NEAR EAST UNIVERSITY
LIBRARY
1988 - LEFKOŞA

TURKISH REPUBLIC OF NORTHERN CYPRUS

NEAR EAST UNIVERSITY

DESIGN AND INVESTIGATION OF THE ANTENNA MEASUREMENT SYSTEMS

A Master Thesis

Prepard by

Hani Attar

Degree of Master of Science in

Electrical & Electronic Engineering

GRADUATE SCHOOL OF APPLIED AND SOCIAL SCIENCES

Nicosia – 1999

Hani Attar: Design and Investigation of the Antenna Measurement Systems

---

Approval of Graduate School of Applied and Social Sciences

Prof. Dr. Ergin İğrek

Drector

We certify that this thesis is satisfactory for the award of degree of Master of Science in Electrical & Electronic Engineering.

Prof. Dr. Fakhraddin Mamedov

Chair of Electrical & Electronic Engineering Department.

Examining Committee in Charge:

Ass. Prof. Sameer M. Ikhdair

Supervisor

Prof. Dr. Halil İsmailov

Dean of the Faculty of Engineering.

Prof. Haldun Gürmen

To

My Great

Family

Learning is not attained by chance,
it must be sought for with ardor and attended to with diligence.

Abigail Adams
(in letter to John Quincy Adams; 1780).

ACNOWLEDGMENTS

I am deeply indebted To my parents for their love and financial support. They have always encouraged me to pursue my interests and ambitions throughout life.

To my supervisor Prof.Dr. Sameer Musbah Ikhdair who has helped me to finish and realize this difficult task, my deep gratitudes and thanks.

To my own Prof.Dr. Fahrettin Mamadove who shows all assistances and advises during my academic study.

To my brothers and sisters, my sincere thanks are beyond words for their continuous encouragement.

To Mr. Yousef and To his staff in BRTK company who have helped me to make all the experiments.

To all my friends especially Raed A.O Alagha who has helped me a lot to print this project and To my house mate Nedal who insured me a good atmosphere for atudy.

To all of them, all my love.

TABLE OF CONTENTS

	Page
ACKNOLEDGEMENTS	**i**
INTRODUCTION	**1**
CHAPTER ONE: FUNDAMENTALS OF THE ANTENNA	**4**
1.1 Antenna Structure	4
1.1.1 Size	4
1.1.2 Supports	5
1.1.3 Feed Line	5
1.1.4 Conductors	7
1.1.5 Insulators	8
1.1.6 Weather Protection	9
1.2 Antenna Parameters	10
1.2.1 Polarization	10
1.2.2 Radiation Pattern	12
1.2.3 Near and Far Field Patterns	18
1.2.4 Antenna Gain	21
1.2.4.1 Directive Gain	23
1.2.4.2 Gain in Decibels	25
1.2.4.3 Practical Significance of Power Gain	25
1.2.5 Beamwidth	26
1.2.5.1 Definition of Beamwidth	26
1.2.5.2 Practical Significance of Beamwidth	27
1.2.6 Minor Lobes	28
1.2.6 Radiation Resistance and Efficiency	30
1.2.8 Input Impedance	33
1.2.9 Bandwidth	35
1.2.10 Beam Area or Beam Solid Angle	36
1.2.11 Capture Area or Receiving Cross Section	38
CHAPTER TWO: ANTENNA MEASUREMENTS	**41**
2.1 Impedance Measurement	43
2.1.1 Bridge Measurement Method	44
2.1.2 Standing-Wave Method	48
2.2 Impedance Charts	58
2.3 Pattern Measurements	67

2.3.1 Pattern Measurement Method.. 68
2.3.2 Low Frequency Pattern Measurements........................... 73
2.3.3 High Frequency Pattern Measurements.......................... 74
2.4 Beamwidth and Side-Lobe-Level Measurement..................... 76
2.5 Gain Measurements... 78
2.5.1 Absolute Field Strength Method.................................. 78
2.5.2 Gain Measurement by Using Standard Antennas................ 80
2.5.3 Gain Measurement by comparison................................ 81
2.6 Antenna Efficiency Measurement..................................... 83
2.6.1 Radiation Efficiency... 84
2.6.2 Aperture Efficiency Measurement................................. 85
2.7 Radiation Resistance... 86
2.8 Polarixation Measurement.. 87
CHAPTER THREE: PRACTICAL ANTENNA MEASUREMENTS....................................... 89
3.1 Radiation Pattern Measurement.. 91
3.1.1 Strength wave Method.. 91
3.1.2 Equipments Required.. 92
3.1.2 Practical Steps.. 92
3.2 Transmission Primary Antenna Method............................... 96
3.2.1 Equipments Required.. 96
3.2.2 Practical Steps.. 96
3.3 Receiving Primary Antenna Method................................... 100
3.3.1 Equipments Required.. 100
3.3.2 Practical Steps.. 100
3.4 Beamwidth Measurement.. 102
3.4.1 Equipments Required.. 102
3.4.2 Practical Steps.. 102
3.5 Practical Gain Measurement.. 104
3.5.1 Practical Gain by Standard Antenna............................. 104
3.5.1.1 Equipments Required.. 104
3.5.1.2 Practical Steps.. 105
3.6 Gain by Measuring the Power Rate.................................... 106
3.6.1 Equipments Required.. 107
3.6.2 Practical Steps.. 107
3.7 Choice of the Antenna and the Antenna Frequency................. 108
3.7.1 Equipments Required.. 108

3.7.1 Practical Steps.. 108
3.8 The Practical BRTK Properties Measurements......................... 111
3.8.1 Radiation Pattern Measurement.................................... 111
3.8.1.1 Equipments Required.. 111
3.8.1.2 Practical Steps.. 111
3.8.2 Practical Beamwidth Measurement.................................. 115
3.8.2.1 Equipments Required.. 115
3.8.2.2 Practical Steps.. 115
3.9 A Self-Study of the Antenna Measurements........................... 116
3.9.1 Impedance Measurement.. 116
3.9.1.1 Equipments Required.. 116
3.9.1.2 Practical Steps.. 117
REFERENCES.. 118

Introduction

We had thought to do our work on the antenna, and then we search for the important parts on this subject since the antenna is one of the most common and important parts in the communication system.

The term antenna is defined by the dictionary [1] as a usually 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, a means for radiating or receiving radio waves. The ideal antenna is, in most applications, one that will radiate all the power delivered to it by a transmitter in the desired direction or directions and with the desired polarization. Practical antennas can never fully achieve 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 antenna technology over the past years since antenna was published the basic principles and theory remain unchanged.

The antenna measurements are very expensive and need gigantic instruments to pursue this work; so that, we decided to search about this subject to make these measurements cheaper and easier ways for finding these results.

Our objetive in this thesis is analysis of the antenna measurement and design a simple method to determine the antenna gain to real antennas. For this purpose the small size simple antenna is used in this measurement system. Antenna gain is determined for different values of the angular position in the horizontal plane at a fixed frequency, and for different frequencies at a fixed angle. The correction coefficient determined by the power ratio of the real and small antennas and it is used to match obtained results with real condition.

Chapter One is primary concerned with definitions and related terminology, which will be needed in the next two chapters. This chapter deals with the antenna parameters, in engineering usage; the parameter word means any measurable characteristic of a physical phenomenon, device, or system, especially those that pertain to performance or merit. It is in this sense that the term is used in Chapter One.

The principal parameters of antennas are associated with the radiation pattern, the radiation efficiency, the input impedance, and the bandwidth. Parameters are defined under each of these categories such as the gain, beamwidth, beam polarization, minor lobe level, radiation efficiency, aperture efficiency, receiving cross section, radiation resistance, and others that have specialized applications. Some of these parameters are interrelated or correlated. For example, if the beamwidth is given, the gain can thereby be estimated, though it can not be calculated exactly from the beamwidth without additional information. The antenna structure has been also defined as the size, supports, feed lines, conductors, insulators, and the weather protection to give perfect conception of the antenna before the entree to the next chapters.

Chapter Two discusses the manner of measuring the parameters which we have mentioned in the previous chapter, so that, an idea about the measuring ways has been studied here. The main measurements are divided into categories as impedance and pattern measurements. The first one deals with one of the most important antenna parameters and the input impedance. The second one, a very broad and equally important one, with many subcategories, such as, measurements of beamwidth, minor lobe level, gain, and polarization characteristics.

In Chapter Three the real 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 for any random antenna to comply the steps that we have studded in the Chapter Two. All these measurements have applied on the BRTK antenna in the Turkish Republic of Northern Cyprus (TRNC) to measure its parameters by using any kind of antenna as a receiving antenna. Since the transmission antenna is the real BRTK antenna, then the real radiation pattern and gain that have been obtained will be for it. Although these two measurements are very difficult and important ones, but they have been made for one time by using very gigantic instruments and costable ones. Finally, the last part in this chapter is concerned only the impedance measurement by using the bridge method and it is a self-study for the antenna measurements, so it will be left for the interested reader.

CHAPTER ONE

ANTENNA PARAMETERS

1.1 Antenna Structure

The structure of the antennas depends upon the type and the destination, but in general, all antennas have the following structure

1.1.1 Size

The size of antenna range from microminiature to gigantic, and it depends on the wavelength, which has proportionality with the operations frequency, and this relationship is simple and fast.

The large antennas are used for low frequencies (high wavelength), and vice versa, small antennas are used for high frequencies (low wavelength), but sometimes-large antennas are used at short wavelength (high frequencies) to obtain a highly directional radiation pattern and high gain in a preferred direction.

In practice field, the increasing of the size is limited, because at determining size, there is no point in increasing this size because it produce a little or no additional gain, and the required precision of construction or maintenance of phase relationship is not attainable. Moreover, very small antennas can be used at long wavelength, when efficiency is not important. In general, the largest antennas are used at the VLF, especially for transmitting, where radiation efficiency is important. As an example of the extremely large VLF antenna is Navy's installation that has tower 1000 feet high, extends over an area of 2 square miles. In contrast, a half wave dipole at the microwave frequencies may be considerably less than an inch long.

1.1.2 Supports

There must often be some supporting structure to place the radiating element or elements in a clear location (with often is synonymous with a high location). Such devices as towers, masts, and pedestals support antennas.

Towers are used when great height is required. Masts may be quite high, but they are often as short as a few feet. Pedestals are the base structures of antennas such as reflectors and lenses, for which height is not important as strength. Sometimes an antenna may be mounted directly on a vehicle, such as an automobile, ship, aircraft, or spacecraft, where no intermediate support is required. Moreover, towers and masts are sometimes themselves used as antennas rather than as supports. In the standard broadcast band (550-1600KHz). As an example, vertical towers of heights up to several hundred feet are used as transmitting antennas.

1.1.3 Feed Line

We can simply define the feed lines as the transmission lines. These lines are used to connect the transmitter or receiver to the antenna. The design of the feed lines and any necessary impedance-matching or power-dividing devices associated with it is one of the most important problems in the calculation of antenna design. At the very lowest frequencies the earth (ground) is a part of the antenna electrical system. Therefore, one terminal of the antenna input is a rod driven into the ground or a wire leading to a system of buried conductors, especially if the earth is dry in the vicinity of the antenna. The other terminal is then usually the base of a tower or other vertically rising conductor. Towers used in this way are usually supported at the base by a heavy insulator or insulators (series feed), but occasionally they are directly grounded and fed by connecting the feed wire a short distance up from the ground (shunt feed).

At somewhat higher frequencies, up to (up to 30MHz), the antenna may be a horizontal wire strung between towers, or other supports (from which it is insulated). The feed line is then often a two-wire balanced line connected at the center of the antenna, either to the two terminals provided by a gap in the antenna wire (series feed), or to two points somewhat separated on the unbroken antenna wire (shunt feed). Sometimes the feed line is connected at the end of the horizontal span, or elsewhere of center, but center feed is preferred because it results in better balance of the currents in the feed wires. The spacing between the two-wire-line is range from less than an inch to 12 inches or more. The last method is used for high frequencies. But coaxial feed lines are commonly used for upper high frequencies UHF (up to 1GHz), because the two-wire-line spacing becomes too great a fraction of the wavelength to prevent appreciable radiation and because waveguides below 1000MHz are quite large and expensive. Coaxial line diameters range from a fraction of an inch up to 9 inches or more. Above 1000MHz, waveguides are commonly use, with some use of mall-diameter coaxial lines in low-power noncritical applications.

We should mention that, when the antenna rotates on a pedestal, or has other motion with respect to its support, the feed line must contain flexing sections or rotating joints, this require is quite important on the antenna measurement operations, as we will see later.

1.1.4 Conductors

Metals are the usual conducting materials of antennas. Metals of high conductivity, such as copper and aluminum (and its alloys), are naturally preferred. Brass may be used for machined parts. Magnesium is sometimes used where ultralight weight is important, usually in an alloy and with a protective coating or treatment. The steel may be used, when the strength is of primary importance, either with or without a coating or plating of copper. The conductivity of unplated steel is adequate when it is used in the form of sheets or other large-surface-area forms (as for the surface of a paraboloidal reflector). Antenna wire is sometimes made with a steel core for strength and to minimize stretching and with a copper coating to increase the conductivity. Such wire is virtually as good a conductor as solid copper. Since the radio frequency RF currents are concentrated near the surfaces of conductors (skin effect). For this reason brass and other metals are sometimes silver plated when exceptionally high conductivity is required. For the same reason large-diameter conductors may be hollow tubes without loss of conductivity. At low radio frequencies the conductivity of large-diameter conductors may be increased, compared to a solid conductor, by interweaving strands of small-diameter insulated wires; the resulting conductor is called Litz wire. This technique is most effective below about

500KHz. At higher frequencies it is not effective because the currents tend to flow only in the outer strands.

Conductor size in antenna design is determined by many factors, principally the permissible ohmic losses and resultant heating effects in some cases, mechanical strength requirements, permissible weight, electrical inductance and capacitance effects, and corona considerations in high-voltage portions of transmitting antennas. Large-diameter conductors minimize the Corona, by avoidance of sharp or highly curved edges, and by using insulators with metal end caps bonded to the insulating material, so that small air gaps between wires and insulators do not exist. Corona can occur on metal supports of the antenna as well as on the antenna conductor itself, as a result of induced voltages.

1.1.5 Insulators

The conducting portions of an antenna not only carry RF currents but also have RF voltages between their different parts and between the conductors and ground. So that, to avoid the short circuiting these voltages, insulators must sometimes be used between the antenna and its supports, or between different parts of the antenna. The insulators are also used as spacer supports for two-wire and coaxial lines and to break up guy wires with masts and towers to prevent the resonant or near-resonant lengths. The maximum permissible uninterrupted length of guy wire sections is about 1/8 wavelength. Also, the insulators are used to support long heavy spans of wire, so that it must be high strength. Typical insulating materials for such insulators are glass and ceramics, other (low loss) materials such as polystyrene and other plastics are used where less strength is required. Very large and heavy insulators are necessary in high-power transmitting applications to prevent flashover. Coaxial lines and waveguides in high-power applications may be filled with an inert gas, or dry air, at a pressure of several atmospheres, to increase the voltage-breakdown.

1.1.6 Weather Protection

The antennas are ordinarily out doors, so that, it must withstand wind, ice, snow, lightning, and sometimes corrosive gases or salt-laden air. Protection against wind and ice loads is primarily a matter of mechanical strength and bracing. Guy wires are used with tall structures or towers, to prevent their overturning in high winds. In the heavy current networks, the ice is sometimes melted from the heating that is produced from the current. Sometimes an antenna is totally enclosed in a protective housing of low-loss insulating material, which is practically transparent to the electromagnetic radiation. Such housing is called radome. Radomes are commonly used on some types of aircraft antenna for aerodynamic reasons. The protection against lightning-induced currents, and static-charge buildup is necessary for some types of antennas such as broadcasting towers, or any structure that stands high above its surrounding, if the conducting path to ground is not heavy, and direct. Insulators may be protected by horn or ball gaps, and static may be drained by connecting high-ohmage resistors across insulators.

1.2Antenna Parameters

The most fundamental properties of antennas are the following

1.2.1 Polarization

The wave polarization refers to the instantaneous component direction on a surface perpendicular to the direction of energy propagation. In the communication system only sinusoidal varying fields are ordinary used.

The radiation of an antenna may be linearly, elliptically, or circularly polarized. Polarization in one part of the total pattern may be different from polarization in anther. As an example, in the case of a directional antenna with a main beam and minor lobes, the polarization may be different in the minor lobes and in the main lobe, or may even vary in different parts of the main lobe.

The simplest antennas radiate (and receive) linearly polarized wave. They are usually oriented so that the polarization (direction of the electric vector) is either horizontal or vertical. But sometimes the choice is dictated by the necessity, at other times by preference based on technical advantages, and sometimes there is no basis for choice one is as good and as easily achieved as the other. For example at the very low frequencies it is practically difficult to radiate a horizontally polarized wave successfully because it will be virtually cancelled by radiation from the image of the antenna in the earth, also vertically polarized waves propagate much more successfully at these frequencies (e.g., below 1000KHz). Therefore vertical polarization is practically required at these frequencies.

At the frequencies of television broadcasting (54 to 890MHz) horizontal polarization has been adopted as standard. The standard frequency is very important to determine the type of polarization. Otherwise, we have to design an antenna such has both polarizations, thus greatly complicating design problem and increasing the received noise level.

At the microwave frequencies (above 1GHz) there is little basis for a choice of horizontal or vertical polarization. Also in specific applications there may be some possible advantages in one or the other. Of course in communication it is essential that the transmitting and receiving antennas have the same polarization.

Circular Polarization has advantages in some VHF, UHF, and microwave applications. As an example, in transmission of VHF and low-UHF signals through the ionosphere, rotation of polarization vector occurs, the amount of rotation being generally unpredictable. Therefore if a linear polarization is transmitted it is advantageous to have a circularly polarized receiving antenna which can receive either polarization, or vice versa. The maximum efficiency is realized if both antennas are circularly polarized.

From the above explanation. It is obvious that in communication circuits it is essential that transmission and receiving antennas have the same polarization. Also it is apparent that the polarization properties of any antenna are an important part of its technical description (parameter of its performance). Sometimes it may be desirable to provide polarization pattern of the antenna, that is, a description of the polarization radiated as a function of the direction angles of a spherical coordinate system, although such a complete picture of the polarization is not ordinarily.

1.2.2 Radiation Pattern

The radiation pattern of an antenna is one of its most fundamental properties, and many of its performance parameters pertain to various aspects of the pattern.

We should mention that antennas have a reciprocal relationship between the processes of radiation and reception, so, it is customary to speak of the antenna pattern as radiation pattern, and a reception pattern as well because it also describes the receiving properties of the antenna.

The radiation pattern describes the relative strength of the radiated field in various directions from the antenna, *at a fixed or a constant distance.*

Because the antenna pattern is three dimensional, a three-dimensional coordinate system is required. So, either cartesian (rectangular) coordinates (x, y, z) or spherical coordinates (R, θ, ϕ) is used. The spherical coordinate system is an appropriate coordinate system to describe the antenna pattern because the radiation pattern may be expressed in terms of the electric field intensity, (for example, at some fixed distance R from the antenna), at all points on the spherical surface at that distance. Spherical points on the surface are then defined by the direction angles θ and ϕ . The pattern then becomes a function of only two independent variables, since R is a constant, and this fact greatly simplifies the matter.

Figure 1-1 illustrates the relationship between the cartesian and spherical coordinates. The projection of this distance r onto the xy-plane is designated θ , ϕ , this means that chainging r couses chainging on θ , ϕ .

