NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronics Engineering

HORN ANTENNAS

Graduation Project
EE 400

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ACNOWLOEDGMENT

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ABSTRACT

Antenna is one of the most common and important parts in the communication system. The antenna is one that will radiate all the power delivered to it by a transmitter in the desired direction and directions with the desired polarization.

The antenna parameters are defined which are useful to achieve this purpose. We demonstrated the basic principle of the antenna parameters although the basic principle and theory remain unchanged. The objective in this analysis of the horn antenna is to demonstrate the theory and investigate some applications to this subject.

Global earth coverage from a geostationary satellite is often required for telemetry and command signals as well as conventional communications traffic. With an increasing number of satellites orbiting the earth, minimizing interference with other satellites is becoming more important than in the past. To achieve this, the amount of sidelobe energy should be as low as possible, both for co- and cross-polarized signals. An ideal full-earth coverage antenna should have a circularly symmetric pattern and, therefore, most global-earth coverage antennas are either circular reflectors or horns. While the beam of a reflector antenna can be shaped to provide the desired earth coverage, a disadvantage of reflectors is that the feed spillover can be significant, thereby increasing the sidelobe energy. Horn antennas, on the other hand have well-controlled sidelobes. Some horns used successfully for global-earth coverage include the smooth-wall conical, multi-mode conical and corrugated-wall types...etc.

TABLE OF CONTENTS

INTRODUCTION

The term antenna is defined by the dictionary as a usually metallic device for radiating or receiving radio waves. The official definition of the Institute of Electrical and Electronics Engineers (IEEE) 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 or 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.

So in this project I will tray to do work in type of antenna called horn antenna, it is one of the simplest and probably the most widely used in the microwave antenna. It is existence and early use dates back to the late 1800s. Although neglected somewhat in the early 1900s,it is revival began in the late 1930s from the interest in the microwaves and waveguide transmission lines during the period of Word War II.since that time a number of articles have been describing its radiation mechanism, optimization design methods, and applications.

The project is going to be consisting of four chapters and conclusion, in the first chapter I will present the primary concerned with definitions and related terminology.

Then in the second chapter I will discuss the horn antenna with its various types without forgetting to overview the behavior and manner of these types.

In the other hand I will not forget in the third chapter to study the horn antenna gain measurement with considering antenna pattern, taper, coverage area, shaped beams and the other impedance, pattern measurement.

Finally in the fourth chapter I will show and explain the applications of the horn antenna in the different field like feed element for large radio astronomy, satellite tracking, communication dishes found installed throughout the word … etc.

At the end I will conclude my project by what I have learned from the previous chapter.

CHAPTER 1

FUNDAMENTALS OF ANTENNA

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 micro miniature 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:

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, fox- 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 Lines

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 30 MHz), 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 1 GHz), 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 used; with some use of mall-diameter coaxial lines in low-power no critical 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 ultra light 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 unplanted 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 500 KHz. 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

1.2 Antenna Parameters

The most fundamental properties of antennas are the following:

1.2.1 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 θ (r, θ, Φ) are 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 Interrelationship of space variables (x, y, z) and (r, θ, Φ)

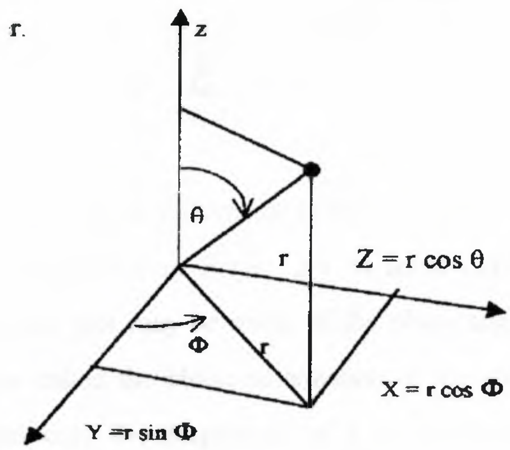


Figure 1-1 illustrates the relationship between the Cartesian and spherical coordinates.

The projection of this distance r onto the x-y plane is designated θ, Φ, this means that changing r courses changing on θ,

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 (θ, ϕ) 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

$$E = \eta o H \tag{1-1}$$

(Of course, they are at right angles to each other and their phase angles are equal) where $\eta o = 377\Omega$ 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 $(\theta,\ \phi)$ known, the relation being

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

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 F 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 l-2a and l-2b compare these two representations.

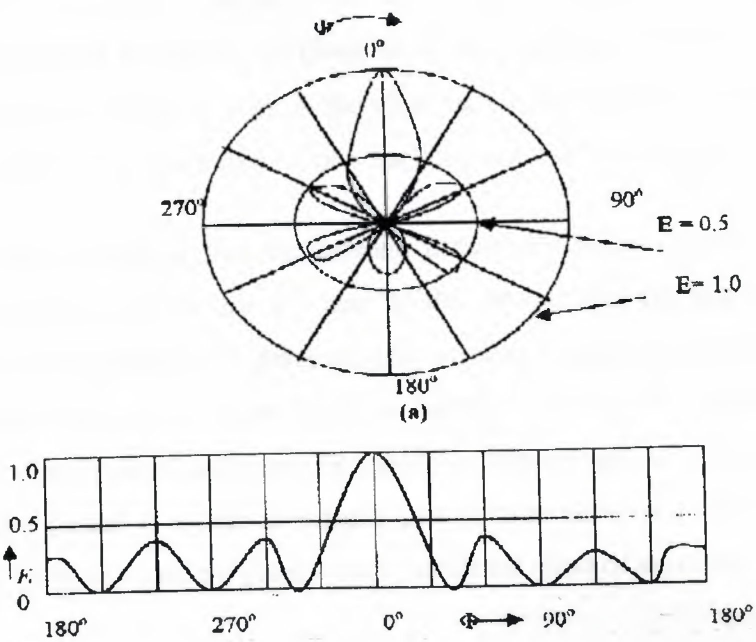


Figure 1-2 Comparison of plane pattern plotted in polar and rectangular form. The same pattern is represented in both cases and the coordinates are the same. Only the plot is different (a) polar (b) rectangular plot.

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 planed 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).

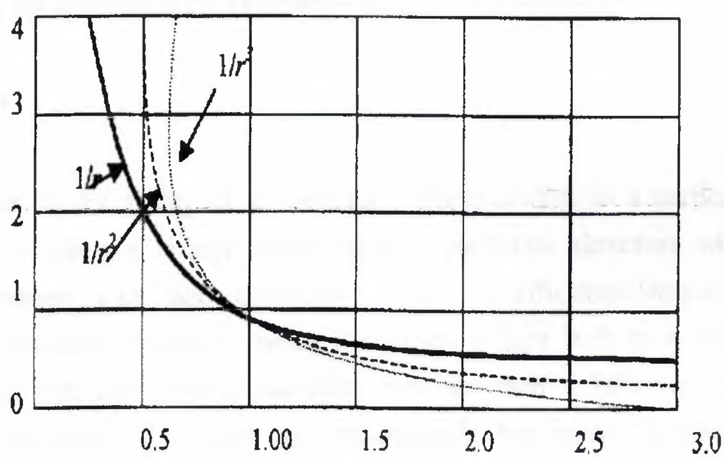
It is also fairly common to express the relative field strength or power density in decibels. This coordinate of the pattern is given as 20 log (E/E_{max}) or 10 log (P / P_{max}). The value at the maximum of the pattern is therefore zero decibels, and at other angles the decibel values are negative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

1.2.2 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 $1/r$, and $1/r^2$, $1/r^3$. The behavior of such terms, as *r* in creases, 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 become much larger than the $1/r$ term dominates the far-field region, as seen in Figurel-3.



Figurel-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

$$r_{\min} = \frac{2d^2}{\lambda} \tag{1-3}$$

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

1.2.3 Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving. The relationship between gain and directivity: *Gain* = efficiency/Directivity. We see the phenomena of increased directivity when comparing a light bulb to a spotlight. A 100-watt spotlight will provide lighter in a particular direction than a 100-watt light bulb, and less light in other directions. We could say the spotlight has more "directivity" than the light bulb. The spotlight is comparable to an antenna with increased directivity. An antenna with increased directivity is hopefully implemented efficiently, is low loss, and therefore exhibits both increased directivity and gain.

1.2.4 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 Ar (or the capture area) is then defined as the ratio between the delivered power Pr watts into the load power density P_i watts per unit area

$$A_r = \frac{p_r}{p_i} \qquad (1\text{-}4)$$

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 isotropic A_{ro} is given as

$$A_{ro} = \frac{\lambda^2}{4\pi} \Rightarrow A_r \frac{G\lambda^2}{4\pi} \quad (1\text{-}5)$$

Where G = $\xi D, \lambda$ is the wavelength, note that λ has relationship with the size, then Ar, G and the size. Equation 1-12 may be proved theoretically and verified experimentally. From this relationship it follows that

$$D = [\frac{4\pi A_r}{\xi \lambda^2}] \quad (1\text{-}6)$$

Where D is the directive gain.

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

$$p_r = \xi[\frac{p_i D \lambda^2}{4\pi}] \quad (1\text{-}7)$$

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.1-15. In general, it is possible to measure the gain from the receiving cross signal, as we will see later.

1.2.5 Beam width

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 Bandwidth Definition

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 1-4 illustrates the procedure of determining the -3dB Beamwidth on a rectangular pattern plot.

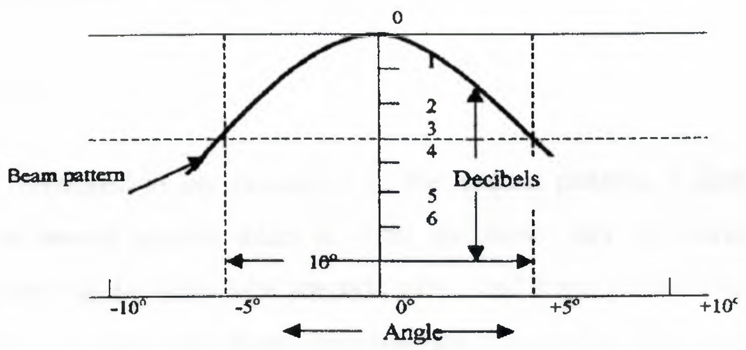


Figure 1-4 Determination of half-power (3dB-down) Beamwidth.

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 Beamwidtb

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 settable; 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 main beam 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 main beam 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.

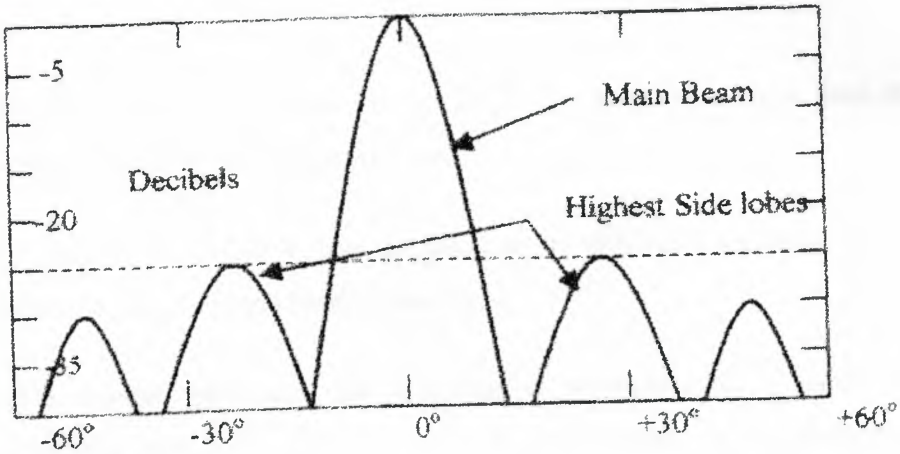


Figure 1-5 Decibel pattern plot, indicated side lobe level

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

$$R_r = \frac{p}{i^2} \qquad (1\text{-}8)$$

When P is given in watts and *I* in amperes, R_i 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. 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. That 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_0, is $Rr = 2P1I^2$, note that

$$I_0 = \sqrt{2} I_{rms} \qquad (1.9)$$

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 comic 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_0 ± Rr)*** whereas the radiation power is I^2Rr. Hence the antenna radiation efficiency ξ_r ***is*** given by

$$\xi_r = \frac{R_r}{R_0 + p_r} \qquad (1\text{-}10)$$

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.1-4, and R_0 is correspondingly equal to p_0 / I^2 Making these substitutions into Eq. 1-5, then it gives the more basic definition of the efficiency:

$$\xi_r = \frac{p_r}{p_0 + p_r} \tag{1-11}$$

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

$$Z = \frac{E_i}{I_i} \tag{1-12}$$

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

$$Z_i = R_i = R_r \tag{1-13}$$

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 input impedance can be defined at the point of connection of the waveguide to the antenna, just as waveguides have 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 $4MH_z$ 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 $155\ MH_z$ to a maximum frequency of 205 MH_z, its bandwidth would be $10MH_z$. 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.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} p_n(\theta,\phi) d\Omega \qquad (1\text{-}13)$$

1.2.10 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 successftilly 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 I GHz) 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 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 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.

1.2.11 Effective area

The effective area multiplied by the wave incident power density in watts per square meter gives the total power delivered to the antenna's feeder. This is for a receive antenna. The effective area A of an antenna is related to the boresight gain G and the free space wavelength lambda of the radiation by the formula G = (4 pi A)/(lambda^2). This is a most important formula.

A half-wave dipole has effective area of 0.13 lambda^2, which is roughly an area lambda/2 by lambda/4. The directivity of a half wave dipole, in the azimuth direction or H-plane, is about 1.67 or about 2.23 dB. Within elevation angles of size about 32.6 degrees

the dipole has higher directivity than an isotropic source; outside this range it has lower directivity.

Considering an antenna as a transmitter, if it is fed with power P (accepted power) then the power density on boresight is G P/(4 pi R^2) at distance R. Here, G is a straight number calculated from the directivity and the efficiency. It is also possible to give the gain G in decibels; remember G is a power gain so in dB a gain G of 10 is 10dB, a gain of 100 is 20dB, a gain of 1000 is 30dB and so on.

If we transmit between two antennas each of gain G, spaced by a distance R, the field strength at the second due to the first is G P/(4 pi R^2) watts per square meter, and the effective area of the second is A=G*(lambda^2)/(4 pi) so the total power transferred from transmitter to receiver is the product of these factors. The received power is therefore P*(G lambda)^2/(4 pi R)^2. This can be factorized into three parts as follows; the gain of the transmitting antenna times the gain of the receiving antenna times a "divergence factor" because not all of the power transmitted is picked up by the receiver. This latter factor is [lambda/(4 pi R)]^2 and the reciprocal of this, namely [(4 pi R)/lambda]^2 is often referred to as the "free space loss". We note that it is not really a "loss" as free space itself is a loss less propagating medium. These antenna transmission formulae only apply in the far field region, so we need to know when we are in the far field.

1.2.12 Reciprocity

ALL the above properties of an antenna are identical whether it is used in transmit or receive mode. There is only one exception to this rule called "reciprocity", and that is when the antenna contains magnetically biased magnetic materials such as ferrites with resonantly rotating electron spin systems.

The physical reason for reciprocity is that the only difference between outgoing and incoming waves lies in the arrow of time. Since the electromagnetic equations are invariant except for the signs of magnetic fields and currents, under time reversal, there can be no difference between transmit and receive mode in the physical current and field distributions. However, if we have a magnet providing a steady bias field, under time-

reversed conditions we would have to reverse the direction of this bias field. But for incoming and outgoing waves, the bias field direction remains the same. Thus it is possible for the system to be non-reciprocal.

1.2.13 Very Long Baseline Interferometer (VLBI)

If we use two aperture antennas, spaced by a great many wavelengths, as an interferometer, the fringe spacing will be of the order of the angle subtended by an object of diameter one wavelength at a distance equal to the separation of the aperture antennas. For example, at 10GHz the free space wavelength is 3cm or 0.03m, so if we separate the antennas by 3000km or 1E8 wavelengths, we can resolve radio sources about 1E-8 radians across, or about 2 milliseconds of arc. By comparison, the beam width of one of the aperture antennas will be of the order of the angle subtended by a wavelength of radiation at a distance equal to the diameter of the reflector. Thus, if we considered a system where there were two 30 meter diameter antennas separated by 3000km, there would be (3E6)/30 = 100,000 interference fringes within the main beam of one of the apertures. Of course, the sensitivity of the interferometer is still governed by the total capture area of the two dishes; but the resolution is now comparable with that of a dish of diameter 3000km.

1.2.14 VSWR and Reflected Power

The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. A VSWR of 2.0:1 or less is considered good. Most commercial antennas, however, are specified to be 1.5:1 or less over some bandwidth. Based on a 100-watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power.

1.2.15 Antenna Placement

Correct antenna placement is critical to the performance of an antenna. An antenna mounted on the roof will function better than the same antenna installed on the hood or trunk of a car. Knowledge of the vehicle may also be an important factor in determining what type of antenna to use. You do not want to install a glass mount antenna on the rear window of a vehicle in which metal has been used to tint the glass. The metal tinting will work as a shield and not allow signals to pass through the glass.

1.2.16 Directional Antennas

Directional antennas focus energy in a particular direction. Directional antennas are used in some base station applications where coverage over a sector by separate antennas is desired. Point to point links also benefit from directional antennas. Yagi and panel antennas are directional antennas.

1.2.17Omnidirectional Antennas

For mobile, portable, and some base station applications the type of antenna needed has an omnidirectional radiation pattern. The omnidirectional antenna radiates and receives equally well in all horizontal directions. Narrowing the beamwidth in the vertical or elevation plane can increase the gain of an omnidirectional antenna. The net effect is to focus the antenna's energy toward the horizon.

Selecting the right antenna gain for the application is the subject of much analysis and investigation. Gain is achieved at the expense of beamwidth: higher-gain antennas feature narrow beamwidths while the opposite is also true. Omnidirectional antennas with different gains are used to improve reception and transmission in certain types of terrain. A 0 dBd gain antenna radiates more energy higher in the vertical plane to reach radio communication sites that are located in higher places. Therefore they are more useful in mountainous and metropolitan areas with tall buildings. A 3-dBd-gain antenna is the compromise in suburban and general settings. A 5-dBd-gain antenna radiates more energy toward the horizon compared to the 0 and 3 dBd antennas to reach radio communication sites that are further apart and less obstructed. Therefore they are best used in deserts, plains, flatlands, and open farm areas.

CHAPTER 2

HORN ANTENNA

2.1 Horns

One of the simplest and probably the most widely used microwave antenna is the horn. Its existence and early use dates back to the late 1800s. Although neglected somewhat in the early I 900s, its revival began in the late 1930s from the interest in microwaves and waveguide transmission lines during the period of World War II. Since that time a number of articles have been written describing its radiation mechanism, optimization design methods, and applications.

The horn is widely used as a feed element for large radio astronomy satellite tracking, and communication dishes found installed throughout the word In addition to its utility as a feed for reflectors and lenses, it is a common element of phased arrays and serves as a universal standard for calibration and gain measurements of other high-gain antennas. Its widespread applicability slams from its simplicity in construction, case of excitation, versatility, large gain, and preferred overall performance.

An electromagnetic horn can take many different forms, four of which are shown in Figure 2.1, The born is nothing more than a hollow pipe of different cross sections which has been tapered to a larger opening. The type, direction, and amount of taper can have a profound effect on the overall performance of the element as a radiator.

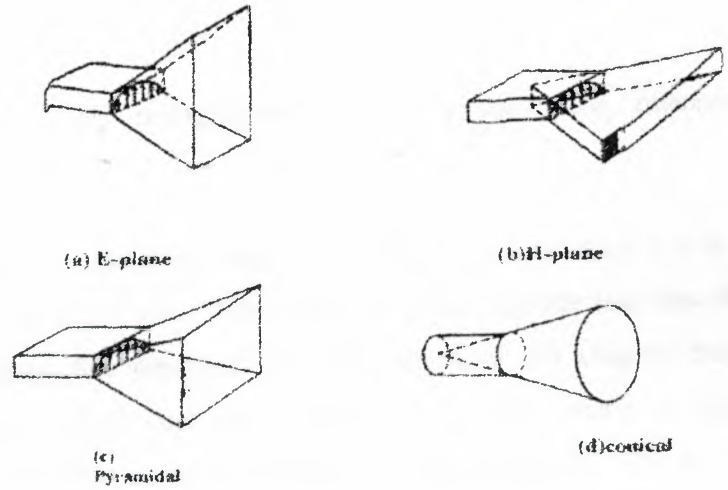


Figure 2.1 Typical Electromagnetic Horn Antennas

Radio wave can be radiated directly from the end of the waveguide in the same way as from the end of an open transmission line. The end of the waveguide represents an abrupt transition from the characteristic impedance of the wave-guide into that of free space, and the radiation resulting is neither efficient nor very directive. This state of affairs can be improved considerably by flaring out the end of the wave-guide to form a horn like structure. A gradual transition can thus take place as the wave passes from the mouth of the horn. Narrow mouthed horns with long flare section produce sharper beams than shallow, wide mouthed ones. Also, the wider mouthed horns tend to produce a wave front with a distinct curvature, which is undesirable. The ideal would be for the waves to leave the horn with a completely planar wave front, and to accomplish this a focusing mechanism, such as a curve reflector or a lens, may be used with the horn.

Three types of horns are shown in figure 2.1. The first is sect oral horn, which is flared in only one plane (fig.2. 1a &2. 1b). It has the top and bottom walls at an O° flare angle. The sidewalls are sometimes hinged to provide adjustable flare angle to Maximum radiations occurs for angles between 40° and 60° the second is the pyramidal horn, which is flared in both planes (fig.2. 1 c). Both of these are used with rectangular wave-guides. The third type is conical and is used with a circular wave-guide to produce a circularly polarized beam (fig.2.1d). Horn type antennas do not provide very high directivity but are of simple,

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HORN ANTENNAS

Graduation Project
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ABSTRACT

Antenna is one of the most common and important parts in the communication system. The antenna is one that will radiate all the power delivered to it by a transmitter in the desired direction and directions with the desired polarization.

The antenna parameters are defined which are useful to achieve this purpose. We demonstrated the basic principle of the antenna parameters although the basic principle and theory remain unchanged. The objective in this analysis of the horn antenna is to demonstrate the theory and investigate some applications to this subject.

Global earth coverage from a geostationary satellite is often required for telemetry and command signals as well as conventional communications traffic. With an increasing number of satellites orbiting the earth, minimizing interference with other satellites is becoming more important than in the past. To achieve this, the amount of sidelobe energy should be as low as possible, both for co- and cross-polarized signals. An ideal full-earth coverage antenna should have a circularly symmetric pattern and, therefore, most global-earth coverage antennas are either circular reflectors or horns. While the beam of a reflector antenna can be shaped to provide the desired earth coverage, a disadvantage of reflectors is that the feed spillover can be significant, thereby increasing the sidelobe energy. Horn antennas, on the other hand have well-controlled sidelobes. Some horns used successfully for global-earth coverage include the smooth-wall conical, multi-mode conical and corrugated-wall types...etc.

