13.3 and Figure 2.8).

(iv) d_f = horizontal distance from transmitter location to the point where the ray enters the top of forest (defined in 2.10.13.3 and Figure 2.8).

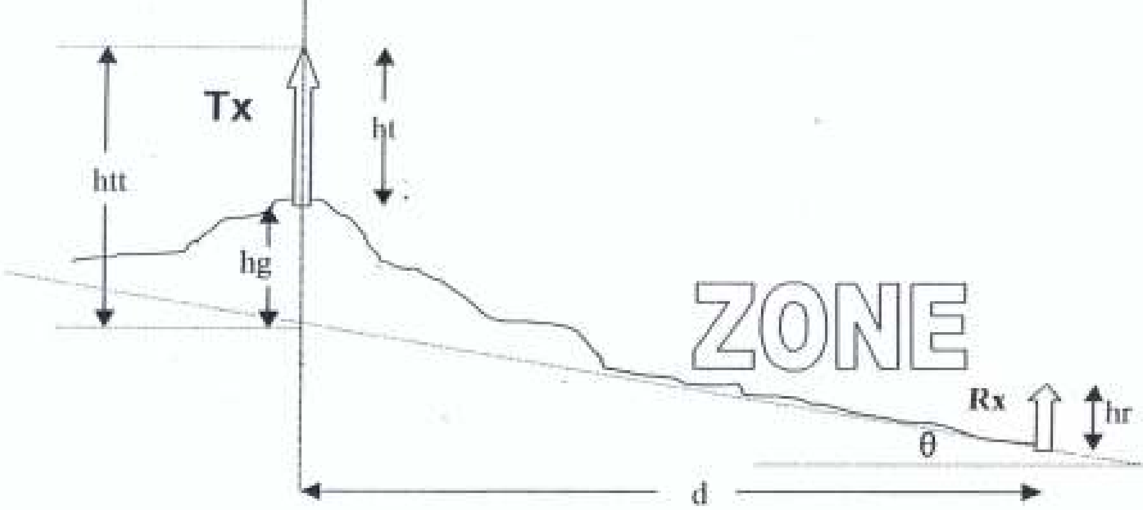


Figure 4.1 A representative land profile diagram for the zones.

(v) l_f = the distance of the rays penetration through the forest before getting to the receiver (defined in 2.10.13.3 and Figure 2.8).

(vii) att_f = total attenuation (as a ratio to the unattenuated ray) of the rays through the forest.

Land Profile Model 1(Figure 2.6) applied for zones 2, 3, 4, 5, 9 and 11, Land Profile Model 2 (Figure 2.7) applied for zones 1, 7, 6, 8(a), 8(b) and 10; and Model 3 (Figure 2.9) for the diffraction region of zone 12. Forested Model (Figure 2.8) was applied where applicable.

Zone 1: North West End/Ibule Edge (1520m - 2500m, Figures 3.5, 2.7 and 2.8)

θ $= 0.57^0$

h_f = 10m average (zone completely covered with thick forest, Jan, 2003. (Figure 3.4)).

d_T = 1210m

d_f $= d(h_{tt} - h_f)/(h_{tt} - h_r)$

h_{tt} $= h_t + 15m = 30m + 15m$

$= 45m$

h_{tr1} $= h_{tt} + h_r$

h_{tr2} $= h_{tt} - h_r$

Zone 2: Obakekere Hostel Area (1520m - 2060m, Figures 3.6 and 2.6)

There is cultivated forest (Jan, 2003) in between the proposed transmitting location and the zone but due to topography, signals arriving at the zone from the top of the antenna mast will be cleared off trees (Figure 3.4).

$$h_{tt} = h_t + 40m$$
$$= 70m$$

Zone 3: Obakekere Staff Quarters (1380m - 1680m, Figures 3.7 and 2.6)

Cultivated forests in between the proposed transmitting location and the zone but due to topography, signals are cleared off trees (Figure 3.4).

$$h_{tt} = h_t + 40m$$
$$= 70m$$

Zone 4: Obanla Hostel Area (460m - 800m, Figures 3.8 and 2.6)

$$h_{tt} = h_t + 20m$$
$$= 50m$$

Zone 5: Administrative/Utility Area (460m - 610m, Figures 3.9 and 2.6)

$$h_{tt} = h_t + 20m$$
$$= 50m$$

Zone 6: North Gate (400m - 460m, Figures 3.10 and 2.7)

$$\theta = 2.49^0$$
$$h_{tt} = h_t + 20m$$
$$= 50m$$

Zone 7: Present Academic Area (230m - 630m, Figures 3.11 and 2.7)

$$\theta = 1.06^0$$
$$h_{tt} = h_t + 14m$$
$$= 44m$$

Zone 8(a): Future Academic Area (760m - 1060m, Figures 3.11 and 2.7)

$\theta = 1.89^0$

$h_{tt} = h_t - 15m$

$= 15m$

Zone 8(b): Future Academic Area (610m - 1370m, Figures 3.12, 2.7 and 2.8)

$\theta = 0.75^0$

$h_{tt} = h_t + 16m$

$= 46m$

h_f = 5m average (zone completely covered with light forest and partly cultivated, Jan, 2003.(Figure 3.4)).

Zone 9: Obanla Staff Quarters (300m - 1000m, Figures 3.13 and 2.6)

Region assumed flat (Plate 3E)

$h_{tt} = h_t + 20m$

$= 50m$

Zone 10: Chancellor's Quarters (1260m - 1420m, Figures 3.14 and 2.7)

$\theta = 1^0$

$h_{tt} = h_t + 6m$

$= 36m$

Zone 11: South West End (1680m - 2400m, Figures 3.15, 2.6 and 2.8)

Region assumed flat and average height of 365m above sea level.

$h_{tt} = h_t + 35m$

$= 65m$

h_f = 10m average (zone completely covered with thick forest, Jan, 2003. (Figure 3.4)).

$d_T = 1590m$

Zone 12: Obakekere Area beyond Rock "M" (Figures 3.16 and 2.9)

H = vertical height of the rock at its midsection = 20m

d_1 = horizontal distance from the transmitter to the rock's midpoint base = 1065m.

$\theta = 1.5^0$

FIELD STRENGTH PREDICTION

TABLE 4.1: ZONE 1:- NORTH WEST END / IBULE EDGE

	Receiver Height, hr = 1.5m						Receiver Height, hr = 3m					
d (m)	lf (m)	Attn.	E(V/m) (P=15W)	**E(dB/uV/m) P=(15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**	lf (m)	Attn.	E(V/m) (P=15W)	**E(dB/uV/m) (P=15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**
1520	297.0	0.358	0.00093	**59.33**	0.00169	**64.56**	253.3	0.417	0.00214	**66.59**	0.0039	**71.82**
1620	316.6	0.335	0.00076	**57.65**	0.00139	**62.87**	270.0	0.394	0.00178	**64.99**	0.0032	**70.22**
1720	336.1	0.313	0.00063	**56.03**	0.00116	**61.26**	286.7	0.372	0.00149	**63.46**	0.0027	**68.69**
1820	355.6	0.293	0.00053	**54.46**	0.00097	**59.69**	303.3	0.351	0.00126	**61.99**	0.0023	**67.22**
1920	375.2	0.274	0.00044	**52.96**	0.00081	**58.18**	320.0	0.331	0.00107	**60.57**	0.0019	**65.80**
2020	394.7	0.256	0.00038	**51.49**	0.00069	**56.72**	336.7	0.313	0.00091	**59.19**	0.0017	**64.42**
2120	414.3	0.239	0.00032	**50.07**	0.00058	**55.30**	353.3	0.295	0.00078	**57.86**	0.0014	**63.09**
2220	433.8	0.224	0.00027	**48.69**	0.00050	**53.92**	370.0	0.279	0.00067	**56.57**	0.0012	**61.80**
2320	453.3	0.209	0.00023	**47.34**	0.00043	**52.57**	386.7	0.263	0.00058	**55.31**	0.0011	**60.54**
2420	472.9	0.195	0.00020	**46.03**	0.00037	**51.26**	403.3	0.248	0.00051	**54.08**	0.0009	**59.31**
2500	488.5	0.185	0.00018	**45.00**	0.00032	**50.22**	416.7	0.237	0.00045	**53.12**	0.0008	**58.35**
2520	492.4	0.183	0.00017	**44.74**	0.00032	**49.97**	420.0	0.234	0.00044	**52.88**	0.0008	**58.11**

* lf - Distance of ray penetration through forest
* Attn. - Attenuation by forest.

FIELD STRENGTH PREDICTION

TABLE 4.2: ZONE 2:- OBAKEKERE HOSTEL AREA

	Receiver height, hr = 1.5m				Receiver height, hr = 3m			
d (m)	E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
1520	0.00399	**72.01**	0.00728	**77.24**	0.00786	**77.91**	0.01435	**83.14**
1570	0.00374	**71.46**	0.00683	**76.68**	0.00738	**77.36**	0.01347	**82.59**
1620	0.00351	**70.92**	0.00642	**76.15**	0.00694	**76.83**	0.01267	**82.05**
1670	0.00331	**70.40**	0.00604	**75.62**	0.00654	**76.31**	0.01194	**81.54**
1720	0.00312	**69.89**	0.00570	**75.12**	0.00617	**75.81**	0.01126	**81.03**
1770	0.00295	**69.40**	0.00539	**74.62**	0.00583	**75.32**	0.01065	**80.55**
1820	0.00279	**68.92**	0.00510	**74.15**	0.00552	**74.84**	0.01008	**80.07**
1870	0.00265	**68.45**	0.00483	**73.68**	0.00523	**74.38**	0.00956	**79.61**
1920	0.00251	**68.00**	0.00458	**73.23**	0.00497	**73.93**	0.00907	**79.16**
1970	0.00239	**67.55**	0.00436	**72.78**	0.00472	**73.49**	0.00863	**78.72**
2020	0.00227	**67.12**	0.00415	**72.35**	0.00450	**73.06**	0.00821	**78.29**
2070	0.00216	**66.70**	0.00395	**71.93**	0.00429	**72.64**	0.00782	**77.87**

TABLE 4.3:

FIELD STRENGTH PREDICTION
ZONE 3:- OBAKEKERE STAFF QUARTERS

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	**E(dB/uV/m) (P=15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**	Receiver height, hr = 3m E(V/m) (P=15W)	**E(dB/uV/m) (P=15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**
1380	0.00482	**73.67**	0.00881	**78.90**	0.00949	**79.55**	0.01733	**84.77**
1430	0.00450	**73.06**	0.00821	**78.29**	0.00885	**78.94**	0.01617	**84.17**
1480	0.00420	**72.47**	0.00767	**77.70**	0.00828	**78.36**	0.01512	**83.59**
1530	0.00393	**71.90**	0.00718	**77.13**	0.00776	**77.80**	0.01417	**83.03**
1580	0.00369	**71.35**	0.00674	**76.58**	0.00729	**77.25**	0.01330	**82.48**
1630	0.00347	**70.81**	0.00634	**76.04**	0.00686	**76.72**	0.01252	**81.95**
1680	0.00327	**70.29**	0.00597	**75.52**	0.00646	**76.21**	0.01180	**81.44**

TABLE 4.4:

FIELD STRENGTH PREDICTION

ZONE 4:- OBANLA HOSTEL AREA

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
460	0.02978	89.48	0.05438	94.71	0.05596	94.96	0.10217	100.19
510	0.02444	87.76	0.04462	92.99	0.04643	93.34	0.08477	98.56
560	0.02040	86.19	0.03725	91.42	0.03908	91.84	0.07136	97.07
610	0.01729	84.75	0.03156	89.98	0.03332	90.45	0.06084	95.68
660	0.01483	83.42	0.02708	88.65	0.02873	89.17	0.05245	94.39
710	0.01286	82.19	0.02348	87.41	0.02501	87.96	0.04566	93.19
760	0.01126	81.03	0.02055	86.26	0.02196	86.83	0.04009	92.06
810	0.00994	79.94	0.01814	85.17	0.01943	85.77	0.03547	91.00

TABLE 4.5: **FIELD STRENGTH PREDICTION**

ZONE 5:- ADMINISTRATIVE AREA

d (m)	Receiver height, hr = 1.5m				Receiver height, hr = 3m			
	E(V/m) (P=15W)	**E(dB/uV/m) (P=15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**	E(V/m) (P=15W)	**E(dB/uV/m) (P=15W)**	E(V/m) (P=50W)	**E(dB/uV/m) (P=50W)**
460	0.02978	**89.48**	0.05438	**94.71**	0.05596	**94.96**	0.10217	**100.19**
510	0.02444	**87.76**	0.04462	**92.99**	0.04643	**93.34**	0.08477	**98.56**
560	0.02040	**86.19**	0.03725	**91.42**	0.03908	**91.84**	0.07136	**97.07**
610	0.01729	**84.75**	0.03156	**89.98**	0.03332	**90.45**	0.06084	**95.68**

FIELD STRENGTH PREDICTION

TABLE 4.6: **ZONE 6:- NORTH GATE**

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
400	0.02400	**87.61**	0.04382	**92.83**	0.04653	**93.35**	0.08495	**98.58**
410	0.02288	**87.19**	0.04177	**92.42**	0.04440	**92.95**	0.08107	**98.18**
420	0.02183	**86.78**	0.03985	**92.01**	0.04242	**92.55**	0.07745	**97.78**
430	0.02085	**86.38**	0.03807	**91.61**	0.04057	**92.16**	0.07406	**97.39**
440	0.01994	**85.99**	0.03640	**91.22**	0.03883	**91.78**	0.07089	**97.01**
450	0.01908	**85.61**	0.03484	**90.84**	0.03720	**91.41**	0.06792	**96.64**
460	0.01828	**85.24**	0.03337	**90.47**	0.03567	**91.05**	0.06512	**96.27**

TABLE 4.7: **FIELD STRENGTH PREDICTION**

ZONE 7:- PRESENT ACADEMIC AREA

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
240	0.08872	98.96	0.16198	104.19	0.14943	103.49	0.27282	108.72
280	0.06717	96.54	0.12263	101.77	0.11837	101.46	0.21611	106.69
320	0.05249	94.40	0.09584	99.63	0.09523	99.58	0.17387	104.80
360	0.04209	92.48	0.07685	97.71	0.07789	97.83	0.14221	103.06
400	0.03447	90.75	0.06293	95.98	0.06470	96.22	0.11812	101.45
440	0.02873	89.17	0.05245	94.40	0.05449	94.73	0.09949	99.96
480	0.02430	87.71	0.04437	92.94	0.04646	93.34	0.08483	98.57
520	0.02082	86.37	0.03801	91.60	0.04005	92.05	0.07312	97.28
560	0.01803	85.12	0.03292	90.35	0.03485	90.85	0.06364	96.07
600	0.01577	83.95	0.02879	89.18	0.03060	89.71	0.05586	94.94
640	0.01390	82.86	0.02538	88.09	0.02706	88.65	0.04941	93.88

TABLE 4.8:

FIELD STRENGTH PREDICTION

ZONE 8(a):- FUTURE ACADEMIC AREA (A)

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
760	0.00683	**76.68**	0.01246	**81.91**	0.01349	**82.60**	0.02463	**87.83**
800	0.00617	**75.80**	0.01126	**81.03**	0.01220	**81.73**	0.02227	**86.96**
840	0.00560	**74.96**	0.01022	**80.19**	0.01108	**80.89**	0.02024	**86.12**
880	0.00511	**74.16**	0.00932	**79.39**	0.01011	**80.10**	0.01847	**85.33**
920	0.00468	**73.40**	0.00854	**78.63**	0.00927	**79.34**	0.01692	**84.57**
960	0.00430	**72.67**	0.00785	**77.89**	0.00852	**78.61**	0.01555	**83.84**
1000	0.00396	**71.96**	0.00724	**77.19**	0.00786	**77.91**	0.01435	**83.14**
1040	0.00367	**71.29**	0.00670	**76.52**	0.00727	**77.24**	0.01328	**82.46**
1080	0.00340	**70.64**	0.00621	**75.87**	0.00675	**76.59**	0.01233	**81.82**

FIELD STRENGTH PREDICTION

TABLE 4.9: **ZONE 8 (b):- FUTURE ACADEMIC AREA (B)**

	Receiver height, hr = 1.5m						Receiver height, hr = 3m					
d (m)	lf (m)	Attn.	E(V/m) (P = 15W)	**E(dB/uV/m) (P = 15W)**	E(V/m) (P = 50W)	**E(dB/uV/m) (P = 50W)**	lf (m)	Attn.	E(V/m) (P = 15W)	**E(dB/uV/m) (P = 15W)**	E(V/m) (P = 50W)	**E(dB/uV/m) (P = 50W)**
610	2.0	0.993	0.01583	**83.99**	0.02891	**89.22**	2.0	0.993	0.03067	**89.74**	0.05600	**94.96**
710	55.8	0.825	0.00977	**79.80**	0.01784	**85.03**	33.0	0.892	0.02064	**86.29**	0.03768	**91.52**
810	63.7	0.802	0.00734	**77.32**	0.01341	**82.55**	37.7	0.878	0.01576	**83.95**	0.02877	**89.18**
910	71.6	0.781	0.00568	**75.09**	0.01038	**80.32**	42.3	0.864	0.01237	**81.85**	0.02259	**87.08**
1010	79.4	0.760	0.00450	**73.07**	0.00822	**78.30**	47.0	0.850	0.00994	**79.94**	0.01814	**85.17**
1110	87.3	0.740	0.00364	**71.22**	0.00664	**76.44**	51.6	0.837	0.00813	**78.20**	0.01484	**83.43**
1210	95.2	0.720	0.00298	**69.50**	0.00545	**74.73**	56.3	0.823	0.00675	**76.59**	0.01233	**81.82**
1310	103.0	0.701	0.00248	**67.90**	0.00453	**73.12**	60.9	0.810	0.00568	**75.09**	0.01038	**80.32**
1410	110.9	0.682	0.00209	**66.39**	0.00381	**71.62**	65.6	0.797	0.00484	**73.69**	0.00883	**78.92**

* lf - Distance of ray penetration through forest
* Attn. - Attenuation by forest.

TABLE 4.10: **FIELD STRENGTH PREDICTION**

ZONE 9:- OBANLA STAFF QUARTERS

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
300	0.06619	**96.42**	0.12085	**101.64**	0.11472	**101.19**	0.20944	**106.42**
400	0.03883	**91.78**	0.07090	**97.01**	0.07158	**97.10**	0.13069	**102.32**
500	0.02539	**88.09**	0.04635	**93.32**	0.04814	**93.65**	0.08789	**98.88**
600	0.01785	**85.03**	0.03259	**90.26**	0.03437	**90.72**	0.06275	**95.95**
700	0.01322	**82.43**	0.02414	**87.66**	0.02569	**88.20**	0.04691	**93.42**
800	0.01018	**80.16**	0.01859	**85.38**	0.01990	**85.98**	0.03633	**91.21**
900	0.00808	**78.15**	0.01475	**83.37**	0.01585	**84.00**	0.02894	**89.23**
1000	0.00656	**76.34**	0.01198	**81.57**	0.01292	**82.22**	0.02358	**87.45**

TABLE 4.11:

FIELD STRENGTH PREDICTION
ZONE 10:- CHANCELLORS' QUARTERS

d (m)	Receiver height, hr = 1.5m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)	Receiver height, hr = 3m E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
1260	0.00301	**69.56**	0.00549	**74.79**	0.00596	**75.51**	0.01089	**80.74**
1280	0.00291	**69.29**	0.00532	**74.52**	0.00578	**75.24**	0.01055	**80.47**
1300	0.00283	**69.02**	0.00516	**74.25**	0.00560	**74.97**	0.01023	**80.20**
1320	0.00274	**68.76**	0.00500	**73.99**	0.00544	**74.71**	0.00993	**79.94**
1340	0.00266	**68.50**	0.00486	**73.73**	0.00528	**74.45**	0.00964	**79.68**
1360	0.00258	**68.24**	0.00472	**73.47**	0.00513	**74.20**	0.00936	**79.42**
1380	0.00251	**67.99**	0.00458	**73.22**	0.00498	**73.94**	0.00909	**79.17**
1400	0.00244	**67.74**	0.00445	**72.97**	0.00484	**73.70**	0.00884	**78.93**
1420	0.00237	**67.50**	0.00433	**72.73**	0.00471	**73.45**	0.00859	**78.68**

FIELD STRENGTH PREDICTION

TABLE 4.12: ZONE 11:- SOUTH WEST END

	Receiver height, hr = 1.5m						Receiver height, hr = 3m					
d (m)	lf (m)	Attn.	E(V/m) (P = 15W)	**E(dB/uV/m) (P = 15W)**	E(V/m) (P = 50W)	**E(dB/uV/m) (P = 50W)**	lf (m)	Attn.	E(V/m) (P = 15W)	**E(dB/uV/m) (P = 15W)**	E(V/m) (P = 50W)	**E(dB/uV/m) (P = 50W)**
1680	90.0	0.733	0.00223	**66.96**	0.00407	**72.19**	90.0	0.733	0.00441	**72.89**	0.00805	**78.11**
1740	150.0	0.596	0.00169	**64.56**	0.00309	**69.79**	150.0	0.596	0.00334	**70.49**	0.00611	**75.72**
1800	210.0	0.484	0.00128	**62.18**	0.00235	**67.40**	203.2	0.496	0.00260	**68.31**	0.00475	**73.54**
1860	249.0	0.423	0.00105	**60.44**	0.00192	**65.67**	210.0	0.484	0.00238	**67.55**	0.00435	**72.77**
1920	257.0	0.412	0.00096	**59.65**	0.00175	**64.88**	216.8	0.473	0.00219	**66.80**	0.00399	**72.03**
1980	265.0	0.400	0.00088	**58.88**	0.00161	**64.11**	223.5	0.462	0.00201	**66.07**	0.00367	**71.30**
2040	273.1	0.389	0.00081	**58.13**	0.00147	**63.36**	230.3	0.451	0.00185	**65.35**	0.00338	**70.58**
2100	281.1	0.379	0.00074	**57.39**	0.00135	**62.62**	237.1	0.441	0.00171	**64.65**	0.00312	**69.88**
2160	289.1	0.368	0.00068	**56.66**	0.00124	**61.89**	243.9	0.431	0.00158	**63.97**	0.00288	**69.19**
2220	297.2	0.358	0.00063	**55.95**	0.00115	**61.18**	250.6	0.421	0.00146	**63.29**	0.00267	**68.52**
2280	305.2	0.349	0.00058	**55.25**	0.00106	**60.48**	257.4	0.411	0.00135	**62.63**	0.00247	**67.86**
2340	313.2	0.339	0.00053	**54.56**	0.00098	**59.79**	264.2	0.402	0.00126	**61.98**	0.00229	**67.21**
2400	321.3	0.330	0.00049	**53.88**	0.00090	**59.11**	271.0	0.392	0.00117	**61.34**	0.00213	**66.57**

* lf - Distance of ray penetration through forest
* Attn. - Attenuation by forest.