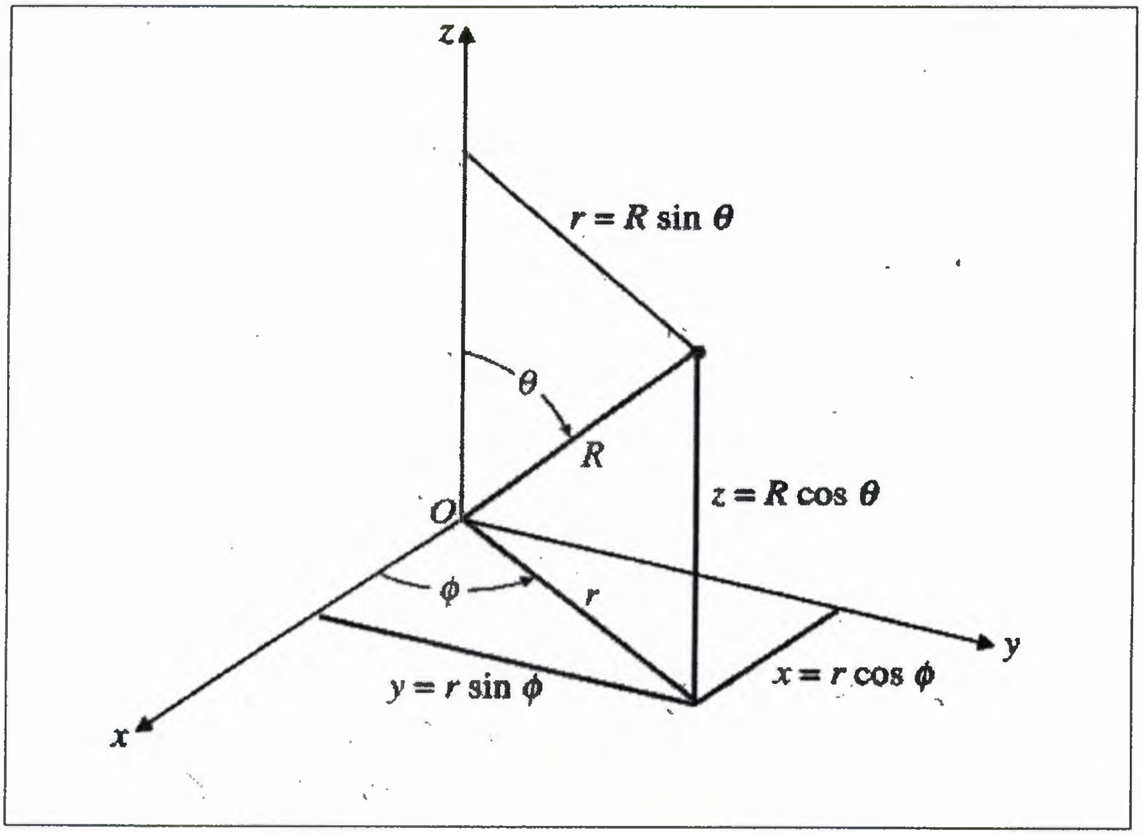

Figure 1-1 Showing interrelationship of space variables (x, y, z) and (R, θ , ϕ).

An antenna is supposed to be located at the center of a spherical coordinate system, its radiation pattern is determined by measuring the electric field intensity over the surface of a sphere at some fixed distance, *R*. Since the field *E* is then a function of the two variables θ and ϕ , so it is written $E(\theta,\phi)$ in functional notation.

A measurement of the electric field intensity $E(\theta,\phi)$ of an electromagnetic field in free space is equivalent to a measurement of the magnetic field intensity $H(\theta,\phi)$, since the magnitudes of the two quantities are directly related by

$$E = \eta_0 H \tag{1-1}$$

(of course, they are at right angles to each other and their phase angles are equal) where $\eta_0 = 377\Omega$ for air. Therefore the pattern could equally be given in terms of E or H.

The power density of the field, $P(\theta,\phi)$, can also be computed when $E(\theta,\phi)$ is known, the relation being

$$P = \frac{E^2}{\eta_0} \tag{1-2}$$

Therefore a plot of the antenna pattern in terms of $P(\theta,\phi)$ conveys the same information as a plot of the magnitude of $E(\theta,\phi)$. In some circumstances, the phase of the field is of some interest, and plot may be made of the phase angle of $E(\theta,\phi)$ as well as its magnitude. This plot is called the phase polarization of the antenna. But ordinarily the term antenna pattern implies only the magnitude of E or P. Sometimes the polarization properties of E may also be plotted, thus forming a polarization pattern.

Although the total pattern of an antenna is three dimensional, the pattern in a particular plane is often of interest. In fact, there is no satisfactory way of making a single plot of the entire three-dimensional pattern on a plane piece of paper. The three-dimensional pattern is usually represented in terms of the two-dimensional pattern in two planes that from 90 degree angles with each other, with the origin of a spherical coordinate system on their intersection line.

The main method of depicting three-dimensional pattern information is to plot contours of constant signal strength on the surface of a sphere containing the antenna at its center. But ordinarily only the principal plane patterns are given, as they convey an adequate picture of the three-dimensional pattern for most purposes.

Pattern in a plane involves only one angle, so that, it is represented by polar coordinates, it would be possible to use Cartesian coordinates. If this were done, the shape of the pattern would be unchanged; but because interpretation of the meaning of the pattern in terms of the cartesian coordinates would be relatively difficult, this is never done. It is fairly common to plot the pattern on rectangular-coordinate graph paper but in terms of the direction angle as the abscissa and field strength or power density as the ordinate. This type of plot distorts the appearance of the pattern geometrically but preserves the interpretability of an angle representation and makes the plotting and the reading of the low amplitude portions of the pattern easier. Figures 1-2a and 1-2b compare these two representations.

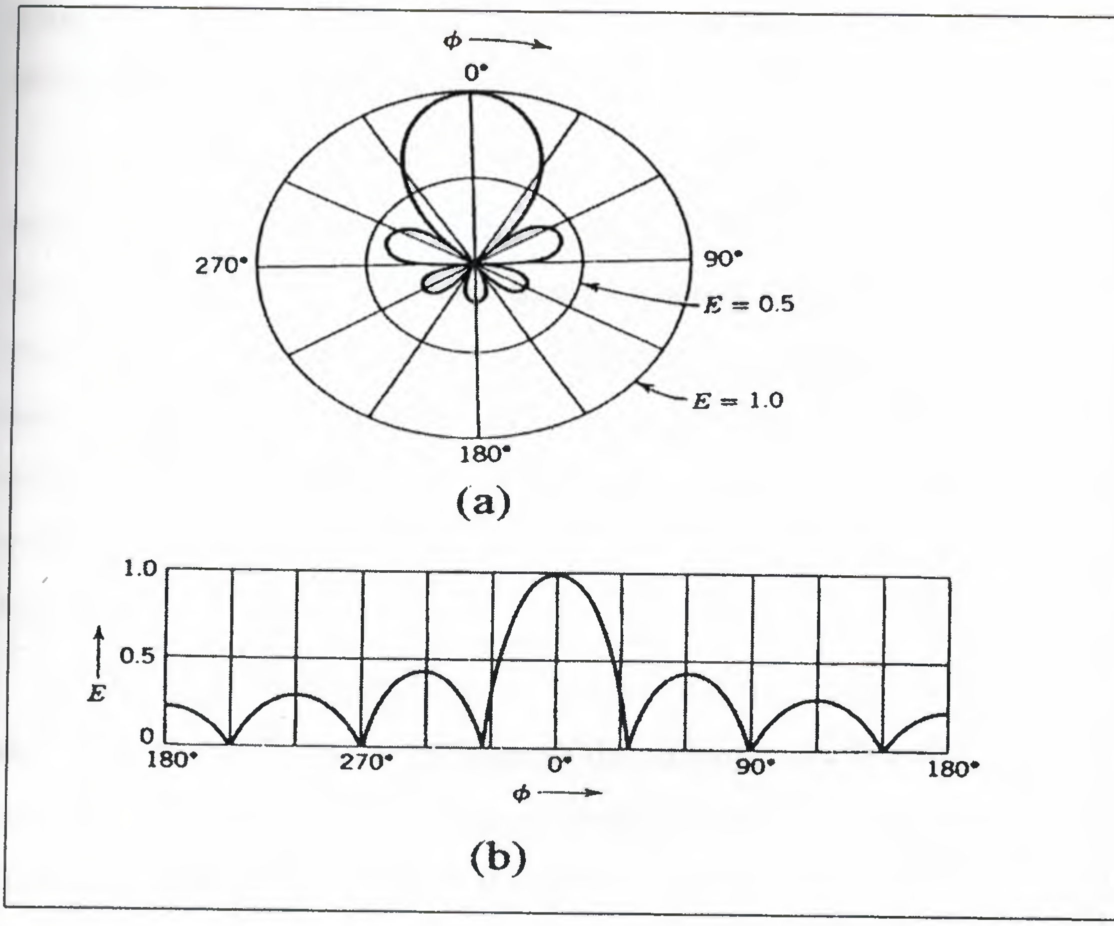

Figure 1.2 Comparison of plane pattern plotted in polar and rectangular form. The same pattern is represented in both cases and the coordinates are the same. Only the plot is different (a) polar (b) rectangular plot.

Note that it is easier to locate the angular positions of nulls (zeros) of the pattern on the rectangular plot.

If the radiation pattern is plotted in terms of the field strength in electrical units, such as volts per meter or the power density in watts per square meter, it is called an absolute pattern. An absolute pattern actually describes not only the characteristics of an antenna but also those of the associated transmitter, since the absolute field strength at a given point in space depends on the total amount of power radiated as well as on the directional properties of the antenna.

Often when the pattern is plotted in relative terms, that is, the field strength or power density is represented in terms of its ratio to some reference value. The reference usually chosen is the field level in the maximum field strength direction. This type of pattern provides as much information about the antenna as does an absolute pattern, and therefore relative patterns are usually plotted when it is desired to describe only the properties of the antenna, without reference to an associated transmitter (or receiver).

It is also fairly common to express the relative field strength or power density in decibels. This coordinate of the pattern is given as $20\log(E/E_{max})$ or $10\log(P/P_{max})$. The value at the maximum of the pattern is therefore zero decibels, and at other angles the decibel values are negative (sine the logarithm of a fractional number is negative).

Finally, we should mention that the antenna patters are usually given for the free-space condition, it being assumed that the user of the antenna will calculate the effect of ground reflection on this pattern for the particular antenna height and ground conditions that apply in the particular case. Some types of antenna are basically dependent on the presence of the ground for their operation, for example, certain types of vertical antennas at low frequencies. The ground is in fact an integral part of these antenna systems as has been shown in Sec.1.1.3. In these cases, the pattern must include the effect of the earth.

1.2.3 Near and Far Field Patterns

In principle it is possible to calculate the values of the electric and magnetic field components set up in space by any antenna.

The mathematical difficulties may be formidable if the antenna is complicated, but the calculation is always possible in principle when we use Maxwell's equations. For some simple types of antennas such calculations may be carried out in considerable detail, and the results illustrate certain features that apply to all antennas and are confirmed by experimental investigations of antenna fields. One such feature is that the radiation pattern in the region close to the antenna is not exactly the same as the pattern at great 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 great distances. The significance of these terms is conveniently illustrated by considering the fields set up by a simple dipole antenna. The mathematical analysis reveals that in a given direction the total electric field can be expressed as the sum of three terms, each of which decreases in magnitude as the distance from the antenna, *R*, increases; but they decrease at different rates.

The electric field intensity is inversely proportional to the first power of the distance. The dipole field is found to have components that decrease inversely as the square of the distance and inversely as the cube of the distance, in addition to the inverse-first-power term. Mathematically this means that one term contains factors $1/R$, $1/R^2$, and $1/R^3$.

The behavior of such terms, as R increases, is illustrated in Fig.1-3. These terms are equal in magnitude at $R = 1$. Or smaller values of R, the factor $1/R^3$ is largest, and the $1/R$ term is smallest. But for large values of R, the $1/R$ factor is larger than the other two, becoming increasingly so as R increases.

Practically in the far zone the field consists of only the term containing the $1/R$ factor. The field at great distance from the dipole behaves like the field of point source, with inverse-first-power dependence of the electric field intensity on the distance from the dipole.

At very close distance, on the other hand, $1/R^3$ and $1/R^2$ terms becomes much larger than the $1/R$ term dominates the far-field region, as seen in Figure 1-3

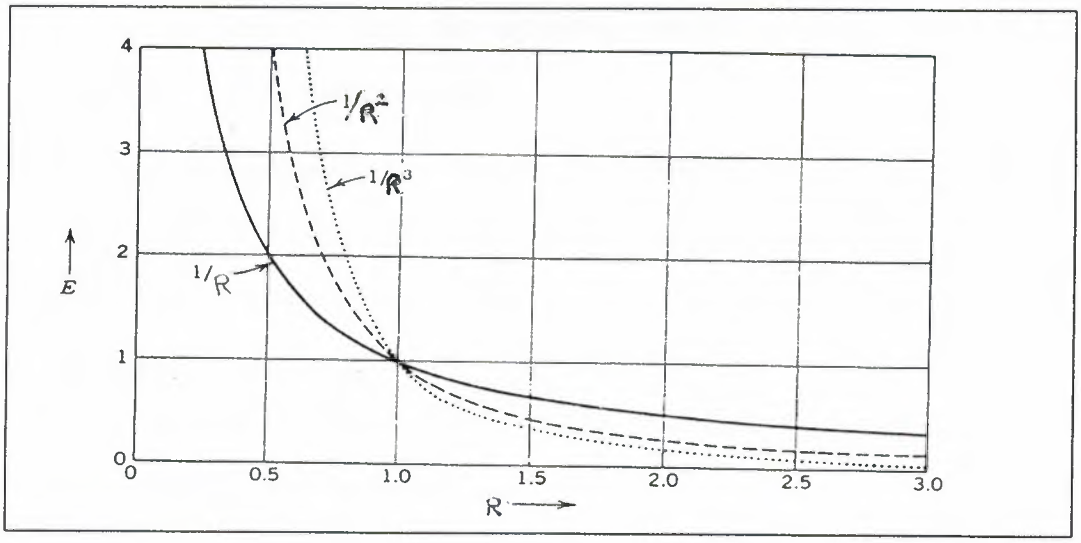

Figure 1-3 Relative variation with distance of short-dipole static ($1/R^3$), induction ($1/R^2$), and radiation ($1/R$) field components (electric intensity).

For more complicated antennas, the near field has more complicated dependence on R. The near-and far-field pattern is in general different; that is, plots of relative field strength at a constant distance do not have the same form. In fact, the pattern taken at different distances in the near field will differ from one another, but all patterns taken in the far field are alike, ordinarily it is the radiated power that is of interest, and so antenna patterns are usually measured in the far field region. For pattern measurement it is therefore important to choose a distance sufficiently large to be definitely in the far field, well out of the near field. The minimum permissible distance depends on the dimension of the antenna in relation to the wavelength. An accepted formula for this distance is

$$R_{Min} = \frac{2d^2}{\lambda} \qquad (1\text{-}3)$$

where R_{Min} is the distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

The factor 2 in this expression is somewhat arbitrary, but it is the factor usually observed in antenna measurement practice. The formula also assumed that d is at least equal to about a wavelength, when d is smaller than λ the distance R_{Min} should be equal to at least a wavelength. In some cases, the calculation for large antennas is too difficult to prove it then it is necessary to resort to measurement.

1.2.4 Antenna Gain

In our discussion of the antenna gain the concept of an isotropic radiator or isotrope is fundamental. Essentially an isotrope is an antenna that radiates uniformly in all directions of space. This pattern is a perfect spherical surface in space; that is, if the electric intensity of the field radiated by an isotrope is measured at all point on an imaginary spherical surface with the isotrope at the center (in free space), the same value will be measured everywhere. Actually such a radiator is not physically realizable for coherent electromagnetic radiation (If the radiation is coherent, the relative phases of the waves in different directions from the source maintain a constant difference. For a noncoherent radiator, these phase difference vary in a random manner, or fluctuate. The sun is an example of a noncoherent radiator) all actual antennas have some degree of non-uniformity in their three-dimensional radiation pattern. It is possible for an antenna to radiate uniformly in all directions in a plane, and to design an antenna that has approximate omnidirectionality in three dimension, but perfect omnidirectionality in three dimensional space can never be achieved. Nevertheless, the concept of such an ideal omnidirectional radiation, an isotrope, is most useful for theoretical purposes. A nonisotropic antenna will radiate more power in some directions than in others and therefore has a directional pattern.

Any directional antenna will radiate more power in its direction (or directions) of maximum radiation than an isotrope would, with both radiating the same total power. It is intuitively apparent that this should be so, since the directional antenna sends less power in some directions than an isotrope does, it follows that it must send more power in other directions, if the total powers radiated are to be the same. This conclusion will now be demonstrated more rigorously.

If an isotrope radiates a total power P_t and is located at the center of a transparent (or imaginary) sphere of radius R meters, the power density over the spherical surface is shown bellow

$$P_{isotrope} = \frac{P_t}{4\pi R^2} \qquad (W/m^2) \tag{1-4}$$

Since the total P_t is distributed uniformly over the surface area of the sphere, which is $(4\pi R^2)$ (m^2).

Imagine that in some way it is possible to design an antenna that radiates the same total power uniformly through one half of the same spherical surface, with no power radiated to the other half. Such a fictitious radiator may be called a semi-isotrope. Since the half sphere has a surface area $(2\pi R^2)$ square meters, the power density is

$$P_{semi-isotrope} = \frac{P_t}{2\pi R^2} \qquad (w/m^2) \tag{1-5}$$

Therefore, we get

$$\frac{P_{semi-isitrope}}{P_{isotrope}} = \frac{(P_t/2\pi R^2)}{(P_t/4\pi R^2)} = 2 \tag{1-6}$$

The last result shows that at any distance, R, the power density radiated by the semi-isotrope is twice as great as that radiated by the isotrope, in the half-sphere within which the semi-isotrope radiates.

In this region, therefore, the semi-isotrope is said to have a directive gain of 2. It is fairly apparent that if the radiation were confined to smaller portions of the total imaginary spherical surface, the resulting directive gain would be greater. For example, if the power P_t uniformly into only on fourth of the spherical surface, the directive gain would be 4, and so on.

1.2.4.1 Directive Gain

The directive gain D, of an antenna is defined, in a particular direction, as the ratio of the power density radiated in that direction, at a given distance, to the power density that would be radiated at the same distance by an isotrope radiating the same total power. The directive gain of a semi-istrope in the hemisphere into which it radiates is 2; its directive gain in the other hemisphere (where no power is radiated) is zero.

Thus D of an antenna is defined as a quantity that may be different in different directions. In fact, the relative power density pattern of an antenna becomes a directive gain pattern if the power density reference value is taken as the power density of an isotrope radiating the same total power (instead of using as a reference the power density of the antenna in its maximum radiation direction). In this case, we define the direction gain of the antenna as

$$D = \frac{P_{antenna}}{P_{isotrope}} \quad (1\text{-}7).$$

were $P_{antenna}$ is the antenna power density, from Eqs.1-2 and 1-4, we find that

$$D = \frac{4\pi R^2 E^2}{377 P_t} = \frac{4\pi R^2 P_{antenna}}{P_t} \qquad (1\text{-}8)$$

where P_t is the total radiation power. If P_t represents the input power to the actual antenna rather than the power radiated, G should be substituted for D on the left hand side of this equation, that is, give the power gain rather than the directive gain. The efficiency factor ξ is the ratio of the power radiated by the antenna to the total input power, it is a number between zero to unity, and it connects the direction gain D with the power gain G in

$$G = \xi D \qquad (1\text{-}9).$$

The maximum directive gain (directivity) is quite important value, as we will see in gain measurement later. This value can be calculated from

$$D_{Max} = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} \left[E(\theta,\phi) / E_{Max}\right]^2 \sin\theta \, d\theta \, d\phi} \qquad (1\text{-}10).$$

Once the directivity D_{Max} has been calculated from the relative pattern, the directive gain in any other direction θ_1, ϕ_1 can also be simply determined from the following relationship

$$D_{(\theta_1,\phi_1)} = D_{Max} \left[\frac{E\,(\theta_1,\phi_1)}{E_{Max}} \right]^2 \qquad (1\text{-}11).$$

1.2.4.2 Gain in Decibels

Antenna gain is a power ratio. The gain of practical antennas may be range from zero to as much as 10,000 or more. As with any power ratio, antenna gain may be expressed in decibels. To illustrate in terms of the antenna power gain G, the value in decibels will be donated by G (dB) and is given by G (dB)=10 $\log_{10} G$. The directive gain in decibels is calculated from the same formula, with *D* substituted for *G*.

1.2.4.3 Practical Significance of Power Gain

It is apparent for a given amount of input power in antenna; the power density at a given point in space is proportional to the power gain of the antenna in that direction. Therefore the signal available to a receiving antenna at that location can be increased by increasing the power gain of the transmitting antenna, without increasing the transmitting power. A transmitter with a power output of 1000 watts and antenna with a power gain of 10 (10dB) will provide the same power density at a receiving point as will a transmitter of 500 watts power and an antenna power gain of 20 (13dB). Obviously this relationship has great economic significance. Sometimes it may be much less expensive to double the gain of the antenna (add 3dB) than it would be to double the transmitter power (though in other cases the converse may be true). But generally speaking it is desirable to use as much antenna gain as may feasibly be obtained, when it is desired to provide the maximum possible field strength in a particular direction.

1.2.5 Beamwidth

When the radiated power of an antenna is concentrated into a single major lobe as seen in the pattern of Fig.1-2, the angular width of this lobe is the beamwidth. The term is applicable only to antennas whose patterns are of this general type. Some antennas have a pattern consisting of many lobes, all of them more or less comparable in their maximum power density, or gain, and not necessarily all of the same angular width. But large classes of antennas do have patterns to which the beamwidth parameter may be appropriately applied.