TABLE OF CONTENTS

INTRODUCTION

The term antenna is defined by the dictionary as a usually metallic device for radiating or receiving radio waves. The official definition of the Institute of Electrical and Electronics Engineers (IEEE) 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 or 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.

So in this project I will tray to do work in type of antenna called horn antenna, it is one of the simplest and probably the most widely used in the microwave antenna. It is existence and early use dates back to the late 1800s. Although neglected somewhat in the early 1900s,it is revival began in the late 1930s from the interest in the microwaves and waveguide transmission lines during the period of Word War II.since that time a number of articles have been describing its radiation mechanism, optimization design methods, and applications.

The project is going to be consisting of four chapters and conclusion, in the first chapter I will present the primary concerned with definitions and related terminology.

Then in the second chapter I will discuss the horn antenna with its various types without forgetting to overview the behavior and manner of these types.

In the other hand I will not forget in the third chapter to study the horn antenna gain measurement with considering antenna pattern, taper, coverage area, shaped beams and the other impedance, pattern measurement.

Finally in the fourth chapter I will show and explain the applications of the horn antenna in the different field like feed element for large radio astronomy, satellite tracking, communication dishes found installed throughout the word … etc.

At the end I will conclude my project by what I have learned from the previous chapter.

CHAPTER 1

FUNDAMENTALS OF ANTENNA

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 micro miniature 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:

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, fox- 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 Lines

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 30 MHz), 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 1 GHz), 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 used; with some use of mall-diameter coaxial lines in low-power no critical 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 ultra light 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 unplanted 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 500 KHz. 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

1.2 Antenna Parameters

The most fundamental properties of antennas are the following:

1.2.1 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 θ (r, θ, Φ) are 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 Interrelationship of space variables (x, y, z) and (r, θ, Φ)

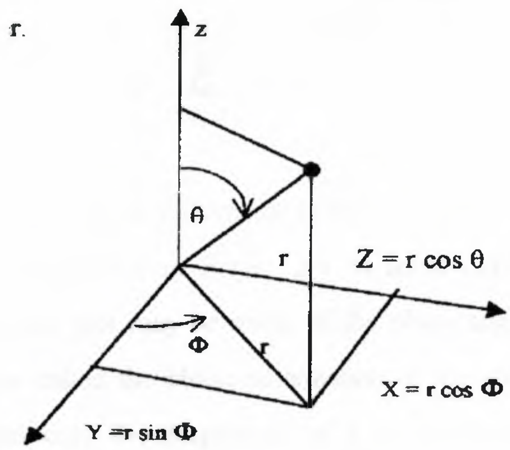


Figure 1-1 illustrates the relationship between the Cartesian and spherical coordinates.

The projection of this distance r onto the x-y plane is designated θ, Φ, this means that changing r courses changing on θ,

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 (θ, ϕ) 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

$$E = \eta o H \tag{1-1}$$

(Of course, they are at right angles to each other and their phase angles are equal) where $\eta o = 377\Omega$ 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 $(\theta,\ \phi)$ known, the relation being

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

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 F 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.

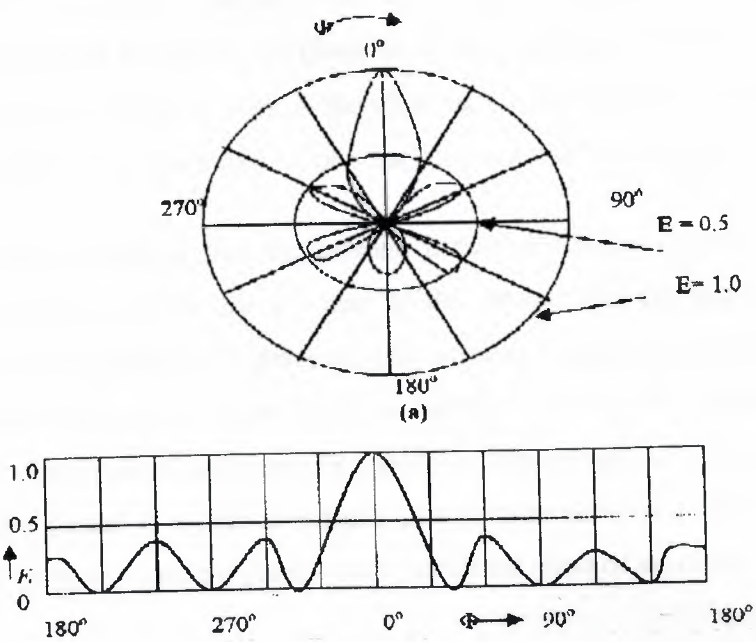


Figure 1-2 Comparison of plane pattern plotted in polar and rectangular form. The same pattern is represented in both cases and the coordinates are the same. Only the plot is different (a) polar (b) rectangular plot.

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 planed 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).

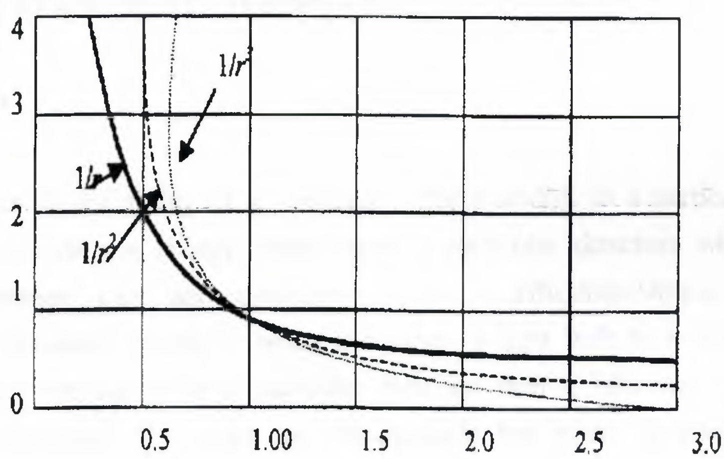
It is also fairly common to express the relative field strength or power density in decibels. This coordinate of the pattern is given as 20 log (E/E_{max}) or 10 log (P / P_{max}). The value at the maximum of the pattern is therefore zero decibels, and at other angles the decibel values are negative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

1.2.2 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 $1/r$, and $1/r^2$, $1/r^3$. The behavior of such terms, as r in creases, 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 become much larger than the $1/r$ term dominates the far-field region, as seen in Figure1-3.



Figurel-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

1.2.3 Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving. The relationship between gain and directivity: *Gain* = efficiency/Directivity. We see the phenomena of increased directivity when comparing a light bulb to a spotlight. A 100-watt spotlight will provide lighter in a particular direction than a 100-watt light bulb, and less light in other directions. We could say the spotlight has more "directivity" than the light bulb. The spotlight is comparable to an antenna with increased directivity. An antenna with increased directivity is hopefully implemented efficiently, is low loss, and therefore exhibits both increased directivity and gain.

1.2.4 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 Ar (or the capture area) is then defined as the ratio between the delivered power Pr watts into the load power density P_i watts per unit area

$$A_r = \frac{p_r}{p_i} \quad (1\text{-}4)$$

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 isotropic A_{ro} is given as

$$A_{ro} = \frac{\lambda^2}{4\pi} \Rightarrow A_r \frac{G\lambda^2}{4\pi} \tag{1-5}$$

Where G = $\xi D, \lambda$ is the wavelength, note that λ has relationship with the size, then Ar, G and the size. Equation 1-12 may be proved theoretically and verified experimentally. From this relationship it follows that

$$D = [\frac{4\pi A_r}{\xi \lambda^2}] \tag{1-6}$$

Where D is the directive gain.

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

$$p_r = \xi[\frac{p_i D \lambda^2}{4\pi}] \tag{1-7}$$

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.1-15. In general, it is possible to measure the gain from the receiving cross signal, as we will see later.

1.2.5 Beam width

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 Bandwidth Definition

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 1-4 illustrates the procedure of determining the -3dB Beamwidth on a rectangular pattern plot.

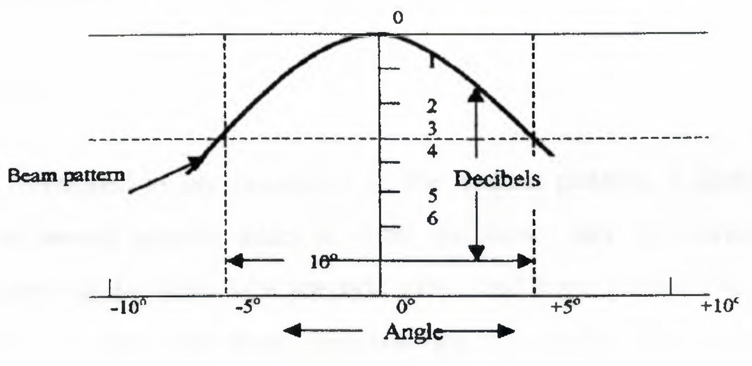


Figure 1-4 Determination of half-power (3dB-down) Beamwidth.

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 Beamwidtb

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 settable; 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 main beam 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 main beam 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.

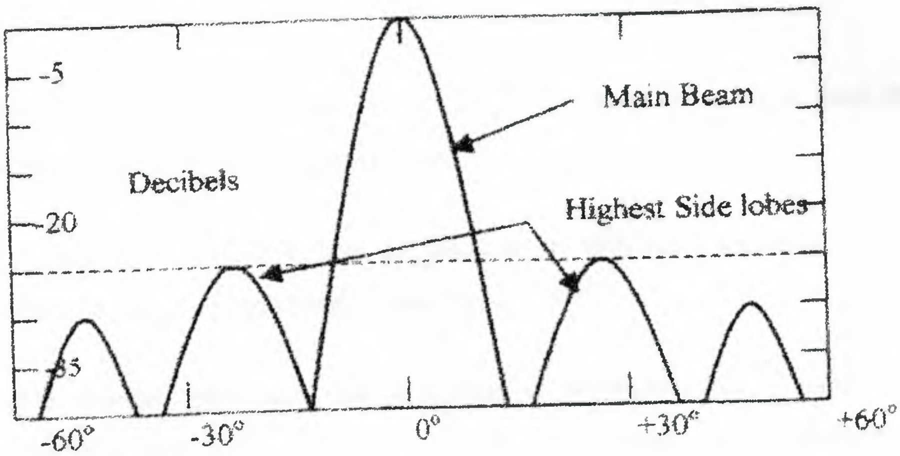


Figure 1-5 Decibel pattern plot, indicated side lobe level

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

$$R_r = \frac{P}{i^2} \qquad (1\text{-}8)$$

When P is given in watts and I in amperes, R_i 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. 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. That 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_0, is $Rr = 2P1I^2$, note that

$$I_0 = \sqrt{2}I_{rms} \qquad (1.9)$$

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 comic 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_0 ± Rr)*** whereas the radiation power is I^2Rr. Hence the antenna radiation efficiency ξ_r ***is*** given by

$$\xi_r = \frac{R_r}{R_0 + p_r} \qquad (1\text{-}10)$$

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.1-4, and R_0 is correspondingly equal to p_0 / I^2 Making these substitutions into Eq. 1-5, then it gives the more basic definition of the efficiency:

$$\xi_r = \frac{p_r}{p_0 + p_r} \qquad (1\text{-}11)$$

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

$$Z = \frac{E_i}{I_i} \qquad (1\text{-}12)$$

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

$$Z_i = R_i = R_r \qquad (1\text{-}13)$$

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 input impedance can be defined at the point of connection of the waveguide to the antenna, just as waveguides have 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 $4MH_z$ 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 $155\ MH_z$ to a maximum frequency of 205 MH_z, its bandwidth would be $10MH_z$. 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.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} p_n(\theta,\phi) d\Omega \qquad (1\text{-}13)$$

1.2.10 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 successftilly 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 I GHz) 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 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 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.

1.2.11 Effective area

The effective area multiplied by the wave incident power density in watts per square meter gives the total power delivered to the antenna's feeder. This is for a receive antenna. The effective area A of an antenna is related to the boresight gain G and the free space wavelength lambda of the radiation by the formula G = (4 pi A)/(lambda^2). This is a most important formula.

A half-wave dipole has effective area of 0.13 lambda^2, which is roughly an area lambda/2 by lambda/4. The directivity of a half wave dipole, in the azimuth direction or H-plane, is about 1.67 or about 2.23 dB. Within elevation angles of size about 32.6 degrees

the dipole has higher directivity than an isotropic source; outside this range it has lower directivity.

Considering an antenna as a transmitter, if it is fed with power P (accepted power) then the power density on boresight is G P/(4 pi R^2) at distance R. Here, G is a straight number calculated from the directivity and the efficiency. It is also possible to give the gain G in decibels; remember G is a power gain so in dB a gain G of 10 is 10dB, a gain of 100 is 20dB, a gain of 1000 is 30dB and so on.

If we transmit between two antennas each of gain G, spaced by a distance R, the field strength at the second due to the first is G P/(4 pi R^2) watts per square meter, and the effective area of the second is A=G*(lambda^2)/(4 pi) so the total power transferred from transmitter to receiver is the product of these factors. The received power is therefore P*(G lambda)^2/(4 pi R)^2. This can be factorized into three parts as follows; the gain of the transmitting antenna times the gain of the receiving antenna times a "divergence factor" because not all of the power transmitted is picked up by the receiver. This latter factor is [lambda/(4 pi R)]^2 and the reciprocal of this, namely [(4 pi R)/lambda]^2 is often referred to as the "free space loss". We note that it is not really a "loss" as free space itself is a loss less propagating medium. These antenna transmission formulae only apply in the far field region, so we need to know when we are in the far field.

1.2.12 Reciprocity

ALL the above properties of an antenna are identical whether it is used in transmit or receive mode. There is only one exception to this rule called "reciprocity", and that is when the antenna contains magnetically biased magnetic materials such as ferrites with resonantly rotating electron spin systems.

The physical reason for reciprocity is that the only difference between outgoing and incoming waves lies in the arrow of time. Since the electromagnetic equations are invariant except for the signs of magnetic fields and currents, under time reversal, there can be no difference between transmit and receive mode in the physical current and field distributions. However, if we have a magnet providing a steady bias field, under time-

reversed conditions we would have to reverse the direction of this bias field. But for incoming and outgoing waves, the bias field direction remains the same. Thus it is possible for the system to be non-reciprocal.

1.2.13 Very Long Baseline Interferometer (VLBI)

If we use two aperture antennas, spaced by a great many wavelengths, as an interferometer, the fringe spacing will be of the order of the angle subtended by an object of diameter one wavelength at a distance equal to the separation of the aperture antennas. For example, at 10GHz the free space wavelength is 3cm or 0.03m, so if we separate the antennas by 3000km or 1E8 wavelengths, we can resolve radio sources about 1E-8 radians across, or about 2 milliseconds of arc. By comparison, the beam width of one of the aperture antennas will be of the order of the angle subtended by a wavelength of radiation at a distance equal to the diameter of the reflector. Thus, if we considered a system where there were two 30 meter diameter antennas separated by 3000km, there would be (3E6)/30 = 100,000 interference fringes within the main beam of one of the apertures. Of course, the sensitivity of the interferometer is still governed by the total capture area of the two dishes; but the resolution is now comparable with that of a dish of diameter 3000km.

1.2.14 VSWR and Reflected Power

The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. A VSWR of 2.0:1 or less is considered good. Most commercial antennas, however, are specified to be 1.5:1 or less over some bandwidth. Based on a 100-watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power.

1.2.15 Antenna Placement

Correct antenna placement is critical to the performance of an antenna. An antenna mounted on the roof will function better than the same antenna installed on the hood or trunk of a car. Knowledge of the vehicle may also be an important factor in determining what type of antenna to use. You do not want to install a glass mount antenna on the rear window of a vehicle in which metal has been used to tint the glass. The metal tinting will work as a shield and not allow signals to pass through the glass.

1.2.16 Directional Antennas

Directional antennas focus energy in a particular direction. Directional antennas are used in some base station applications where coverage over a sector by separate antennas is desired. Point to point links also benefit from directional antennas. Yagi and panel antennas are directional antennas.

1.2.17Omnidirectional Antennas

For mobile, portable, and some base station applications the type of antenna needed has an omnidirectional radiation pattern. The omnidirectional antenna radiates and receives equally well in all horizontal directions. Narrowing the beamwidth in the vertical or elevation plane can increase the gain of an omnidirectional antenna. The net effect is to focus the antenna's energy toward the horizon.

Selecting the right antenna gain for the application is the subject of much analysis and investigation. Gain is achieved at the expense of beamwidth: higher-gain antennas feature narrow beamwidths while the opposite is also true. Omnidirectional antennas with different gains are used to improve reception and transmission in certain types of terrain. A 0 dBd gain antenna radiates more energy higher in the vertical plane to reach radio communication sites that are located in higher places. Therefore they are more useful in mountainous and metropolitan areas with tall buildings. A 3-dBd-gain antenna is the compromise in suburban and general settings. A 5-dBd-gain antenna radiates more energy toward the horizon compared to the 0 and 3 dBd antennas to reach radio communication sites that are further apart and less obstructed. Therefore they are best used in deserts, plains, flatlands, and open farm areas.

CHAPTER 2

HORN ANTENNA

2.1 Horns

One of the simplest and probably the most widely used microwave antenna is the horn. Its existence and early use dates back to the late 1800s. Although neglected somewhat in the early I 900s, its revival began in the late 1930s from the interest in microwaves and waveguide transmission lines during the period of World War II. Since that time a number of articles have been written describing its radiation mechanism, optimization design methods, and applications.

The horn is widely used as a feed element for large radio astronomy satellite tracking, and communication dishes found installed throughout the word In addition to its utility as a feed for reflectors and lenses, it is a common element of phased arrays and serves as a universal standard for calibration and gain measurements of other high-gain antennas. Its widespread applicability slams from its simplicity in construction, case of excitation, versatility, large gain, and preferred overall performance.

An electromagnetic horn can take many different forms, four of which are shown in Figure 2.1, The born is nothing more than a hollow pipe of different cross sections which has been tapered to a larger opening. The type, direction, and amount of taper can have a profound effect on the overall performance of the element as a radiator.

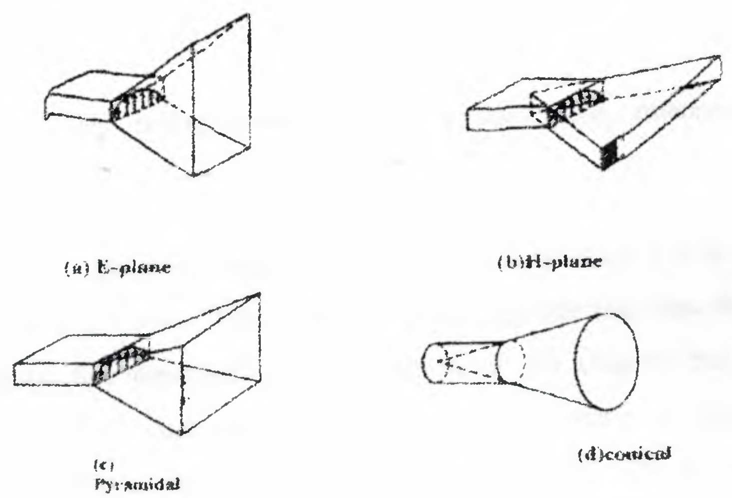


Figure 2.1 Typical Electromagnetic Horn Antennas

Radio wave can be radiated directly from the end of the waveguide in the same way as from the end of an open transmission line. The end of the waveguide represents an abrupt transition from the characteristic impedance of the wave-guide into that of free space, and the radiation resulting is neither efficient nor very directive. This state of affairs can be improved considerably by flaring out the end of the wave-guide to form a horn like structure. A gradual transition can thus take place as the wave passes from the mouth of the horn. Narrow mouthed horns with long flare section produce sharper beams than shallow, wide mouthed ones. Also, the wider mouthed horns tend to produce a wave front with a distinct curvature, which is undesirable. The ideal would be for the waves to leave the horn with a completely planar wave front, and to accomplish this a focusing mechanism, such as a curve reflector or a lens, may be used with the horn.

Three types of horns are shown in figure 2.1. The first is sect oral horn, which is flared in only one plane (fig.2. 1a &2. 1b). It has the top and bottom walls at an O° flare angle. The sidewalls are sometimes hinged to provide adjustable flare angle to Maximum radiations occurs for angles between 40° and 60° the second is the pyramidal horn, which is flared in both planes (fig.2. 1 c). Both of these are used with rectangular wave-guides. The third type is conical and is used with a circular wave-guide to produce a circularly polarized beam (fig.2.1d). Horn type antennas do not provide very high directivity but are of simple,

rugged construction. This makes them ideal as primary feed antennas for parabolic reflectors and lenses

A wave-guide is capable or radiating energy into open space if it is suitably excited at one end and open at the other. This radiation is much greater than that obtained from the two-wire transmission line described at the beginning of this chapter, but it suffers from similar difficulties, Only a small proportion of the forward energy in the wave guide is radiated, and much of it is reflected back by the open circuit. As with the transmission line, the open circuit is a discontinuity, which matches the wave-guide very poorly to space. Detraction around the edges will give the radiation a poor, nondirective pattern. To overcome these difficulties, the mouth of the wave-guide may be opened out, as was done to the transmission line, but this time an electromagnetic horn results instate of the dipole.

2.2 Basic Horns

When a wave-guide is terminated by a horn, such as any of those show in Figural, the abrupt discontinuity that existed is replaced by a gradual transformation. Provided that impedance matching is correct, the entire energy-traveling forward in the wave-guide will now be radiated. Directivity will also be improved, and diffraction reduced. There are several possible horn configurations; some of the most common are shown below. If flare angle **Φ** of Figure la & lb is too small, resulting in a shallow horn, the wave front leaving the horn will be spherical rather than plane, and the radiated beam will not be directive. The same applies to the two flare angles of the pyramidal horn. If the Φ is too small, so will be the mouth area of the horn, and directivity will once again suffer (not to mention that diffraction is now more likely). It is therefore apparent that the flare angle has an optimum value and is closely related to the length L of Figure 1a & 1b, as measured in wavelengths.

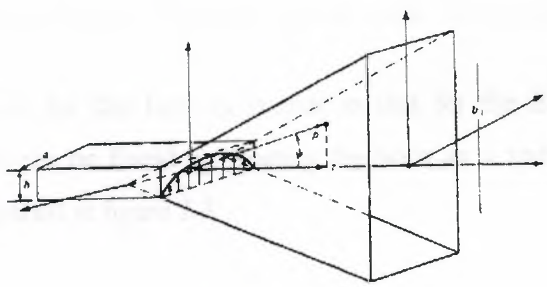
In practice, **Φ** varies from 40° when L/λ =6, at which the beam width in the plane of the horn in 66° and the maximum directive gain is 4, to 15 when L/λ, for which beam width is 23°and gain is 12. The use of a pyramidal or conical horn will improve overall directivity because flare is now in more than one direction. In connection with parabolic reflectors, this is not always necessary. The horn antenna is not nearly as directive as an antenna with a parabolic reflector, but it does have quite good directivity, an adequate bandwidth (in the vicinity of 10 percent) and simple mechanical construction. It is a very convenient antenna to use with a wave-guide. Simple horns such as the ones shown (or with exponential instead of straight sides) are often employed, sometimes by themselves and sometimes as primary radiators for parabolic reflectors.