FIELD STRENGTH PREDICTION

TABLE 4.13: **ZONE 12:- OBAKEKERE AREA BEHIND ROCK "M"**

ht = 30m, d1 = 1065m, H = 20m, slope angle = 1.5 degrees

d (m)	E(V/m) (P=15W)	E(dB/uV/m) (P=15W)	E(V/m) (P=50W)	E(dB/uV/m) (P=50W)
1100	0.001634	**64.263**	0.002982	**69.492**
1150	0.002472	**67.860**	0.004513	**73.088**
1200	0.003004	**69.555**	0.005485	**74.784**
1250	0.003382	**70.584**	0.006175	**75.813**
1300	0.003661	**71.272**	0.006684	**76.500**
1350	0.003869	**71.752**	0.007064	**76.981**
1400	0.004025	**72.094**	0.007348	**77.323**
1450	0.004140	**72.340**	0.007559	**77.569**
1500	0.004224	**72.515**	0.007712	**77.744**
1520	0.004250	**72.569**	0.007760	**77.798**

* ht - Transmitter (mast) height.
* d1 - Horizontal distance of the Rock's mid-point from the proposed transmitting antenna location.
* H - Vertical height of the Rock from its base.

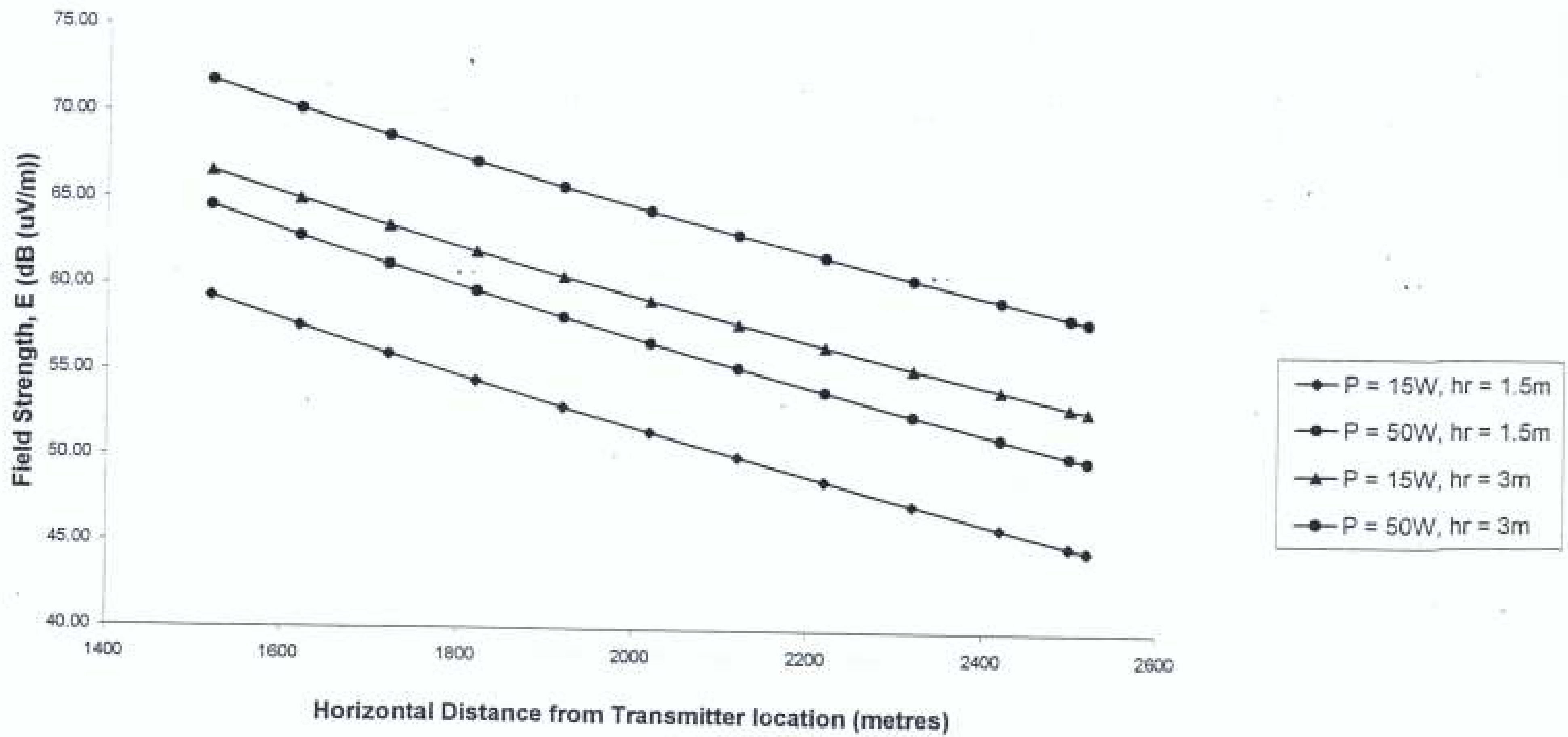


Figure 4.2 Graph of Predicted Field Strength against Distance (Zone 1, North West End/Ibule Edge)

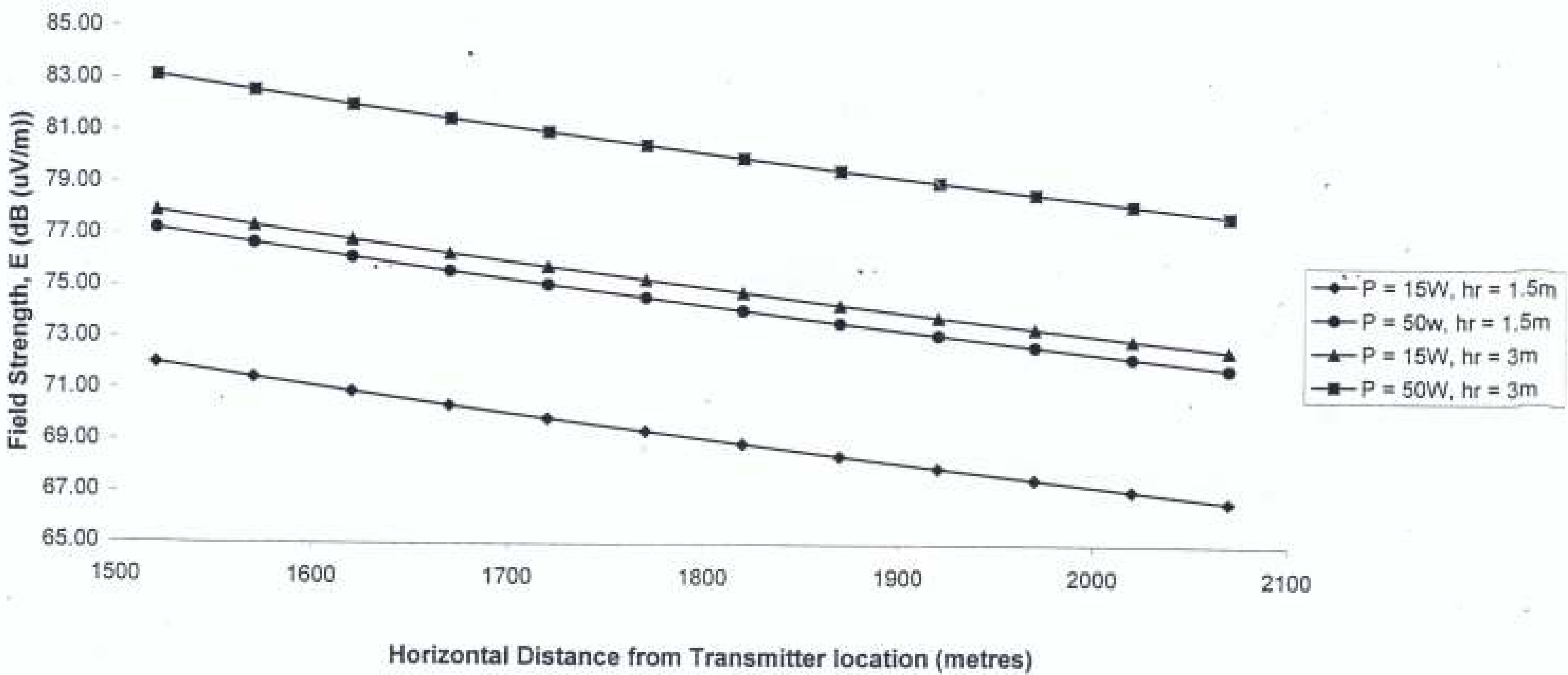


Figure 4.3 Graph of Predicted Field Strength against Distance (Zone 2, Obakekere Hostel Area)

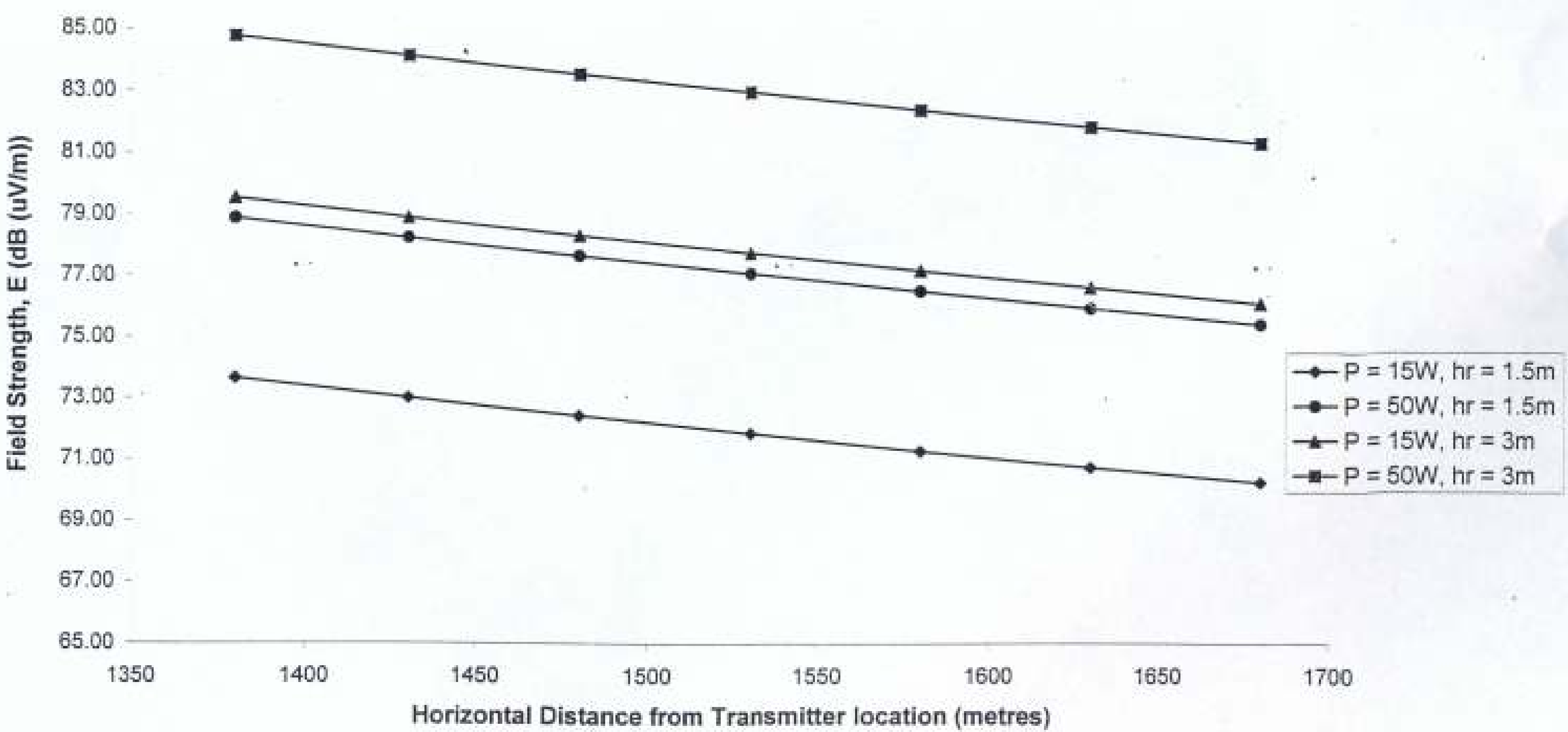


Figure 4.4 Graph of Predicted Field Strength against Distance (Zone 3, Obakekere Staff Quarters)

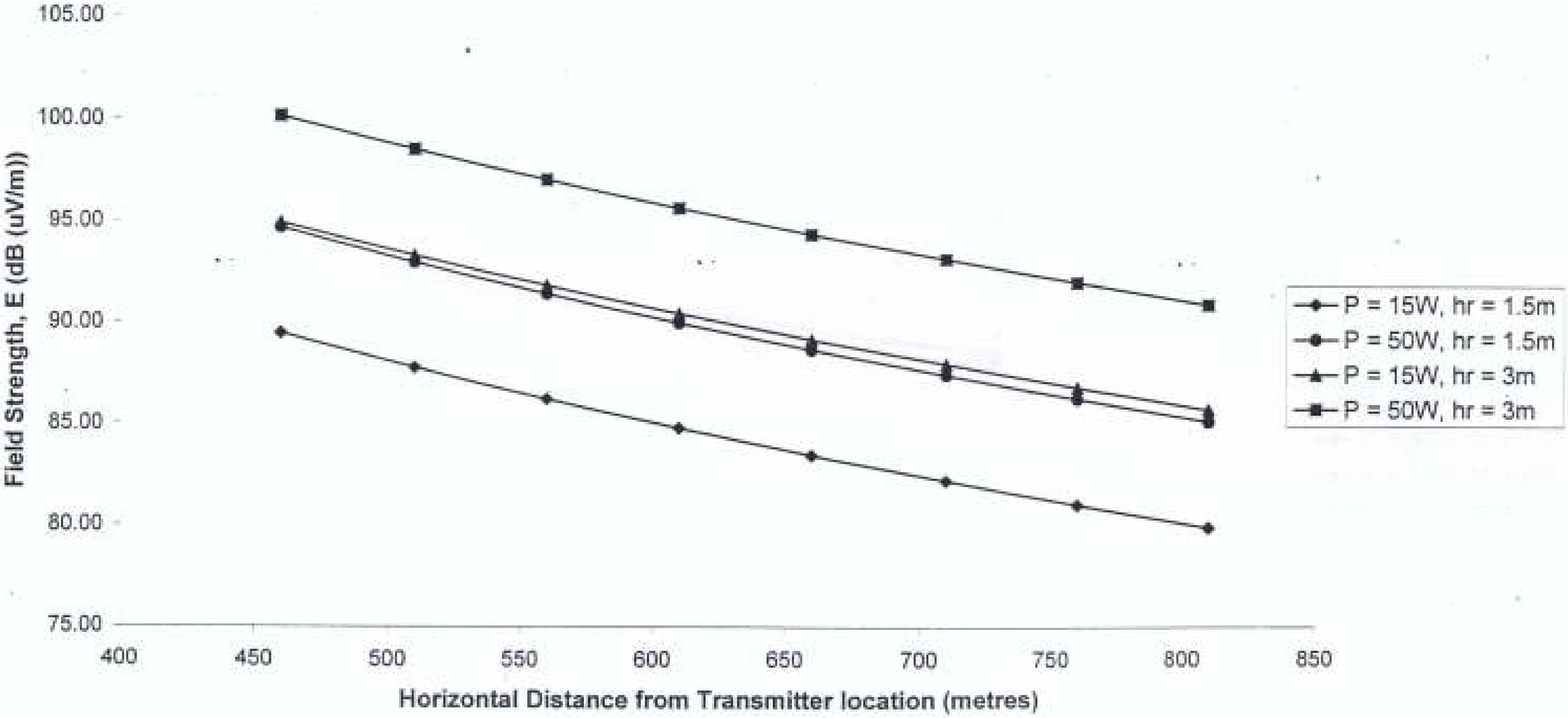


Figure 4.5 **Graph of Predicted Field Strength against Distance (Zone 4, Obanla Hostel Area)**

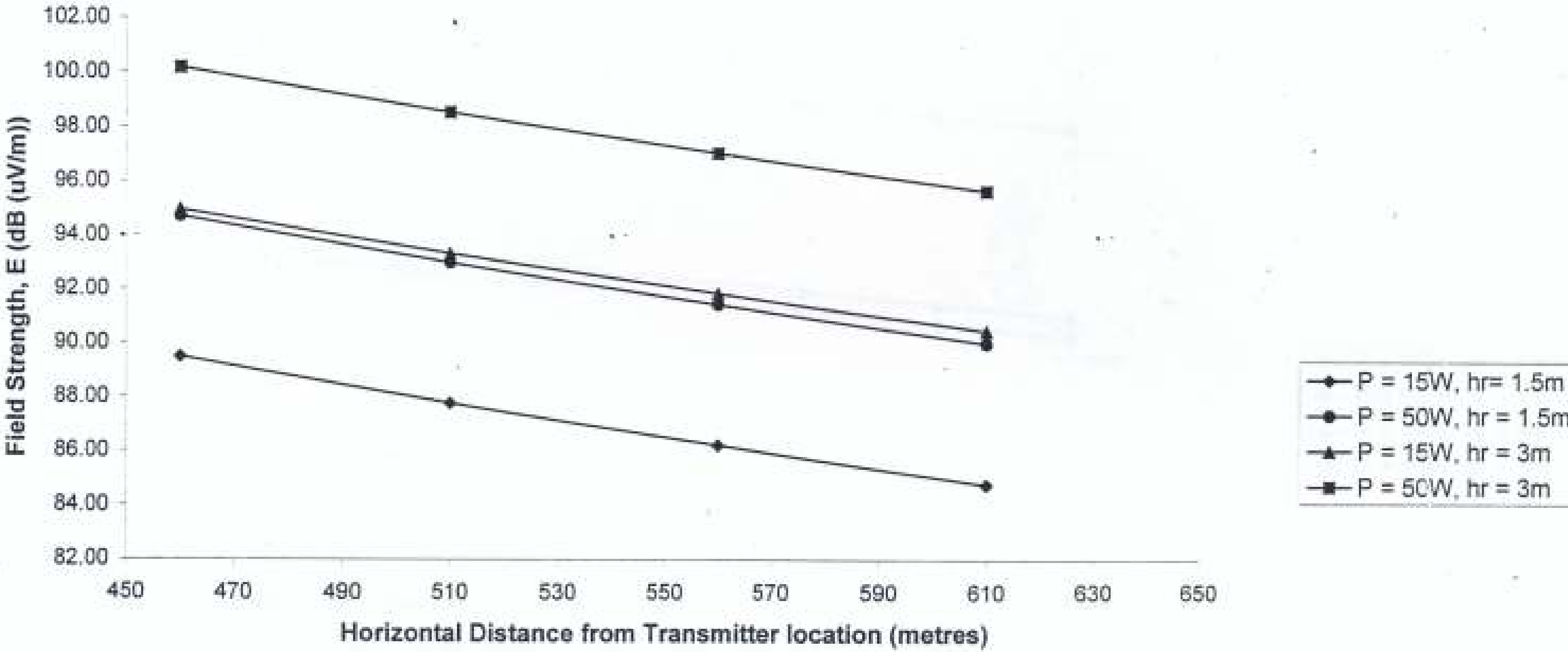


Figure 4.6 Graph of Predicted Field Strength against Distance (Zone 5, Administrative Area)