1.2.5.1 Definition of Beamwidth

It is logical to define the width of a beam in such a way that it indicates the angular range within which radiation of useful strength is obtained, or over which good reception may be expected. From this point of view the convention has been adopted of measuring beamwidth between the points on the beam pattern at which the power density is half the value at the maximum. In a plot of the electric intensity pattern, the corresponding points are those at which the intensity is equal to 0.707 of the maximum value. The angular width of the beam between these points is called the half-power beamwidth. When a beam pattern is plotted with the ordinate scale in the minus 3dB points. For this reason the half power beamwidth is often referred to as the -3dB beamwidth. Figure 2-4 illustrates the procedure of determining the -3dB beamwidth on a rectangular pattern plot.

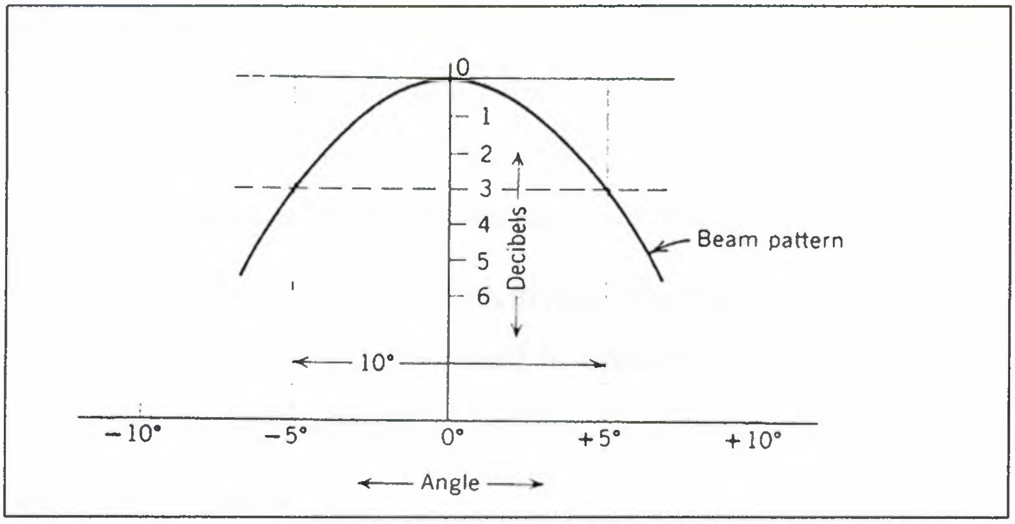

Figure 1-4 Determination of half-power (3dB-down) beamwidth.

This 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 example, at -3dB, -10dB, and at the nulls (if they are present). Some beams may have an asymmetric shape. Special methods of describing such beams can be employed. In the final analysis the best description of a beam is a plot of its pattern.

1.2.5.2 Practical Significance of Beamwidth

If an antenna has a narrow beam and is used for reception, it can be used to determine the direction from which the received signal is arriving, and consequently it provides information on the direction of the transmitter. To be useful for this purpose, the antenna beam must be steerable; that is, capable of being pointed in various directions. It is intuitively apparent that for this direction-finding application, a narrow beam is desirable and the accuracy of direction determination will be inversely proportional to the beamwidth. In some applications receiving may be unable to discriminate completely against an unwanted signal that is either at the same frequency as the desired signal or on nearly the same frequency.

In such a case, pointing a narrow receiving antenna beam in the direction of the desired signal is helpful; resulting in greater gain of the antenna for the desired signal, and reducing gain for the undesired one.

1.2.6 Minor Lobes

As we have mentioned in our discussion of the antenna patterns, a directional antenna usually has lobe of several smaller lobes in other directions; they are minor lobes of the pattern. Those adjacent to the main lobe are side lobes, and these occupy the hemisphere in the direction opposite to the mainbeam direction are back lobes. Minor lobes ordinarily represent radiation (or reception) in undesired directions, and the antenna designer therefore attempts to minimize them, that are to reduce their level relative to that of the main beam. This level is expressed in terms of the ratio of the power densities in the mainbeam maximum and in the strongest minor lobe, and often expressed in decibels.

Since the side lobes are usually the largest of the minor lobes, this ratio is often called the side-lobe ratio or side-lobe level. A typical side-lobe level, for an antenna in which some attempt has been made to reduce the side-lobe level, is 20dB, which means that the power density in the strongest side lobe is 1% of the power density in the main beam.

Side-Lobe levels of practical well designed directional antennas typically range from about 13dB (power-density ratio 20) to about 40dB (power density ratio 10,000). Attainment of a side-lobe level better than 30dB requires very careful design and construction. Figure 1-5 shows a typical antenna pattern with a main beam and minor lobes, plotted on a decibel scale to facilitate determination of the side-lobe level, which is here seen to be 25dB.

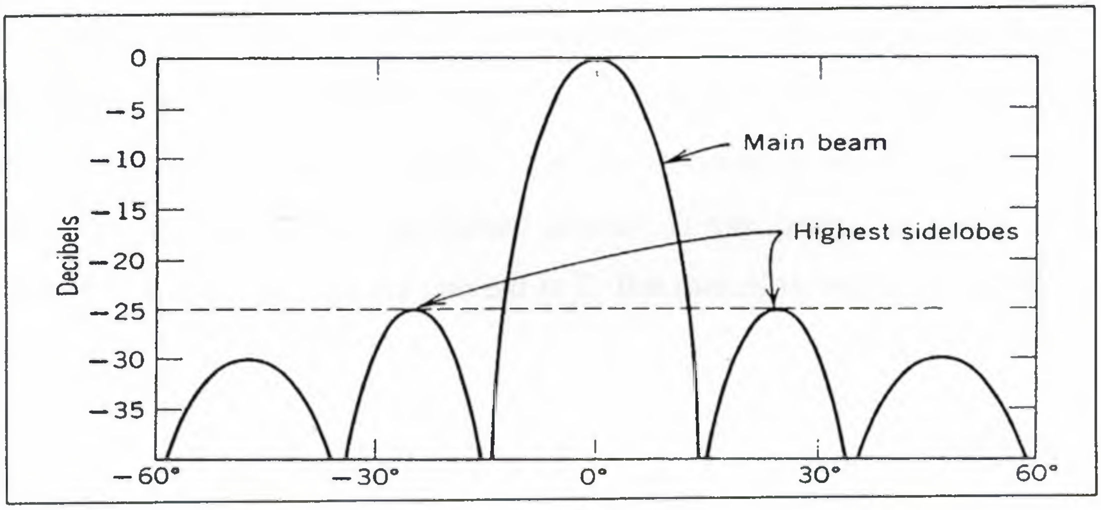

Figure 1-5. Decibel pattern plot, indicated side lobe level.

In some applications side lobes are not especially harmful unless their level becomes comparable to the main-beam level. In other applications it may be important to hold the side-level to an absolute minimum. In most radar systems, a low side-lobe level is important. If the radar is very sensitive, a large target located in the direction of one of the antenna side lobes (or even a back lobe) may appear on indicator oscilloscope as though it were a target in the main beam.

1.2.7 Radiation Resistance and Efficiency

In a large class of antennas the radiation is associated with a flow of RF current in a conductor or conductors. As is well known in elementary electric circuit theory, when a current I flows in a resistance R, an amount of power $P = RI^2$ will be dissipated, that is, electrical energy will be converted into heat at this rate. In an antenna, even if there is no resistance in the conductors, the electrical energy supplied by the transmitter is lost just as though it had been converted in to heat a resistance, although in fact it is radiated. It is customary to associate this loss of power, through radiation, with a fictitious radiation resistance that bears the same relationship to the current and the radiation power as an actual resistance bears to the current and dissipated power. If the power radiated by the antenna is P and the antenna current is I, the radiation resistance is defined as

$$R_r = \frac{P}{I^2} \qquad (1\text{-}12)$$

when P is given in watts and I in amperes, R_r is obtained in ohms from this formula, which is effect a definition of radiation resistance.

This concept is applicable only to antennas in which the radiation is an associated with a definite current in a single linear conductor.

In this limited application, the definition is ambiguous as it stands, because the current is not the same everywhere even in a linear conductor, it is therefore necessary to specify the point in the conductor at which the current will be measured. Two points sometimes specified are the point at which the current has its maximum value and the feed point (input terminals). These two points are sometimes one and the same points, as center-fed in a dipole, but they are not always the same. The value obtained for the radiation resistance of the antenna depends on which point is specified; this value of the radiation resistance referred to that point. The current maximum of a standing-wave pattern is known as a current loop, so the radiation resistance referred to the current maximum is sometimes called the loop radiation resistance.

The word maximum here refers to the effect current rms in that part of the antenna where it has its greatest value. It does not mean the peak value of the current at this point during the RF cycle, when Eq.1-12 is used as the definition. In some texts, however, formulas for radiation resistance are written in terms of this peak value, which is the amplitude of the current sine wave. Equation 1-12 will yield a value of radiation resistance only half as great as the true value if the current amplitude is used for I, the correct formula in terms of the current amplitude I_o, is $R_r = 2P/I^2$, note that $I_o = \sqrt{2} I_{rms}$.

The radiation resistance of some types of antennas can be calculated, when there is clearly defined current value to which it can be referred, but for other types the calculation cannot be made practically, and the value must be obtained by measurement. Methods of making such a measurement will be described later.

The typical values of the loop radiation resistance of actual antennas range from a fraction of an ohm to several hundred ohms. The very low values are undesirable because they imply large antenna current, and therefore the possibility of considerable ohmic loss of power, that is, dissipation of power as heat rather than as radiation. An excessively high value of radiation resistance would also be undesirable because it would require a very high voltage to be applied to the antenna. Very high voltage values do not occur in practical antennas, because there is always some ohmics resistance whereas very low values sometimes do occur unavoidably.

Antennas always do have some omic resistance, although sometimes it may be so small as to be negligible. The ohmic resistance is usually distributed over the antenna, and since the antenna current varies, the resulting loss may be quite complicated to calculate. In general, however, the actual loss can be considered to be equivalent to the loss in a fictitious lumped resistance placed in series with the radiation resistance. If this equivalent ohmic loss resistance is denoted by R_0, the full power (dissipated plus radiated) is $I^2 = (R_o + R_r)$, whereas the radiation power is I^2R_r. Hence the antenna radiation efficiency ξ_r is given by

$$\xi_r = \frac{R_r}{R_o + R_r} \qquad (1\text{-}13)$$

It must be acknowledged that this definition of efficiency is not really very useful even though it may occasionally be convenient. The fact is both R_0 and R_0 is fictitious quantities, derived from measurements of current and power; R_r is given in these terms by Eq.1-12, and R_o is correspondingly equal to P_0 / I^2. Making these substitutions into Eq.1-13, then it gives the more basic definition of the efficiency:

$$\xi_r = \frac{P_r}{P_o + P_r} \tag{1-14}$$

1.2.8 Input Impedance

An antenna whose radiation results directly from the flow of RF current in a wire or other linear conductor must somehow have this current introduced into it from a source of RF power transmitters. The current is usually carried to the antenna through a transmission line. To connect the line to the antenna, a small gap is made in the antenna conductor, and the two wires of the transmission line are connected to the terminals of the gap at antenna input terminals. At this point of connection the antenna presents load impedance to the transmission line. This impedance is also the input impedance of the antenna and it is equal to the characteristic of the line Z_0, the input impedance of the antenna is one of it is important parameters. Measurement of the antenna input impedance would be discussed later.

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 and it can be written as

$$Z = \frac{E_i}{I_i} \tag{1-15}$$

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

$$Z_i = R_i = R_r + R_o \tag{1-16}$$

If this reactance has a large value, the antenna-input voltage must be very large to produce an appreciable input current. If in addition the radiation resistance is very small, the input current must be very large to produce appreciable radiated power. Obviously this combination of circumstances, which occurs with the short dipole antenna that must be used at very low frequencies, results in a very difficult feed problem or impedance-matching problem, they are usually fed by waveguides rather than by transmission line. The equivalent of an input impedance can be defined at the point of connection of the waveguide to the antenna, just as waveguides have a characteristic wave impedance analogous to the characteristic impedance of a transmission line. For some types of antennas consisting of current-carrying conductors this is difficult, and it may even be difficult to define input impedance. This is true, as an example, for an array of dipoles, when each dipole is fed separately; sometimes each dipole, or groups of dipole, will be connected to separate transmitting amplifiers and receiving amplifiers. The input impedance of each dipole or group may then be defined, but the concept becomes meaningless for the antenna as a whole, as does also for simple linear-current radiation elements; but they comprise a very large class of antennas.

1.2.9 Bandwidth

All antennas are limited in the range of frequency over which they will operate satisfactorily. This range is called the bandwidth of the antenna. Bandwidth is a concept that is probably familiar in other applications, sometimes by another name. For example, a television I-f amplifier must have a bandwidth of approximately 4MHz in order to pass all the frequency components of a television signal. A television-transmitting antenna must have sufficient bandwidth to receive all the channels to which the receiving set can be tuned.

If an antenna were capable of operating satisfactory from a minimum frequency of 155MHz to a maximum frequency of 205MHz, its bandwidth would be 10MHz. It would also be said to have a 5% bandwidth (the actual bandwidth divided by the center frequency of band, times 100). Some antennas are required to operate only at a fixed frequency with a signal that is narrow in its bandwidth; consequently there is no bandwidth problem in designing such an antenna. In other applications much greater bandwidths may be required; in such cases special techniques are needed. Some recent developments in broadband antennas permit bandwidths so great as they are described by giving the numerical ratio of the highest to the lowest operating frequency, rather than as a percentage of the center frequency. In these terms, bandwidths of 20 to 1 are readily achieved with these antennas, and ratios as great as 100 to 1 are possible.

1.2.10 Beam Area or Beam Solid Angle

An arc of a circle seen from the center of this circle subtends an angle θ. Thus, referring to Fig.2-6a, the arc length θR subtends the angle θ. The total angle in the circle is 2π rad so the total arc length is 2πR.

BY using the same concept, an area A of a sphere surface seen from the center of the sphere subtends a solid angle Ω as shown in Fig .1-6b

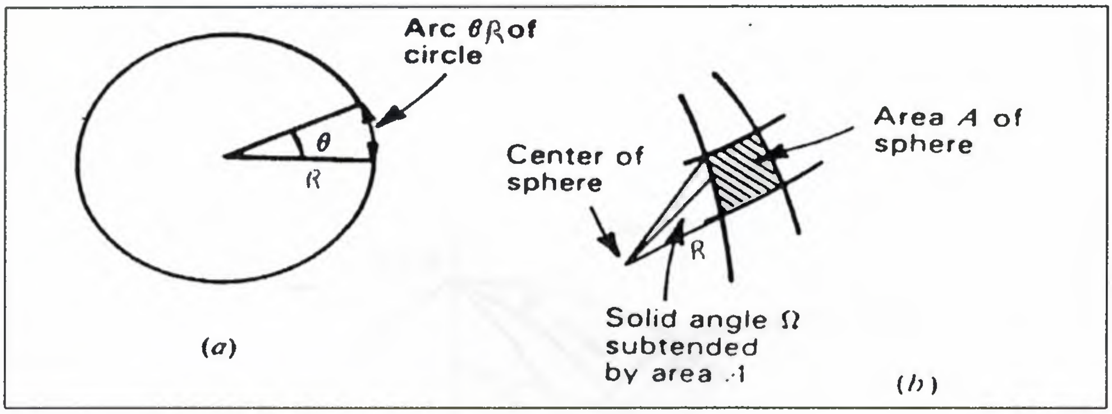

Figure 1-6 (a) Arc length Rθ of circle has radius R subtends the angle θ. The area A of a sphere of radius R subtends a solid angle Ω.

The total solid angle subtended by the sphere is 4π steradians (or square radians), abbreviated sr.

By using Fig.1-7 we can discuss the solid angle in more details. From Fig.1-7, it is shown that the solid angle $d\Omega$ subtended by dA is

$$d\Omega = \sin\theta \; d\theta \; d\phi \qquad (1\text{-}17)$$

To more declaration, the incremental area dA of the surface of a sphere is given by $dA = (R\sin\theta \; d\phi)\,(Rd\theta) = R^2 \sin\theta \; d\phi \; d\theta = R^2 d\Omega$ the area of the strip of width Rdθ extending around the sphere at a constant angle θ is given by dAs= $(2\pi R \sin\theta)(R d\theta)$.

Integrating this for θ values from 0 to π yields the area of the sphere. Thus,

$$Area\ of\ sphere = 2\pi R^2 \int_0^{\pi} \sin\theta\ d\theta = 4\pi R^2 \qquad (1\text{-}18)$$

By comparing this result with $dA = (R\sin\theta\ d\phi\ (Rd\theta) = R^2 \sin\theta\ d\phi\ d\theta = R^2 d\Omega$ we fined that $d\Omega$ for the whole sphere surface is 4π

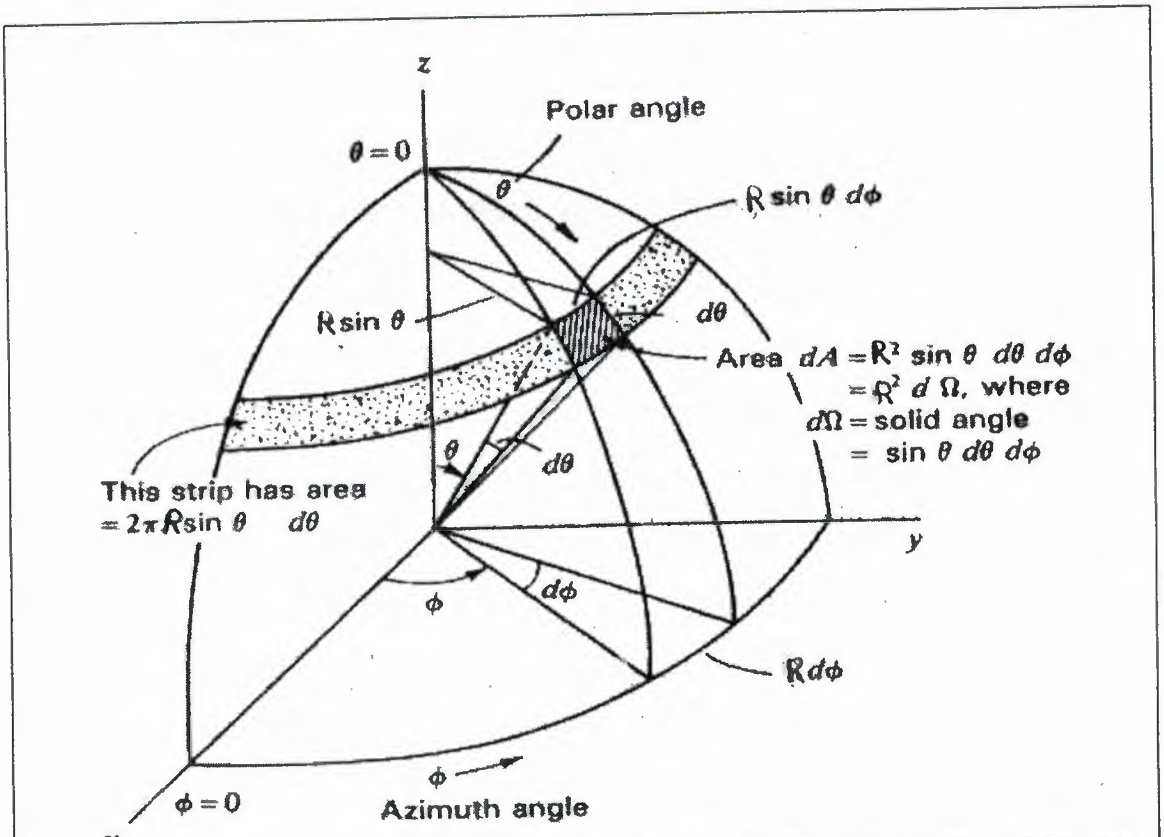

Figure 1-7 Spherical coordinates in relation to the area dA solid angle $d\Omega = \sin\theta\ d\theta\ d\phi$.

Now the beam area (or beam solid angle) Ω_A for an antenna is given by the integral of the normalized power pattern over a sphere (4π, sr)

$$\Omega_A = \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)d\Omega \qquad (1\text{-}19)$$

1.2.11 Capture Area or Receiving Cross Section

Although there is a reciprocal relationship between the transmitting and the receiving properties of antennas, it is sometimes more convenient to describe the receiving properties in a somewhat different way. Whereas the power gain is the natural parameter to use for describing the increases power density of the transmitted signal due to the directional properties of the antenna, a related quantity called the receiving cross section, sometimes also called the capture area, is a more natural parameter for describing the reception properties of the antenna.

