NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical & Electronic Engineering

Antenna Measurements and UHF/VHF Applications

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 and with the desired polarization.

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

The very-high-frequency (VHF) and ultrahigh frequency (UHF) bands are used for private and public-access services carrying speech, data, and facsimile information. The ends of a link may be installed at fixed locations or in vehicles (including ships and aircraft) or may be carried in an operator's hand. The length of a link may vary from a few tens of meters up to the maximum over which reliable communication can be obtained. This wide variety of applications generates a need for many different types of antennas. In this project we examine the selection of antennas to perform various tasks, together with aspects of reliability, siting, and economics.

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INTRODUCTION

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

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.

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

Our objective in this project is analysis of the antenna measurement and designs a simple, method to determine the antenna gain to real antennas. For this purpose the small size simple antenna is used in this measurement system. Antenna gain is determined for different values of the angular position in the horizontal plane at a fixed frequency, and for different frequencies at a fixed angle. The correction coefficient determined by the power ratio of the real and small antennas and it is used to match obtained results with real condition, also we present the VHF/UHF application and there techniques.

This Project is divided in to four Chapters and conclusion, chapter one is present the primary concerned with definitions and related terminology.

Chapter Two discusses the manner of measuring the parameters which we have mentioned in the previous chapter, so that, an idea about the measuring ways has been studied here. The main measurements are divided into categories as impedance and pattern measurements.

Chapter Three studies techniques for VHF and UHF antenna. We discuss the system planning objectives, antennas for point to point links, base station antenna and system considerations.

Chapter Four, we present the application of the VHF and UHF antennas, we give overview about the VHF and UHF transmitting and receiving antenna, and we give some examples for the VHF and UHF antennas showing the out put and the input.

Conclusion presents the important results obtained by the author of the project and practical antennas measurements and the VHF / UHF antennas.

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 microminiature to gigantic, and it depends on the wavelength, which has proportionality with the operations frequency, and this relationship is simple and fast.

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

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

1.1.2 Supports

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

Towers are used when great height is required. Masts may be quite high, but they are often as short as a few feet. Pedestals are the base structures of antennas such as

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 30MHz), the antenna may be a horizontal wire strung between towers, or other supports (from which it is insulated). The feed line is then often a two-wire balanced line connected at the center of the antenna, either to the two terminals provided by a gap in the antenna wire (series feed), or to two points somewhat separated on the unbroken antenna wire (shunt feed). Sometimes the feed line is connected at the end of the horizontal span, or elsewhere of center, but center feed is preferred because it results in better balance of the currents in the feed wires. The spacing between the two-wire-line is range from less than an inch to 12 inches or more. The last method is used for high frequencies. But coaxial feed lines are commonly used for upper high frequencies UHF (up to 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 use, with some use of mall-diameter coaxial lines in low-power noncritical applications.
We should mention that, when the antenna rotates on a pedestal, or has other motion with respect to its support, the feed line must contain flexing sections or rotating joints, this require is quite important on the antenna measurement operations, as we will see later.

1.1.4 Conductors

Metals are the usual conducting materials of antennas. Metals of high conductivity, such as copper and aluminum (and its alloys), are naturally preferred. Brass may be used for machined parts. Magnesium is sometimes used where ultralight weight is important, usually in an alloy and with a protective coating or treatment. The steel may be used, when the strength is of primary importance, either with or without a coating or plating of copper. The conductivity of unplated steel is adequate when it is used in the form of sheets or other large-surface-area forms (as for the surface of a paraboloidal reflector). Antenna wire is sometimes made with a steel core for strength and to minimize stretching and with a copper coating to increase the conductivity. Such wire is virtually as good a conductor as solid copper. Since the radio frequency RF currents are concentrated near the surfaces of conductors (skin effect). For this reason brass and other metals are sometimes silver-plated when exceptionally high conductivity is required. For the same reason large-diameter conductors may be hollow tubes without loss of conductivity. At low radio frequencies the conductivity of large-diameter conductors may be increased, compared to a solid conductor, by interweaving strands of small-diameter insulated wires; the resulting conductor is called Litz wire. This technique is most effective below about 500KHz. At higher frequencies it is not effective because the currents tend to flow only in the outer strands.

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

1.1.5 Insulators

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

1.1.6 Weather Protection

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

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 coordinatesθ (r,θ,Φ) is used. The spherical coordinate system is an appropriate coordinate system to describe the antenna pattern because the radiation pattern may be expressed in terms of the electric field intensity, (for example, at some fixed distance *r* from the antenna), at all points on the spherical surface at that distance. Spherical points on the surface are then defined by the direction angles θ and Φ. The pattern then becomes a function of only two independent variables, since *r* is a constant, and this fact greatly simplifies the matter.

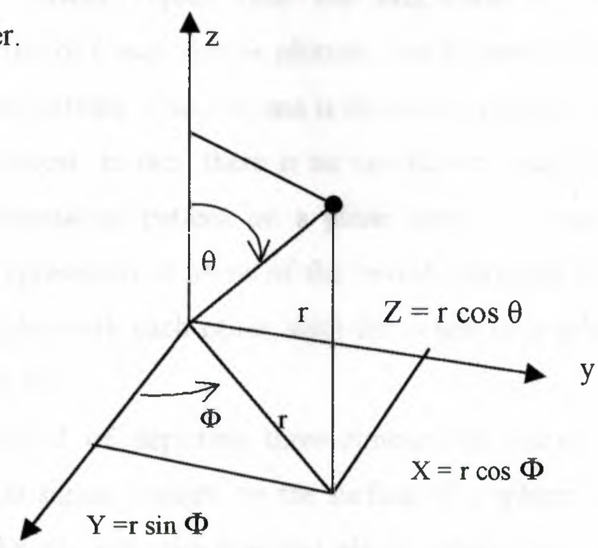


Figure 1-1 Interrelationship of space variables (x, y, z) and (r, θ, Φ).

Figure 1-1 illustrates the relationship between the Cartesian and spherical coordinates. The projection of this distance r onto the xy-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 $E(\theta, \phi)$ in functional notation.

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

$$E = \eta_{\circ} H \qquad (1\text{-}1)$$

(Of course, they are at right angles to each other and their phase angles are equal) where $\eta_{\circ} = 377\,\Omega$ 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

$$P = \frac{E^2}{\eta_{\circ}} \qquad (1\text{-}2)$$

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

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

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

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

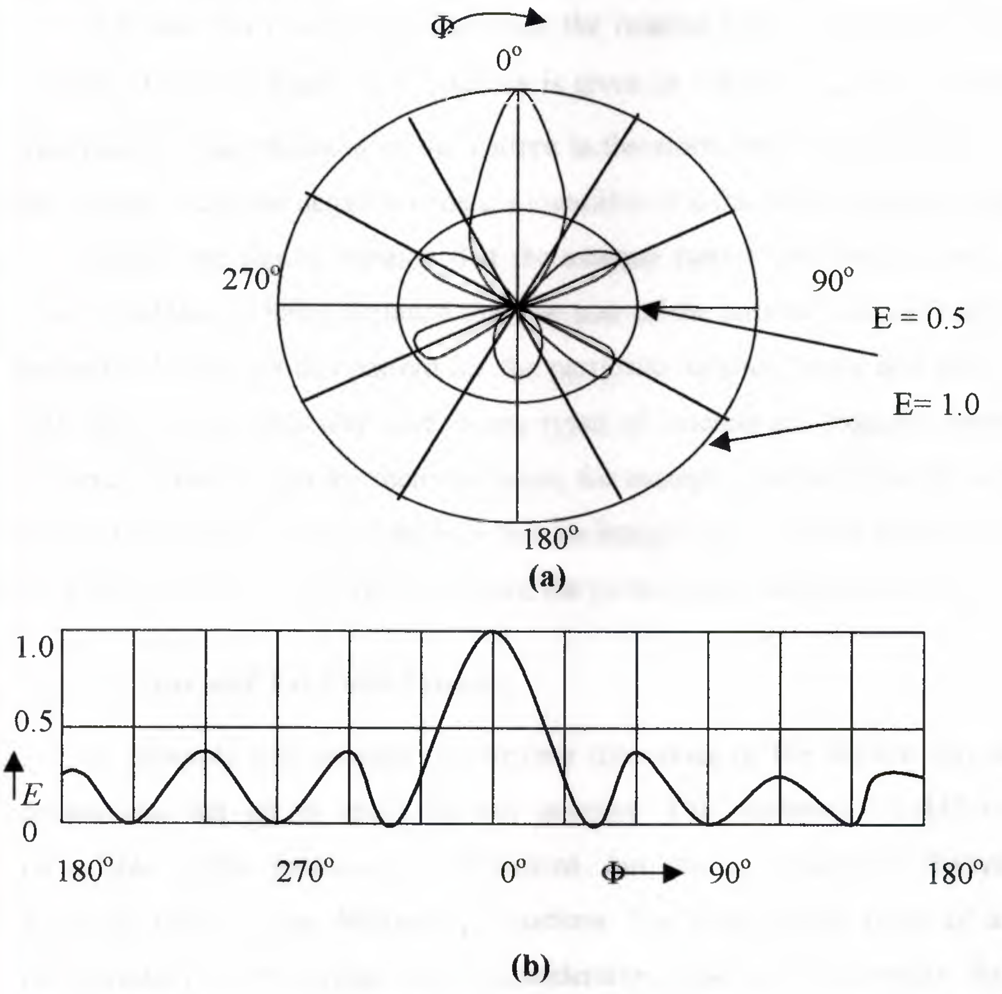


Figure 1-2 Comparison of plane pattern plotted in polar and rectangular form. The same pattern is represented in both cases and the coordinates are the same. Only the plot is different (a) polar (b) rectangular plot.

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

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

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

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

1.2.2 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 $1/r$, $1/r^2$, and $1/r^3$.

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

Practically in the far zone the field consists of only the term containing the $1/r$ factor. The field at great distance from the dipole behaves like the field of point source, with inverse-first-power dependence of the electric field intensity on the distance from the dipole. At very close distance, on the other hand, $1/r^3$ and $1/r^2$ terms becomes much larger than the $1/r$ term dominates the far-field region, as seen in Figure1-3.