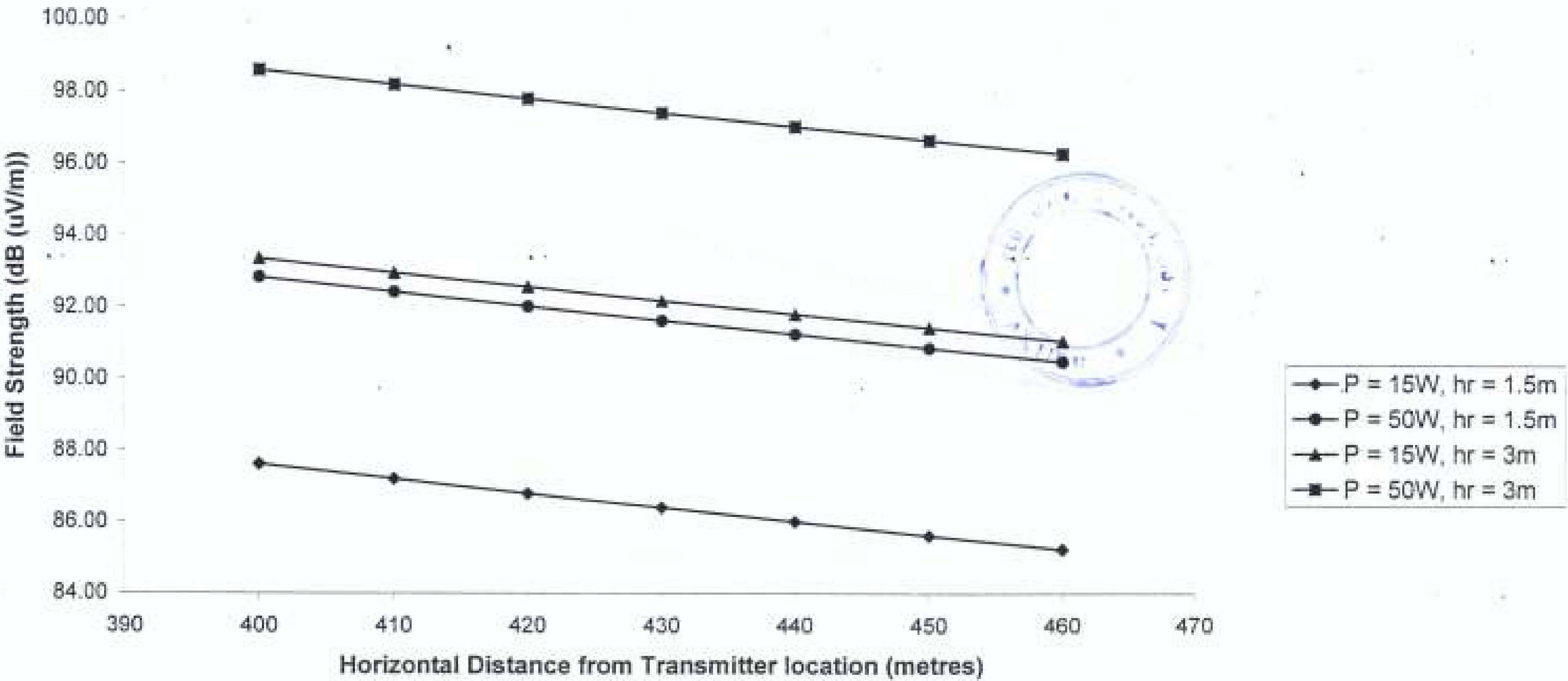


Figure 4.7 Graph of Predicted Field Strength against Distance (Zone 6, North Gate)

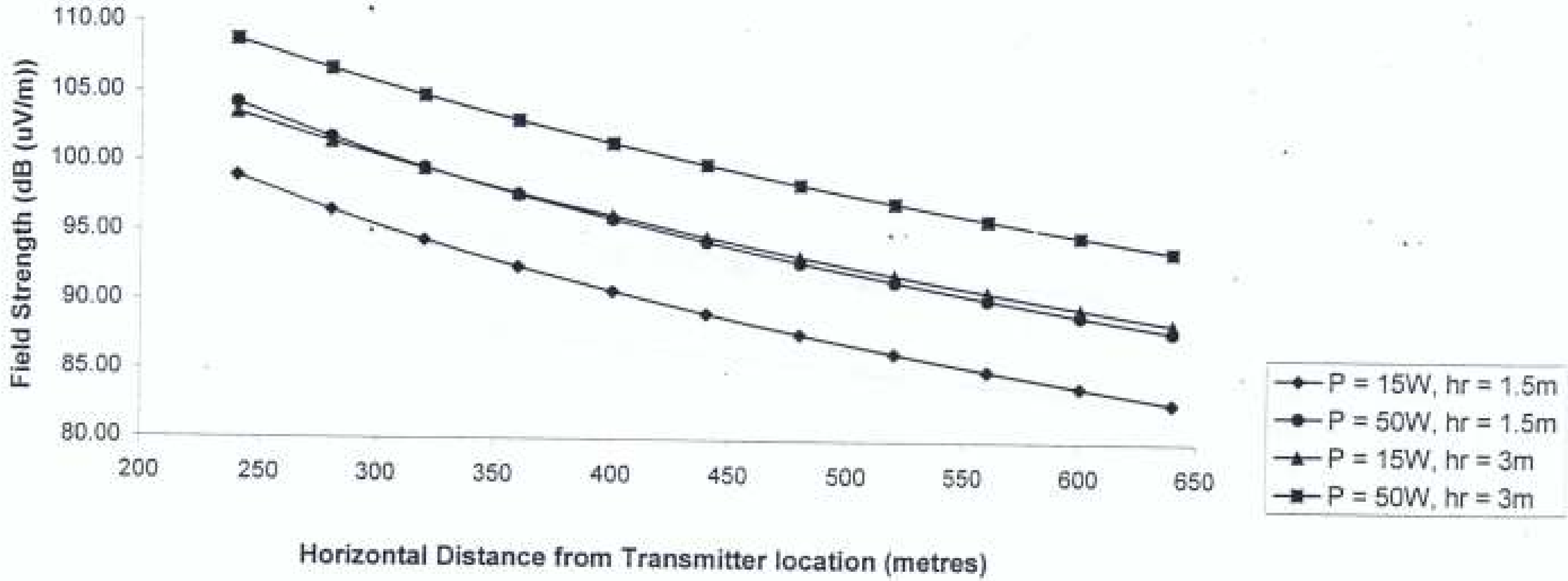


Figure 4.8 Graph of Predicted Field Strength against Distance (Zone 7, Present Academic Area)

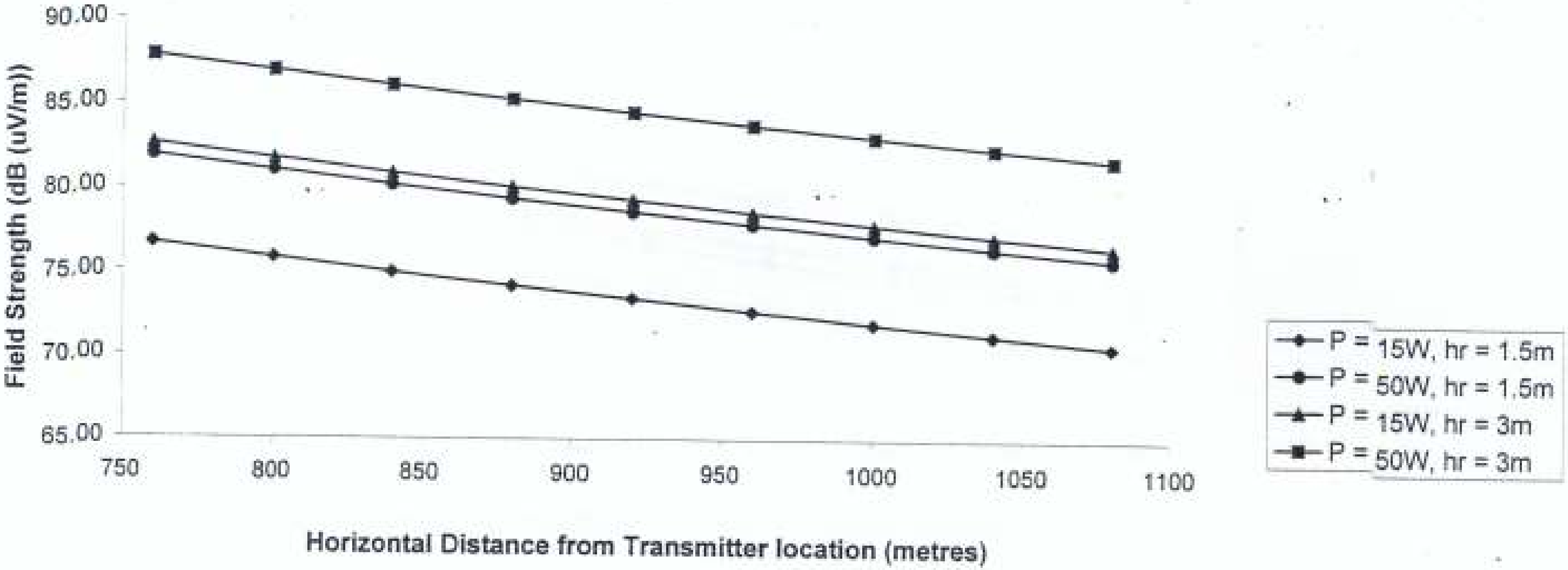


Figure 4.9 Graph of Predicted Field Strength against Distance (Zone 8(a), Future Academic Area (A))

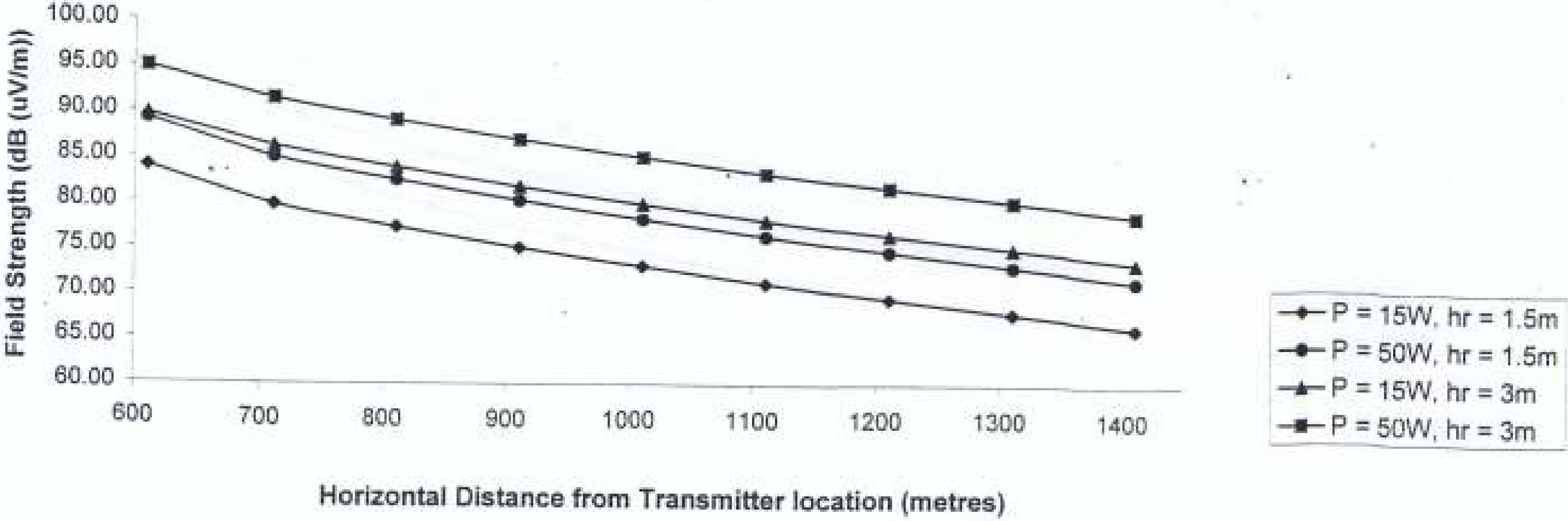


Figure 4.10 Graph of Predicted Field Strength against Distance (Zone 8(b), Future Academic Area (B))

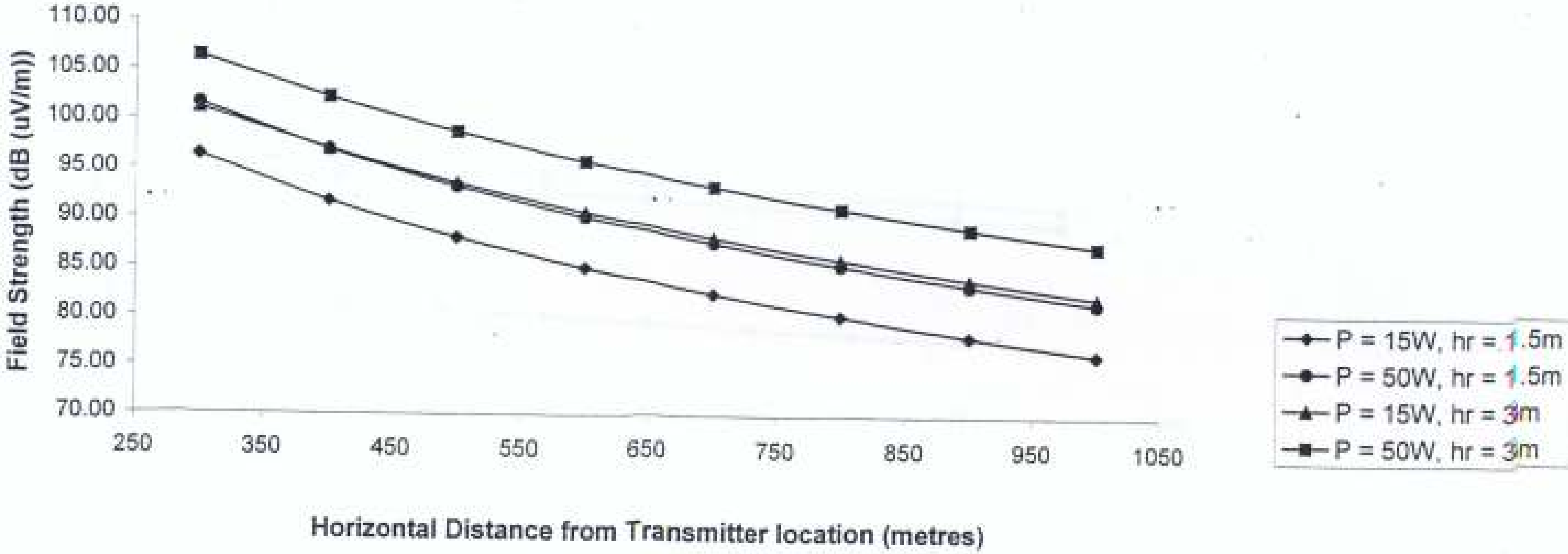


Figure 4.11 Graph of Predicted Field Strength against Distance (Zone 9, Obanla Staff Quarters)

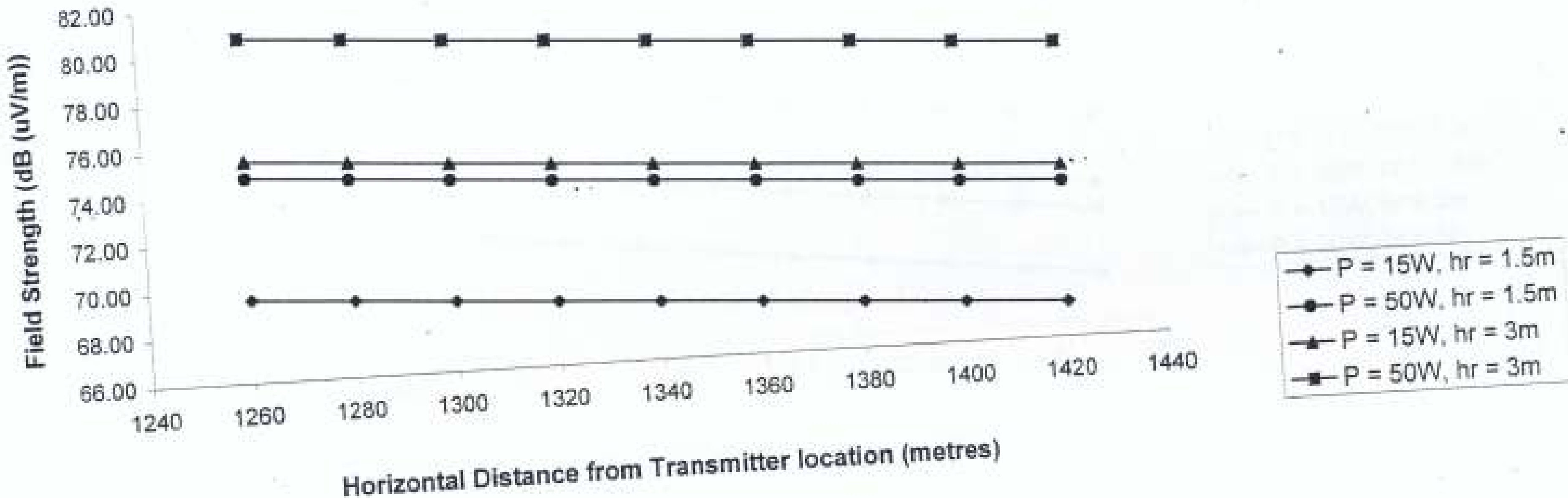


Figure 4.12 Graph of Predicted Field Strength against Distance (Zone 10, Chancellors' Quarters)

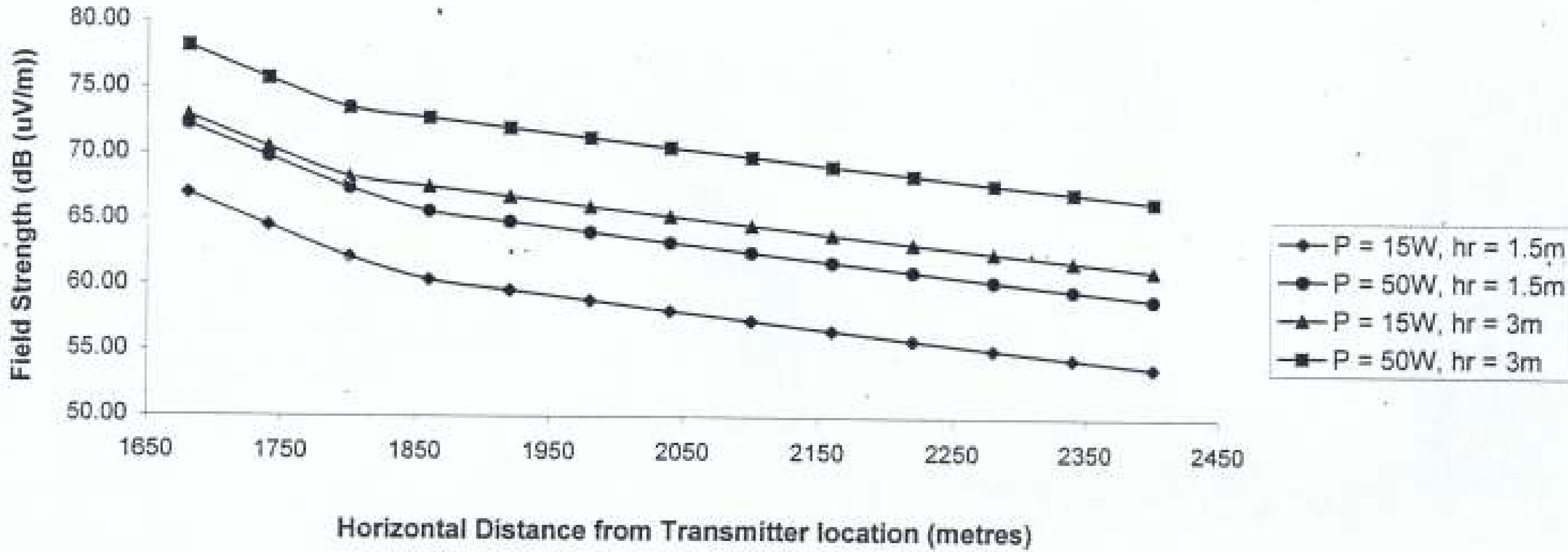


Figure 4.13 Graph of Predicted Field Strength against Distance (Zone 11, South West End)

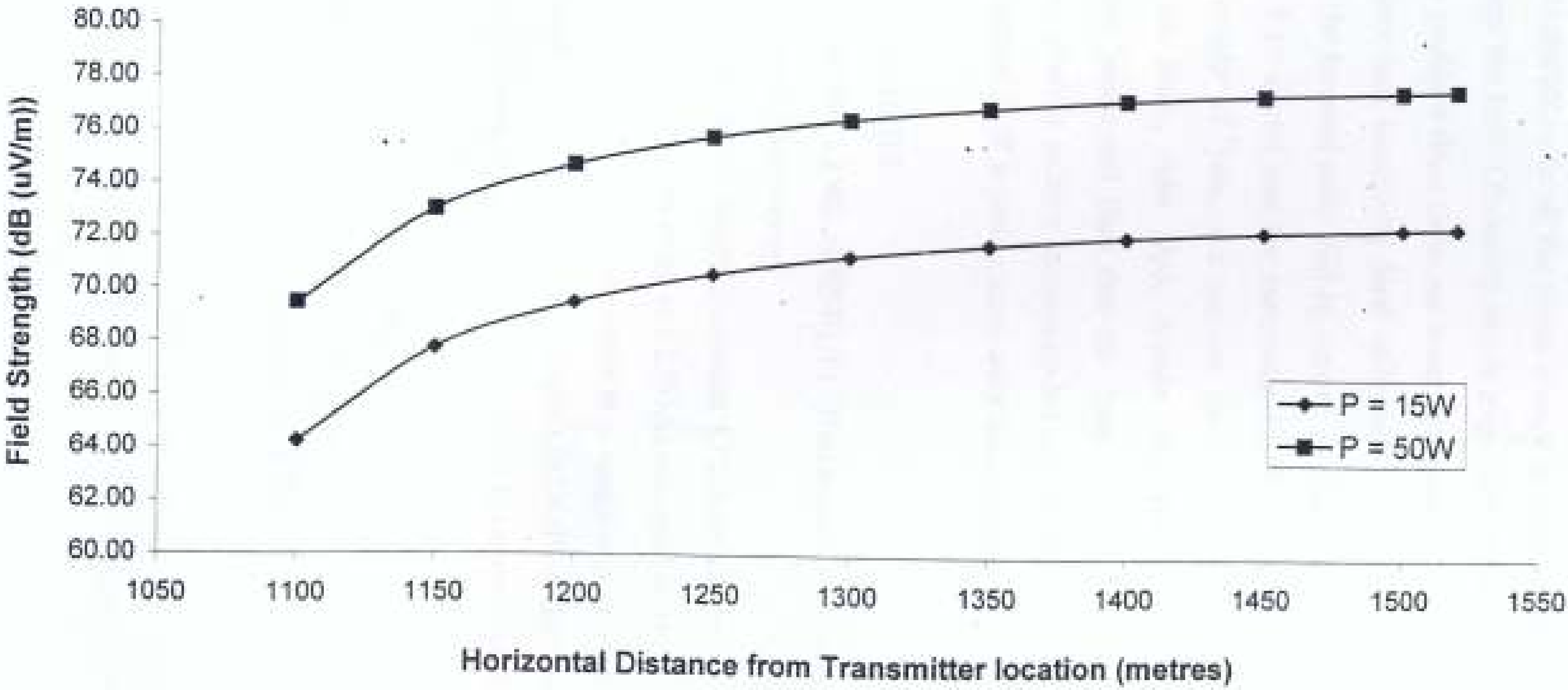


Figure 4.14 Graph of Predicted Field Strength against Distance (Zone 12, Obakekere Area behind Rock "M")

4.1.2 DISCUSSION

The predicted results show that for a minimum EIRP of 15W and the two receiver heights, there would be signal strength more than the recommended minimum field intensity (MFI) of 60 dB/uV/m in all the zones except in forested zones where the field strength may be below the MFI. Obviously this is expected due to the presence of dense forests. This is not a problem since these are areas where nobody lives. In the near or far future, as development and increasing land utilization continues to take place in the community, more of the forested areas will be cleared allowing for satisfactory reception.

