NEAR EAST UNIVERSITY

GRADUATE SCHOOL OF APPLIED AND SOCIAL SCIENCES

IMPLEMENTATION AND MEASUREMENTS ON THE HALF-WAVE DIPOLE ANTENNA

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Master Thesis

Department of Electrical and Electronic Engineering

Nicosia - 2003

Hani Albreem: Implementation and Measurements on the Half-wave Dipole Antenna

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AKNOWLEDGMENTS

"Firstly, I would like to thank my supervisor Assoc. Prof. Dr. Sameer Ikhdair for intellectual support, guidance, encouragement and enthusiasm which made this thesis possible and his patience for correcting my scientific errors.

Secondly, I would like to thank Dean of Engineering Prof. Dr. Fakhraddin Mamedov and Chairman of Electrical and Electronic engineering Assoc. Prof. Dr. Adnan Khashman for providing guidance and support throughout all stages to prepare the thesis.

Thirdly, special thanks for Mr. Yousef and his staff in BRTK station, who have helped me to overcome many problems faced in the experiments.

Fourthly, I would also like to thank my family, especially my parents, without their endless support and love for me I would never achieved my current position. I wish my mother lives happily always, and my father in the heaven to be proud of me.

Finally, I would like to thank all my friends especially my house mates Samy Albreem, Mohammed Khillah and Islam Almadhoun who have helped me in printing this thesis and who have also worked with me hardly in the work site, respectively"

Dedicated to

My father and mother

ABSTARCT

To describe performance and efficiency of the antenna, we do variety of practical measurements on the antenna such as, radiation pattern and gain measurement. Further, we calculated gain from power gain has also been done.

The main goal of this thesis is to implement and investigate the important parts of these measurements by using simple methods and equipments. Our measurements are made on a simple antenna such as half-wave dipole antenna. The half-wave dipole antenna has been chosen for such measurement because it is simple in construction, low cost and has wide range of frequencies which give us ability to adjust our equipments according to the desired frequency.

Different techniques and methods were used which are often familiar and commonly used in the broadcasting cooperation and communication company to check their transmitting or receiving radiation pattern and gain for antenna system. These methods are strength wave method, the radiation pattern of primary receiving and transmitting antenna method and the compression method to find gain at different frequencies needed.

Finally, we remark that our results are very good and compatible to the theoretical ones. The main problems we faced in our measurements are due to standard measurement procedure or methods on antenna and the expensive costs of the equipments which are needed to implement these measurements

CONTENTS

INTRODUCTION

We had thought to do our work on the antenna, and then we have searched the important parts on this subject since the antenna is one of the most common and important parts in the communication system nowadays. The term antenna is defined by the dictionary [1] as usually a metallic device (as a rod or wire) for radiating or receiving radio waves. The official definition of the Institute of Electrical and Electronics Engineers (IEEE) [2] is simply as means for radiating or receiving radio waves. The ideal antenna in most applications is a one that will radiate all of the power delivered by a transmitter in the desired direction or directions with the desired polarization. Practical antennas can never fully achieved this ideal performance, but their merit is conveniently described in terms of the degree to which they do so. For this purpose, certain parameters of antenna performance are defined.

Although there has been an explosion and a revolution in the antenna technology over the past few years since antenna was published, the basic principles and theory remain unchanged.

Antenna measurements are very expensive and require gigantic instruments to pursue this work; so that, we decided to search about this subject to make these measurements cheaper and much easier in finding results. Therefore, our objectives in this thesis are to analyze the antenna measurements and implement simple methods to determine the antenna gain to real antennas. For his purpose the small size simple antenna is used in this measurement which is half-wave dipole antenna. The antenna gain has also been determined for different values of the angular in the horizontal plane at a fixed frequency, and also for different frequencies at a fixed angle. The correction coefficient is determined by the ratio of the real and small antennas are used to match the results obtained with real condition.

The aims of this work are:

1. Implementation and investigation of practical measurements on the antenna by using simple methods, cheaper instruments and simple antenna such as half-wave dipole antenna.
2. Implementation simple antenna for measurements purpose which is multi-band dipole antenna.

The content of this thesis is as follows:

Chapter one, is primarily concerned with definitions and related terminologies deals with the antenna parameters in the engineering usage. Principal parameters of antennas are associated with the radiation efficiency, the input impedance, and the bandwidth. Parameters are defined under each of these categories such as the gain, beamwidth, polarization, minor lobe level, radiation efficiency, aperture efficiency, receiving cross section, radiation resistance, and others specialized applications. Some of these parameters are interrelated or correlated.

In Chapter Two, we discuss and analyze a center-fed linear dipole with sinusoidal current distribution based on far-zone fields, E_θ and H_ϕ of a vertical antenna. Pattern function of a linear dipole antenna when having half-length $h=\lambda/2$ has been investigated. We have also shown and explained all these types of the dipole antenna. Moreover, we have introduced a multiband parallel dipole antenna design and construction and their appellations.

In Chapter three, we investigate the parameters measurements, which we have already mentioned in the previous chapter. The measuring methods has been studied and explained in detail. The main measurements are divided into two categories as input impedance and radiation pattern measurements.

In Chapter four, the real practical measurements have been made by using different instruments. The radiation pattern measurement and a detailed study of the gain have been done here. Moreover, we have measured the radiation pattern for transmission and receiving primary antenna, and then we have also measured the beamwidth and gain for any random antenna to be complied with the steps that we have studied in the chapter two. It is worthwhile to note that all these measurements have been applied on the BRTK station in the Turkish Republic of Northern Cyprus (TRNC).

Finally, the results and conclusion of the work presented within this thesis will be described.

CHAPTER ONE

ANTENNA PARAMETERS

1.1 Overview

One of the most critical elements of a wireless communications system is the antenna. A base station antenna represents only a small part of the overall cost of a communications site, but its performance impact is enormous. Its function is to transform conduction currents (found on wires, coaxial cable, and waveguides) into displacement currents and this invisible phenomenon makes radio communications possible. The antenna impact on the radio system is determined by choosing the antenna with an appropriate characteristics defined by its specifications [8].

In the followings we describe and define the most common parameters used to specify base station antennas.

1.2 Antenna Structure

An antenna is a structure usually made from a good conducting material that has been designed to have a shape and size such that it will radiate electromagnetic power in an efficient manner. It is a well-established fact that time-varying current will radiate electromagnetic waves. Thus, an antenna is a structure on which time-varying currents can be excited with relatively amplitude when the antenna is connected to a suitable source usually by means of the transmission line or waveguide. There is an almost endless variety of structure shapes that can be for an antenna, however, for practical point of those structures that are simple and economical to fabricate are the ones most commonly used. In order to radiate efficiently, the minimum size of the antenna must be comparable to the wavelength. A very common antenna is the half-wavelength dipole antenna, which consists of two conducting rods each of a quarter wavelength long and are placed end to end with a small spacing at the center at which a transmission line is connected [5].

1.3 Antenna Parameters

To describe the performance of an antenna definitions of various parameters. Some of the parameters are interrelated and not all of them need to be specified for complete description of antenna performance. Most of parameters definitions in this study will be briefly given and discussed.

1.3.1 Polarization

The polarization of an antenna is a property of the radio wave that is produced by the antenna. Polarization describes how the radio wave (displacement current, electric field vector) varies in space with time. This is an important concept because for a radio wave transmitted with a given polarization to be received by another antenna. Thus, the received antenna must be able to receive this polarization and has to be oriented to do so. An antenna is a transducer that converts radio frequency electric current to an electromagnetic waves that are then radiated into space. The electric field $\vec{E}$ plane in mathematical form determines the polarization or orientation of the radio wave. In general, most antennas radiate either linear or circular polarization.

At a given point in space, the general shape traced by the electric field vector is an ellipse, as shown in Figure 1.1.

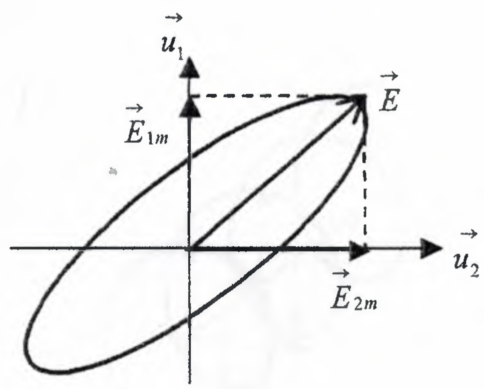


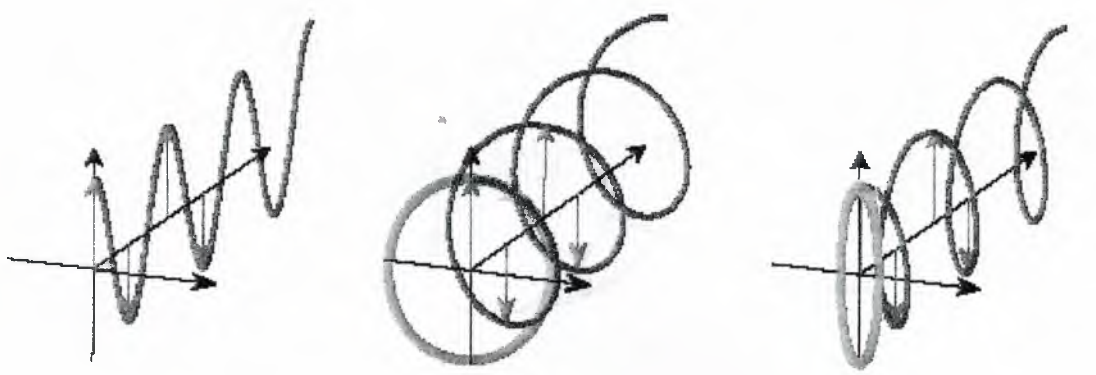
Figure 1.1 General shape traced by the electric field vector in ellipse

The instantaneous value of the wave can be written as

$$\vec{E}(t) = E_{1m}\cos(\omega t)\vec{u_1} + E_{2m}\cos(\omega t + \delta)\vec{u_2}, \qquad (1\text{-}1)$$

where δ is the phase by which the u_1-componet leads the u_1-components [8].

Thus, the linearly polarized antenna radiates wholly in one plane containing the direction of propagation. Further, in a circular polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. If the rotation is clockwise and looking in the direction of propagation, the sense is called right-hand-circular (RHC) whereas if the rotation is counterclockwise then the sense is called left-hand-circular (LHC). An antenna is said to be vertically polarized (linear) when its electric field is perpendicular to the Earth's surface as shown in the Figure 1.2(a). As an example of a vertical antenna is a broadcast tower for AM radio or the (whip) antenna on an automobile. Horizontally polarized (linear) antennas have their electric field parallel to the Earth's urface. Television transmissions in the USA use horizontal polarization. Further, the circularly polarized wave radiates energy in both the horizontal and vertical planes and all planes in between. The difference between the maximum and the minimum peaks as the antenna is rotated through all angles, is called the axial ratio or ellipticity and is usually specified in decibels (dB). If the axial ratio is near 0 dB, the antenna is said to be circularly polarized as shown in the Figure 1.2 (b). Overmore, if the axial ratio is greater than 1-2 dB, the polarization is often referred to as elliptical as in Figure 1.2 (c) [9].



(a) Linear Polarization (b) Circular Polarization (c) Elliptic polarization

Figure 1.2 Types of Polarizations.

1.3.2 Radiation Pattern

The radiation pattern is qualitatively similar to the current elements patterns but is somewhat compressed in the z direction [4]. The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a fixed or constant distance. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but it is difficult to display the three-dimensional radiation pattern in a meaningful manner, further, it is also time consuming to measure a three-dimensional radiation pattern. Often the radiation pattern measured are a slice of the three-dimensional pattern, and is of course a two-dimensional radiation pattern and can be displayed easily on a screen or piece of paper. These pattern measurements are presented in either a rectangular or a polar format [10] as shown in Figure 1.3 for which one can draw polar sectional plots in the $\vec{E}$-plane and in the $\vec{H}$-plane. The $\vec{E}$-plane contains the direction of propagation of the electric field vector. The $\vec{H}$-plane contains the direction of propagation and the magnetic field vector. The $\vec{E}$-plane is at right angles to the $\vec{H}$-plane and their plots are normally regarded as sufficient to characterise an antenna [11].

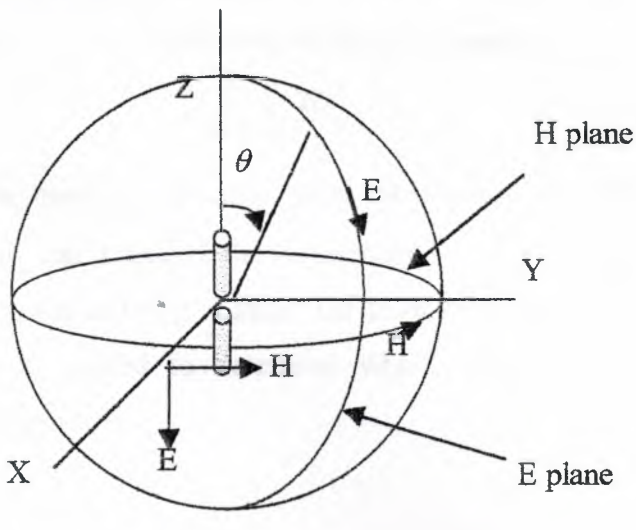


Figure 1.3 $\vec{E}$-Plane radiation Pattern and $\vec{H}$-palne radiation Pattern

1.3.2.1 Absolute and Relative Pattern

The absolute radiation patterns are presented in absolute units of field strength or power. Whereas the relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative pattern measurements and then the gain. Therefore, the transfer method is then used to establish the absolute gain of the antenna [10].

1.3.3.2 Near-Field and Far-Field Patterns

The radiation pattern in a region close to the antenna is not exactly the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna; the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is of much concern. The near-field is called the induction field (although it also has a radiation component). Ordinarily, it is the radiated power that is of much interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement, it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field.

The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is

$$r_{\min} = \frac{2D^2}{\lambda}, \qquad (1\text{-}2)$$

where $r_{\min}$ denotes the minimum distance from the antenna, D denotes the largest dimension of the antenna, and λ denotes the wavelength.

When extremely high power is being radiated (as from some modern radar antennas). The near-field pattern is needed to determine what regions near the antenna are hazardous to human beings [10].

1.3.2.3 Beamwidth

Depending on the radio system in which an antenna is being employed there can be many definitions of beamwidth. A common definition is the half power beamwidth, as in the Figure 1.4. The peak radiation intensity is found and then the points on either side of the peak represent half the power of the peak intensity are located. The angular distance between the half power points traveling through the peak is the beamwidth. Half the power is -3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth [10].

1.3.3 Sidelobes Levels

Sidelobes of a directive (nonisotropic) pattern represent regions of unwanted radiation; they should have levels as low as possible. Generally, the levels of distant sidelobes are lower than the levels of those near the main beam. Hence, when one talks about the sidelobes levels of an antenna pattern, one usually refers to the first (nearest and highest) sidelobes. As shown in the Figure 1.4, the region of maximum radiation between the first null points around it's the main beam, and the regions of minors maxima are sidelobes. Between these side lobes are directions in which little or no radiation occurs and termed nulls. The nulls may represent a 30dB reduction (less than one-thousandth the energy of the main beam) in received signal level in that direction [8].

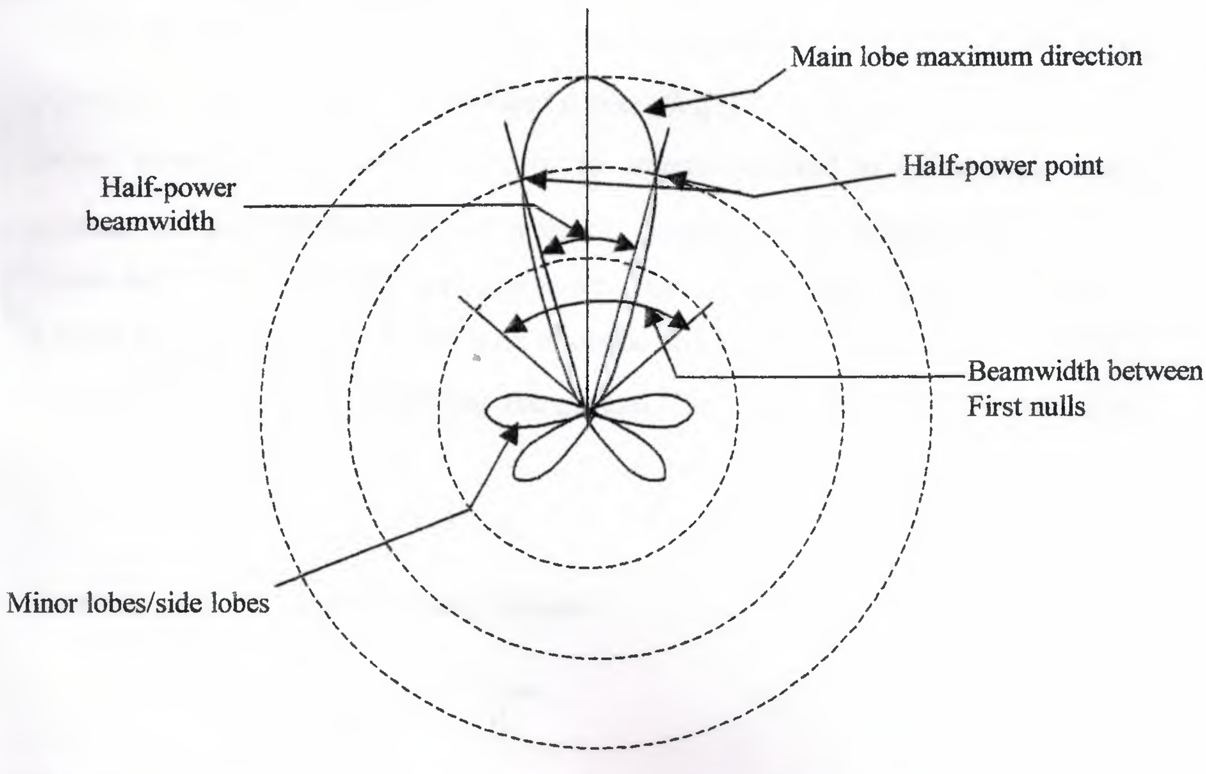


Figure 1.4 A typical antenna pattern with sidelobes [13].

1.4.4 Directivity and Gain

Directive gain in a given direction is defined as the ratio of the radiation intensity in that direction to the radiation intensity of a reference antenna (an isotropic source). Directivity is the value of the directive gain in the direction of its maximum value. So the directivity of a nonistropic source is equal to the ratio of its maximum radiation intensity over that of an isotropic source. They are expressed as

$$D_G = \frac{U}{U_0} = \frac{4\pi U}{P_r}, \tag{1-3}$$

and

$$D_0 = \frac{U|_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_r}. \tag{1-4}$$

where D_G is the directive gain (dimensionless), D_0 is the directivity (dimensionless), U is the radiation intensity (W/unit solid angle), $U_{\max}$ is the maximum radiation intensity (W/unit solid angle), U_0 is the radiation intensity of isotropic source (W/unit solid angle), and P_{rad} is the total radiated power (W)[7].

Further, power gain or the gain; G_p of an antenna referred to an isotropic source represent the ratio of its maximum radiation intensity to the radiation intensity of a lossless isotropic source with the same power input. The directive gain in Equation (1-3) based on radiated power P_r, because of ohmic power loss P_λ in the antenna as well as in nearby lossy structures including the ground. Here P_r is less than the total input power P_i. So, we have

$$P_i = P_r + P_\lambda. \tag{1-5}$$

The power gain of an antenna is then become

$$G_p = \frac{4\pi U_{\max}}{P_i}, \tag{1-6}$$

and the ratio gain to the directivity of an antenna is the radiation efficiency

$$\xi_r = \frac{G_P}{D} = \frac{P_r}{P_i}, \tag{1-7}$$

where ξ_r denotes the radiation efficiency, G_P denotes the power gain, P_λ denotes the ohmic power loss, D denotes the directivity, P_i denotes the total input power and P_r denotes the radiated power [3].

1.3.5 Radiation Resistance

To deliver sufficient power to the antenna it must be connected to a transmission line. To prevent standing waves from occurring within the line and for maximum power transfer, the resistance of the transmission line must be equal to the resistance of the antenna. So, the antenna resistance is termed radiation resistance. This is defined as a fabricated resistance, which would dissipate as much power as an antenna in question and it is radiating as if it were connected to the same transmission line. Therefore, not all energy absorbed by an antenna is radiated. Losses can occur within the antenna (imperfect dielectrics, eddy currents, etc) as such antenna efficiency is

$$\xi_r = \frac{P_{transmitted}}{P_{input}} = \frac{R_r}{R_r + R_l}, \tag{1-8}$$

where R_r is the resistance of the antenna and R_l is resistance due to losses [13].

1.3.6 Input Impedance

The input impedance determines how large a voltage must be applied at the antenna input terminals to obtain the desired current flow and hence the desired amount of radiated power. Thus, the impedance is equal to the ratio of the input voltage E_i to the input current I_i. So, it can be written as

$$Z = \frac{E_i}{I_i}, \tag{1-9}$$

which is in general complex. If the gap in the antenna conductor (feeding point) is at a current maximum, and if there is no reactive component to the input impedance, then it will be equal to the sum of the radiation resistance and the loss resistance, that is,

$$Z_i = R_i = R_r + R_0 \ . \tag{1-10}$$

If the reactance has a large value, the antenna-input voltage must be very large to produce an appreciable input current. On other hand, if the radiation resistance is very small, the input current must be very large to produce appreciable radiated power [6].

1.3.7 Bandwidth

The bandwidth of the antenna is defined as the ranges of frequencies within which the performance of the antenna with respect to some characteristic conforms to as specified standard. The bandwidth can be considered to be range of frequencies, on either side of a center frequencies (usually the resonance frequency for a dipole), where the antenna characteristics (such input impedance, pattern, beamwidth, polarization, sidelobe level, gain, beam direction, radiation efficiency) are within acceptable value of those at the center of frequency. For broadband antennas, the bandwidth usually expressed as the ratio of the upper-to-lower frequencies acceptable operation [7].

1.3.8 Beam Solid Angle

The definition is motivated by the case of a highly directive antenna, which concentrates all of its radiated power P_{rad} into a small solid angle, as illustrated in Figure 1.5.

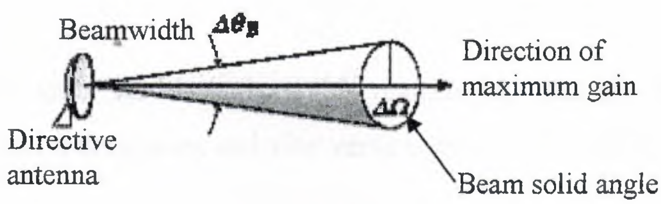


Figure 1.5 Beam solid angle and beamwidth of a highly directive antenna.