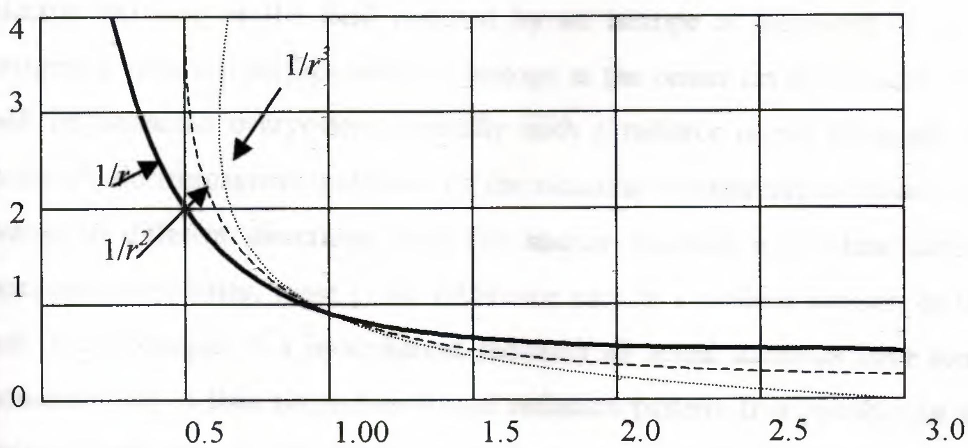


Figure1-3 Relative variation with distance of short-dipole static ($1/r^3$), induction ($1/r^2$), and radiation ($1/r$), field components (electric intensity).

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 Antenna Gain

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_t and is located at the center of a transparent (or imaginary) sphere of radius r meters, the power density over the spherical surface is shown bellow

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

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

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

$$P_{semi-isotrope} = \frac{P_t}{2\pi r^2} \quad (W/m^2) \tag{1-5}$$

Therefore, we get:

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

The last result shows that at any distance, r, the power density radiated by the semi-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 gain would be 4, and so on.

1.2.3.1 Directive Gain

The directive gain D, of an antenna is defined, in a particular direction, as the ratio of the power density radiated in that direction, at a given distance, to the power density that would be radiated at the same distance by an 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

$$D = \frac{P_{antenna}}{P_{isotrope}} \tag{1-7}$$

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

$$D = \frac{4\pi r^2 E^2}{377 P_t} = \frac{4\pi r^2 P_{antenna}}{P_t} \tag{1-8}$$

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

$$G = \xi D \tag{1 -9}$$

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

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

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

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

1.2.3.2 Gain in Decibels

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

1.2.3.3 Practical Significance of Power Gain

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

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

$$A_r = \frac{P_r}{P_i} \tag{1-12}$$

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

$$A_{ro} = \frac{\lambda^2}{4\pi} \Rightarrow A_r \frac{G\lambda^2}{4\pi} \tag{1-13}$$

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

$$D = \left(\frac{4\pi A_r}{\xi \lambda^2}\right) \tag{1-14}$$

Where D is the directive gain.

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

$$P_r = \xi\left(\frac{P_i D \lambda^2}{4\pi}\right) \tag{1-15}$$

Therefore the concept of the receiving cross section of an antenna is not a necessary one. It is possible to calculate the received-signal power without using Eq.1-23. In general, it is possible to measure the gain from the receiving cross signal, as we will see later.

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 Beamwidth 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.

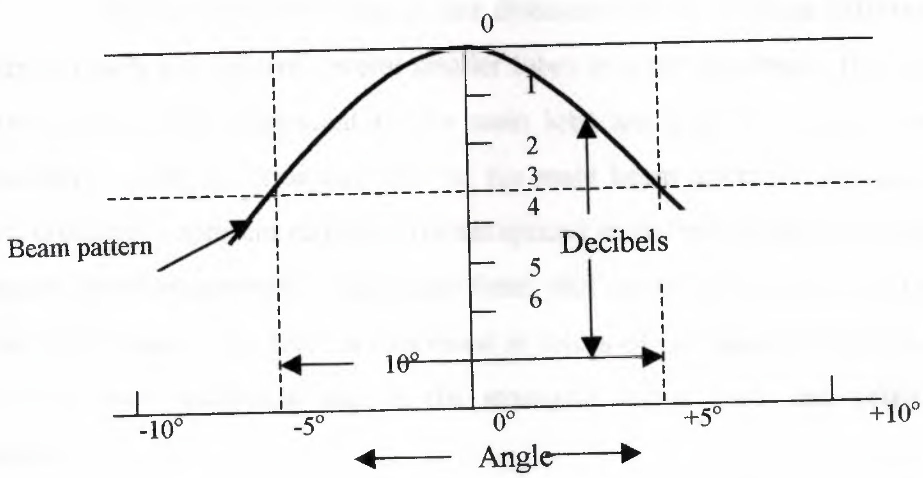


Figure 1-4 Determination of half-power (3dB-down) Beamwidth.

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 Beamwidth

If an antenna has a narrow beam and is used for reception, it can be used to determine the direction from which the received signal is arriving, and consequently it provides information on the direction of the transmitter. To be useful for this purpose, the antenna beam must be 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.

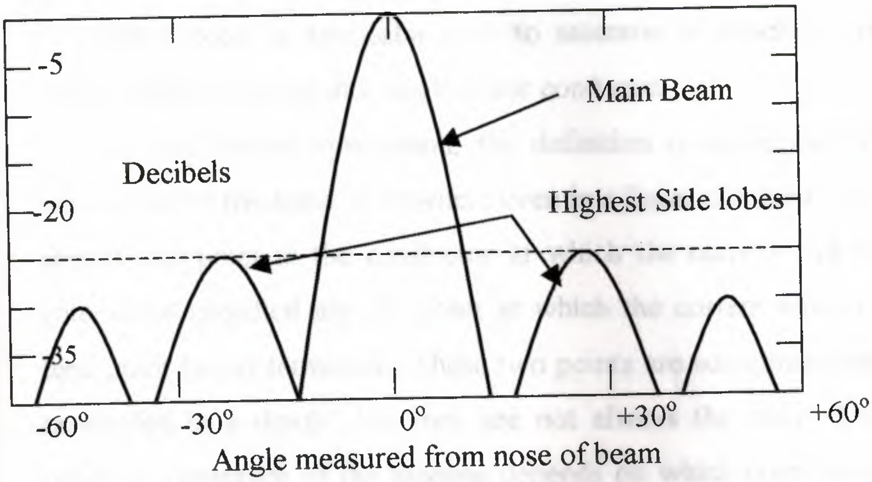


Figure 1-5 Decibel pattern plot, indicated side lobe level

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

$$R_r = \frac{P}{I^2} \tag{1-16}$$

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

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

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

The word maximum here refers to the effect current rms in that part of the antenna where it has its greatest value. It does not mean the peak value of the current at this point during the RF cycle, when Eq. 1-12 is used as the definition. In some texts, however, formulas for radiation resistance are written in terms of this peak value, which is the amplitude of the current sine wave. Equation 1-12 will yield a value of radiation resistance only half as great as the true value if the current amplitude is used for I, the correct formula in terms of the current amplitude I_0, is $R_r = 2P/I^2$, note that $I_0 = \sqrt{2I_{rms}}$.

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

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

Antennas always do have some 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 $I^2 = (R_0 + R_r)$ whereas the radiation power is $I^2 R_r$. Hence the antenna radiation efficiency ξ_r is given by

$$\xi_r = \frac{R_r}{R_0 + R_r} \qquad (1\text{-}17)$$

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

$$\xi_r = \frac{P_r}{P_0 + P_r} \qquad (1\text{-}18)$$

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

$$Z = \frac{E_i}{I_i} \tag{1-19}$$

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

$$Z_i = R_i = R_r + R_0 \tag{1-20}$$

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

1.2.9 Bandwidth

All antennas are limited in the range of frequency over which they will operate satisfactorily. This range is called the bandwidth of the antenna. Bandwidth is a concept that is probably familiar in other applications, sometimes by another name. For example, a television I-f amplifier must have a bandwidth of approximately $4MH_Z$ 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 $10 MH_Z$. 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.

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} P_n(\theta, \phi) d\Omega \tag{1-21}$$

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 successfully polarization is practically required at these frequencies.

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

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

CHAPTER 2

ANTENNA MEASUREMENTS

The antenna measurements are needed often to validate theoretical data, and sometimes to determine some values, which are very difficult to have by calculations. The antenna measurements almost lie within two basic categories: impedance measurements and pattern measurements. The first category (input impedance) deals with one of the most important antenna parameters, and the second one (radiation pattern) is a very broad and equally important one, with many subcategories, such as measurements of Beamwidth, minor lobe level, gain, and polarization characteristics.

Measurements of efficiency and noise may also be desired in some instances. Not all these possible measurements need to be made in every situation. It is seldom that the complete antenna pattern is measured, including side lobes and polarization characteristics in all direction, often, at the higher frequencies, it can be assumed that antenna ohmic losses are negligible, and therefore the radiation efficiency factor need not be measured. The Beamwidth, gain, and side lobe level are also frequently important, especially at the higher frequencies where directional antennas are often used. Polarization measurements are important only in special cases. For the second category, the input impedance is practically always important.

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

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

2. In many cases, it may be impractical to move the antenna from the operating environment to the measuring site.

3. For some antennas, such as phased arrays, the time required to measure the necessary characteristics may be enormous.

4. Outside measuring system faces an uncontrolled environment and it does not possess an all-weather capability.

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

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

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

2.1 Impedance Measurement

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

$$Z = \frac{V}{I} \tag{2-1}$$

The impedance is a complex quantity and it is expressed as

$$Z = R + jX \tag{2-2}$$

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

$$\tan\theta = \frac{X}{R} \tag{2-3}$$

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

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

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

$$R = \frac{V}{I}\cos\theta \tag{2-5}$$

And

$$X = \frac{V}{I}\sin\theta \tag{2-6}$$

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

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

2.1.1 Bridge Measurement Method

This method uses a bridge circuit and it is essentially a device for measuring unknown impedance by comparing it with known impedance. The basic arrangement consists of four impedances connected as shown in Fig 2-1. The detector may be any device that can respond to a current from the a-c signal applied to 1 and 4 terminals.

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

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

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

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

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

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

When the antenna is being measured, care must be taken that points 1 and 3 of the bridge are balanced with respect to the ground.

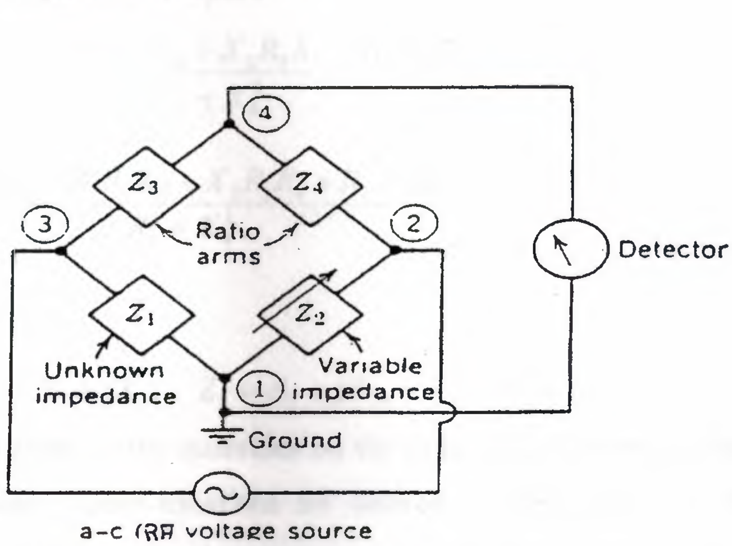


Figure 2-1 Impedance bridge circuit.