Also, Figure 3.17 shows that for maximum EIRP of 50W; the antenna location selected and mast height of 30m, the service range would be about 4km radius. Communities such as Ibule, Aba Oyo, Awule and Ita Oniyan will be within. Communities of Gaga, Ipinsa and Ilara that are close to FUTA may have little or no reception due to the radiation pattern recommended and produced by the transmitting antenna. Minimum EIRP of 15W is just to serve only the community (FUTA).

4.2 ANTENNA SYNTHESIS

4.2.1 HARDWARE MODELING RESULT: Radiation characteristic of the modeled and tested LPDA Array

The polar plot of the tested single 5-element LPDA is shown in Plate 4A. The polar plot of the same LPDA but in an array of 3 LPDAs mounted as shown in Plate 3L is shown in Plate 4B. The measurements were made at a frequency of 1400 MHz. Figure 4.15 and Figure 4.16 is the frequency plot of the single LPDA (Plate 3K) and the 3 LPDA array respectively over operating (transmitting) frequencies between 1200 MHz and 1800 MHz.

Plate 4A shows the unidirectional radiation characteristic of the LPDA though with some minor lobes at the rear. Figure 4.15 shows that for the LPDA tested, it maintains fairly a constant gain within frequencies of 1400 MHz and 1700MHz. The same is true for the 3 LPDA array, Figure 4.16.

The polar plot of Plate 4B for the 3 LPDA array is close to the recommended radiation pattern (Figure 3.18) though with some minor lobes where the main null is expected.

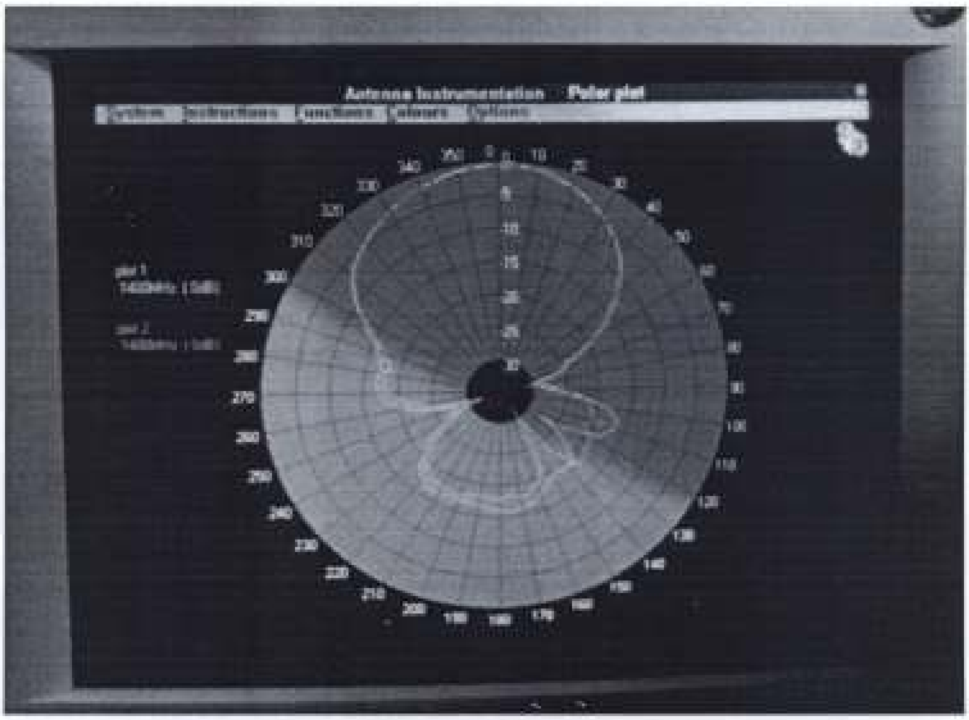


PLATE 4A POLAR PLOT OF THE RADIATION PATTERN OF THE TESTED (MODEL) 5-ELEMENT LOG-PERIODIC DIPOLE ANTENNA AT 1400 MHZ (PLATE 3I)

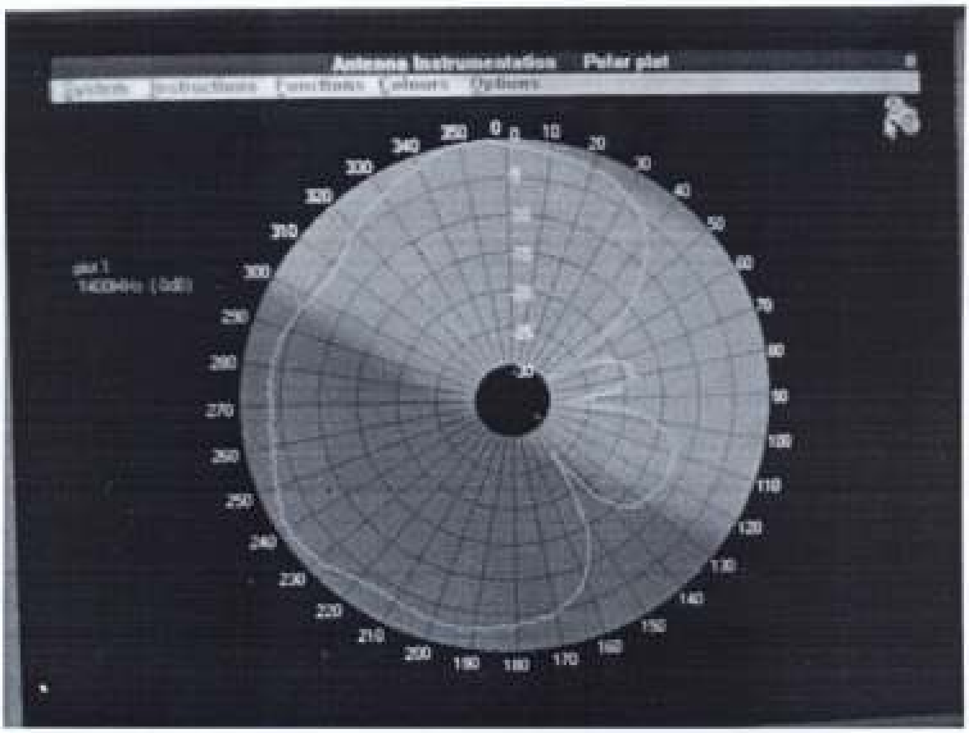


PLATE 4B POLAR PLOT OF THE RADIATION PATTERN OF THE TESTED (MODEL) 3, 5-ELEMENT LOG-PERIODIC DIPOLE ANTENNA ARRAY AT 1400 MHZ (PLATE 3J)

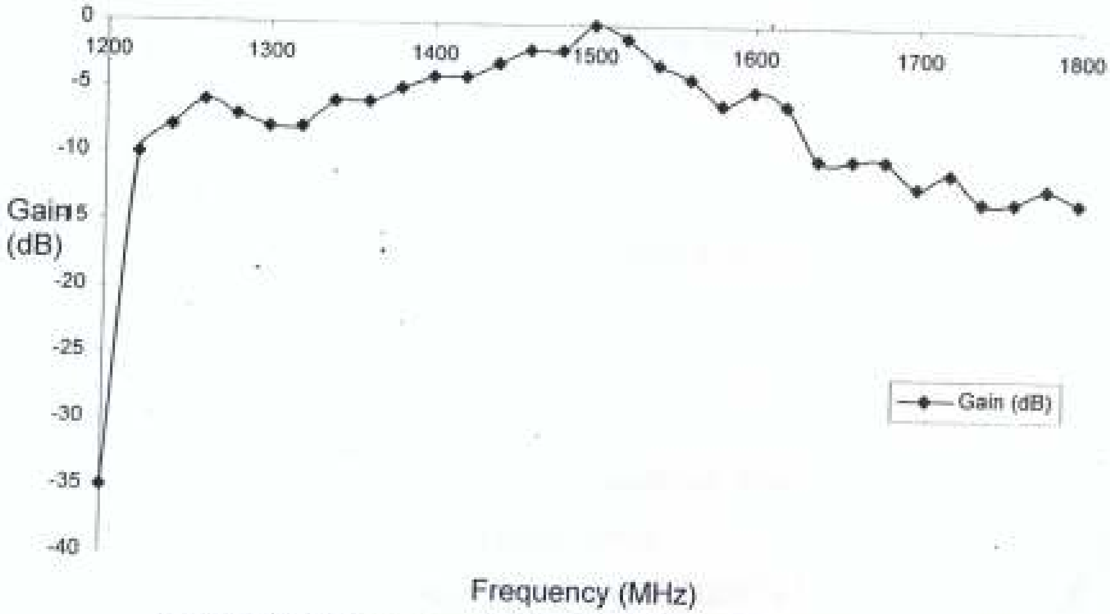


Figure 4.15 Frequency Plot of the Tested (Model) 5-Element Log-Periodic Dipole Antenna

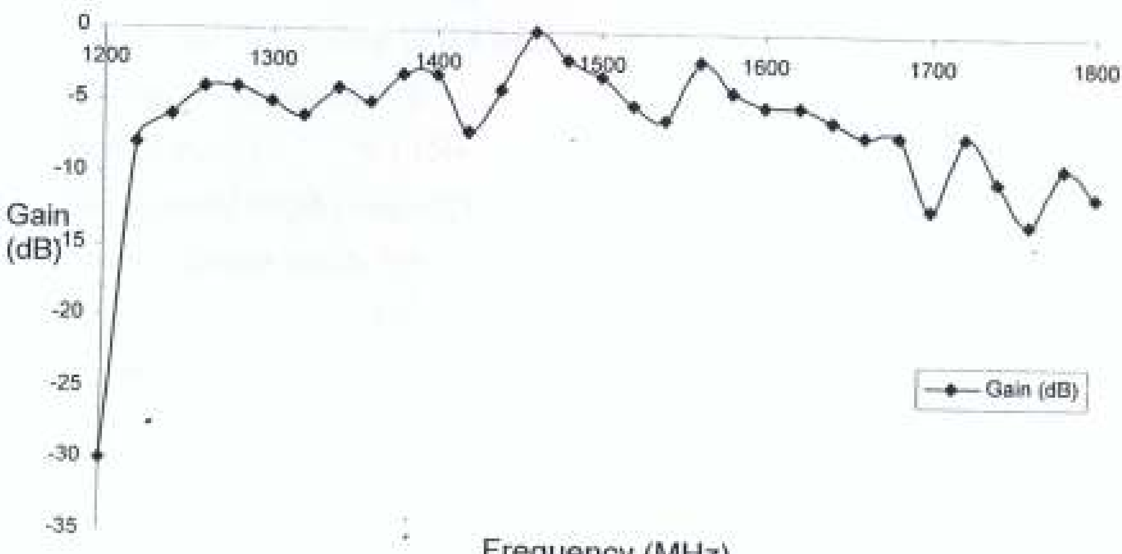


Figure 4.16 Frequency Plot of the Tested (Model) 3, 5-Element Log-Periodic Dipole Antenna Array

4.2.2 ANTENNA DESIGN RESULT

The model antenna used for the hardware modeling has these design parameters.

$\tau = 0.91$

$\sigma = 0.19$

N = 5 elements

Using the same design parameters for the antenna to be designed for the service band (87.5MHz – 108 MHz) results in

L (Boom Length) = 3.61m and

N = 9 elements

This boom length is too long and N too much considering weight and cost. Also, the overall dimension of the 3 LPDA array will be too much.

From Figure 2.21, for Directivity of 7dB and $\tau = 0.8$ (giving bearable dimensions),

$\sigma = 0.12$

For the service concerned (VHF Band II),

Lowest frequency = 87.5 MHz,

And highest frequency = 108 MHz.

Using the QBASIC Program, (Appendix B), and eliminating the LPDA feeder termination, Z_t, the result for the LPDA array dimensions are:

Number of elements, N = 5

Boom length, L = 1.15m

First element length (longest), l_1 = 1.71m

Second element length, l_2 = 1.368m

Third " " , l_3 = 1.1m

Fourth " " , l_4 = 0.876m

Fifth " " , l_5 = 0.7m

Element spacings,

d_{12} = 0.41m

d_{23} = 0.328m

d_{34} = 0.262m

d_{45} = 0.21m

Using aluminum alloy T6061 tubing (Appendix C) for the antenna and letting the element diameters be as the following:

Element 1 diameter, diam1 = 7/8 inch (2.27cm)

" 2 ", diam2 = ¾ inch (1.9cm)

" 3 ", diam3 = 5/8 inch (1.6cm)

" 4 ", diam4 = 7/16 inch (1.1cm)

" 5 ", diam5 = 3/8 inch (0.95cm)

then,

for the LPDA input impedance, R_o = 100 Ω (so as to have 2 : 1 balun matching with the 50 Ω coaxial transmission line from the transmitter),

Characteristic impedance of the interconnecting transmission line, Z_o = 145 Ω

If the interconnecting transmission line conductor is made to be the boom and its diameter be that of the longest element i.e. boom diameter = 2.27cm, then,

The boom center-to-center spacing, S = 3.8cm leading to boom gap spacing of 1.53cm. This is illustrated in Figure 4.17.

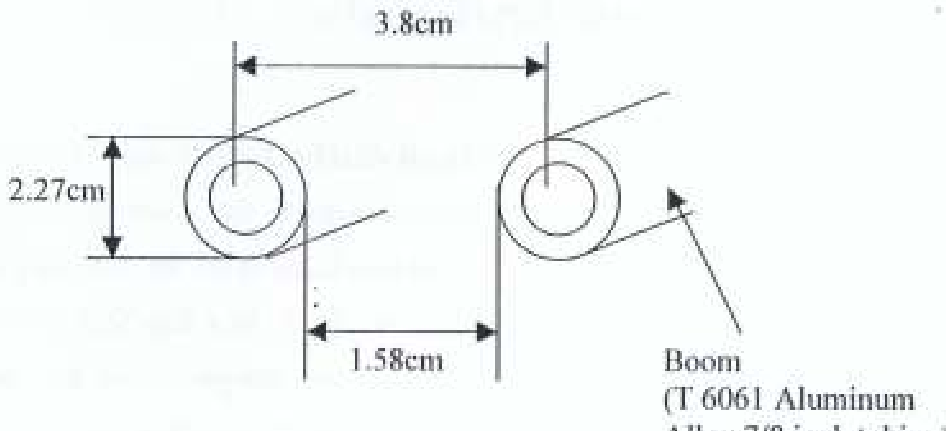


Figure 4.17 The LPDA Antenna Boom Spacing

The designed antenna dimensions are illustrated in Figure 4.18.

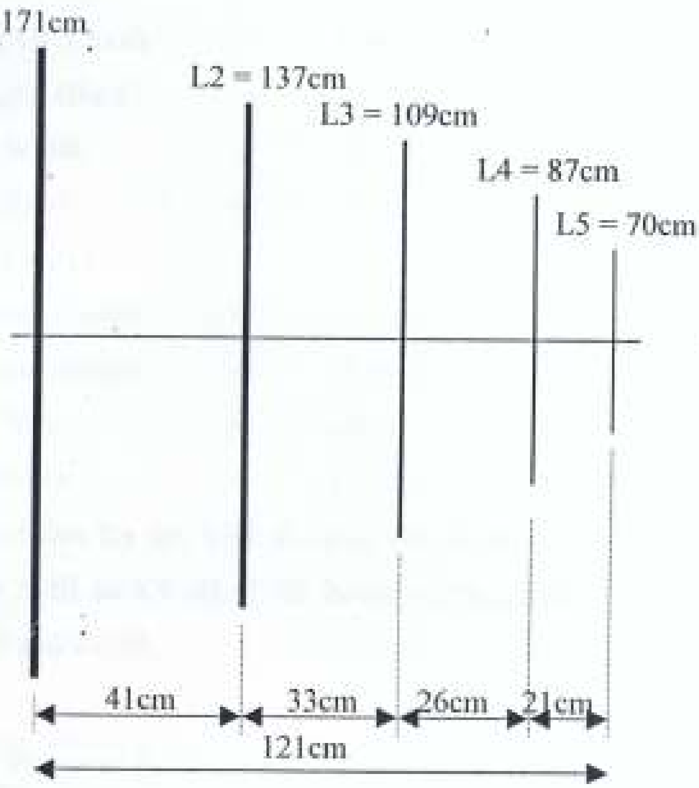


Figure 4.18 The Designed LPDA Dimension

4.2.3 SOFTWARE SIMULATION RESULT

The polar plot of the radiation pattern of the designed single 5-element LPDA for the service band (VHF II) as simulated by the Antenna NEC-WIN Software is shown in Figures 4.19, 4.20 and 4.21. They are the radiation pattern simulated at 88 MHz, 100 MHz and 108 MHz respectively. The figures also show result of gain analysis as performed by the software. They all show the unidirectional radiation pattern of the antenna. Major lobe in the forward direction and minor lobe in the backward direction. In the design (Section 4.2.2), the antenna was designed for directivity of 7 dB.

From the simulation result, at 88 MHz (Figure 4.19),

Maximum gain (Front)	=	5.31 dB
Maximum gain (Back)	=	-4.48 dB
3 dB Beam Width	=	74^0
Front/Back Ratio	=	9.79 dB

At 100 MHz (Figure 4.20),

Maximum gain (Front)	=	6.49 dB
Maximum gain (Back)	=	-12.19 dB
3 dB Beam Width	=	70^0
Front/Back Ratio	=	18.68 dB

At 108 MHz (Figure 4.21),

Maximum gain (Front)	=	6.88 dB
Maximum gain (Back)	=	-8.82 dB
3 dB Beam Width	=	68^0
Front/Back Ratio	=	15.7 dB

The simulation result shows that for the VHF II band, the designed individual (single) LPDA gain ranges from 5.3 dB to 6.9 dB, 3 dB beam width within 68^0 and 74^0 and front/back ratio within 9 dB and 19 dB.

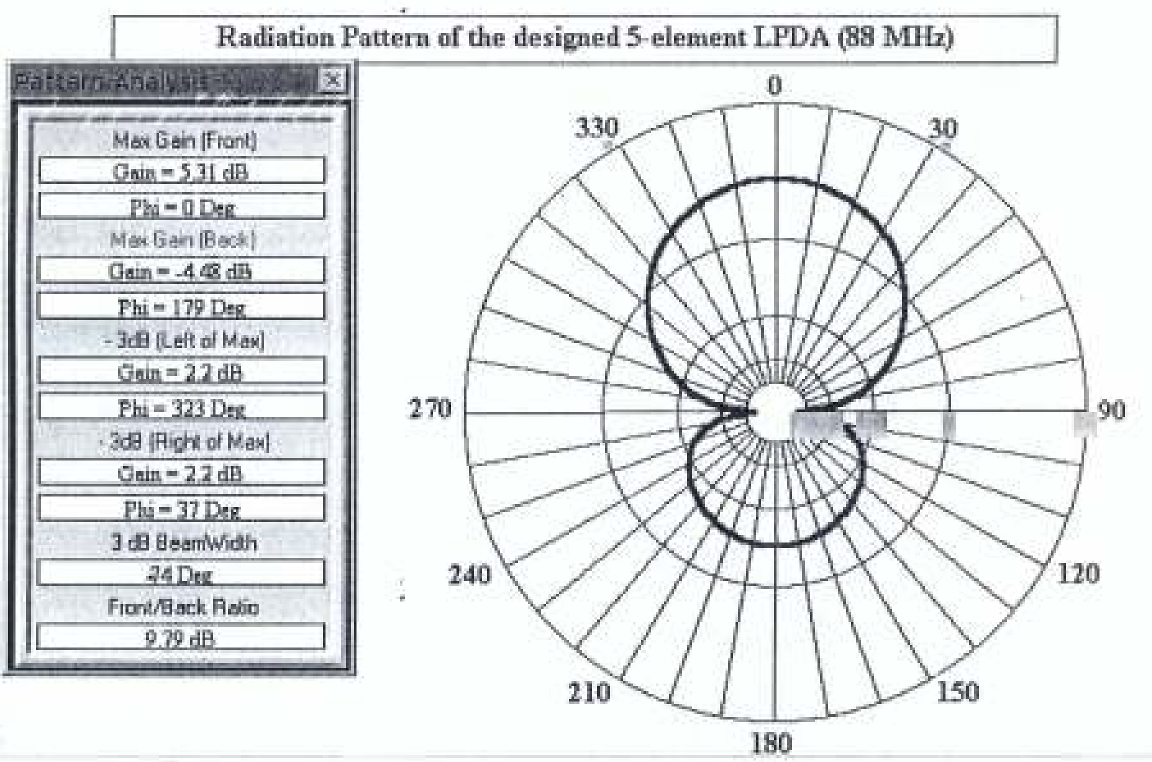


Figure 4.19 Simulated Radiation Pattern of the designed 5 – element LPDA at 88 MHz