Some conditions dictate the use of a short, shallow horn, in which case the wave front leaving it is curved, not plane as so far considered. When this is unavoidable, a *dielectric lens* may be employed to correct the curvature.

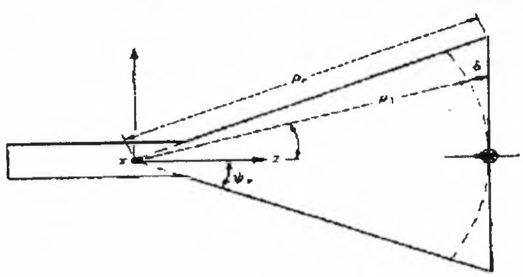
2.3 Sectoral Oral Horn

2.3.1 E-plane Sectoral Horn

Is one of whose opening is flared in the direction of the E-filed, and it is shown in figure 2.2 below:



(a)



(b)

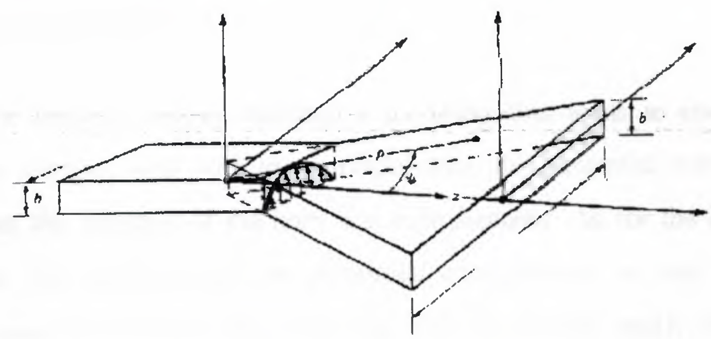
Figure 2.2 (a, b) E-plane sectoral horns

The horn can be treated as an aperture antenna. The fields at the aperture of the horn can be found by treating the horn as a radial wave-guide. The field within the horn can expressed in terms of cylindrical TE and TM wave functions, which include Hankel functions. This method finds the fields not only at the aperture of the horn but also within the horn. To find the field radiated by the horn, only the tangential components of the E- and /or H-fields over a closed surface must by known. The closed surface is chosen to coincide with an infinite plane passing through the mouth of the horn. The directivity is one of the parameters that are often used as a figure-of –merit to describe the performance of an antenna. To find the directivity the maximum radiation is formed.

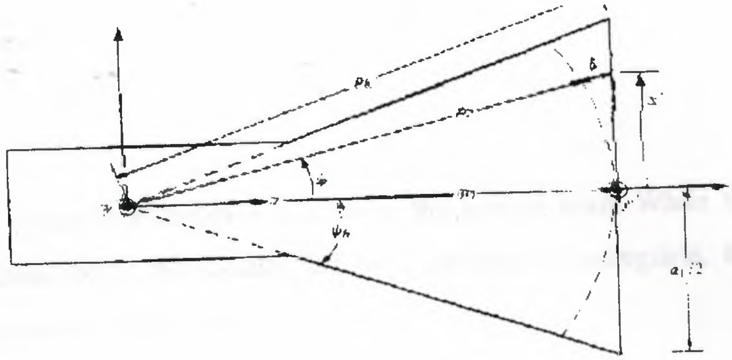
2.3.2 H- plan sectoral horn

Flaring the dimensions of a rectangular wave-guide in the direction of the H-field while keeping the other constant forms an H-plane sectoral horn shown in figure.

The analysis procedure for this horn is similar to that for the E-plane horn. The field at the aperture of the horn can be found by treating the horn as a radial waveguide forming an imaginary apex shown dashed in figure 2.3



(a)



(b)

Figure2.3 H-plane sectoral horn

The fields radiated by the horn can be found by first formulating the equivalent current densities. To the directivity of the H-plan sectoral horn, a procedure similar to that for E-plan is used. As for the E-plan sectoral horn the maximum radiation I directed nearly along the z-axis (θ =0).

2.4 Pyramidal Horn

The most widely used horn is the one, which is flared in both directions, It is widely referred to as pyramidal horn, and it is radiation characteristic are essentially a combination of E-plan and H-plan sectoral horns.

To simplify the analysis and to maintain a modeling that leads to computations that have been shown to correlate well with experimental data, the tangential components of the E- and H- fields over the aperture of the horn are approximated. As for the E-plane and H-plane sectoral horns, the directivity of the pyramidal configuration is vital to the antenna designer. The maximum radiation of the pyramidal horn is directed nearly along the z-axis (θ = 0).

The pyramidal horn is widely used as a standard to make gain measurement of other antennas and as such it is often referred to as standard gain horn. To design a pyramidal horn, one usually knows the desired gain G and the dimensions a, b of the rectangular feed wave-guide. The objective of the design is to determine the remaining dimensions that will lead to an optimum gain.

2.5 Conical Horn

Another very practical microwave antenna is the conical horn. While the pyramidal E-, and H-plane sectoral horns are usually fed by a rectangular waveguide, the feed of a conical horn is often a circular waveguide.

The first rigorous treatment of the fields radiated by a conical horn is that of Schorr and Beck. The modes within the horn are found by introducing a spherical coordinate system and are in terms of spherical Bessel functions and Legendre polynomials.

The behavior of a conical horn is similar to that of a pyramidal or *a* sectoral born. As the flare angle increases, the directivity for a given length horn increases until it reaches a maximum beyond which it begins to decrease, The decrease is a result of the dominance of the quadratic phase error at the aperture.

2.6 Corrugated Horn

The large emphasis placed on horn antenna research in the I 960s was inspired by the need to reduce spillover efficiency and cross polarization losses and increase aperture efficiencies of large reflectors used in radio astronomy and satellite communications. In the 1970s high-efficiency and rotationally symmetric antennas were needed in microwave radiometry. Using conventional feeds, aperture efficiencies of 50—60% were obtained. However, efficiencies of the order of 75—80% can be obtained with improved feed systems utilizing corrugated horns.

In 1964 Kay IS) realized that grooves on the wails of a horn antenna would present the same boundary conditions to all polarization and would taper the field distribution at the aperture in all the planes. The creation of the same boundary conditions on all four walls- would eliminate the spurious diffractions at the edges of the aperture. For a square aperture, this would lead to an almost rotationally symmetric pattern with equal *E*- and H-plane beamwidths. Corrugated (grooved) pyramidal horn, with corrugations in the E-plane walls. Since diffractions at the edges of the aperture in the H-plane are minimal, corrugations are usually not placed on the walls of that plane. Corrugations can also be placed in a conical horn forming a conical corrugated horn to form a very effective corrugated surface. It usually requires I0 or more slots (corrugations) per wavelength.

2.7 Special Horns

There are two antennas in use, which are rather difficult to classify, since each is across between a horn and a parabolic reflector. They are the Cass - horn and tnply folded horn reflector, the latter more commonly called the hog horn antenna

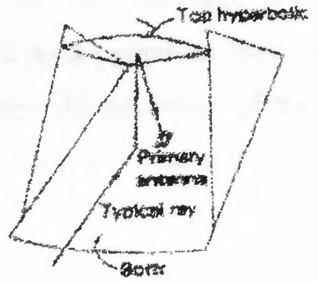


Figure 2.4 Feeding the Cass-horn antenna

In the Cass-horn antenna, radio waves are collected by the large bottom surface shown figure 2, which is slightly (parabolically) curved, and are reflected upward at an angle of 45° Upon hitting the top surface, which is a large hyperbolic cylinder, they are reflected downward to the focal point which, as indicated in figure 2, is situated in the center of the bottom surface.

Once they are collected by the conical horn placed at the focus. In the case of transmission the exact reverse happens. This type of horn reflector antenna has a gain and beam width comparable to those of a paraboloid reflector of the same diameter. Like the Cassegrain feed, after which it is named, it has the geometry to allow the placement of the receiver (or transmitter) at the focus, this time without any obstruction. It is therefore a low-noise antenna and is used in satellite tracking and communications stations. The one shown comes from such a station in Carnarvon (Western Australia).

Figure 2.5 Hog horn antenna (a) perspective view (b) ray paths

The hog horn antenna of Figure 2.5 is another combination of paraboloid and horn. It is a low-noise microwave antenna like the Cass-horn and has similar applications. It consists of a parabolic cylinder joined to a pyramidal horn, with rays emanating from, or being received at, the apex of the horn. An advantage of the hog horn antenna is that the receiving point does not move when the antenna is rotated about its axis.

2.8 Circular Horn Antennas

The conical horn can be directly excited from a circular waveguide. Optimum dimensions can be determined by taking $\delta=0.322\lambda$

The biconical horns of have patterns that are non-directional in the horizontal plane (axis of horns vertical). These horns may be regarded as modified pyramidal horns with a 360° angle in the horizontal plane. The optimum vertical-plane flare angle is about the same as for a sectoral horn of the same cross section excited in the same mode

2.9 Horns and Satellite

A variety of antenna types are used in satellite communications. The most widely used narrow beam antennas are reflector antennas. The shape is generally a paraboloid of revolution. For full earth coverage from a geostationary satellite, a horn antenna is used. Horns are also used as feeds for reflector antennas.

In a direct feed reflector, such as on a satellite or a small earth terminal, the feed horn is located at the focus or may be offset to one side of the focus. Large earth station antennas have a subreflector at the focus. In the Cassegrain design, the subreflector is convex with a results instead hyperboloidal surface, while in the Gregorian design it is concave with an ellipsoidal surface.

The subreflector permits the antenna optics to be located near the base of the antenna. This configuration reduces losses because the length of the waveguide between the transmitter or receiver and the antenna feed is reduced. The system noise temperature is also reduced because the receiver looks at the cold sky instead of the warm earth. In addition, the mechanical stability is improved, resulting in higher pointing accuracy.

Phased array antennas may be used to produce multiple beams or for electronic steering. Phased arrays are found on many nongeostationary satellites, such as the Iridium, Globalstar, and ICO satellites for mobile telephony.

2.10 Phase Center

In navigation, tracking, homing. Landing, and other aircraft and space systems it is usually desirable to assign to the antenna a reference point such that for a given frequency, $\psi (\theta, \Phi)$ is independent of θ and Φ [i.e., $\psi (\theta, \Phi)$ = constant]. The reference point that makes $\Psi (\theta, \Phi)$ independent of θ and Φ is known as the phase center of the antenna. When referenced to the phase center, the fields radiated by the antenna are spherical waves with ideal spherical wave fronts or equiphase surfaces.

For practical antennas such as arrays, reflectors, and others, a single-phase center valid for all values of θ and Φ, does not exist. However, in many antenna systems a reference point can be found such that $\Psi (\theta, \Phi)$= constant over most of the angular space, especially over the main lobe.

The, need for the phase center can best he explained by examining the radiation characteristics of a paraboloidal reflector (parabola of revolution). Plane waves incident on a paraboloidal reflector focus at a single point, which is known as the focal point. Conversely, spherical waves emanating from the focal point are reflected by the paraboloidal surface and form plane waves Thus in the- receiving mode all the energy is collected at a single point In the transmitting mode, ideal plane waves are formed if the radiated waves have spherical wave fronts and emanate from a single point.

In practice, no antenna is a point source with ideal spherical equiphases. However many of there contain a point from which their radiation, over most of the angular space, seems to have spherical wave fronts. When such an antenna is used as a feed for a reflector, its phase center must be placed at the focal point.

The horn is a microwave antenna, which is widely used as a feed for reflectors. To perform as an efficient feed for reflectors, it is imperative that its phase center is known and it is located at the focal point of the reflection Instead of presenting analytical formulations for the phase center of a horn, graphical data will be included to illustrate typical phase centers.

Usually the phase center of a horn is not located at its mouth (throat) or at its aperture but between its imaginary apex point and its aperture. The exact location depends on the dimensions of the horn, especially on its flare angle. For large flare angles, the phase center as closer to the apex. As the flare angle of the horn becomes smaller, the phase center moves toward the aperture of the horn. For small flare angles, the *E*- and H-plane phase centers are identical. Although each specific design has its own phase center. If the *E*- and H-phase centers of a pyramidal horn are not identical, its phase center can be taken to be the average of the two. Phase center nomographs for conical horns are available.

CHAPTER 3

GAIN MEASUREMENT

3.1 Introduction

In our discussion of the antenna gain the concept of an isotropic radiator or isotope is fundamental. Essentially an isotope 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 isotope is measured at all point on an imaginary spherical surface with the isotope 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 nonuniformity 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 dimensions, but perfect omnidirectionality in three-dimensional space can never be achieved, Nevertheless, the concept of such an ideal omnidirectional radiation, an isotope, 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 isotope 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 isotope 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 isotope radiates a total power P 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

$$P_{sotope} = \frac{P_t}{4\pi r^2}(W / m2) \tag{3-1}$$

Since the total P_t , is distributed uniformly over the surface area of the sphere, which is (4π r) (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-isotope. Since the half sphere has a surface area ($2\pi r^2$) square meters, the power density is

$$P_{semi-isotrope} = \frac{p_t}{2\pi r^2}(WIm2) \tag{3-2}$$

$$\frac{P_{semi-isotrope}}{p_{isotrope}} = \frac{(p_t / 2\pi r^2)}{(p_t / 4\pi r^2)} = 2 \tag{3-3}$$

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

In this region, therefore, the semi-isotope 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 gains would be 4, and so on.

3.2. Antenna Gain

The fundamental characteristics of an antenna are its gain and half power beamwidth. According to the reciprocity theorem, the transmitting and receiving patterns of an antenna are identical at a given wavelength The gain is a measure of how much of the input power is concentrated in a particular direction. It is expressed with respect to a hypothetical isotropic antenna, which radiates equally in all directions. Thus in the direction (θ, ϕ), the gain is

$$G(\theta, \phi) = (dP/d\Omega)/(P_{in}/4\pi) \quad (3\text{-}4)$$

Where P_{in} is the total input power and dP is the increment of radiated output power in solid angle $d\Omega$. The gain is maximum along the bore sight direction. The input power is

$$P_{in} = E_a^2 A / \eta Z_0 \quad (3\text{-}5)$$

Where E_a is the average electric field over the area A of the aperture, Z_0 is the impedance of free space, and η is the net antenna efficiency. The output power over solid angle $d\Omega$ is $dP = E^2 r^2 d\Omega / Z_0$, where E is the electric field at distance r. But by the Fraunhofer theory of diffraction, $E = E_a A / r \lambda$ along the bore sight direction, where λ is the wavelength. Thus the important relation gives the bore sight gain in terms of the size of the antenna

$$G = \eta (4\pi / \lambda^2) A \quad (3\text{-}6)$$

This equation determines the required antenna area for the specified gain at a given wavelength.

The net efficiency η is the product of the aperture taper efficiency η_a, which depends on the electric field distribution over the antenna aperture (it is the square of the average divided by the average of the square), and the total radiation efficiency $\eta^* = P/P_{in}$ associated with various losses. These losses include spillover, ohmic heating, phase no uniformity, blockage, surface roughness, and cross polarization. Thus $\eta = \eta_a \eta^*$. For a typical antenna, $\eta = 0.55$.

For a reflector antenna, the area is simply the projected area. Thus for a circular reflector of diameter D, the area is $A = \pi D^2/4$ and the gain is

$$G = \eta (\pi D / \lambda)^2 \quad (3\text{-}7)$$

Which can also be written

$$G = \eta\,(\pi D f / c)^2 \qquad (3\text{-}8)$$

Since $c = \lambda f$, where c is the speed of light (3×10^8 m/s), λ is the wavelength, and f is the frequency. Consequently, the gain increases as the wavelength decreases or the frequency increases.

For example, an antenna with a diameter of 2 m and an efficiency of 0.55 would have a gain of 8685 at the C-band uplink frequency of 6 GHz and wavelength of 0.050 m. The gain expressed in decibels (dB) is 10 log (8685) = 39.4 dB. Thus the power radiated by the antenna is 8685 times more concentrated along the bore sight direction than for an isotropic antenna, which by definition has a gain of 1 (0 dB). At Ku-band, with an uplink frequency of 14 GHz and wavelength 0.021 m, the gain is 49,236 or 46.9 dB. Thus at the higher frequency, the gain is higher for the same size antenna.

The bore sight gain G can be expressed in terms of the antenna beam solid angle Ω_A that contains the total radiated power as $G = \eta^* (4\pi / \Omega_A)$. Which takes into account the antenna losses through the radiation efficiency η^*. The antenna beam solid angle is the solid angle through which all the power would be concentrated if the gain were constant and equal to its maximum value. The directivity does not include radiation losses and is equal to G / η^*.

The half power beamwidth is the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum values. For a reflector antenna it may be expressed

$$\text{HPBW} = \alpha = k\,\lambda / D. \qquad (3\text{-}9)$$

Where k is a factor that depends on the shape of the reflector and the method of illumination. For a typical antenna, $k = 70°$ (1.22 if α is in radians). Thus the half power beamwidth decreases with decreasing wavelength and increasing diameter.

For example, in the case of the 2-meter antenna, the half power beamwidth at 6 GHz is approximately 1.75°. At 14 GHz, the half power beamwidth is approximately 0.75°. As an extreme example, the half power beamwidth of the Deep Space Network 64 meter antenna in Goldstone, California is only 0.04 ° at X-band (8.4 GHz).

The gain may be expressed directly in terms of the half power beamwidth by eliminating the factor D/λ. Thus,

$$G = \eta\,(\pi\, k\, /\, \alpha)\, 2 \qquad (3\text{-}10)$$

Inserting the typical values $\eta = 0.55$ and $k = 70°$, one obtains $G = 27{,}000/\,(\alpha°)\, 2$ Where $\alpha°$ is expressed in degrees. This is a well-known engineering approximation for the gain (expressed as a numeric). It shows directly how the size of the beam automatically determines the gain. Although this relation was derived specifically for a reflector antenna with a circular beam, similar relations can be obtained for other antenna types and beam shapes. The value of the numerator will be somewhat different in each case.

For example, for a satellite antenna with a circular spot beam of diameter 1°, the gain is 27,000 or 44.3 dB. For a Ku-band downlink at 12 GHz, the required antenna diameter determined from either the gain or the half power beamwidth is 1.75 m.

A horn antenna would be used to provide full earth coverage from geostationary orbit, where the angular diameter of the earth is 17.4°. Thus, the required gain is 89.2 or 19.5 dB. Assuming an efficiency of 0.70, the horn diameter for a C-band downlink frequency of 4 GHz would be 27 cm.

For the RF link budget, the two required antenna properties are the equivalent isotropic radiated power (EIRP) and the "figure of merit" G/T. These quantities are the properties of the transmit antenna and receive antenna that appear in the RF link equation and are calculated at the transmit and receive frequencies, respectively.

The equivalent isotropic radiated power (EIRP) is the power radiated equally in all directions that would produce a power flux density equivalent to the power flux density of the actual antenna. The power flux density Φ is defined as the radiated power P per unit area S, or $\Phi = P/S$. But $P = \eta * P_{in}$, where P_{in} is the input power and η * is the radiation efficiency, and $S = d^2\, \Omega_A$, where d is the slant range to the center of coverage and Ω_A is the solid angle containing the total power. Thus with some algebraic manipulation,

$$\Phi = \eta * (4\pi / \Omega_A)(P_{in} / 4\pi d^2) = G P_{in} / 4\pi d^2 \quad (3\text{-}11)$$

Since the surface area of a sphere of radius d is $4\pi d^2$, the flux density in terms of the EIRP is

$$\Phi = \text{EIRP} / 4\pi d^2 \quad (3\text{-}12)$$

Equating these two expressions, one obtains EIRP = $G P_{in}$ Therefore, the equivalent isotropic radiated power is the product of the antenna gain of the transmitter and the power applied to the input terminals of the antenna. The antenna efficiency is absorbed in the definition of gain.

The "figure of merit" is the ratio of the antenna gain of the receiver G and the system temperature T. The system temperature is a measure of the total noise power and includes contributions from the antenna and the receiver. Both the gain and the system temperature must be referenced to the same point in the chain of components in the receiver system. The ratio G/T is important because it is an invariant that is independent of the reference point where it is calculated, even though the gain and the system temperature individually are different at different points.

3.2.1 Antenna Pattern

Since electromagnetic energy propagates in the form of waves, it spreads out through space due to the phenomenon of diffraction. Individual waves combine both constructively and destructively to form a diffraction pattern that manifests itself in the main lobe and side lobes of the antenna.

The antenna pattern is analogous to the "Airy rings" produced by visible light when passing through a circular aperture. Sir George Bid dell Airy, Astronomer Royal of England during the nineteenth century, studied these diffraction patterns to investigate the resolving power of a telescope. The diffraction pattern consists of a central bright spot surrounded by concentric bright rings with decreasing intensity. The central spot is produced by waves that combine constructively and is analogous to the main lobe of the antenna. A dark ring, where waves combine destructively, that is analogous to the first null, borders the spot. The surrounding bright rings are analogous to the side lobes of the antenna pattern. As noted by Hertz, the only difference in this behavior is the size of the pattern and the difference in wavelength.

Within the main lobe of an ax symmetric antenna, the gain $G(\theta)$ in a direction θ with respect to the bore sight direction may be approximated by the expression

$$G(\theta) = G - 12 (\theta / \alpha) 2 \tag{3-13}$$

Where G is the bore sight gain. Here the gains are expressed in dB. Thus at the half power points to either side of the bore sight direction, where $\theta = \alpha / 2$, the gain is reduced by a factor of 2, or 3 dB. The details of the antenna, including its shape and illumination, are contained in the value of the half power beamwidth α. This equation would typically be used to estimate the antenna loss due to a small pointing error.

An envelope can approximate the gain of the side lobes. For new earth station antennas with $D/\lambda > 100$, the side lobes must fall within the envelope $29 - 25 \log \theta$ by international regulation. This envelope is determined by the requirement of minimizing interference between neighboring satellites in the geostationary arc with nominal 2° spacing.

3.2.2 Taper

The gain pattern of a reflector antenna depends on how the antenna is illuminated by the feed. The variation in electric field across the antenna diameter is called the antenna taper.

The total antenna solid angle containing all of the radiated power, including side lobes, is

$$\Omega_A = \eta * (4\pi / G) = (1/\eta_a) (\lambda^2 / A) \tag{3-14}$$

Where η_a is the aperture taper efficiency and η * is the radiation efficiency associated with losses. The beam efficiency is defined as

$$\varepsilon = \Omega_M / \Omega_A \tag{3-15}$$

Where Ω_M is the solid angle for the main lobe. The values of η_a and are ε calculated from the electric field distribution in the aperture plane and the antenna radiation pattern, respectively.