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

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

$$R_1 = \frac{R_2R_3R_4 - X_2X_3R_4 + X_2R_3X_4 + R_2X_3X_4}{R_4^2 + X_4^2} \qquad (2\text{-}9)$$

And

$$X_1 = \frac{X_2X_3X_4 - R_2R_3X_4 + X_2R_3R_4 + R_2X_3R_4}{R_4^2 + X_4^2} \qquad (2\text{-}10)$$

Where

$$Z_1 = R_1 + jX_1, \quad Z_2 = R_2 + jX_2, \quad Z_3 = R_3 + jX_3, \quad Z_4 = R_4 + jX_4$$

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

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

2.1.2 Standing-Wave Method

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

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

Where $|r|$ is the magnitude of the complex quantity and θ is the phase angle. The magnitude of the reflection coefficient is the ratio of the reflected $V_{0(r)}$ and incident $V_{0(i)}$ voltage (or current)

$$r = \frac{V_{0(r)}}{V_{0(i)}} \tag{2-12}$$

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

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

$$r = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{(Z_L / Z_0) - 1}{(Z_L / Z_0) + 1} \tag{2-13}$$

Where Z_0 is the characteristic impedance [3].

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

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

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

$$V_{Min} = V_{0(i)} - V_{0(r)} \tag{2-15}$$

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

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

Obviously the *VSWR* is a number equal to or greater than one. (It is equal to one when there is no reflected wave). From Eqs.2-12 and 2-13 it is apparent that *VSWR*=1 when r =O and therefore when $Z_0 = Z_L$.

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

$$Z_l = Z_0 \left(\frac{1+r}{1-r} \right) \tag{2-17}$$

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

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

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

In accordance with Eq.2- 17 the additional ingredient required is of course the phase angle as shown in Eq.2- 11. To solve this problem we can determine another quantity that is called the first voltage minimum *d* that has the following relationship with 0 as in

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

Where θ is in radian, and the phase constant $\beta = \frac{2\pi}{\lambda}$ (rad/m) and λ is the wave length (m), if the two quantities *(VSWR* and *d)* are measured Z_L can be calculated from Eqs.2-1 land 2-17 through 2-19. With Z_L known, we can find the impedance presented to a source at the transmission-line input terminals Z_i, from

$$Z_i = Z_0\left[\frac{(Z_L / Z_0) + j\tan\beta l}{1 + j(Z_L / Z_0)\tan\beta l}\right] \qquad (2\text{-}20)$$

When l - is the total length of line.

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

$$Z_i = Z_0\left[\frac{\left(\frac{1+r}{1-r}\right) + j\tan\beta l}{1 + j\left(\frac{1+r}{1-r}\right)\tan\beta l}\right] \qquad (2\text{-}21)$$

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

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

It is clear that the Eqs.2-1 1 and 2-19 show the complex reflection coefficient of the load *r* that can be found from measurement of *VSWR* and *d,* then the load impedance Z_L can be calculated while *r* is known.

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

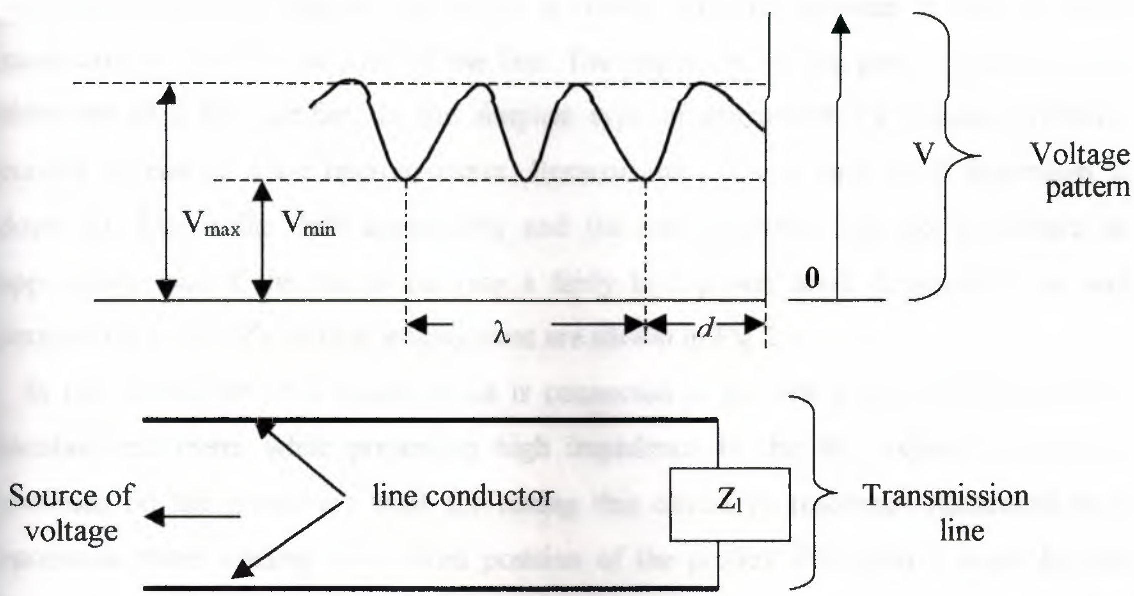


Figure 2-2 Diagram showing quantities to be measured in standing-wave method of impedance determination.

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

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

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

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

In this simple device a tuned circuit is connected to provide a d-c path through the rectifier and meter while presenting high impedance to the RF voltage. A knob is provided on the condenser shaft for tuning this circuit to resonance (indicated by a maximum meter reading for a fixed position of the probe). Provision is made for the box to slide smoothly on the slotted surface and to keep the probe properly positioned in the center of the slot. Lower powered source of RF signal for making the impedance measurement. This is made possible by employing in place of the microammeter, an amplifier. If the RE signal is modulates with an audio-frequency waveform an audio amplifier may be used.

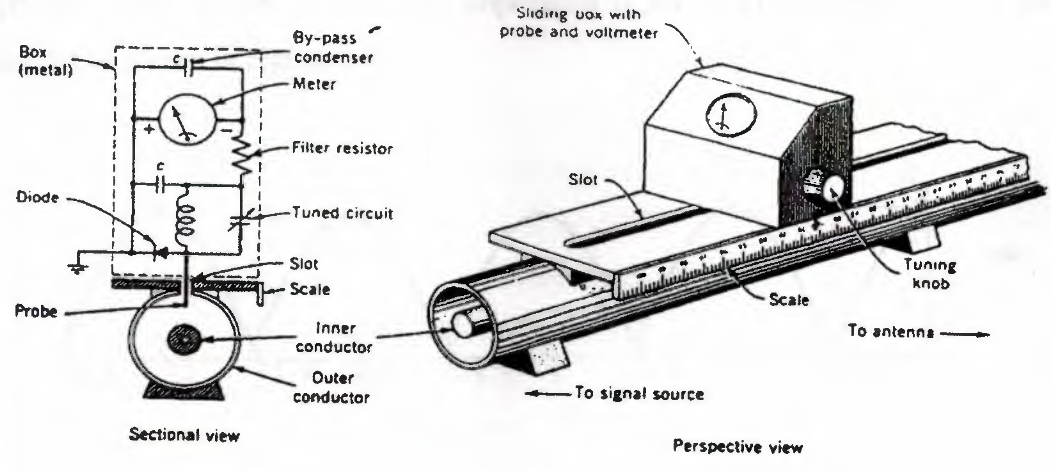


Figure 2-3 Slotted lines and probe voltmeter

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

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

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

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

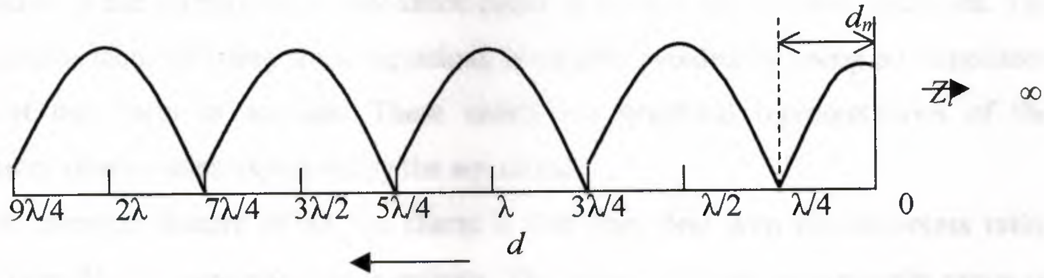


Figure 2-4 Standing-wave voltage patterns for $Z_L = 0$ condition.

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

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

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

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

2.2 Impedance Charts

When *VSWR* and the position of a voltage minimum d have been measured, calculation of the antenna input impedance could be made from the basic equations. The considerable labor of using these equations is usually avoided by using an impedance chart of one form or another. These charts are graphical representations of the impedance relationships expressed by the equations.

A common feature of all the charts is that they deal with dimensionless ratio, rather than directly with physical quantities. The ratios involved are primarily ratios of impedance, length, and voltage, specifically, the ratio of the load impedance of the line to its characteristic impedance (Z_L / Z_0),the ratio of the distance from the load to a voltage minimum to the wavelength (d/λ), and the ratio of maximum to minimum standing-wave voltages VSWR. Conversions from two of these ratios to the physical quantities Z_L and d, and vice versa, are readily made, since Z_0 and l are presumed to be known quantities. Because they deal with ratios, the same charts can be used for all characteristic impedances, frequencies, and absolute voltage levels.

The Smith chart is the most widely used impedance chart it was devised by P.H.Smith. It is in effect a special form of graph paper, for plotting impedances .The basic plan of the Smith Chart is shown in Fig.2-5.