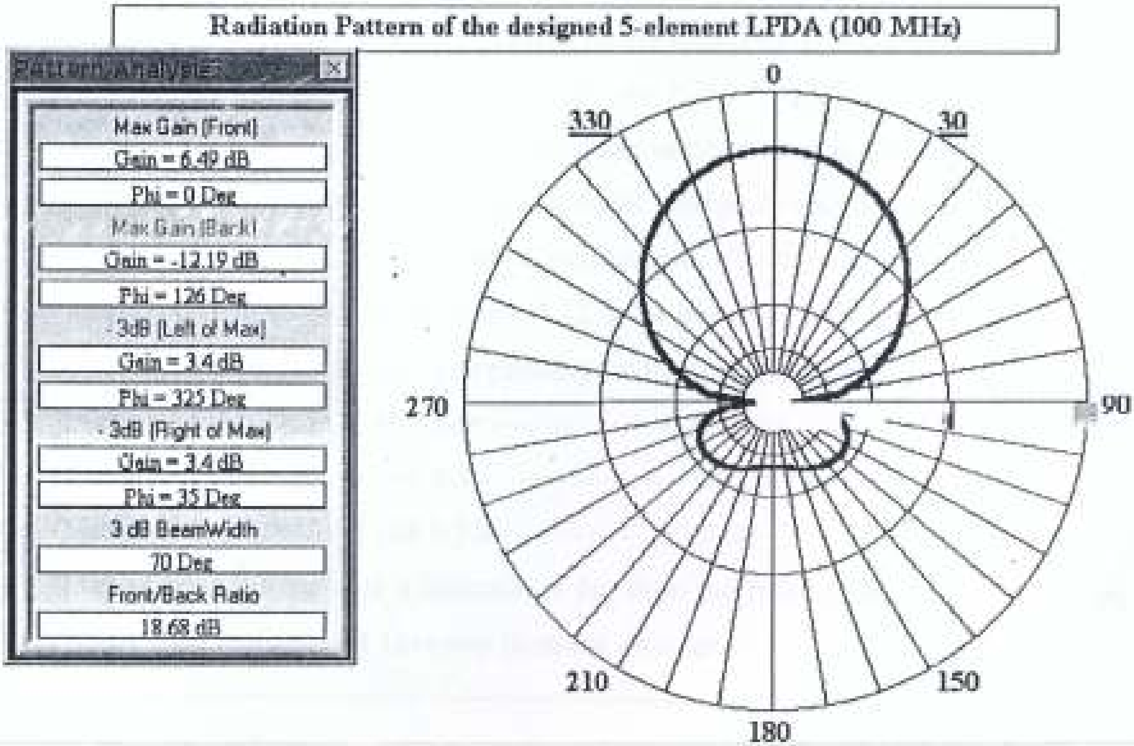


Figure 4.20 Simulated Radiation Pattern of the designed 5 – element LPDA at 100 MHz

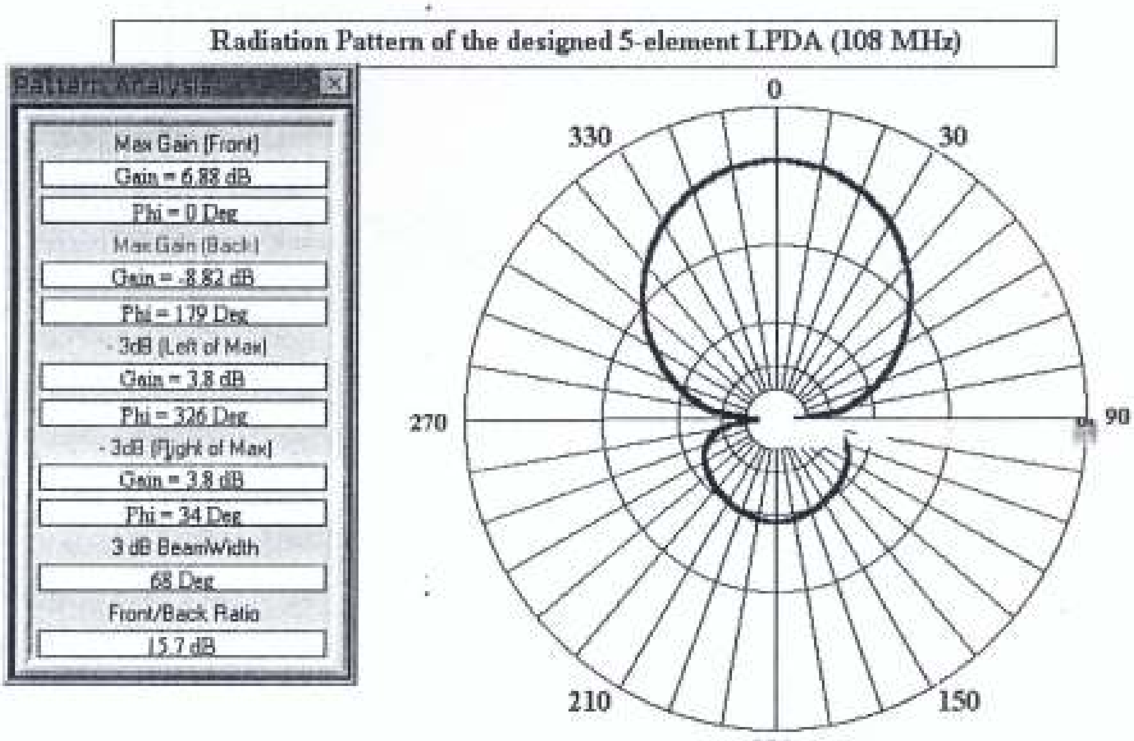


Figure 4.21 Simulated Radiation Pattern of the designed 5 – element LPDA at 108 MHz

4.2.4 THE 3 LPDA ARRAY SIMULATION

The polar plot of the radiation pattern of the designed 3, 5-element LPDA array for the service band (VHF II) as simulated by the NEC – WIN Antenna Software is shown in Figures 4.23, 4.25 and 4.27. The array arrangement producing the plots is shown in Figure 4.22. Each antenna is given equal amplitude and co-phased excitation. Several different array arrangements were simulated by the software and the radiation plots examined. The arrangement in Figure 4.22 is the one producing acceptable radiation patterns for the entire service band. The patterns are the free space patterns.

Maximum array gain at 88 MHz ------------------- 3.53 dB

Maximum array gain at 100 MHz ------------------ 3.08 dB

Maximum array gain at 108 MHz --------------- 3.03 dB

The antenna on top is at a distance of 1m from the two antennas below. Among the two below, one is displaced 1m away from the array axis.

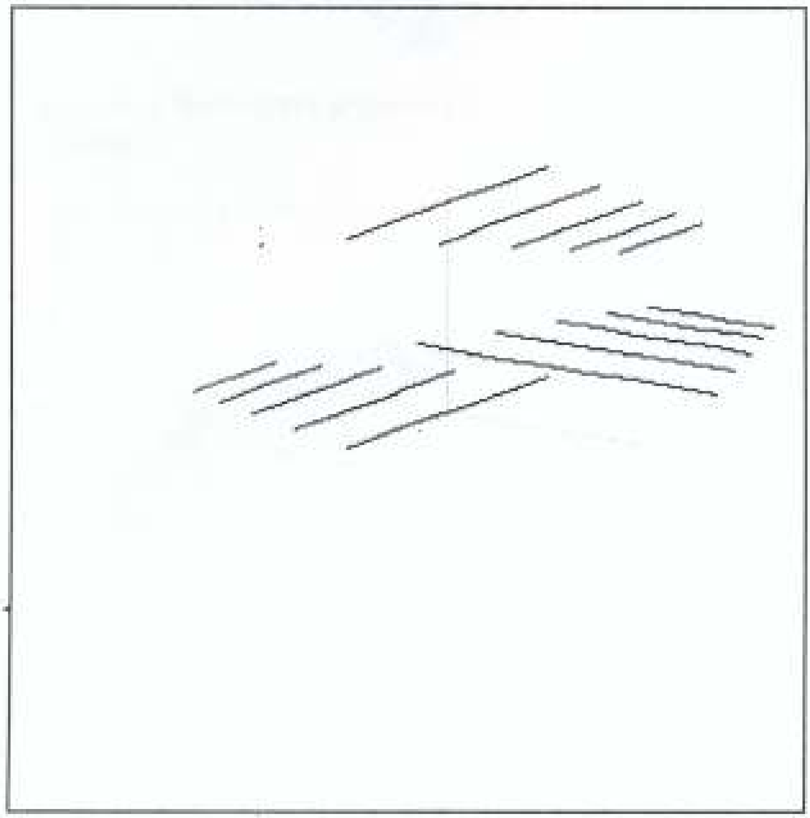


Figure 4.22 The LPDA Array Arrangement producing the plots of Figures 4.23 to 4.28

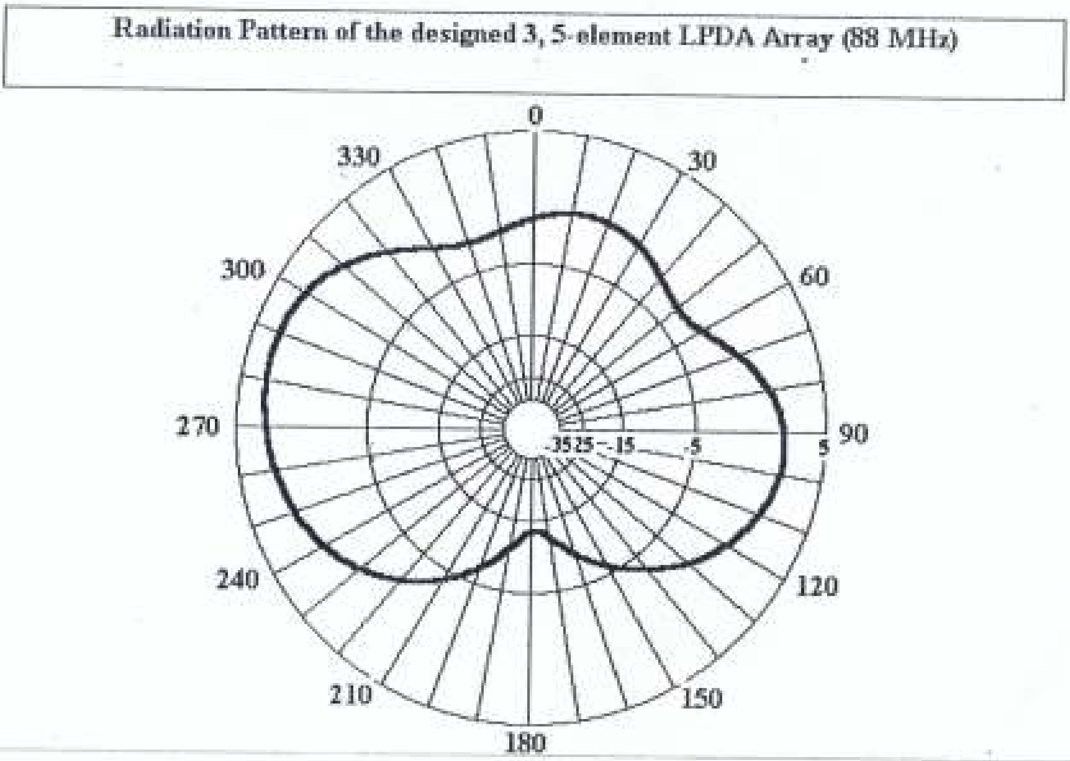


Figure 4.23 Simulated Radiation Pattern of the designed 3, 5-element LPDA Array at 88MHz

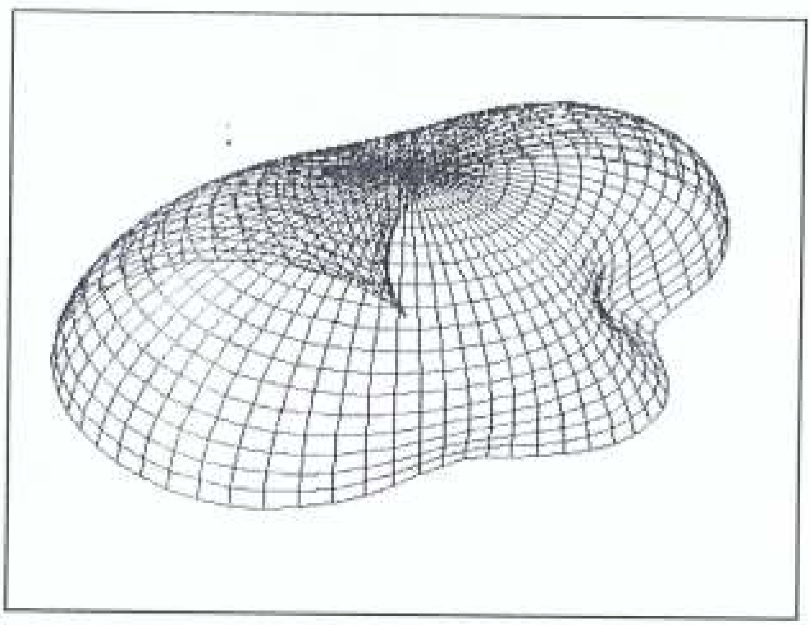


Figure 4.24 Simulated 3 – D Radiation Pattern of the Array at 88 MHz

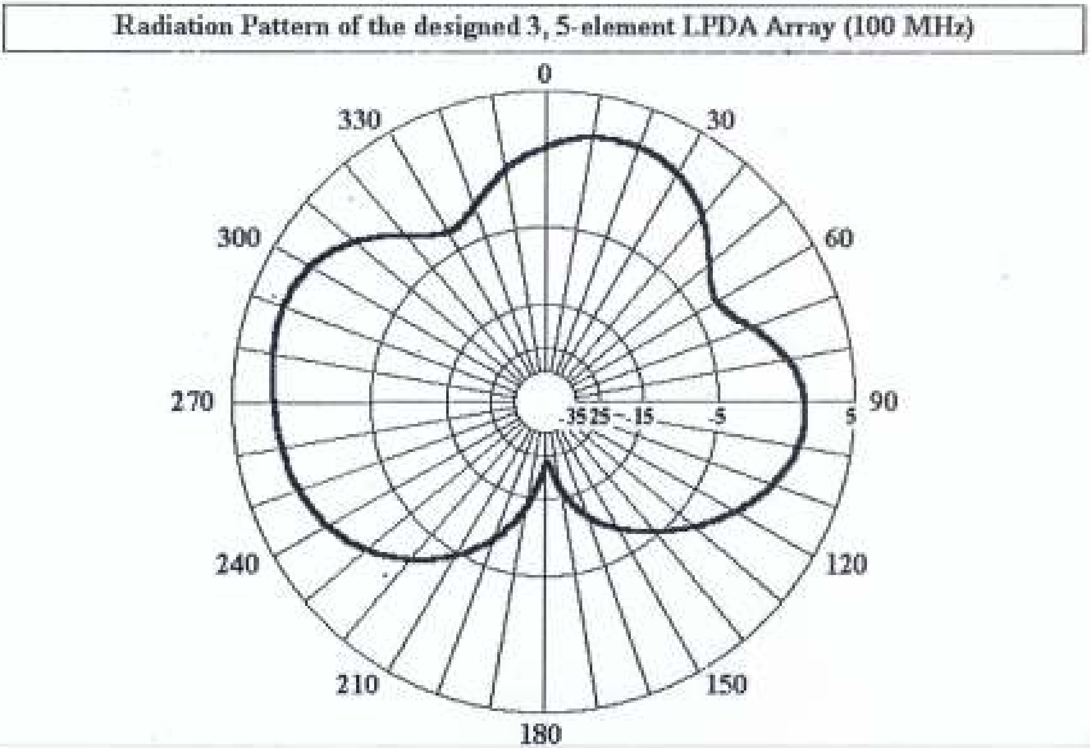


Figure 4.25 Simulated Radiation Pattern of the designed 3, 5-element LPDA Array at 100 MHz

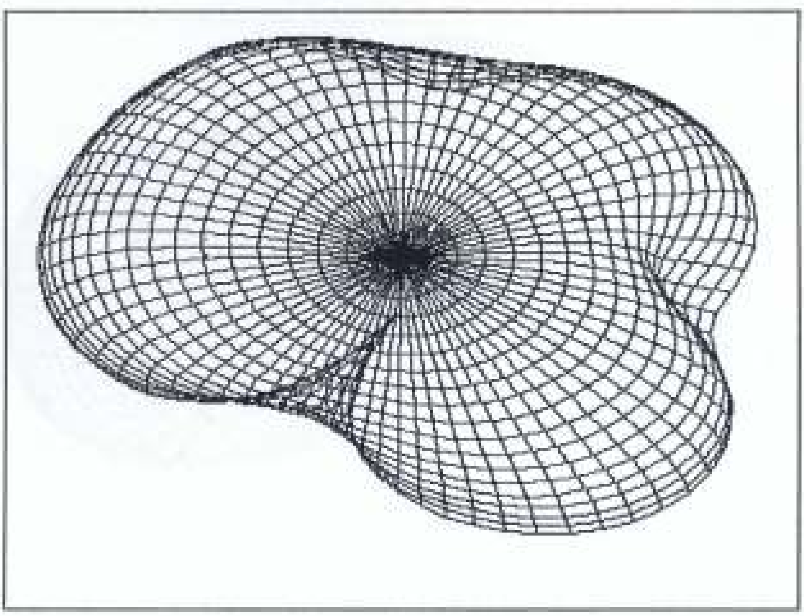


Figure 4.26 Simulated 3 – D Radiation Pattern of the Array at 100 MHz

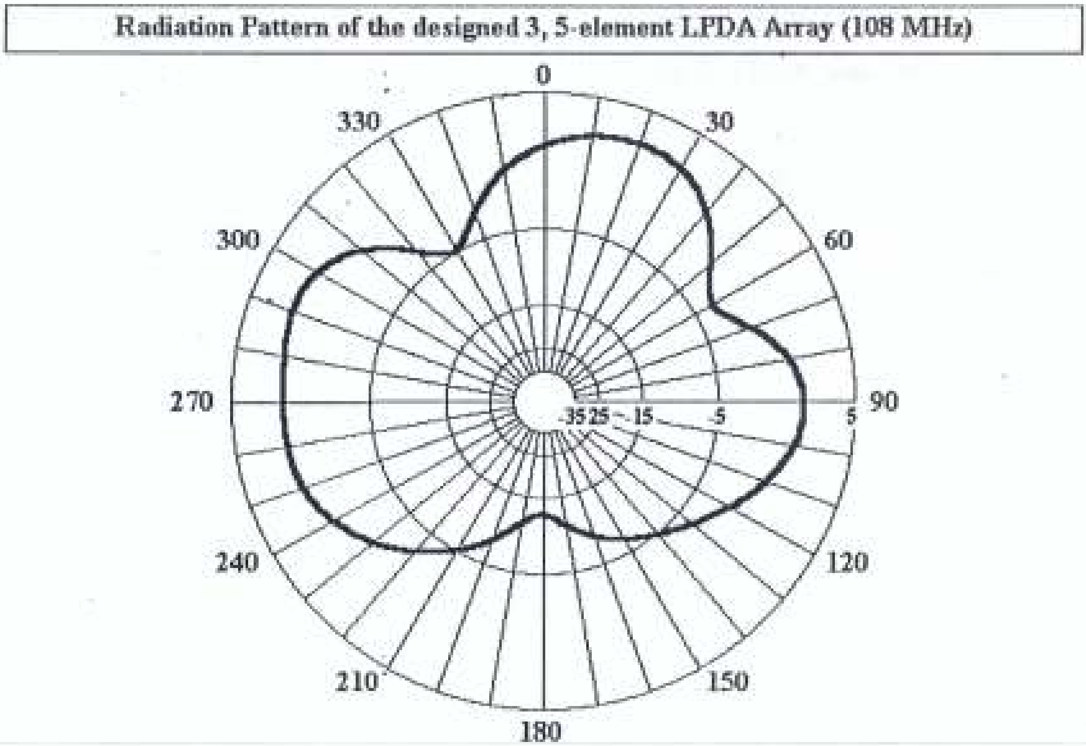


Figure 4.27 Simulated Radiation Pattern of the designed 3, 5-element LPDA Array at 108 MHz

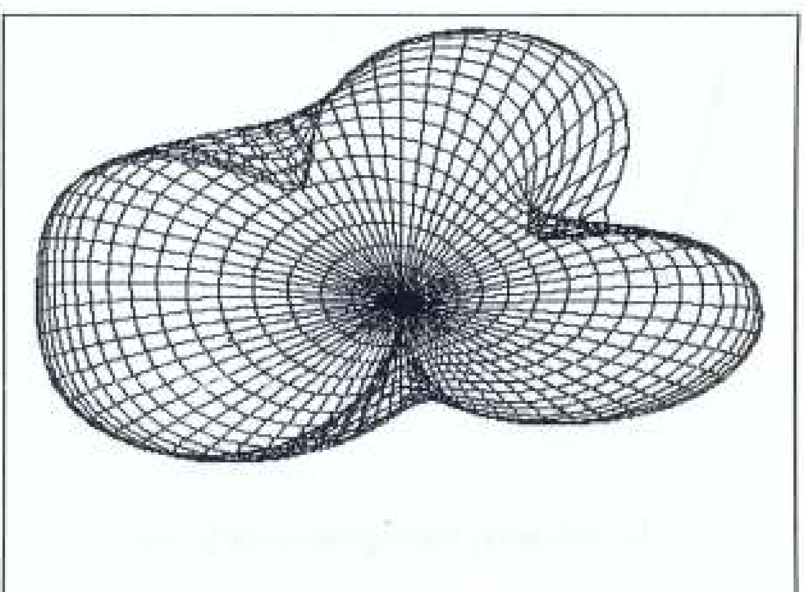


Figure 4.28 Simulated 3 – D Radiation Pattern of the Array at 108 MHz

4.2.5 THE PROPOSED ARRAY ARRANGEMENT AND ORIENTATION

From the software simulation result, the 3 LPDA antennas forming the array should be aligned in the West – East and South direction. One antenna pointing in the 120^0 direction with respect to the True North, another in the 210^0 direction and the third in the 300^0 direction with respect to the True North. All the antennas should be given equal and co-phased excitation. The proposed orientation is illustrated in Figure 4.29 & 4.30. Those pointing in the 120^0 & 210^0 direction placed at the same level, the 210^0 one (Antenna B) displaced 1m from the axis. The 300^0 one (Antenna C) placed 1m above the plane of A & B.