For a theoretically uniform illumination, the electric field is constant and the aperture taper efficiency is 1. If the feed is designed to cause the electric field to decrease with distance from the center, then the aperture taper efficiency decreases but the proportion of power in the main lobe increases. In general, maximum aperture taper efficiency occurs for a uniform distribution, but maximum beam efficiency occurs for a highly tapered distribution.

For uniform illumination, the half power beamwidth is 58.4° λ /D and the first side lobe is 17.6 dB below the peak intensity in the bore sight direction. In this case, the main lobe contains about 84 percent of the total radiated power and the first side lobe contains about 7 percent.

If the electric field amplitude has a simple parabolic distribution, falling to zero at the reflector edge, then the aperture taper efficiency becomes 0.75 but the fraction of power in the main lobe increases to 98 percent. The half power beamwidth is now 72.8° λ /D and the first side lobe is 24.6 dB below peak intensity. Thus, although the aperture taper efficiency is less, more power is contained in the main lobe, as indicated by the larger half power beamwidth and lower side lobe intensity.

If the electric field decreases to a fraction C of its maximum value, called the edge taper, the reflector will not intercept all the radiation from the feed. There will be energy spillover with a corresponding efficiency of approximately $1 - C^2$. However, as the spillover efficiency decreases, the aperture taper efficiency increases. The taper is chosen to maximize the illumination efficiency, defined as the product of aperture taper efficiency and spillover efficiency.

The illumination efficiency reaches a maximum value for an optimum combination of taper and spillover. For a typical antenna, the optimum edge taper C is about 0.316, or – 10 dB (20 log C). With this edge taper and a parabolic illumination, the aperture taper efficiency is 0.92, the spillover efficiency is 0.90, the half power beamwidth is 65.3° λ /D, and the first side lobe is 22.3 dB below peak. Thus the overall illumination efficiency is 0.83 instead of 0.75. The beam efficiency is about 95 percent.

3.2.3 Coverage Area

The gain of a satellite antenna is designed to provide a specified area of coverage on the earth. The area of coverage within the half power beamwidth is

$$S = d^2 \Omega \qquad (3\text{-}16)$$

Where d is the slant range to the center of the footprint and Ω is the solid angle of a cone that intercepts the half power points, which may be expressed in terms of the angular dimensions of the antenna beam. Thus it is $= K \alpha \beta$.

Where α and β are the principal plane half power beam widths in radians and K is a factor that depends on the shape of the coverage area. For a square or rectangular area of coverage, $K = 1$, while for a circular or elliptical area of coverage, $K = \pi /4$.

The relation may approximate the bore sight gain in terms of this solid angle

$$G = \eta'(4\pi / \Omega) = (\eta' / K)(41{,}253 / \alpha^{\circ} \beta^{\circ}) \qquad (3\text{-}17)$$

Where α° and β° are in degrees and η' is an efficiency factor that depends on the half power beamwidth. Although η' is conceptually distinct from the net efficiency η, in practice these two efficiencies are roughly equal for a typical antenna taper. In particular, for a circular beam this equation is equivalent to the earlier expression in terms of α if

$$\eta' = (\pi k / 4)^2 \eta. \qquad (3.18)$$

If the area of the footprint S is specified, then the size of a satellite antenna increases in proportion to the altitude. For example, the altitude of Low Earth Orbit is about 1000 km and the altitude of Medium Earth Orbit is about 10,000 km. Thus to cover the same area on the earth, the antenna diameter of a MEO satellite must be about 10 times that of a LEO satellite and the gain must be 100 times, or 20 dB, as great.

On the Iridium satellite there are three main mission L-band phased array antennas. Each antenna has 106 elements, distributed into 8 rows with element separations of 11.5 cm and row separations of 9.4 cm over an antenna area of 188 cm × 86 cm. The pattern produced by each antenna is divided into 16 cells by a two-dimensional Butler matrix power divider, resulting in a total of 48 cells over the satellite coverage area. The maximum gain for a cell at the perimeter of the coverage area is 24.3 dB.

From geostationary orbit the antenna size for a small spot beam can be considerable. For example, the spacecraft for the Asia Cellular Satellite System (ACeS), being built by Lockheed Martin for mobile telephony in Southeast Asia, has two unfurl able mesh antenna reflectors at L-band that are 12 meters across and have an offset feed. Having different transmit and receive antennas minimizes passive intermediation (PIM) interference that in the past has been a serious problem for high power L-band satellites using a single reflector. The antenna separation attenuates the PIM products by from 50 to 70 dB.

3.2.4 Shaped Beams

Often the area of coverage has an irregular shape, such as one defined by a country or continent. Until recently, the usual practice has been to create the desired coverage pattern by means of a beam-forming network. Each beam has its own feed and illuminates the full reflector area. The superposition of all the individual circular beams produces the specified shaped beam.

For example, the C-band transmit hemi/zone antenna on the Intelsat 6 satellite is 3.2 meters in diameter. This is the largest diameter solid circular aperture that fits within an Arian 4 launch vehicle fairing envelope. The antenna is illuminated by an array of 146 Potter horns. The beam diameter α for each feed is 1.6° at 3.7 GHz. By appropriately exciting the beam-forming network, the specified areas of coverage are illuminated. For 27 dB spatial isolation between zones reusing the same spectrum, the minimum spacing σ is given by the rule of thumb $\sigma \geq 1.4\ \alpha$, so that $\sigma \geq 2.2°$. This meets the specification of $\sigma = 2.5°$ for Intelsat 6.

Another example is provided by the HS-376 dual-spin stabilized Galaxy 5 satellite, operated by PanAmSat. The reflector diameter is 1.80 m. There are two linear polarizations, horizontal and vertical. In a given polarization, four beams might cover the contiguous United States (CONUS), each with a half power beamwidth of 3° at the

C-band downlink frequency of 4 GHz. From geostationary orbit, the angular dimensions of CONUS are approximately $6° \times 3°$. For this rectangular beam pattern, the maximum gain is about 31 dB. At edge of coverage, the gain is 3 dB less. With a TWTA output power of 16 W (12 dBW), a waveguide loss of 1.5 dB, and an assumed beam-forming network loss of 1 dB, the maximum EIRP is 40.5 dBW.

The shaped reflector represents a new technology. Instead of illuminating a conventional parabolic reflector with multiple feeds in a beam-forming network, there is a single feed that illuminates a reflector with an undulating shape that provides the required region of coverage. The advantages are lower spillover loss, a significant reduction in mass, lower signal losses, and lower cost. By using large antenna diameters, the roll off along the perimeter of the coverage area can be made sharp. The practical application of shaped reflector technology has been made possible by the development of composite materials with extremely low coefficients of thermal distortion and by the availability of sophisticated computer software programs necessary to analyze the antenna. One widely used antenna software package is called GRASP, produced by TICRA of Copenhagen, Denmark. This program calculates the gain from first principles using the theory of physical optics.

The intended area of coverage determines the gain of an antenna. The gain at a given wavelength is achieved by appropriately choosing the size of the antenna. The gain may also be expressed in terms of the half power beamwidth. Reflector antennas are generally used to produce narrow beams for geostationary satellites and earth stations. The efficiency of the antenna is optimized by the method of illumination and choice of edge taper. Phased array antennas are used on many LEO and MEO satellites. New technologies include large, unfurl able antennas for producing small spot beams from geostationary orbit and shaped reflectors for creating a shaped beam with only a single feed.

3.3 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 isotope radiating the same total power.

The directive gain of a semi-strobe 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 isotope 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

$$D = \frac{P_{antenna}}{P_{isotrope}} \tag{3-19}$$

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

$$D = \frac{4\pi r^2 E^2}{377 p_t} = \frac{4\pi r^2 p_{antenna}}{p_t} \tag{3-20}$$

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

$$G = \xi D \tag{3-21}$$

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

$$D_{Max} \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}[E(\theta,\phi)/E_{Max}]^2 \sin\theta d\theta d\phi} \tag{3-22}$$

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

$$D_{(\theta 1,\phi 1)} = D_{Max}[\frac{E(\theta_1,\phi_1)}{E_{Max}}]^2 \qquad (3\text{-}23)$$

3.4 Gains 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 IogG. The directive gain in decibels is calculated from the same formula, with D substituted for G.

3.5 Measurement Gain

One method of measuring gain is by comparing the antenna under test against a known standard antenna. This is technically known as a gain transfer technique. At lower frequencies, it is convenient to use a 1/2-wave dipole as the standard. At higher frequencies, it is common to use a calibrated gain horn as a gain standard, with gain typically expressed in dBi.

Another method for measuring gain is the 3-antenna method. Transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance. The Fries transmission formula is used to develop three equations and three unknowns. The equations are solved to find the gain expressed in dB of all three antennas. Radiall/Larsen uses both methods for measurement of gain. The method is selected based on antenna type, frequency, and customer requirement. Use the following conversion factor to convert between dBd and dBi: 0 dBd = 2.15 dBi.

3.6 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 increasing the power gain of the transmitting antenna, without increasing the transmitting power, can increase the signal available to a receiving antenna at that location. 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.

3.7 Antenna Measurements

Measurements on antennas are difficult. Monitoring the reflection coefficient with a network analyser over a band of frequencies best sees the behaviour of an antenna, and for convenience a frequency about 1 GHz is appropriate. At 1 GHz a wavelength is 30 cm; the antenna is a reasonable size and it is possible to investigate the effects of adjacent objects, and different feed lengths, without too much difficult physical manipulation. The results may safely be transferred to other frequency bands by thought and analogy. When this is done, one rapidly appreciates that an antenna cannot be considered as a closed, isolated component having well-defined properties. Its environment and physical mounting grossly affect nearly every electronic measurement on an antenna. One might well ask the question, "What is an antenna?" or equivalently, "Where do the antenna stop and the outside world begin?" A sensible answer to this question is to consider all objects inside the near field as contributing to the radiation.

A helpful example is a Yagi-Uda antenna. We might regard this as a simple dipole with lots of resonant rods placed in the near field. But if we just consider the properties of the driven "antenna", namely the driven dipole, we know we will be grossly in error in assessing the performance of the installation. So why should we stop considering the effects of metallic structures at the end of the boom? We should add in the scattering from the mast, guys, feed (outer coaxial shields can carry induced current) and even dielectric objects (like the chimney stack or adjacent building) in the near field.

Many people now have access to software, which accurately simulates antenna behavior. To do this it is necessary to construct a model. The process of "modeling" is critical to this enterprise as the simulation has limitations of accuracy depending on the kind of model chosen. In itself, the software is essentially accurate and useful. However, the results it returns, for simulation of real antennas, depends critically on what is built into the model. It is not usually possible, in the NEC2 and miniNEC and NEC4 software, to add in all the local effects, which will affect the results. This is not just because it is too difficult; there are difficulties in principle, knowing the correct dielectric and conductivity parameters to put in for a real-world installation. Details of the feed arrangement are also difficult to get right. So it is often difficult to know if the results from the simulation of the model represent the real behavior of the antenna it was intended to investigate. The process of running the software always returns a result, and the internal checks on validity, while possible, are subtle. Belief in the results often dissolves into a matter of opinion or faith. This can be the subject of strongly held views, which can only be resolved by recourse to measurements.

Thus, simulation should be regarded (taking the most cautious view) as merely a rough guide to an antenna's behavior in a real installation. Any modeling process needs careful validation by measurements. One is then presented with the choice of which to believe, if there is disagreement. I have seen people worry about 1/10 dB in gain in a simulation. This is probably unsound, and one wonders how many hundreds of hour's people spend (no doubt happily) in this kind of activity.

3.8 Arrays of antenna elements

If we want to increase the gain of a dipole antenna we can add another dipole antenna alongside it. This is the simplest form of array antenna. Why is the gain increased, and what is the bore sight gain of this "two element array"?

First, we assume the antennas are fed in phase with each other and spaced lambda/2 apart. Considering the radiation in a direction, which is normal to the plane containing the dipoles, the contribution from each element arrives in phase with the other. The field strength in this direction is double that for one element, so the radiated power density, which is the square of the field strength, is four times that for one element. However, the two elements together are fed with twice the power of a single element. The increase in gain is therefore a factor 4/2 = 2.

This calculation scales with the number of elements. If we use a 10 by 10 array, the bore sight power gain is increased by a factor of 100, which is the number of elements. The field strength is 100 times more along bore sight than for a single element, so the power density is 10,000 times greater. But 100 times the power is being fed to the array compared with a single element, so the gain increase is a factor of 100 as stated. This gain increase is over and above any bore sight gain of the individual elements. If we start off with an array of 100 horn feeds at 10GHz, of size 14 cm by 14 cm each, their intrinsic gain is about 20dB and the array factor gives an additional power gain of 100 which is 20dB so the combined structure has a foresight gain of 40dB or so.

Now consider, are we "getting something for nothing" or does this increased gain along the bore sight come at the expense of gain elsewhere in the radiation pattern? The answer is clearly that the array concentrates the total radiated power along certain directions at the expense of others. If we go back to our 2 element dipole array, spaced lambda/2, there can be no radiation along a line joining the centers of the two dipoles as their contributions are in anti-phase in this direction, there being a lambda/2 path difference to get from one to the other.

In general then, the element pattern times the array pattern equals the total radiation pattern of the arrangement. What is the array pattern? It is the pattern you would observe for a set of isotropic radiators spaced as the array elements are actually spaced, and fed with the same amplitudes and phases of signals that the actual array elements receive.

2.9 Antenna calculations

Given a geometrical current distribution on the antenna structure, it is relatively straightforward to calculate the radiation integrals to determine the radiation patterns. Often this has to be done numerically. The difficulty with most antenna theory lies in determining the current distributions on the antenna conductors, given an arrangement of feeds, and the terminal voltages at the antenna ends of the feeds.

The Hertzian dipole is artificial in that it assumes there is a uniform current density along the arms of the dipole. There is thus an unphysical current discontinuity at the ends of the arms, which cannot be realized in practice. However, given a uniform current distribution, the properties of the antenna are reasonably straightforward to calculate. That is why this unphysical situation is so often presented in textbooks.

An equivalent problem pertains in simple loop antennas. Here it is often assumed that the current is constant around the loop. That is only a reasonable assumption if the loop perimeter is short compared to a wavelength. There is capacitance between the opposite sides of the loop, which can carry displacement current, which results from a build up of charge due to the voltage drop around the loop, which has inductive impedance. One can easily see that although there is only a single continuous conductor, the current does not have to be the same everywhere around the loop, as some of it goes to charge the stray capacitance.

Normally, self-consistent calculations are used to calculate together the current distributions and the radiated fields. The "method of moments" is popular. In this method the antenna structure is spilt up into a number of regions, on each of which the current distribution is assumed uniform. The integral equations for the antenna then reduce to solving (what may be a quite large) matrix equation. This is well adapted to computer solution. There are issues of accuracy, and sensitivity to the model framework assumed. This method is also used to work out radar cross sections of complicated objects such as helicopters and aircraft.

In a reflector-aperture antenna fed from the front by a sub-reflector and/or a feed, the far field radiation pattern can be calculated from the Fourier Transform of the field distribution across the aperture, accounting as well for phase variations across the illuminated area. The side lobe behavior of a reflector antenna is particularly well suited to this calculation method. A process known as "Apodisation" (after "a pod" = "without foot") tapers the amplitude ("amplitude taper") illumination across a dish reflector antenna so that there are no sudden changes of excitation amplitude, especially at the edges of the reflector. We recall from Fourier Transform theory that sudden changes in a function give rise to the presence of high frequencies in the Fourier Transform. In this particular case the sudden change in spatial illumination gives rise to high spatial frequencies in the transform, which directs the energy well away from bore sight as the "spatial frequency" translates into the deviation of the propagation direction from bore sight.

There is a good discussion of the side lobe suppression process by using apodisation techniques in volume 1 of the book "The Handbook of Antenna Design", publishers Peter Peregrines, 1982, on behalf of the British IEE, editors A W Rudge, K Milne, A D Olver and P Knight, ISBN 0-906048-82-6, table 1-3 page 43. As always there is a trade-off, in this case the beam width of the main beam is increased by some tens of percent depending on the illumination profile, for the benefit of reducing the side lobe levels. For reference purposes, this table 1-3 is reproduced here with minor modifications.

NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronics Engineering

HORN ANTENNAS

Graduation Project
EE 400

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ABSTRACT

Antenna is one of the most common and important parts in the communication system. The antenna is one that will radiate all the power delivered to it by a transmitter in the desired direction and directions with the desired polarization.

The antenna parameters are defined which are useful to achieve this purpose. We demonstrated the basic principle of the antenna parameters although the basic principle and theory remain unchanged. The objective in this analysis of the horn antenna is to demonstrate the theory and investigate some applications to this subject.

Global earth coverage from a geostationary satellite is often required for telemetry and command signals as well as conventional communications traffic. With an increasing number of satellites orbiting the earth, minimizing interference with other satellites is becoming more important than in the past. To achieve this, the amount of sidelobe energy should be as low as possible, both for co- and cross-polarized signals. An ideal full-earth coverage antenna should have a circularly symmetric pattern and, therefore, most global-earth coverage antennas are either circular reflectors or horns. While the beam of a reflector antenna can be shaped to provide the desired earth coverage, a disadvantage of reflectors is that the feed spillover can be significant, thereby increasing the sidelobe energy. Horn antennas, on the other hand have well-controlled sidelobes. Some horns used successfully for global-earth coverage include the smooth-wall conical, multi-mode conical and corrugated-wall types...etc.

TABLE OF CONTENTS

INTRODUCTION

The term antenna is defined by the dictionary as a usually metallic device for radiating or receiving radio waves. The official definition of the Institute of Electrical and Electronics Engineers (IEEE) 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 or 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.

So in this project I will tray to do work in type of antenna called horn antenna, it is one of the simplest and probably the most widely used in the microwave antenna. It is existence and early use dates back to the late 1800s. Although neglected somewhat in the early 1900s,it is revival began in the late 1930s from the interest in the microwaves and waveguide transmission lines during the period of Word War II.since that time a number of articles have been describing its radiation mechanism, optimization design methods, and applications.

The project is going to be consisting of four chapters and conclusion, in the first chapter I will present the primary concerned with definitions and related terminology.

Then in the second chapter I will discuss the horn antenna with its various types without forgetting to overview the behavior and manner of these types.

In the other hand I will not forget in the third chapter to study the horn antenna gain measurement with considering antenna pattern, taper, coverage area, shaped beams and the other impedance, pattern measurement.

Finally in the fourth chapter I will show and explain the applications of the horn antenna in the different field like feed element for large radio astronomy, satellite tracking, communication dishes found installed throughout the word ... etc.

At the end I will conclude my project by what I have learned from the previous chapter.

CHAPTER 1

FUNDAMENTALS OF ANTENNA

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 micro miniature 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:

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, fox- 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 Lines

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 30 MHz), 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 1 GHz), 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 used; with some use of mall-diameter coaxial lines in low-power no critical 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 ultra light 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 unplanted 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 500 KHz. 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

1.2 Antenna Parameters

The most fundamental properties of antennas are the following:

1.2.1 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 θ (r, θ, Φ) are 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 Interrelationship of space variables (x, y, z) and (r, θ , Φ)

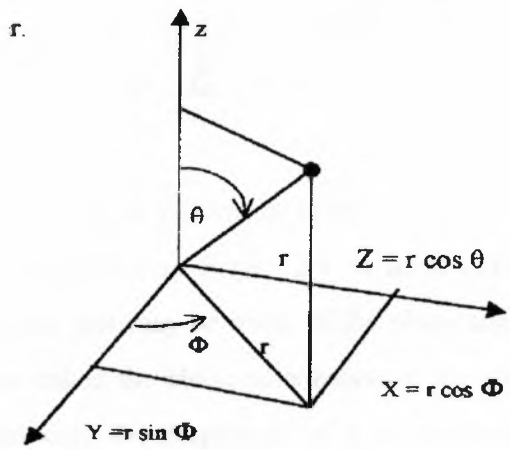


Figure 1-1 illustrates the relationship between the Cartesian and spherical coordinates.

The projection of this distance r onto the x-y plane is designated θ, Φ, this means that changing r courses changing on θ,

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 (θ, ϕ) 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

$$E = \eta o H \tag{1-1}$$

(Of course, they are at right angles to each other and their phase angles are equal) where $\eta o = 377\Omega$ 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 $(\theta,\ \phi)$ known, the relation being

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

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 F 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.

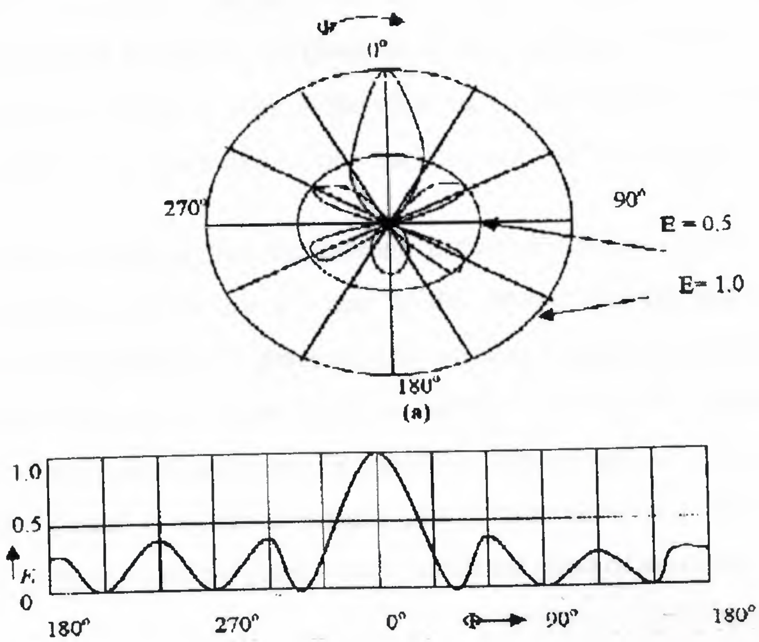


Figure 1-2 Comparison of plane pattern plotted in polar and rectangular form. The same pattern is represented in both cases and the coordinates are the same. Only the plot is different (a) polar (b) rectangular plot.

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 planed 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).