The radiation intensity in the direction of the solid angle

$$U = \frac{\Delta P}{\Delta\Omega} = \frac{P_r}{\Delta\Omega}, \tag{1-11}$$

where $\Delta P = P_r$ by assumption and then it follows that

$$D_{\max} = \frac{4\pi U}{P_r} = \frac{4\pi}{\Delta\Omega}. \tag{1-12}$$

Thus, the more concentrated the beam, the higher the directivity. Although Equation (1-11) was derived under the assumption of a highly directive antenna, it may be used as the definition of the beam solid angle for any antenna [7], that is,

$$\Delta\Omega = \frac{4\pi}{D_{\max}}. \tag{1-13}$$

1.3.9 Receiving Cross Section

The antenna receiving cross section A_r is defined as the ratio between the delivered power $P_r\,(W)$ into the load power density, $P_i\,(W/m^2)$ as shown in the Figure 1.5. Thus, we have

$$A_r = \frac{p_r}{p_i}. \tag{1-14}$$

Further there is a relationship between the gain of the antenna and its physical size. Therefore, it's expressed as the receiving cross section area in isotropic area A_{ro}

$$A_{ro} = \frac{G\lambda^2}{4\pi}, \tag{1-15}$$

where λ denotes the wavelength and $G = \xi D$. From this relationship, it follows that

$$D = \frac{4\pi A_r}{\xi\lambda^2}, \tag{1-16}$$

where D is the directive gain. Its clear from this relationship that the gain increase when A_r increases and λ and ξ decreases, and vice versa is true. Thus, the power is

$$P_r = \xi\left(\frac{P_i D\lambda^2}{4\pi}\right). \tag{1-17}$$

Therefore, the concept of the receiving cross section of an antenna is not a necessary one. It is possible to calculate the received signal power without using Equation (1-17). It possible to measure gain from the receiving cross signal, as we will see later [6].

1.4 Transmission Lines

Transmission lines are used to connect the antenna to a radio or some other devices. For this purpose, the transmission lines are of two geometries, a balanced twin conductor made up of two parallel conductors as shown in Figure 1.6(a). and a coaxial unbalanced line made of two coaxial conductors as shown in Figure 1.6(b). The most important parameters to be considered are impedance, propagation velocity, loss and mode. All transmission lines have a characteristic impedance which is determined mainly by the geometry of the conductors and the dielectric constant of the material supporting them. It is usually very important that the impedance of the antenna and the radio match that of the transmission line otherwise there will be reflections at the discontinuity and the power transfer will less than perfect. Coaxial transmission lines usually have a lower impedance than the open wire twin lead or ladder wire. So far, consideration has been given only to transmission lines that are matched at both ends. While this is desirable in most cases, there are some situations where transmission lines that are not matched are useful. As one moves away from a mismatched termination the impedance varies as one moves along the transmission line,if you design anetnna and try to get match impedance you will never get full characteristic impedance of the transmission line. The impedance will vary in value from that of the termination to that given by

$$Z_T = \frac{Z_0 * Z_0}{Z_L}, \qquad (1\text{-}18)$$

where Z_0 is the characteristic impedance of the transmission line, Z_L is the value of the termination and Z_T is the extreme impedance transformation [14].

(a) Balanced parallel twin Transmission line.

(b) Unbalanced coaxial transmission Line.

Figure 1.6

Geometries of Transmission Lines.

1.5 Summary

So far, we have discussed the definitions and related terminologies, which will be needed in the next chapters. This chapter deals with the antenna parameters, associated with the radiation pattern, the radiation efficiency, the input impedance, and the bandwidth. Parameters were defined under each of these categories such as the gain, beam width, polarization, minor lobe level, radiation efficiency, receiving across section, radiation resistance and the other that have specialized applications.

CHAPTER TWO

LINEAR DIPOLE ANTENNA

2.1 Overview

Dipole antennas have been widely used since the early days of radio. Simplicity and effectiveness for a wide range of communications needs are the reasons for this use. The radiation patterns of half wavelength elemental dipoles end to end and the current in each elemental dipole would be constant and equal to the average current in the corresponding section of the half-wave dipole. The current in each distribution is half cycle of a sinusoid with the maximum at the dipole center. Further, it has a constant phase angle everywhere on a half-wave dipole so that all the elemental dipoles are assumed to be in phase.

This chapter present the parameters associated with dipole antenna such as, distribution current on the center-fed linear dipole, Beamwidth, radiation resistance, and directivity. Moreover, we introduced the types of dipole antenna and we choose one of them to be our antenna design as in the following sections.

2.2 Thin Linear Dipole Antenna

We will examine the characteristics of a center fed thin straight antenna having a length comparable to wavelength, as shown in the Figure 2.1, such an antenna is called a linear dipole antenna. If the current distribution along the antenna is known, we can find its radiation field by integrating the radiation field due to an elemental dipole over the entire length of the antenna. The determination of the exact current distribution on such a seemingly simple geometrical configuration is a very difficult boundary-value problem. For our purpose we assume a sinusoidal space variation constitutes a kind of standing wave over the dipole, as sketched in Figure 2.1, it represents a good approximation [3].

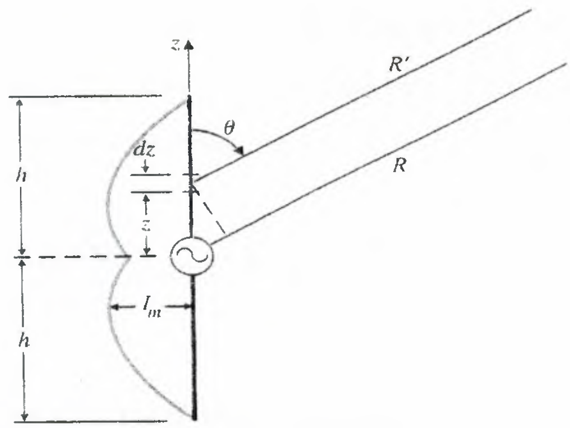


Figure 2.1 A center-fed linear dipole with sinusoidal current distribution

Since the dipole is a center-driven, the currents on he two halves of the dipole are symmetrical and go to zero at the ends. Hence, we write the current phasor as

$$I(z) = I_m \sin\beta(h-|z|) = \begin{cases} I_m \sin \beta(h-z), & z > 0, \\ I_m \sin \beta(h+z), & z < 0. \end{cases} \tag{2-1}$$

We are interested only in the far-zone fields, so the mathematical expression for the Far field radiation pattern is

$$H_\phi = j\frac{Id\ell}{4\pi}\left(\frac{e^{-j\beta R}}{R}\right)\beta\sin\theta \quad \text{(A/m)}, \tag{2-2}$$

and this will give the far fields of a Hertzian dipole antenna as

$$E_\theta = j\frac{Id\ell}{4\pi}\left(\frac{e^{-j\beta R}}{R}\right)\eta_0\beta\sin\theta = \mu_0 H_\phi \quad \text{(V/m)}. \tag{2-3}$$

Thus, making use of Equations (2-2) and (2-3), the far field contribution from the differential current element becomes

$$dE_\theta = \mu_0 dH_\phi = j\frac{Idz}{4\pi}\left(\frac{e^{-j\beta R'}}{R'}\right)\eta_0\beta\sin\theta. \tag{2-4}$$

It is worthwhile to note that R' in Equation (2-4) is slightly different from R measured to be the origin of the specerical coordinates, which coincides with the center of the dipole. In the far zone case, $R \geq h$, we have

$$R' \cong R - z\cos\theta. \tag{2-5}$$

The magnitude difference between $1/R'$ and $1/R$ is insignificant, but the approximate relation, Equation (2-5), must be retained in the phase term. Putting Equations (2-1) and (2-5) in Equation (2-4) and then integrating, we get

$$E_\theta = \eta_0 H_\phi = j\frac{I_m \eta_0 \beta \sin\theta}{4\pi R} e^{-j\beta R} \int_{-h}^{h} \sin\beta\left(h-|z|\right) e^{j\beta z\cos\theta}\, dz. \tag{2-6}$$

2.2.1 Pattern Function of a Half-Wave Dipole

The integrand in Equation (2-6) is a product of an even function of z, that is, $\sin\beta\left(h-|z|\right)$ and $e^{j\beta z\cos\theta} = \cos(\beta z\cos\theta) + j\sin(\beta z\cos\theta)$, where $(\beta z\cos\theta)$ is an odd function of z. Integrating between symmetrical limits $-h$ and h, we know that only the part of the integrated containing the product of two even function of z, $\sin\beta\left(h-|z|\right)\cos(\beta z\cos\theta)$, yields a nonzero value. Equation (2-6) then reduces to

$$E_\theta = \eta_0 H_\phi = \frac{j60 I_m}{R} e^{-j\beta R} F(\theta), \tag{2-7}$$

where

$$F(\theta) = \frac{\cos(\beta h\cos\theta) - \cos\beta h}{\sin\theta}. \tag{2-8}$$

So, Equations (2-7) through (2-8) is rewritten as

$$E_\theta = j\eta_0 \frac{e^{j\beta r}}{2\pi} I_m = \frac{\cos[(\beta h/2)\cos\theta] - \cos(\beta h/2)]}{\sin\theta}. \tag{2-9}$$

The factor $|F(\theta)|$ is the E-plane pattern function of a linear dipole antenna. The exact shape of the radiation pattern represented by $|F(\theta)|$ in Equation (2-8) depends on the value of $\beta h = 2\pi h/\lambda$ and can be quite different for different antenna lengths. The radiation pattern, however, is always symmetrical with respect to the $\theta = \pi/2$ plane.

Figure 2.3 shows the E-plane patterns for four different dipole lengths measured in term of wavelengths: $2h/\lambda = \frac{1}{2}, \frac{2}{2}$ and $\frac{3}{2}$. The H-plane patterns are circles much as $F(\theta)$ is independent of φ. From the patterns in Figure 2.3 we have seen that the direction of maximum radiation tends to shift a way from $\theta = 90^0$ plane when the dipole length approaches $3\lambda/2$. For $2h = 2\lambda$ case there is no radiation in the $\theta = 90^0$ plane [3].

The half-wave dipole having a length $2h = \lambda/2$ is of particular practical importance because of its desirable pattern and impedance characteristics. Therefore with $\beta h = 2\pi h/\lambda = \pi/2$.

2.2.2 Estimation of Half-Power Beamwidth for Different λ

The angular width of the beam between these points is called the half-power beamwidth. When a beam pattern is plotted with ordinate scale in the -3 dB points, for this reason the half power beamwidth is often referred to as the -3 dB beamwidth. Figure 2.2 illustrate the procedure of determining the -3 dB beamwidth on a rectangular pattern plot.

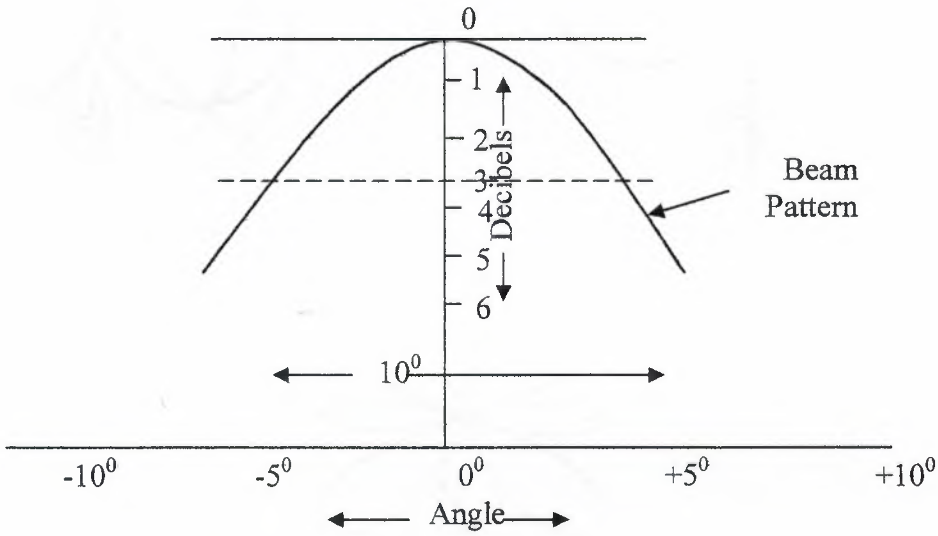


Figure 2.2 Determination of half-power (3dB-down) beamwidth.

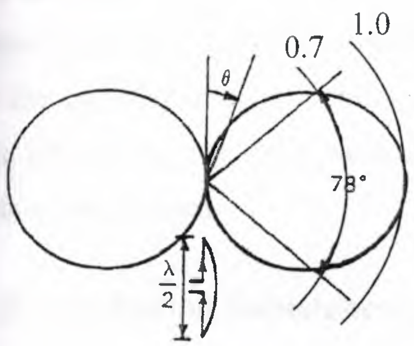
The criterion of beamwidth, although adequate and convenient in many situations, it does not always provide a sufficient description of the beam characteristics. When beams have different shapes. An additional description may be given by measuring the width of the beam at several points, as an examples, -3 dB, -10 dB, an at the nulls. Some beams ay have an asymmetric shape. In our following examples we calculated beamwidth for unity.

2.2.2.1 Half-wave (λ/2) Antenna

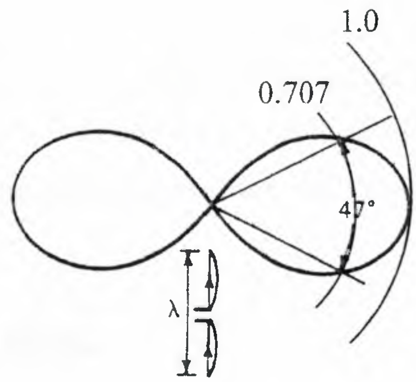
For $h = \lambda/2$, the far field pattern from Equation (2-9) becomes as

$$F(\theta) = \frac{\cos[(\pi/2)\cos\theta]}{\sin\theta}. \tag{2-10}$$

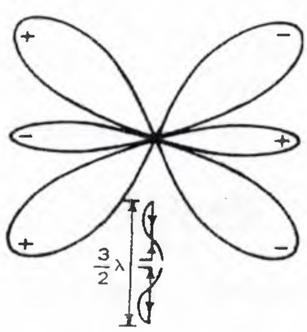
So, the normalized electric field pattern of a half-wave dipole. The half-power beamwidth $\lambda/2$ is 78^0 and its pattern plot is shown in Figure 2.3 (a).



a) $2h/\lambda = 1/2$.



(b) $2h/\lambda = 1$.



(c) $2h/\lambda = 3/2$.

Figure 2.3 E-plane radiation patterns for center-fed dipole antennas.

2.2.2.2 Full-wave (λ) Antenna

For $h = \lambda$, the normalized electric field pattern from Equation (2-9) is

$$F(\theta) = \frac{\cos(\pi\cos\theta) + 1}{\sin\theta}. \tag{2-11}$$

The pattern is shown in Figure 2.3 (b). The half –power beamwidth is 47^0.

2.2.2.3 Wave of (3λ /2) Antenna

For $h = 3\lambda/2$, the normalized eclectic field pattern from Equation (2-9) is

$$F(\theta) = 0.714 \frac{\cos(\frac{3}{2}\pi\cos\theta)}{\sin\theta}. \tag{2-12}$$

The factor 0.7148 is normalization constant which is very near to half-power beamwith value 0.707. The pattern for this case is presented in Figure 2.3(c). With the midpoint of the antenna as phase center, the phase shifts 180^0 at each null, the relative phase the lobes being indicated by the + and - signs. Moreover, it has a multiple lobe structure due to the canceling effect of oppositely directed currents on the antenna. In all three cases, (a), (b) and (c), the space pattern is a figure-of-revolution of pattern shown around the axis of the antenna.

2.2.3 Radiation Resistance of a Half-Wave Dipole

From Equation (2-7), the Far-zone field phasors are given by

$$E_0 = \eta_0 H_\phi = \frac{j60I_m}{R} e^{-j\beta R}\left\{-\frac{\cos[(\pi/2)\cos\theta]}{\sin\theta}\right\}, \tag{2-13}$$

and the magnitude of time-average Poynting vector is

$$P_{av}(\theta) = \frac{1}{2} E_\theta H_\phi^* = \frac{15I_m^2}{\pi R^2}\left\{\frac{\cos[(\pi/2)\cos\theta]}{\sin\theta}\right\}^2. \tag{2-14}$$

The total power radiated by a half-wave dipole is obtained by integrating $P_{av}(\theta)$ over the surface of a great sphere:

$$P_r = \int_0^{2\pi}\int_0^{\pi} P_{av}(\theta) R^2 \sin\theta \, d\theta \, d\phi = 30 I_m^2 \int_0^{\pi} \frac{\cos^2[(\pi/2)\cos\theta]}{\sin\theta} d\theta. \tag{2-15}$$

The integral in Equation (2-15)can be evaluated numerically to give a value 1.218. Hence

$$P_r = 36.54 I_m^2 \ (W), \tag{2-16}$$

From which we obtain the radiation resistance of free-standing half-wave dipole:

$$R_r = \frac{2P_r}{I_m^2} = 73.1 \ (\Omega). \tag{2-17}$$

Neglecting losses, we find that the input resistance of a thin half dipole equals 73.1(Ω) and that the input reactance is small positive number that can be made to vanish when the dipole length is adjusted to slightly shorter than $\lambda/2$.

2.2.4 Directivity of a Half-Wave Dipole

The directivity of a half-wave dipole can be found by using Equation (1-4) as

$$D=\frac{4\pi U_{\max}}{P_r}=\frac{60}{36.54}=1.64, \qquad (2\text{-}18)$$

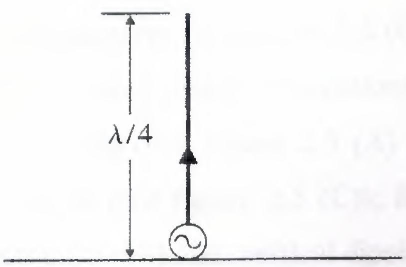
where

$$U_{msx}=R^2 P_{av}\left(90^0\right)=\frac{15}{\pi} I_m^2. \qquad (2\text{-}19)$$

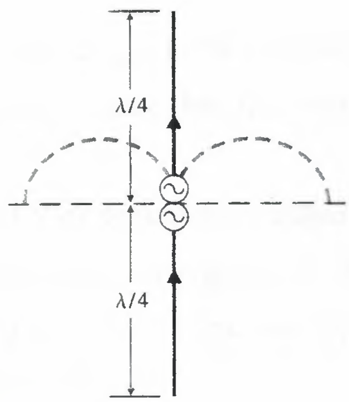
The directive value in Equation (2-18) corresponds to $10\log_{10} 1.64$ or 2.15 dB referring to an omnidirectional radiator. But although an isotropic antenna doesn't exist in practice but it is having power gain of unity [17].

2.3 A Quarter-Wave Monopole

When the single-ended sources placed over a conducting plane, a quarter-wave monopole antenna excited by a source at its base as shown in Figure 2.4 exhibits the same radiation pattern in the region above the ground as a half-wave dipole in free space. This is because from the image theory, the conducting plane can be replaced with the image of a $\lambda/4$ monopole. However, the monopole can only radiate above the ground plane [3]. Therefore, the radiated power is limited to $0 \le \theta \le \pi/2$. Hence the $\lambda/4$ monopole radiates only half as much power as the dipole [15].



(a) Quarter-wave monopole antenna.



(b) Equivalent half-wave dipole antenna

Figure 2.4 Quarter-wave monopole over a conducting ground and its equivalent half-wave dipole.

2.3.1 Radiation Resistance of a Quarter-Wave Monopole

The magnitude of the time-average Poynting vector, P_{av}, in Equation (2-14), holds for $0 \le \theta \le \pi/2$. In addition, the quarter-wave radiates into the upper half-space, its total radiated power is only one-half that given in Equation (2-16):

$$P_r = 18.27 I_m^2 (W), \tag{2-20}$$

and consequently, the radiation resistance is

$$R_r = \frac{2P_r}{I_m^2} = 36.54(\Omega) \tag{2-21}$$

which is one-half of the radiation resistance of a half-wave antenna in free-space.

2.3.2 Directivity of a Quarter-Wave Monopole

To calculate directivity, we note that both the maximum radiation intensity, $U_{\max}$, and the average radiation intensity, $P_r/2\pi$ remains the same as those for the half-wave dipole. Thus,

$$D = \frac{U_{\max}}{U_{av}} = \frac{U_{\max}}{P_r/2\pi} = 1.64. \tag{2-22}$$

Therefore, this is the same as the directivity of a half-wave antenna [3].

2.4 Types of Dipole Antennas

Part of the beauty of dipole antennas, like many other simple things, is their flexibility. Dipoles can be installed in an infinite number of configurations other than the classical flat-top arrangement (see Figure 2.5 (G)).

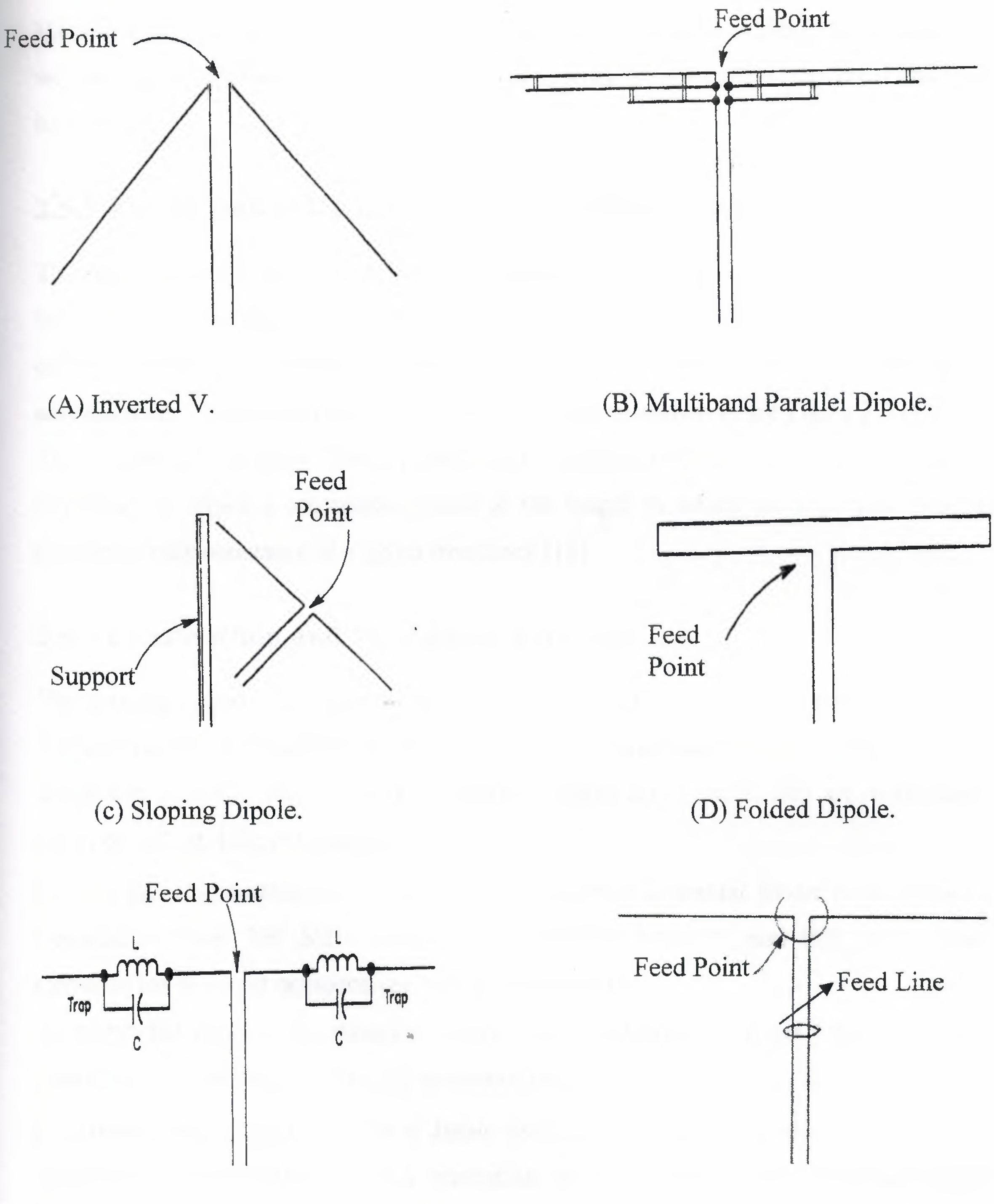
Some of the more common variations include the inverted V or sometimes is called the drooping dipole (see Figure 2.5 (A)); multiband parallel dipole (see Figure 2.5 (B)); sloping dipole (see Figure 2.5 (C)); folded dipole (see Figure 2.5 (D)); and trap dipole (see Figure 2.5 (E)) and vertical dipole rotated 90^0 (see Figure2.5 (F)).