To define the antenna receiving cross section, suppose that an antenna radiates an amount power which passes through each unit area of any imaginary surface perpendicular to the direction of propagation the waves, then a power density P_i will be passed to the receiving antenna. This power density induces radio frequency power P_r at the receiving antenna terminals be delivered to a load (e.g., the input circuit of a receiving). In principle the power available at these terminals can be measured (in practice it may be so small, so it is amplified and then read). The antenna receiving cross section A_r (or the capture area) is then defined as the ratio between the delivered power P_r watts into the load power density P_i watts per unit area

$$A_r = \frac{P_r}{P_i} \qquad (1\text{-}20)$$

Also there is a relationship between the gain of the antenna and its physical size, this relationship suggests that there may also be a connection between the gain and the receiving cross section area and this indeed turns out to be true.

The receiving cross section area in istropic A_{ro} is given as

$$A_{ro} = \frac{\lambda^2}{4\pi} \Rightarrow A_r = \frac{G\lambda^2}{4\pi} \qquad (1\text{-}21)$$

where $G=\xi D$, λ is the wavelength, note that λ has relationship with the size, then A_r , G and the size. Equation 1-20 may be proved theoretically and verified experimentally. From this relationship it follows that

$$D = (\frac{4\pi A_r}{\xi \lambda^2}) \qquad (1\text{-}22)$$

where D is the directive gain.

It is clear from this relationship that the gain increases when A_r increases, and λ and ξ decrease, and vice versa. Thus, the power is

$$P_r = \xi (\frac{P_i D \lambda^2}{4\pi}) \qquad (1\text{-}23)$$

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 Eq.1-23. In general, it is possible to measure the gain from the receiving cross signal, as we will see later.

CHAPTER TWO

ANTENNA MEASUREMENTS

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 first category (input impedance) deals with one of the most important antenna parameters, and the second one (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. It is seldom that the complete antenna pattern is measured, including side lobes and polarization characteristics in all direction, often, 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.

For the second category, the input impedance is practically always important.

The experimental investigations suffer from a number of drawbacks such as:

1. For pattern measurements, the distance to the far-field region ($R > \frac{2d^2}{\lambda}$) 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 system faces an uncontrolled environment and it does not possess an all-weather capability.

5. Enclosed measuring systems usually cannot accommodate large antenna systems (such as ships, aircraft, large spacecraft, etc).

6. Measurement techniques are expensive, because it needs gigantic instruments to perform these measurements.

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 measurement, and automated commercial equipment specifically designed for antenna measurements and utilizing computer assisted techniques, but these methods are excessively expensive.

2.1 Impedance Measurement

Impedance is a quantity basically defined at a pair of electrical terminals, in terms of the current, *I*, that flows if a voltage *V* is applied between the terminals as shown in

$$Z = \frac{V}{I}, \quad (2\text{-}1)$$

The impedance is a complex quantity and it is expressed as

$$Z = R + jX, \quad (2\text{-}2)$$

where *R* and *X* are the resistive real and reactive imaginary parts, respectively. The relationship between Eqs.2-1 and 2-2 lies in the fact that there is in general (except when $X = 0$), a phase difference between the voltage *V* and *I*, expressed as an angle θ. This angle is related to *R* and *X* by the equation:

$$\tan\theta = \frac{X}{R}. \quad (2\text{-}3)$$

it can readily be shown that the impedance may be expressed as

$$Z = \left|\frac{V}{I}\right|(\cos\theta + j\sin\theta). \quad (2\text{-}4)$$

Thus, *Z* can be found by measuring the voltage and current at the pair of terminals and the phase angle between them. From Eq.2-4 we find that

$$R = \frac{V}{I}\cos\theta, \quad (2\text{-}5)$$

and

$$X = \frac{V}{I}\sin\theta . \qquad (2\text{-}6)$$

At low ratio frequencies, voltmeters and ammeters are practical instruments by using a cathode ray method. The direct measurement of the phase angle is not a simple matter but by using this method it can be done. Simply, this method is to apply a small voltage derived from the current I to one deflection axis of a cathode ray tube, with suitable amplification, and a sample of the voltage I to the other axis. The resulting pattern will be an ellipse if there is a phase difference; the value of the phase angle θ can be determined from the dimensions of the ellipse.

This direct method of impedance measurement may sometimes be useful because it measures θ directly from I and V, but this method is used at low frequency. But comparison methods are more commonly employed, such as the bridge method that used at high range of frequencies.

2.1.1 Bridge Measurement Method

This method uses a bridge circuit and it is essentially a device for measuring unknown impedance by comparing it with known impedance. The basic arrangement consists of four impedances connected as shown in Fig 2-1.

The detector may be any device that can respond to a current from the a-c signal applied to 1 and 4 terminals.

By simple circuit analysis it can be shown that the voltage between points 1 and 4 of the bridge will be zero if the following relationship exists among the impedances

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}, \tag{2-7}$$

then the bridge is said to be balanced. When the bridge is unbalanced, the meter of the detector circuit will indicate the presence of a voltage between point 1 and 4. Then, the variable impedance Z_2 is adjusted until a zero reading of the meter is obtained, the bridge will be balanced, and the value of the unknown impedance can be computed by

$$Z_1 = \frac{Z_2 Z_3}{Z_4} \tag{2-8}$$

which is simply a rearrangement of Eq.2-7.

For measurement of antenna input impedance, the antenna input terminals are connected as the unknown impedance to terminals 1 and 3 of the bridge. In Fig.2-1, point 1 should be grounded. This would be a suitable arrangement for an antenna with one grounded input terminal, such as a vertical low-frequency antenna operated in conjunction with the ground, or any antenna whose feed line has one side grounded. When the antenna is being measured, care must be taken that points 1 and 3 of the bridge are balanced with respect to the ground.

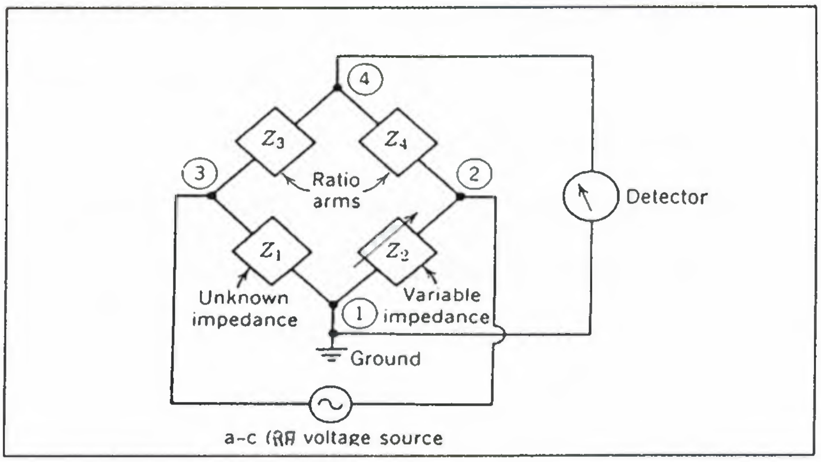

Figure 2-1. Impedance bridge circuit.

The voltage source must provide a radio frequency RF signal of appropriate voltage level at the frequency of operation of the antenna. For more sensitive to the detecting instrument, the less voltage is required from the source. A typical value is a few millivolts if the detector is a fairly sensitive radio receiver.

The actual indicating instrument can then be either a d-c meter in the output circuit of the receiver detector or an audio-frequency meter if an audio-frequency modulation is used to modulate the RF signals. Precaution must be taken that pickup of extraneous signals by the antenna does not corrupt the measurement. The use of audio modulation is helpful for this purpose, as a tuned filter can then be used in the receiver output circuit to eliminate most, if not all, undesired signals. Equation 2-4 hides the fact that each of the four impedances is complex, consisting in general of resistive and reactive components. Therefore, Eq.2-8 is really a complex variable equation and is equivalent to two separate real variable equations; that is, if each side of the complex equation is separated into real and imaginary parts, the real parts of each side and the imaginary parts must be separately equal to one another. Then, instead of a single equation for the unknown impedance, Z_1, there are two equations, one for the resistive part and the other for the reactive part. Moreover, in order to balance the bridge, both the resistive and reactive parts of the variable impedance, Z_2, must be separately adjusted. In the most general case the reactance may be either inductive or capacitative, so that Z_2 must be capable of being adjusted for either type of reactance. The solution of Eq.2-8 for the resistive and reactive components of Z_1 are

$$R_1 = \frac{R_2 R_3 R_4 - X_2 X_3 R_4 + X_2 R_3 X_4 + R_2 X_3 X_4}{R_4^2 + X_4^2} \qquad (2\text{-}9)$$

and

$$X_1 = \frac{X_2 X_3 X_4 - R_2 R_3 X_4 + X_2 R_3 R_4 + R_2 X_3 R_4}{R_4^2 + X_4^2} \qquad (2\text{-}10)$$

where $Z_1 = R_1 + jX_1$, $Z_2 = R_2 + jX_2$, $Z_3 = R_3 + jX_3$, and $Z_4 = R_4 + jX_4$.

In a practical bridge some of the quantities on the right-hand side may be zero, thus simplifying the equations. These equations are derived on the assumption that each impedance consists of a resistance and a reactance in series. Some bridges may employ parallel arrangements, which will result in quite different-appearing equations.

Bridges especially designed for antenna impedance measurements are commercially available and are furnished with instruction books that give the equations in a form applicable to the particular impedance arrangement employed. For measurement of low-frequency antenna impedances bridges are virtually always employed, and up to about 30MHz they are the method of choice. From 30MHz to perhaps as high as 1000MHz the bridge method may be used, although the bridge impedance arms may then consist partly of transmission line elements rather than purely lumped capacitances and inductances. [3].

2.1.2 Standing-Wave Method

The Voltage Standing Wave Ratio *VSWR* requires a brief study on the reflection coefficient and *VSWR* concepts. The fraction of incident wave voltage (or current) reflected from the load end of a line and the phase change that occurs in the reflection are described by a reflection coefficient ***r***. It is a complex number, since it describes both magnitude and a phase angle, and hence it is expressed in the form

$$r = |r|e^{j\theta} = |r|(\cos\theta + j\sin\theta) \quad (2\text{-}11)$$

where $|r|$ is the magnitude of the complex quantity and θ is the phase angle. The magnitude of the reflection coefficient is the ratio of the reflected $V_{o(r)}$ and incident $V_{o(i)}$ voltage (or current)

$$r = \frac{V_{o(r)}}{V_{o(i)}}. \quad (2\text{-}12)$$

The phase angle is the phase difference between the phase of the incident θ_i and reflected θ_r waves relative to an arbitrary reference phase.

This method requires another relation to determine the reflection coefficient as relationship with the load impedance Z_L. Analysis shows that the relationship is

$$r = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{(Z_L / Z_o) - 1}{(Z_L / Z_o) + 1} \tag{2-13}$$

where Z_0 is the characteristic impedance [3].

Taking into consideration that the voltage incidence and reflection at some points on the line will be in phase and will add to obtain a maximum voltage value V_{Max} as

$$V_{Max} = V_{o(i)} + V_{0(r)} \tag{2-14}$$

At other points the two voltage waves will be exactly out of phase and will therefore subtract, this result of voltage is called the minimum voltage V_{Max} and is given by

$$V_{Min} = V_{o(i)} - V_{o(r)} \,. \tag{2-15}$$

The ratio of the maximum to the minimum voltage is called the Voltage Standing Wave Ratio *VSWR* and is written

$$VSWR = \frac{V_{Max}}{V_{Min}} = \frac{V_{o(i)} + V_{0(r)}}{V_{o(i)} - V_{o(r)}} \,. \tag{2-16}$$

Obviously the *VSWR* is a number equal to or greater than one. (It is equal to one when there is no reflected wave). From Eqs.2-12 and 2-13 it is apparent that *VSWR*=1 when *r*=0 and therefore when $Z_o = Z_L$.

Equation 2-13 indicates that if the reflection coefficient is known, the load impedance Z_L can also be determined. This is shown more explicitly by rearrangement of the Eq.2-13 as

$$Z_L = Z_o\left(\frac{1+r}{1-r}\right). \tag{2-17}$$

And the relationship between reflection coefficient **r** and *VSWR* can be obtained from Eqs.2-12 and 2-16 as in

$$|r| = \frac{VSWR-1}{VSWR+1}. \tag{2-18}$$

Thus, a measurement of VSWR provides one ingredient (essential but does not sufficient) necessary for determination of Z_L.

In accordance with Eq.2-17 the additional ingredient required is of course the phase angle as shown in Eq.2-11. To solve this problem we can determine another quantity that is called the first voltage minimum d that has the following relationship with θ as in

$$\theta = \pi - 2\beta d = \pi\left(1-\frac{4d}{\lambda}\right) \quad \text{(Radians)} \tag{2-19}$$

where θ is in radian, and the phase constant $\beta = \frac{2\pi}{\lambda}$ (rad/m) and λ is the wave length (m), if the two quantities (*VSWR* and d) are measured Z_L can be calculated from Eqs.2-11and 2-17 through 2-19. With Z_L known, we can find the impedance presented to a source at the transmission-line input terminals Z_I, from

NEAR EAST UNIVERSITY
LIBRARY
1988 - LEFKOŞA

$$Z_i = Z_o \left[\frac{(Z_L / Z_o) + j \tan \beta l}{1 + j (Z_L / Z_o) \tan \beta l} \right] \tag{2-20}$$

when l - is the total length of line.

Also Z_i can be calculated directly by substituting Eq.2-17 into 2-20 that gives

$$Z_i = Z_o \left[\frac{(\frac{1+r}{1-r}) + j \tan \beta l}{1 + j (\frac{1+r}{1-r}) \tan \beta l} \right] \tag{2-21}$$

where Z_L is the impedance connected at load end of line.

For frequencies above 30MHz, it becomes practical to measure the antenna input impedance by determining the *VSWR* on the feed line, and the distance from the antenna terminals to the first voltage minimum on the line (*d*) together with Eqs.2-18 through 2-21 and 2-14 through 2-15 to find Z_L and Z_L.

It is clear that the Eqs.2-11 and 2-19 show the complex reflection coefficient of the load ***r*** that can be found from measurement of *VSWR* and *d*, then the load impedance Z_L can be calculated while ***r*** is known.

The Smith chart can also be employed to determine Z_L directly from the values *VSWR* and *d*, without any calculation, or determination of the reflection coefficient, ***r***. Therefore, this method consists of measuring the quantities *VSWR* and *d*, and then making use of the Smith chart, as will be discussed later. The quantities to be measured are depicted graphically in Fig.2-2

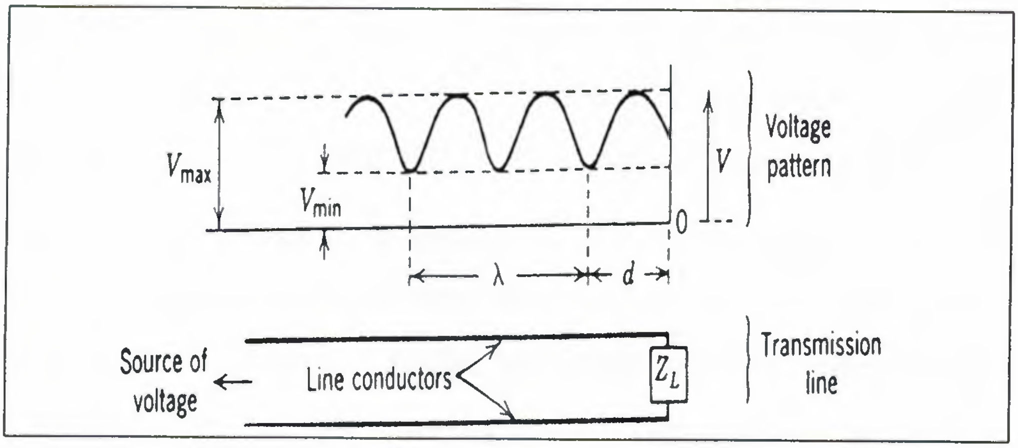

Figure 2-2. Diagram showing quantities to be measured in standing-wave method of impedance determination.

Figure 2-2 shows only one of many possible patterns that might be observed. Note that the wavelength, λ, is twice the separation of the voltage minimum. The ratio d / λ rather than d itself are the quantity actually used in the calculation. Although λ may be measured from the manner shown, it can also be calculated from the frequency, f, and the velocity of the propagation, v, by using the formula $\lambda = v / f$.

The basic procedure for measuring the position of the voltage minimum, and the *VSWR*, is to move a RF voltmeter along the line and find the positions at which it reads maximum and minimum values. The voltmeter must be one that does not itself constitute an appreciable load on the line at the position where it is measuring the voltage. A second requirement is that it must not distort the field between the line conductors, thereby causing a reflected wave that will result in an erroneous voltage reading. Finally, it must provide a means of indicating the exact position on the line that corresponds to its voltage reading.

To compass these requirements, it is customary to employ a special slotted line, which it is a horizontal section of coaxial transmission line that has a long narrow slot cut into the top of its outer conductor along its length.

A similarly slotted flat plate is brazed or otherwise joined to the upper surface of the outer conductor, to provide a surface on which the voltmeter can slide. A short metal pins, or probe, project through the center of the slot (without touching the wall side) into the space containing the interconductor field of the line. The probe is not long enough to touch the center conductor, but it has a voltage induced between it and the outer conductor by the electric field of the line. The upper end of the probe connects to an electrode of a RF rectifier. In the simplest type of instrument the resulting rectifier current is read by a d-c microammeter. Because the probe is such small dimension, it does not disturb the field appreciably and the micrommeter does not constitute an appreciable load if the line is carrying a fairly high power level. Cross-sectional and perspective views of a typical arrangement are shown in Fig.2-3.

In this simple device a tuned circuit is connected to provide a d-c path through the rectifier and meter while presenting high impedance to the RF voltage. A knob is provided on the condenser shaft for tuning this circuit to resonance (indicated by a maximum meter reading for a fixed position of the probe). Provision is made for the box to slide smoothly on the slotted surface and to keep the probe properly positioned in the center of the slot.

lower powered source of RF signal for making the impedance measurement.

This is made possible by employing in place of the microammeter, an amplifier. If the RF signal is modulate with an audio-frequency waveform an audio amplifier may be used.

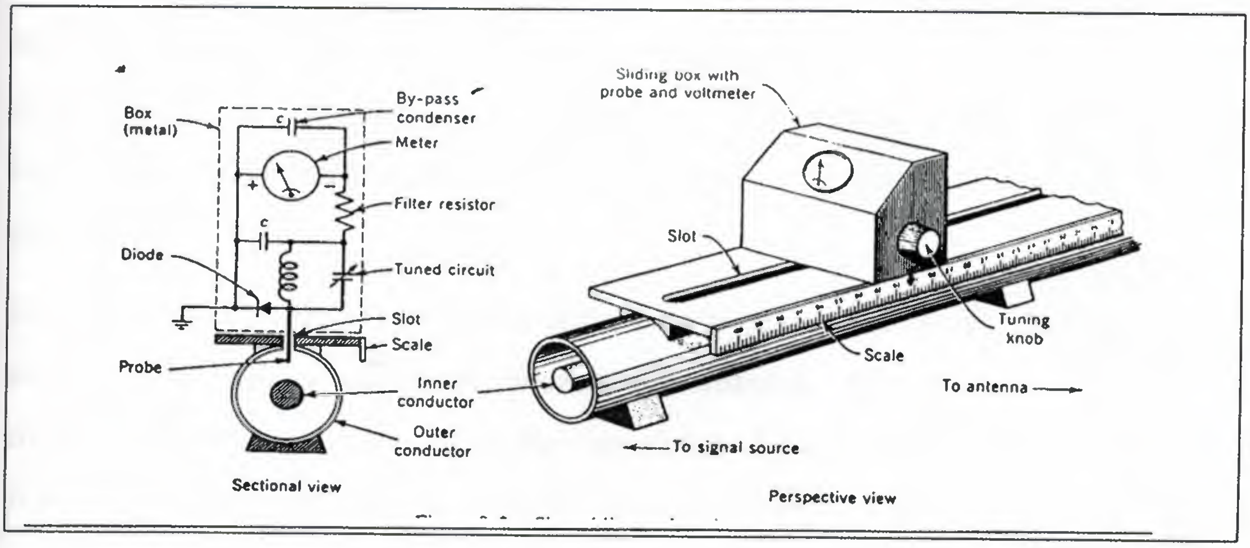

Figure 2-3.Slotted line and probe voltmeter

It must be precisely linear and highly stable; or if it is not linear, the associated meter must be calibrated accordingly. Its output used to actuate a meter. The amplifier and meter are not usually mounted in the sliding probe assembly but are connected to it though a length of flexible coaxial cable. The crystal detector, is located close to the probe in the sliding assembly, so that all RF circuitry localized, The detector and amplifier must be thoroughly shielded against pickup of stray field, so that only a field in the coaxial line cane cause a meter reading. If the impedance of a high gain antenna is being measured, the antenna beam should be pointed away from the measuring apparatus.