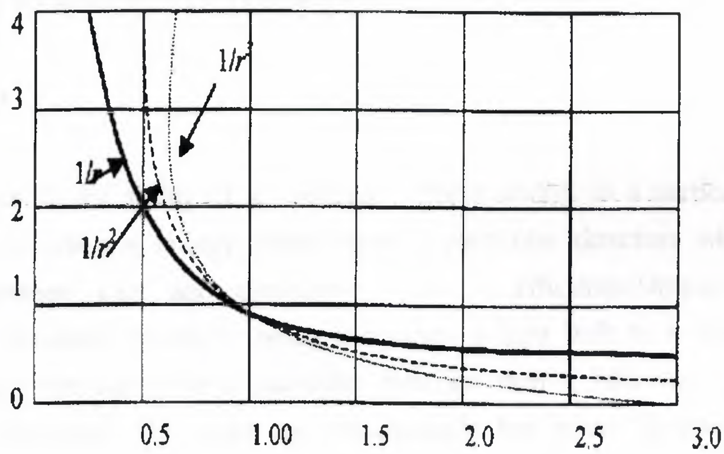
It is also fairly common to express the relative field strength or power density in decibels. This coordinate of the pattern is given as 20 log (E/E_{max}) or 10 log (P / P_{max}). The value at the maximum of the pattern is therefore zero decibels, and at other angles the decibel values are negative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

1.2.2 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, and $1/r^2$, $1/r^3$. The behavior of such terms, as r in creases, 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 become much larger than the $1/r$ term dominates the far-field region, as seen in Figure1-3.



Figurel-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

1.2.3 Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting or to receive energy better from a particular direction when receiving. The relationship between gain and directivity: *Gain* = efficiency/Directivity. We see the phenomena of increased directivity when comparing a light bulb to a spotlight. A 100-watt spotlight will provide lighter in a particular direction than a 100-watt light bulb, and less light in other directions. We could say the spotlight has more "directivity" than the light bulb. The spotlight is comparable to an antenna with increased directivity. An antenna with increased directivity is hopefully implemented efficiently, is low loss, and therefore exhibits both increased directivity and gain.

1.2.4 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 Ar (or the capture area) is then defined as the ratio between the delivered power Pr watts into the load power density P_i watts per unit area

$$A_r = \frac{p_r}{p_i} \tag{1-4}$$

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 isotropic A_{ro} is given as

$$A_{ro} = \frac{\lambda^2}{4\pi} \Rightarrow A_r \frac{G\lambda^2}{4\pi} \qquad (1\text{-}5)$$

Where G = $\xi D, \lambda$ is the wavelength, note that λ has relationship with the size, then Ar, G and the size. Equation 1-12 may be proved theoretically and verified experimentally. From this relationship it follows that

$$D = [\frac{4\pi A_r}{\xi \lambda^2}] \qquad (1\text{-}6)$$

Where D is the directive gain.

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

$$p_r = \xi[\frac{p_i D \lambda^2}{4\pi}] \qquad (1\text{-}7)$$

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.1-15. In general, it is possible to measure the gain from the receiving cross signal, as we will see later.

1.2.5 Beam width

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 Bandwidth Definition

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 1-4 illustrates the procedure of determining the -3dB Beamwidth on a rectangular pattern plot.

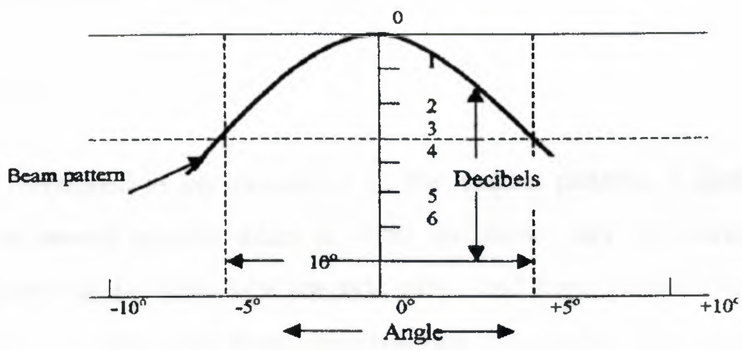


Figure 1-4 Determination of half-power (3dB-down) Beamwidth.

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 Beamwidtb

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 settable; 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 main beam 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 main beam 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.

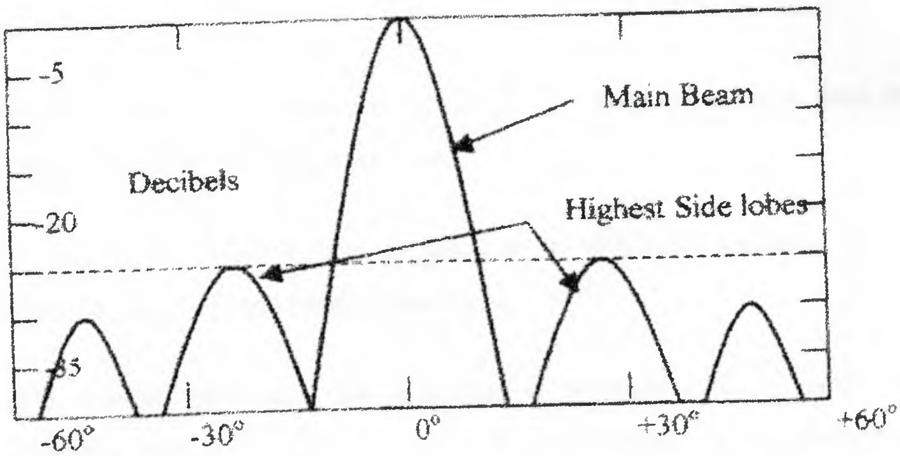


Figure 1-5 Decibel pattern plot, indicated side lobe level

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

$$R_r = \frac{p}{i^2} \qquad (1\text{-}8)$$

When P is given in watts and *I* in amperes, R_i 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. 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. That 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_0, is $Rr = 2P1I^2$, note that

$$I_0 = \sqrt{2}I_{rms} \qquad (1.9)$$

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 comic 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 = $(R_0 \pm$ $Rr)$ whereas the radiation power is I^2Rr. Hence the antenna radiation efficiency ξ_r ***is*** given by

$$\xi_r = \frac{R_r}{R_0 + p_r} \qquad (1\text{-}10)$$

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.1-4, and R_0 is correspondingly equal to p_0 / I^2 Making these substitutions into Eq. 1-5, then it gives the more basic definition of the efficiency:

$$\xi_r = \frac{p_r}{p_0 + p_r} \qquad (1\text{-}11)$$

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

$$Z = \frac{E_i}{I_i} \qquad (1\text{-}12)$$

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

$$Z_i = R_i = R_r \qquad (1\text{-}13)$$

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 input impedance can be defined at the point of connection of the waveguide to the antenna, just as waveguides have 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 $4MH_z$ 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 $155\ MH_z$ to a maximum frequency of 205 MH_z, its bandwidth would be $10MH_z$. 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.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} P_n(\theta,\phi) d\Omega \qquad (1\text{-}13)$$

1.2.10 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 successftilly 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 I GHz) 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 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 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.

1.2.11 Effective area

The effective area multiplied by the wave incident power density in watts per square meter gives the total power delivered to the antenna's feeder. This is for a receive antenna. The effective area A of an antenna is related to the boresight gain G and the free space wavelength lambda of the radiation by the formula G = (4 pi A)/(lambda^2). This is a most important formula.

A half-wave dipole has effective area of 0.13 lambda^2, which is roughly an area lambda/2 by lambda/4. The directivity of a half wave dipole, in the azimuth direction or H-plane, is about 1.67 or about 2.23 dB. Within elevation angles of size about 32.6 degrees

the dipole has higher directivity than an isotropic source; outside this range it has lower directivity.

Considering an antenna as a transmitter, if it is fed with power P (accepted power) then the power density on boresight is G P/(4 pi R^2) at distance R. Here, G is a straight number calculated from the directivity and the efficiency. It is also possible to give the gain G in decibels; remember G is a power gain so in dB a gain G of 10 is 10dB, a gain of 100 is 20dB, a gain of 1000 is 30dB and so on.

If we transmit between two antennas each of gain G, spaced by a distance R, the field strength at the second due to the first is G P/(4 pi R^2) watts per square meter, and the effective area of the second is A=G*(lambda^2)/(4 pi) so the total power transferred from transmitter to receiver is the product of these factors. The received power is therefore P*(G lambda)^2/(4 pi R)^2. This can be factorized into three parts as follows; the gain of the transmitting antenna times the gain of the receiving antenna times a "divergence factor" because not all of the power transmitted is picked up by the receiver. This latter factor is [lambda/(4 pi R)]^2 and the reciprocal of this, namely [(4 pi R)/lambda]^2 is often referred to as the "free space loss". We note that it is not really a "loss" as free space itself is a loss less propagating medium. These antenna transmission formulae only apply in the far field region, so we need to know when we are in the far field.

1.2.12 Reciprocity

ALL the above properties of an antenna are identical whether it is used in transmit or receive mode. There is only one exception to this rule called "reciprocity", and that is when the antenna contains magnetically biased magnetic materials such as ferrites with resonantly rotating electron spin systems.

The physical reason for reciprocity is that the only difference between outgoing and incoming waves lies in the arrow of time. Since the electromagnetic equations are invariant except for the signs of magnetic fields and currents, under time reversal, there can be no difference between transmit and receive mode in the physical current and field distributions. However, if we have a magnet providing a steady bias field, under time-

reversed conditions we would have to reverse the direction of this bias field. But for incoming and outgoing waves, the bias field direction remains the same. Thus it is possible for the system to be non-reciprocal.

1.2.13 Very Long Baseline Interferometer (VLBI)

If we use two aperture antennas, spaced by a great many wavelengths, as an interferometer, the fringe spacing will be of the order of the angle subtended by an object of diameter one wavelength at a distance equal to the separation of the aperture antennas. For example, at 10GHz the free space wavelength is 3cm or 0.03m, so if we separate the antennas by 3000km or 1E8 wavelengths, we can resolve radio sources about 1E-8 radians across, or about 2 milliseconds of arc. By comparison, the beam width of one of the aperture antennas will be of the order of the angle subtended by a wavelength of radiation at a distance equal to the diameter of the reflector. Thus, if we considered a system where there were two 30 meter diameter antennas separated by 3000km, there would be (3E6)/30 = 100,000 interference fringes within the main beam of one of the apertures. Of course, the sensitivity of the interferometer is still governed by the total capture area of the two dishes; but the resolution is now comparable with that of a dish of diameter 3000km.

1.2.14 VSWR and Reflected Power

The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. VSWR is often abbreviated as SWR. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna. VSWR and reflected power are different ways of measuring and expressing the same thing. A VSWR of 2.0:1 or less is considered good. Most commercial antennas, however, are specified to be 1.5:1 or less over some bandwidth. Based on a 100-watt radio, a 1.5:1 VSWR equates to a forward power of 96 watts and a reflected power of 4 watts, or the reflected power is 4.2% of the forward power.

1.2.15 Antenna Placement

Correct antenna placement is critical to the performance of an antenna. An antenna mounted on the roof will function better than the same antenna installed on the hood or trunk of a car. Knowledge of the vehicle may also be an important factor in determining what type of antenna to use. You do not want to install a glass mount antenna on the rear window of a vehicle in which metal has been used to tint the glass. The metal tinting will work as a shield and not allow signals to pass through the glass.

1.2.16 Directional Antennas

Directional antennas focus energy in a particular direction. Directional antennas are used in some base station applications where coverage over a sector by separate antennas is desired. Point to point links also benefit from directional antennas. Yagi and panel antennas are directional antennas.

1.2.17Omnidirectional Antennas

For mobile, portable, and some base station applications the type of antenna needed has an omnidirectional radiation pattern. The omnidirectional antenna radiates and receives equally well in all horizontal directions. Narrowing the beamwidth in the vertical or elevation plane can increase the gain of an omnidirectional antenna. The net effect is to focus the antenna's energy toward the horizon.

Selecting the right antenna gain for the application is the subject of much analysis and investigation. Gain is achieved at the expense of beamwidth: higher-gain antennas feature narrow beamwidths while the opposite is also true. Omnidirectional antennas with different gains are used to improve reception and transmission in certain types of terrain. A 0 dBd gain antenna radiates more energy higher in the vertical plane to reach radio communication sites that are located in higher places. Therefore they are more useful in mountainous and metropolitan areas with tall buildings. A 3-dBd-gain antenna is the compromise in suburban and general settings. A 5-dBd-gain antenna radiates more energy toward the horizon compared to the 0 and 3 dBd antennas to reach radio communication sites that are further apart and less obstructed. Therefore they are best used in deserts, plains, flatlands, and open farm areas.

CHAPTER 2

HORN ANTENNA

2.1 Horns

One of the simplest and probably the most widely used microwave antenna is the horn. Its existence and early use dates back to the late 1800s. Although neglected somewhat in the early I 900s, its revival began in the late 1930s from the interest in microwaves and waveguide transmission lines during the period of World War II. Since that time a number of articles have been written describing its radiation mechanism, optimization design methods, and applications.

The horn is widely used as a feed element for large radio astronomy satellite tracking, and communication dishes found installed throughout the word In addition to its utility as a feed for reflectors and lenses, it is a common element of phased arrays and serves as a universal standard for calibration and gain measurements of other high-gain antennas. Its widespread applicability slams from its simplicity in construction, case of excitation, versatility, large gain, and preferred overall performance.

An electromagnetic horn can take many different forms, four of which are shown in Figure 2.1, The born is nothing more than a hollow pipe of different cross sections which has been tapered to a larger opening. The type, direction, and amount of taper can have a profound effect on the overall performance of the element as a radiator.

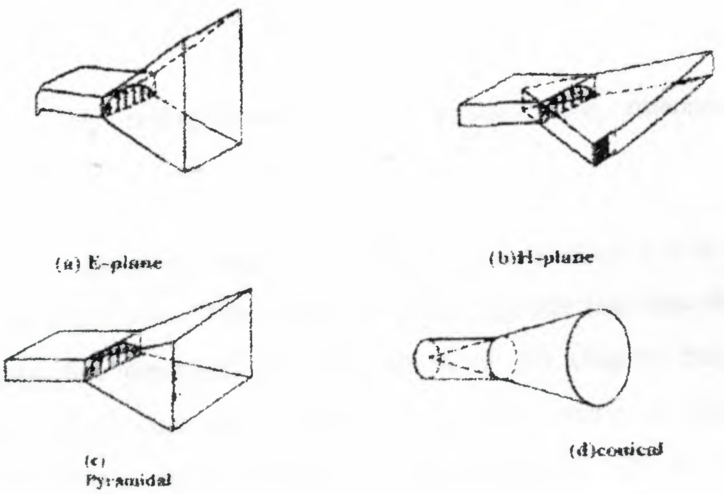


Figure 2.1 Typical Electromagnetic Horn Antennas

Radio wave can be radiated directly from the end of the waveguide in the same way as from the end of an open transmission line. The end of the waveguide represents an abrupt transition from the characteristic impedance of the wave-guide into that of free space, and the radiation resulting is neither efficient nor very directive. This state of affairs can be improved considerably by flaring out the end of the wave-guide to form a horn like structure. A gradual transition can thus take place as the wave passes from the mouth of the horn. Narrow mouthed horns with long flare section produce sharper beams than shallow, wide mouthed ones. Also, the wider mouthed horns tend to produce a wave front with a distinct curvature, which is undesirable. The ideal would be for the waves to leave the horn with a completely planar wave front, and to accomplish this a focusing mechanism, such as a curve reflector or a lens, may be used with the horn.

Three types of horns are shown in figure 2.1. The first is sect oral horn, which is flared in only one plane (fig.2. 1a &2. 1b). It has the top and bottom walls at an O° flare angle. The sidewalls are sometimes hinged to provide adjustable flare angle to Maximum radiations occurs for angles between 40° and 60° the second is the pyramidal horn, which is flared in both planes (fig.2. 1 c). Both of these are used with rectangular wave-guides. The third type is conical and is used with a circular wave-guide to produce a circularly polarized beam (fig.2.1d). Horn type antennas do not provide very high directivity but are of simple,

rugged construction. This makes them ideal as primary feed antennas for parabolic reflectors and lenses

A wave-guide is capable or radiating energy into open space if it is suitably excited at one end and open at the other. This radiation is much greater than that obtained from the two-wire transmission line described at the beginning of this chapter, but it suffers from similar difficulties, Only a small proportion of the forward energy in the wave guide is radiated, and much of it is reflected back by the open circuit. As with the transmission line, the open circuit is a discontinuity, which matches the wave-guide very poorly to space. Detraction around the edges will give the radiation a poor, nondirective pattern. To overcome these difficulties, the mouth of the wave-guide may be opened out, as was done to the transmission line, but this time an electromagnetic horn results instate of the dipole.

2.2 Basic Horns

When a wave-guide is terminated by a horn, such as any of those show in Figural, the abrupt discontinuity that existed is replaced by a gradual transformation. Provided that impedance matching is correct, the entire energy-traveling forward in the wave-guide will now be radiated. Directivity will also be improved, and diffraction reduced. There are several possible horn configurations; some of the most common are shown below. If flare angle **Φ** of Figure la & lb is too small, resulting in a shallow horn, the wave front leaving the horn will be spherical rather than plane, and the radiated beam will not be directive. The same applies to the two flare angles of the pyramidal horn. If the Φ is too small, so will be the mouth area of the horn, and directivity will once again suffer (not to mention that diffraction is now more likely). It is therefore apparent that the flare angle has an optimum value and is closely related to the length L of Figure 1a & 1b, as measured in wavelengths.

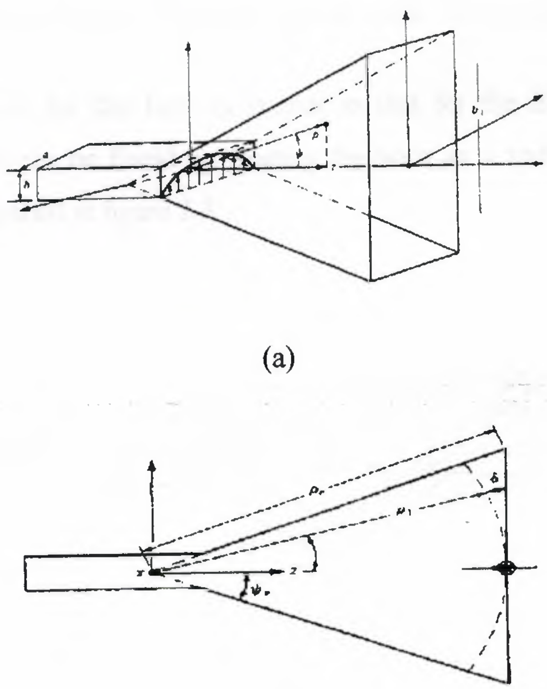
In practice, **Φ** varies from 40° when L/λ =6, at which the beam width in the plane of the horn in 66° and the maximum directive gain is 4, to 15 when L/λ, for which beam width is 23°and gain is 12. The use of a pyramidal or conical horn will improve overall directivity because flare is now in more than one direction. In connection with parabolic reflectors, this is not always necessary. The horn antenna is not nearly as directive as an antenna with a parabolic reflector, but it does have quite good directivity, an adequate bandwidth (in the vicinity of 10 percent) and simple mechanical construction. It is a very convenient antenna to use with a wave-guide. Simple horns such as the ones shown (or with exponential instead of straight sides) are often employed, sometimes by themselves and sometimes as primary radiators for parabolic reflectors.

Some conditions dictate the use of a short, shallow horn, in which case the wave front leaving it is curved, not plane as so far considered. When this is unavoidable, a *dielectric lens* may be employed to correct the curvature.

2.3 Sectoral Oral Horn

2.3.1 E-plane Sectoral Horn

Is one of whose opening is flared in the direction of the E-filed, and it is shown in figure 2.2 below:



(a)

(b)

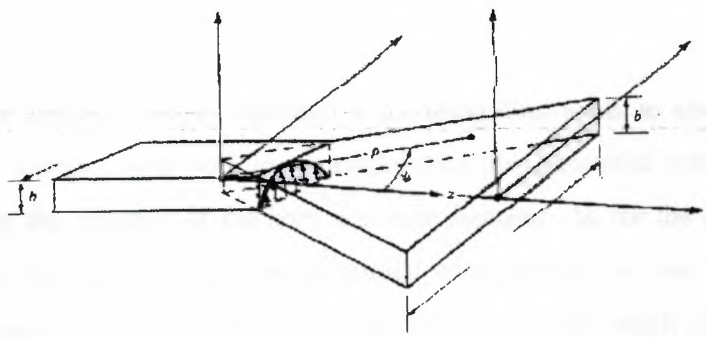
Figure 2.2 (a, b) E-plane sectoral horns

The horn can be treated as an aperture antenna. The fields at the aperture of the horn can be found by treating the horn as a radial wave-guide. The field within the horn can expressed in terms of cylindrical TE and TM wave functions, which include Hankel functions. This method finds the fields not only at the aperture of the horn but also within the horn. To find the field radiated by the horn, only the tangential components of the E- and /or H-fields over a closed surface must by known. The closed surface is chosen to coincide with an infinite plane passing through the mouth of the horn. The directivity is one of the parameters that are often used as a figure-of –merit to describe the performance of an antenna. To find the directivity the maximum radiation is formed.

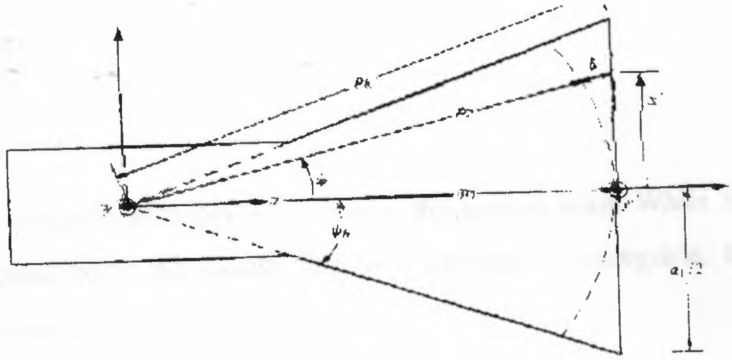
2.3.2 H- plan sectoral horn

Flaring the dimensions of a rectangular wave-guide in the direction of the H-field while keeping the other constant forms an H-plane sectoral horn shown in figure.

The analysis procedure for this horn is similar to that for the E-plane horn. The field at the aperture of the horn can be found by treating the horn as a radial waveguide forming an imaginary apex shown dashed in figure 2.3



(a)



(b)

Figure2.3 H-plane sectoral horn

The fields radiated by the horn can be found by first formulating the equivalent current densities. To the directivity of the H-plan sectoral horn, a procedure similar to that for E-plan is used. As for the E-plan sectoral horn the maximum radiation I directed nearly along the z-axis (θ =0).

2.4 Pyramidal Horn

The most widely used horn is the one, which is flared in both directions, It is widely referred to as pyramidal horn, and it is radiation characteristic are essentially a combination of E-plan and H-plan sectoral horns.

To simplify the analysis and to maintain a modeling that leads to computations that have been shown to correlate well with experimental data, the tangential components of the E- and H- fields over the aperture of the horn are approximated. As for the E-plane and H-plane sectoral horns, the directivity of the pyramidal configuration is vital to the antenna designer. The maximum radiation of the pyramidal horn is directed nearly along the z-axis (θ = 0).