Inverted-V dipoles are probably more common than flat-top versions. As we might expect, the inverted V gets its name from its shape. The main advantages of inverted V are that they need only one high support, and that you can get more total wire into the

same horizontal space using this configuration. This is often an important advantage on the lower-frequency bands, where real estate and support height suitable for putting up a full-size dipole are at a premium. Inverted V usually work almost as well as horizontal flat-top dipoles when the dipole's height is the same as the feed-point height of an inverted V. Another common dipole configuration is the multiband parallel version.
In such an antenna (Figure 2.5 (B)), multiple dipole elements are fed at the same point, with a single feed line, and supported by spacers attached to the longest dipole element. The main advantage of parallel dipoles is multiband coverage with resonant elements on each band, allowing the use of a single coaxial feed line for several bands without the need for an antenna tuner. An inherent disadvantage of parallel dipoles, however, is narrower bandwidth than single dipoles provide.

Two other fairly popular dipole variations are the trap dipole and the folded dipole. Traps are tuned circuits (consisting of inductance and capacitance) that electrically isolate the inner and outer sections of the antenna at certain frequencies, providing multiband resonant coverage from a single antenna. At a trap's resonant frequency, it presents high impedance and therefore isolates the outer segments of the dipole, making the antenna electrically shorter than it is physically. At frequencies below the trap's resonance, it has a low impedance, which makes it transparent to radio frequency (RF) (i.e., it doesn't isolate any part of the antenna). Traps aren't used only in dipoles: Trap Yagi beams and verticals are also popular.

Folded dipoles are a bit less common in Amateur Radio use, they use full-length parallel wires shorted at the ends, and have feed-point impedances that provide good matches to balanced feed lines. FM-broadcast receivers usually use folded dipoles made from TV twin lead [18].



(A) Inverted V.

(B) Multiband Parallel Dipole.

(c) Sloping Dipole.

(D) Folded Dipole.

(E) Trap Dipole.

(G) Vertical Dipole.

Figure 2.5 Variations on the dipole are numerous

2.5 Implementing Multiband Parallel Dipole Antenna

Having discussed the characteristics, radiation shape and types of dipole antennas, thus, we choose a multiband parallel dipole antenna since it is simple in construct and also low in cost.

2.5.1 The Technical Definition of the Dipole Antenna

The dipole gets the name from the two of halves the on two sides of its center. It is a balanced antenna, meaning that the poles are symmetrical. They are equal lengths and extend in opposite directions from the feed point. Its simplest form, a dipole is an antenna made of wire aluminum and fed at its center as shown in see Figure 2.5 (F).

To be resonant, a dipole must be electrically a half wavelength long at the operating frequency. A dipole's resonance occurs at the length at which its impedance has no reactance, only resistance at a given frequency [18].

2.5.2 Construction and Impedance Matching

The antenna system shown in the Figure 2.6 consists of a group of center-fed dipoles. All are connected in parallel at the point where the transmission line joins them. The dipole elements are stagger-tuned as shown in Figure 2.6. That is, they are individually cut to be $\lambda/2$ at different frequencies.

Here in this implementation we have 5 elements with a coaxial feeder cover range of frequencies from 500 MHz, 600 MHz, 700MHz, 800MHz and 900 MHz, those elements has been cut perspectives with the frequencies.

To match the range of frequencies, it has been found difficult to get a good match to coaxial line on all bands. The $\lambda/2$ resonant length of any one dipole in the presence of the others is not the same as for a dipole itself due to interaction, and the attempts to optimize all four lengths can be a frustrating procedure. The problem is compounded because the optimum tuning changes in a different antenna environment, so what works for one amateurs with limited antenna space are willing to accept the mismatch on some bands just so they can operate on those frequencies using a single coaxial feed line [16]. Since this antenna system is balanced, it is desirable to use a balanced transmission line to feed it. The most desirable type of line is 75-Ω transmission twin-lead as shown in Figure 2.6.

The separation between the dipoles for the various frequencies does not seem to be especially critical. One set of wires can be suspended from the next larger set, using wounding spreaders to give a separation of a few inches. Users of this antenna often run some of the dipoles at right angles to each other to help reduce interaction [16].

The formula may we need to implement these elements is in section 2.2.1, rewritten as

$$2h = \frac{\lambda}{2} \tag{2-23}$$

The elements we need to implement a parallel multiband antenna has been calculated as of Equation (2-23) and listed in the Table 2.1.

Table 2.1 Elements designed

Number of element	Frequency range	Calculated element for 2h
1	500 MHz	0.3 m
2	600 MHz	0.25 m
3	700 MHz	0.214 m
4	800 MHz	0.1875 m
5	900 MHz	0.167 m

Having calculated the lengths of the five elements, we then show their general multiband parallel configuration in the Figure 2.6.

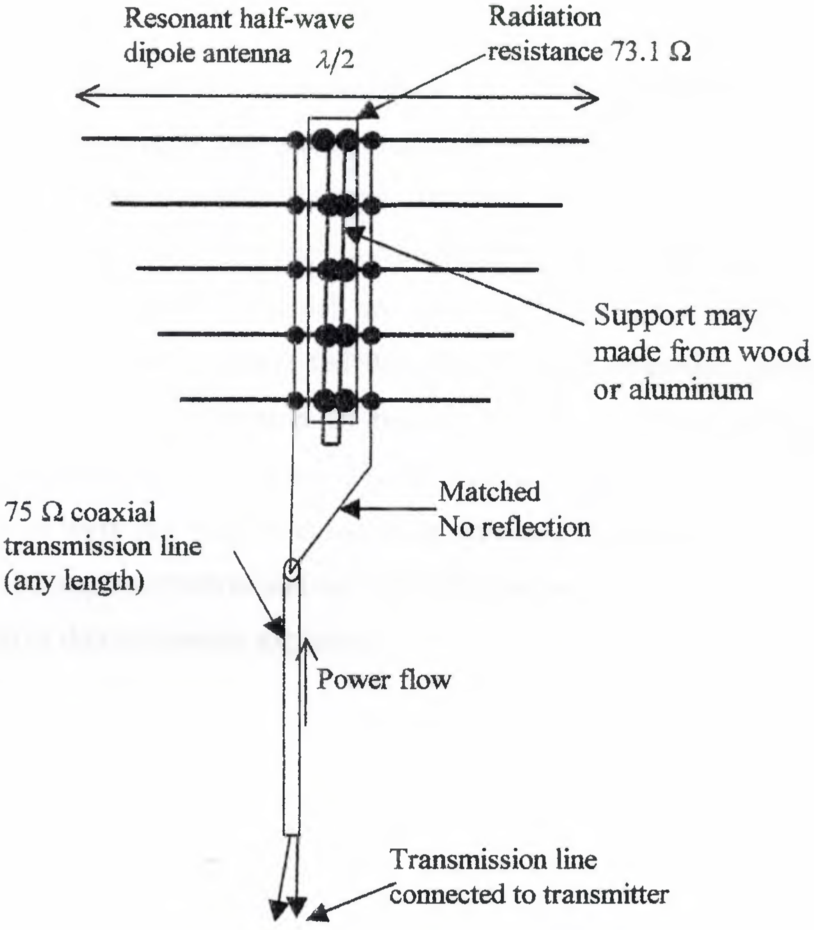


Figure 2.6 Multiband antenna using paralleled dipoles all connected to common coaxial cable feeding at half-wave dipole antenna.

2.6 Advantages and Applications of Dipole Antenna

For almost any kind of MF/HF operation, dipoles are easy to build and install, and they give good results when put up at any reasonable height. That is anywhere from a few feet and up, depending on the bad. A good general height guideline is half a wavelength or more, especially on 40, 80 and 160 meters. At the least, a dipole should clear any surrounding buildings, and other large obstacles, for good performance. Many hams do quite well with dipole antennas that are electrically low; as a bonus, this antenna works even better at higher frequencies [18].

2.7 Summary

So far, the radiation fields and characteristic properties of an elemental electric dipole. We then consider finite-length thin linear antennas of which the half-wave dipole antenna is an important special case. We have discussed the dipole length and manner which it is excited and how much the radiation characteristics are largely determined by length and manner of it. Parameters which are associated with linear dipole antennas; these are current distribution on center-fed thin linear dipole antennas, far-zone field intensities, pattern function, estimation of beamwidth, the radiation resistance and directivity of a center-fed linear half-wave dipole antenna. Types of antenna have been discussed and one of them has been selected as an practical example for our study and discussed thought of implementation and its configuration, such as a multiband antenna. Finally application of dipole antenna explained.

CHAPTER THREE

ANTENNA MEASUREMENTS

3.1 Overview

The antenna measurements are needed often to validate theoretical data, and sometimes to determine some values, which are very difficult to have by calculations. The antenna measurements almost lie within two basic categories: impedance measurements and pattern measurements. The input impedance deals with one of the most important antenna parameters, and the radiation pattern is a very broad and equally important one, with many subcategories, such as measurements of beamwidth, minor lobe level, gain, and polarization characteristics. Measurements of efficiency and noise may also be desired in some instances. Not all these possible measurements need to be made in every situation

This chapter present the measurements methods associated with basic categories above mentioned.

3.2 Problems of the Measurements

It is seldom that the complete antenna pattern is measured, including side lobes and polarization characteristics in all directions, at the higher frequencies; it can be assumed that antenna ohmic losses are negligible, and therefore the radiation efficiency factor need not be measured. The beamwidth, gain, and side lobe level are also frequently important, especially at the higher frequencies where directional antennas are often used. Polarization measurements are important only in special cases.

Experimental investigations suffer from a number of drawbacks such as:

I. For pattern measurements, the distance to the far-field region $\left(r > 2D^2/\lambda\right)$ is too long even for outside ranges. It also becomes difficult to keep unwanted reflections from the ground and the surrounding objects below acceptable levels.

2. In many cases, it may be impractical to move the antenna from the operating environment to the measuring site.
3. For some antennas, such as phased arrays, the time required to measure the necessary characteristics may be enormous.
4. Outside measuring systems provide an uncontrolled environment, and they do not possess an all-weather capability.
5. Enclosed measuring systems usually cannot accommodate large antenna systems (such as ships, aircraft, large spacecrafts, etc.).
6. Measurement techniques in general, are expensive.

Some of the above shortcomings can be overcome by using special techniques such as the far-field pattern prediction from near-field measurements. Scale model measurements and automated commercial equipment specifically designed for antenna measurements and utilizing computer assisted techniques, but these methods are excessively expensive [6].

3.3 Measurements Method

3.3.1 Impedance Measurements

There are two types of input impedance measurement associated with an antenna; self- and mutual impedance. When the antenna is radiating into an unbounded medium and there is no coupling between it and other antennas or surrounding obstacles, the self-impedance is also the driving-point impedance of the antenna. If there is coupling between the antenna under test and other sources or obstacles, the driving-point impedance is a function of its self-impedance and the mutual impedances between it and the other sources or obstacles. In practice, the driving-point impedance is usually referred to as the input impedance.

To attain maximum power transfer between a source or a source transmission line and an antenna, a conjugate match is usually desired. In some applications, this may not be the most ideal match. For example, in some receiving systems minimum noise is attained if the antenna impedance is lower than the load impedance. However, in some transmitting systems, maximum power transfer is attained if the antenna impedance is greater than the load impedance. If conjugate matching does not exist, the power lost can be computed by using

$$\frac{P_{lost}}{P_{available}} = \left| \frac{Z_{ant} - Z^*_{cct}}{Z_{ant} + Z_{cct}} \right|^2 . \tag{3-1}$$

where Z_{ant} is input impedance of the antenna and Z_{cct} s input impedance of the circuits which are connected to the antenna at its input terminals.

When a transmission line (see Sec. 1.4) is associated with the system, as is usually the case, the matching can be performed at either end of the line. In practice, however, the matching is performed near the antenna terminals, because it usually minimizes line losses and voltage peaks in the line and maximizes the useful bandwidth of the system. In a mismatched system, the degree of mismatch determines the amount of incident or available power which is reflected at the input antenna terminals into the line. The degree of mismatch is a function of the antenna input impedance and the characteristic impedance of the line. These are related to the input reflection coefficient and the input VSWR at the antenna input terminals by the standard transmission line relationships given by

$$\frac{P_{refl}}{P_{inc}} = |\Gamma|^2 = \frac{|Z_{ant} - Z_c|^2}{|Z_{ant} + Z_c|^2} = \left| \frac{|VSWR - 1|}{VSWR + 1} \right|^2 , \tag{3-2}$$

where $\Gamma = |\Gamma| e^{j\gamma}$ which denotes voltage reflection coefficient at the antenna input terminals, VSWR denotes voltage standing wave ratio at the antenna input terminals and Z_c denotes characteristic impedance of the transmission line.

Hence, Equation (3-2) shows a direct relationship between the antenna input impedance Z_{ant} and the VSWR. In fact, if Z_{ant} is known, the VSWR can be computed using Equation (3-2). In practice, however, that is not the case. What is usually measured is the VSWR, and it alone does not provide sufficient information to uniquely determine the complex input impedance. To overcome this, the usual procedure is to measure the VSWR, and to compute the magnitude of the reflection coefficient using Equation (3-2). The phase of the reflection coefficient can be determined by locating a voltage maximum or a first voltage minimum (from the antenna input terminals) in the transmission line as in Figure 3.1. Since in practice the minima can be measured more accurately than the maxima, they are usually preferred. In addition, the first minimum is usually chosen unless the distance from it to the input terminals is too small to measure accurately. The phase γ of the reflection coefficient is then computed using by using

$$\gamma = 2\beta x_n \pm (2n-1)\pi = \frac{4\pi}{\lambda_g} x_n \pm (2n-1)\pi, \quad n = 1, 2, 3 \ldots \tag{3-3}$$

where n denotes the voltage minimum from the input terminals (i.e., n is used to locate the first voltage minimum), X_n denotes distance from the input terminals to the nth voltage minimum and λ_g denotes wavelength measured inside the input transmission line (it is twice the distance between two voltage minima or two voltage maxima).

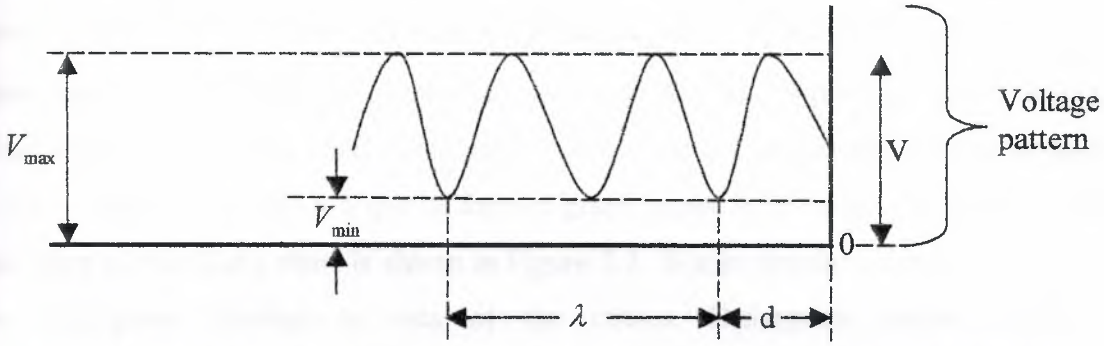


Figure 3.1, Diagram showing quantities to be measured in sand-wave method of impedance determination.

Once the reflection coefficient is completely described by its magnitude and phase, it can be used to determine the antenna impedance by

$$Z_{ant} = Z_c\left[\frac{1+\Gamma}{1-\Gamma}\right] = Z_c\left[\frac{1+|\Gamma|e^{j\gamma}}{1-|\Gamma|e^{j\gamma}}\right]. \tag{3-4}$$

Other methods, utilizing impedance bridges, slotted lines, and broadband swept-frequency network analyzers can be used to determine the antenna impedance [7].

3.3.1.1 Impedance Charts

When VSWR and the position of a voltage minimum d have been measured, calculation of the antenna input impedance could be made from the basic equations. The considerable labor of using these equations is usually avoided by using an impedance chart of one form or another. These charts are graphical representations of the impedance relationships expressed by the equations. A common feature of all the charts is that they deal with dimensionless ratio, rather than directly with physical quantities. The ratios involved are primarily ratios of impedance, length, and voltage, specifically, the ratio of the load impedance of the line to its characteristic impedance (Z_L / Z_0), the ratio of the distance from the load to a voltage minimum to the wavelength (d /λ), and the ratio of maximum to minimum standing-wave voltages VSWR. Conversions from two of these ratios to the physical quantities Z_L and d, and vice versa are readily made since Z_0 and Z_l are presumed to be known quantities. Because they deal with ratios, the same charts can be used for all characteristic impedances, frequencies, and absolute voltage levels. The Smith chart is the most widely used impedance chart it was devised by P.H. Smith. It is in effect a special form of graph paper, for plotting impedances. The basic plan of the Smith chart is shown in Figure 3.2. Within circular boundary there are two orthogonal families or sets of the circles. Orthogonal means, roughly, perpendicular, in the sense that the circles of one family intersect those of the other family perpendicularly, that is, at right angles. There is one point on the chart through which every circle of both families passes, this is the point at the exact bottom of the chart. The circles of one family pass through this point horizontally; those of the other family go through it vertically. The first of these families of circles represent constant values of the ratio R_L/Z_O and will be referred to as R circles. The second family of circles corresponds to constant values of X_L/Z_o and will be referred to as the X circles. R_L and X_L are of course the resistive and reactive components of the load impedance Z_L. The X circles to the left of the center line are negative values of X_L/Z_o, representing capacitive reactance, and those on the right are positive, representing inductive reactance. The vertical center line is the $X_L = 0$ line. The R circle that passes through the exact center of the chart represents R_L/Z_L equal to 1. Therefore the exact center point of the chart corresponds to load impedance that is a pure resistance of value equal to the characteristic impedance; that is, at this point R_L/Z_L and $X_L = 0$. This point is the load value that results in a unity value of *VSWR*. These two families of circles are in effect a system of coordinates, one coordinate set representing the resistive component and the other set the reactive component of the load impedance. Any particular point on the chart corresponds to load impedance, Z_L whose components are given by the two orthogonal R and X circles that intersect at that point. In addition to these R and X coordinates, there is another set of coordinates for measured quantities *VSWR* and d/λ. These coordinates are not printed on the chart, since they would result in a hodgepodge of lines and make it difficult to read the chart. Instead, they are to be plotted in by the user for the specific measured values in a particular case. The *VSWR* coordinates are circles whose centers are at the center of the Smith chart, that is, at the $(X_L/Z_0 = 0, R_L/Z_0 = 1)$ point. This point corresponds to *VSWR=1* and the circles of increasing size correspond to increasing values of *VSWR*.

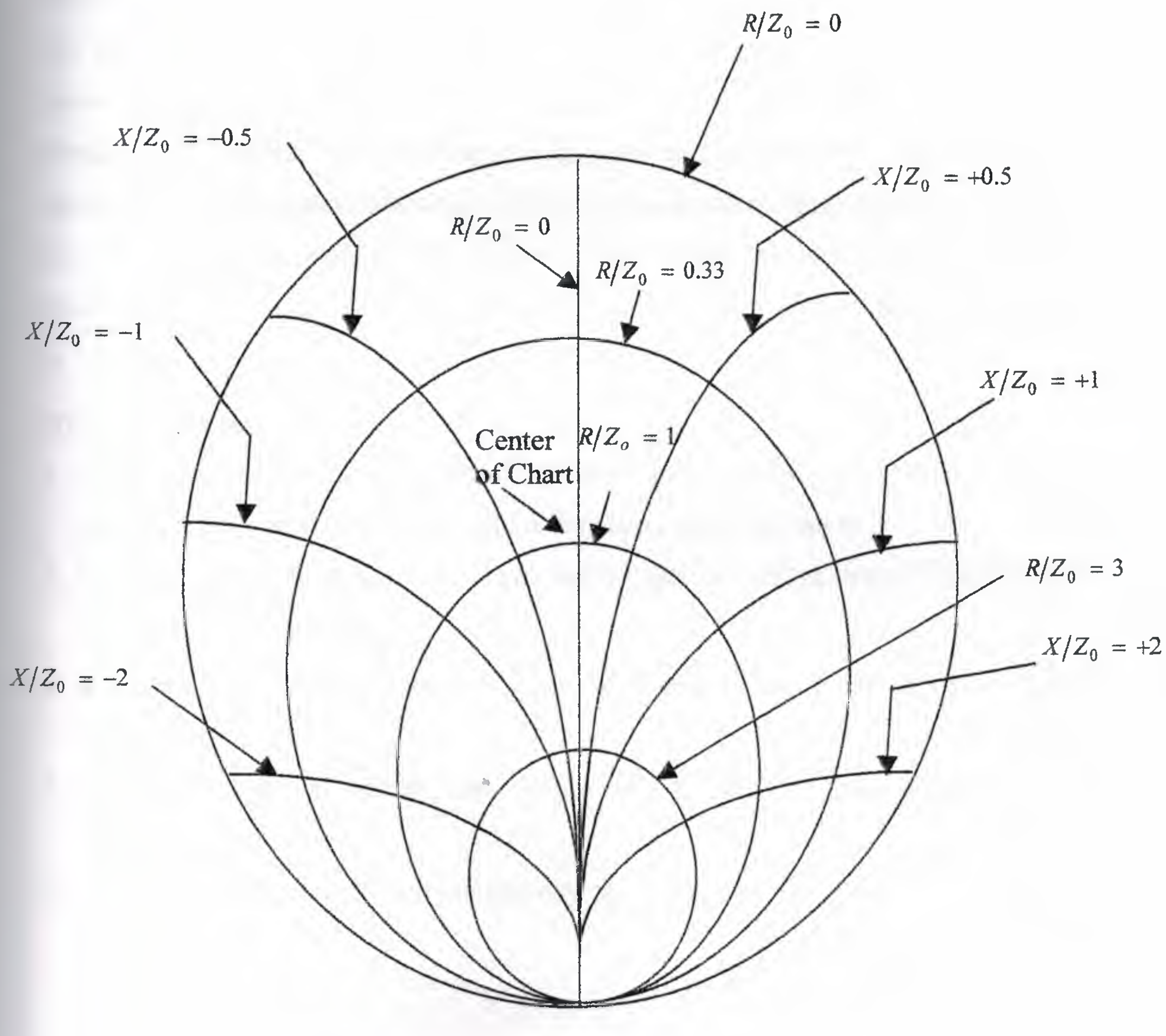


Figure 3.2 Basic construction of the Smith chart.