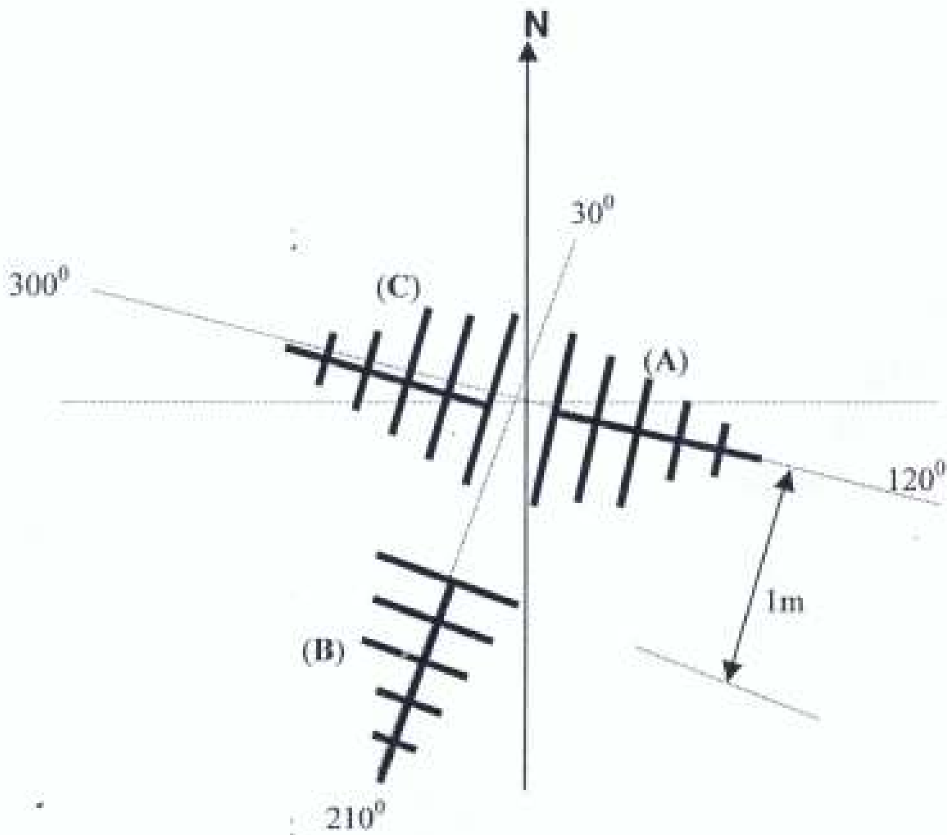


Figure 4.29 Proposed array arrangement (View from above)

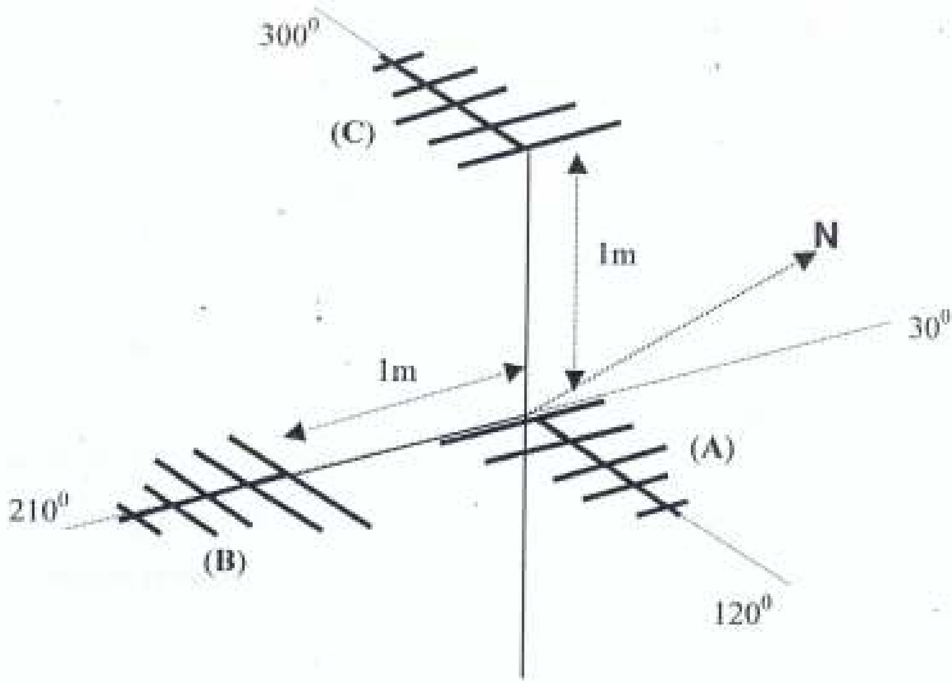


Figure 4.30 Proposed array arrangement (Oblique View)

4.2.6 SIMULATION WITH ANTENNA TOWER OVER REAL GROUND

The Radiation Patterns of the 3 LPDA Array simulated with 30 metres steel antenna tower over real ground (soil constants of ε_r = 15 & σ = 0.005 S/m) representative of the proposed transmitting location are shown in Appendix F.

4.3 CHOICE OF TRANSMISSION LINE AND TRANSMITTER POWER

Some important factors affecting the choice of transmission lines (as explained in Chapter Two) includes transmitter output power (TPO), line length, line loss at the operating frequency and antenna gain (and EIRP). Determination of the maximum power the line must carry is important.

Ordinarily, choice is for the smallest transmission line possible consistent with the required power handling capacity, but in a case where a very long transmission line is required, it may be more important to keep losses (and the long term operating cost) down than the initial investment.

Neglecting losses in the coupling accessories, for a given EIRP,

$$\text{Transmitter output power (TPO)} = \frac{\text{EIRP}}{\text{Antenna gain } (G_A) \times \text{Line loss } (L_t\text{, as a ratio})} \quad \text{--(4.1)}$$

$$= \frac{P}{G_A \times L_t} \quad \text{----------------------(4.2)}$$

= Line Input Power

$$\text{Also, TPO} = \frac{\text{Antenna Input Power}}{\text{Line loss } (L_t)}$$

$$\text{where Antenna Input Power} = \frac{\text{EIRP}}{\text{Antenna gain } (G_A)}$$

For a given maximum EIRP,

$$\text{Maximum TPO (max TPO)} = \frac{\text{EIRP}_{(max)}}{\text{Antenna gain} \times \text{Line loss}} \quad \text{-----(4.3)}$$

= Maximum Line Input Power

In operation, the line has to be derated for Voltage Standing Wave Ratio (VSWR). The line must be able to withstand the maximum TPO at the operating VSWR.

Derating for VSWR of 2 (often worst case in practice, modern transmitters often employ protection circuitry to reduce the output power automatically if the SWR rises to more than about 2: 1), therefore,

$$\text{Maximum Line Power Rating, } PLT_{(max)} \geq \frac{2 \times P}{G_A \times L_t} \quad \text{-------------------(4.4)}$$

The chosen line maximum power rating must be greater than the value for $PLT_{(max)}$ from the expression above.

$$\text{Maximum voltage on line (rms)} = \sqrt{\max TPO \times Z_o \times VSWR} \qquad \text{----------(4.5)}$$

where Z_o is the characteristic impedance of the line.

The chosen line maximum operating voltage (rms) must be at least greater than twice the value got from the above expression.

4.3.1 LINE LENGTH

Minimum length of transmission line required from the transmitter house to the antenna is 40 metres (30 metres of mast height and 10 metres distance from the sports complex building to the top of the ridge (Plate 3B)).

4.3.2 TRANSMISSION LINE AND POWER CALCULATIONS

Transmission line from the transmitter to the antenna chosen is coaxial type. This is due to:

- It is convenient and safer to use for the service (FM Radio Service) at the range of operating frequencies and at low radiation power. They are often used at VHF and UHF.
- The characteristic impedance, Z_o of most coaxial cables match the output impedance of most transmitters (50Ω - 100Ω) and that of some radiating elements.
- If properly matched to load, it does not radiate signals i.e. RF currents are confined within the cable by the outer screen.
- It can be installed with little or no regard for its surroundings.
- It requires no insulation, can be bent around corners with a reasonable radius. It can be taped to the legs of metal towers without problem.
- It provides certain amount of transient surge protection for the equipment to which it is attached. The outer conductor shields the center conductor from the transient field.

Since the computed radiated power for the community is low, therefore the flexible or semi flexible type is appropriate.

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- It can be installed with little or no regard for its surroundings.
- It requires no insulation, can be bent around corners with a reasonable radius. It can be taped to the legs of metal towers without problem.
- It provides certain amount of transient surge protection for the equipment to which it is attached. The outer conductor shields the center conductor from the transient field.

Since the computed radiated power for the community is low, therefore the flexible or semi flexible type is appropriate.

Some common flexible coaxial cables are: -

- RG-58 series, RG-59 series
- RG-11, RG-12 series
- RG-8, 9, 13, 213, 214, 215 series
- Belden- 9913 and
- RG-17 (RG-218), RG-18 series

RG-17, 18 series is semi flexible. The price of the cables increases in the order as they are listed above.

For the calculations, a minimum antenna gain of one (1) will be assumed for worst-case condition. All practical antenna systems have gain greater than one.

(1) For RG-58 ($Z_0 = 50\Omega$) series

From Figure 2.12

Attenuation at 100 MHz (dB/100 feet) = 5 dB.

" " " (dB/m) = 0.164 dB

Transmission line length = 40m

Loss in 40m of line length = 0.164 x 40

= 0.56 dB

i.e. $$10\log\frac{P_o}{P_i} = -0.56$$

Therefore, $$\frac{P_o}{P_i} = L_l = 0.22$$

From equation 4.1

$$\text{TPO} = \frac{\text{EIRP}}{\text{Antenna gain x Line loss}}$$

For $\text{EIRP}_{(max)}$ of 50W,

Maximum TPO = 50/(1 x 0.22)

= 227.3 W

= Maximum Line Input Power

Choosing VSWR of 2 for Line power derating

Therefore, maximum line power rating (derated) for worst case VSWR = 2 x 227.3

= 454.5 W

From equation 4.5

Maximum line voltage (rms) $= \sqrt{227.3 \times 50 \times 2}$

= 150V rms

This will call for a 250W transmitter and line of maximum operating voltage ≥ 300V rms

(2) For RG-59 series (Z_o = 75 Ω)

Attenuation at 100 MHz (dB/100 feet)	= 3.8 dB
" " " (dB/m)	= 0.1246 dB
Loss in 40m of line length	= 4.99 dB
L_t = 0.317	
For EIRP $_{(max)}$ of 50W,	
Maximum TPO	= 50/(1 x 0.317)
	=157.6 W
Maximum Line Power Rating (derated)	= 2 x 157.6
	= 315 W
Maximum Line Voltage (rms)	$= \sqrt{157.6 \times 75 \times 2}$
	= 153.75V rms

This will call for a 150W transmitter, 75 Ω output impedance and line of maximum operating voltage ≥ 300V rms

(3) For RG-11, RG-12 series (Z_o = 75 Ω)

Attenuation at 100 MHz (dB/100 feet)	= 2.5 dB
" " " (dB/m)	= 0.082 dB
Loss in 40m of line length	= 3.28 dB
L_t	= 0.47
For EIRP $_{(max)}$ of 50W,	
Maximum TPO	= 50/(1 x 0.47)
	=106.4 W

Maximum Line Power Rating (derated) = 2 x 106.4

= 212.76 W

Maximum Line Voltage (rms) = $\sqrt{106.4 \times 75 \times 2}$

= 126.3 V rms

This will call for a 100W transmitter, 75 Ω output impedance and line of maximum operating voltage ≥ 250V rms

(4) For RG-8, RG-9, RG-213, 214, 215 series (Z_o = 50 Ω)

Attenuation at 100 MHz (dB/100 feet) = 2.5 dB

Therefore, maximum TPO is the same as for RG-11.

Maximum Line Power Rating (derated) = 212.76W

Maximum Line Voltage (rms) = $\sqrt{106.4 \times 50 \times 2}$

= 103.2V rms

This will call for a 100W transmitter, 50 Ω output impedance and line of maximum operating voltage ≥ 200V rms (For RG-213, maximum operating voltage = 3700V).

(5) For Belden 9913 Type (Z_o = 50 Ω)

Attenuation at 100 MHz (dB/100 feet) = 1.4 dB

" " " (dB/m) = 0.0459 dB

Loss in 40m of line length = 1.8368 dB

L_t = 0.655

For EIRP $_{(max)}$ of 50W,

Maximum TPO = 50/(1 x 0.655)

=76.3 W

Maximum Line Power Rating (derated) = 2 x 76.3

= 152.6 W

Maximum Line Voltage (rms) = $\sqrt{76.3 \times 50 \times 2}$

= 87.35 V rms

This will call for a 75W transmitter, 50 Ω output impedance and line of maximum operating voltage ≥ 200V rms

(6) For RG-218 (RG-17), RG-18 series ($Z_o = 52\ \Omega$)

Attenuation at 100 MHz (dB/100 feet)	= 1 dB
" " " (dB/m)	= 0.0328 dB
Loss in 40m of line length	= 1.312 dB
L_4	= 0.74

For EIRP $_{(max)}$ of 50W,

Maximum TPO	= 50/(1 x 0.74)
	= 67.57 W
Maximum Line Power Rating (derated)	= 2 x 67.57
	= 135 W
Maximum Line Voltage (rms)	$= \sqrt{67.57 \times 52 \times 2}$
	= 83.8 V rms

This will call for a 70W transmitter, 50 Ω output impedance and line of maximum operating voltage $\geq$ 150V rms.

Economic Consideration

From the above calculations for the coaxial cables treated, two transmission lines are of interest because of flexibility, weight, performance and cost. They are RG-213 and RG-218 (or RG-17). For minimum loss in the transmission line, RG-218 (RG-17) is the best choice but RG-218 is more expensive than RG-213. RG-213 is flexible, outer diameter of 1 cm but RG-218 is semi flexible, outer diameter of 2.2 cm.

Because of cost of transmitters and transmission lines, transmitter of lower power to the ones calculated for the cables will be chosen since: -

(i) Minimum antenna gain of 1 was used in the calculation (rare in practice). Most practical antennas have gain more than unity e.g. a dipole in free space has a gain of 1.64.

(ii) The radiated power to the community must not be lower than the computed minimum radiated power of 15 W and should not also be more than maximum radiated power of 50 W. It is not compulsory that the operating radiated power should be up to 50 W.

Therefore for the above reasons, a transmitter of 60W is recommended for operation into RG-213 transmission line or a 40W transmitter into RG-218 (RG-17) cable. The two cables have maximum operating voltage rating much greater than the calculated (VSWR derated) maximum line voltage rating. The transmitters should be fully VSWR protected against load faults or mismatch.

For RG-213 and transmitter power of 60W, 50Ω output impedance,

$$\text{EIRP}_{(max)} = \text{max. TPO} \times L_t \times G_A \qquad \text{-----------(4.6)}$$

$$= 60 \times 0.47 \times G_A$$

$$= 28.2G_A \text{ (W)}$$

$$= 28.2\text{W (for antenna gain of 1)}$$

$$= 46\text{W (for a dipole).}$$

Actual maximum EIRP depends on the antenna gain. The transmitter output power (TPO) in operation is adjusted down (or up) to the level that will give (depending on the antenna gain) the desired operating EIRP at any time as need arises.

For the designed LPDA array simulated, free space gain = 3.03 dB (2)

Therefore, $\text{EIRP}_{(max)} = 56.4\text{W}$.

For RG-218 (RG-17) and transmitter power of 40W, 50Ω output impedance,

$$\text{EIRP}_{(max)} = \text{max. TPO} \times L_t \times G_A$$

$$= 40 \times 0.74 \times G_A$$

$$= 29.6G_A \text{ (W)}$$

$$= 29.6\text{W (for antenna gain of 1)}$$

$$= 48.2\text{W (for a dipole).}$$

For the designed LPDA array simulated, $\text{EIRP}_{max} = 59.2\text{W}$.

The transmitter output power (TPO) in operation is adjusted down (or up) to the level that will give the desired operating EIRP at any time as need arises.

Transmitter Specification: -

(1) FM Stereo transmitter of 60W, 50 Ω output impedance, fully VSWR protected and continuously (or digitally) tunable over the entire VHF II band (87.5MHz

– 108 MHz) for operation with RG-213 coaxial cable for transmission. The transmitter output power range should be user selectable.

OR

(2) FM Stereo transmitter of 40W, 50 Ω output impedance, fully VSWR protected and continuously (or digitally) tunable over the entire VHF II band (87.5MHz – 108 MHz) for operation with RG-218 (RG-17) coaxial cable for transmission. The transmitter output power range should be user selectable.

The final choice for implementation will depend on the prevailing time-market price of the combinations and availability.

4.4 FREQUENCY RECOMMENDATION

This exercise is to recommend some frequencies on which the proposed station could operate. The exercise is not to pre-empt the work of the licensing authority since final specification of operating frequency at any time depend solely on the licensing authority in the country (NBC).

Major constraints on the frequencies that could be chosen for a broadcasting station are set by the level of interference from other stations transmitting in the same channel or an adjacent channel. Also, attention is required to be given to other various situations of interference which has to do with electromagnetic compatibility (EMC). They include:

- Reception of the local oscillator output or its harmonics radiated by nearby receivers.
- Interference from broadcasting stations operating at the image frequencies of the broadcasting receiver.
- Powerful signals of broadcasting stations, though remote from the tuning point of the receiver but which generate harmonics or intermodulation products in the receiver input stages thereby causing interference with the wanted signal.

Operating frequencies was recommended after due consideration to signal strength measurement result (Table 3.3); FM standards and regulations by the regulatory bodies; current frequency allocation of neighbouring FM stations; co-channel interference (CCI);

adjacent channel interference (ACI); image channel interference (ICI) and local oscillator interference (LOI).

VHF band II starts from 87.5MHz to 108MHz (Table 2.2). Channel bandwidth is 150KHz with 25KHz guard band on either side of each channel.

Local Oscillator Frequency = Carrier Frequency + Intermediate Frequency (IF) where IF (for FM sound broadcast) = 10.7MHz.

Table 4.14 shows the carrier frequencies of some neighbouring stations, adjacent channel's frequencies, local oscillator frequencies and image frequencies.

Table 4.14: - Neighbouring Stations Channel, Adjacent, Local Oscillator and Image Frequencies.

Neighbouring Stations Channel frequencies	Adjacent Channels		Local Oscillator frequencies (MHz)	Channels adjacent to Local Oscillator frequency		Image frequencies
	Immediate Lower (MHz)	Immediate Upper (MHz)		Lower MHz)	Upper (MHz)	
90.5	90.3	90.7	101.4	101.3	101.5	*111.9
91.5	91.3	91.7	102.2	102.1	102.3	*112.9
92.3	92.1	92.5	103	102.9	103.1	*113.7
95.7	95.5	95.7	106.4	106.3	106.5	*117.1
96.5	96.3	96.7	107.2	107.5	107.7	*117.9
102.5	102.3	102.7	*113.2	*113.5	*113.7	*123.9
#108.5	108.3	108.7	*119.2	*119.1	*119.3	*129.9

* ---- Frequency out of VHF II band. # ---- Not an FM Radio Station.

Result of the signal strength measurement of neighbouring FM stations (Table 3.3) showed that at present, there is no spectrum congestion within the locality, therefore, no need for co-channel and adjacent channel operation with any of the existing and functioning neighbouring stations. Hence no need for protection ratio consideration.

Recommended range of operating frequencies (MHz) are:-

88.3 – 90.1,

92.9 – 93.9,

97.5 – 101.5, and

103.5 – 105.5.

Each channel carrier frequency separation is 0.2MHz.

*** Final operating frequency recommendation is by NBC.**

4.5 ANTENNA SUPPORT

Major contribution in the selection of a support for an antenna is that of structural safety. Some localities have building regulations that require a permit to be obtained in advance of erection of certain structures including antenna poles or towers. Such regulations at times govern the method and materials used in construction of those structures.

Since the service is for FUTA community (a separate local community though part of the main city of Akure), the municipal building regulations on antenna tower installations may not necessarily apply within. Nevertheless, care should be taken to select a type of support that will contribute as much safety as possible to the installation, occupy less space and of minimal cost. If collapse occurs, chances of injury or property damage should be minimised by careful choice of design and erection methods.

4.5.1 THE ANTENNA TOWER (MAST)

Most common variety of tower is the guyed tower made of stacked identical sections. Guy wires restrain the tower against the force of the wind. They translate the lateral force of the wind into a downward compression that forces the tower down onto the base. If there are not enough guys or if they are not properly spaced, a heavy gust of wind may over stress the structure causing the tower to buckle at a weak point. There should be equal angular spacing between the guy wires.

Some towers are not guyed; they are usually referred to as freestanding or self-supporting towers. The wind blowing against the side of the tower creates an overturning movement that would topple the tower if it were not for the anchoring at the base. Figure 4.31 shows the forces involved.