The pyramidal horn is widely used as a standard to make gain measurement of other antennas and as such it is often referred to as standard gain horn. To design a pyramidal horn, one usually knows the desired gain G and the dimensions a, b of the rectangular feed wave-guide. The objective of the design is to determine the remaining dimensions that will lead to an optimum gain.

2.5 Conical Horn

Another very practical microwave antenna is the conical horn. While the pyramidal E-, and H-plane sectoral horns are usually fed by a rectangular waveguide, the feed of a conical horn is often a circular waveguide.

The first rigorous treatment of the fields radiated by a conical horn is that of Schorr and Beck. The modes within the horn are found by introducing a spherical coordinate system and are in terms of spherical Bessel functions and Legendre polynomials.

The behavior of a conical horn is similar to that of a pyramidal or *a* sectoral born. As the flare angle increases, the directivity for a given length horn increases until it reaches a maximum beyond which it begins to decrease, The decrease is a result of the dominance of the quadratic phase error at the aperture.

2.6 Corrugated Horn

The large emphasis placed on horn antenna research in the I 960s was inspired by the need to reduce spillover efficiency and cross polarization losses and increase aperture efficiencies of large reflectors used in radio astronomy and satellite communications. In the 1970s high-efficiency and rotationally symmetric antennas were needed in microwave radiometry. Using conventional feeds, aperture efficiencies of 50—60% were obtained. However, efficiencies of the order of 75—80% can be obtained with improved feed systems utilizing corrugated horns.

In 1964 Kay IS) realized that grooves on the wails of a horn antenna would present the same boundary conditions to all polarization and would taper the field distribution at the aperture in all the planes. The creation of the same boundary conditions on all four walls- would eliminate the spurious diffractions at the edges of the aperture. For a square aperture, this would lead to an almost rotationally symmetric pattern with equal *E*- and H-plane beamwidths. Corrugated (grooved) pyramidal horn, with corrugations in the E-plane walls. Since diffractions at the edges of the aperture in the H-plane are minimal, corrugations are usually not placed on the walls of that plane. Corrugations can also be placed in a conical horn forming a conical corrugated horn to form a very effective corrugated surface. It usually requires I0 or more slots (corrugations) per wavelength.

2.7 Special Horns

There are two antennas in use, which are rather difficult to classify, since each is across between a horn and a parabolic reflector. They are the Cass - horn and tnply folded horn reflector, the latter more commonly called the hog horn antenna

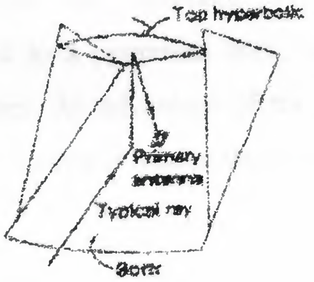


Figure 2.4 Feeding the Cass-horn antenna

In the Cass-horn antenna, radio waves are collected by the large bottom surface shown figure 2, which is slightly (parabolically) curved, and are reflected upward at an angle of 45° Upon hitting the top surface, which is a large hyperbolic cylinder, they are reflected downward to the focal point which, as indicated in figure 2, is situated in the center of the bottom surface.

Once they are collected by the conical horn placed at the focus. In the case of transmission the exact reverse happens. This type of horn reflector antenna has a gain and beam width comparable to those of a paraboloid reflector of the same diameter. Like the Cassegrain feed, after which it is named, it has the geometry to allow the placement of the receiver (or transmitter) at the focus, this time without any obstruction. It is therefore a low-noise antenna and is used in satellite tracking and communications stations. The one shown comes from such a station in Carnarvon (Western Australia).

Figure 2.5 Hog horn antenna (a) perspective view (b) ray paths

The hog horn antenna of Figure 2.5 is another combination of paraboloid and horn. It is a low-noise microwave antenna like the Cass-horn and has similar applications. It consists of a parabolic cylinder joined to a pyramidal horn, with rays emanating from, or being received at, the apex of the horn. An advantage of the hog horn antenna is that the receiving point does not move when the antenna is rotated about its axis.

2.8 Circular Horn Antennas

The conical horn can be directly excited from a circular waveguide. Optimum dimensions can be determined by taking $\delta=0.322\lambda$

The biconical horns of have patterns that are non-directional in the horizontal plane (axis of horns vertical). These horns may be regarded as modified pyramidal horns with a 360° angle in the horizontal plane. The optimum vertical-plane flare angle is about the same as for a sectoral horn of the same cross section excited in the same mode

2.9 Horns and Satellite

A variety of antenna types are used in satellite communications. The most widely used narrow beam antennas are reflector antennas. The shape is generally a paraboloid of revolution. For full earth coverage from a geostationary satellite, a horn antenna is used. Horns are also used as feeds for reflector antennas.

In a direct feed reflector, such as on a satellite or a small earth terminal, the feed horn is located at the focus or may be offset to one side of the focus. Large earth station antennas have a subreflector at the focus. In the Cassegrain design, the subreflector is convex with a results instead hyperboloidal surface, while in the Gregorian design it is concave with an ellipsoidal surface.

The subreflector permits the antenna optics to be located near the base of the antenna. This configuration reduces losses because the length of the waveguide between the transmitter or receiver and the antenna feed is reduced. The system noise temperature is also reduced because the receiver looks at the cold sky instead of the warm earth. In addition, the mechanical stability is improved, resulting in higher pointing accuracy.

Phased array antennas may be used to produce multiple beams or for electronic steering. Phased arrays are found on many nongeostationary satellites, such as the Iridium, Globalstar, and ICO satellites for mobile telephony.

2.10 Phase Center

In navigation, tracking, homing. Landing, and other aircraft and space systems it is usually desirable to assign to the antenna a reference point such that for a given frequency, ψ (θ, Φ) is independent of θ and Φ [i.e., ψ (θ, Φ) = constant]. The reference point that makes Ψ (θ, Φ) independent of θ and Φ is known as the phase center of the antenna. When referenced to the phase center, the fields radiated by the antenna are spherical waves with ideal spherical wave fronts or equiphase surfaces.

For practical antennas such as arrays, reflectors, and others, a single-phase center valid for all values of θ and Φ, does not exist. However, in many antenna systems a reference point can be found such that Ψ (θ, Φ)= constant over most of the angular space, especially over the main lobe.

The, need for the phase center can best he explained by examining the radiation characteristics of a paraboloidal reflector (parabola of revolution). Plane waves incident on a paraboloidal reflector focus at a single point, which is known as the focal point. Conversely, spherical waves emanating from the focal point are reflected by the paraboloidal surface and form plane waves Thus in the- receiving mode all the energy is collected at a single point In the transmitting mode, ideal plane waves are formed if the radiated waves have spherical wave fronts and emanate from a single point.

In practice, no antenna is a point source with ideal spherical equiphases. However many of there contain a point from which their radiation, over most of the angular space, seems to have spherical wave fronts. When such an antenna is used as a feed for a reflector, its phase center must be placed at the focal point.

The horn is a microwave antenna, which is widely used as a feed for reflectors. To perform as an efficient feed for reflectors, it is imperative that its phase center is known and it is located at the focal point of the reflection Instead of presenting analytical formulations for the phase center of a horn, graphical data will be included to illustrate typical phase centers.

Usually the phase center of a horn is not located at its mouth (throat) or at its aperture but between its imaginary apex point and its aperture. The exact location depends on the dimensions of the horn, especially on its flare angle. For large flare angles, the phase center as closer to the apex. As the flare angle of the horn becomes smaller, the phase center moves toward the aperture of the horn. For small flare angles, the *E*- and H-plane phase centers are identical. Although each specific design has its own phase center. If the *E*- and H-phase centers of a pyramidal horn are not identical, its phase center can be taken to be the average of the two. Phase center nomographs for conical horns are available.

CHAPTER 3

GAIN MEASUREMENT

3.1 Introduction

In our discussion of the antenna gain the concept of an isotropic radiator or isotope is fundamental. Essentially an isotope 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 isotope is measured at all point on an imaginary spherical surface with the isotope 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 nonuniformity 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 dimensions, but perfect omnidirectionality in three-dimensional space can never be achieved, Nevertheless, the concept of such an ideal omnidirectional radiation, an isotope, 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 isotope 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 isotope 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 isotope radiates a total power P 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

$$P_{sotope} = \frac{P_t}{4\pi r^2} (W / m2) \quad (3\text{-}1)$$

Since the total P_t , is distributed uniformly over the surface area of the sphere, which is $(4\pi r)$ (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-isotope. Since the half sphere has a surface area $(2\pi r^2)$ square meters, the power density is

$$P_{semi-isotrope} = \frac{p_t}{2\pi r^2} (WIm2) \quad (3\text{-}2)$$

$$\frac{P_{semi-isotrope}}{p_{isotrope}} = \frac{(p_t / 2\pi r^2)}{(p_t / 4\pi r^2)} = 2 \quad (3\text{-}3)$$

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

In this region, therefore, the semi-isotope 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 gains would be 4, and so on.

3.2. Antenna Gain

The fundamental characteristics of an antenna are its gain and half power beamwidth. According to the reciprocity theorem, the transmitting and receiving patterns of an antenna are identical at a given wavelength The gain is a measure of how much of the input power is concentrated in a particular direction. It is expressed with respect to a hypothetical isotropic antenna, which radiates equally in all directions. Thus in the direction (θ, ϕ), the gain is

$$G(\theta, \phi) = (dP/d\Omega)/(P_{in}/4\pi) \quad (3\text{-}4)$$

Where P_{in} is the total input power and dP is the increment of radiated output power in solid angle $d\Omega$. The gain is maximum along the bore sight direction. The input power is

$$P_{in} = E_a^2 A / \eta Z_0 \quad (3\text{-}5)$$

Where E_a is the average electric field over the area A of the aperture, Z_0 is the impedance of free space, and η is the net antenna efficiency. The output power over solid angle $d\Omega$ is $dP = E^2 r^2 d\Omega / Z_0$, where E is the electric field at distance r. But by the Fraunhofer theory of diffraction, $E = E_a A / r \lambda$ along the bore sight direction, where λ is the wavelength. Thus the important relation gives the bore sight gain in terms of the size of the antenna

$$G = \eta (4\pi / \lambda^2) A \quad (3\text{-}6)$$

This equation determines the required antenna area for the specified gain at a given wavelength.

The net efficiency η is the product of the aperture taper efficiency η_a, which depends on the electric field distribution over the antenna aperture (it is the square of the average divided by the average of the square), and the total radiation efficiency $\eta^* = P/P_{in}$ associated with various losses. These losses include spillover, ohmic heating, phase no uniformity, blockage, surface roughness, and cross polarization. Thus $\eta = \eta_a \eta^*$. For a typical antenna, $\eta = 0.55$.

For a reflector antenna, the area is simply the projected area. Thus for a circular reflector of diameter D, the area is $A = \pi D^2/4$ and the gain is

$$G = \eta (\pi D / \lambda)^2 \quad (3\text{-}7)$$

Which can also be written

$$G = \eta\,(\pi D f / c)^2 \qquad (3\text{-}8)$$

Since $c = \lambda f$, where c is the speed of light (3×10^8 m/s), λ is the wavelength, and f is the frequency. Consequently, the gain increases as the wavelength decreases or the frequency increases.

For example, an antenna with a diameter of 2 m and an efficiency of 0.55 would have a gain of 8685 at the C-band uplink frequency of 6 GHz and wavelength of 0.050 m. The gain expressed in decibels (dB) is 10 log (8685) = 39.4 dB. Thus the power radiated by the antenna is 8685 times more concentrated along the bore sight direction than for an isotropic antenna, which by definition has a gain of 1 (0 dB). At Ku-band, with an uplink frequency of 14 GHz and wavelength 0.021 m, the gain is 49,236 or 46.9 dB. Thus at the higher frequency, the gain is higher for the same size antenna.

The bore sight gain G can be expressed in terms of the antenna beam solid angle Ω_A that contains the total radiated power as $G = \eta^* (4\pi / \Omega_A)$. Which takes into account the antenna losses through the radiation efficiency η^*. The antenna beam solid angle is the solid angle through which all the power would be concentrated if the gain were constant and equal to its maximum value. The directivity does not include radiation losses and is equal to G / η^*.

The half power beamwidth is the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum values. For a reflector antenna it may be expressed

$$\text{HPBW} = \alpha = k\,\lambda / D. \qquad (3\text{-}9)$$

Where k is a factor that depends on the shape of the reflector and the method of illumination. For a typical antenna, $k = 70°$ (1.22 if α is in radians). Thus the half power beamwidth decreases with decreasing wavelength and increasing diameter.

For example, in the case of the 2-meter antenna, the half power beamwidth at 6 GHz is approximately 1.75°. At 14 GHz, the half power beamwidth is approximately 0.75°. As an extreme example, the half power beamwidth of the Deep Space Network 64 meter antenna in Goldstone, California is only 0.04 ° at X-band (8.4 GHz).

The gain may be expressed directly in terms of the half power beamwidth by eliminating the factor D/λ. Thus,

$$G = \eta\, (\pi\, k / \alpha)^2 \tag{3-10}$$

Inserting the typical values $\eta = 0.55$ and $k = 70°$, one obtains $G = 27{,}000/(\alpha°)^2$ Where $\alpha°$ is expressed in degrees. This is a well-known engineering approximation for the gain (expressed as a numeric). It shows directly how the size of the beam automatically determines the gain. Although this relation was derived specifically for a reflector antenna with a circular beam, similar relations can be obtained for other antenna types and beam shapes. The value of the numerator will be somewhat different in each case.

For example, for a satellite antenna with a circular spot beam of diameter 1°, the gain is 27,000 or 44.3 dB. For a Ku-band downlink at 12 GHz, the required antenna diameter determined from either the gain or the half power beamwidth is 1.75 m.

A horn antenna would be used to provide full earth coverage from geostationary orbit, where the angular diameter of the earth is 17.4°. Thus, the required gain is 89.2 or 19.5 dB. Assuming an efficiency of 0.70, the horn diameter for a C-band downlink frequency of 4 GHz would be 27 cm.

For the RF link budget, the two required antenna properties are the equivalent isotropic radiated power (EIRP) and the "figure of merit" G/T. These quantities are the properties of the transmit antenna and receive antenna that appear in the RF link equation and are calculated at the transmit and receive frequencies, respectively.

The equivalent isotropic radiated power (EIRP) is the power radiated equally in all directions that would produce a power flux density equivalent to the power flux density of the actual antenna. The power flux density Φ is defined as the radiated power P per unit area S, or $\Phi = P/S$. But $P = \eta^* P_{in}$, where P_{in} is the input power and η^* is the radiation efficiency, and $S = d^2\, \Omega_A$, where d is the slant range to the center of coverage and Ω_A is the solid angle containing the total power. Thus with some algebraic manipulation,

$$\Phi = \eta * (4\pi / \Omega_A)(P_{in} / 4\pi d^2) = G P_{in} / 4\pi d^2 \quad (3\text{-}11)$$

Since the surface area of a sphere of radius d is $4\pi d^2$, the flux density in terms of the EIRP is

$$\Phi = \text{EIRP} / 4\pi d^2 \quad (3\text{-}12)$$

Equating these two expressions, one obtains EIRP = $G P_{in}$ Therefore, the equivalent isotropic radiated power is the product of the antenna gain of the transmitter and the power applied to the input terminals of the antenna. The antenna efficiency is absorbed in the definition of gain.

The "figure of merit" is the ratio of the antenna gain of the receiver G and the system temperature T. The system temperature is a measure of the total noise power and includes contributions from the antenna and the receiver. Both the gain and the system temperature must be referenced to the same point in the chain of components in the receiver system. The ratio G/T is important because it is an invariant that is independent of the reference point where it is calculated, even though the gain and the system temperature individually are different at different points.

3.2.1 Antenna Pattern

Since electromagnetic energy propagates in the form of waves, it spreads out through space due to the phenomenon of diffraction. Individual waves combine both constructively and destructively to form a diffraction pattern that manifests itself in the main lobe and side lobes of the antenna.

The antenna pattern is analogous to the "Airy rings" produced by visible light when passing through a circular aperture. Sir George Bid dell Airy, Astronomer Royal of England during the nineteenth century, studied these diffraction patterns to investigate the resolving power of a telescope. The diffraction pattern consists of a central bright spot surrounded by concentric bright rings with decreasing intensity. The central spot is produced by waves that combine constructively and is analogous to the main lobe of the antenna. A dark ring, where waves combine destructively, that is analogous to the first null, borders the spot. The surrounding bright rings are analogous to the side lobes of the antenna pattern. As noted by Hertz, the only difference in this behavior is the size of the pattern and the difference in wavelength.

Within the main lobe of an ax symmetric antenna, the gain $G(\theta)$ in a direction θ with respect to the bore sight direction may be approximated by the expression

$$G(\theta) = G - 12 (\theta / \alpha) 2 \qquad (3\text{-}13)$$

Where G is the bore sight gain. Here the gains are expressed in dB. Thus at the half power points to either side of the bore sight direction, where $\theta = \alpha / 2$, the gain is reduced by a factor of 2, or 3 dB. The details of the antenna, including its shape and illumination, are contained in the value of the half power beamwidth α. This equation would typically be used to estimate the antenna loss due to a small pointing error.

An envelope can approximate the gain of the side lobes. For new earth station antennas with $D/\lambda > 100$, the side lobes must fall within the envelope $29 - 25 \log \theta$ by international regulation. This envelope is determined by the requirement of minimizing interference between neighboring satellites in the geostationary arc with nominal 2° spacing.

3.2.2 Taper

The gain pattern of a reflector antenna depends on how the antenna is illuminated by the feed. The variation in electric field across the antenna diameter is called the antenna taper.

The total antenna solid angle containing all of the radiated power, including side lobes, is

$$\Omega_A = \eta * (4\pi / G) = (1/\eta_a)(\lambda^2 / A) \qquad (3\text{-}14)$$

Where η_a is the aperture taper efficiency and η * is the radiation efficiency associated with losses. The beam efficiency is defined as

$$\varepsilon = \Omega_M / \Omega_A \qquad (3\text{-}15)$$

Where Ω_M is the solid angle for the main lobe. The values of η_a and are ε calculated from the electric field distribution in the aperture plane and the antenna radiation pattern, respectively.

For a theoretically uniform illumination, the electric field is constant and the aperture taper efficiency is 1. If the feed is designed to cause the electric field to decrease with distance from the center, then the aperture taper efficiency decreases but the proportion of power in the main lobe increases. In general, maximum aperture taper efficiency occurs for a uniform distribution, but maximum beam efficiency occurs for a highly tapered distribution.

For uniform illumination, the half power beamwidth is 58.4° λ /D and the first side lobe is 17.6 dB below the peak intensity in the bore sight direction. In this case, the main lobe contains about 84 percent of the total radiated power and the first side lobe contains about 7 percent.

If the electric field amplitude has a simple parabolic distribution, falling to zero at the reflector edge, then the aperture taper efficiency becomes 0.75 but the fraction of power in the main lobe increases to 98 percent. The half power beamwidth is now 72.8° λ /D and the first side lobe is 24.6 dB below peak intensity. Thus, although the aperture taper efficiency is less, more power is contained in the main lobe, as indicated by the larger half power beamwidth and lower side lobe intensity.

If the electric field decreases to a fraction C of its maximum value, called the edge taper, the reflector will not intercept all the radiation from the feed. There will be energy spillover with a corresponding efficiency of approximately $1 - C^2$. However, as the spillover efficiency decreases, the aperture taper efficiency increases. The taper is chosen to maximize the illumination efficiency, defined as the product of aperture taper efficiency and spillover efficiency.

The illumination efficiency reaches a maximum value for an optimum combination of taper and spillover. For a typical antenna, the optimum edge taper C is about 0.316, or − 10 dB (20 log C). With this edge taper and a parabolic illumination, the aperture taper efficiency is 0.92, the spillover efficiency is 0.90, the half power beamwidth is 65.3° λ /D, and the first side lobe is 22.3 dB below peak. Thus the overall illumination efficiency is 0.83 instead of 0.75. The beam efficiency is about 95 percent.

3.2.3 Coverage Area

The gain of a satellite antenna is designed to provide a specified area of coverage on the earth. The area of coverage within the half power beamwidth is

$$S = d^2\,\Omega \qquad (3\text{-}16)$$

Where d is the slant range to the center of the footprint and Ω is the solid angle of a cone that intercepts the half power points, which may be expressed in terms of the angular dimensions of the antenna beam. Thus it is $= K\,\alpha\,\beta$.

Where α and β are the principal plane half power beam widths in radians and K is a factor that depends on the shape of the coverage area. For a square or rectangular area of coverage, $K = 1$, while for a circular or elliptical area of coverage, $K = \pi/4$.

The relation may approximate the bore sight gain in terms of this solid angle

$$G = \eta'(4\pi/\Omega) = (\eta'/K)(41{,}253/\alpha^\circ\beta^\circ) \qquad (3\text{-}17)$$

Where α° and β° are in degrees and η' is an efficiency factor that depends on the half power beamwidth. Although η' is conceptually distinct from the net efficiency η, in practice these two efficiencies are roughly equal for a typical antenna taper. In particular, for a circular beam this equation is equivalent to the earlier expression in terms of α if

$$\eta' = (\pi\,k/4)^2\,\eta. \qquad (3.18)$$

If the area of the footprint S is specified, then the size of a satellite antenna increases in proportion to the altitude. For example, the altitude of Low Earth Orbit is about 1000 km and the altitude of Medium Earth Orbit is about 10,000 km. Thus to cover the same area on the earth, the antenna diameter of a MEO satellite must be about 10 times that of a LEO satellite and the gain must be 100 times, or 20 dB, as great.

On the Iridium satellite there are three main mission L-band phased array antennas. Each antenna has 106 elements, distributed into 8 rows with element separations of 11.5 cm and row separations of 9.4 cm over an antenna area of 188 cm × 86 cm. The pattern produced by each antenna is divided into 16 cells by a two-dimensional Butler matrix power divider, resulting in a total of 48 cells over the satellite coverage area. The maximum gain for a cell at the perimeter of the coverage area is 24.3 dB.

From geostationary orbit the antenna size for a small spot beam can be considerable. For example, the spacecraft for the Asia Cellular Satellite System (ACeS), being built by Lockheed Martin for mobile telephony in Southeast Asia, has two unfurl able mesh antenna reflectors at L-band that are 12 meters across and have an offset feed. Having different transmit and receive antennas minimizes passive intermediation (PIM) interference that in the past has been a serious problem for high power L-band satellites using a single reflector. The antenna separation attenuates the PIM products by from 50 to 70 dB.

3.2.4 Shaped Beams

Often the area of coverage has an irregular shape, such as one defined by a country or continent. Until recently, the usual practice has been to create the desired coverage pattern by means of a beam-forming network. Each beam has its own feed and illuminates the full reflector area. The superposition of all the individual circular beams produces the specified shaped beam.