Slotted lines and the associated equipment are commercially available, in various types for different frequency ranges. At frequencies up to about 1000MHz, coaxial slotted lines of $50(\Omega)$ characteristic impedance are standard. At still higher frequencies, a slotted waveguide can be used. Since the position of the probe must be measured fairly precisely at microwave frequencies, the carriage may be driven by a screw connected to a handcrank with a dial or scale calibrated precisely in millimeters of travel of the probe.

Especially at the very short wavelengths, it may be difficult or impossible to observe the voltage minimum nearest the antenna terminals, since this minimum may occur at a point in the line ahead of the beginning of the slot. It is not actually necessary to locate this particular minimum.

This position can be measured indirectly by the following method. First, the antenna terminals are short-circuited by a short heavy conductor. The probe voltmeter is then moved along the slotted line until a voltage null is found. (The voltage minimum becomes a null, or zero, when load impedance is zero). The position of this null is recorded as shown in Figure 2-4

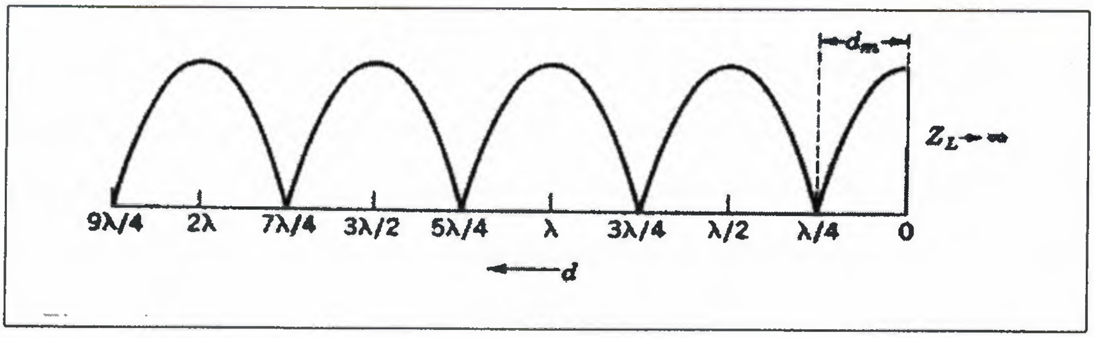

Figure 2-4. Standing-wave voltage patterns for Z_L =0 condition.

The short circuit is removed, and this causes the voltage minimum to move to a new position. The distance from the original null position to the nearest minimum in the direction of the generator (signal source) corresponds to the distance *d* of Fig.2-2.

Numerous precautions are necessary in standing wave measurements to avoid errors. The need for elimination of extraneous signals has already been mentioned in this section. It is also important to point or locate the antenna so that it will not receive reflected signals from nearby objects; such reflections will act in the same way as an impedance mismatch in causing a reflected wave in the transmission line.

A special problem arises if a high value of *VSWR* exists. The voltage calibration of the VSWR meter may not hold for too high or too low values of RF voltage applied to the crystal rectifier. One technique for circumventing this difficulty is to measure the voltage at points on the transmission line other than the maximum and minimum positions and from these measurements deduce the maximum and minimum values.

This can be done by means of an analysis employing the fundamental transmission-line equations. Another, and more satisfactory approach is to employ a detector element that can be calibrated over a greater range of RF voltages. A device often used is the bolometer, which detects by the variation of its resistance when it is heated by the RF current. The resistance variation follows the RF signal modulation and is used to modulate a d-c current passed through it. The resulting modulation is amplified and measured in usual way.

Take care that the bolometer elements are sensitive to burnout if subjected to too large a RF current.

2.2 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_o), 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 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 Fig.2-5.

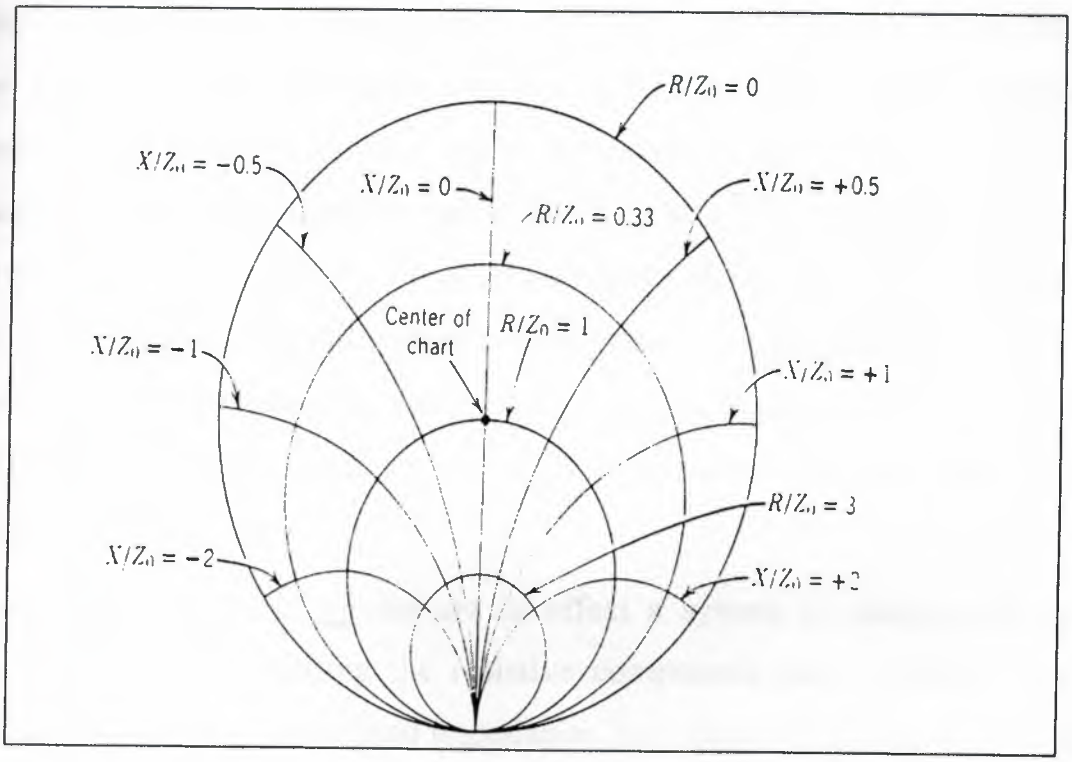

Figure 2-5 Basic construction of the Smith Chart.

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 a 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=o. 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_o=0, R_L/Z_o=1) point. This point corresponds to *VSWR*=1 and the circles of increasing size correspond to increasing values of *VSWR*.

The largest of these circles forms the outer boundary of the chart represents an infinite *VSWR*.

The d/λ 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 $Z_o=50_{(\Omega)}$.

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 2-6.

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

[X=0.6 and$X$=1.4].

5- From R and X, R_L and X_L are calculated as $R_L=RZ_o$, and $X_L=XZ_o$.

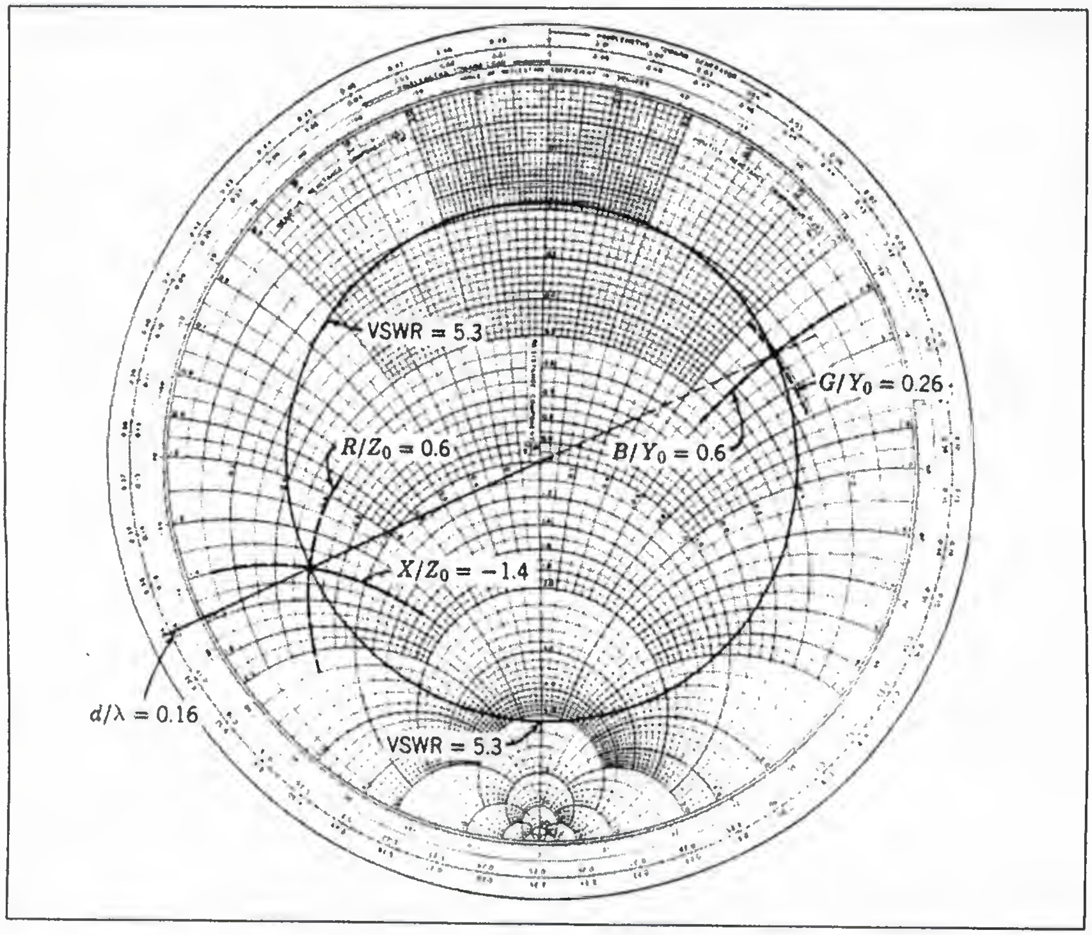

Figure 2-6. Example of impedance and admittance calculation, using Smith Chart.

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

The previous example illustrates the basic use of the Smith Chart .

It can also be sued 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=(30-j70) (Ω).

In this case ***r*** is found according to Eq.2-17 as

$$1.523\angle -66.8 = \frac{1+r}{1-r}$$

from which we find that

$$r = 1.46\angle 64$$

when

$$\theta = 64 .$$

From Eq.2-18, we find *VSWR* as

$$VSWR = \frac{2.46}{0.46} \cong 5.3 .$$ (As shown in the last example.)

Equation 2-19 is used to find d/λ as

$$\theta = 180(1-\frac{4d}{\lambda})$$

$$64 = 180(1-\frac{4d}{\lambda}) \Rightarrow \frac{d}{\lambda} = 0.161 \cong 0.16$$ (As it has been found).

Another example is to find the input impedance at the short circuit of a 50 (Ω) to lossless transmission line that is $\lambda = 0.1m$, by using Smith Chart, and compare the result with the calculation method.

In this case, $Z_L=0(\Omega)$ (short circuit), $Z_o=50(\Omega)$, $\lambda=0.1m$ toward the generator, at $X=0$, and $R=0(\Omega)$, it is the top of the chart, from the top toward the generator put P_1 point, at point P_1 read $VSWR=0$ and $R=0(\Omega)$. $\Rightarrow X_1=j0.725(\Omega)$, as shown in Fig.2-7. Thus, $Z_1=50\times j0.725=j36.3$ $R=0(\Omega)$, (the input impedance is purely inducting).

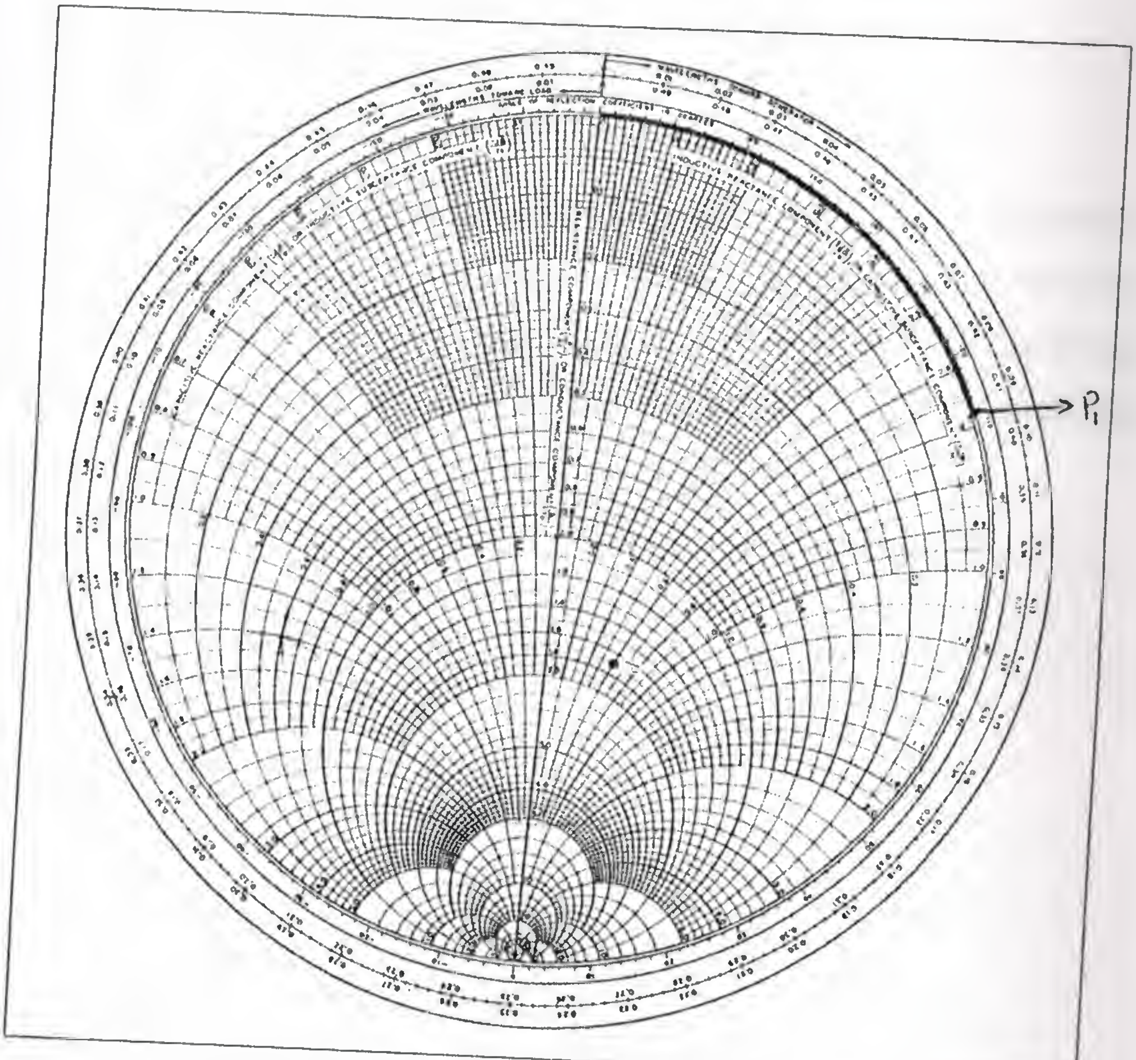

Figure 2-7 Smith Chart to the example.

By using the calculation method, Eq.2-20 is used

$$Z_i = Z_o \left[\frac{(Z_L / Z_o + j \tan \beta l}{1 + j(Z_L / Z_o) \tan \beta l} \right]$$

to gather with, Z_L=o, we get

$$Z_i = j50 \tan(\frac{2\pi}{\lambda}) \times 0.1\lambda = j36\Omega$$

(which has been found above by using Smith Chart).

Although it is basically designed on the assumption that the line is lossless, it can also be used to find the decrease of *VSWR* with distance from the load for lines with some loss; it should not be used for calculations involving high-loss line. A high lossline in this context is one for which the attenuation is appreciable in a half wavelength.

For further details of the Smith Chart specialized texts are referred.

2.3 Pattern Measurements

The radiation or reception pattern in Sec.1.2.2 is a description of the field strength or power density (in the transmitting case), 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 antenna.

We should mention here that all patterns measurement is made at a sufficient distance from the antenna to conform to far-field criterion (Eq.2-3).

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, and since the patterns in particular planes usually provide adequate information, patterns are usually measured and plotted in planes.

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.

2.3.1 Pattern Measurement Method

The measurement of a pattern always involves two antennas, the one whose pattern is being measured, and another some distance a way. One antenna transmits (radiates) and the other receives. Because of the reciprocity principal, the antenna whose 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, regardless of which one transmits and which receives.

Two procedures are possible for measuring the pattern in a particular plane. In the first procedure the primary antenna can be held stationary, then it is 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. If the secondary antenna, 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. 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 Fig.2-2.

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. If the both antennas are in the horizontal plane, the primary antenna is then rotated about a vertical axis 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 at suitable number of fixed points, to take the readings; or, if a pattern recorded on a chart that plots the pattern automatically, these pattern recorders are commercially available.

Consider that the antenna under test is situated at the original of the coordinates of Fig.2-8, with the Z-axis vertical. Then, pattern of θ and ϕ components of the electric field (E_θ and E_ϕ) are measured as function of ϕ along constant θ circles, where ϕ is the longitude or azimuthal angle which complement of the latitude angle.

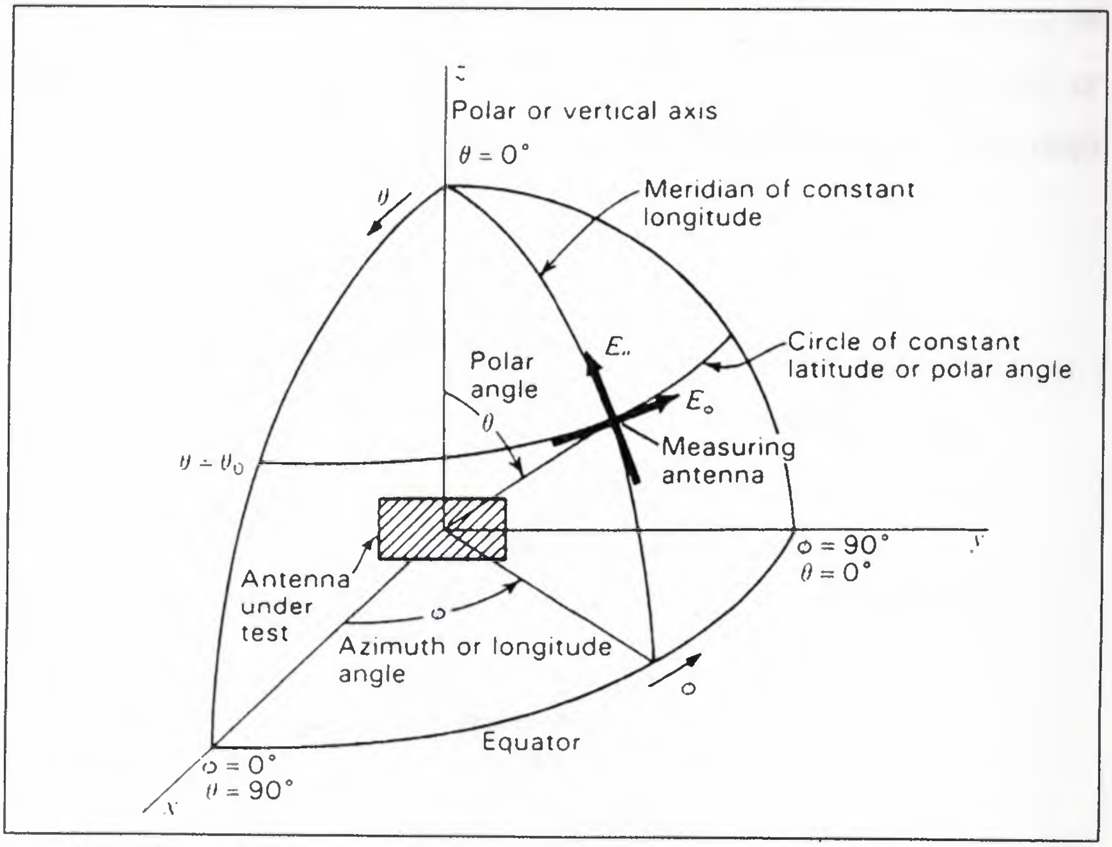

Figure 2-8 Antenna and coordinates for pattern measurements.

These patterns may be determined by moving the measuring antenna (secondary) with antenna under test fixed (primary), or by rotating the antenna under test on its vertical Z-axis as in state of Fig.2-8 with the measuring antenna fixed.