The largest of these circles forms the outer boundary of the chart represents an infinite *VSWR*. The coordinates are radial lines emanating from the center of the chart. A circular scale of values of d/λ is provided on the outer periphery of the chart. The full circle spans the range from $d/\lambda = 0$, at the top of the chart, through $d/\lambda = 0.25$ at the bottom of the chart, to $d/\lambda = 0.5$ again at the top; thus the complete circle of values corresponds to values of d going from zero to 0.5 wavelength. The values increase counterclockwise, when d is the distance from the antenna terminals to the first voltage minimum. This direction on the scale is usually marked wavelength toward the load, which refers to the location of the null when the load is short circuited, with respect to the voltage minimum with the short removed. A complementary scale is also usually provided, marked wavelengths toward the generator. This scale increases in the opposite direction and corresponds to the distance from the voltage minimum (short removed) to the nearest null (load shorted) in the direction of the generator (signal source).

An example of this method, it is supposed that *VSWR* has been measured to be 3.5 (unitless) and d/λ also has been measured to be 0.16 (unitless). It is required to find Z_L if $Z_0 = 50\Omega$ [6].

By using the following steps

1. Circle whose center is at the center of Smith Chart, passing through the VSWR=3.5 point on the vertical center line, will be drawn, as shown in Figure 3.3.
2. Determine the d/λ point on the chart, and a radial line will be drawn from the center of the chart to this point.
3. At intersection of this circle and radial line a pair of the X and R circles will be found.
4. From R and X circles the values of R and X are obtained to be [$R = 0.6$ and $X = 1.4$].
5. From R, X, R_L and X_L are calculated as $R_L = RZ_0$, and $X_L = XZ_0$.

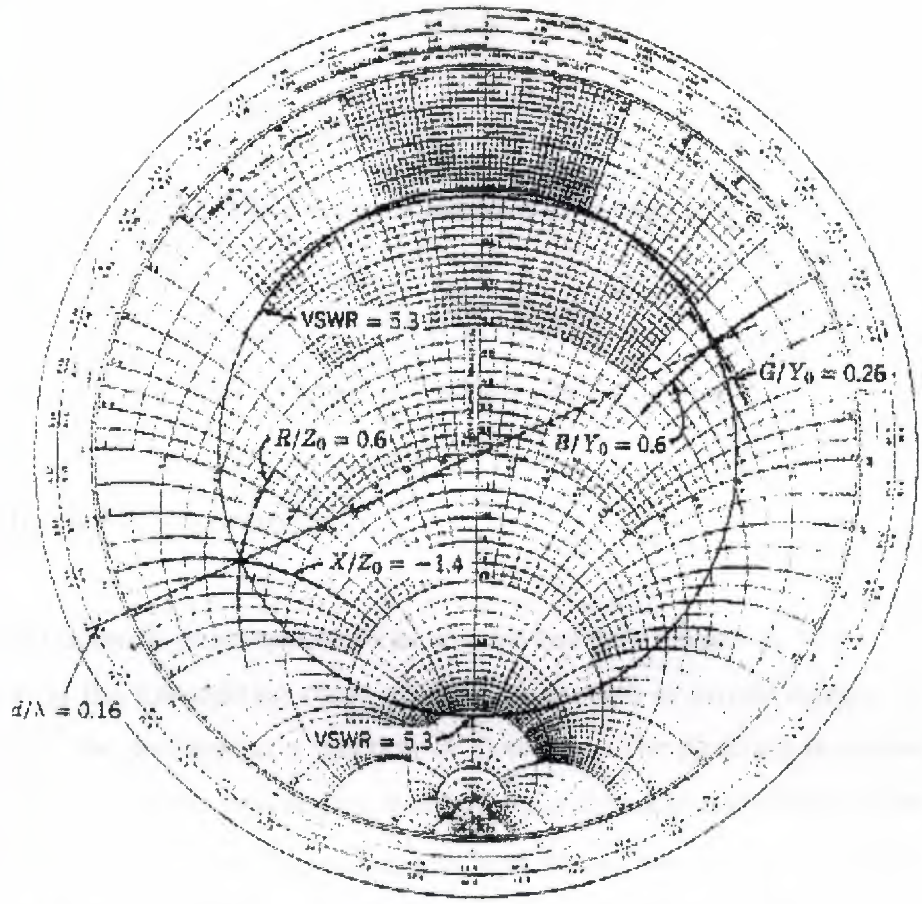


Figure 3.3 Example of impedance and admittance calculation using Smith chart [6].

Therefore, the antenna input impedance in this case consists of a resistive component $R_L = 0.6Z_0$ and negative (capacitive) reactance component $X_L = -1.4Z_o$, while the characteristic impedance is 50Ω, then $R_L = 30\Omega$ and $X_L = -70\Omega$, so that $Z_L = (30 - j70)\Omega$.

The previous example illustrates the basic use of the Smith chart. It can be used to solve impedance–matching problem, for this purpose it is often convenient to work with admittance, rather than impedance which found on the chart for the knowledge no more, but it is out of this studying scope. It is useful to compare this result with the calculation method by assuming that Z_L is known with Z_L is known $Z_L = (30 - j70)\Omega$ [6].

In this case Γ is found via to Equation (3-4) as

$$1.523\angle -66.8 = \frac{1+\Gamma}{1-\Gamma}, \tag{3-5}$$

which gives

$$\Gamma = 1.46\angle 64. \tag{3-6}$$

Moreover, by Equation (3-2), we find VSWR as

$$VSWR = \frac{2.46}{0.46} \cong 5.3, \tag{3-7}$$

As shown in the last example. Finally, Equation (3-6) is used also to find d/λ as

$$\theta = \pi\left(1 - \frac{4d}{\lambda}\right) \text{ radians}, \tag{3-8}$$

$$64^0 = 180^0(1 - \frac{4d}{\lambda}) \text{ which yields } \frac{d}{\lambda} \cong 0.16.$$

3.3.2 Pattern Measurements

The pattern (radiation or reception) of an antenna has been defined in Sec. 1.3.2. It is a description (in the transmitting case) of the field strength or power density, at a fixed distance from the antenna, as a function of direction. The direction is conventionally expressed in terms of the two angles, θ and ϕ, of a spherical coordinate system whose origin is at the antenna. We should mention here that all patterns measurement is made at a sufficient distance from the antenna to conform to the far-field criterion (See sec. 1.3.3.2). A complete pattern measurement consists of measurement of the field strength and direction (polarization) for many different values of the angles θ and ϕ. In practice, the number of specific angular directions in which measurements must be made depends on the complexity of the pattern and the need for detailed pattern information in the particular application. Quite often only limited information is required since complete three-dimensional patterns are virtually impossible to plot on a plane sheet of paper. Also the horizontal and vertical patterns suffice practically for all applications. The main-lobe pattern in oblique directions can usually be adequately estimated from these principal plane patterns. However, if the detailed side-lobe patterns are of concern, as they may be in some radar applications and in other special cases, oblique-plane patterns will be of interest, for the side Lobes in these planes cannot be inferred from the principal-plane patterns[6].

3.3.2.1 Pattern Measurement Methods

The measurement of a pattern always involves two antennas-the one whose pattern is being measured, and another some distance away. One antenna transmits (radiates) and the other receives. Because of the reciprocity principle, the antenna whose pattern is being measured can be either the transmitting or the receiving member of the pair. The measured pattern will be the same in either case. In the following discussion the antenna whose pattern is being measured will be called the primary antenna, and the one used as the other terminal of the transmit-receive path will be called the secondary antenna, regardless of which one transmits and which one receives.

Two procedures are possible for measuring the pattern in a particular plane, such as the horizontal plane. In the first procedure the primary antenna can be held stationary-fixed in both position and aiming of the beam-while the secondary antenna is transported around it, along a circular path at a constant distance. The secondary antenna, if directional, is kept aimed at the primary antenna, so that only the primary antenna pattern will affect the result. In this procedure the primary antenna is most often the transmitting member of the pair, although this is by no means a necessary condition. Field-strength readings and direction of the secondary antenna from the primary antenna are recorded at various points along the circle. By measuring the field at enough points, a plot of the pattern of the primary antenna can be made. Examples of such a plot in both polar and rectangular forms are shown in Figure 3.4.

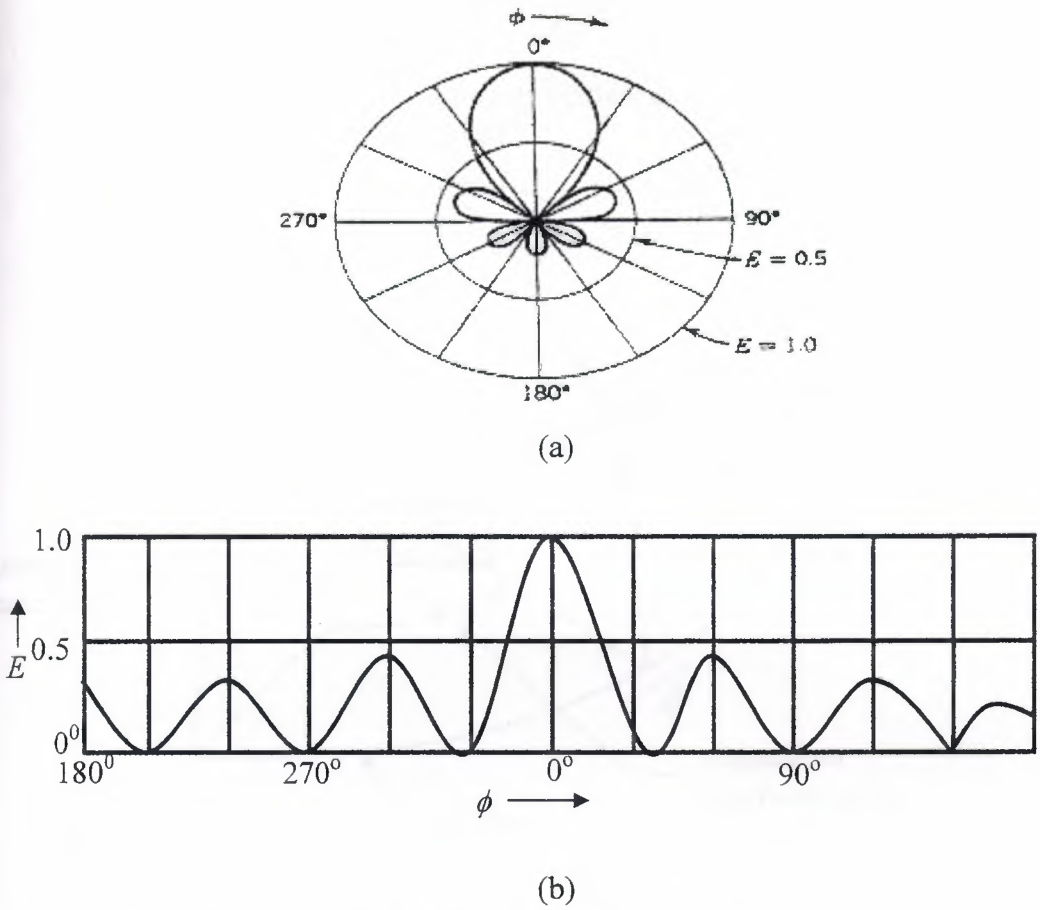


Figure 3.4 Comparison of plane pattern plotted in (a) Polar and (b) Rectangular form.

In the second procedure both antennas are held in fixed positions, with suitable separation and with the secondary antenna beam aimed at the primary antenna. The primary antenna is then rotated about a vertical axis (assuming both antennas to be in the horizontal plane) through an angular sector in which it is desired to measure the pattern (usually 360 degrees). In this method it is most convenient to transmit with the secondary antenna, so that both the field-strength readings and the direction measurements can be made at the primary antenna. The measurements can be made at a suitable number of fixed points, stopping the rotation of the antenna to take the readings; or if a pattern recorder is available, these pattern recorders are commercially available. Consider that the antenna under the test is situated at the original of the coordinates of Figure 3.5, with the Z-axial vertical. Then the pattern of θ and ϕ components of the electrical field (E_θ and E_ϕ) are measured as function of ϕ along constant θ circles ,

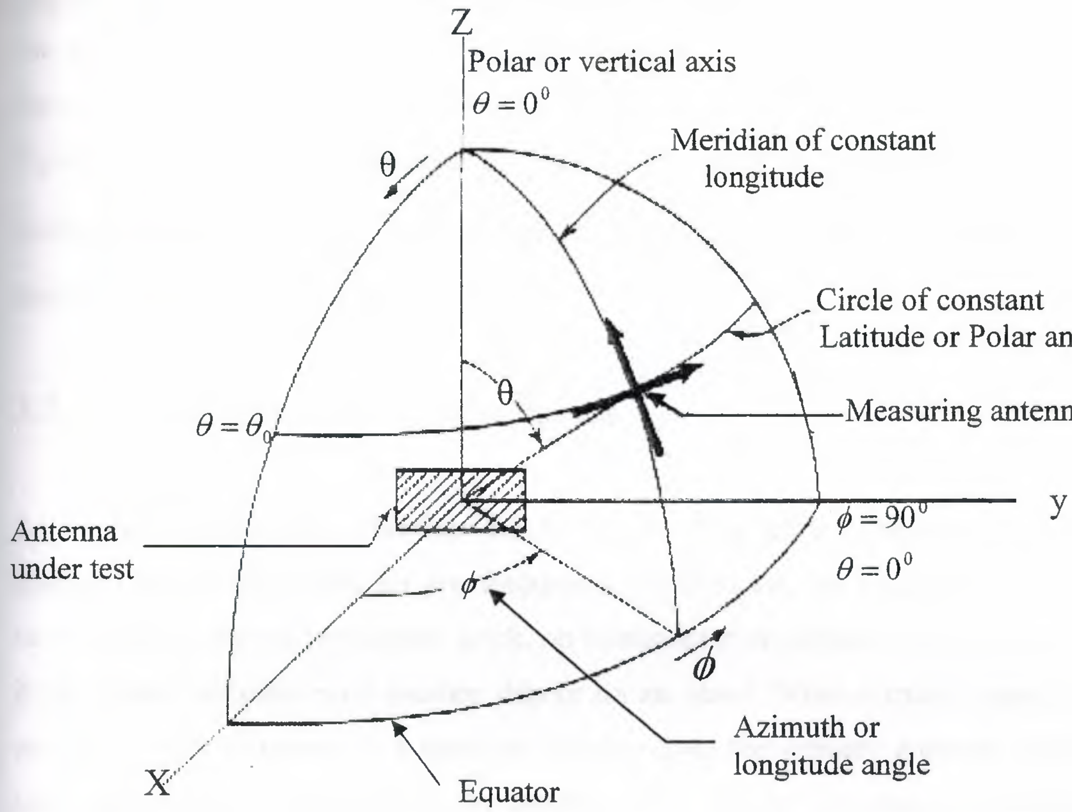


Figure 3.5 Antenna and coordinates for pattern measurements

where ϕ is the azimuthal angle which complement of the latitude angle. These patterns may be determined by moving the measuring antenna (secondary) with antenna under the test fixed (primary), or by rotating the antenna under the test on the vertical z-axial as shown in Figure 3.5 with the measuring antenna fixed [6].

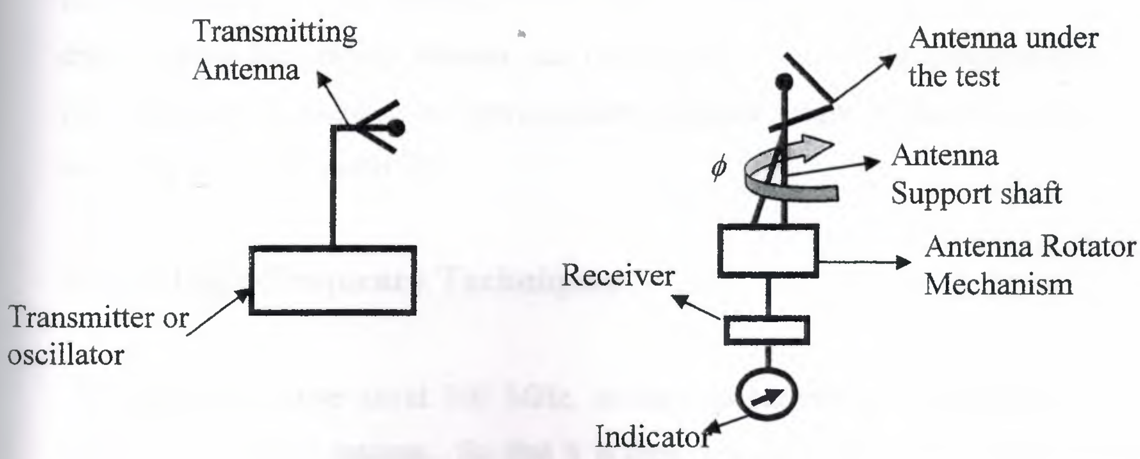


Figure 3.6 Antenna pattern measuring arrangement

The pattern measurement arrangements illustrated in Figure 3.6, with the antenna under the test acting as a receiving antenna, the transmitting antenna is fixed in position and the antenna under the test is rotated on a vertical axis by the antenna support shaft. The $E_\phi(\theta = 90, \phi)$ pattern is measured by rotating the antenna support shaft with both horizontal as in Figure 3.6. To measure the $E_\phi(\theta, \phi = 0)$ pattern, the antenna support shaft is rotated with both antennas vertical.

3.3.2.2 Low-Frequency Measurements

As we have mentioned in the Sec. 3.3.1, the first fixed primary antenna procedure is used to measure the pattern for low frequencies. In this case, the secondary antenna may be mounted on the roof of a panel truck, on a helicopter or airplane, or on a ship or boat if the primary antenna is on another ship or on an island. When a truck is used, it may not be possible to remain at a constant distance from the primary antenna, because of the obstructions or inaccessibility of certain areas. If the field-strength readings are taken at different distances in the different directions, they must be corrected to a constant distance to plot a meaningful pattern. The correction factor must be determined experimentally, since the law of field-strength decreases with distance cannot be reliably predicted for propagation of a surface wave over irregular terrain of varying conductivity. To determine the applicable correction, in a given direction, a number of readings must be taken at different distances on the same radial line from the primary antenna that is, in the same direction. This procedure is not necessary when the measurements are made with the secondary antenna on a ship or aircraft, if a constant distance from the primary antenna can be maintained during the measurements. It is also necessary to maintain an approximately constant height of the secondary antenna above the ground or water [6].

3.3.2.3 High-Frequency Techniques

At frequencies above about 100 MHz, an antenna pattern is customarily obtained by rotating the primary antenna. So that it is then especially important to make the field-strength measurements at points that are in the clear not too close to large buildings or power and telephone lines, when the pattern is to be measured by rotating the primary antenna, both antennas should be located so that they have an unobstructed view of each other, and also have the required separation to insure a far-field measurement.

A further requirement is that the area between the antennas be clear of sizable reflecting objects, not only in the direct line between them but for an appreciable distance on both sides. This requirement is important if an accurate measurement of low-amplitude side lobes is to be made. The secondary antenna is indicated to be the transmitting antenna, which is the customary arrangement because it permits all the measurements to be made at a single location, that is, at the primary antenna.

If a large reflecting object illuminated by the secondary antenna, some signal will be reflected toward the primary antenna, arriving at the angle α off the in-line direction between the two antennas. This signal will be considerably less than the in-line signal and will not seriously affect the measurement in the main lobe of the primary antenna, when the reflected signal will be received in the side-lobe portion of the primary antenna pattern. When the primary antenna is rotated to allow measurement of its sidelobe pattern at the angle α off axis, however, its main lobe will point directly at the reflecting object, as shown in the Figure 3.7. Then the reflected signal received in this way may be comparable to or even in excess of the in-line signal received in the side lobe, so that a considerably erroneous measurement will result. This effect is minimized by using a secondary antenna that is fairly directional, with high gain in the direction of the primary antenna and considerably reduced gain or perhaps even a null in the direction of the reflecting object. However, this requires that the secondary antenna be quite sizable and expensive.

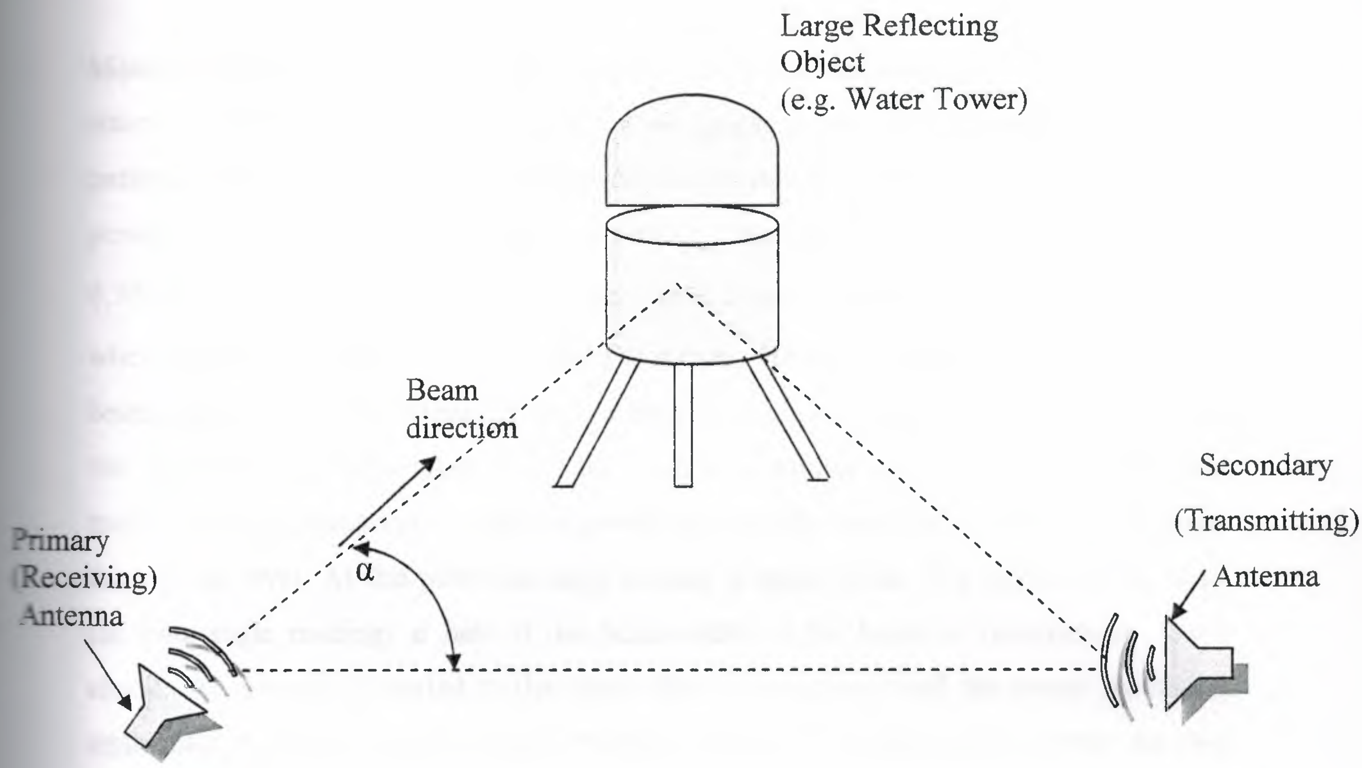


Figure 3.7 Effect of nearby reflecting object on pattern measurement.