For example, the C-band transmit hemi/zone antenna on the Intelsat 6 satellite is 3.2 meters in diameter. This is the largest diameter solid circular aperture that fits within an Arian 4 launch vehicle fairing envelope. The antenna is illuminated by an array of 146 Potter horns. The beam diameter α for each feed is 1.6° at 3.7 GHz. By appropriately exciting the beam-forming network, the specified areas of coverage are illuminated. For 27 dB spatial isolation between zones reusing the same spectrum, the minimum spacing σ is given by the rule of thumb $\sigma \geq 1.4\ \alpha$, so that $\sigma \geq 2.2°$. This meets the specification of $\sigma = 2.5°$ for Intelsat 6.

Another example is provided by the HS-376 dual-spin stabilized Galaxy 5 satellite, operated by PanAmSat. The reflector diameter is 1.80 m. There are two linear polarizations, horizontal and vertical. In a given polarization, four beams might cover the contiguous United States (CONUS), each with a half power beamwidth of 3° at the

C-band downlink frequency of 4 GHz. From geostationary orbit, the angular dimensions of CONUS are approximately $6° \times 3°$. For this rectangular beam pattern, the maximum gain is about 31 dB. At edge of coverage, the gain is 3 dB less. With a TWTA output power of 16 W (12 dBW), a waveguide loss of 1.5 dB, and an assumed beam-forming network loss of 1 dB, the maximum EIRP is 40.5 dBW.

The shaped reflector represents a new technology. Instead of illuminating a conventional parabolic reflector with multiple feeds in a beam-forming network, there is a single feed that illuminates a reflector with an undulating shape that provides the required region of coverage. The advantages are lower spillover loss, a significant reduction in mass, lower signal losses, and lower cost. By using large antenna diameters, the roll off along the perimeter of the coverage area can be made sharp. The practical application of shaped reflector technology has been made possible by the development of composite materials with extremely low coefficients of thermal distortion and by the availability of sophisticated computer software programs necessary to analyze the antenna. One widely used antenna software package is called GRASP, produced by TICRA of Copenhagen, Denmark. This program calculates the gain from first principles using the theory of physical optics.

The intended area of coverage determines the gain of an antenna. The gain at a given wavelength is achieved by appropriately choosing the size of the antenna. The gain may also be expressed in terms of the half power beamwidth. Reflector antennas are generally used to produce narrow beams for geostationary satellites and earth stations. The efficiency of the antenna is optimized by the method of illumination and choice of edge taper. Phased array antennas are used on many LEO and MEO satellites. New technologies include large, unfurl able antennas for producing small spot beams from geostationary orbit and shaped reflectors for creating a shaped beam with only a single feed.

3.3 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 isotope radiating the same total power.

The directive gain of a semi-strobe 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 isotope 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

$$D = \frac{p_{antenna}}{p_{isotrope}} \quad \text{(3-19)}$$

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

$$D = \frac{4\pi r^2 E^2}{377\, p_t} = \frac{4\pi r^2 p_{antenna}}{p_t} \quad \text{(3-20)}$$

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

$$G = \xi D \quad \text{(3-21)}$$

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

$$D_{Max} \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}[E(\theta,\phi)/E_{Max}]^2 \sin\theta d\theta d\phi} \quad \text{(3-22)}$$

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

$$D_{(\theta 1,\phi 1)} = D_{Max}[\frac{E(\theta_1,\phi_1)}{E_{Max}}]^2 \tag{3-23}$$

3.4 Gains 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 IogG. The directive gain in decibels is calculated from the same formula, with *D* substituted for *G*.

3.5 Measurement Gain

One method of measuring gain is by comparing the antenna under test against a known standard antenna. This is technically known as a gain transfer technique. At lower frequencies, it is convenient to use a 1/2-wave dipole as the standard. At higher frequencies, it is common to use a calibrated gain horn as a gain standard, with gain typically expressed in dBi.

Another method for measuring gain is the 3-antenna method. Transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance. The Fries transmission formula is used to develop three equations and three unknowns. The equations are solved to find the gain expressed in dB of all three antennas. Radiall/Larsen uses both methods for measurement of gain. The method is selected based on antenna type, frequency, and customer requirement. Use the following conversion factor to convert between dBd and dBi: 0 dBd = 2.15 dBi.

3.6 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 increasing the power gain of the transmitting antenna, without increasing the transmitting power, can increase the signal available to a receiving antenna at that location. 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.

3.7 Antenna Measurements

Measurements on antennas are difficult. Monitoring the reflection coefficient with a network analyser over a band of frequencies best sees the behaviour of an antenna, and for convenience a frequency about 1 GHz is appropriate. At 1 GHz a wavelength is 30 cm; the antenna is a reasonable size and it is possible to investigate the effects of adjacent objects, and different feed lengths, without too much difficult physical manipulation. The results may safely be transferred to other frequency bands by thought and analogy. When this is done, one rapidly appreciates that an antenna cannot be considered as a closed, isolated component having well-defined properties. Its environment and physical mounting grossly affect nearly every electronic measurement on an antenna. One might well ask the question, "What is an antenna?" or equivalently, "Where do the antenna stop and the outside world begin?" A sensible answer to this question is to consider all objects inside the near field as contributing to the radiation.

A helpful example is a Yagi-Uda antenna. We might regard this as a simple dipole with lots of resonant rods placed in the near field. But if we just consider the properties of the driven "antenna", namely the driven dipole, we know we will be grossly in error in assessing the performance of the installation. So why should we stop considering the effects of metallic structures at the end of the boom? We should add in the scattering from the mast, guys, feed (outer coaxial shields can carry induced current) and even dielectric objects (like the chimney stack or adjacent building) in the near field.

Many people now have access to software, which accurately simulates antenna behavior. To do this it is necessary to construct a model. The process of "modeling" is critical to this enterprise as the simulation has limitations of accuracy depending on the kind of model chosen. In itself, the software is essentially accurate and useful. However, the results it returns, for simulation of real antennas, depends critically on what is built into the model. It is not usually possible, in the NEC2 and miniNEC and NEC4 software, to add in all the local effects, which will affect the results. This is not just because it is too difficult; there are difficulties in principle, knowing the correct dielectric and conductivity parameters to put in for a real-world installation. Details of the feed arrangement are also difficult to get right. So it is often difficult to know if the results from the simulation of the model represent the real behavior of the antenna it was intended to investigate. The process of running the software always returns a result, and the internal checks on validity, while possible, are subtle. Belief in the results often dissolves into a matter of opinion or faith. This can be the subject of strongly held views, which can only be resolved by recourse to measurements.

Thus, simulation should be regarded (taking the most cautious view) as merely a rough guide to an antenna's behavior in a real installation. Any modeling process needs careful validation by measurements. One is then presented with the choice of which to believe, if there is disagreement. I have seen people worry about 1/10 dB in gain in a simulation. This is probably unsound, and one wonders how many hundreds of hour's people spend (no doubt happily) in this kind of activity.

3.8 Arrays of antenna elements

If we want to increase the gain of a dipole antenna we can add another dipole antenna alongside it. This is the simplest form of array antenna. Why is the gain increased, and what is the bore sight gain of this "two element array"?

First, we assume the antennas are fed in phase with each other and spaced lambda/2 apart. Considering the radiation in a direction, which is normal to the plane containing the dipoles, the contribution from each element arrives in phase with the other. The field strength in this direction is double that for one element, so the radiated power density, which is the square of the field strength, is four times that for one element. However, the two elements together are fed with twice the power of a single element. The increase in gain is therefore a factor 4/2 = 2.

This calculation scales with the number of elements. If we use a 10 by 10 array, the bore sight power gain is increased by a factor of 100, which is the number of elements. The field strength is 100 times more along bore sight than for a single element, so the power density is 10,000 times greater. But 100 times the power is being fed to the array compared with a single element, so the gain increase is a factor of 100 as stated. This gain increase is over and above any bore sight gain of the individual elements. If we start off with an array of 100 horn feeds at 10GHz, of size 14 cm by 14 cm each, their intrinsic gain is about 20dB and the array factor gives an additional power gain of 100 which is 20dB so the combined structure has a foresight gain of 40dB or so.

Now consider, are we "getting something for nothing" or does this increased gain along the bore sight come at the expense of gain elsewhere in the radiation pattern? The answer is clearly that the array concentrates the total radiated power along certain directions at the expense of others. If we go back to our 2 element dipole array, spaced lambda/2, there can be no radiation along a line joining the centers of the two dipoles as their contributions are in anti-phase in this direction, there being a lambda/2 path difference to get from one to the other.

In general then, the element pattern times the array pattern equals the total radiation pattern of the arrangement. What is the array pattern? It is the pattern you would observe for a set of isotropic radiators spaced as the array elements are actually spaced, and fed with the same amplitudes and phases of signals that the actual array elements receive.

2.9 Antenna calculations

Given a geometrical current distribution on the antenna structure, it is relatively straightforward to calculate the radiation integrals to determine the radiation patterns. Often this has to be done numerically. The difficulty with most antenna theory lies in determining the current distributions on the antenna conductors, given an arrangement of feeds, and the terminal voltages at the antenna ends of the feeds.

The Hertzian dipole is artificial in that it assumes there is a uniform current density along the arms of the dipole. There is thus an unphysical current discontinuity at the ends of the arms, which cannot be realized in practice. However, given a uniform current distribution, the properties of the antenna are reasonably straightforward to calculate. That is why this unphysical situation is so often presented in textbooks.

An equivalent problem pertains in simple loop antennas. Here it is often assumed that the current is constant around the loop. That is only a reasonable assumption if the loop perimeter is short compared to a wavelength. There is capacitance between the opposite sides of the loop, which can carry displacement current, which results from a build up of charge due to the voltage drop around the loop, which has inductive impedance. One can easily see that although there is only a single continuous conductor, the current does not have to be the same everywhere around the loop, as some of it goes to charge the stray capacitance.

Normally, self-consistent calculations are used to calculate together the current distributions and the radiated fields. The "method of moments" is popular. In this method the antenna structure is spilt up into a number of regions, on each of which the current distribution is assumed uniform. The integral equations for the antenna then reduce to solving (what may be a quite large) matrix equation. This is well adapted to computer solution. There are issues of accuracy, and sensitivity to the model framework assumed. This method is also used to work out radar cross sections of complicated objects such as helicopters and aircraft.

In a reflector-aperture antenna fed from the front by a sub-reflector and/or a feed, the far field radiation pattern can be calculated from the Fourier Transform of the field distribution across the aperture, accounting as well for phase variations across the illuminated area. The side lobe behavior of a reflector antenna is particularly well suited to this calculation method. A process known as "Apodisation" (after "a pod" = "without foot") tapers the amplitude ("amplitude taper") illumination across a dish reflector antenna so that there are no sudden changes of excitation amplitude, especially at the edges of the reflector. We recall from Fourier Transform theory that sudden changes in a function give rise to the presence of high frequencies in the Fourier Transform. In this particular case the sudden change in spatial illumination gives rise to high spatial frequencies in the transform, which directs the energy well away from bore sight as the "spatial frequency" translates into the deviation of the propagation direction from bore sight.

There is a good discussion of the side lobe suppression process by using apodisation techniques in volume 1 of the book "The Handbook of Antenna Design", publishers Peter Peregrines, 1982, on behalf of the British IEE, editors A W Rudge, K Milne, A D Olver and P Knight, ISBN 0-906048-82-6, table 1-3 page 43. As always there is a trade-off, in this case the beam width of the main beam is increased by some tens of percent depending on the illumination profile, for the benefit of reducing the side lobe levels. For reference purposes, this table 1-3 is reproduced here with minor modifications.

CHAPTER 4

APPLICATIONS OF HORN ANTENNA

4.1 Nearfield Application

Planar near-field systems are ideal for medium to high gain antennas when most of the energy is radiated in the forward hemisphere, typically within ±70 degrees. For antennas, which are directional in one plane and broad in the other, a cylindrical near-field measurement system is recommended. For antennas, which are extremely broad, or omni directional in both planes, a spherical near-field system is usually required. (Fig 4.1) shows a model 255-planar/cylindrical systems implemented for Anuran Microwave. The XY scanner provides a 5' by 5' travel range for planar near-field measurements on directive antennas. The antenna under test is mounted on an azimuth rotator, which remains fixed for planar testing and is moved in combination with the Y-axis of the XY scanner to perform cylindrical near-field measurements.

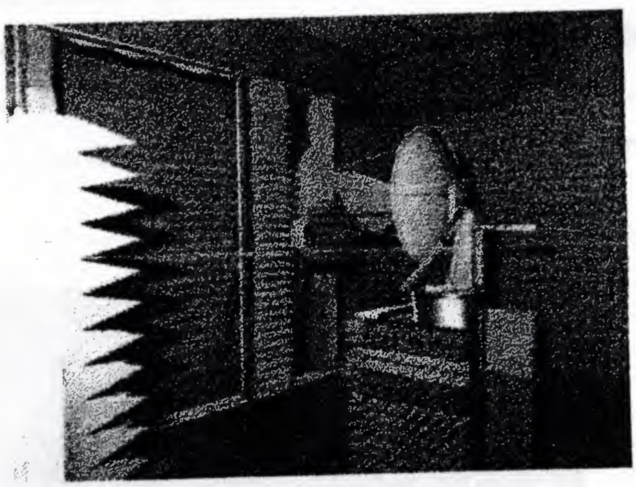


Figure4.1 - NSI 5' by 5' planar/cylindrical near-field system

Another type of planar near-field system uses a plane-polar scanning geometry. Plane-polar scanning yields a circularly symmetric set of data points on a plane in front of the antenna aperture, and is ideal for antennas, which have approximate circular symmetry in their radiation patterns. A large reduction in the number of data points required is often possible, which will significantly reduce data acquisition and processing time. NSI has used this scanning technique for numerous satellite dish antennas with excellent results. For these antennas, both axes of a Cartesian XY scanner were driven simultaneously to provide continuous path motion of the probe along the radius cuts of the plane polar scan.

A combination of probe linear motion and antenna under test rotation about it is axis is often used to perform a plane-polar scan. This was the method used by JPL for the Galileo 16' antenna. This method is sometimes referred to as the 'barbecue' method due to the antenna motion.

Allowing the antenna under test to remain motionless during testing is an advantage of using a Cartesian XY scanner to perform the plane-polar scan. NSI has also built another type of plane-polar scanner, which does not require antenna under test motion. (Fig4. 2) shows a 12' diameter plane-polar scanner, which is implemented by rotating a 6' radius stage through a complete circle using a large rotary stage at one end, somewhat like a half bladed propeller. The probe is de-spun with a small rotary stage, keeping the probe polarization constant. This system was designed and built for the specific purpose of testing a customer's antenna, which could not be moved to a test chamber, and would be difficult to rotate around its axis. In order to increase the accuracy of the scanner, an optical skeleton system was added to track the probe position errors (Slater, 1991). This system has subsequently been leased to two additional customers for performing antenna measurements and chamber quiet zone scanning.

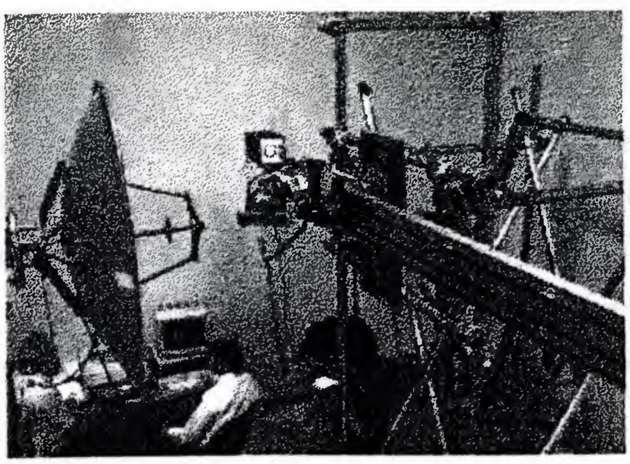


Figure4. 2 - 12' diameter plane-polar system

Portable near-field scanners are ideally suited for use in measuring the quiet zone performance of anechoic chambers and compact ranges. One large aerospace customer to calibrate the angle of arrival of the plane wave of multiple quiet zone areas from the compact range reflector system for subsequent satellite antenna testing used the 12' diameter plane-polar system described above. NSI's small 2' by 2' scanner has also been used to diagnose the quiet zone of an anechoic chamber. Contrary to popular belief, the quiet zone does not need to be completely mapped to derive useful results. Sampling a smaller area of the quiet zone and using a windowing function to taper the data, allows chamber reflection performance to be evaluated using SAR imaging techniques. 3 show a 3-D waterfall image of a chamber with numerous defects. The tallest peak is the desired signal from the illumination horn. The peak next to it is a severe RF leakage in the receiving system. The other lower peaks represent reflections from a support structure on the floor and a light fixture in the ceiling. Analysis of this type of plot can lead to corrective action such as adding isolation in the receiving system and improving the placement of absorber. The end result will be an anechoic chamber, which provides more accurate antenna measurements.

4.1.1 Portability

NSI has designed and implemented numerous portable systems with linear dimensions ranging from 2' to 20'. Several of the systems are dedicated to lease applications and have been easily transported and set up many times. Following is a list of primary considerations of importance for each application.

4.1.2 Measurement accuracy

Careful attention to detail can provide excellent results with portable near-field systems. One of the largest potential error sources is multipart interference, which can be fairly high when testing antennas in the absence of an anechoic chamber. Another important error source to characterize is the scanner accuracy, since the typical portable system is prone to larger structural errors than a similarly sized permanent installation. Fortunately, techniques exist to help minimize the effects of these errors.

4.1.3 Multipart suppression

Multipart reflections can induce large errors in side lobe measurements if ignored. Techniques for identifying multipart in a test system include measurements at multiple Z distances, testing the antenna under test in different orientations, and performing time domain measurements. Time gating can be applied in some cases to eliminate the unwanted reflections; however there is usually a severe penalty in data acquisition time, and the antenna must be reasonably broadband. Traditional methods of dealing with multipart have included averaging data sets from multiple tests with different antenna to probe separations, however these can also significantly increase test time. Careful analysis of the nature of the multipart can allow explicit steps to be taken to effectively eliminate the errors in many cases. A technique developed by NSI.

(Hyndman, 1989) provides reduction of the side lobe noise floor due to multipart to -50 dB by measuring near-field data on two Z-planes separated in space by 1/4. 5 show the multipart energy spectrum before suppression, the residual multipart after suppression, and the error corrected antenna pattern. The technique is particularly useful for portable and leased systems, which are not always used in an anechoic chamber.

4.1.4 Scanner structure calibration

Probe positioning accuracy of a typical portable 5' by 5' system is on the order of 0.005" RMS. The pattern error introduced by this position error is quite small for most applications and can be included in the overall uncertainty budget. For applications requiring higher accuracy, the system can be calibrated using optical techniques to map the errors into a lookup table, and using interpolation between points, or by augmenting the system with a real-time optical monitoring skeleton (Slater, 1991). The first approach works quite well when the system is used in a stable environment. 6 show the scanner error map from one of NSI's model 244 scanners. Table 2 shows the expected side lobe errors from a 5 mil RMS scanner due to the uncelebrated scanner errors and what can be expected due to residual errors after calibration for a typical X-band antenna

4.1.5 Ease of use

Portable systems are ideally suited for short-term lease applications, and must therefore be designed to be set up and operated by relatively inexperienced users. The hardware setup should be able to be performed by two or three technicians with standard tools.

NSI uses a structured and logical software menu system, which is both flexible and convenient. Expert system concepts are used to guide the user through test design, equipment setup, data acquisition and data processing steps. Clear, complete system and software documentation is also a key element.

4.1.6 Reliability and Cost

Increased reliability in portable systems can result from minimizing the overall number of components in the system. This can also significantly reduce the system cost. As an example, the computer is used to directly generate the pulses, which command the stepper motors, eliminating the need for a complex and costly smart controller. Since stepper motors can be controlled quite reliably without encoder or synchrony feedback (which is typically found in antenna measurement systems), these can also be eliminated.

NSI's development of a receiver post-processor (Slater, 1991) also follows this general philosophy. A simple, phase modulated interferometer (PMI) with very few components can be used to provide accurate near-field measurements, by performing software corrections to the data using Hilbert transform techniques. (Fig 4.3) show a portable system with NSI's PMI receiver interfaced to the Cosmotron FS2000B synthesizer.

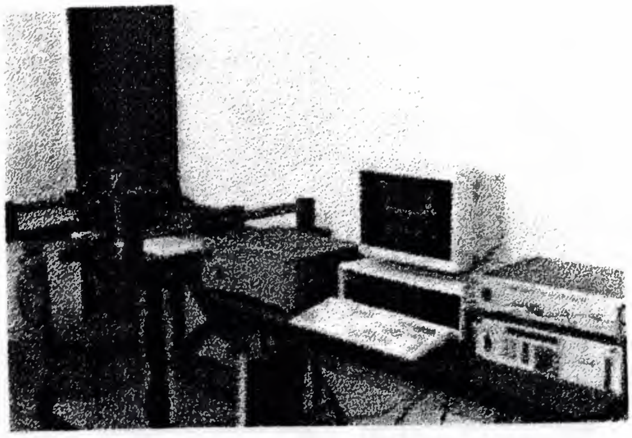


Figure4.3 - Portable system and phase modulated interferometer

At the end we can say that we discussed numerous design and operational considerations for portable near-field antenna measurement systems. Versatile, low cost systems can be implemented without sacrificing performance, by using appropriate design techniques.

4.2 Conical Horn Application

Antennas For Communications offers full design and manufacturing capabilities for Conical Horn Reflector Antenna Systems.AFC's monolithic antenna design enables a level of horn precision that no metal horn can match. There are no seams on the reflector or radome to affect the radiation pattern, and no moisture intrusion, with AFC's proprietary molding process. AFC is recognized as a world leader in the development of 7-, 8-, and 10-foot models offering performance, which has long been the industry standard. Expandability and competitive price are additional benefits. AFC offers its customers a complete line of waveguide, combining networks, couplers, hangers, and dehydrators. Their experienced erection team is capable of handling any installation, whether atop a skyscraper or on a mountainside.

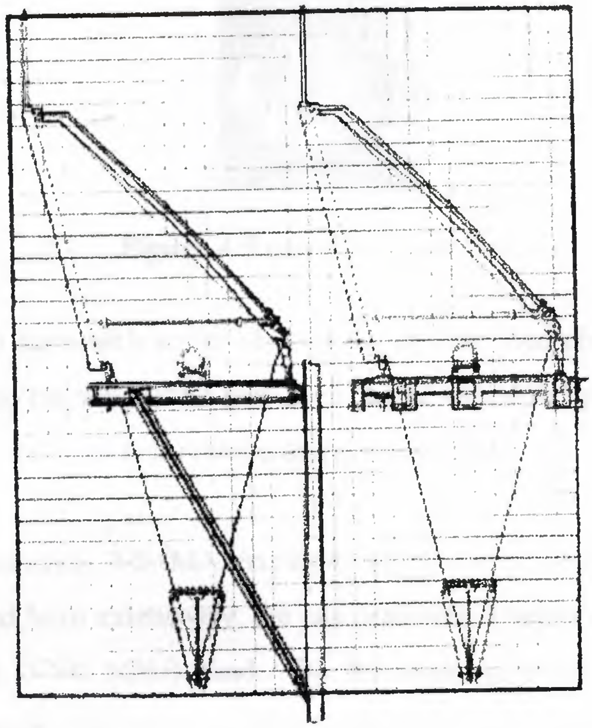


Figure 4.4 AFC's Conical Horn

4.2.1Advantage of the AFC's Horn

1. Single frequency or multiband - AFC networks enable you to combine up to three bands on one antenna; AFC couplers are available with single- or dual-polarized operation from 1.7 GHz to 17 GHz.