The detailed pattern measurements are sometimes required, but in general fewer patterns are frequently sufficient. Thus, suppose that the antenna is a directional type with a main beam in the X direction, as suggested in Fig.2-9.The principal plane patterns arise, but bisecting the main beam may suffice. If the antenna is horizontally polarized the xz and xy-plane patterns of E_ϕ, as indicated in Fig.2-9a, are measured. If the antenna is vertically polarized then xz and xy-plane patterns of E_θ, as indicated in Fig.3-9b, are measured. If the antenna is elliptically or circularly polarized both sets of measurements (4 patterns) plus axial ratio data are required.

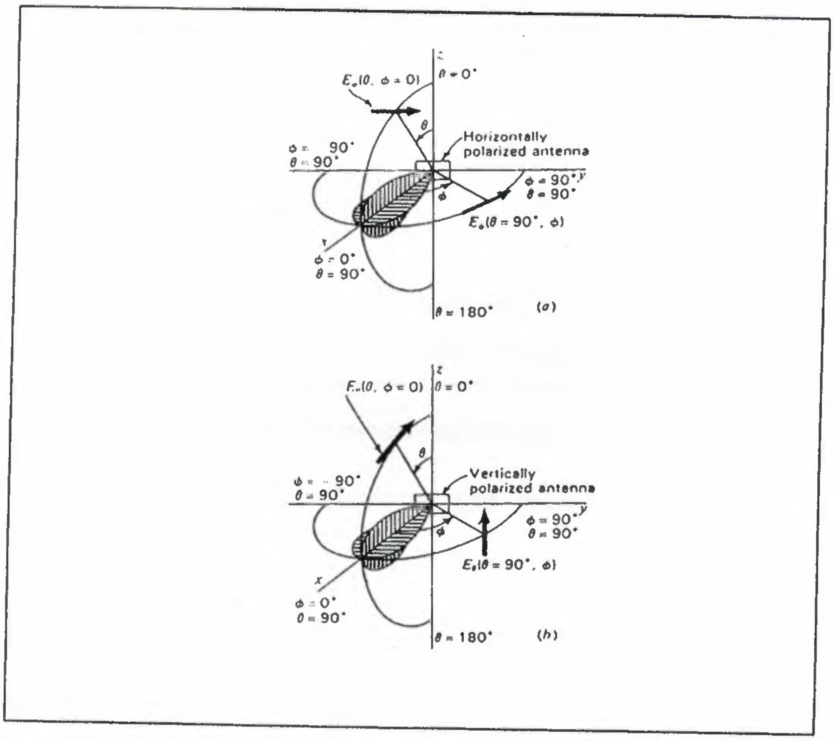

Figure 2-9 Vertical and horizontal plane patterns for horizontally polarized antenna (a) and vertically polarized antenna (b).

If the antenna is linearly polarized, like those measurements are desirable to establish polarization purity.

The pattern measurement arrangements are illustrated in Fig.2-10, with the antenna under test acting as a receiving antenna, The transmitting antenna is fixed in position and the antenna under 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 antennas horizontal as in Fig.2-9. To measure the $E_\phi(\theta, \phi = 0)$ pattern, the antenna support shaft is rotated with both antennas vertical.

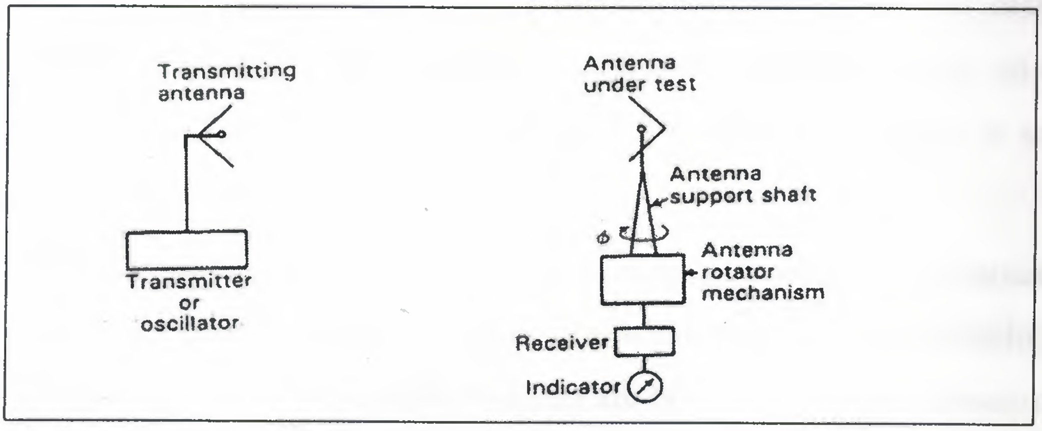

Figure 2-10 Antenna pattern measuring arrangement.

To facilitate the measuring of pattern the indicator automatic pattern recorder is normally used.

The second procedure, which has many advantages, is used whenever it is possible. In addition to the fact that use of a pattern recorders possible, the distance between the two antennas remains fixed, whereas in the first procedure this distance may vary unless great care is taken to keep it constant. However, the second method can be used only when the primary antenna is sufficiently small and high to be placed on a rotating mount, or if it has its own rotating mechanism. Many antennas, especially low frequency transmitting antennas, are much too large to be rotated, whereas at sufficiently high frequencies antennas are virtually always small enough to be rotated. Therefore the first procedure tends to be associated with low frequencies and the second with high frequencies.

2.3.2 Low Frequency Pattern Measurements

As we have mentioned in Sec.2.3.1, 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 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 constant distance from the primary antenna, because of obstruction 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 decrease 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 distance 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.

2.3.3 High Frequency Pattern Measurements

At frequencies above about 100MHz, an antenna pattern is customarily obtained by rotating the primary antenna. So that it is 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, for instance.

When the pattern is to be measured by rotating the primary antenna, both antennas should be located so that they have an unobsrtucted 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 reflection 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 measurement to be made at a single location, that is, at the primary antenna. If a large reflecting object illuminate 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 side lobe pattern at the angle α off axial, its main lobe will point directly at the reflecting object, as shown in the diagram in Fig.2-11. 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.

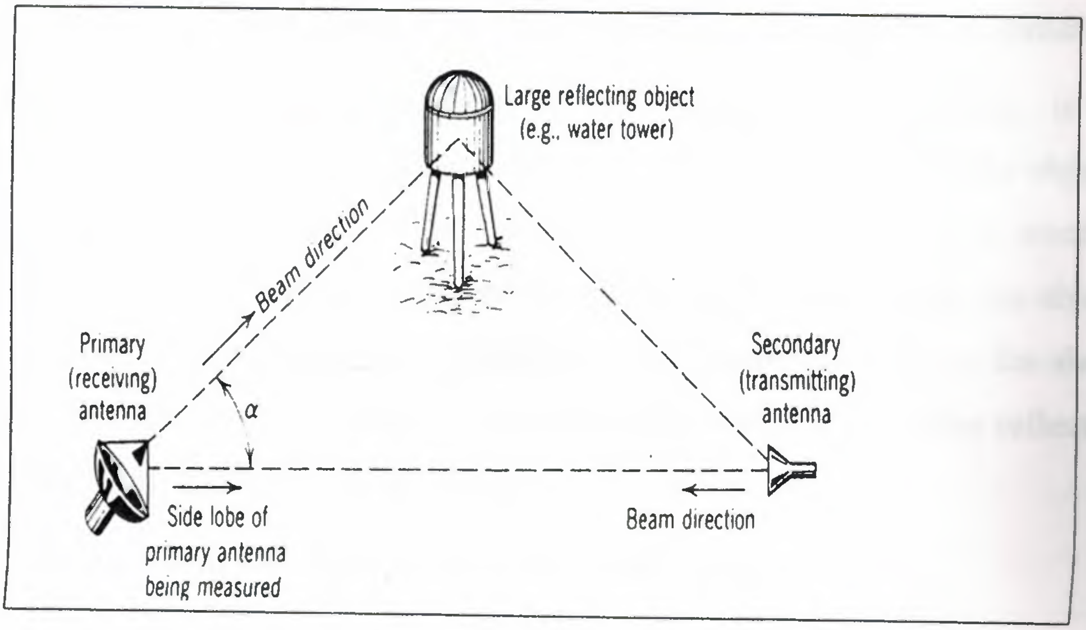

Figure 2-11. Effect of nearby reflecting object on pattern measurement.

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 has very small, or perhaps even a null, gain in the direction of the reflecting object. This requires that the secondary antenna be quite sizable and expensive. 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 polarization. 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 present the reflecting object problems, 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.

2.4 Beamwidth 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. From the Section 1.2.5.1, we have defined the beamwidth and we have said that the beamwidth is determined by determining the maximum power density P_{Max} or the maximum field strength E_{Max}, whereas the beamwidth is determined at $0.5P_{Max}$ or $0.707E_{Max}$. Also when the pattern is plotted by ordinate scale the beamwidth is then at -3dB.

It is also possible, to measure these quantities without plotting the pattern, when the primary antenna is on a rotatable mount. To measure the beamwidth, the beam maximum is first found, and 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 these two angles is the half of the beamwidth, 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 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 the negative value of the result is caused because the logarithm of a number less than one is negative.

2.5 Gain Measurements

In principle, the directive gain can also be determined from the pattern measurement, in accordance with Eqs.1-10 and 1-11. 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 pattern, because the integration of Eq.1-10 is a solid angle integral over the entire three dimensions 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. This method yields the directive gain as defined in Sec.1.2.4.1.

In general, the methods to measure the gain are illustrated down in the following subsection.

2.5.1 Absolute Field Strength Method

This method of gain measurement is based on Eq.1-8, which is rewritten here for reference

$$D = \frac{4\pi R^2 E^2}{377 P_t} = \frac{4\pi R^2 P_{antenna}}{P_t} \qquad (2\text{-}22)$$

This method requires an absolute measurement of the field intensity E or power density 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. If this method is to give the direction of the antenna itself, using Eq.2-22, the measurement must be made under free space propagation condition that is, with no multipath interference due to the earth reflection, or any other factors that modify the free space. Otherwise, we should take the propagation factor F into the consideration,

$$F = \frac{E}{E_d} \qquad (2\text{-}23)$$

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 Eq.2-22 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 is actually measured by analysis of the reflection interference effect it may be calculated that the field density is great or less than the value that would have been measured if free space propagation existed, by the propagation factor F, as defined by Eq.2-23, in term of this factor. Equation 2-22 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

$$D = \frac{4\pi R^2 E^2}{377 P_t F^2} = \frac{4\pi R^2 P_{antenna}}{P_t F^2} \quad (2\text{-}24)$$

Equation 2-24 conforms with Eq.1-8 when F=1 (free space). The absolute field intensity E can be measured at low frequencies, as described in Sec.1.2.4.1. At higher frequencies, it is more convenient to make the measurement in terms of the received power P_r. This quantity is related to the receiving antenna capture cross section A_r by

$$P_i = \frac{P_r}{A_r} = \frac{4\pi P_r}{\xi D_r \lambda^2}. \quad (2\text{-}25)$$

which is a rearrangement of Eqs.1-23, with the receiving antenna directivity denoted by D_r, and P_i is the receiving 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.

2.5.2 Gain Measurement by Using 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 receiving power P_r are both measured. The directivity of the antennas can then be calculated by an application of Eqs.2-24 and 2-25. If the second expression given for P in Eq.2-25 is substituted into Eq.2-22, then the result is

$$D_t = \left(\frac{4\pi R^2}{P_t F^2}\right)\left(\frac{4\pi\, P_r}{\xi\; D_r \lambda^2}\right). \tag{2-26}$$

where the transmitting antenna directivity denoted by D_t , the quantity P_t has been defined as the radiated power. 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, the power gain of the two identical antennas

$$G = \frac{41R}{\frac{7}{8} F}\sqrt{\frac{P_r}{P_t}}, \tag{2-27}$$

This procedure is 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 [3].

2.5.3 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 received until the output indication is the same as it was with the gain standard antenna. If the attenuation factor L, expressed as the power ratio greater than one, the gain of the unknown antenna G_a is

$$G_a = L\, G_s \tag{2-28}$$

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

$$G_{a(dB)} = G_{s(dB)} + L_{dB} \tag{2-29}$$

In the unlikely event that the unknown antenna has a smaller gain than the standard, L in Eq.2-28 is expressed as a number less than one, and the decibel value of L in Eq.2-29 is negative. The basic set up for gain measurement by the comparison method is diagrammed in Fig.2-12.

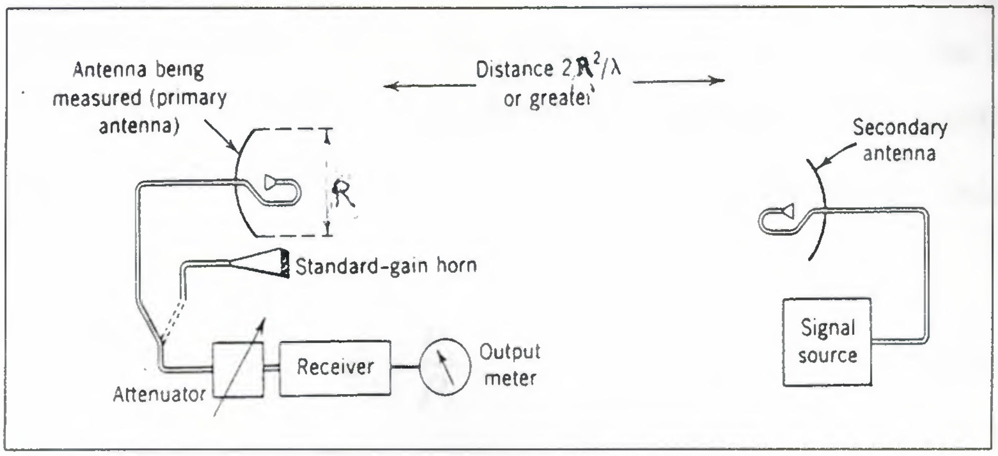

Figure 2-12. Set up for gain measurement by comparison method.

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 to make *VSWR* measurements with 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.

2.6 Antenna Efficiency Measurement

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

2.6.1 Radiation Efficiency

The radiation efficiency ξ_r, a number less than one, expresses the ratio of the power radiated P_r to the total power deliveredP_t, to the antenna-input terminals or port. The difference of these two quantities is the power dissipated P_D in ohmic losses. The radiation efficiency is also the factor applied to the directive gain *D* to obtain the power gain *G* in accordance with Eq.1-9. There are in principle several ways of measuring ξ_r, indicated by

$$\xi_r = \frac{P_r}{P_t} \qquad (2\text{-}30)$$

which can be written as

$$\xi_r = \frac{P_t - P_D}{P_t} \qquad (2\text{-}31)$$

or

$$\xi_r = \frac{G}{D}. \qquad (2\text{-}32)$$

The first 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 second equation 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.

The third equation is not directly useful, but it may be combined with Eq.2-24 to obtain

$$\xi_r = \frac{4\pi R^2 E^2}{377 P_t^2 F^2 D} \qquad (2\text{-}33)$$

The last equation is especially useful at VHF with short vertical grounded radiators. For these antenna, *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 distance *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 $2\, d_a^2 / \lambda$, or greater than λ.

2.6.2 Aperture Efficiency Measurement

The other connotation of the term efficiency relates to the equation for the directive gain of the large aperture type antenna, large unidirectional planar array, parabolic reflector, or lens. As in Eq.1-24

$$D = (\frac{4\pi A_r}{\xi_r \lambda^2}) \qquad (2\text{-}34)$$

where A_r is the Cross Section Area of the aperture and λ is the wavelength, In this context, ξ_r is called the aperture efficiency. If the field intensity over the aperture of an antenna is uniform then, $\xi_r = 1$. This is the largest value of ξ_r practically attainable, but the typical values of ξ_r range from somewhat less than 0.5 to nearly 1.0. The measurement of directive gain D leads to the determination of ξ_r

$$\xi_r = \frac{4\pi A_r}{D\lambda^2} \tag{2-35}$$

2.7 Radiation Resistance

The radiation resistance of an antenna is defined by Eq.1-12 it is the ratio of the power radiation to the square of the antenna current (rms value). As mentioned, it is in a sense a fictitious quantity, sense it is referred to an arbitrary point in the antenna and has different values for difference 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, an example is the case of a current fed dipole as mentioned in Sec.1.2.7. 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

$$R_r = R_{r(feedpoint)} \left[\frac{I_{feedpoit}}{I_{maximum}} \right] \quad (3\text{-}36)$$

where I denotes the rms 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 Eqs.1-13 and 1-16 the radiation resistance is found to be

$$R_r = \xi_r R_i \quad (3\text{-}37)$$

where R_i 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 measurable. It has no meaning for antenna in which there is no clearly defined current value to which it can be referred.

2.8 Polarization Measurement

The polarization of the radiated field from an antenna may be measured by measuring the received signal voltage with a linearly polarized receiving (secondary) antenna as its polarization is rotated in direction through 360 degrees. If two maximum and two nulls are observed, the field is linearly polarized in the direction corresponding to the maximum. The maxima will be 180 degrees apart, and the nulls will be 90 degrees from the maximum.

The direction of the null can be measured more accurately than the maximum.

If the maximum and the minimum (rather than nulls, or zeros) are observed, the field is elliptically polarized, and the ratio of the maximum to the minimum field intensity is called the polarization ratio or ellipticity. When this quantity is measured in the axis of the main beam of the antenna under test, it is called the axial ratio.

When the field intensity is constant as the secondary antenna polarization is rotated, the field is circularly polarized. Whereas, the circular polarization is of course just special case of elliptical polarization for which the polarization ratio is one.

The most common linearly polarized antenna used for such measurements is the half-wave dipole. A dipole array or a dipole with a reflector may also be used. In fact, any linearly polarized antenna will serve. Polarization measurements may also be made using two fixed receiving antennas linearly polarized at right angles to each other, and measuring the ratio of intensities received by each. If the field is elliptically polarized, the phase difference of the signals in the two antennas must be measured. The method by details is described by Kraus [4].

CHAPTER THREE

PRACTICAL ANTENNA MEASUREMENTS

In the last chapters we have concentrated on the theoretical side to give an idea about the general antenna measurements, and how it can be done.

In this chapter we shall study the practical side of these measurements and perform some of the last measurements, also, a detailed study of the gain has been done. The gain factor has relationship with the frequency and the angle

$$G = F\left\{ (f,\theta) \right\}.$$

Firstly, the frequency had been changed at a fixed angle in our work which is the maximum gain angle (both antennas are directed to each other) and after that the frequency versus the gain graph has been drawn. This test is used to choose the frequency that gives the best gain and this means the optimum frequency for the antenna under test.

Secondly, the gain versus the angle at a fixed frequency had been measured and after that the graph has been drawn.

In our work, several notes should be taken which are shown bellow:

First, we have used a small antenna as the measurement antenna to measure the transmission and receiving gain.

Second, these measurements have been made for OMORPHO antennas by taking a full round about it in a circular path with R=3km its radius.

Thirdly, we have compared our results with the BRTK results, and we have found them closed to each other. But in some parts it is not consistent with these results which justified by the difficulty in keeping the radius at a fixed length (3km), and the cause of the amounted area, so that it is impossible to take the results of several points at 3km radius, which justified the changing in the radius to be 2.5km on sometimes and 3.5km on the other times.

Fourthly, we have used a small antenna instead of a big one and this is better for determining the angle. Moreover it is better for adjusting its frequency at the BRTK frequency (570MHz for channel 41 at which we have measured its radiation pattern). Also we have rotated the antenna by hands, and this is one of the disadvantages of this method but it is not a big error, which disturbs our results.

Finally, we have written our conclusions from the radiation pattern graph of the gain versus the angle at a fixed frequency. Moreover, from this graph the boundwidth and other parameters have been calculated.

For more information about the gain measurements we have used two antennas to measure the transmission and receiving gain and we compared our results with the ideal results to estimate it and our conclusions have been written.

Last thing, we have calculated the gain from the P (dB) results by using power ratio method and this is illustrated in a separate part which is Sec.3.6.

We should mention here that all measurements are made on the BRTK station in the Turkish Republic of Northern Cyprus (TRNC).

3.1 Radiation Pattern Measurement

In this part we have drawn the radiation pattern of the double wave antenna. The equipments used in this measurement are very expensive and are not available in TRNC. Therefore, we have performed this measurement as much as we can by using a simple and primitive equipments and methods.

As we have remarked before, the radiation pattern measurement has two different ways and these two ways depend on the frequency and the size of the antennas. The first case, when the primary antenna is a transmission antenna and the second one when the primary antenna is receiving.

We have explained these methods and the relation of the size (or the frequency) which determine the method that we have to choose.

In general there is a famous way to do this measurement, and this method will also be explained and used.