If there is just one major reflecting object in a troublesome position, a null of the secondary antenna may be directed toward the object, if this is possible without too greatly reducing the radiation in the desired direction or giving it an incorrect polarization. It is essential for the secondary antenna to have the same polarization as the primary antenna. Ideally, the polarization of the secondary antenna should be controllably variable, so that the pattern of the primary antenna can be investigated for all polarizations. This is especially important in applications where very low side lobes are important, because side lobes may sometimes have a polarization different from that of the main-beam part of the pattern. Other possible remedies for the reflecting-object problem exist. One is to interpose absorbing material between the secondary antenna and the object, or between the object and the primary antenna. Another is to erect a reflecting barrier that will intercept the radiation going to or from the object and reflect it in some harmless direction. This barrier is usually a flat sheet of solid metal or mesh material set at an angle that will direct the reflected waves away from the primary antenna [6].

3.3.3 Beam width and Side-Lobe-Level Measurement

Measurements of beamwidth and side-lobe level are automatically obtained if the antenna pattern is measured and plotted on graph paper, either manually or with a pattern recorder. Therefore, the beamwidth is determined by determining the maximum power density or the maximum field density $E_{\max}$, so that it is determined at 0.5 $P_{\max}$ or 0.707 $E_{\max}$. It's also possible to measure these quantities without plotting the pattern when the primary antenna is on a rotatable mount. Hence measure the beam-width, the beam maximum is first found and then a field strength reading is taken. The reading of the angle setting is also taken. Then the antenna is rotated in either direction until the meter reading corresponds to half the power level of the beam maximum or 0.707 times the voltage level. At this point the angle reading is again taken. The difference between the two angle readings is half of the beam-width, if the beam is symmetrical. As a check, the antenna is rotated to the other side of maximum, until the power reading is again half maximum, and the angle reading is taken. The difference between the two half-maximum angle readings is the beamwidth. To measure the side-lobe level, the antenna is rotated and the meter reading is observed as the side-lobe portion of the pattern is traversed. The reading is noted at the maximum of the highest side lobe. The ratio of the power reading in this highest side lobe to the beam-maximum power reading or the ratio of the squares of the voltage readings give the side-lobe level expressed as a fraction. Ten times the logarithm of this fraction gives the side-lobe level in decibels, but we should note that negative value of the result is caused because the logarithm of a number less than one is negative [19].

3.3.4 Gain Measurement

In principle the directive gain can also be determined from the pattern measurement in accordance with to Equations 3.5 and 3.6.

$$D_{\max} = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}[E(\theta,\phi)/E_{\max}]^2 \sin\theta \, d\theta \, d\phi}, \tag{3-9}$$

Once the directivity $D_{\max}$ has been calculated from the relative pattern (see sec. 1.3.2.1) the directive gain in any other direction θ_1, ϕ_1 can also be simply determined from the following relationship

$$D_{(\theta_1,\phi_1)} = D_{\max}\left[\frac{E(\theta_1,\phi_1)}{E_{\max}}\right]^2. \tag{3-10}$$

This method is useful for antennas whose patterns are simple but it is of limited use for high-gain antennas with complicated side-lobe patterns or for multilobed patterns because the integration of Equation (3-10) is a solid-angle integral over the entire three-dimensional pattern of the antenna rather than over a plane pattern. Since the patterns as measured cannot ordinarily be expressed as analytic functions numerical integration is required. This is a very tedious procedure if carried out manually. The computation may be programmed for a high-speed digital electronic computer if such measurements are being made frequently, but the programming is too costly if it is to be used only once or a few times. The methods used to measure the gain are illustrated down in the following subsections [7].

3.3.4.1 Absolute-Field-Strength Method

This method of gain measurement is based on

$$D_t = \frac{4\pi R^2 E^2}{377 P_t} = \frac{4\pi R^2 P_{anetnna}}{P_t}. \tag{3-11}$$

This method requires an absolute measurement of the field intensity E or power density P at distance R from the antenna when it is radiating a total power P_t, the measurement being made in the direction of maximum radiation. However, if this method is to give the directive gain of the antenna itself, then the measurement must be made under free-space propagation conditions, that is, with no multipath interference due to earth reflection or any other factors that modify the free-space. Otherwise, we should take the propagation factor F into consideration as

$$F = \frac{E}{E_d}, \tag{3-12}$$

where E_d is the field strength in the free space and E is the measured field strength. On the other hand, if the measurement is made using Equation (3-11) with the antenna in its operating location, the gain measured is the effective gain of the antenna in combination with its environment. When earth reflection is involved, this gain will depend on the elevation angle of the measuring point, as well as on the antenna height and the reflection coefficient of the earth. If these factors are known or can be measured, the gain of the antenna by itself can be deduced. If a value of field intensity E is actually measured, by analysis of the reflection interference effect it may be calculated that E is greater or less than the value that would have been measured if free-space propagation existed, by the propagation factor F, as defined by Equation (3-12). In terms of this factor, Equation (3-11) can be rewritten so that it expresses the free-space gain of the antenna even if the field intensity E or the power density P is measured under nonfree-space conditions,

$$D_t = \frac{4\pi R^2 E^2}{377 P_t F^2} = \frac{4\pi R^2 P_{anetnna}}{P_t F^2}. \tag{3-13}$$

The absolute field intensity E can be measured at low frequencies as described in Sec. 3.3.1. At higher frequencies, it is more convenient to make the measurement in terms of the received power density P_r. This quantity is related to the receiving-antenna capture cross section (effective receiving area) A_r by

$$\rho_r = \frac{P_r}{A_r} = \frac{4\pi P_r}{K D_r \lambda^2}, \tag{3-14}$$

Which is a rearrangement of Equation (1-17), with the receiving antenna directivity denoted by D_r and P_i is the received power density. This formula can be used only if the effective area A_r of the receiving antenna is known and if the received power P_r can be measured [6].

3.3.4.2 Gain Measurement by Gain-Standard Antennas

A gain-standard antenna is one whose gain is accurately known so that it can be used in measurement of other antennas. Certain simple forms of antenna can be constructed to have gain of known amount. Alternatively, a standard antenna can be obtained by a gain measurement that does not require an antenna of known gain. This method, in its simplest form, does require two antennas that are identical. One is used as a transmitting antenna and the other for receiving, separated by a distance R. The transmitted power P_t and the received power P_r are both measured. The directivity of the antennas can then be calculated by an application of Equations (3-11) and (3-12). If the second expression given for P in Equation (3-12) is substituted into Equation (3-11), the result is

$$D_t = \left(\frac{4\pi R^2}{P_t F^2}\right)\left(\frac{4\pi P_r}{\xi D_r \lambda^2}\right), \tag{3-15}$$

where D_t denote the transmitting antenna directivity, If now it is instead regarded as the power delivered to the transmitting antenna terminals, D_t must be replaced by $G_t = \xi D_t$ and D_r by $G_r = \xi D_r$ Since it has already been stipulated that $G_t = G_r$, and the equation can then be solved for G, then the power gain of the two identical antennas:

$$G = \frac{4R}{7/8F}\sqrt{\frac{P_r}{P_t}}. \tag{3-16}$$

This procedure is most likely to be successful when $F \cong 1$, that is, under effectively free-space conditions or no earth-reflection interference effects. It can also be applied successfully under conditions that permit accurate calculation of F, as an example, when reflection occurs from a smooth water surface between the two antennas [6].

3.3.4.3 Gain Measurement by Comparison

At high frequencies the most common method of gain measurement is by comparison of the signal strengths transmitted or received with the unknown-gain antenna and a standard-gain antenna. This comparison is most conveniently made on a pattern range, with the same general setup of equipment used in pattern measurement and with the secondary antenna transmitting. The gain of this antenna need not be known, nor does the propagation factor, F affect the result as long as F does not vary appreciably over the apertures of the primary antenna and the gain standard. All that is required of the secondary antenna and its associated transmitter is that they do not vary the amount or frequency of the radiated power in the direction of the primary antenna throughout the measurement procedure. Since the gain of the unknown antenna is ordinarily higher than the gain of the gain standard, the standard antenna is first connected to the receiver, and aimed at the secondary antenna. The receiver gain is adjusted to give a convenient output meter indication. Then the antenna whose gain is to be measured is connected in place of the standard-gain antenna, and attenuation is introduced into the transmission line between the antenna and receiver until the output indication is the same as it was with the gain-standard antenna. If the attenuation factor, L, expressed as a power ratio greater than one, then the gain of the unknown antenna, G_a, is given by

$$G_a = LG_S \tag{3-17}$$

where G_s is the standard-antenna gain. Inasmuch as antenna gains and attenuator calibrations are often expressed in decibels, it is frequently convenient to make the calculation in decibels, in which multiplication is replaced by addition:

$$G_{a(dB)} = G_{s(dB)} + L_{dB} \tag{3-18}$$

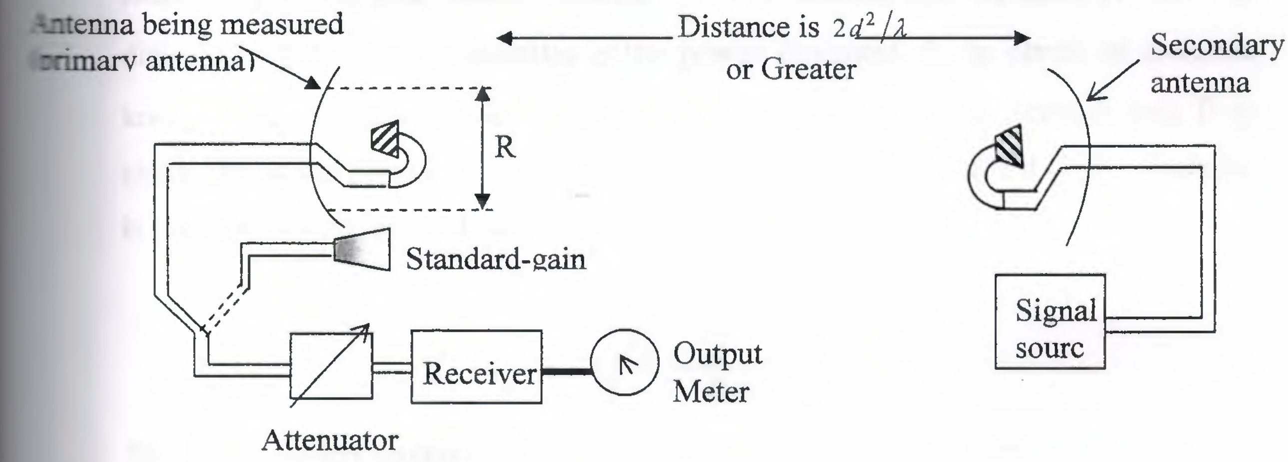


Figure 3.8 Set-up for gain measurement by comparison method.

In the unlikely event that the unknown antenna has a smaller gain than the standard, L in Equation (3-17) is expressed as a number less than one, and the decibel value of L in Equation (3-15) is negative. The basic set-up for gain measurement by the comparison method is diagrammed in Figure 3.8. It is essential in this method of gain measurement that both the unknown and the standard antenna are equivalently impedance-matched to the load presented to them by the transmission line. The best way to insure this is to make VSWR measurements with each of them connected in turn, and adjust the matching of each for a flat line (VSWR = 1). This method basically compares antenna power gains, but directivities may also be determined if the antenna radiation-efficiency factors are known [7].

3.3.5 Antenna Efficiency Measurement

The term efficiency has two different connotations in its application to antennas. One is related to the dissipative losses and the others to the ratio of the directivity to the aperture area.

3.3.5.1 Radiation Efficiency Measurement

The radiation efficiency ξ_r, a number less than one, expresses the ratio of the power radiated P_r to the total power delivered P_t, to the antenna input terminals or port. The difference of these two quantities is the power dissipated P_D in ohmic or dielectric losses. The radiation efficiency is also the factor applied to the directive gain D to obtain the power gain G in accordance with Equations (1-5) throughout (1-7). There are in principle several ways of measuring ξ_r, indicated by:

$$\xi_r = \frac{P_r}{P_t} = \frac{P_t - P_D}{P_t} = \frac{G}{D} \tag{3-19}$$

The last equation requires direct measurement of the total radiated power, which is possible only in special cases. Measurement of the total input power to the antenna P_t is not difficult, since this power flows in the transmission line connecting the transmitter to the antenna. The equation also requires measurement of the dissipated power P_D. This can sometimes be done, especially at low frequencies, by measuring the resistance of conductors in which current flows, and multiplying these resistances by the square of the current. Therefore, Equation (3-11) can be written as

$$K_R = \frac{4\pi R^2 E^2}{377 P_t^2 F^2 D}. \tag{3-20}$$

This equation is especially useful at VHF with short vertical grounded radiators (monopoles) as has been explained before in section 3.4 and shown in Figure 3.3 (a). For these antennas, D is already found, and we assume that $F \cong 1$. Therefore, if the total input power to the antenna P_t can be measured, and also the field strength E at distances D from the antenna, the radiation efficiency can be determined. Since the definition of ξ_r requires E to be the radiated field strength, R must be a distance satisfying the far-field criterion; that is, R must be greater than $2D_a{}^2/\lambda$ or greater than λ.

3.3.5.2 Aperture Efficiency Measurement

The other connotation of the term "efficiency" relates to the equation for the directive gain of a large-aperture type antenna-a horn, large unidirectional planar array, parabolic reflector, or lens. Equation 1-15 is written as

$$D = \xi_A\left(\frac{4\pi A}{\lambda^2}\right) \tag{3-21}$$

where A denotes the geometric area of the aperture and λ denotes the wavelength. In this context, ξ_A is called the aperture efficiency. If the field intensity over the aperture of an antenna is uniform then $\xi_A = 1$. This is the largest value of ξ_A practically attainable, typical values of ξ_A range from somewhat less than 0.5 to nearly 1.0. The measurement of directive gain D leads to the determination of ξ_A by

$$\xi_A = \frac{D\lambda^2}{4\pi A} \tag{3-22}$$

3.3.6 Radiation Resistance Measurement

The radiation resistance of an antenna, by Equation (1-9), is the ratio of the power radiated to the square of the antenna current. As mentioned, it is in a sense a fictitious quantity, since it is referred to an arbitrary point in the antenna and has different values for different reference points. It is conventional to refer it to the current-maximum point, although it may also be referred to the feed point. In many cases the two points are one and the same; as an example is the case of a center-fed dipole as mentioned in Sec2.2 and shown in Figure 2.1.

When referred to the current-maximum point, it is sometimes known as the loop radiation resistance, since a current maximum is also called a current loop. If there is no ohmic loss in the antenna, that is, if all the input power is radiated then the radiation resistance referred to the feed point is equal to the resistive component of the antenna input impedance. In this case, measurement of the antenna input impedance constitutes a measurement of its radiation resistance. If the feed point is not a current-maximum point, the loop radiation resistance may be calculated from the feed-point radiation resistance from the formula:

$$R_{r(loop)} = R_{R(feedpoit)}\left[\frac{I_{feedpoint}}{I_{\max imum}}\right]^2, \tag{3-23}$$

where I denotes the currents at the points indicated by the subscript notation. If there is appreciable ohmic loss, so that the antenna radiation efficiency factor ξ_r is less than one. From Equation (1-9), the radiation resistance is found to be

$$R_r = \xi_r R_i, \tag{3-24}$$

where R is the input resistance, that is, the resistive component of the input impedance. It is apparent that the radiation resistance is sometimes a rather nebulous concept and not always easily measured. In general, it is a useful concept only when it is readily measurable. It has no meaning for antennas in which there is no clearly defined current value to which it can be referred [6].

3.3.7 Polarization Measurement

The polarization has been explained before in Sec. 1.3.1 and here are four methods for polarization measurements.

1. Polarization-pattern method. A linearly polarized antenna is used to measure a polarization pattern and two circularly polarized antennas are used to determine the hand of rotation.
2. Linear-component method. Two perpendicular linearly polarized antennas are used to measure the linearly polarized components of the wave and also their phase difference.
3. Circular-component method. Two circularly polarized antennas are used to measure the circularly polarized components of the wave of opposite hand and the phase

angle between them.

3. Power measurement (without phase) method. Some waves may consist of superposition of a large number of statistically independent waves of a variety of polarizations. The resultant wave is said to be randomly polarized or unpolarized. Thus waves may be partially polarized and partially unpolarized.

Table 3-1 Wave characteristic determined by power measurements of six antennas

Wave	Vp Dipole	HP Dipole	$+35^0$ Dipole	-45^0 Dipole	RCP helix	LCP helix
VP	1	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
HP	0	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
$+45^0$ LP	$\frac{1}{2}$	$\frac{1}{2}$	1	0	$\frac{1}{2}$	$\frac{1}{2}$
-45^0 LP	$\frac{1}{2}$	$\frac{1}{2}$	0	1	$\frac{1}{2}$	$\frac{1}{2}$
RCP	1	1	1	1	1	0
LCP	1	1	1	1	0	1
Unpolarized	1	1	1	1	1	1

In ordinary communications the waves are usually completely polarized but in radio astronomy the waves from celestial sources are partially polarized and in many cases completely unpolarized. The interest here is that polarization characteristics of a wave (including any unpolarized components may be completely determined without any phase measurements by noting power response of 6 antennas: 1 vertically polarized (VP), 1 horizontally polarized (HP), 1 linearly polarized (LP) at a slant angle of $+45^0$, 1 linearly polarized (LP) at a slant angle of - 45^0 and 2 circularly polarized (CP) antennas, one right-circularly polarized (RCP) and the other left-circularly polarized (LCP). The linearly polarized antennas may be dipoles and the circularly polarized antennas nionofilar axial-mode helices, one wound right- handed and the other left-handed. For a completely polarized wave only 3 independent measurements are necessary so there is some redundancy. An example of the responses of the 6 antennas to a wave of unit incident power density is shown in Table 3-1. The power response of all 6 antennas normalized to unity for a wave of unit incident power density of the same polarization. We note that each type of wave polarization produces a differ set of power responses [13].

3.3.7.1 Polarization-Pattern Method

In this method a rotatable linearly polarized antenna, such as the $\lambda/2$ dipole antenna in Figure 3.9(a) is connected to a receiver calibrated to read relative voltage. Let the wave be approaching (out page). Then as the antenna is rotated in the plane of the page, the voltage observed at each position is proportional to the maximum component of $\vec{E}$ in direction of the antenna. Such measurements of the incident wave with a rotable linearly polarized antenna do not yield the polarization ellipse of the wave but rather its polarization pattern Figure 3.9 (b). Thus, if the tip of the electric vector $\vec{E}$ describes the polarization ellipse shown in Figure 3.9 (b) (dashed curve), the variation measured with a linearly polarized receiving antenna is given by the Polarization pattern in Figure 3.9 (b). For a given orientation *OP* of the linearly polarized antenna, the response is proportional to the greatest ellipse dimension measured normally to *OP*. As shown in Figure 3.9 (b), this is the length *OP'*. If the linearly polarized antenna orientation is *OQ*, the response is proportional to the length *OQ'*. For the case of linear polarization, the polarization ellipse degenerates to a straight line and the corresponding polarization pattern is a figure-of-eight, as indicated in Figure 3.9 (c). By graphical construction as in Figure 3.9 (b) and (c), the polarization ellipse can be constructed if the polarization pattern is known, or vice versa is true.

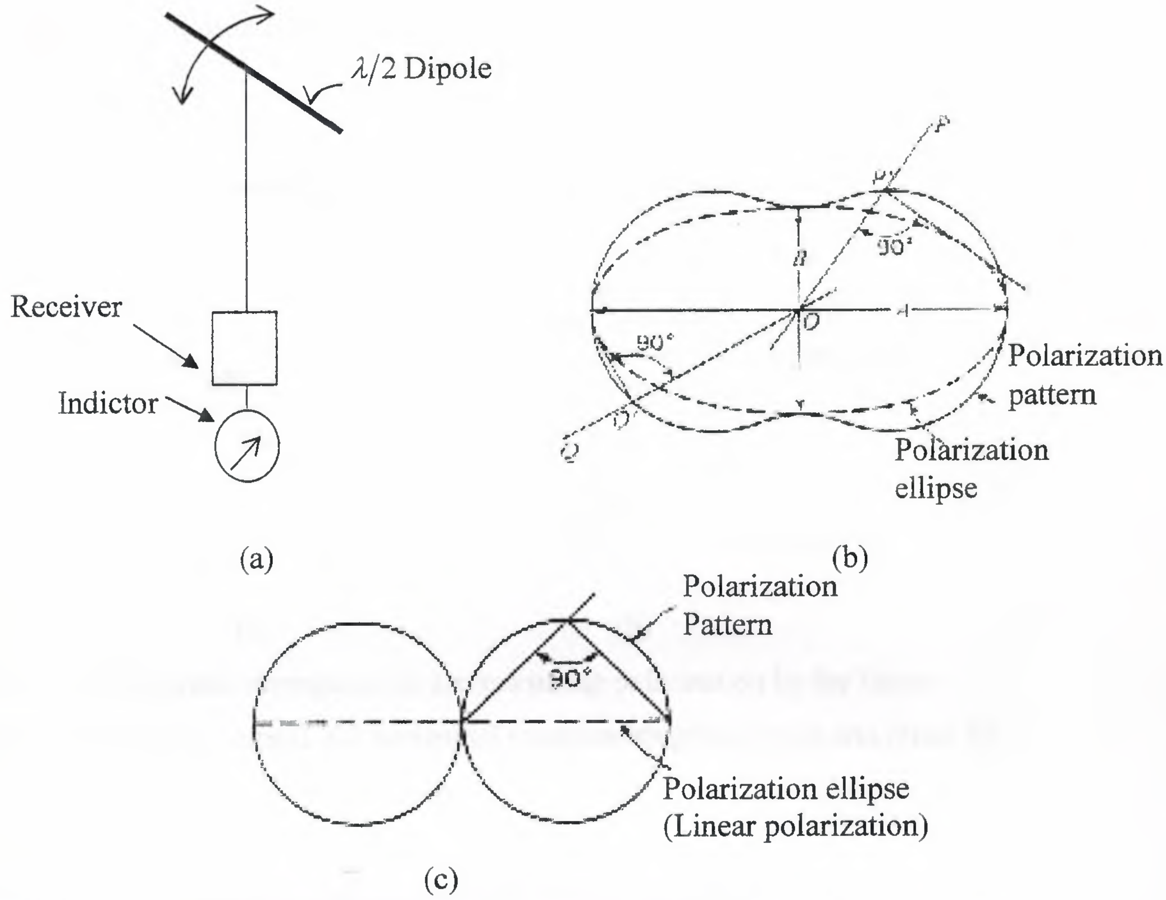


Figure 3.9 (a) Schematic arrangement for measuring wave polarization by the polarization-pattern method. (b) Measured polarization pattern and polarization ellipse for elliptical polarization. (c) Measurements polarization pattern for linear polarization with polarization ellipse collapsed to a line.

To determine the direction of rotation of $\vec{E}$ an auxiliary measurement is necessary. For example, the output of 2 circularly polarized antennas could be compared, one responsive to right- and the other to left-circular polarization. The rotation direction of $\vec{E}$ then corresponds to the polarization of the antenna with the larger response.