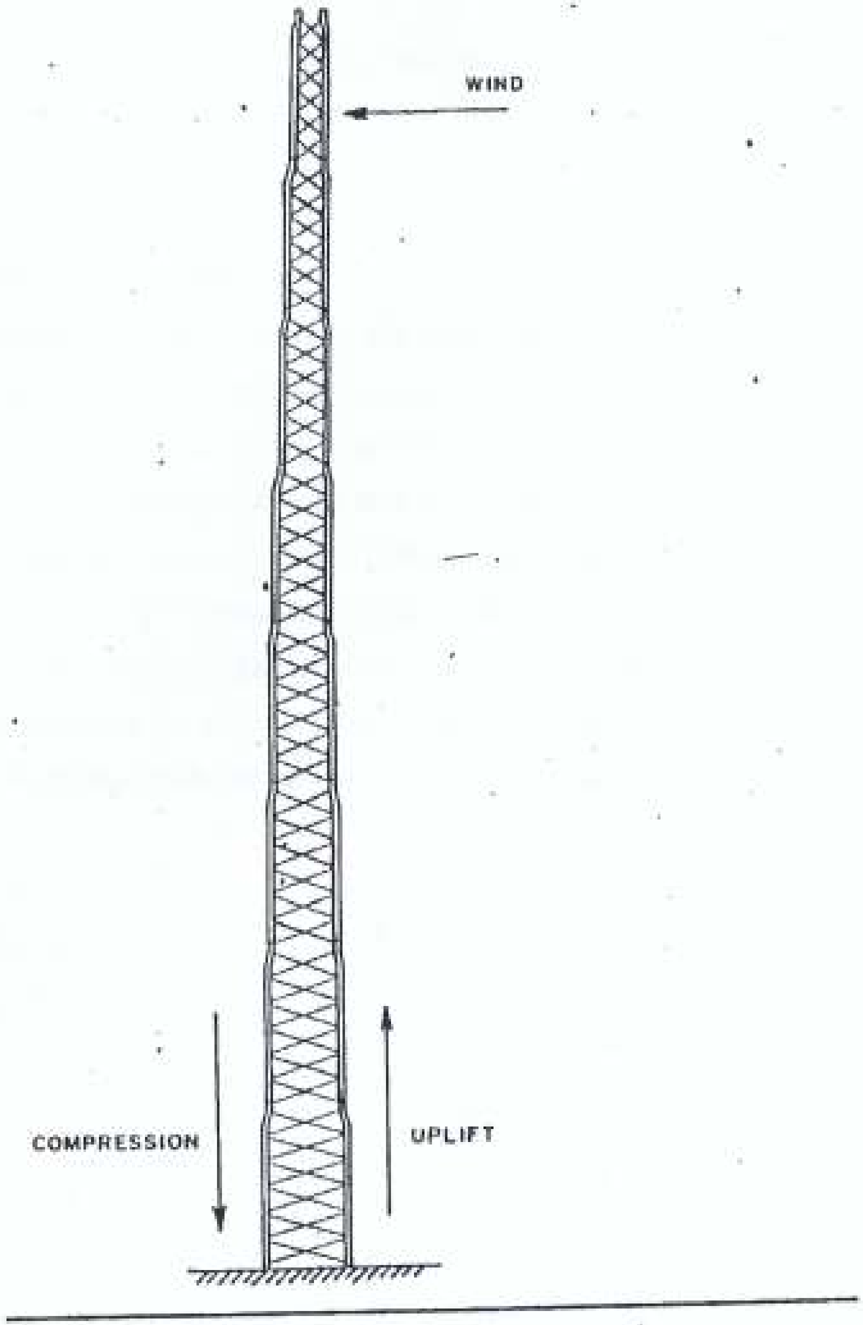

Figure 4.31 Typical free-standing (unguyed) tower. Arrows indicate the directions of the forces acting upon the structure.

As the wind blows against one side of the tower, the opposite side is compressed downward as in the guyed installation. But because there are no guys to restrain the top, the side on which the wind is blowing is simultaneously pulled up (uplift). The force of the wind creates a moment that tends to pivot about a point at the base of the tower. The base of guyed towers holds the tower up but the base of the freestanding tower must simultaneously hold one side of the tower up and the other side down. Therefore for this reason, a great deal of more concrete is required in the base of freestanding towers than in the base of guyed towers.

4.5.2 RECOMMENDED TOWER

For the community service in concern, the freestanding tower is recommended because it occupies less space and erection easier than that of guyed tower. Also, for the height recommended (30m) the cost per metre investment is comparable to that of guyed tower. The tower must be strong enough to be able to support the weight of the antenna, its own weight and withstand wind i.e. its wind-load capability must be able to withstand the local prevailing wind. The freestanding tower will (often) be made of stacked identical sections and each section bolted atop the next lower section. The height of the tower will be the sum of the height of the sections. An example of a freestanding tower is shown in Plate 4C. Suggested base dimension of the tower (post to post) is shown in Figure 4.32.

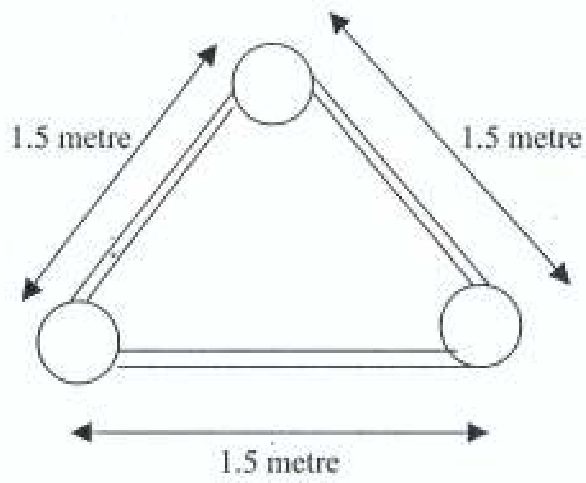

Figure 4.32 Dimension of the recommended freestanding tower.

PLATE 4C   A FREE STANDING TOWER

CHAPTER FIVE

STATION SET UP

5.1 BASIC ITEMS AND OPERATIONS FOR STATION SET UP

The following are some suggested items and operations needed carrying out for the station set up.

5.1.1 Studio

- Audio Mixer (8 - channels minimum)
- Microphones
- Microphone hanger & stand.
- Sound players and recorders e.g. sound decks, players, cassette, CD players etc.
- FM Radio (Monitor).
- Electric Standing (or Table) Fan.
- Miscellaneous e.g. Studio Development, Chairs, tables, Studio Transmitting Equipment Installation, etc.

5.1.2 RF Transmission

- FM Stereo Transmitter (60W, 50 ohms output impedance, tunable between 87.5 MHz and 108 MHz, fully VSWR protected and output power range user selectable) for operation into RG 213 (or RG 8) coaxial cable (40 metres) for transmission.

OR

- FM Stereo Transmitter (40W, 50 ohms output impedance, tunable between 87.5 MHz and 108 MHz, fully VSWR protected and output power range user selectable) for operation into RG 218 (or RG 17) coaxial cable (40 metres) for transmission.
- FM Stereo Limiter/Compressor (if not in the Transmitter).
- RG 213 or RG 218 coaxial cable (minimum of 40 metres) for transmission.
- Cable end - connectors and sockets.

- VHF/UHF Transmission line Lightning Surge Protector.
- DC Power Supply Unit (13.8V , 7A) (optional if not part of the Transmitter).
- AC Voltage Regulator (2 KVA minimum).
- AC Generator (2 KVA)
- Miscellaneous

5.1.3 Antenna and Support

- Mast construction (Free-standing Tower, 30 metres length).
- Mast erection
- Lightning Arrester Installation.
- Mast Lighting Installation.
- Antenna Construction (suggested type, array of 3, 5 – element Log Periodic Dipole Antenna, Figure 4.18 and Section 4.2.2).
- Antenna mounting accessories and Installation
- RF (VHF) 1 to 3 – way low power splitter.
- 3, 50Ω 2 : 1 balun
- Miscellaneous.

5.1.4 FM Limiter/Compressor: -

This is needed in order to avoid over modulation of the FM transmitter when broadcasting live speech. Pre-recorded music may not cause over modulation since it is often roughly at the same loudness level, but live speech can cause both over modulation and under modulation. This is because live speech can vary by up to twenty times in level. The FM Limiter/Compressor acts as an automatic volume control and will make sure the transmitted sound is as loud as it can be but not over modulated. Over modulation causes 'splatter' at either side of the FM carrier, which may cause interference to other radio stations.

5.1.5 Audio Mixer: -

This serves these purposes:

- From varieties of sound sources both pre-recorded and live, it allows selection of the one to be broadcast or combination (mixing) of many sources together for simultaneous broadcast.
- Some facilitates 'effects' on the enabled or combined audio signals.

5.1.6 FM Radio Monitor: -This is an ordinary FM radio receiver in the transmitter house to monitor what is being received by other receivers.

5.1.7 AC Generator :- This is to supply electricity to the station in the event of failure of public power supply.

Block diagram of the station's proposed set up is illustrated in Figure 5.1

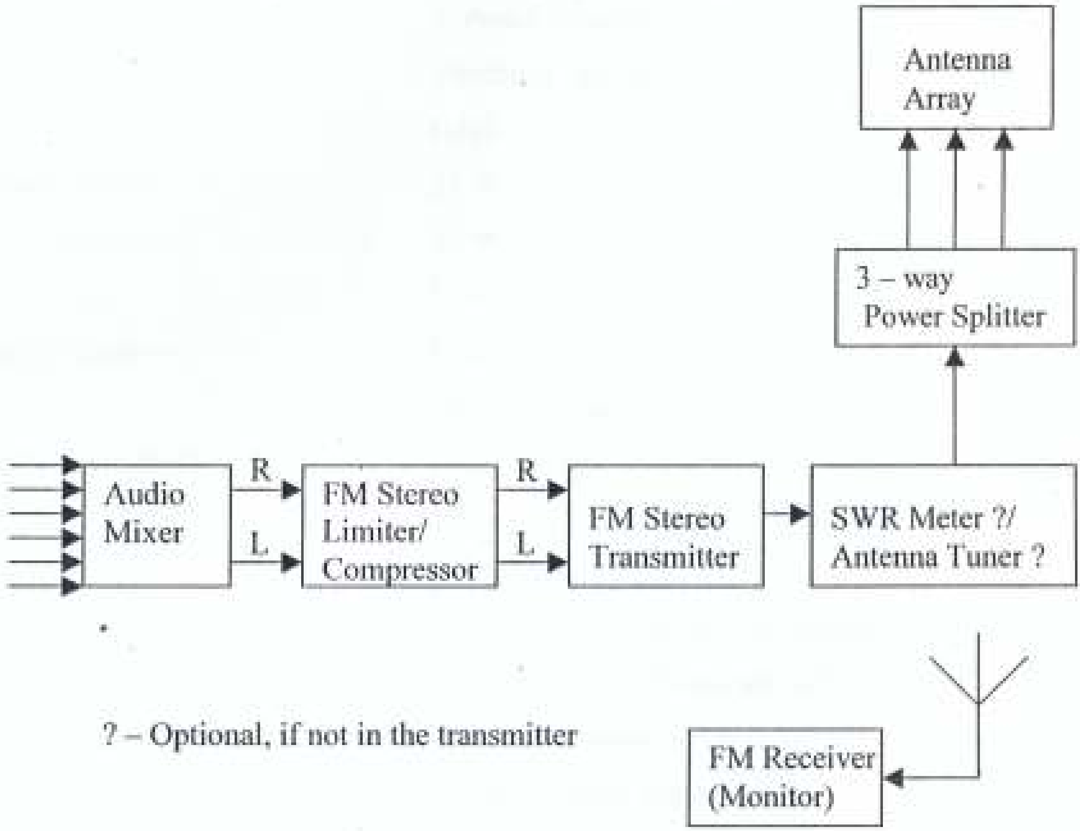

Figure 5.1 Proposed Station's Set Up

CHAPTER SIX

6.1 CONCLUSION

The FM Radio Service planning work for FUTA community was done with a main goal of ensuring adequate reception of radio signals within the community and achieving this by making efficient and economic use of resources. If the parameters specified were followed during implementation in the future, satisfactory results would be obtained.

The parameters recommended for FUTA community are compiled in Table 6.1. Some recommendations (EIRP and operating frequencies) are liable to changes with time and development within the community.

Table 6.1: Transmitting Parameters For FUTA Community

Transmitting site:	Obanla Sports Complex
Antenna location & height:	Antenna mounted on top of 30 m steel mast (free-standing) erected on the Obanla Sports Complex ridge.
Minimum EIRP:	15 W
Maximum EIRP:	50 W
Polarisation:	Horizontal
Radiation pattern:	Cardioid with normalised –3 dB reduction opposite that of the main null.
Transmission mode:	Stereophonic, pilot – tone system, 50 μs pre-emphasis and +/- 75 KHz maximum frequency deviation.
Suggested Antenna type:	Array of 3, 5-element Log Periodic Dipole Antenna made of T6061 Aluminum Alloy.
Antenna orientation:	The 3 antennas aligned in west-east and south direction. One orientated in 120^0 direction with respect to the True North, another in 210^0 direction displaced 1m away from the central axis and the third in 300^0 direction with respect to the True

	North placed 1m above the plane of the first two antennas. Array placed on 0.5m insulating support on the mast.
Individual antenna gain:	5.3 dB to 6.9 dB over the VHF II band (horizontal).
Antenna array gain:	3.03 dB to 3.53 dB over the VHF II band (horizontal).
Antenna excitation:	Equal amplitude and co-phased.
Operating frequencies (MHz):	88.3 – 90.1, 92.9 – 93.9, 97.5 – 101.5, and 103.5 – 105.5. Each channel carrier frequency separation is 0.2MHz.

6.2 SUGGESTION FOR FUTURE WORK

A team could later be formed to realize the project following the specified parameters in the report and integrate it into FUTA Communication Network.

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APPENDIX A

LPDA DESIGN EQUATIONS AND PROCEDURE

1. The operating bandwidth, B between the lowest frequency, f_L and the highest frequency, f_H.

$$B = \frac{f_h(MHz)}{f_l(MHz)} \quad \text{-------(A1)}$$

2. Choose ι and σ to give the desired directivity (or gain) (Figure 2.20)

$$0.8 \le \tau \le 0.98 \quad \text{-------(A2)}$$

$$0.05 \le \sigma \le \sigma_{opt} \quad \text{-------(A3)}$$

$$\sigma_{opt} = 0.243\tau - 0.051 \quad \text{-------(A4)}$$

3. Determine the value of cotangent of the apex half angle α

$$\cot\alpha = \frac{4\alpha}{1-\tau} \quad \text{-------(A5)}$$

4. Determine the active region bandwidth, B_{ar}

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot\alpha \quad \text{-------(A6)}$$

5. Determine the structure (array) bandwidth, B_s

$$B_s = B \times B_{ar} \quad \text{-------(A7)}$$

6. Determine the longest free space wavelength, λ_{max}

$$\lambda_{max}(metres) = \frac{300}{f_L(MHz)} \quad \text{-------(A8)}$$

7. Determine the longest element length, l_l

$$l_1(m) = \frac{\lambda_{max}}{2} \quad \text{-------(A9)}$$

8. Determine the boom length, L

$$L = \frac{\lambda_{max}}{4}\left(1 - \frac{1}{B_s}\right)\cot\alpha \quad \text{-------(A10)}$$

9. Determine the number of elements, N

$$N = 1 + \frac{\log_e B_s}{\log_e \frac{1}{\tau}} \quad \text{-------(A11)}$$

Usually, calculated value for N will not be an integral number of elements. If the fractional value is more than about 0.3, the next higher integer value should be taken for N. (Actual value of L will also increase). Examine L and N to determine whether or not the array size is acceptable. If the array is too large, decrease σ or ι and repeat steps 2 through 9. (Decreasing σ will decrease the boom length. Decreasing ι will decrease both the boom length and the number of elements).

10. Determine the terminating stub, Z_t (if included). For VHF and UHF arrays,

$$Z_t = \frac{\lambda_{max}}{8} \qquad \text{------(A12)}$$

11. Solve for the remaining element lengths,

$$l_2 = \tau l_1$$
$$l_3 = \tau l_2$$
$$= \tau^2 l_1$$
$$l_n = \tau l_{(n-1)} \qquad \text{------(A13)}$$

12. Determine the element spacing d_{12} from

$$d_{12} = \frac{1}{2}(l_1 - l_2)\cot\alpha \qquad \text{------(A14)}$$

and the remaining element spacings

$$d_{23} = \tau d_{12} \qquad \text{------(A15)}$$
$$d_{34} = \tau d_{23}$$

13. Choose R_o, the desired feed-point resistance, to give the lowest SWR for the intended balun ratio (matching) and feed-line impedance. Determine the necessary antenna feeder impedance, Z_o

$$Z_o = \frac{R_o^{\,2}}{8\sigma' Z_{av}} + R_o\sqrt{\left(\frac{R_o}{8\sigma' Z_{av}}\right)^2 + 1} \qquad \text{------(A16)}$$

where,

Z_{av} = average characteristic impedance of a dipole

$$= 120\left[\log_e\left(\frac{l_n}{d_{nnn}}\right) - 2.25\right] \qquad \text{------(A17)}$$

$\frac{l_n}{d_{nmm}}$ = length to diameter ratio of *nth* element.

σ' = mean spacing factor

$$= \frac{\sigma}{\sqrt{\tau}} \qquad \text{---(A18)}$$

14. Select a combination of conductor size and spacing that will provide Z_o from

$$S = \frac{diam}{2} \times 10^{\frac{Z_o}{276}} \qquad \text{---(A19)}$$

where,

S = center-to-centre distance between conductors

diam = outer diameter of conductor (in same units as S)

Z_o = intended characteristic impedance for antenna feeder (ie the transmission line interconnecting the dipole elements). The equation assumes round feeder conductors.

If an impractical spacing results for the antenna feeder, select a different conductor diameter and repeat step 13. The LPDA design is complete once a satisfactory feeder arrangement is found.

APPENDIX B

The QBASIC Program For The LPDA Design

```
5 CLS
10 PRINT
15 PRINT " PROGRAM FOR THE DESIGN OF LOG PERIODIC DIPOLE ANTENNA
(DIMENSIONS COMPUTATION)"
20 PRINT "------------------------------------------------------------------------
-------------------"
25 PRINT
30 PRINT "(1) DECIDE ON AN OPERATING BANDWIDTH, B BETWEEN FL, LOWEST
FREQUENCY AND FH,"
31 PRINT "    HIGHEST FREQUENCY."
35 PRINT "(2) CHOOSE DESIGN CONSTANT, T AND RELATIVE SPACING CONSTANT,
M TO GIVE THE"
36 PRINT "    DESIRED GAIN (OR DIRECTIVITY)"
40 PRINT "               0.8 <= T <= 0.98 AND"
45 PRINT "              0.05 <= M <= M(OPTIMUM)"
50 PRINT
55 INPUT "CHOOSE DESIGN CONSTANT, T ?", T
60 PRINT
65 MT = .243 * T - .051
70 PRINT "M(OPTIMUM) =", MT
75 PRINT
80 INPUT "ENTER RELATIVE SPACING CONSTANT, M", M
85 PRINT
90 INPUT "ENTER THE LOWEST FREQUENCY (IN MHz)", FL
95 PRINT
100 INPUT "ENTER THE HIGHEST FREQUENCY (IN MHz)", FH
105 PRINT
110 B = FH / FL
115 C = (4 * M) / (1 - T)
120 BA = 1.1 + (7.7 * C * (1 - T) ^ 2)
125 BS = B * BA
130 W = 300 / FL
135 L = ((W * C) / 4) * (1 - (1 / BS))
140 NI = 1 + (LOG(BS) / LOG(1 / T))
145 L1 = W / 2
150 PRINT "COMPUTED BOOM LENGTH, L =", L, "metres"
155 PRINT
160 PRINT "COMPUTED MINIMUM NUMBER OF ELEMENTS, NI =", NI
165 PRINT
170 PRINT "CHOOSE THE NUMBER OF ELEMENTS N; (IF THE FRACTIONAL VALUE OF
THE"
175 PRINT "COMPUTED NUMBER IS MORE THAN ABOUT 0.3, INCREASE THE CHOSEN
VALUE"
180 INPUT "TO THE NEAREST HIGHER INTEGER)", N
185 PRINT
190 PRINT "FIRST ELEMENT LENGTH, L 1 =", L1; "metres"
195 PRINT
200 FOR I = 2 TO N
205 L(I) = L1 * T ^ (I - 1)
210 PRINT "L"; I; "="; L(I); "metres"
215 NEXT I
220 PRINT
225 LET ZT = W / 8
```

```
230 PRINT "TERMINATING STUB, St DISTANCE (If used) ="; ZT; "metres"
235 PRINT
240 D1 = .5 * C * (L1 - L(2))
245 PRINT "FIRST ELEMENT SPACING, D 1 ="; D1; "metres"
250 PRINT
255 FOR I = 2 TO (N - 1)
260 D(I) = D1 * T ^ (I - 1)
265 PRINT "D"; I; "="; D(I); "metres"
270 NEXT I
275 PRINT
280 INPUT "ENTER DIAMETER OF THE LAST ELEMENT (SHORTEST) IN mm", DN
285 LET LDN = 1000 * (L(N) / DN)
290 ZAV = 120 * (LOG(LDN) - 2.25)
295 MM = M / T ^ .5
300 PRINT "ELEMENT DIAMETERS"
305 PRINT
310 LD1 = 1000 * (L1 / LDN)
315 PRINT "Diam 1 ="; LD1; "mm"
320 FOR I = 2 TO N
325 DIA(I) = 1000 * (L(I) / LDN)
330 PRINT "Diam"; I; "="; DIA(I); "mm"
335 NEXT I
340 PRINT
345 INPUT "CHOOSE R,(DESIRED FEED POINT RESISTANCE (IN OHMS))", R
350 ZO = (R ^ 2 / (8 * MM * ZAV)) + R * ((R / (8 * MM * ZAV)) ^ 2 + 1)
^ .5
355 PRINT
360 PRINT "TRANSMISSION LINE XTERISTIC IMPEDANCE, ZO (OHMS) =", ZO;
"Ohms"
365 SD = .5 * 10 ^ (ZO / 276)
370 PRINT
375 PRINT "TRANSMISSION LINE CENTRE-TO-CENTRE TO DIAMETER RATIO, (S/D)
=", SD
380 PRINT
385 IF SD > 1 THEN GOTO 400
390 PRINT "IMPRACTICABLE SPACING, CHOOSE ANOTHER R"
395 GOTO 340
400 INPUT "ENTER THE BOOM OR THE TRANSMISSION LINE CONDUCTOR DIAMETER
IN cm"; DB
405 CS = DB * SD
410 PRINT
415 PRINT "BOOM OR TRANSMISSION LINE CONDUCTOR SPACING ="; CS; "cm"
420 END
```

APPENDIX C

ALUMINUM

Aluminum is a malleable, ductile metal with a density of 2.7 g/cm3. It can be polished to a high brightness and retain the polish in dry air. The metal forms an oxide coating (Al_2O_3) in the presence of moisture that protects it from further corrosion. If connected to another dissimilar metal, the point of connection should be given protective coating to protect against galvanic corrosion.