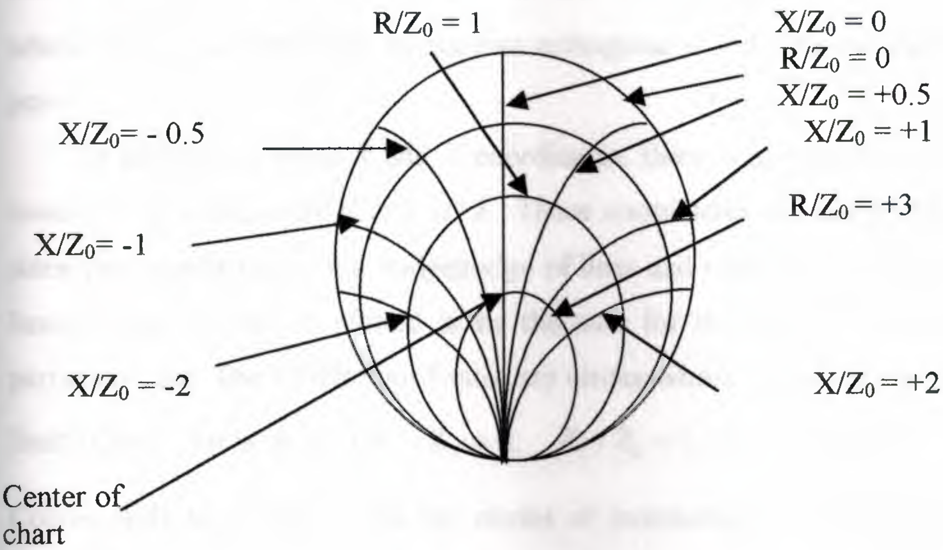


Figure 2-5 Basic construction of the Smith Chart.

Within circular boundary there are two orthogonal families or sets of the circles. Orthogonal means, roughly, perpendicular, in the sense that the circles of one family intersect those of the other family perpendicularly, that is, at right angles.

There is one point on the chart through which every circle of both families passes; this is the point at the exact bottom of the chart. The circles of one family pass through this point horizontally; those of the other family go through it vertically. The first of these families of circles represent constant values of the ratio R_L / Z_0, and will be referred to as *R* circles. The second family of circles corresponds to constant values of X_L / Z_o and will be referred to as the *X* circles. R_L And X_L are of course the resistive and reactive components of the load impedance, Z_L. The *X* circles to the left of the centerline are negative values of X_L / Z_0, representing capacitive reactance, and those on the right are positive, representing inductive reactance. The vertical centerline is the $X_{L=0}$ line. The *R* circle that passes through the exact center of the chart represents R_L / Z_L equal to1. Therefore the exact center point of the chart corresponds to a load impedance that is a pure resistance of value equal to the characteristic impedance; that is, at this point R_L / Z_L and $X_L = 0$. This point is the load value that results in a unity value of *VSWR*.

These two families of circles are in effect a system of coordinates, one coordinate set representing the resistive component and the other set the reactive component of the load impedance. Any particular point on the chart corresponds to load impedance, Z_L whose components are given by the two orthogonal *R* and *X* circles that intersect at that point.

In addition to these *R* and *X* coordinates, there is another set of coordinates for measured quantities *VSWR* and d/λ. These coordinates are not printed on the chart, since they would result in a hodgepodge of lines and make it difficult to read the chart. Instead, they are to be plotted in by the user for the specific measured values in a particular case. The *VSWR* coordinates are circles whose centers are at the center of the Smith Chart, that is, at the ($X_L / Z_0 = 0, \quad R_L / Z_0 = 1$) point. This point

Corresponds to *VSWR*=1 and the circles of increasing size correspond to increasing values of *VSWR*. The largest of these circles forms the outer boundary of the chart represents an infinite *VSWR*.

The d/λ coordinates are radial lines emanating from the center of the chart. A circular scale of values of d/λ is provided on the outer periphery of the chart. The full circle spans the range from $d/\lambda = 0$, at the top of the chart, through $d/\lambda = 0.25$ at the bottom of the chart, to $d/\lambda = 0.5$ again at the top; thus the complete circle of values corresponds to values of *d* going from zero to 0.5 wavelength.

The values increase counterclockwise, when *d* is the distance from the antenna terminals to the first voltage minimum. This direction on the scale is usually marked wavelength toward the load, which refers to the location of the null when the load is short circuited, with respect to the voltage minimum with the short removed. A complementary scale is also usually provided, marked wavelengths toward the generator. This scale increases in the opposite direction and corresponds to the distance from the voltage minimum (short removed) to the nearest null (load shorted) in the direction of the generator (signal source).

An example of this method, it is supposed that *VSWR* has been measured to be 3.5 (unit less) and d/λ also has been measured to be 0.16 (unites).

It is required to find Z_L if $Z_0 = 50 \quad (\Omega)$.

By using the following steps

1- Circle whose center is at the center of Smith Chart, passing through the VSWR=3.5 point on the vertical centerline, will be drawn, as shown in Figure 2-6.

2- Determine the d/λ point on the chart, and a radial line will be drawn from the center of the chart to this point.

3- At intersection of this circle and radial line a pair of the X and R circles will be found.

4- 4-From R and X circles the values of R and X are obtained to be [X=0.6 and X=1.4].

5- From R and X, R_L and X_L are calculated as $R_L = R\,Z_0$, and $X_L = X\,Z_0$.

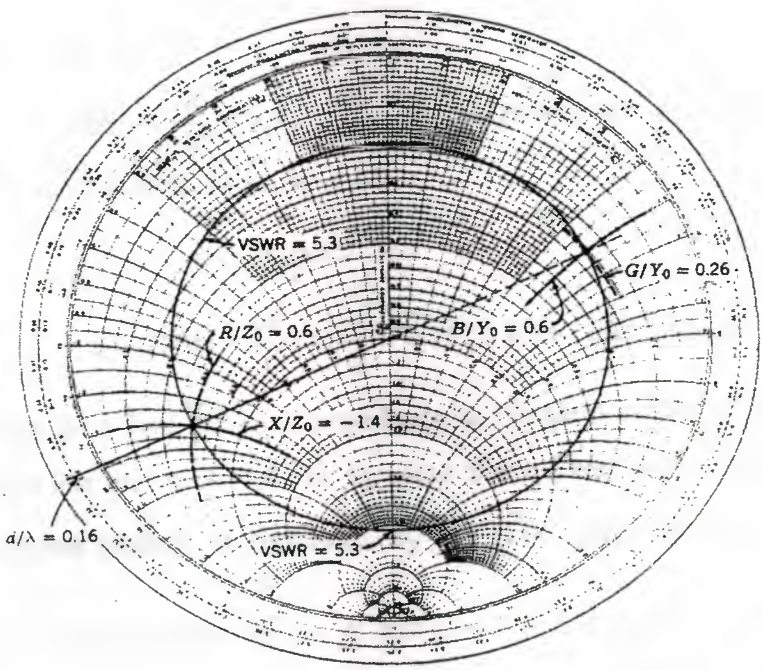


Figure 2-6 Example of impedance and admittance calculation, using Smith Chart.

Therefore, the antenna input impedance in this ease consists of a resistive component $R_L = 0.6\,Z_0$ and negative (capacitive) reactance component $X_L = -1.4\,Z_0$, while the characteristic impedance is 5O(Ω), then R_L =3O(Ω), and X_L = -70 ohms, so that Z_L=(3O-j7O) (Ω).

The previous example illustrates the basic use of the Smith Chart. It can also be sued to solve impedance-matching problem, for this purpose it is often convenient to work with admittance, rather than impedance, which found on the chart for the knowledge no more, but it is out of this studying scope. It is useful to compare this result with the calculation method by assuming that Z_L is known with

$Z_L = (30 - j70) \qquad (\Omega)$

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

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

From which we find that

$$r = 1.46\angle 64$$

When

$$\theta = 64$$

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

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

Equation 2-19 is used to find d/λ. As

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

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

Another example is to find the input impedance at the short circuit of a 50 (Ω)to loss less transmission line that is $\lambda = 0.1\ m$, by using Smith Chart, and 7 compare the result with the calculation method. In this case, $Z_L = 0\ (\Omega)$ (short circuit), $Z_0 = 50\ (\Omega)$, $\lambda = 0.1m$ toward the generator, at $X = 0$, and $R = 0(\Omega)$, it is the lop of the chart, from the top toward the generator put P_1 point, at point P_1 read $VSWR = 0$ and $R = 0, (\Omega), \Rightarrow X_1 = j\,0.725(\Omega)$ as shown in Fig.2-7. Thus,

$Z_1 = 50 \times j0.725 = j36.3, \mathrm{R} = 0\,(\Omega)$, (The input impedance is purely inducting).

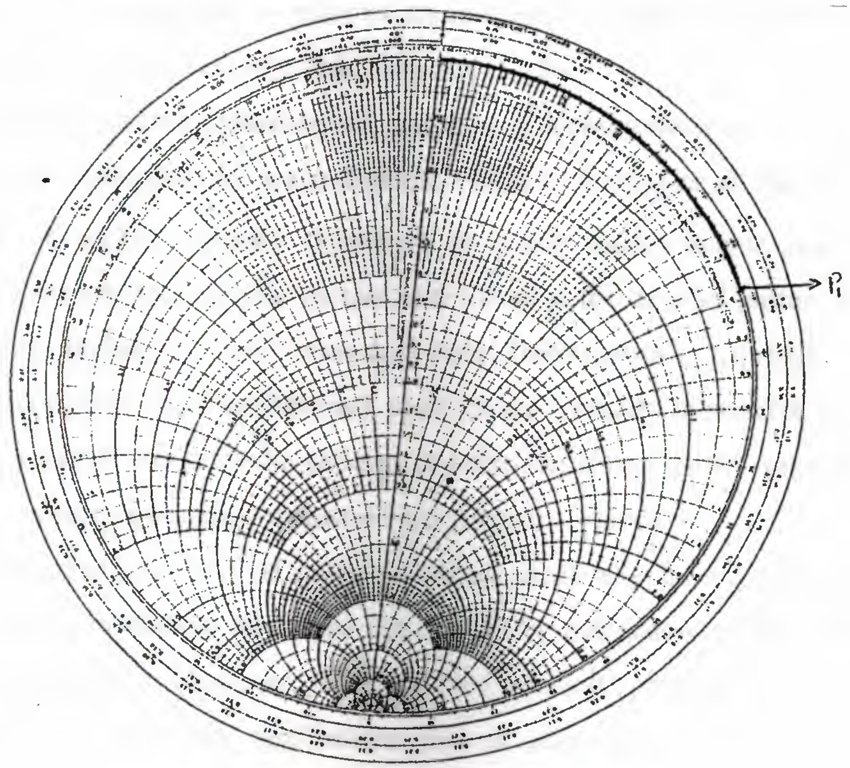


Figure 2-7 Smith Chart to the example.

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

$$Z_i = Z_0\left[\frac{(Z_L/Z_0)+j\tan\beta\ell}{1+j(Z_L/Z_0)\tan\beta\ell}\right]$$

To gather with, $Z_L = 0$, we get

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

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

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

2.3 Pattern Measurements

The radiation or reception pattern in Sec. 1.2.2 is a description of the field strength or power density (in the transmitting case), at a fixed distance from the antenna, as a function of direction. The direction is conventionally expressed in terms of the two angles, θ and ϕ, of a spherical coordinate system whose origin is at antenna.