3.1.1 Strength Wave Method

It is the most simple and the most widely used method. 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 $\vec{E}$ at any desired point. We shall measure $\vec{E}$ at distant R from the antenna for different places, and by taking $\vec{E}$ for full circle with R its radius, we will obtain the pattern.

3.1.2 Equipments Required

1- Two antennas of the same or different types.

2- Strength wave measuring equipment, which is Hiresenmann fernsen pegemessyenat FPM 136.E2ZV.

3- Carrying vehicle to carry the strength wave meter wherever we need but in this part it has not been used because a small distance is used (R=5m).

4- Angle meter plate.

3.1.3 Practical Steps

1- Determine any distance from the antenna that satisfies the far zone condition ($R \rangle \frac{2d^2}{\lambda}$).

2- Measure the values of the field strength at that distance and set that point as a reference point $\theta = 0$ (both antennas are aimed to each other).

3- Move the meter to another point that is far distance R=5 m from the antenna and record the value of the field strength $\vec{E}$ and a new angle θ.

4- Repeat the last step for sufficient points and for each point record the value of $\vec{E}$ and the corresponding angle θ in the Table 3-1.

θ (deg)	0	10	20	30	45	60	70	80
E(dB)	5.1	5.02	4.82	4.81	4.8	4.76	4.74	4.86
θ (deg)	90	100	110	120	140	150	170	180
E(dB)	4.69	4.23	4.66	5.01	4.61	3.61	3.71	3.12

Table 3-1 Measurement of the field strength in dB for various angles

5- draws the radiation pattern from Table 3-1.

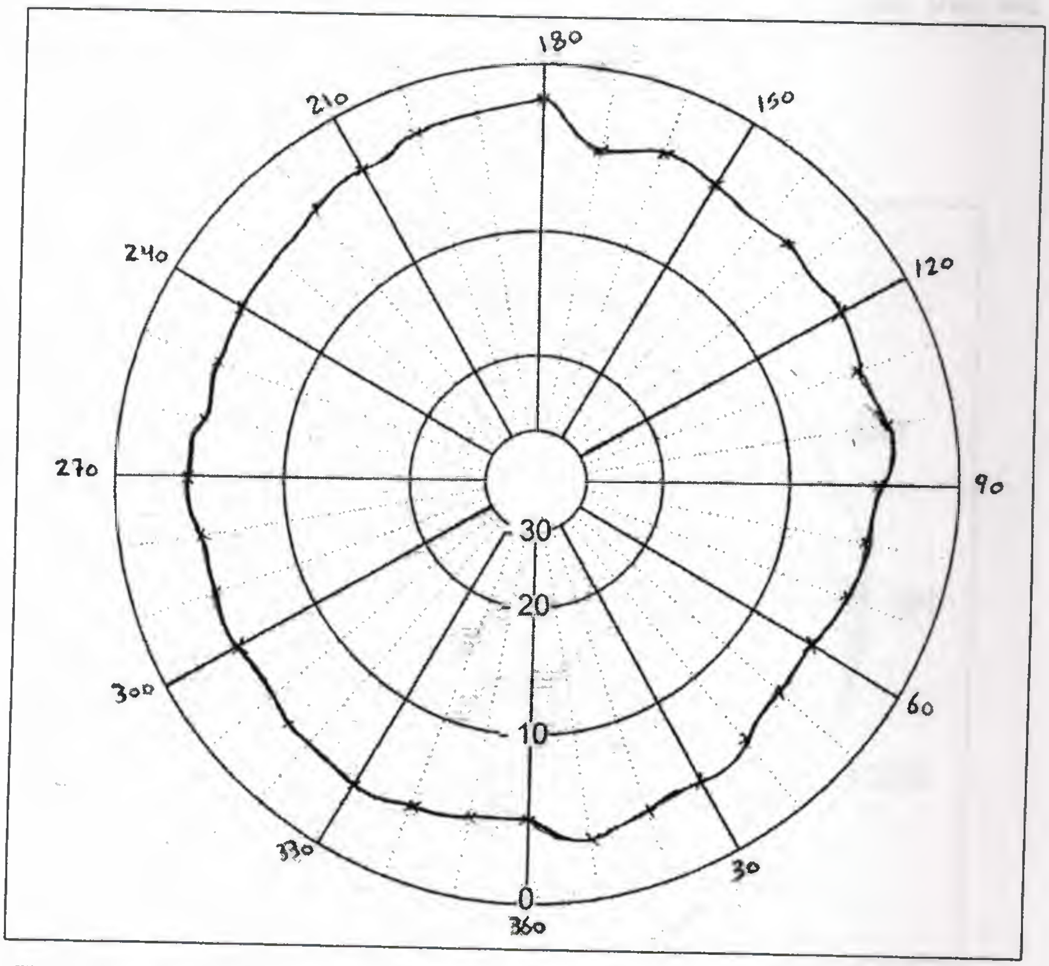

Figure 3-1 The radiation pattern measurement for random antenna by using strength wave method with R=5m.

It is noted from the Fig.3-1 that the gain has different values and these values depend on θ but maximum value at $\theta = 0$, which means that both antennas (receiving and transmission) are directed to each other and this thing is consistent with the theoretical point. Also from this diagram we can see that this antenna has very good characteristic at this distance (5m) and this is justified by the short measurement distance, so it covers all receiving directions without any main lobes or side lodes, and this means that the beamwidth is full and equal to 360°. Moreover, it is an ideal case that we can obtain by using four bays.

The identical case for this measurement is illustrated in Fig.3-1

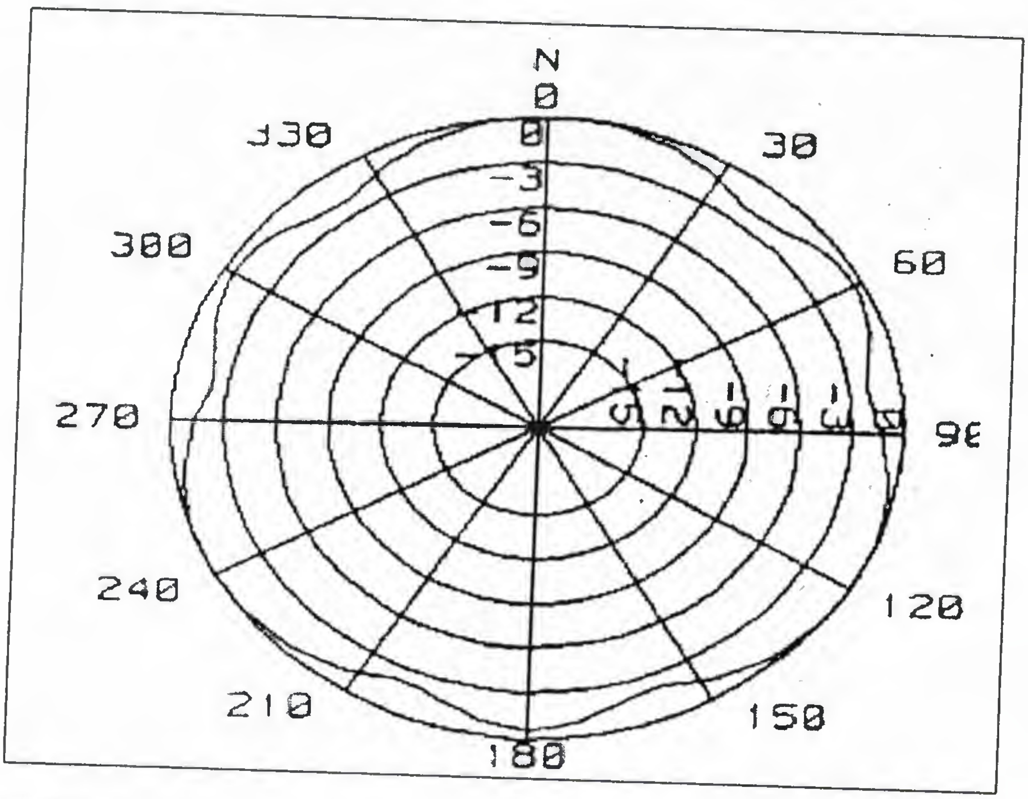

Figure 3-2 The ideal radiation pattern of an antenna which has four bays

It is clear from the graph that the test weather is very good and the measurement is done in the clear, in the BRTK building, so that the results are very close to the theoretical tests.

Care should be taken that the ideal graph is to any distance between the antenna and the measurement instrument and it gives the difference by *P* (dB) between the angles.

3.2 Transmission Primary Antenna Method

This method has been explained before. The primary antenna has to be fixed, and the secondary antenna (receiving) will be rotated. Also, this type of measurement is done when the primary antenna (transmission antenna) is very big in size (for LF, and VLF), so that, it is very difficult to rotate this antenna. In this case the secondary antenna is being rotated.

3.2.1 Equipments Required

1- Two antennas (receiving and transmission), such as the dipole antenna.

2- Pulse generator.

3- Gain direction measurement equipment which is hp.spectrom analizer.

4- Rotator motor, or by hand (as in our work).

5- Angle meter plate.

3.2.2 Practical Steps

1- First of all, we find the frequency by setting the wavelength as 1.45m, f=206.8MHz.

2- Adjust the pulse generator to this frequency to be 206.8MHz.

3- Fix the primary antenna at any direction.

4- Switch on the pulse generator.

5- Keep the secondary antenna at a far distance R=3m from the primary antenna, and then fix this distance.

6- For the first reading, the secondary antenna directed to the primary antenna and take this angle as a reference angle ($\theta = 0$), and P (dB) as reference (0dB).

7- Rotate the secondary antenna around the primary antenna in a circular path whose radius is R, and during this rotation keep the secondary antenna aims to the primary one.

8- Stop the rotation in different points, and for each point take your records and fill the Table 3-2

(deg)	0	30	50	60	70	80	90	100	110	120	130	150	180
P(dB)	0	-2	-4	-6	-10	-11	-12	-11	-10	-6	-4	-2	0

Table 3-2. Measurement of the power in dB for various angles

9- Plot θ versus P to rad.path.

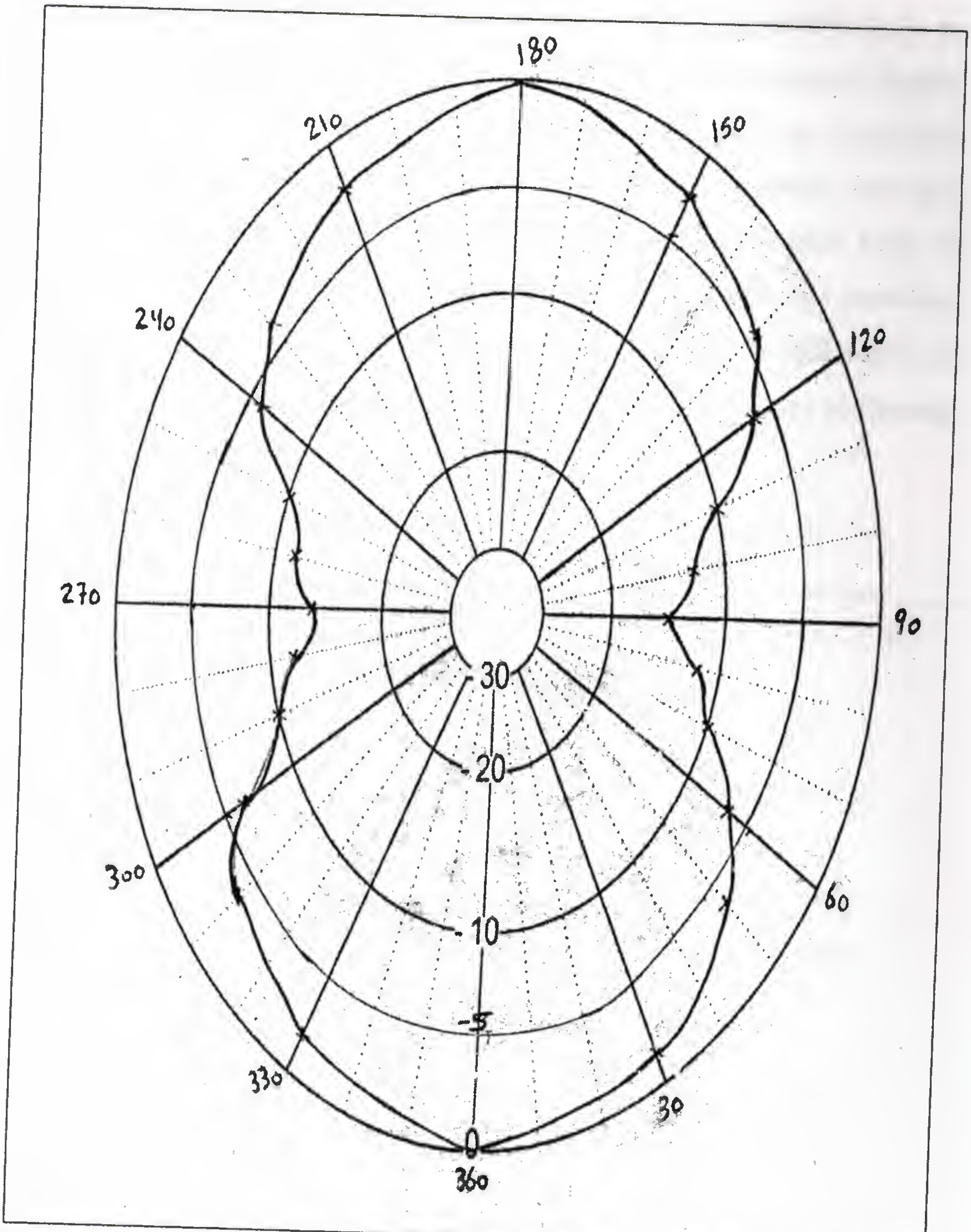

Figure 3-3 The radiation pattern of dipole antenna by using transmission primary antenna method with R=3m.

It is noted from the Figure 3-3 that maximum value is achieved at $\theta = 0$, as we have illustrated before in Figure 3-2. Also the radiation pattern figure is identified from $0^{\circ}$to 180° resembler to $180^{\circ}$to 360° and this is justified by the characteristics of the dipole antenna, which is consistent with the theoretical characteristics of the dipole antenna. The difference here at $\theta = 90^{0}$ is that the ideal dipole antenna has not any wave but in this practical work we have the minimum value which is not zero. This difference is justified by the primitive equipments we were using, and is also attributed to the weather conditions.

The ideal figure for the dipole antenna is illustrated in Fig.3-4.

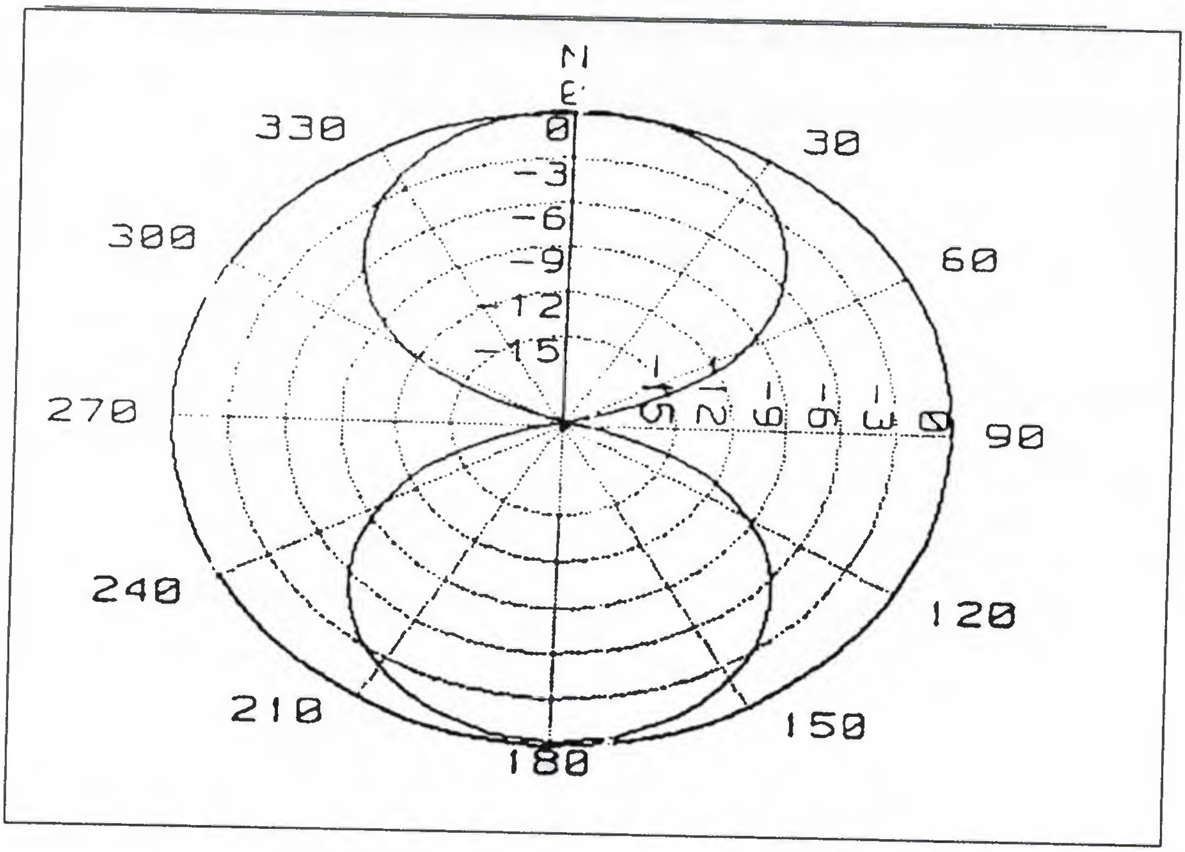

Figure 3-4 The ideal radiation pattern of the dipole antenna.

3.3 Receiving Primary Antenna Method

This method is generally used in the HF, and VHF waves whenever the size is small, and we can rotate the primary antenna in its place. In this method both antennas will be fixed, and the secondary antenna aims to the primary one.

3.3.1 Equipments Required

The equipments used in this part are similar to those used in Sec.3.2

3.3.2 Practical Steps

1-Determine the frequency and adjust the pulse generator to this frequency; namely, 206.8MHz, as in the last part from step 1 to 4.

2-Fix the two antennas, and keep the distance between them as R=3m (same distance in the last part).

3-Let the main beam of the secondary antenna aims to the primary antenna.

4-Record the value of P (dB) and let it be a reference point with $\theta = 0$ at this point.

5-Turne the primary antenna for full rotating, and during this, stop the primary antenna and then record the P (dB) at each θ shown in the Table 3-3

θ (deg)	0	10	30	45	60	80	90	100	120	135	150	170	180
G(dB)	0	-1	-2	-6	-10	-13	-24	-13	-10	-6	-2	-1	0

Table 3-3 Measurement of the G (dB) for various angles.

6- Draw the radiation pattern from the Table 3-3.

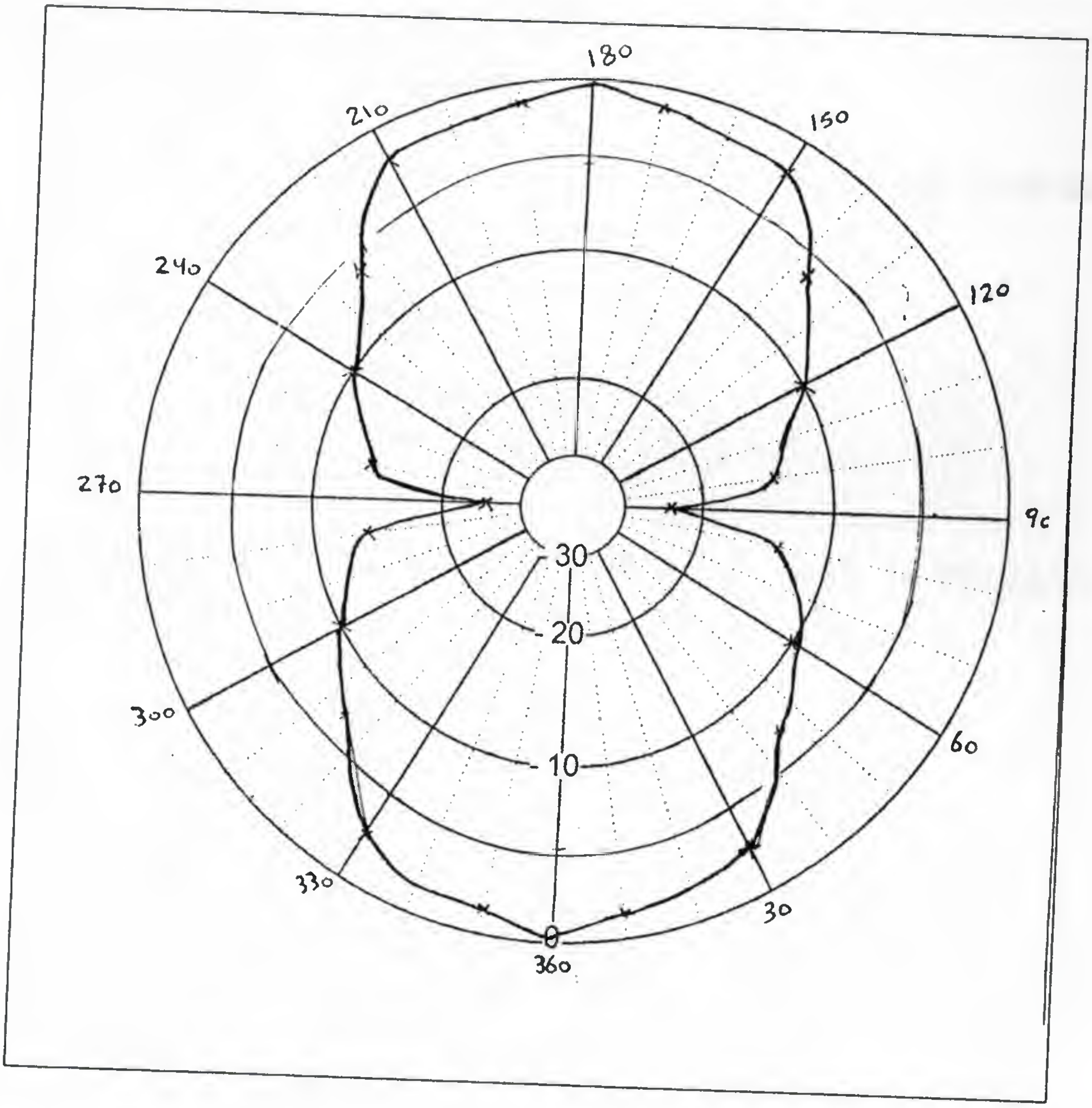

Figure 3-5 The radiation pattern of dipole antenna by using receiving primary antenna method with R=3.