Thus, by this method the polarization ellipse can be drawn and the rotation direction indicated. Although such a diagram completely describes the polarization characteristics of a wave, it is simpler to measure merely the maximum amplitude $A/2$ and the minimum amplitude $B/2$ and take the ratio of the two amplitudes which is the axial ratio of the polarization ellipse or simply the axial ratio (AR). The axial ratio is expressed so that it is equal to or greater than unity.

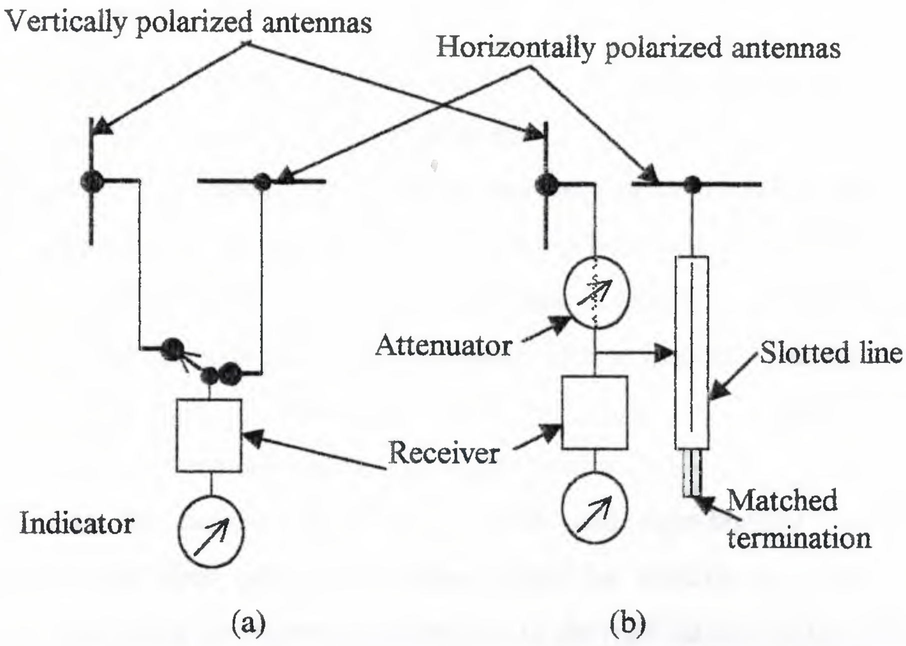


Figure 3.10 Schematic arrangements for measuring polarization by the linear-component method with vertical and horizontal components given by (a) and phase by (b).

The axial ratio of the polarization ellipse of Figure 3.9(b) is given by

$$AR = \frac{A}{B}. \quad (3\text{-}25)$$

Thus, by specifying AR, the tilt angle and the rotation direction of E the polarization characteristics are completely described [20].

3.3.7.2 Linear-Component Method

In this method, 2 fixed linearly polarized antennas can be mounted at right angles, like the two $\lambda/2$ antennas in Figure 3.10(a). The wave is approaching normally out of the page. By connecting the receiver first to the terminals of one antenna and then the other, the ratio E_2/E_1 can be measured. Then, by connecting both antennas to a phase comparator, the δ angle can be measured. This may be done as in Figure 3.10(b), using a match slotted line. From knowledge of E_1, E_2 and δ the polarization ellipse can calculated and the direction of rotation E determined [20].

3.3.7.3 Circular-Component Method

In this method 2 circularly polarized antennas of opposite hand are connected successively to the receiver and the amplitudes E_L and E_R of the circularly polarized component waves measured. The antennas can very conveniently consist of 2 long monofilar axial-mo helical antennas, one wound left-handed and the other wound right-handed as Fig.3.11. The left-handed helix responds to left-circular polarization and the right-handed helix to right-circular polarization. The le circular component E_L of the wave is measured with the switch to the left as Figure 3.11 so that the receiver is connected to the left-handed helix. The right-circular component E_R of the wave is measured with the switch thrown to the Left- and right-handed components are measured by individual helices and phase angle by rotating one helix with both connected right so that the receiver is connected to the right-handed helix [20].

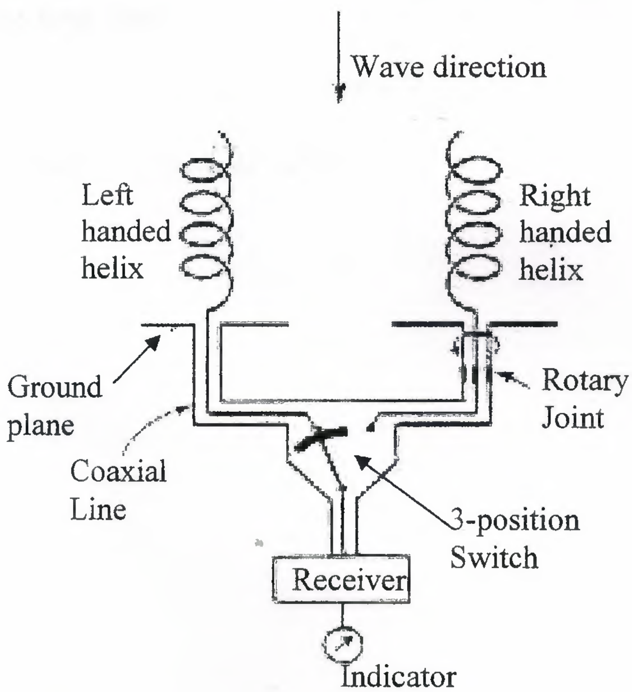


Figure 3.11 Arrangement for measuring polarization by the circular-component method.

The axial ratio (AR) of the received wave is then given by

$$AR = \frac{E_R + E_L}{E_R - E_L}. \tag{3-26}$$

According to Equation (3-26) the axial ratio may have values between + I and + ∞ and between - 1 and - ∞. For positive values of AR the wave is right-elliptical and for negative values it is left-elliptical. The tilt angle τ of the polarization ellipse may be measured by finding the direction of maximum E with a rotatable linearly polarized antenna, or τ may be determined with the helical antennas of Figure 3.11. By rotating one helix on its axis with both helices connected in parallel to the receiver. Assuming that the axes of the helices are in a horizontal plane, let the helix rotation angle be δ' and let its reference point ($\delta' = 0$) be taken when the receiver output is a minimum for a horizontally polarized incident wave. Then for any type of polarization with the polarization ellipse at a tilt angle τ to the horizontal, $\tau = \delta'/2$. Thus, three measurements, E_L, E_R and δ', with the helical antennas determine the polarization characteristics of the received wave completely. The circular-component method using helical antennas is suitable for measurements over a considerable frequency range. The accuracy depends on the circularity of polarization of the helices [20]. This is improved (AR near unity) by making the helices long since

$$AR = \frac{2n+1}{2n}, \qquad (3\text{-}27)$$

where n denotes the number of turns of the helix.

3.4 Summary

In Chapter one, we discussed the principle parameters of the antenna with the related terminologies. This chapter has been considered as the second of our study because measuring ways has been analyzed and studied here. The main measurements discussed in this part about impedance, patterns measurement and impedance measurement deal with the input impedance measurement.

Whereas pattern measurement very common one deals with many subcategories such as measurements of gain, beamwith, minor lobes level, and polarization.

CHAPTER FOUR

PRACTICAL ANTENNA MEASUREMENTS

4.1 Overview

In the previous chapters we have investigated the theoretical side of half-wave dipole of the antenna to give an idea about the general antenna measurements. In this chapter we shall extend our study into the practical side of these measurements and perform practically some of these measurements such as radiation pattern and polarization by using strength wave method, transmission primary antenna method and receiving primary method. Further, the beamwidth can also be found by calculating the maximum electric field radiation pattern.

Finally the practical gain measurement methods have been introduced and a detailed study of the gain has also been done. It is worthwhile to mention here that all of our measurements were made on BRTK station in the Turkish Republic of Northern Cyprus (TRNC).

4.2 Radiation Pattern Measurement

In this part we have drawn the radiation pattern of the half-wave dipole antenna or chapter three which we have been theoretically explained in previous chapters. The equipments used in such measurement are very expensive and are not all of them available in BRTK. Therefore, we have performed this measurement as much as we can by using a simple equipments and methods.

As we have stated before in section 3.3.2.1, the radiation pattern measurement has two different ways that depend on the frequency and the size of the antennas. The first case when the primary antenna is a transmission antenna and the secondary antenna is a receiving one. The second case when the primary antenna is a receiving antenna and the secondary antenna is a transmitting one.

Thus, the two ways mentioned above are also using different ways and equipments to implement them.

We have already explained such methods therefore. Further, size or frequency is helpful to determine the method that we have to choose. In general, there is a famous way to do this measurement. Moreover, the method will also be explained and used in forthcoming.

4.2.1 Strength Wave Method

The method has been studied and its applications used in sections 3.2.2.2, 3.3.2.3 and 3.3.4.1. It is the most simple and the most widely used method because it just needs the strength wave meter and a vehicle to carry this meter into different places. The strength meter gives the electric field strength E at a distance R from the antenna for different places and by taking E for full circle with R as its radius then we can obtain the pattern. So, the main purposes of this method are receiving radiation pattern by measuring electric field strength and showing the polarization pattern [23].

The Equipments required and practical steps will be explained in the following sections,

4.2.1.1 Equipments Required

1- Two Antenna same or different type, here we have used half-wave Dipole antenna for both receiving and transmitting (Referred to Appendix I).

2- Spectrum analyzers (Model 8552B referred to Figure II.1, Appendix II), for more details see reference number [24].

(Spectrum analyzers are perhaps the most popular pieces of equipment in radio frequency (RF) (referred to Figure II.2, Appendix II) engineering because of their wide range of application in this area. Their primary area of applications is mostly in the analysis of signals from a source such as the output of an oscillator, the output from modulator and the input to the receiver as well as its capable of meaning the frequency response together with tracking generator) [22].

3- Tracking Generator (referred to Figure II.3 and 4, Appendix II) the tracking generator output signal is generated by mixing the swept oscillator signal of the spectrum analyzer and a fixed frequency oscillator signal at the spectrum analyzer immediate frequency (IF) referred to Figure II.1, Appendix II,) [22].

4- Remote measuring equipment or a signal level meter which is MC-99 model (referred to Figure II.5, Appendix II). The MC-99 is the most advanced model of the PROMAX TV and satellite level meters. The range of frequencies covered makes it an excellent instrument for FM radio, and ground, cable, and satellite TV applications. Its accuracy and reliability will meet the needs of the most demanding users [23].

5- Carrying vehicle to carry the strength wave meter where ever we need but in our case it has not been used because a small distance is used, that is, $R = 3m$.

6- Two towers, the first tower is fixed to hold the transmitting antenna and second one a rotator with base angle calibrated to 360^0 to hold the receiving antenna.

7- The receiving antenna should be attached in vertical polarization.

4.2.1.2 Practical Steps

1- Determine any distance between the transmitting and receiving antenna pertaining the far zone condition, that is,

$$R > \frac{2d^2}{\lambda} \tag{3-1}$$

2- Connect the coaxial cable feeder for the first antenna which is a transmitting antenna with output frequency strength wave measuring equipment and then adjust the strength wave measuring equipment as well as adjust spectrum analyzer to antenna's frequency of the UHF band 479.25MHz (Referred to Appendix III).

3- Connect coaxial cable feeder for the second antenna, a receiving antenna, with Immediate Frequency (IF) tracking generator.

4- Switch on both of strength wave measuring equipment and tracking generator.

5- Keep the transmitting and receiving antennas directed to each other, In the first reading take the angle as a reference angle (say, $\theta = 0$), and also for reading the signals from the strength wave measuring equipment will be also taken in *(dB)* as reference value for reading next changing in the signal.

6- Rotate the receiving antenna around the transmitting antenna in a circular path of radius R with full around about 360^0. During this rotation keep the receiving antenna aims to transmitting antenna.

7- Measure the value of the field strength E on the antenna at different angles.

8- Records the value of the field strength E in the Table 4.1.

9- Plot each value of the field strength E versus angle either manually or Microsoft Excel.

Table 4.1 Measurement of the field strength in dB for various angles

Angle(θ)	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
E (dB)	5.09	4.57	3.49	4.01	4.46	4.76	5	5.14	5.15	5.16	5.07	4.94
Angle (θ)	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**
E (dB)	4.54	4.95	5.01	5.22	5.01	4.88	5.09	4.88	4.4	4.44	4.98	4.78
Angle (θ)	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**
E (dB)	4.71	4.81	4.95	5.01	4.65	4.57	4.3	4.76	4.46	4.01	3.89	4.64

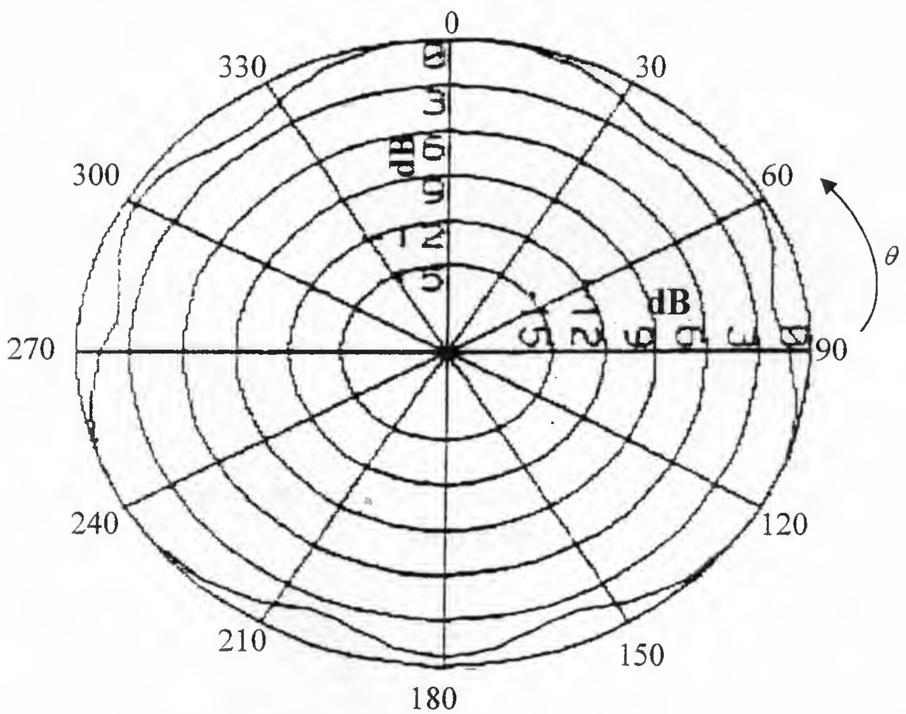
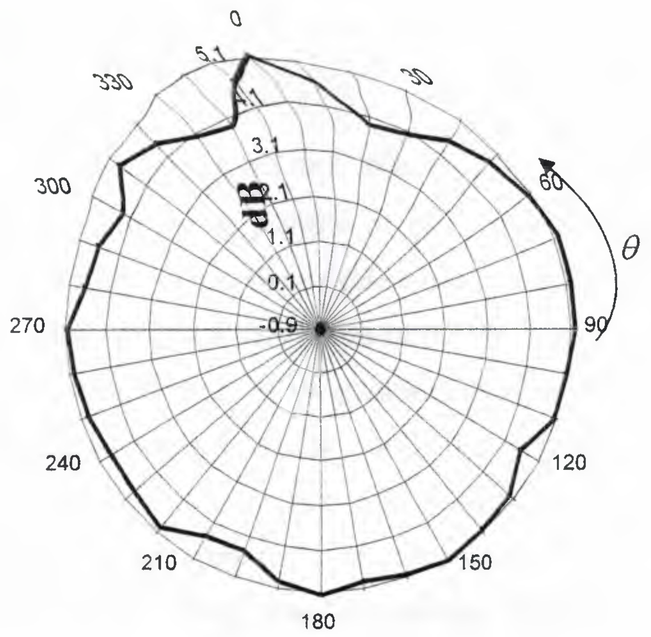
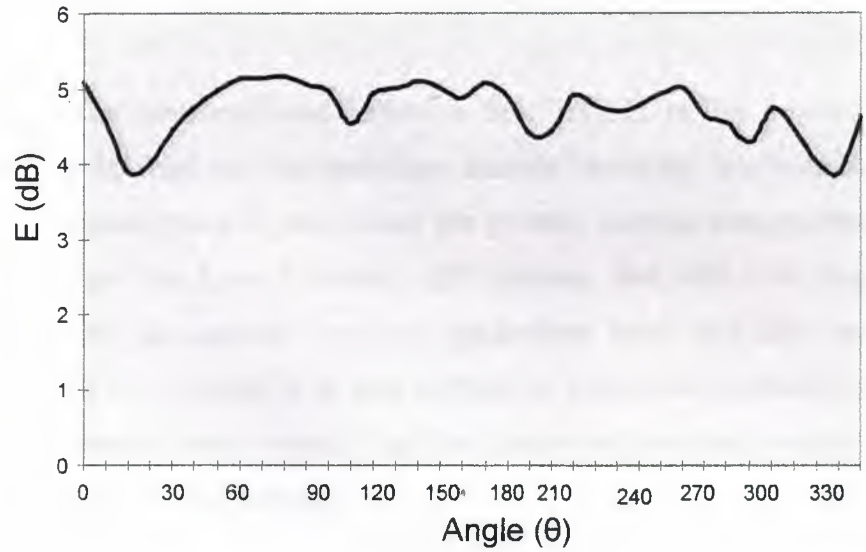


Figure 4.1 The ideal radiation pattern in E-plane dipole antenna which has four bays.



(a)



(b)

Figure 4.2 The radiation pattern measurement for half-wave dipole antennas by using strength wave method with $R = 3m$, in E-plane pattern is plotted in (a) Polar and (b) Rectangular coordinates.

4.2.1.3 Results and Comments

It is worthwhile to note from Figure 4.2 that this type of antenna has very good characteristic at a distance (3m) and its justified by far field measurement. It covers all receiving directions without any main lobes or side lobes, which means that the beam is full and equal to 360^0. Moreover, it is very closer to the ideal field pattern of half-wave dipole antenna in Figure 4.1 in as much as the polarization pattern which clearly that its indicate that its ellipse polarization and also verify the theoretical point in section 3.3.7.1 and Figure 3.9(b). The measurement was done in the clear outside BRTK building which provides very close shape to the theoretical one.

Finally, we must take the up most care in changing the distance between the transmitting and receiving antenna to achieve an ideal graph because such a change leads to a substantial difference in E (dB) for any given angle.

4.2.2 Transmission Primary Antenna Method

This method has been explained before in Sec. 3.3.2.2. In this process, the primary antenna has to be fixed and the secondary antenna (receiving) has to rotate. Moreover, this type of measurement is done when the primary antenna (transmission antenna) is very big in size (for Low frequency (LF) antenna and very low frequency (VLF) antenna designed for general receiving applications have very little requirement for efficiency) [19]. As a result, it is very difficult to rotate this antenna. In this case the secondary antenna is being rotated. The Equipments required and practical steps will be explained in the following section,

4.2.2.1 Equipments Required

1- Two antennas of same or different type, here we have used (half-wave dipole antenna for receiving and transmitting purposes).
2- Tracking generator
3- Gain direction measurements equipment or spectrum analyzer.

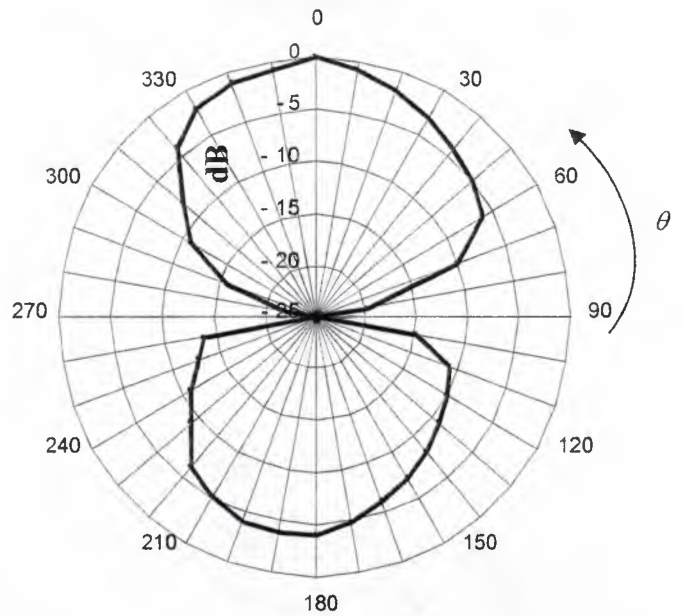
4- Two towers, the first one are fixed (transmitting antenna) and the second is rotating (receiving antenna) with base angle calibrated to 360^0.

4.2.2.2 Practical Steps

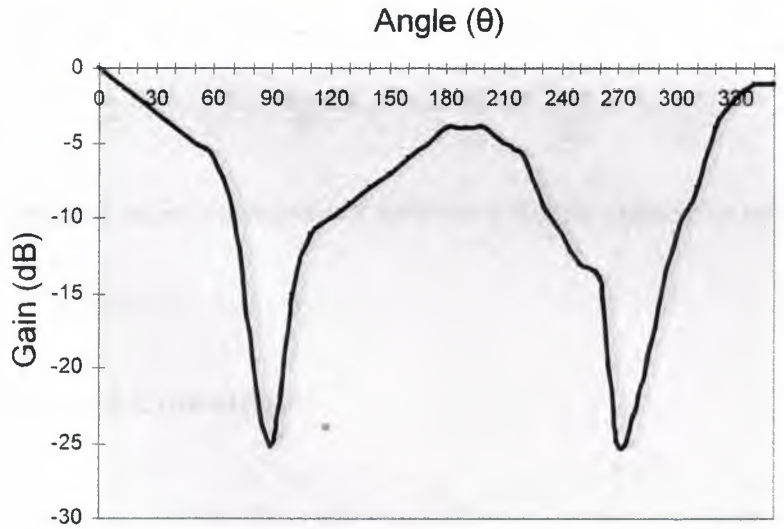
1- Determine the distance between the primary antenna (transmitting) and the secondary antenna (receiving) that satisfies the far zone in Equation (4-1).
2- Connect the coaxial cable feeder for the first antenna which is primary antenna with output frequency spectrum analyzer and adjust the spectrum analyzer to the antenna's frequency which is here 500 MHz.
3- Connect coaxial cable feeder for the second antenna which is secondary antenna with immediate frequency (IF) tracking generator.
4- Switch on both of spectrum analyzer and tracking generator.
5- Keep both of primary and secondary antennas directed to each other.
6- Keep the transmitting and receiving antennas directed to each other, for the first reading take this angle as a reference angle (say, $\theta = 0$) for reading the signals from spectrum analyzer for the first reading will also take 0 *(dB)* as reference value for reading next changing in the signal.
7- Rotate the secondary antenna (receiving) around the primary antenna (transmitting) in a circular path whose radius R and full around about 360^0 and during this rotation keep the secondary antenna aims to transmitting antenna.
8- Stop the rotation in different angles and for each angle take your records and full it in Table 4.2.
9- Plot θ and versus G manually or by using Microsoft Excel as we have done.