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

A complete pattern measurement, consists of measurement of the field strength and direction (polarization) for many different values of the angles θ and ϕ. In practice, the number of specific angular directions in which measurements must be made depends on the complexity of the pattern and the need for detailed pattern information in the particular application. Quite often only limited information is required.

Since complete three-dimensional patterns are virtually impossible to plot on a plane sheet of paper, and since the patterns in particular planes usually provide adequate information, patterns are usually measured and plotted in planes.

Also the horizontal and vertical patterns suffice practically for all applications. The main-lobe pattern in oblique directions can usually be adequately estimated from these principal plane patterns. However, if the detailed side-lobe patterns are of concern, as they may be in some radar applications and in other special cases, oblique-plane patterns will be of interest, for the side lobes in these planes cannot be inferred from the principal-plane patterns.

2.3.1 Pattern Measurement Method

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

Two procedures are possible for measuring the pattern in a particular plane. In the first procedure the primary antenna can be held stationary, then it is fixed in both position and aiming of the beam while the secondary antenna is transported around it, along a circular path at a constant distance. If the secondary antenna, directional is kept aimed at the primary antenna, so that only the primary antenna pattern will affect the result. In this procedure the primary antenna is most often the transmitting member of the pair. Field-strength readings and direction of the secondary antenna from the primary antenna are recorded at various points along the circle. By measuring the field at enough points, a plot of the pattern of the primary antenna can be made. Examples of such a plot in both polar and rectangular forms are shown in Fig.2-2.

In the second procedure both antennas are held in fixed positions, with suitable separation and with the secondary antenna beam aimed at the primary antenna. If the both antennas are in the horizontal plane, the primary antenna is then rotated about a vertical axis through an angular sector in which it is desired to measure the pattern (usually 360 degrees). In this method it is most convenient to transmit with the secondary antenna, so that both the field strength readings and the direction measurements can be made at the primary antenna. The measurements at suitable number of fixed points, to take the readings; or, if a pattern recorded on a chart that plots the pattern automatically, these pattern recorders are commercially available. Consider that the antenna under test is situated at the original of the coordinates of Fig.2-8, with the Z-axis vertical. Then, pattern of θ and ϕ components of the electric field (E_θ and E_ϕ) are measured as function of along constant ϕ circles, where θ is the longitude or azimuthal angle which complement of the latitude angle.

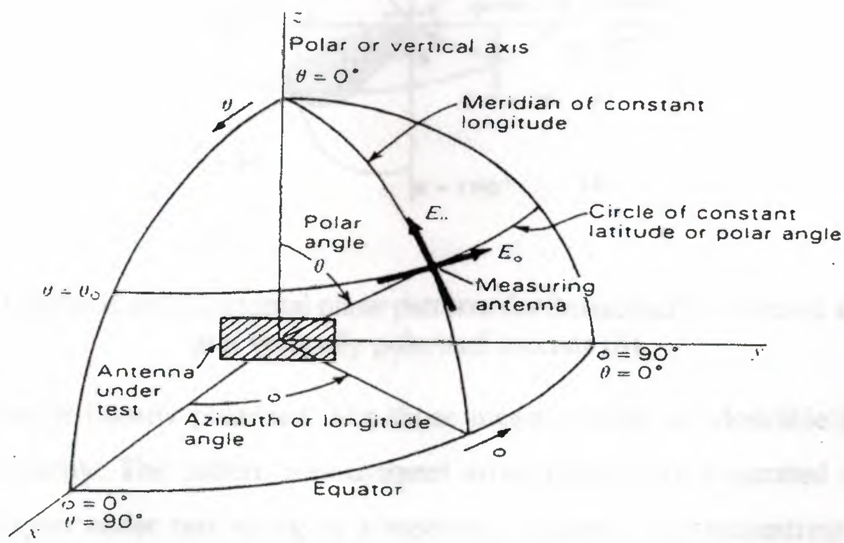


Figure 2-8 Antenna and coordinates for pattern measurements.

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

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

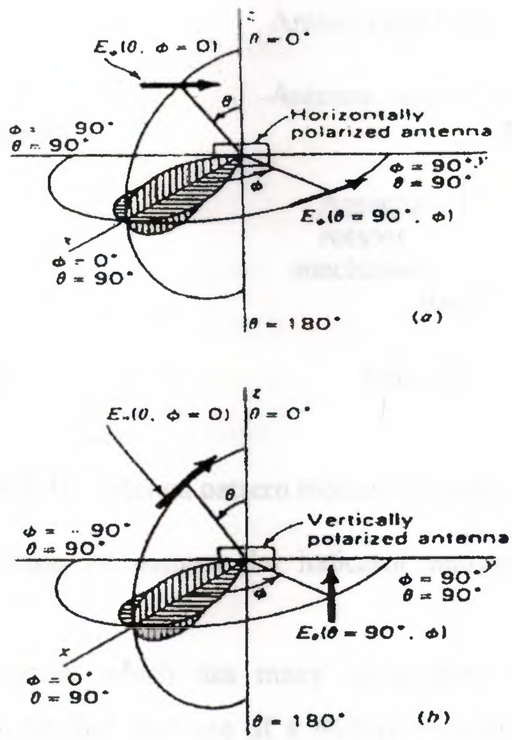


Figure 2-9 Vertical and horizontal plane patterns for horizontally polarized antenna (a) and vertically polarized antenna (b).

If the antenna is linearly polarized, like those measurements are desirable to establish polarization purity. The pattern measurement arrangements are illustrated in Fig2-10, with the antenna under test acting as a receiving antenna, The transmitting antenna is fixed in position and the antenna under test is rotated on a vertical axis by the antenna support shaft. The $E_\phi(\theta = 90, \phi)$ pattern is measured by rotating the antenna support shaft with both antennas horizontal as in Fig.2-9. To measure the $E_\phi(\theta., \phi = 0)$ pattern, the antenna support shaft is rotated with both antennas vertical.

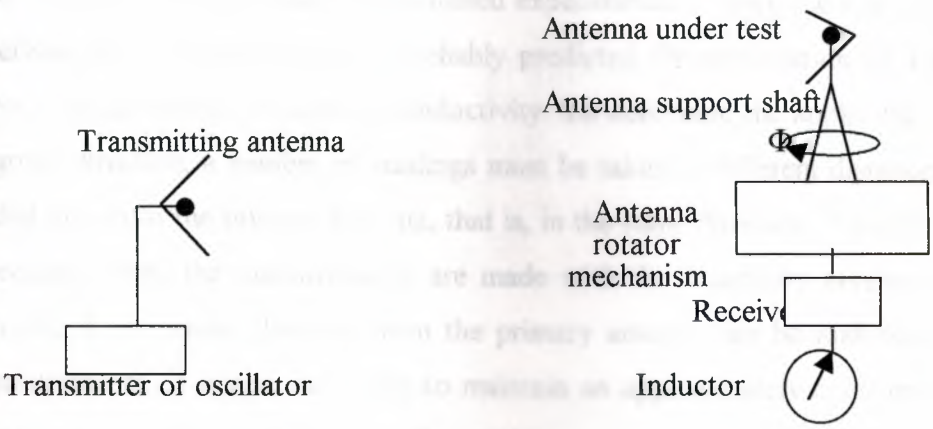


Figure 2-10 Antenna pattern measuring arrangement.

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

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

2.3.2 Low Frequency Pattern Measurements

As we have mentioned in Sec.2.3. 1, the first (fixed primary antenna) procedure is used to measure the pattern for low frequencies. In this case, the secondary antenna may be mounted on the roof of a panel truck, on a helicopter or airplane, or on ship or boat if the primary antenna is on another ship or on an island.

When a truck is used, it may not be possible to remain at constant distance from the primary antenna, because of obstruction or inaccessibility of certain areas. If the field strength readings are taken at different distances in the different directions, they must be corrected to a constant distance to plot a meaningful pattern.

The correction factor must be determined experimentally, since the law of field strength decrease with distance cannot be reliably predicted for propagation of a surface wave over irregular terrain of varying conductivity. To determine the applicable correction, in a given direction, a number of readings must be taken at different distance on the same radial line from the primary antenna, that is, in the same direction. This procedure is not necessary when the measurements are made with the secondary antenna on a ship or aircraft, if a constant distance from the primary antenna can be maintained during the measurements. It is also necessary to maintain an approximately constant height of the secondary antenna above the ground or water.

2.3.3 High Frequency Pattern Measurements

At frequencies above about MH_z, an antenna pattern is customarily obtained by rotating the primary antenna. So that it is especially important to make the field strength measurements at points that are in the clear, not too close to large buildings or power and telephone lines, for instance.

When the pattern is to be measured by rotating the primary antenna, both antennas should be located so that they have an unobstructed view of each other, and also have the required separation to insure a far-field measurement. A further requirement is that the area between the antennas be clear of sizable reflection objects, not only in the direct line between them but for an appreciable distance on both sides. This requirement is important if an accurate measurement of low amplitude side lobes is to be made.

The secondary antenna is indicated to be the transmitting antenna, which is the customary arrangement because it permits all the measurement to be made at a single location, that is, at the primary antenna. If a large reflecting object illuminate by the secondary antenna, some signal will be reflected toward the primary antenna, arriving at the angle a off the in-line direction between the two antennas. This signal will be considerably less than the inline signal and will not seriously affect the measurement in the main lobe of the primary antenna, when the reflected signal will be received in the side lobe portion of the primary antenna pattern.

When the primary antenna is rotated to allow measurement of its side lobe pattern at the angle a off axial, its main lobe will point directly at the reflecting object, as shown in the diagram in Fig.2-11. Then the reflected signal received in this way may be comparable to or even in excess of the in-line signal received in the side lobe, so that a considerably erroneous measurement will result.

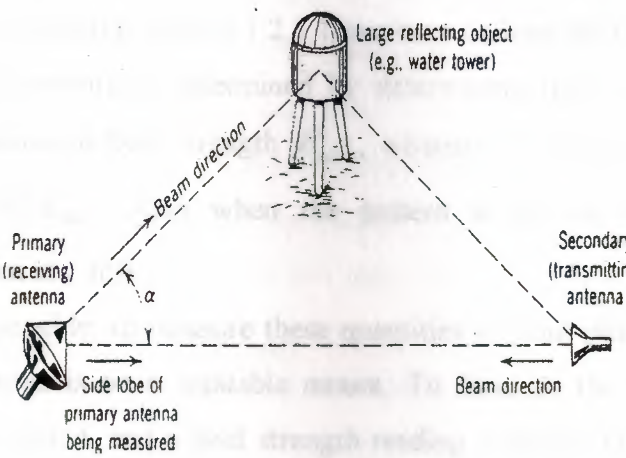


Figure 2-11 Effect of nearby reflecting object on pattern measurement.