7- Write your notes and conclusions.

By compressing Figs.3-3 and 3-5 with Fig.3-4, it is appear that the radiation pattern by using the receiving primary antenna is more precise than the transmission primary antenna, and this is justified by the frequency (208.6MHz).

3.4 Beamwidth Measurement

The beamwidth can be found by the radiation pattern, if not, we do this work.

3.4.1 Equipments Required

1- Two antennas.

2- Pulse generator.

3- Strength wave measurement instrument, which is PROMAX LEVEL METER MC-944B, which measures the field.

4- Angle meter plate.

3.4.2 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} and then record θ_1.

3- At $0.707E_{max}$, read θ_2.

4- Calculate the beamwidth as $2(\theta_1 - \theta_2)$.

5- Fill out the Table 3-4 and find the result (the beamwidth).

θ (deg)	E(μdB)	θ (deg)	E(μdB)
0	51	100	42.3
10	50.2	110	46.6
20	48.2	120	48
30	48	130	53.2
45	48	140	46
60	47.6	150	36
70	47.4	160	37.5
80	48.6	170	31
90	50	180	51

Table 3-4 Measurements of the field strength for various angles

From Table 3-4, it is clear that E_{max} =53.2(μ dBV), so $\theta_1 = 130^o$ and,

0.707 E_{max} =37.6(μ dBV), so $\theta_2 = 160^o$, then the beamwidth is equal to

$2(160^o - 130^o) = 60^o$.

3.5 Practical Gain Measurement

The gain has been defined as a quantity that may differ in different directions at a given distance, *R*. So that, we have to determine the direction that we need to measure the gain at it. And we also need to determine the distance *R*.

The gain can be measured by different ways, but the famous methods will be done here. The gain measurement by comparison was explained and we will do it by using two dipole antennas.

3.5.1 Practical Gain by Standard Antenna

In this part we are using dipole antenna instead of the parabolic, as explained before. The standard antenna can be any antenna but here we are using the dipole antenna.

3.5.2 Equipments Required

1- Three antennas, one of them is standard.

2- Gain measurement equipment which is hp-spectrom analizer.

3- Pulse generator.

4- Angle meter plate.

3.5.3 Practical Steps

1- Determine the antenna frequency, and adjust the pulse generator at this frequency. Here the frequency is found to be 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 –35dB.

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

4- The antenna gain then will be the different between those antennas, and it is -28-(-35) = 7dB.

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

6- For more information about the gain, change the frequency of the antenna and measure the gain as illustrated in the Table 3-5

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

Table 3-5 Shows the gain versus the frequency.

7- Write down your notes and the conclusions.

There is no fixed relation between the gain and the frequency, and this is justified by another coefficients like the type of the antenna, the quality of the instruments, and the outside conditions.

Unfortunately, we could not verify this result because we did not have two antennas of the same type and characteristic but to avoid this problem we had measured antenna was already measured and we obtained the same result. In general this is a trust and easy way to measure the gain.

3.6 Gain by Measuring the Power Rate

In this part, we should mention that

$$G(dB) = 10 \log G \tag{3-1}$$

and

$$G(dB)=\frac{P_r}{P_{istrope}} \tag{3-2}$$

From Eq.2-27, which is written here for remembering

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

where F here is one, because there is no any reflected object.

Equation 1-4 can be rewritten as

$$P_t = 4\pi R^2 P_{istrope} \tag{3-4}$$

and then substituting Eq.3.4 into Eq.3.3, we find

$$G = 13.2\sqrt{\frac{P_r}{P_{istrope}}} \tag{3-5}$$

Equation 3-5 is the main equation to measure the gain by this method and it is used to match the results by using big and small antennas.

3.6.1 Equipments Required

The equipments used in this part are similar to those used in Sec.3.2.

3.6.2 Practical Steps

1- Repeat the same steps from 1to 4 in the Sec.3.4.2, and use the same results in Table 3.3.

2-Find the gain from Eqs.3.1, 3.2 and 3.5 and record it in Table 3- 6 by taking into consideration that R=3m.

θ (deg)	G(dB)	$P_r/P_{istrope}$	G(calculated)
0	0	1	13.2
10	-1	0.8	10.56
30	-2	0.63	8.3
45	-6	0.25	3.3
60	-10	0.1	1.32
80	-13	0.05	0.66
90	-24	0.04	0.53
100	-13	0.05	0.66
120	-10	0.1	1.32
135	-6	0.25	3.3
150	-2	0.63	8.3
170	-1	0.8	10.56

Table 3-6 The gain calculated for various angles when R=3m.

Note that, the maximum gain is at $\theta = 0$ and it means that the two antennas are in the same direction and both of them are directed to one another. It is the main point from the theory point of view. Also note that at angles between (80 to 120 degree) the received power is less than the isotropic power and the opposite directions of the two antennas justify this.

3.7 Choice of the Antenna and the Antenna's Frequency

In this part, we shall determine which antenna has the best fit among the others. Also, we shall determine the best frequency used for a random antenna. Note that we do not know any thing about the antennas used.

3.7.1 Equipments Required

1- Transmission antenna, which is the real Selvilitepe Station.

2- PROMAX LEVEL METER.

3- Four antennas, all of them are connected separately.

3.7.2 Practical Steps

1- Switch on the PROMAX instrument.

2- Connect the first antenna, and record its angle as a reference.

3- Adjust the tuning switch at the clearest photo.

4- Record the field strength at this photo in the Table 3-7.

5- Replace the antennas two, three, and four respectively.

6- Record the field strength in the table to each antenna.

Antenna one	48.2 dB μ v
Antenna two	47.5 dB μ v
Antenna three	46.1 dB μ v
Antenna four	44.2 dB μ v

Table 3-7 The field strength for different antennas

7- From Table 3-7, it is clear that antenna one is the best one, because it gives the most field strength.

To determine which frequency is the best we are going to make the same thing but we will connect one antenna and we are going to draw the frequency gain property, which is illustrated bellow

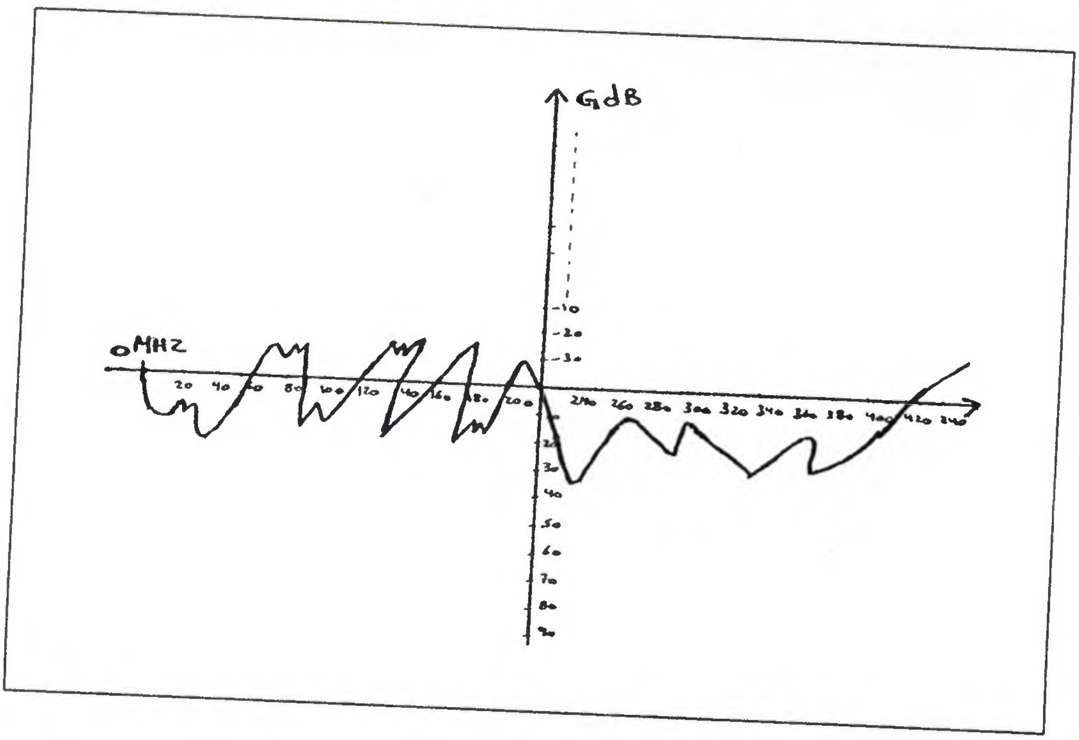

Figure 3-5 the frequency versus the gain for random antenna at fixed angle (θ=0).

Note that the gain changes randomly with the frequency. So that, when we want to use a new antenna we have to perform this test to determine which frequency gives the maximum gain.

Sometimes we perform this test for more than one antenna at a determine frequency to choose which one gives the maximum gain at this frequency.

This test is one of the most widely used methods in the BRTK, here in TRNC. For instance the ideal use of the last antenna can be obtained at 240MHz, which gives the maximum gain (35dB).

3.8 The Practical BRTK's Properties Measurements

In this part we have studied the real measurements of the BRTK's antenna, and also we have determined the gain, radiation pattern, and the beamwidth.

3.8.1 Radiation Pattern Measurement

We are using the rotating receiver method because we cannot remove the BRTK's antenna (the primary antenna) which has a gigantic size, so that in this part we shall rotate the secondary antenna.

3.8.1.1 Equipments Required

1- Two antennas which the MORPHO antenna is the transmission one.

2- Hp-spectrom analizer which measures the *P* (dB).

3- Angle meter plate to keep the receiving antenna aims to the OMORPHO antenna.

4- Carry vehicle to carry the secondary antenna and the meter instruments around the OMORPHO antenna for full round.

3.8.1.2 Practical Steps

1- Carry the secondary antenna and the measuring instruments by the vehicle to the test field.

2- Determine the distance between the primary and the secondary antennas, which the radiation patterns, will be measured at it. In our test it is 3km.

3- Let the secondary antenna aims to the primary (OMORPHO) and in this case let the angle meter take this direction as the reference ($\theta = 0$).

4- Measure the P (dB) at this point.

5- Repeat steps 3 and 4, but take care that θ will change to keep the secondary antenna aims to the primary. Then take the angle and P (dB) for sufficient points as in the table 3-8.

Note that it is very difficult to take the results at all the angles and it is impossible to keep the distance fixed at 3km, the rocky area justifies this. So that we have taken a number of readings which approximately sufficient.

θ(deg)	PdB(real)	PdB(measure)
0	-16	-15
20	-18.5	-19
45	-15.2	-16
65	-18.7	19.5
85	-15.8	-16.3
115	-18	-18.5
135	-15.2	-15.8
155	-18.7	-17.5
170	-16.3	-17.3
200	-18.7	-18
210	-17.1	-18.2
230	-15.3	-15.6
250	-18.6	-21
275	-16.6	-16.5
290	-18.5	-20
315	-15	-16
335	-19.3	-19.7
345	-18	-19.2
360	-16	-15

Table 3-8 Measurements of power gain for various angles

4- Draw the radiation patterns from the above table (3-8) with the real graph to compare the real and measured results.

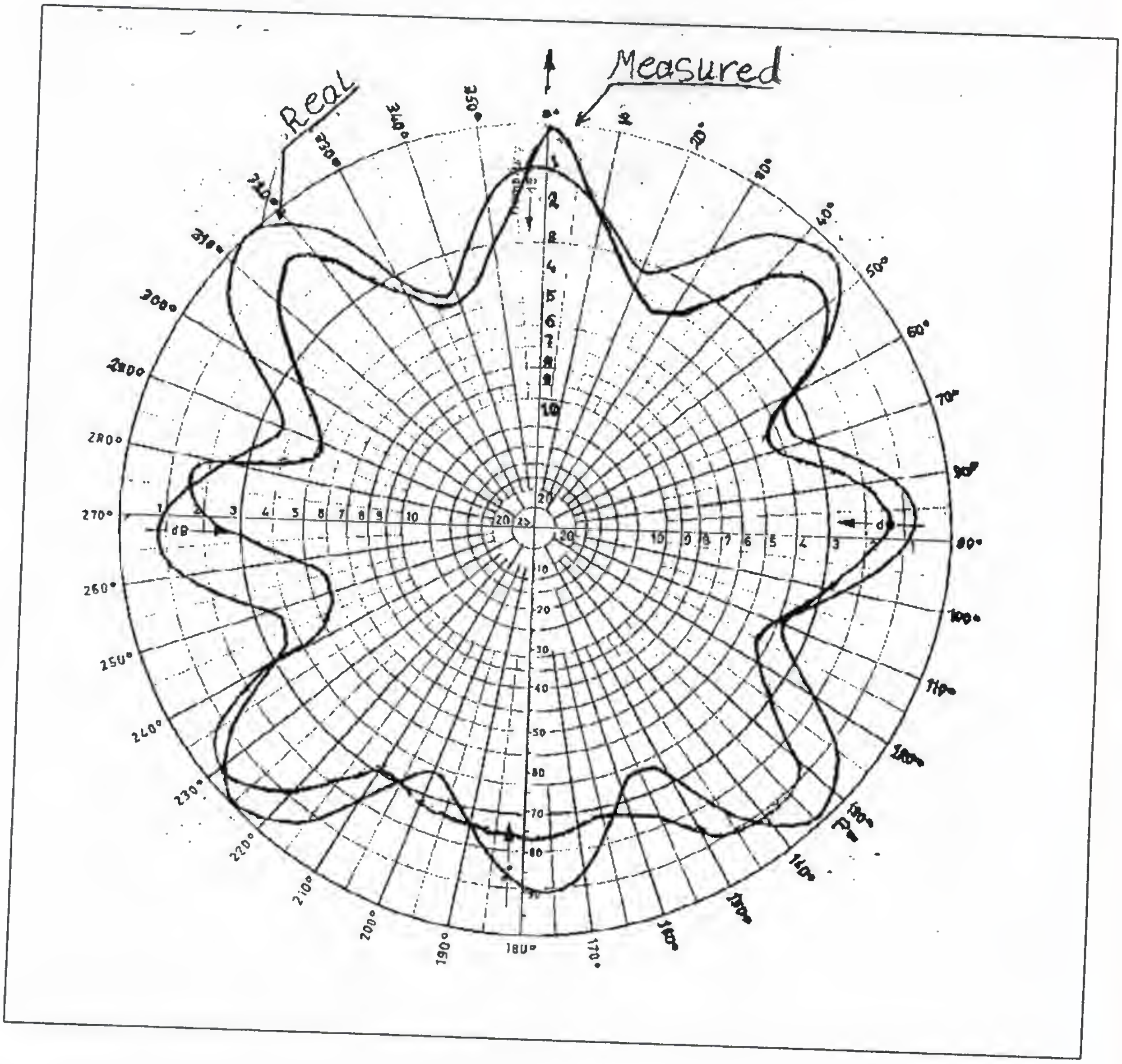

Figure 3-7 The radiation pattern of OMORFOU station for channel41 at f=570MH.

Note from the graph that at angles from 145° to 165° have had gain factor better than the ideal one and this is justified by the distance which was taken 2.5km because it was impossible to take it at 3km because it falls in a valley area.

3.8.2 Practical Beamwidth Measurement

In this part, the gain graph has been used, where beamwidth is being determined at -3dB, which subtends the half-maximum power P_{max} as we have mentioned before in Sec.2-5.

3.8.2.1 Equipments Required

The equipments used in this part are similar to those used in Sec.3-9.

3.8.2.2 Practical Steps

1- Determine the -3dB on the radiation pattern graph, and record the angle that subtends it.

2- As we see in Table 3-9, there are seventeen angles, 15°, 35°, 60°, 75°, 100°, 125°, 210°, 240°, 276°, 282°, 303°, 326°, and 350° degrees.

3- Calculate the beamwidth as (350° - 325°) = 25°, (60° - 35°) = 26°, (75°-100°)=25°, (210°-130°)=80°, (240°-210°)=30°, (282°-267°)=15° and (326° -303°) = 26°.

Note that we have seven beamwidths, and the four bays justify this.

Note that the distance between the primary and the secondary antennas is 3km, and when we change the distance the result will be changed as in Eq.2-27.

It is noted that the maximum gain is at $\theta = 0$ and this means that the both antennas are aimed to each other. This result confirms with the theoretical side and it means that the measurement justifies the theoretical point in this side. Moreover, we note that this gain changes in the same way with the power, and this means that the relationship between them is as shown in the Eq.3-2.

In this measurement the weather conditions is good, so that the results are precise and covers the theoretical side.

3.9 A Self-Study of the Antenna Measurements

This part is left for the interested reader in the antenna measurements as a self study because it is easy, short, and important.

3.9.1 Impedance Measurement

As we have mentioned before, the bridge method is the most widely used method to measure the antenna impedance. This method will be explained here.

3.9.1.1 Equipments Required

1- Different types of bridge can be used but the commonly used one in this work is bridge.

2- Variation frequency source.

3.9.1.2 Practical Steps

1- Replace the antenna in the bridge to be as the unknown arm in the bridge.

2- Adjust the frequency for the source to be as the antenna frequency, and setting the frequency to be 1MHz.

3- Change the adjustable arm impedance until the balance condition is being achieved.

4- Measure the impedance of the adjustable arm, as antenna impedance.

5- Apply Eq.2-3, to obtain the antenna impedance for each measurement.

6- Investigate and study the antenna impedance property with the frequency by changing the frequency to be 1MHz, 2MHz, 5MHz, and 10MHz respectively. In each case read the impedance which makes the balance of the bridge, and then calculate the antenna impedance.

7- Plot the frequency versus the impedance and try to find the slope for each reading.

References

[1] G.G Merriam Co, Springfield, Mass, 1963, p.38 Webster Seventh New Collegiate Dictionary.

[2] IEEE Test Procedure for Electrical and Electronics Engineering, New York (January 1965).

[3] L.V. Blake book, Antenna, 1985.

[4] J.D Kraus, Antennas, Mc Graw-hill, New York, 1950.

[5] Lo, Y.I, Antenna Handbook: theory, Application.

[6] Weeks, W.L, Watter. L, Antenna Engineering.

[7] Morita, N. Integral Equation Methods for Electric.

[8] Balanis, Constantine, Antenna Theory: Analysis and Design.

[9] Stutzman, Warren L.C.N, Aneanna Theory and Design.

[10] Silver, Samuue, Microwave Antenna Theory and Design 1915.

[11] Brookner, Elli, Practical Phased-array Antenna System 1931.

[12] Hirskn, Herbert, Practical Simulation of Radar Antenna.

[13] Johnson, Richard C.CR, Antenna Engineering Handbook.

[14] Hirasawa, Razuniro, L Analysis, Design, and Measurement.

[15] Carr, Jose Ph.Practical Antenna Handbook.

[16] Machamara, Theraza, Handbook of Antenna for EMC/Th.

[17] K.Fuimoto, A.Henderson, K.Hirasawa and J.K.James, Small Antennas.

[18] David K.Cheng, Fund. Engineering Electromagnetics. 1997.