Table 4.2 measurement of the Gain in dB for various angles

Angle (θ)	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
Gain (dB)	0	-1	-2	-3	-4	-5	-6	-10	-20	-25	-15	-11
Angle (θ)	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**
Gain (dB)	-10	-9	-8	-7	-6	-5	-4	-4	-4	-5	-6	-9
Angle (θ)	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**
Gain (dB)	-11	-13	-14	-25	-22	-16	-11	-8	-4	-2	-1	-1



(a)



(b)

Figure 5.3 The radiation pattern of dipole antenna using transmission primary antenna method with $R = 3$, the E-plane pattern is plotted in (a) Polar and (b) Rectangular coordinates.

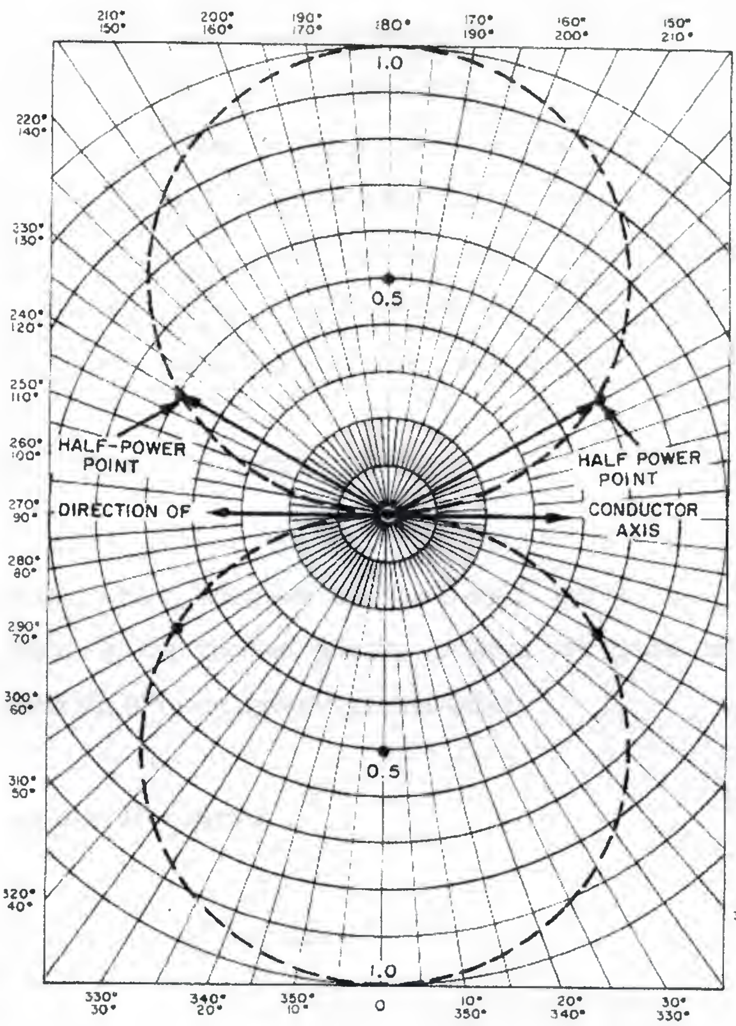


Figure 4.4 The ideal radiation pattern of half-wave dipole antenna in ratio value [21].

4.2.2.3 Results and Comments

It is noted from Figure 4.3 that the gain has different values and these values depend totally on θ the value is achieved at $\theta = 0$ means that both antennas (receiving and transmission) are directed to each other. Moreover, the radiation pattern is identified from 0^0 to 360^0 and this is also justified by the characteristics of the dipole antenna as shown in the Figure 4.4. Here, from this diagram we can see that this antenna has very good characteristic at this distance (3m). This justified by far field measurements which are explained in sec. 1.3.3.2, and cover all receiving directions without any main lobes or side lobes, Moreover, it is very closer to the ideal field pattern of half-wave dipole antenna in Figure 4.4 but the differences between them is justified by the primitive equipments we were using and also attributed to the weather conditions. In as much as the polarization pattern it indicates that its linear polarization is also verified by the theoretical point of view as in section 3.3.7.1 and Figure 3.9(c).

Finally, we must take the up most care in changing the distance between the transmitting and receiving antenna to achieve an ideal graph because such a change leads to a substantial difference in *G* (dB) for any given angle.

4.2.3 Receiving Primary Antenna Method

This method is generally used for high frequency in the HF (High Frequency) and VHF (Very High Frequency) band, whenever the size is small, and we can rotate the primary antenna in its place. In this method primary antenna will rotate and the secondary antenna will be fixed but both are directed to each other.

4.2.3.1 Equipments Required

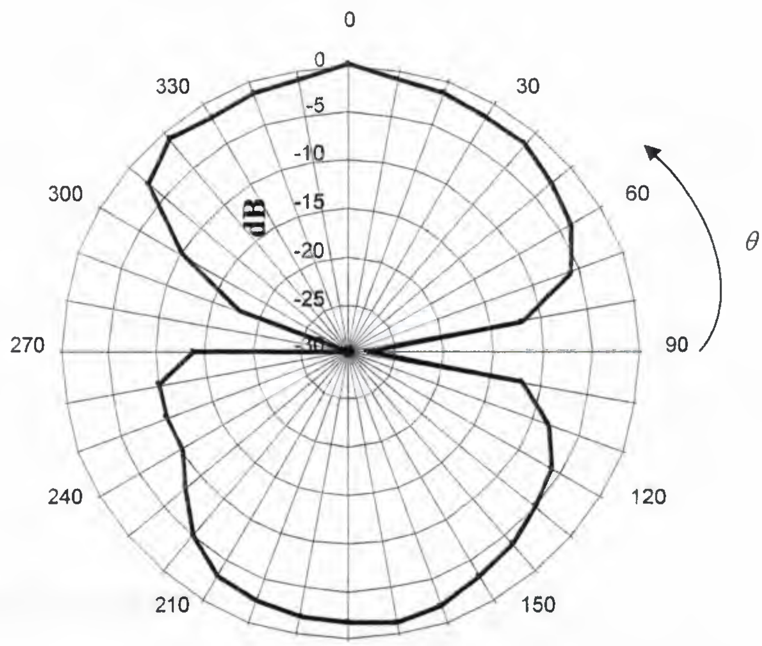
The equipment used in this part similar to those in sec. 4.2.2.1.

4.2.3.2 Practical Steps

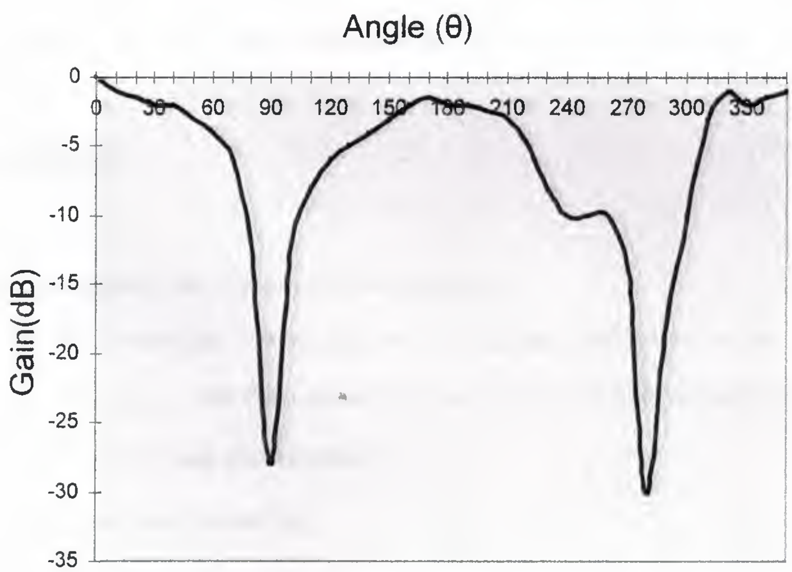
The practical steps used in this part are also same as before in sec. 4.2.2.2. But only one change which is primary antenna will rotate and the secondary antenna will be fixed.

Table 4.3 measurement of the Gain in dB for various angles

Angle (θ)	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
Gain (dB)	0	-1	-1.5	-2	-2	-3	-4	-6	-12	-28	-12	-8
Angle (θ)	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**
Gain (dB)	-6	-5	-4	--3	-2	-1.5	-2	-2	-2.5	-3	-5	--8
Angle (θ)	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**
Gain (dB)	-10	-10	-10	-14	-30	-18	-10	-3	-1	-2	-1.5	-1



(a)



(b)

Figure 4.4 The radiation pattern of dipole antenna using the receiving primary antenna method with R = 3, the E-plane pattern is plotted in (a) Polar and (b) Rectangular coordinates.

4.2.3.3 Results and Comments

By combining Figures 4.3 and 4.5 with Figure 4.4, we note that the radiation pattern in using the receiving primary antenna is more precise than the transmission primary antenna at the fixed frequency 400MHz.

4.3 Beamwidth Measurement

The procedure of determining the value of half-power of beamwidth was explained in sections 2.2.2. and 3.3.3. The beamwidth can be found by the radiation pattern, if not, we do the following

4.3.1 Equipments Required

1- Two antennas of the same type or of different types.
2- Pulse generator or tracking generator mixing with spectrum analyzer.
3- Strength wave measurement instrument which measures the field.
4- Two towers, the first one is fixed which carry transmitting antenna and the other one is rotator with base angle calibrated to 360^0 and carry receiving antenna

4.3.2 Practical Steps

1- Adjust the frequency on the antenna's frequency.
2- Determine the maximum wave strength by making full round of the antenna. At this point take E_{max} , we then determine half-power (3dB-down) beamwidth so, $E_{max} - 3dB$ then we read and record θ_1.
3- At $0.707E_{max}$ read and record θ_2.
4- Calculate the beamwidth as $(\theta_1 - \theta_2)$.
5- Fill out the Table 4.4 and then apply the above-mentioned producers to calculate the beamwidth.

Table 4.4 Measurements of the field strength for various angles

Angle (θ)	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**
E (dBμV)	50.9	45.7	36.9	34.9	44.6	47.6	50	51.4	51.5	51.6	50.7	49.4
Angle (θ)	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**
E (dBμV)	45.4	49.5	50.1	52.2	50.1	48.8	50.9	48.8	44	44.4	49.8	47.8
Angle (θ)	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**
E (dBμV)	47.1	48.1	49.5	50.1	46.5	45.7	43	47.6	44.6	40.1	36.0	46.4

From Table 4.4, practically we note that $E_{\max} = (52.2\eta dBV)$, so, half-power is equal $E_{\max} = 52.2dB\mu V - 3dB = 49.2dB\mu V$, so, we note that this value near to 49.4, we then read angle respect to it, we then found that $\theta_1 = 110^0$ and thereby $0.707\,E_{\max} = 34.7dB\eta V$, $\theta_2 = 30^0$ which provides thus, the half-power beamwidth is equal $(110^0 - 30^0) = 80^0$. This beamwidth is very closer and verify to theoretical part of the beamwidth of half-wave dipole antenna mentioned in section 2.2.2.1.

4.4 Practical Gain Measurement

The gain has been defined as a quantity that may differ in different directions at a given distance R. So, we need to determine the directions necessary to measure the gain and we also need to determine the distance R. The gain can be measured by different ways, all of them have been discussed in detail before in the Sec.3.3.4, but we will do some of them which are famous methods, the gain measurement by compression (see Sec.3.3.4.3) and gain measuring by power rate (see Sec. 3.3.4.2).

4.4.1 Compression Method

4.4.1.1 Equipments Required

1- Three Antennas, one of them is standard (half-dipole antenna, referred to Figure I.2, 3, 4 and 5, Appendix I).
2- Tracking Generator.

3- Gain direction measurements equipment, which is, spectrum analyzer.

4- Two the first one is fixed which carry transmitting antenna and other is rotator with base angle meter which carry receiving antenna.

4.4.1.2 Practical Steps

1- Determine the antenna frequency and adjust the spectrum analyzer at this frequency. The proper at 200MHz.

2- Connect the standard antenna with any other antenna and measure its gain to be the reference gain. It has been measured to be -35 dB.

3- Replace the other antenna instead of the standard one and measure its gain. It has been measured to be -28 dB.

4- The antenna gain then will be the different between those antennas according to Equation (3-18), its -28-(-35) = 7 dB.

5- Repeat the same measurement for all directions and different distances, but one is enough here.

6- Change frequency of the antenna and measure the gain and fill them in the table

Table 4.5 The gain versus the frequency

F (MHz)	100	200	300	400	500	600	700	800	900	1000	1100	1200
G (dB)	-13	-28	-32	-40	-36	-35	-45	-45	-42	-50	-60	-65

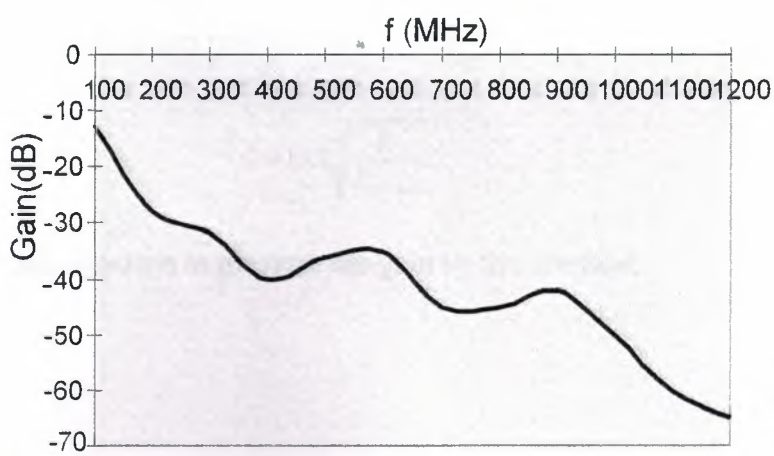


Figure 4.6 Shows the gain versus frequency.

4.4.1.2 Results and Comments

In the previous methods we have been measured the gain at different angles but at a fixed frequency. Here we have done the opposite, we have measured the gain at different frequencies but at fixed angle. As seen in Figure 4.6 it is clear that the relationship between the gain and frequency are proportional. Moreover, this method is easy and a trust to measure gain. But this relation not static between gain and frequency because the antenna is justified by another coefficients like the type of the antenna, the quality of the instruments and outside conditions such as weather, reflection...and so on.

4.4.2 Gain by Measuring Power Rate

In this part we should mention that

$$G(dB) = 10\log G = \frac{P_r}{P_{istrope}} \tag{4-2}$$

We may rewrite Equation (3-16) in the form

$$G = \frac{41R}{7/8F}\sqrt{\frac{P_r}{P_t}}, \tag{4-3}$$

where F = 1 because there is no any reflected object and

$$P_t = 4\pi R^2 P_{istrope}\,. \tag{4-4}$$

Therefore Equation (4-3) can rewritten as

$$G = 13.2\sqrt{\frac{P_r}{P_{istrope}}}. \tag{4-5}$$

which is the main equation to measure the gain by this method.

4.4.2.1 Equipments Required

The equipments used in this part are same as those used in Sec.4.2.2.1.

4.4.2.2 Practical steps

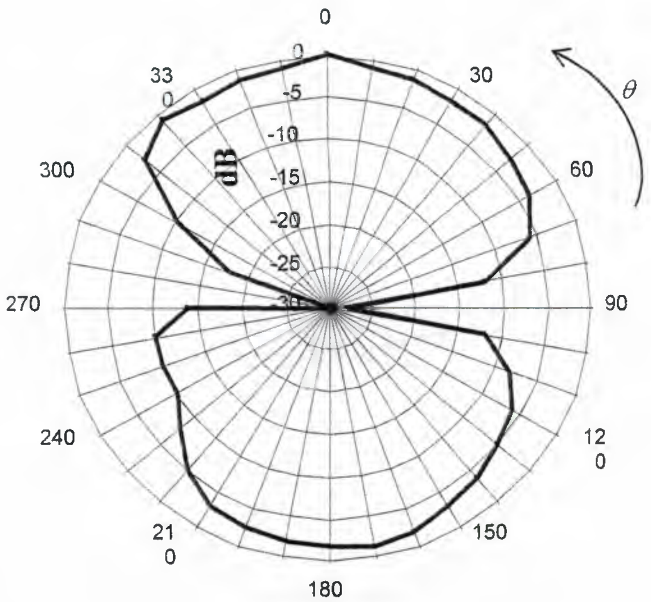
1- Repeat the same steps as in the Sec. 4.2.2.1,

2- Use the same results in the Table 4.2, to calculate the gain from (4-5) and fill them in the Table 4.6.

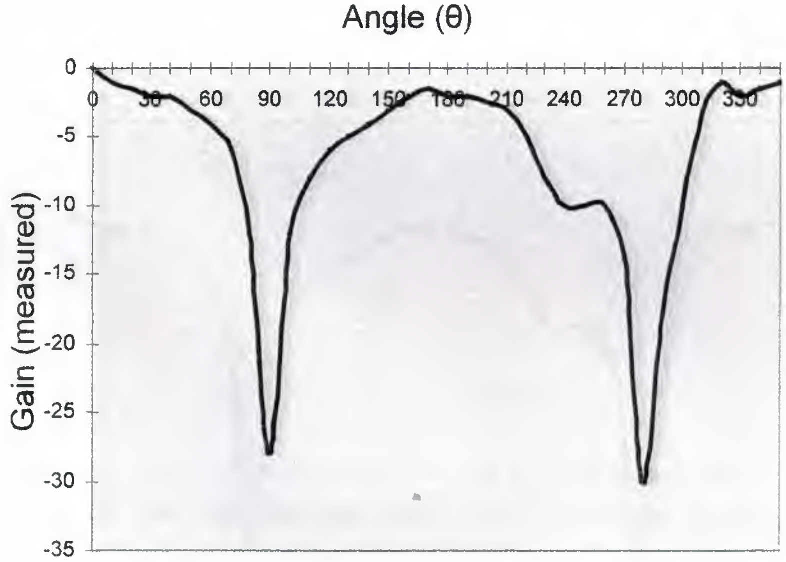
3- Redraw the radiation pattern for the measured and calculated gain.

Table 4.6 The gain calculated for various angles when $R = 3$.

Angle (θ)	0	10	20	30	40	50	60	70	80	90	100	110
$G(measured)$	0	-1	-1.5	-2	-2	-3	-4	-6	-12	-28	-12	-8
$P_r/P_{istrope}$	1	0.8	0.707	0.63	0.63	0.5	0.4	0.25	0.06	0.0015	0.06	0.15
$G(calculated)$	13.2	11.76	11.10	10.48	10.48	9.34	8.32	6.6	3.3	0.5	3.3	5.25
$G(dB)$	11.2	10.7	10.45	10.2	10.2	9.7	9.2	8.19	5.18	-3	5.18	7.2
Angle (θ)	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**
$G(measured)$	-6	-5	-4	-3	-2	-1.5	-2	-2	-2.5	-3	-5	-8
$P_r/P_{istrope}$	0.25	0.3	0.4	0.5	0.63	0.708	0.63	0.63	0.56	0.5	0.3	0.15
$G(calculated)$	6.61	7.4	8.32	9.34	10.48	11.10	10.48	10.48	9.9	9.34	7.4	5.25
$G(dB)$	8.19	8.7	9.2	9.7	10.2	10.45	10.2	10.2	9.95	9.7	8.7	7.2
Angle (θ)	**240**	**250**	**260**	**270**	**280**	**290**	**300**	**310**	**320**	**330**	**340**	**350**
$G(measured)$	-10	-10	-10	-14	-30	-18	-10	-3	-1	-2	-1.5	-1
$P_r/P_{istrope}$	0.1	0.1	0.1	0.04	0.001	0.015	0.1	0.5	0.8	0.63	0.4	0.8
$G(calculated)$	4.17	4.17	4.17	2.63	0.41	1.66	4.17	9.34	11.76	10.48	11.10	11.76
$G(dB)$	6.2	6.2	6.2	4.19	-3.87	2.2	6.2	9.7	10.7	10.2	10.45	10.7

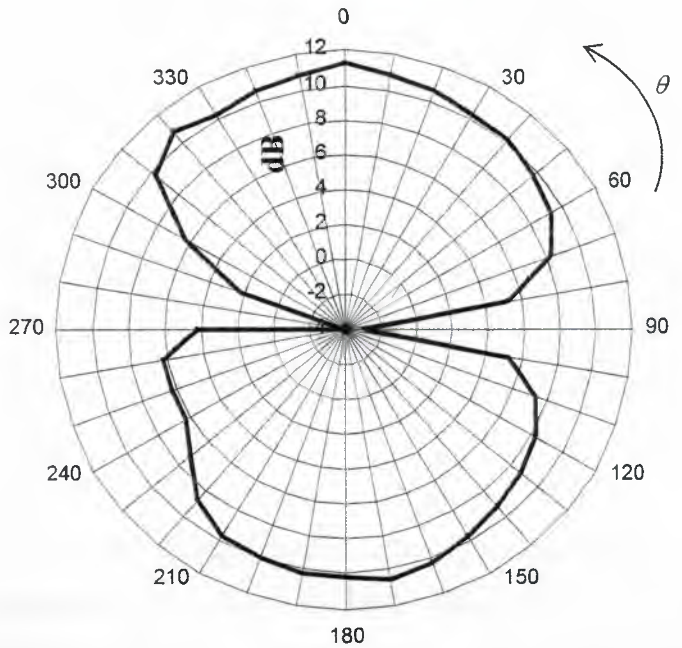


(a)

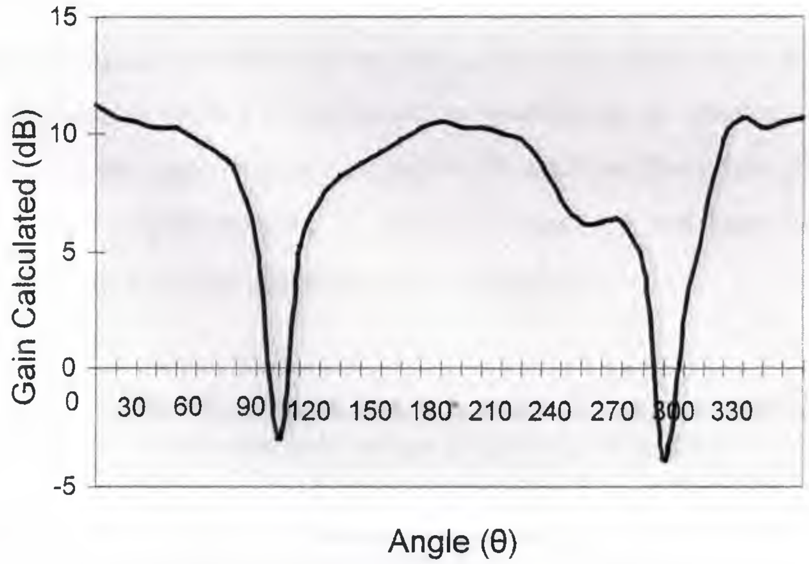


(b)

Figure 4.7 Radiation pattern for gain measured with $R = 3$, the E-plane pattern is plotted in (a) Polar and (b) Rectangular coordinates.



(a)



(b)

Figure 4.8 Radiation pattern in E-plane for gain calculated in the (a) Polar, and (b) Rectangular coordinates.

4.4.2.3 Results and Comments

We note that the maximum gain is at $\theta = 0$ which means that the two antennas are in the same direction and both of them are directed to each other. Moreover, as shown in the Figure 4.8, radiation pattern for the measured gain is very closer to radiation pattern for calculated gain, and this result agree with the theoretical side. But the difference between Figures 4.7 and 4.8 in changing the distance between the transmitting and receiving antenna to achieve an ideal graph because such a change leads to a substantial difference in G(dB) for any given angle.