This effect is minimized by using a secondary antenna that is fairly directional, with high gain in the direction of the primary antenna and considerably has very small, or perhaps even a null, gain in the direction of the reflecting object. This requires that the secondary antenna be quite sizable and expensive. If there is just one major reflecting object in a troublesome position, a null of the secondary antenna may be directed toward the object, if this is possible without too greatly reducing the radiation in the desired direction or giving it an incorrect polarization. It is essential for the secondary antenna to have the same polarization as the primary antenna. Ideally, the polarization of the secondary antenna should be controllably variable, so that the pattern of the primary antenna can be investigated for all polarization. This is especially important in applications where very low side lobes are important, because side lobes may sometimes have a polarization different from that of the main beam part of the pattern.

Other possible remedies present the reflecting object problems, is to interpose absorbing material between the secondary antenna and the object, or between the object and the primary antenna. Another is to erect a reflecting barrier that will intercept the radiation going to or from the object and reflect it in some harmless direction. This barrier is usually a flat sheet of solid metal or mesh material set at an angle that will direct the reflected waves away from the primary antenna.

2.4 Beamwidth and Side-Lobe-Level Measurement

Measurements of Beamwidth and side lobe level are automatically obtained if the antenna pattern is measured and plotted on graph paper, either manually or with a pattern recorder. From the Section 1.2.5.1, we have defined the Beamwidth and we have said that the Beamwidth is determined by determining the maximum power density P_{Max}, or the maximum field strength E_{Max}, whereas the Beamwidth is determined at $0.5 P_{Max}$ or $0.707 E_{Max}$. Also when the pattern is plotted by ordinate scale the Beamwidth is then at - 3dB.

It is also possible, to measure these quantities without plotting the pattern, when the primary antenna is on a rotatable mount. To measure the Beamwidth, the beam maximum is first found, and a field strength reading is taken. The reading of the angle setting is also taken. Then the antenna is rotated in either direction until the meter reading corresponds to half the power level of the beam maximum, or 0.707 times the voltage level. At this point the angle reading is again taken. The difference between these two angles is the half of the Beamwidth, if the beam is symmetrical. As a check, the antenna is rotated to the other side of maximum, until the power reading is again half maximum, and the angle reading is taken. The difference between the two half-maximum angle readings is the Beamwidth.

To measure the side lobe level, the antenna is rotated and the meter reading is observed as the side lobe portion of the pattern is traversed. The reading is noted at the maximum of the highest side lobe. The ratio of the power reading in this highest side to the beam maximum power reading, or the ratio of the squares of the voltage readings give the side lobe level, expressed as a fraction. Ten times the logarithm of this fraction gives the side lobe level in decibels, but we should note that the negative value of the result is caused because the logarithm of a number less than one is negative.

2.5 Gain Measurements

In principle, the directive gain can also be determined from the pattern measurement, in accordance with Eqs.1-10 and 1-11. This method is useful for antennas whose patterns are simple, but it is of limited use for high gain antennas with complicated side lobe patterns, or for multilobed pattern, because the integration of Eq. 1-10 is a solid angle integral over the entire three dimensions pattern of the antenna, rather than over a plane pattern. Since the patterns as measured cannot ordinarily be expressed as analytic functions, numerical integration is required. This is a very tedious procedure if carried out manually. The computation may be programmed for a high speed digital electronic computer if such measurements are being made frequently, but the programming is too costly if it is to be used only once or a few times. This method yields the directive gain as defined in Sec.1.2.4.1.

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

2.5.1 Absolute Field Strength Method

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

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

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

$$F=\frac{E}{E_d} \tag{2-23}$$

Where E_d is the field strength in the free space, and E is the measured field strength. On the other hand, if the measurement is made using Eq.2-22 with the antenna in its operating location, the gain measured is the effective gain of the antenna in combination with its environment. When earth reflection is involved, this gain will depend on the elevation angle of the measuring point, as well as on the antenna height and the reflection coefficient of the earth.

If these factors are known or can be measured, the gain of the antenna by itself can be deduced. If a value of field intensity is actually measured by analysis of the reflection interference effect it may be calculated that the field density is great or less than the value that would have been measured if free space propagation existed, by the propagation factor F, as defined by Eq.2-23, in term of this factor. Equation 2-22 can be rewritten so that it expresses the free space gain of the antenna even if the field intensity E or the power density P is measured under nonfree space conditions

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

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

$$P_i = \frac{P_r}{A_r} = \frac{4\pi \mathrm{P_r}}{\xi \mathrm{D_r} \lambda^2} \tag{2-25}$$

Which is a rearrangement of Eqs.1-23, with the receiving antenna directivity denoted by D_r, and P_i, is the receiving power density. This formula can be used only if the effective area A_r of the receiving antenna is known and if the received power P_r can be measured.

2.5.2 Gain Measurement by Using Standard Antennas

A gain standard antenna is one whose gain is accurately known so that it can be used in measurement of other antennas. Certain simple forms of antenna can be constructed to have gain of known amount.

Alternatively, a standard antenna can be obtained by a gain measurement, that does not require an antenna of known gain. This method, in its simplest form, does require two antennas that are identical. One is used as a transmitting antenna and the other for receiving, separated by a distance R .The transmitted power P_t and the receiving power P_r are both measured. The directivity of the antennas can then be calculated by an application of Eqs.2-24 and 2-25. If the second expression given for P in Eq.2-25 is substituted into Eq.2-22, then the result is

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

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

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

this procedure is likely to be successful when $F \cong 1$ that is, under effectively free space conditions or no earth reflection interference effects. It can also be applied successfully under conditions that permit accurate calculation of F, as an example, when reflection occurs from a smooth water surface between the two antennas [3].

2.5.3 Gain Measurement by Comparison

At high frequencies the most common method of gain measurement is by comparison of the signal strengths transmitted or received with the unknown gain antenna and a standard gain antenna. This comparison is most conveniently made on a pattern range, with the same general setup of equipment used in pattern measurement and with the secondary antenna transmitting. The gain of this antenna need not be known, nor does the propagation factor, F, affect the result as long as F does not vary appreciably over the apertures of the primary antenna and the gain standard. All that is required of the secondary antenna and its associated transmitter is that they do not vary the amount or frequency of the radiated power in the direction of the primary antenna throughout the measurement procedure.

Since the gain of the unknown antenna is ordinarily higher than the gain of the gain standard, the standard antenna is first connected to the receiver, and aimed at the secondary antenna. The receiver gain is adjusted to give a convenient output meter indication. Then the antenna whose gain is to be measured is connected in place of the standard gain antenna, and attenuation is introduced into the transmission line between the antennas and received until the output indication is the same as it was with the gain standard antenna. If the attenuation factor L, expressed as the power ratio greater than one, the gain of the unknown antenna G_a is

$$G_a = LG_s \tag{2-28}$$

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

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

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

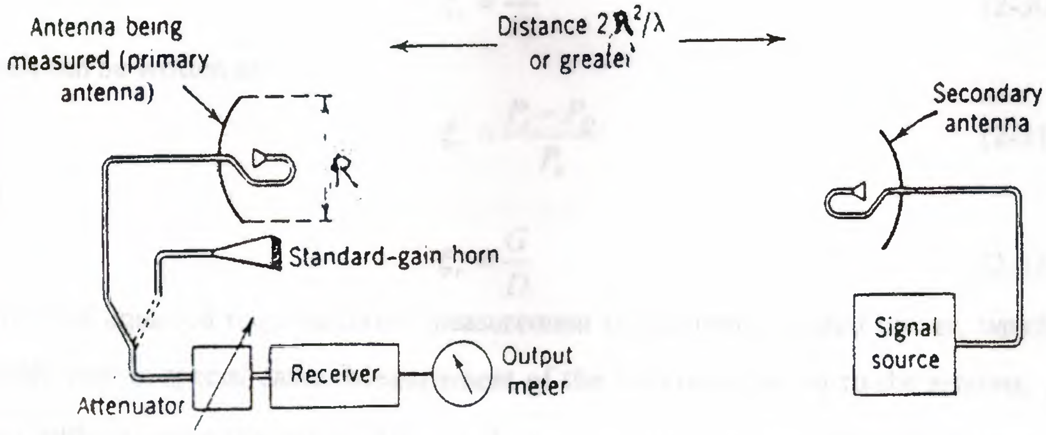


Figure 2-12 Set tip for gain measurement by comparison method.

It is essential in this method of gain measurement that both the unknown and the standard antenna are equivalently impedance-matched to the load presented to them by the transmission line The best way to insure this to make *VSWR* measurements with each for a flat line *(VSWR=1)*. This method basically compares antenna power gains, but directivities may also be determined if the antenna radiation efficiency factors are known.

2.6 Antenna Efficiency Measurement

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

2.6.1 Radiation Efficiency

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

$$\xi_r = \frac{P_r}{P_t} \tag{2-30}$$

Which can be written as

$$\xi_r = \frac{P_t - P_D}{P_t} \tag{2-31}$$

Or

$$\xi_r = \frac{G}{D} \tag{2-32}$$

The first equation requires direct measurement of the total radiated power, which is possible only in special cases. Measurement of the total input power to the antenna, P_t, is not difficult, since this power flows in the transmission line connecting the transmitter to the antenna.

The second equation requires measurement of the dissipated power, P_D. This can sometimes be done, especially at low frequencies, by measuring the resistance of conductors in which current flows, and multiplying these resistance's by the square of the current. The third equation is not directly useful, but it may be combined with Eq.2-24 to obtain

$$\xi_r = \frac{4\pi \mathrm{R}^2 E^2}{377 P_t^2 F^2 D} \tag{2-33}$$

The last equation is especially useful at VHF with short vertical grounded radiators. For these antenna, D is already found, and we assume that $F \cong 1$. Therefore, if the total input power to the antenna, P_t, can be measured, and also the field strength E at distance D from the antenna, the radiation efficiency can be determined. Since the definition of ξ_r requires E to be the radiated field strength, R must be a distance satisfying the far field criterion; that is, R must be greater than $2d_a^2 / \lambda$, or greater than λ.

2.6.2 Aperture Efficiency Measurement

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

$$D = \left(\frac{4\pi\, A_r}{\xi_r \lambda^2} \right) \tag{2-34}$$

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

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

2.7 Radiation Resistance

The radiation resistance of an antenna is defined by Eq.1-12 it is the ratio of the power radiation to the square of the antenna current (rms. value). As mentioned, it is in a sense a fictitious quantity, sense it is referred to an arbitrary point in the antenna and has different values for difference points. It is conventional to refer it to the current maximum point, although it may also be referred to the feed point. In many cases the two points are one and the same, an example is the case of a current fed dipole as mentioned in Sec. 1.2.7. When referred to the current maximum point, it is sometimes known as the loop radiation resistance, since a current maximum is also called a current loop.