2. Fully equipped horns, Every AFC antenna arrives complete with stabilizers, adjustment tools, lightning rods, safety rails, waveguide hangers, and all necessary hardware: you need not "shop" for critical parts of an AFC system.

4.3 Feed Horn Applications

The first version of this antenna used was suffered from low illumination efficiency and relatively high noise temperature, due primarily to the simple cylindrical waveguide feed horn employed. The addition of a single choke ring around an existing feed horn can improve overall system performance by more than 1 dB. (Fig 4.5) shows the author with the prototype of a new SETI feed horn, which has been duplicated by the scientist, and it is also commercially available.

Figure 4.5 new SETI feed horn

Finished SETI feed horn with scalar choke ring, as described above. The placement of the choke ring along the waveguide feed horn can be varied to optimize performance for maximum gain, or minimum noise temperature, as described.

Barry Malowanchuk, VE4MA, has explored the use of a single scalar-mode choke on a cylindrical feed horn extensively. He has presented a nicely optimized dish feed for the amateur 5 cm (5760 MHz) band. By fortuitous coincidence, the frequency for which Barry designed his horn is almost precisely four times that of the neutral hydrogen line. Since dimensions for waveguide scale linearly with wavelength, if we desire to build a hydrogen line feed using Barry's design, all we need do is multiply all of his dimensions precisely by four. This scaling process gives us the working dimensions shown in (Table 4.1) below.

Table 4.1 Showing the Working Dimensions

Dimension	Cm	Inches
Inside Diameter of Waveguide	15.6	6.14
Total waveguide length	27.8	10.94
Inside Diameter of Choke Ring	36.0	14.17
Depth of Choke Ring	10.6	4.17
Length of Coax Probe	4.6	1.81
Placement of Coax Probe	8.8	3.46

The final dimension above is measured with respect to the shorted end of the waveguide. See (Fig4.6) for details of the quarter-wavelength monopole probe.

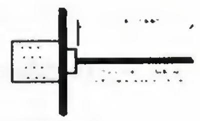


Figure 4.6 *SETI League drawing*

Construction details of the quarter-wavelength coaxial probe, which serves as the interface between the cylindrical waveguide feed horn and the feed line (or antenna-mounted low-noise amplifier). The flange-type coaxial connector is mounted through the side of the cylindrical waveguide at the specified dimension, and receives a type N coaxial connector or adapter. For circular polarization, two such probes may be mounted 90 degrees apart on the feed horn, and their outputs combined 90 degrees out of phase electrically by using a phase-quadrature hybrid coupler.

Feed horn dimensions are typically selected to illuminate the surface of a dish as fully and uniformly as possible, to achieve the highest possible antenna gain. Industry practice is to utilize a 10 dB edge illumination taper. That is, with respect to the center of the dish, signals reaching the feed from the very edge of the dish are 10 dB lower in amplitude. With simple cylindrical waveguide feed horns, the result is typically a 55% efficient antenna system. For most communications applications, where range and margin are a function of recovered signal strength, this is indeed an appropriate design technique.

SETI, on the other hand, is a unique application in that the strength of the anticipated receive signal is entirely unknown. Our range and sensitivity are largely noise- limited. That is, in order to maximize our sensitivity, we need to reduce antenna noise temperature to the absolute minimum. This can be accomplished by deliberately under-illuminating the dish. Let's calculate an example based upon a 5-meter parabolic reflector operating at the 1420 MHz Hydrogen line. If we use a 15 dB illumination taper, the antenna gain goes down almost one dB (from +34.8 to +34.0 dB), as efficiency drops to say 45%. But for a SETI system with a low noise front end, reducing antenna gain and efficiency actually improves sensitivity. Here's Let's imagine our receiver uses a GaAs PHEMT front end, running at 50 K receive noise temperature. With a dish designed for optimum gain, the antenna noise temperature, dominated by

Earth-seeing side lobes, is about 50 K. The overall system noise temperature is thus 100 K, and sensitivity (given 10 Hz bin width and 10 second integration) is on the order of 1.3 E-22 W/m^2. Now under-illuminate for 10 K of antenna noise. Antenna gain decreases 0.8 dB as discussed above, but overall noise temperature reduces to 60 K, a 2.2 dB decrease in noise. System sensitivity is now 9.4 E-23 W/m^2, a net system improvement of 1.4 dB!

Is the cited sensitivity adequate to the task of meaningful SETI? In 1977, NASA SP-419, The Search for Extraterrestrial Intelligence articulated this goal "Existing antennas could be used to search ... the entire microwave window to as low as ~10 E-23 W/m^2 in a few years of observing time." By increasing to 120 seconds the integration time constant of the system just described, overall sensitivity improves to on the order of 2.7 E-23 W/m^2. Thus, two decades later, amateur SETI is just now closing in on NASA's sensitivity goal for SETI sky surveys.

The chief determinant of illumination taper for scalar-ring feed horns is the placement of the choke ring along the waveguide feed horn. The choke ring must be designed so as to slide back and forth on the waveguide horn, in order to optimize the illumination pattern of the feed for noise vs. gain, as well as the particular focal length to diameter ratio (F/D) of the dish being used. Here are the critical dimensions for the distance between the front of the horn and the back of the choke ring. They are shown in (Table 4.2) for dishes of various F/D ratios, for both lowest antenna noise temperature (the preferred condition for SETI) and greatest antenna gain (which you would choose for a transmit antenna). All dimensions are in cm (inches).

Table 4.2 Show the dimensions between the distances

F/D =	0.50	0.45	0.40	0.35	0.30	0.25
LoNoise	8.52(3.35)	9.08(3.57	10.6(4.17)	11.36(4.47)	12.4(4.88)	12.8(5.04)
HiGain	10.08(3.97)	10.6(4.17	11.6 4.57)	12.4 (4.88)	13.2(5.20)	n/a

Prototypes of this feed have been fabricated from sheet copper and galvanized sheet steel. Materials do not appear particularly critical. The flange by which the scalar ring attaches to the waveguide horn assembly can be drilled and tapped for setscrews, or notched to simulate finger-stock, and held in place with a large hose clamp. Radio Astronomy Supplies is now offering a commercial version of this improved feed. Made of cast aluminum, the unit is priced at $160 US plus shipping, handling and insurance, with a $10 discount to SETI League members in good standing.

(Fig 4.7) shows how Project Argus pioneers Magin Casanitjana; EA3UM added a choke ring to his antenna feeds. It also illustrates how mounting one horn slightly offset from the focal point of the dish can accommodate dual feedhorns. This approach skews the antenna pattern slightly, but peaking the antenna on sun noise, and compensating aiming accordingly easily measure the result. Such a dual feed horn design is a viable alternative for those members wishing to use a single dish simultaneously for satellite TV reception and SETI.

Figure 4.7 EA3UM

Close-up view of the dual feed horns installed on the EA3UM five-meter SETI dish. These cylindrical waveguide feed horns utilize choke rings per the VE4MA design, to improve illumination efficiency. Note that the hydrogen-line feed is slightly offset from center. This technique allows Project Argus participants to do parasitic SETI with a dish normally utilized for some other purpose. An alternative method of mounting a feed horn to a dish is seen in (Fig4.8).

Figure 4.8 *WA7CRE*

This close-up shows how SETI League charter member WA7CRE mounted a hydrogen-line cylindrical waveguide feed horn to the focal point of a TVRO dish.

Please note when mounting the feed horn to the dish that the actual focal point of the parabolic reflector must fall slightly inside the mouth of the feed horn. Although feed horn focus is generally determined empirically (tweaking the feed horn placement for best reception of a calibration signal), the general relationship is:

$a = (d * f) / D - (d * D) / (16 * f)$

Where:

a = distance the focus should be inside the feed horn

D = diameter of the dish

d = diameter of the feed horn (not of choke ring)

f = focal length of dish.

Note that a, d, D, and f are all measured in the same units.

Since the feed horn just described was scaled from an EME design, we now return to the moon bounce application, and challenge a basic principle of antenna design: that of reciprocity. It's widely held that an antenna will function equally well in receive and transmit modes. This is because, to a first order approximation, antennas are impedance matching transformers, matching the characteristic impedance of a feed line (typically 50 ohms) to that of free space (120 pi, or about 377 ohms). We depend upon the principle of reciprocity when we measure the gain of transmit antennas on the antenna range, by receiving a test signal through them.

To be sure, passive impedance matching networks are bi-directional, and the primary function of antennas is to match impedances. But the secondary function of any but an omni directional antenna is to direct energy, and the directivity needs of transmit and receive systems may well differ. Such is certainly the case in EME communications.

Consider that when transmitting toward the Moon (or anywhere else), our primary objective is to maximize effective isotropic radiated power (EIRP) in a desired direction. If using a parabolic reflector for transmits, we would then choose to illuminate the reflector for maximum power gain. The optimum illumination taper should tend to minimize side lobes (on the principle that side lobe power is wasted power), but the optimum feed illumination for forward gain is not necessarily that which minimizes side lobes.

In receive mode, we have shown system sensitivity to be a function of both antenna gain and noise temperature. Our calculations indicate that optimum performance can result if we sacrifice some gain for a reduction in side lobes. Again, the optimum feed illumination for side lobe reduction is not necessarily that which maximizes forward gain.

It then appears that for EME, the optimum choke ring placement, as seen in Table 4.2, varies between transmits and receives use. SETI League president Richard Factor, WA2IKL, has suggested an unconventional approach to feed horn design for EME use. He proposes a design wherein the choke rings be mounted to the cylindrical feed horn on a track, allowing the choke to be readily slid fore and aft during use. The assembly would then be motorized, with mechanical stops, such that the choke ring is positioned toward the back of the horn (that is, in highest gain position) during transmit cycles, and forward (to the low noise position) for receive. The mechanical switching time should not present EME operators with any difficulty, considering that EME echo time is just over two seconds, and that transmit/receive sequences typically range from 30 seconds to 2 minutes, depending on the band used. At present, I have not physically implemented Richard's suggestion, but it seems almost trivial to do so.

4.3.1 Scalar Feed Horn

It is one of most expensive and highest performance horn. Beam shape is virtually independent of rotational angle (i.e. E- and H-plane radiation patterns are very similar). They are ideal when highly symmetrical antenna patterns are desired and well suited for reflector or lens antenna system feeds. Low VSWR and low sidelobes are also among the benefits of these horns.

4.3.2 Special Application Feed Horns

A variety of system applications, such as plasma diagnostics, depth or range measurement and receiver/transmitter arrays, require specially designed and produced feed horns or antennas. QuinStar can custom designs such antennas and provide detailed measurements on their radiation characteristics.

The following parameters are necessary to completely specify a feed horn. However, QuinStar can propose a solution for your application if only some of the parameters are provided:

1. Horn type-conical, pyramidal, scalar, sectoral, or custom (if unspecified QuinStar will select the best type).

2. Beam shape-beamwidth in E- and H-plane, beam symmetry and any special features.

3. Aperture-size and length constraints, if any.

4. VSWR requirements.

5. Sidelobe levels and cross polarization isolation requirements.

4.3.3 Conical Feed Horn

Least expensive horn and well suited for the majority of general-purpose applications. Beam patterns in the E- and H-planes are dissimilar and gain ranges from 10 to 26 dB for most frequencies depending on aperture (beamwidth) and frequency.

4.3.4 Pyramidal Feed Horn

Relatively inexpensive and well suited for most general-purpose applications. Beam patterns in the E- and H-planes are generally dissimilar and gain ranges from 10 to 27 dB depending on aperture and frequency.

4.3.5 Sectoral Feed Horn

Radiates a fan-shaped beam, which is broad in one plane and relatively narrow in the other for wide angular coverage. Typical beamwidths are 25 to 90 degrees in one plane and a few degrees in the other plane. The narrow beam can be obtained in either of the two planes (E- or H-plane).

4.4 Pyramidal Horn Antenna Application

4.4.1 Modeled with Concerto

Concerto can model all types of antenna from wire, patch, and patch arrays to more complex radiating horns or helical structures. This example shows Concerto modeling a horn antenna driven from a ridged waveguide. The horn is defined as an external object and its dimensions and properties can be easily modified. This model was based on a real antenna and the designer was able to use Concerto to rapidly obtain the optimum specification for his application.

(Fig4.9) Shows the model viewed with the ACIS viewer. This allows full rotation and inspection of the model.

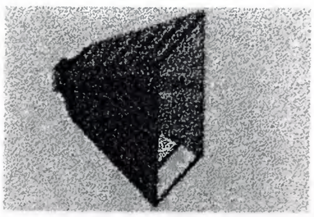


Figure 4.9 ACIS view of Horn Antenna

(Fig4.10) shows the model viewed with the 3d window in Concerto. The model was generated using a parameterized object.

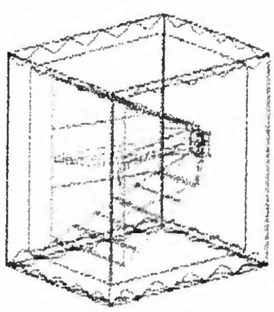


Figure 4.10 Concerto 3d View of Antenna

The object has been created using a simple parametric language with the parameters. The parameters are adjustable when the object is read in so that for example, an antenna with a different width and number of rods could easily be created

(Fig4.11) Shows some results from the horn antenna compared with measurements.

The blue lines indicate the horizontal plane and the red lines indicate the vertical plane. The dashed lines are those calculated in Concerto and the solid lines are the measured results.

Figure 4.11 Concerto calculations compared with measurements

4.5 The Gauge Horn Antenna Application

Figure 4.12 Horn Antenna Gauge, RTG 3920

The RTG 3920 Horn Antenna Gauge uses an 8" stainless steel horn antenna with a computer calculated precise curvature to achieve highest accuracy. The relatively small diameter of this antenna using free propagation makes the antenna beam wide. In order to still be able to install near the tank wall, the emitted microwaves are polarized so that only the antenna picks up the reflection from the liquid surface. The RTG 3920 is suitable for all liquids except for asphalt and similar products where the RTG 3930 is recommended. Installation is made on any tank opening with a minimum 8" diameter.

Table 4.3 Technical Data for RTG 3920

Instrument accuracy	±0,5 mm (1/32")
Operating temperature in tank	Max. +230 °C (+445 °F)
Measuring range	0, 85 m below flange to 20 m (3' - 65') Range can be extended to 0,3-30 m (1'-100') with reduced accuracy.
Pressure	-0.2 to 2 bar (-3 to 30 psi)
Material exposed to tank atmosphere	Acid proof steel (type 316), PTFE (Teflon) and FPM FPM (Viton (R) - Viton is a registered trademark of DuPont Dow Elastomers)
Total weight	Approximately 20 kg (44 lbs) excluding flange
Mounting flange	8" flange ANSI B 16.5 150 lbs or a DN 200 PN 10 flange DIN 2632/SS2032 or a British Standard 4504 Table 10.2 DN 200

4.6 Brod Band Horn Applications

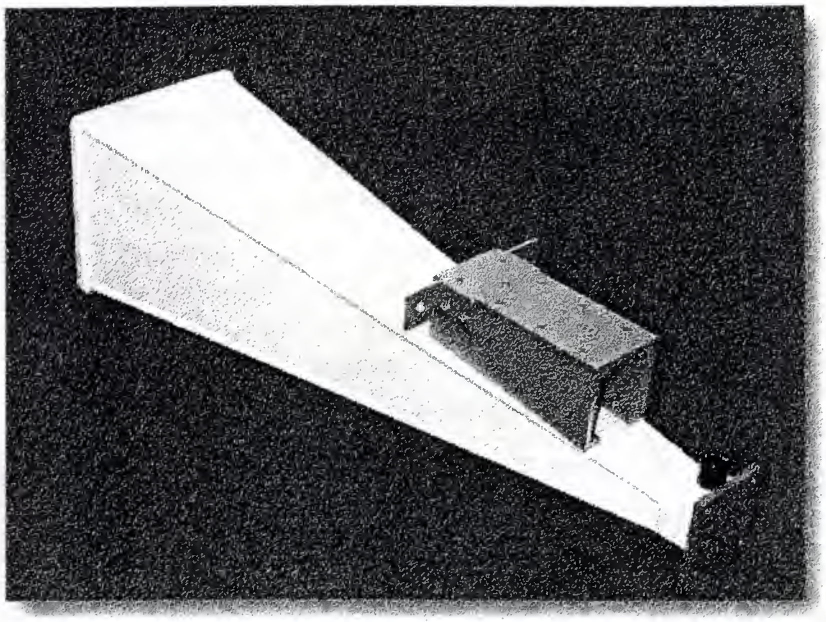


Figure 4.13 (1.5 to 18 GHz High Gain Horn Antenna)

This high gain high performance ridged waveguide horn; Model Number 6878/24H is ideal for EMI/RFI testing, EMC measurements, wide-band spectrum surveillance or materials evaluation etc. The horn covers frequencies used for PCN, PCS, GSM, GPS, direct to home satellite broadcasting, and many others. It is especially useful for receiving very low-level signals or transmitting moderate power levels. The horn can be used where a parabolic reflector antenna may have been previously used to increase the gain, or where it is not practical to install a wide band standard reflector antenna. This horn is cheaper than an equivalent feed and reflector antenna assembly.

Special techniques have been incorporated to prevent higher order waveguide modes. The construction is an aluminum/plastic composite. The horn comes with a specially designed weatherproof radome that provides good protection against the elements but has very little loss across the frequency band. A mounting bracket is shown that provides a useful way to set the antenna in either Horizontal or Vertical polarization. This type of horns offers excellent value for money.

Table 4.4 Specification of the brod band horn

Model Number	6878/24H
Frequency	1.5 to 18 GHz
Nominal Gain	Varies from 6 to 22 dB across the band
Nominal Beam width	'H' plane varies from 46 - 6.5 degrees 'E' Plane varies from 40 - 9.5 degrees
VSWR	< 2:1 across the band
Construction	Aluminum/plastic composite
Dimensions	620 x 160 x 160 mm approx. i.e. 24.5 " x 6.3" x 6.3"
Power	50 Watts (c.w.)
Connector	SMA or Type N (others available)
Weight	2.6 kg (5.7 lbs)
Temperature	-40 °C to +70 °C

Table 4.5 Gain of the brod band horn

Frequency (GHz)	Gain (dB)
1.5	6
1.7	9
2	11.5
4	16
6	18
8	19
10	19
12	20
14	21.5
16	22
18	22

4.7 Pyramidal horn Application

And 20 A typical X-hand (8.2- 12.4 GHz) horn is a lightweight precision born antenna; which is usually cast of Aluminum and it can be used as a:

1. Standard for calibrating other antennas
2. Feed for reflectors and lenses
3. Pickup horn for sampling power
4. Receiving and /or transmitting antenna

It possesses an exponential taper and its dimensions and typical gain characteristic are indicated in the figure. The half – power beamwidth in both E- and H- planes is about 28° while the side lobes in the E-and H- planes are respectively, about 13 dB down.

4.8 Millimeter Wave Hog Horn Antenna Application

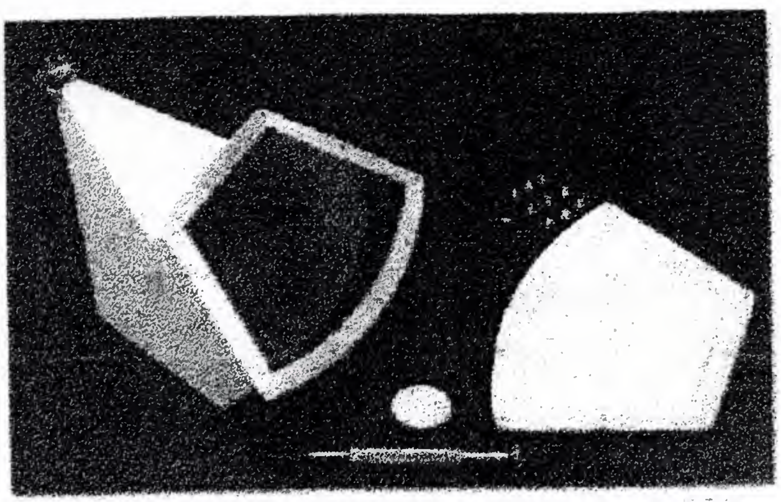


Figure 4.14 -Millimeter Wave Hog Horn

This form of antenna has previously been used only at low frequencies. However it has several advantages over conventional antennas at millimeter wavelengths. These are:

1. Low side lobes (with edge blinders fitted)
2. Good cross-polar performance

3. Broad-band operation

4. Mechanically rugged

5. High efficiency

Q-par Angus is the first company to offer this type of antenna, theMINIHOG, at millimeter wave frequencies. Versions can be supplied from 30 GHz to over 200 GHz with various gain and beam width options. Construct can be in metal or plastic.

This demanding design was requested by a major space organization for experimental use. It consists of a conical horn, antenna polarizes, hybrid OMT (Ortho Mode Transducer) with WG22 transitions fitted with K type connectors for RHCP / LHCP working. An outline drawing of the unit is shown below. Dimensions shown in mm.

4.8.1 Specification of Millimetrec Horn

Frequency	32 GHz
Gain	22d8i
VSWR	<1.2:1
Axial Ratio	0.5 dB
Connector	Type K
Constriction	Anodized Aluminum Alloy

CONCLUTION

The term antenna is one of the very important branches that communication depending on, so and after I stepped forward insight this branch I found that its really very difficult and interesting subject in the same time with its different types, manners and applications.

After I finished my research and analysis in the horn antenna I got that it's the most widely used microwave antenna. And it can be treated as an aperture antenna, the fields at the aperture of the horn can be found by treating the horn as a radial waveguide. The fields within the horn can be expressed in terms of cylindrical TE and TM wave functions, which include Hankle functions. This method finds the field not only at the aperture of the horn but also within the horn.

Also an electromagnetic horn can take many different forms, I have mentioned most of them in the project. The horn is nothing more than a hollow pipe of different cross sections, which has been tapered to a larger opening. the type, direction and amount of taper can have a profound effect on the overall performance of the element as a radiator.

In the other hand in this project I learned from the fundamental theory of the horn antennas the operation of the horn and its design as an efficient radiator.

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