This means that our measurements are justified by the theoretical point of view. In as much, we note that this gain changes in the same way as the power, and this means that the relationship between them is as shown in the Equation (4-5). In this measurement the weather conditions was fair, so that, our results are precise and agree with the theoretical side.

4.5 Approximate Cost Reduction

As we have mentioned before that our aim goal of this thesis is to reduce the cost of equipments which is needed to implement measurements on antenna as possible as we can. So, to calculate approximate cost reduction we listed the prices of the equipments before and after implementation. In Table 4.7 and 4.8, we have listed the cost of equipments before and after implementation respectively.

Table 4.7. The cost of equipment and parts used in implementation of antenna measurements system before implementation.

Equipment or Part Name	Price
Digital Spectrum Analyzer	$23,000
Sweep Generator	$20,000
Two rotator motor	$20
Half-Wave Dipole Antenna	$20
Total cost	$ 43040

Table 4.8. The cost of equipment and parts used in implementation of antenna measurements system after implementation.

Equipment or Part Name	**Price**
Spectrum Analyzer 8552B with tracking Generator	$5,000
Strength Wave Meter MC-944B (PROMAX)	$2,000
Two rotator tower with base angle made from steel and wood	$10
Aluminum per kg	$ 2
Total Aluminum used 1.5 Kg	$ 3
Coaxial transmission line per Meter	$ 2.5
Total used is 6 M	$15
Other accessories (screw ,connector, clips…etc)	$ 2
Workshop	Free
Total cost	$ 7034.5

After we have calculated the total cost of equipments before and after implementation, we have found that, the approximate cost reduction is $ 36005.5.

4.5 Summary

So far, we have discussed the most commonly used practical methods for measurements. Such methods used are the strength wave method, transmission primary antenna method, receiving primary antenna method, gain measurements by standard antenna and finally measurement of power gain method. In all of these methods we have used many instruments such as, spectrum analyzer, tracking generator and strength wave meter; these instruments had used to measure power gain and electric fields, respectively. After performing the measurements, we have used the measurements values to visualize the shape of radiation pattern in polar or rectangular format by using Microsoft excel. We have also calculated the bandwidth and gain from electric fields and measured power gain, respectively.

CONCLUSIONS

Antenna measurements have been investigated by using simple methods and instruments. Further, the antenna implantation has also been made. Our measurements were about some parts of parameters which are needed to validate theoretical data. Such measurements are found in our investigation to the half-wave dipole antenna. Further, the experiments were implemented in parallel with the theoretical parts, such as, the most important factor is gain on which the performance and other properties of the antenna depend. Hence, the higher is the gain, the better is the antenna, and the gain factor has a relationship with the frequency and the angle as in $G = F\{(f,\theta)\}$.

Firstly, in Figures 4.3 and 4.4, the angle had been changed at a fixed frequency in our work which is the maximum gain angle (both of antennas are directed to each other) and after having the gain measured in far field zone condition from the relation between gain and angle we calculated the half-wave dipole antenna with a very good gain. So, the dipole, in free space exhibits a high degree of polarization purity. However, the broad radiation pattern in many directions indicates that the antenna quality has been constructed in good manner and in perfect way. Moreover, this antenna provides the mostly used and universally gains standards (with gain of about 2.1 dB).

Secondly, the change of frequency at a fixed angle in our work provides that the gain measured in Figure 4.6. Gain versus frequency graph, is a test used to qualify the choice of antenna's frequency that gives the best gain and this means the optimum frequency for the antenna under the test.

Thirdly, in Figure 4.7, in the gain measurements we have used two antennas to measure the transmission and receiving gain and we compared it with the ideal results to make an estimation of such a gain.

Fourthly, in Figure 4.8, we have calculated the gain from the P (dB) results by using power ratio method and then we compared it with the measured power gain in Figure 4.7. They were found to be very close and compatible with our theoretical point of view.

Fifthly, we measured the electric field intensity, E, by using strength wave methods. We then plotted radiation pattern graph of the E versus the angle (θ), at a fixed frequency as in Figure 4.2. Moreover, from such graph, we have also calculated the beamwidth. Our results are found to be good and close to theory.

In Chapter one, we may need for our study; we have discussed the definitions and related terminologies. This chapter deal with the antenna parameters, associated with the radiation pattern, the radiation efficiency, the input impedance, and the bandwidth. Parameters were defined under each of these categories such as the gain, beam width, polarization, minor lobe level, radiation efficiency, receiving across section, radiation resistance and the other that have specialized applications.

In Chapter two, the radiation fields and characteristic properties of an elemental electric dipole has been explained. We then consider finite-length thin linear antennas of which the half-wave dipole antenna is an important special case. We have discussed the dipole length and manner which it is excited and how much the radiation characteristics are largely determined by length and manner of it. Parameters which are associated with linear dipole antennas; these are current distribution on center-fed thin linear dipole antennas, far-zone field intensities, pattern function, the radiation resistance and directivity of a center-fed linear half-wave dipole antenna. Types of antenna have been discussed and one of them has been selected as an instant example for our study and discussed thought of design and its configuration, such as a multiband antenna. Finally application of dipole antenna explained.

In Chapter three, we discussed the principle parameters of the antenna with the related terminologies. This chapter has been considered as the second of our study because measuring ways has been analyzed and studied here. The main measurements discussed in this part about impedance, patterns measurement and impedance measurement deal with the input impedance measurement.
Whereas pattern measurement very common one deals with many subcategories such as measurements of gain, beamwith, minor lobes level, and polarization

In chapter four, we have discussed the most commonly used practical methods for measurements. Such methods used are the strength wave method, transmission primary antenna method, receiving primary antenna method, gain measurements by standard antenna and finally measurement of power gain method. In all of these methods we have used many instruments such as, spectrum analyzer, tracking generator and strength wave meter; these instruments had used to measure power gain and electric fields, respectively. After performing the measurements, we have used the measurements values to visualize the shape of radiation pattern in polar or rectangular format by using Microsoft excel. We have also calculated the bandwidth and gain from electric fields and measured power gain, respectively.

The aims of this work are:

1. Implementation and investigation of practical measurements on the antenna by using simple methods, cheaper instruments and simple antenna such as half-wave dipole antenna.
2. Implementation a simple antenna for measurements purpose which is multi-band dipole antenna.

We have implemented these objectives in above mentioned and we have found that radiation pattern was linearly polarized which satisfies the ideal results for thin linear antenna (half-wave dipole antenna). Wherever we have implemented these measurements there were disadvantages for these methods, which requires the antenna be rotated by hands. Moreover, instruments have some external radiation, so, they cause a decreasing or increasing in signal which they are receiving or transmitting, and consequently these are one of the disadvantages of these methods but it's not a big error which disturbs our results.

In this work, we have done our measurements with simple methods and cheaper instruments, but some times we might need to use expensive equipments to measure other useful measurements. The half-wave dipole antenna is used to be under the test and verify the measurements; the Microsoft Excel is used to plot the graphs.

In our measurements we have used a small antenna (the half-wave dipole antenna).The reason behind using the half-wave dipole antenna in our measurements, is low cost and it is easy construction. So, the practical antenna systems used in commercial high-frequency radio communications ranges from the simple horizontal or vertical dipole to the more elaborate directive arrays. All of these radiating systems, however, are based on the fundamentals of the half-wave type of linear-conductor antenna. The linear radiator will perform most efficiently when it is resonant at the operating frequency. Moreover, in our measurements on this kind of antenna, we have found that the design construction and pattern shape are fully dependent on the wavelength, but generally, those shapes are linearly polarized; such shapes have been investigated theoretically and practically in Chapters two and four, respectively.

Theoretically, most of the half-wave dipole antennas have single elements, because most of the broadcasting co-operations need to transmit specific frequency band, which means again that this kind of antenna has great advantages. Using a single element in our measurements is considered as bad thing, because we should every time change the element that respective different frequency, when a change of frequency is required.

To avoid such a problem, we have designed multi-band half-wave dipole antenna. But, however, this design is based on the fundamentals of the half-wave dipole antenna; this antenna system is shown in the Figure 2.6 consisting of a group of center-fed dipoles. We see that are all elements connected in parallel at the point where the transmission line joins them. That is, they are individually cut to be $\lambda/2$ at different frequencies. When half-wave dipole element is fed at the center, the radio frequency current must travel from the feed point to the ends. But, to match the range of frequencies, it has been found difficult to get a good match to coaxial line on all bands. The $\lambda/2$ resonant length of any one dipole in the presence of the others is not the same as for a dipole itself due to interaction, and the attempts to optimize all four lengths can be a frustrating procedure. Hence, the frequency desired and pattern shape antenna will not be corresponding to the ideal radiation pattern.

Thus, to solve such a problem, so they can operate on those frequencies using a single coaxial feed line, it is desirable to use a balanced transmission line to feed it. The most desirable type of line is 75-Ω transmission twin-lead as shown in Figure 2.6.

The use of this kind of antenna especially, with transmitting antenna system design it requires transmitting different frequencies at the same time and we can use this kind of antenna in measurements because it gives multi-band frequencies at the same time, instead changing each element while doing any measurements.

Finally, instead of using a big antenna to measure the transmitting and receiving gain. Here, we conclude that using of a small antenna (the half-wave dipole) in our measurement is better for determining the angle. Moreover, it is better and convenient for adjusting the desired frequency which is also the main advantage of this method. That is the main reason of not using other types of antennas such as Yagi-Uda antenna since they are very bulky antennas at low frequencies. However, they are used most often in the VHF range and they have a high directional gain, but their structures are very large and cumbersome. This means that we will have problem in moving these antenna while determining the angle. Moreover, radiation pattern of Ygi-Uda antenna has several minor lobes in other directions which decrease the efficiency of radiation pattern in the desired direction.

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APPENDIX I

HALF-WAVE DIPOLE ANTENNA WITH INTERCHANGEABLE BAND RODS

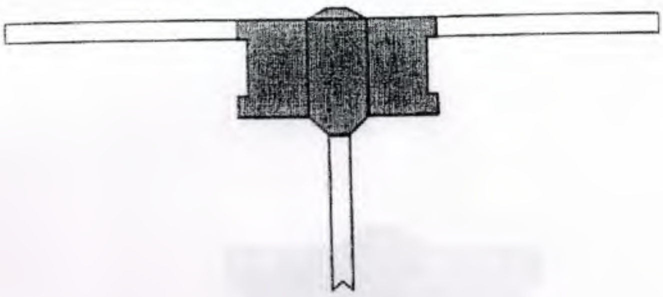

Figure I.1 Long rods configuration for 45 to 70 MHz, low frequency (LF) band.

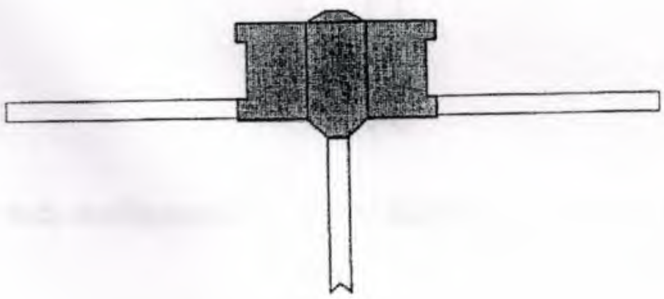

Figure I.2 Long rods configuration for 85 to 110 MHz, frequency modulation (FM) band.

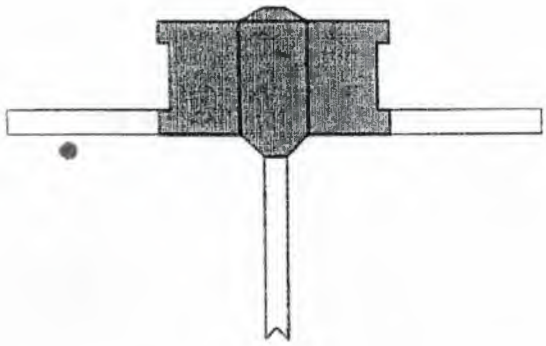

Figure I.3 Medium-Length rods configuration for 175 to 230 MHz, very high frequency (VHF) band.

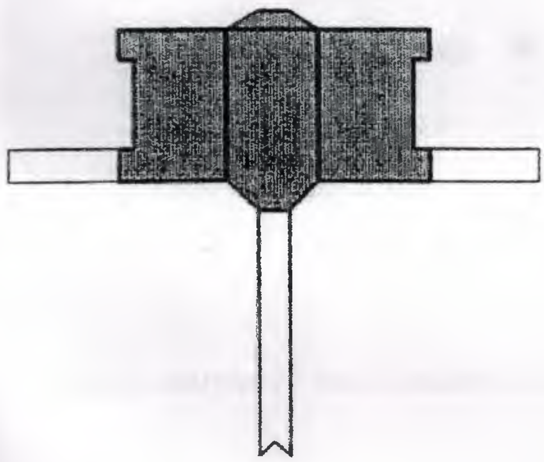

Figure I.4 Short rods configuration for 470 to 860 MHz, ultra-high frequency (UHF) band.

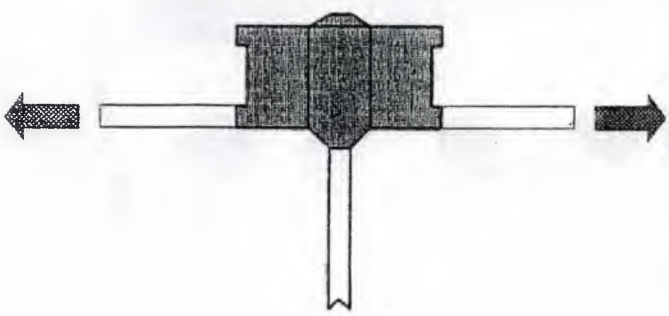

Figure I.5 Replacement of the rods.

APPENDIX II

INSTRUMENTS MODELS

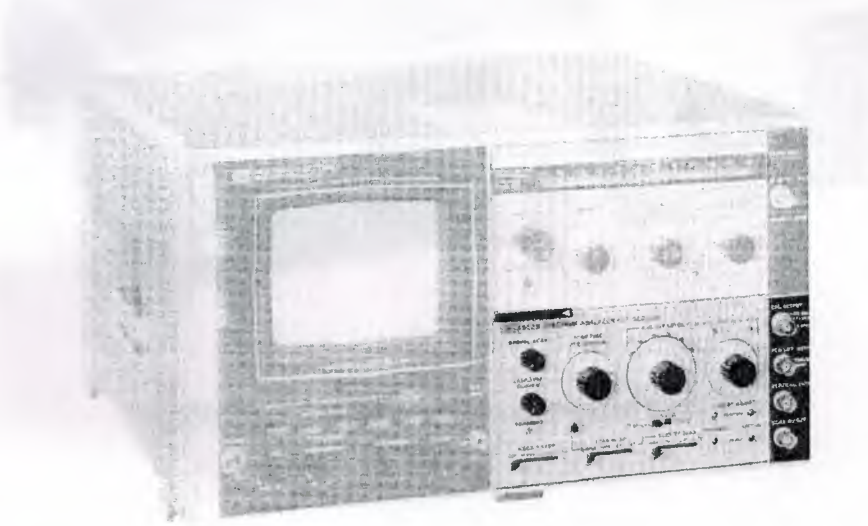

Figure II.2 Spectrum analyzer IF section model 8554B

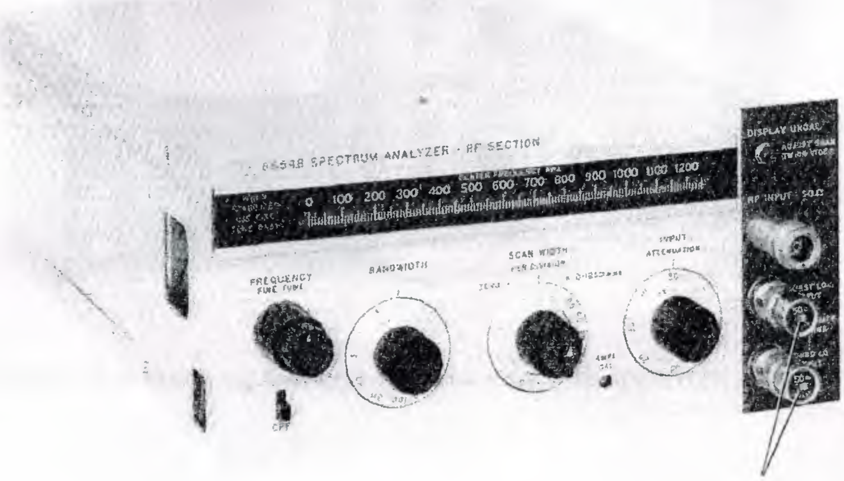

Figure II.2 Spectrum analyzer RF section model 8554B

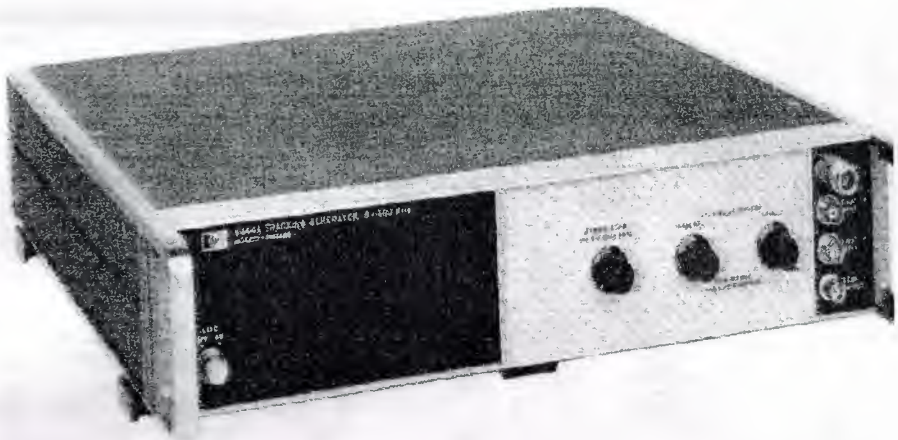

Figure II.3 Tracking generator Model 8444A.

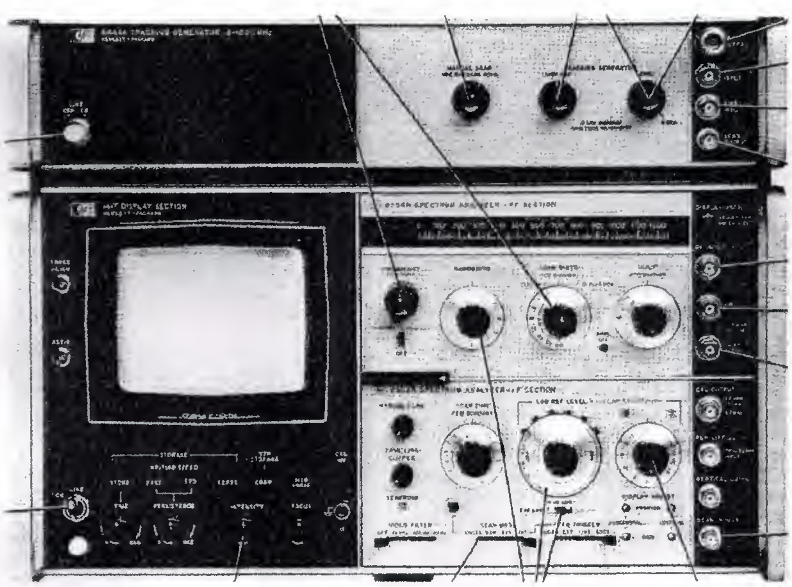

Figure II.4 Tracking Generator operations with spectrum analyzer

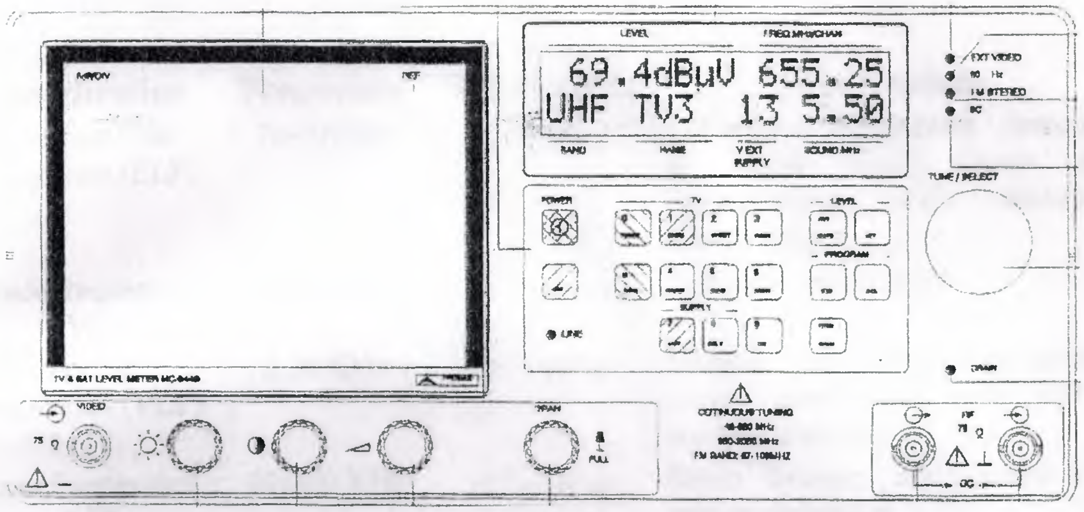

Figure II.5 Multi-standard TV and SAT level Meter MC-944B (PROMAX).

APPENDIX III

SPECTRUM OF ELECTROMAGNETIC WAVES

Classification	Frequency	Wavelength	Applications
Extremely low frequencies (ELF)	30-300 Hz	$10^7 - 10^5 m$	Power line frequencies, detection of buried metal objects and communication with submarine, electric power
Voice frequencies (VF)	300-3000 Hz	$10^6 - 10^5 m$	Telephone audio range
Very low frequencies (VLF)	3-30 KHz	$10^5 - 10^4 m$	Musical instruments, navigation, sonar, government and military communications
Low frequencies (LF)	30-300 KHz	$10^4 - 10^3 m$	Radio beacon, aeronautical and marine navigation
Medium Frequencies(MF)	300 KHz- 3 MHz	$10^3 - 10^2 m$	AM broadcasting, maritime radio and direction finding
High frequencies (HF)	3-30 MHz	$10^2 - 10^1 m$	Facsimile, SW radio, citizen's band, Government and military services use these frequencies for two-way communication
Very high frequencies (VHF)	30-300 MHz	$10^1 - 1m$	Mobile radio, TV channels, FM, police and air traffic control
Ultra high frequencies (UHF)	300 MHz - 3 GHz	$1 - 10^{-1} m$	Land mobile communications and services, radar, navigation services and TV channel
Super high frequencies (SHF)	3 – 30 GHz	$10^{-1} - 10^{-2} m$	Radar and satellite communication.
Extremely high frequencies (EHF)	30 – 300 GHz	$10^{-2} - 10^{-3} m$	Radar and space exploration
infrared	-	$0.7 - 10 \mu m$	Night vision
The visible spectrum (light)	-	0.4×10^{-6} - $0.8 \times 10^{-6} m$	Sterilization, medical diagnosis and food irradiation cancer therapy