If there is no ohmic loss in the antenna, that is, if all the input power is radiated, then the radiation resistance referred to the feed point is equal to th~ resistive component of the antenna input impedance. In this case, measurement of the antenna input impedance constitutes a measurement of its radiation resistance. If the feed point is not a current maximum point, the loop radiation resistance may be calculated from the feed point radiation resistance from the formula

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

Where I denotes the rms currents at the points indicated by the subscript notation.

If there is appreciable ohmic loss, so that the antenna radiation efficiency factor ξ_r is less than one, from Eqs.1-13 and 1-16 the radiation resistance is found to be

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

Where R_i, is the input resistance, that is, the resistive component of the input impedance. It is apparent that the radiation resistance is sometimes a rather nebulous concept and not always easily measurable. It has no meaning for antenna in which there is no clearly defined current value to which it can be referred.

2.8 Polarization Measurement

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

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

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

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

CHAPTER 3

TECHNIQUES FOR VHF AND UHF ANTENNA

3.1 System-Planning Objectives

The design of antennas for a radio link must provide an adequate signal-to-noise ratio at the receiver. The necessary signal-to-noise ratio will depend on the nature of the information to be transmitted and the grade of service that is required. A power budget must be drawn up to determine the total antenna gain and input power needed in the system. The antenna engineer must decide how the necessary gain can be obtained and how it should be divided between the two ends of the link, In many point-to-point applications the most economical design is obtained by using transmitting and receiving antennas of equal gain. Mobile or portable stations do not generally allow the use of high-gain antennas, so as much gain as possible must be obtained from the base-station antenna.

The electromagnetic spectrum is a limited resource, and restricting the field strength, which may be laid down outside the area where communication is required, controls its use. This often implies a limitation on the permitted effective radiated power (ERP) both inside and outside the main-beam direction of the transmitting antenna. The sensitivity of receiving antennas must be restricted in directions outside the main beam to prevent interference being caused by the reception of signals from stations other than that intended which use the same or an immediately adjacent frequency. The system designer and antenna engineer must acquaint themselves with the requirements of the regulatory authority (Federal Communications Commission or other government agency) to make sure that a new system will work without suffering or causing interference

To allow the largest possible number of links to be established in a given geographical area on a particular frequency band, it is desirable that each station use a very low transmitter power together with a highly directive high-gain antenna. By this means the area over which any station lays down a field, which may cause interference to others, is limited. A specification template for a radiation pattern defines the minimum acceptable radiation-pattern performance for an antenna and leaves scope for the designer to decide how to achieve it.

3.1.1 Reliability

A communication link or system must provide an adequate level of reliability. A link may become unusable if the signal-to-noise ratio falls below the design level; it is important that the design objectives for a system specify the fraction of time for which this may occur. A downtime of 0.01 percent or even less may be necessary for a link to a lifesaving emergency service, but 1 percent downtime may be as little as can be economically justified for a radiotelephone in a boat used for leisure-time fishing.

Fading due to statistical fluctuations in the propagation path is usually guarded against by a fade margin in the power budget. In a severe case a diversity system may be used to reduce the impact of fading on system reliability. This takes advantage of low correlation between fading events over two physically separate paths, at two frequencies, or for two polarizations. Other important causes of system failure are given below.

3.1.2 Wind-Induced Mechanical Failures

The oscillating loads imposed by wind on antennas and their supporting structures cause countless failures. Aluminum and its alloys are very prone to fatigue failure, and the antenna engineer must be aware of this problem. To achieve real reliability:

1 Examine available wind-speed data for the location where the antenna is to be used.

2 Consider possible local effects such as turbulence around tall buildings or accelerated airflow over steeply sloping ground.

3 Use derated permissible stress levels to allow for fatigue.

4 Check antenna designs for mechanical resonance.

5 Damp out, stiffen up, or guy parts of the antenna system, which are prone to vibration or oscillation.

Aerodynamic and structural analysis can be carried out on a desktop computer workstation using finite-element methods, allowing designers to check their calculations and to optimize the shape of critical antenna components. A wide variety of commercial software is now available, and every organization engaged in antenna design needs to have access to a set of programs appropriate to the complexity of the work in which it is engaged.

3.1.3 Corrosion

The effects of corrosion and wind-induced stresses are synergistic, each making the other worse. They are almost always responsible for the eventual failure of any antenna system. Every antenna engineer should also be a corrosion engineer; it is always rewarding to examine old antennas to see which causes of corrosion could have been avoided by better design. The essence of good corrosion engineering is:

1 Selection of suitable alloys for outdoor exposure and choice of compatible materials when different metals or alloys are in contact .A contact potential of 0.25 V is the maximum permissible for long life in exposed conditions.

2 Specification of suitable protective processes-electroplating, painting, galvanizing, etc.

There is an enormous variety in the severity of the corrosion environment at different locations, ranging from dry, unpolluted rural areas to hot, humid coastal industrial complexes.

Plastics do not corrode, but they degrade by oxidation and the action of ultra-violet light. Additives reduce these effects to the bulk materials.

3.1.4 Ice and Snow

The accumulation of ice and snow on an antenna causes an increase in the input voltage standing-wave ratio (VSWR) and a reduction in gain. The severity of these effects, caused by the capacitive loading of antenna elements and absorption of radio frequency (RF) energy, increases as the frequency rises.

The fundamental design precaution is to ensure that the antenna and its mounting are strong enough to support the weight of snow and ice, which will accumulate on them. This is very important, as even when the risk of a short loss of service due to the electrical effects of ice can be accepted, the collapse of even a part of the antenna is certainly unacceptable. Ice falling from the upper parts of a structure onto antennas below is a major cause of failure; safeguard against it by fitting lightweight antennas above more solidly constructed ones or by providing vulnerable antennas with shields to deflect falling ice.

In moderate conditions, antennas may be provided with radomes to cover the terminal regions of driven elements or even whole antennas. As conditions become more severe, heaters may be used to heat antenna elements or to prevent the buildup of ice and snow on the radome. A wide range of surface treatments has been tried to prevent the adhesion of ice; some of these show initial promise but become degraded and ineffective after a period of exposure to sunlight and surface pollution. Flexible radome membranes and nonrigid antenna elements have been used with some success.

3.1.5 Breakdown under Power

An inadequately designed antenna will fail by the overheating of conductors, dielectric heating, or tracking across insulators. The power rating of coaxial components may be determined from published data, but any newly designed antenna should be tested by a physical power test. An antenna under test should be expected to survive continuous operation at 1.5 times rated mean power and at 2 times rated peak voltage; for critical applications even larger factors of safety should be specified. For multichannel systems with n channels:

$$P_{average} = P_1 + P_2 + \dots$$

$$= nP_{channel} \qquad \text{If all channels have equal mean power}$$

$$v_{Peak} = v_1 + v_2 + \dots$$

$$P_{Peak} = (\sqrt{P_1} + \sqrt{P_2} + \dots)^2$$

$$= n^2 P_{channel} \qquad \text{If all channels have equal power}$$

3.1.6 Lightning Damage

Antennas mounted on the highest point of a tower are particularly prone to lightning damage. The provision of a solid, low-inductance path for lightning currents in an antenna system reduces the probability of severe damage to the antenna. Good antenna design and system grounding, supplemented by gas tubes connected across the feeder cables best protect electronic equipment. Figure 3-1 shows a typical system with good grounding to prevent side-flash damage and danger to personnel.

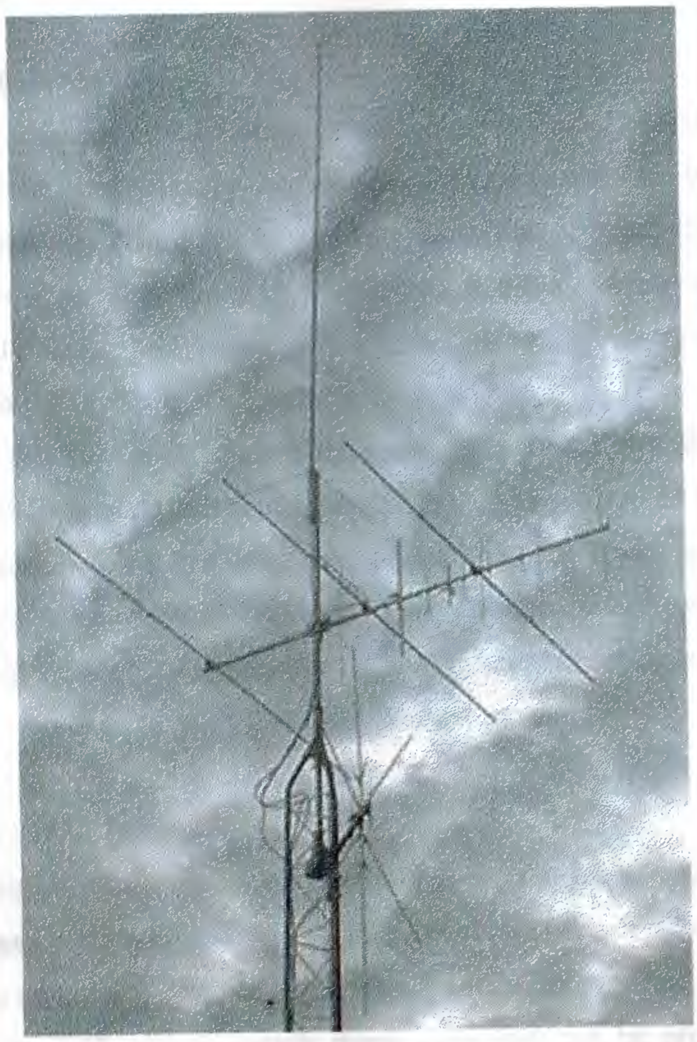


Figure 3 -1 Typical example of good grounding practice.

3.1.7 Precipitation and Discharge Noise

This is caused when charged raindrops fall onto an antenna or when an antenna is exposed to an intense electric field in thunderstorm conditions. Precipitation noise can be troublesome at the lower end of the VHF band and may be experienced frequently in some locations. When problems arise, antenna elements may be fitted with insulating covers. These prevent the transfer of the charges from individual raindrops into the antenna circuit and reduce the energy coupled to the antenna when a charge passes between drops.

3.1.8 Choice of Polarization

Base stations for mobile services use vertical polarization because it is then simple to provide an omnidirectional antenna at both the mobile terminals and the base station. There is sometimes an advantage in using horizontal polarization for obstructed point-to-point links in hilly terrain, but the choice of polarization is often determined by the need to control cochannel interference. Orthogonal polarizations are chosen for antennas mounted close together in order to increase the isolation between them.