Aluminum is non-toxic, can be drilled and sawed easily. Lightweight and high conductivity make aluminum ideal for antenna applications. A four-digit system is used to identify aluminum alloys, such as 6061. Type 6061 has good resistance to corrosion and has medium strength. Table C1 gives the characteristics of some common aluminum alloys.

Table C1: Characteristics of some common Aluminum Alloys.

Common Alloy Numbers	
Type	Characteristics
2024	Good formability, high strength.
5052	Excellent surface finish, excellent corrosion resistance, normally not heat treatable for high strength.
6061	Good machinability, good weldability, can be brittle at high tempers.
7075	Good formability, high strength.

Common Tempers	
Type	Characteristics
T0	Special soft condition.
T3	Hard.
T6	Very hard, possibly brittle
TXXX	Three digit tempers – usually specialized high strength heat treatments, similar to T6

General uses	
Type	Uses
2024 – T3	Chassis boxes, antennas, anything bent or flexed repeatedly
7075 – T3	
6061 – T6	Mounting plates, welded assemblies or machined parts

Source: ARRL Antenna Book, 1997.

APPENDIX D

THE DISCOVERY SOFTWARE, ANTENNA INSTRUMENTS VERSION 2.50

The Discovery Software is a combination of hardware and software, which together form an integrated learning environment. The software is available for different fields in electrical/electronic engineering e.g. control, electronics, communications etc. The Discovery Software for antenna systems in communication is the Antenna Instruments Version 2.50

The software is a user-friendly graphical user interface intended to be used to investigate the parameters of a wide variety of antenna systems and a number of measurement functions. The main emphasis is on practical work. Much of the tedious laboratory work is carried out by the computer so that the user is able to concentrate on the measured results and observations. Both the software and the hardware make up the '57-200 Antenna Lab System'. The system is designed to explore antenna parameters and operates between 1.2 GHz and 1.8 GHz. Its simplicity makes it easy to be used at any teaching level and when operated in a low – reflection environment, is capable of producing data suitable for research and development.

The system comprises of the following:

- An RF generator unit, incorporated into a servo-controlled antenna mount (Generator Tower).
- A receiver unit, (Receiver Tower)
- A set of antenna elements from which various antennas can be made and tested.
- A suitable interface (Feedback MIC926 Interface)
- A compatible computer, used to control the system and display results.

The Computer has control and access to the following:

- Generator frequency
- Receiver frequency
- Antenna position
- Antenna rotation speed and direction
- Received signal level.

The following parameters can be measured using the system.

- Directivity and gain, displayed as polar diagrams
- Bandwidth, displayed as graph of amplitude against frequency
- Matching, displayed as graph of return loss against frequency.

The system is a product of Feedback Instruments Ltd., Park Road, Crowborough, E. Sussex, TN62QR, UK. http:// www.fbk.com

NEC – WIN BASIC, ANȚENNA ANALYSIS SOFTWARE VERSION 1.0

NEC –WIN Basic Antenna Analysis Software is an intuitive program that helps antenna designers quickly and effectively designs and analyse antennas. The program is easy to use for both novice and advanced designers. The program uses the powerful Numerical Electromagnetics Code (NEC) as a core for antenna analysis. The NEC is a user-oriented computer code for analysis of the electromagnetic response of antennas and other metal structures. It was built around the numerical solution of integral equation for the currents induced on the structure by voltage or current sources. The code combines integral equations for smooth surfaces with one specialized to wires to provide for easy and accurate modeling of a wide range of structures. The integral equation approach is best suited to structures with dimensions up to several wavelengths.

The NEC-WIN Basic is user-friendly through the use of graphical screens and dialogue boxes. Antenna geometry description is entered as numbers in a spreadsheet. Three-dimensional representation of the antenna is provided and can be rotated, panned, zoomed and printed. Numerical results are presented in form of tables or as pattern plots. The software is a product of Nittany Scientific, Inc, 1700 Airline Highway, Suite 361, Hollister, California 95023-5621, USA.

APPENDIX F

ARRAY SIMULATIONWITH ANTENNA TOWER OVER REAL GROUND

The Radiation Patterns of the 3 LPDA Array by WIN-NEC simulated with 30 metres steel antenna tower over real ground (soil constants of $\varepsilon_r = 15$ & $\sigma = 0.005$ S/m) representative of the proposed transmitting location (Obanla Sports Complex Area) are shown in Figures F2, F3 & F4. The model is shown in Figure F1. It is assumed that the array is held together by insulating support separating the array from the steel tower by a distance of 0.5 metres. The results show the same pattern as that of free space but with improvement in gain.

Maximum array gain at 88 MHz	=	9.5 dB
Maximum array gain at 100 MHz	=	8.74 dB
Maximum array gain at 108 MHz	=	8.2 dB

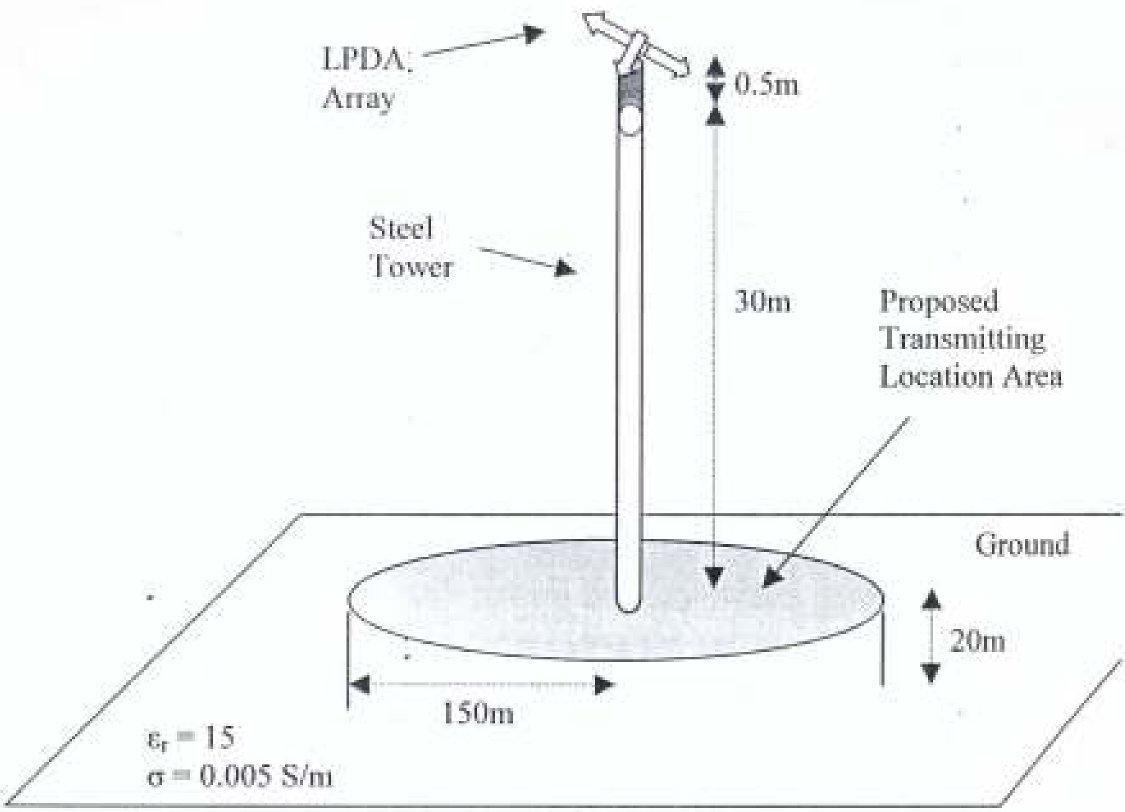

Figure F1 Model for Radiation Pattern Simulation of the Array over Real Ground with the Antenna Tower.

Radiation Pattern of the designed 3, 5-element LPDA Array simulated with 30 metre steel mast over real ground (rep. of the Transmitting location) at 88 MHz

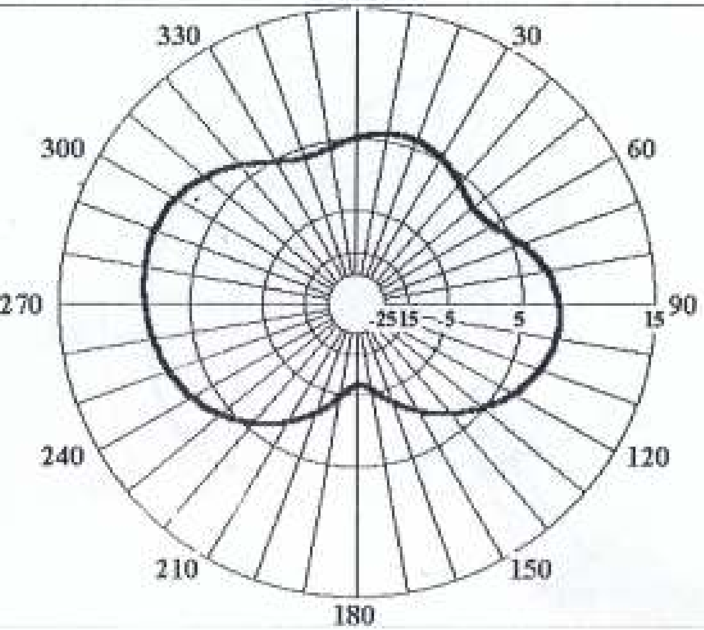

Figure F2 Simulated Radiation Pattern of the LPDA Array with the Antenna Tower over Real Ground at 88 MHz

Radiation Pattern of the designed 3, 5-element LPDA Array simulated with 30 metre steel mast over real ground (rep. of the Transmitting location) at 100 MHz

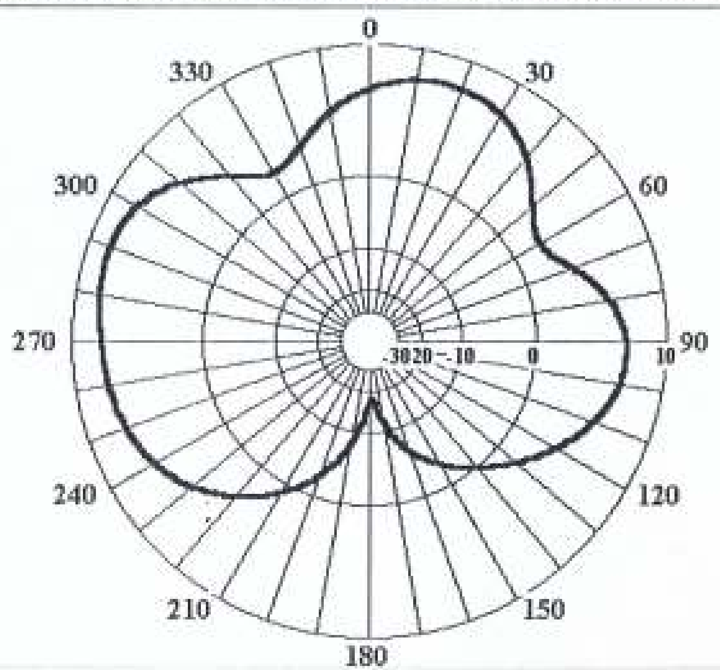

Figure F3 Simulated Radiation Pattern of the LPDA Array with the Antenna Tower over Real Ground at 100 MHz

Radiation Pattern of the designed 3, 5-element LPDA Array simulated with 30 metre steel mast over real ground (rep. of the Transmitting location) at 108 MHz

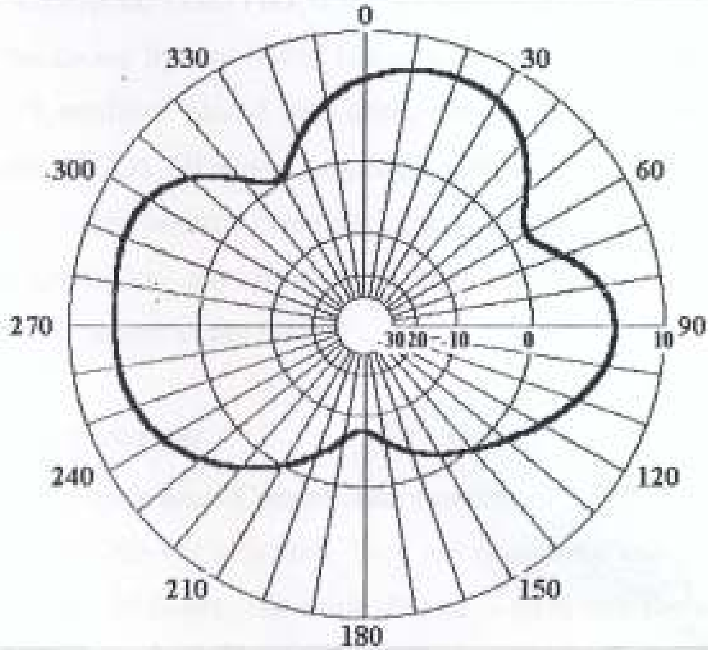

Figure F4 Simulated Radiation Pattern of the LPDA Array with the Antenna Tower over Real Ground at 108 MHz

APPENDIX G

GLOBAL POSITIONING SYSTEM (GPS)

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit, controlled and funded by the U.S. Department of Defense. (DOD). GPS was originally intended for military applications, but in the 1980s, the U.S government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.

THE GPS SATELLITE SYSTEM

The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours about 20,200 km altitudes. They are constantly moving, making two complete orbits in less than 24 hours. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). The satellites are travelling at speeds of roughly 7,000 miles an hour

There are six orbital planes (with nominally four satellites in each), equally spaced (60 degrees apart), and inclined at about fifty-five degrees with respect to the equatorial plane. This constellation provides users with between five and eight satellites visible from any point on the earth.

THE GPS SATELLITE

GPS satellites (also called NAVSTAR, the official U.S. Department of Defense name for GPS) are powered by solar energy. They have backup batteries onboard to keep them running in the event of a solar eclipse, when there is no solar power. Small rocket boosters on each satellite keep them orbiting in the correct path.

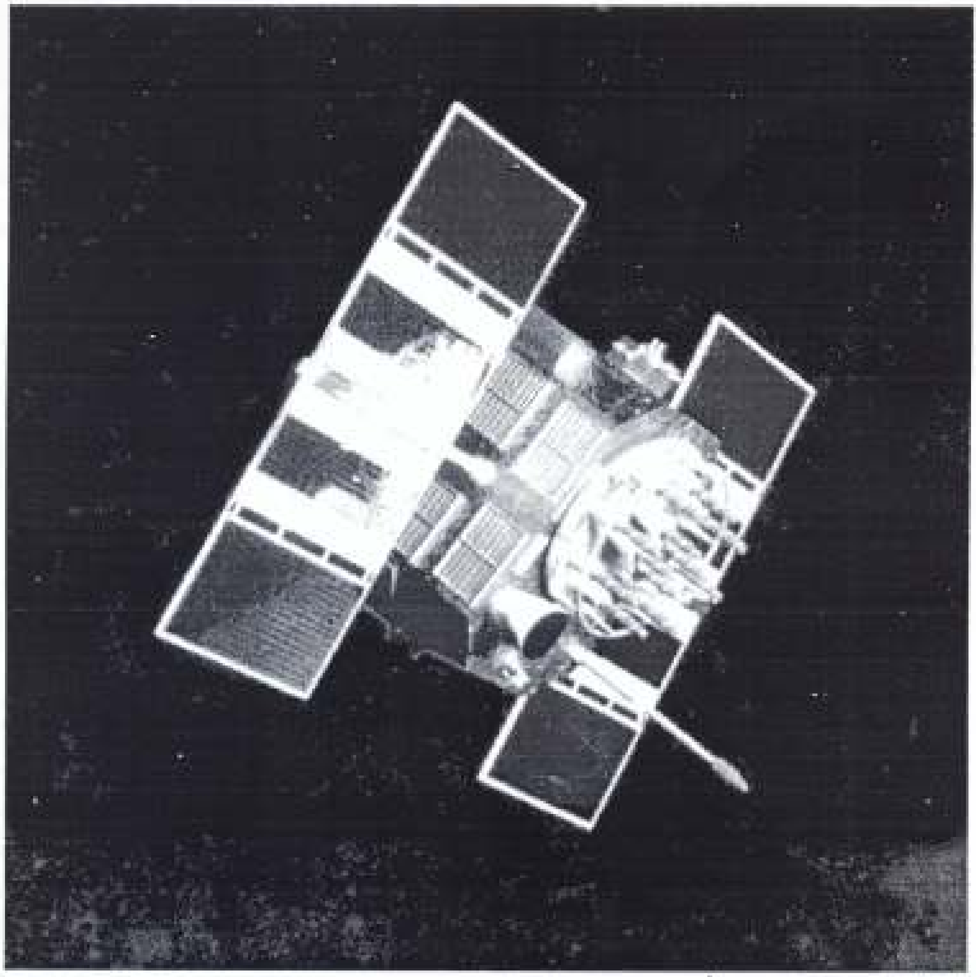

PLATE G A GPS SATELLITE

Some interesting facts about GPS satellites are:

- The first GPS satellite was launched in 1978.
- A full constellation of 24 satellites was achieved in 1994.
- A GPS satellite weighs approximately 2,000 pounds and is about 17 feet across with the solar panels extended.
- Transmitter power is only 50 watts or less.
- Each satellite is built to last about 10 years. Replacements are constantly being built and launched into orbit.

THE GPS SIGNAL

GPS satellites transmit two low power radio signals, designated L1 (1575.42 MHz) and L2 (1227.60 MHz). Civilian GPS uses the L1 frequency, which carries the navigation message and Standard Positioning Service (SPS) code signals. The L2 frequency is used to measure ionospheric delay by Precise Positioning Service (PPS) equipped receivers. The signals travel by line of sight, they will pass through clouds, glass and plastic but will not go through most solid objects such as buildings and mountains.

A GPS signal contains three different bits of information — a pseudorandom code, ephemeris data and almanac data. The Pseudorandom Code is simply an I.D. code that identifies which satellite is transmitting information. Ephemeris data, which is constantly transmitted by each satellite, contains important information about the status of the satellite (healthy or unhealthy), current date and time. This part of the signal is essential for determining a position. The Almanac data tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite transmits almanac data showing the orbital information for that satellite and for every other satellite in the system.

USER SEGMENT (GPS RECEIVERS)

GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. With distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map or display.

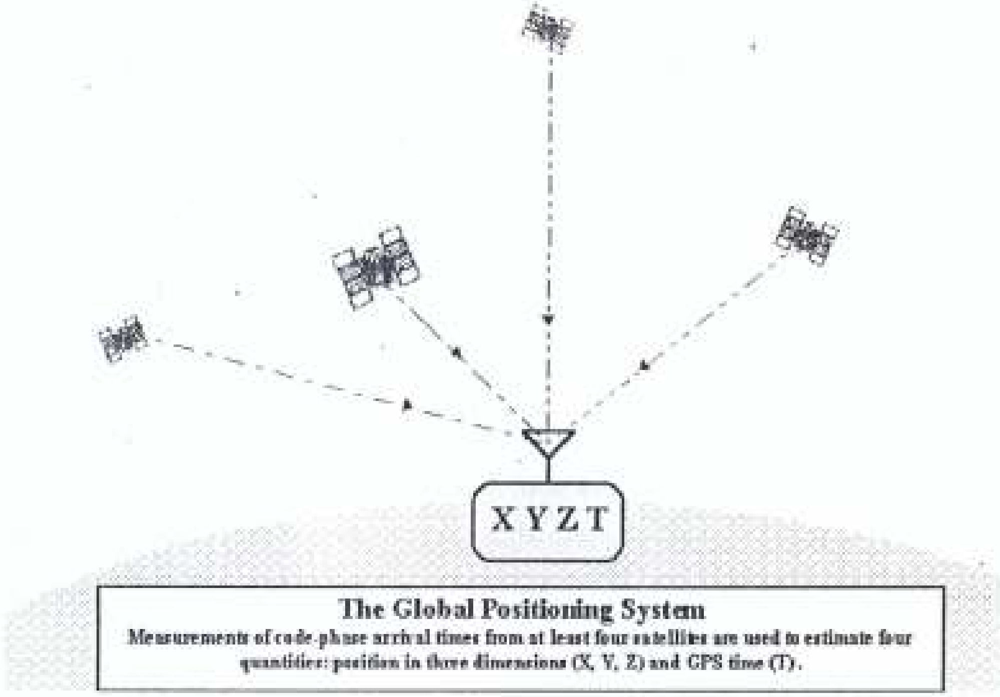

Figure G1 Global Positioning System

A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more.

THE STANDARD POSITIONING SERVICE (SPS)

SPS is a positioning and timing service and is provided on the GPS L1 frequency. Civil users worldwide use the SPS without charge or restrictions. Most receivers receive and use the SPS signal. The SPS accuracy is intentionally degraded by the DOD by the use of Selective Availability (SA). The SA was turned off in May 2000.

THE PRECISE POSITIONING SERVICE (PPS)

The PPS service is available to authorized users with cryptographic equipment and keys and specially equipped receivers.

SOURCES OF GPS SIGNAL ERRORS

Factors that can degrade the GPS signal and thus affect accuracy include the following:

- **Ionospheric and tropospheric delays** — The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error.
- **Signal multipath** — This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.
- **Receiver clock errors** — A receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have very slight timing errors.
- **Orbital errors** — Also known as ephemeris errors, these are inaccuracies of the satellite's reported location.
- **Number of satellites visible** — The more satellites a GPS receiver can "see," the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground.
- **Satellite geometry/shading** — This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.
- **Intentional degradation of the satellite signal** — Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. Department of Defense. SA was intended to prevent military adversaries from using the highly accurate GPS signals. The U.S. government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.