It has been found that the use of circular polarization (CP) reduces the effects of destructive interference by reflected multipath signals, so CP should be considered for any path where this problem is expected. CP has been used with success on a number of long grazing-incidence oversea paths where problems with variable sea-surface reflections had been expected to be troublesome. Each end of a CP link must use antennas with the same sense of polarization.

3.1.9 Meeting Cost Objectives

The designer of a communications system must strive to provide the necessary overall performance for the lowest cost. A100 percent reliability is often very difficult and costly to achieve and is only necessary for a small number of services. By comparison, 99 percent availability will entirely satisfy many users and can be provided much more readily; the user cannot justify the high cost of that extra 1 percent.

Cost-effective design is only obtained by:

1 Identifying the availability needed

2 Determining the environment at both ends of the link

3 Estimating the propagation characteristics of the path and judging the reliability of the estimates

4 Selecting the right equipment and antennas for the link to meet the communications and reliability objectives

3.1.10 Trade-Offs

The interdependence of various parameters deserves careful consideration. For any major scheme the following checklist should always be worked through.

1 Examine the interactions of structure height, transmitter power, feeder attenuation, and antenna gain.

2 Consider using split antennas and duplicate feeders to increase reliability.

3 Consider the use of diversity techniques to achieve target availability instead of a single system with higher powers and gains.

4 Review the propagation data, especially the probability of multipath or cochannel interference. Don't engineer a system with 99.9 percent hardware availability and find 3 percent outage due to cochannel problems. Check the cost of antennas designed to reduce cochannel problems by nulling out the troublesome signals.

5 Visit the chosen sites. General wind data are useless if the tower is near a cliff edge, and a careful estimate of actual conditions must be made. Similarly, a nearby industrial area may mean a corrosive environment, and nearness to main roads indicates a high electrical noise level. Look for local physical obstructions in the propagation path.

6 Don't over design to cover ignorance. Find out!

3.2 Antennas For Point-To-Point Links

3.2.1 Yagi-Uda Antennas

Yagi-Uda antennas are very widely used as general-purpose antennas at frequencies up to at least 2.5 GHz. They are cheap and simple to construct, have reasonable bandwidth, and will provide gains of up to about 17 dBi or more if a multiple array is used.

At low frequencies the gain, which can be obtained, is limited by the physical size of the antenna; in the UHF band, a reflector antenna may be simpler, less costly, and more reliable if a large gain is required.

Yagi-Uda antennas provide unidirectional beams with moderately low side and rear lobes. The characteristics of the basic antenna can be modified in a variety of useful ways, some of which are shown in Fig. 3-2. The basic antenna *(a) can be arrayed in linear or* planar arrays (b). When the individual antennas are correctly spaced, an array of *N* antennas will have a power gain *N* times as large as that of a single antenna, less an allowance for distribution feeder losses. Table 3-1 indicates typical gains and arraying distances for Yagi-Uda antennas of various sizes. Different array spacings may be used when it is required to provide a deep null at a specified bearing, but the forward gain will be slightly reduced.

The bandwidth over which the front-to-back ratio is maintained may be increased by replacing a simple single reflector rod by two or three parallel rods (c). The back-to-front ratio of a simple Yagi-Uda antenna may be increased either by the addition of a screen (d) or by arraying two antennas with a quarter-wavelength axial displacement, providing a corresponding additional quarter wavelength of feeder cable to the forward antenna (e). A well-designed screen will provide a back-to-front ratio of as much as 40 dB, while that available from the quadrature-fed system is about 26 dB.

Circular polarization can be obtained by using crossed Yagi-Uda antennas: a pair of antennas mounted on a common boom with their elements set at right angles. The two antennas must radiate in phase quadrature, so they must be fed in quadrature or be fed in phase and mutually displaced by a quarter wavelength along the boom.

There has been some interest in slow-wave end-fire arrays which use long, closed forms for their elements, e.g., rings or squares, but they have not proved popular in practice, probably because they have narrower bandwidths than an optimal Yagi-Uda antenna and are more complex to manufacture. The cigar antenna is the only alternative to have remained in currency; in this design, flat circular disks replace the linear elements of the Yagi-Uda array.

3.2.2 Log-Periodic Antennas

These are widely used for applications in which a large frequency bandwidth is needed. The gain of a typical VHF or UHF log-periodic antenna is about 10 dBi, but larger gains can be obtained by arraying two or more antennas. The disadvantage of all log-periodic designs is the large physical size of an antenna with only modest gain. This is due to the fact that only a small part of the whole structure is active at any given frequency.

The most common design used on the VHF-UHF bands is the log-periodic dipole array (LPDA). After selecting suitable values for the design ratio τ and apex angle α, the designer must decide on the compromises necessary to produce a practical antenna at reasonable cost. The theoretical ideal is for the cross-sectional dimensions of the elements and support booms to be scaled continuously along the array; in practice, the elements are made in-groups by using standard tube sizes, and the support boom is often of uniform cross section. The stray capacitances and inductances associated with the feed region are troublesome, especially in the UHF band, and can be compensated only by experiment.

The coaxial feed cable is usually passed through one of the two support booms, thus avoiding the need for a wideband balun.

Printed-circuit techniques can be applied to LPDA design in the UHF band, as the antenna is easy to divide into two separate structures, which may be etched onto two substrate surfaces. At the lower end of the VHF band the dipole elements may be constructed from flexible wires supported from an insulating catenary cord.

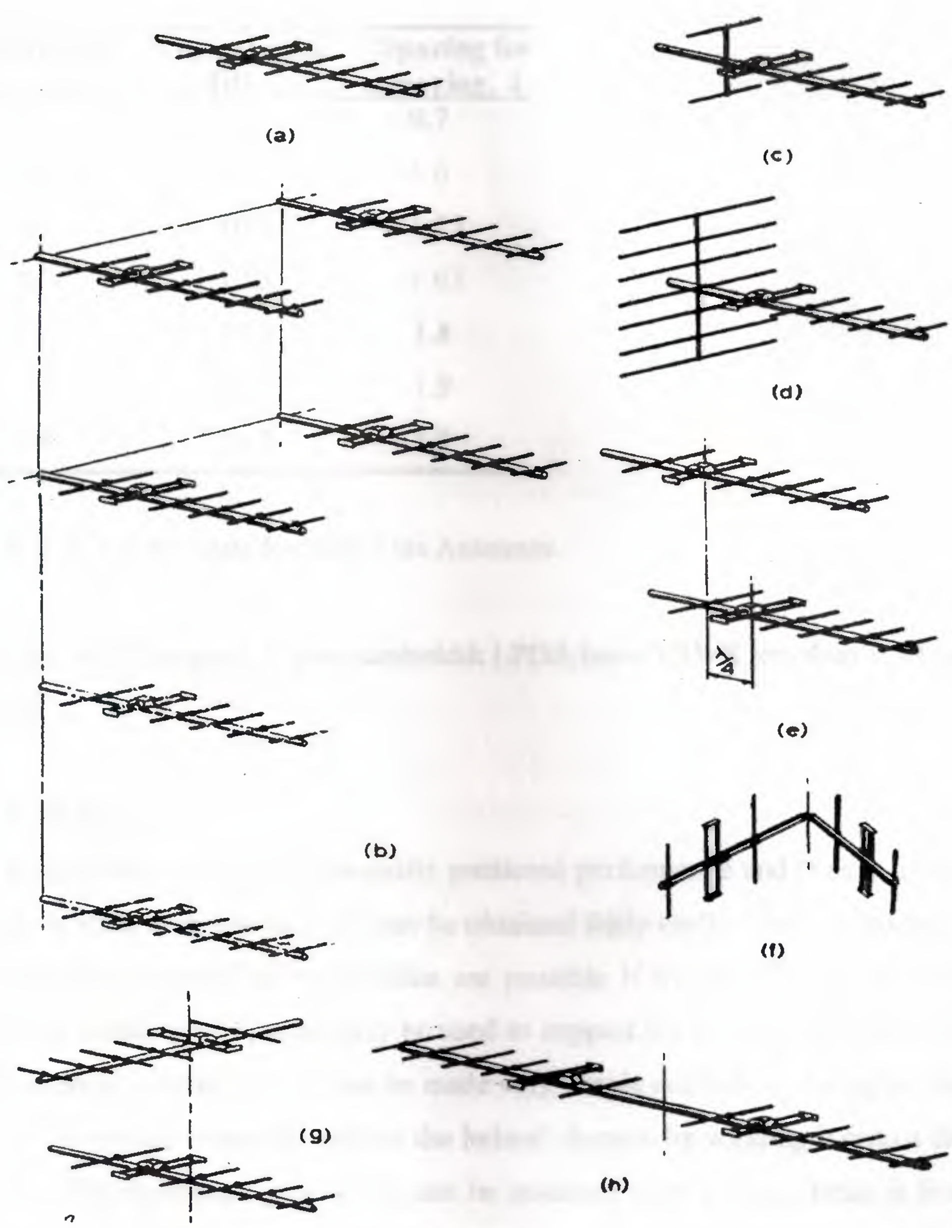


Figure 3 -2 Configurations of Yagi-Uda antennas. (a) Standard six-element antenna. (b) Stacked and bayed arrays. (C) Double reflector rods. *(d)* Reflector screen. (e) Increased *F/b* ratio by λ /4 offset. (f), (g), (h) Arrangements to produce azimuth radiation patterns for special applications.

Number of elements	Typical gain, dBi	Spacing for arraying, λ
3	7	0.7
4	9	1.0
6	10.5	1.25
8	12.5	1.63
12	14.5	1.8
15	15.5	1.9
18	16.5	2.0

Table 3 -1 Typical Data for Yagi-Uda Antennas

A typical well-designed octave-bandwidth LPDA has a VSWR less than 1.3:1 and a gain of 10 dBi.

3.2.3 Helices

A long helical antenna has an easily predicted performance and is easy to construct and match. A VSWR as low as 1.2:1 can be obtained fairly easily over a frequency bandwidth of 20 percent, and wider bandwidths are possible if the helix is tapered or stepped in diameter. Conductive spacers may be used to support the helical element from the central support boom, so the antenna can be made very simple and robust. At higher frequencies it may be more convenient to support the helical element by winding it onto a dielectric rod or tube. The maximum gain which can be obtained from a single helix is limited by the physical length that can conveniently be supported, typically ranging from 12 dBi at 150 MHz to 20 dBi at 2 GHz.

Helices may be arrayed for increased gain; to obtain correct phasing the start position of each helix in the array must be the same.

3.2.4 Panel Antennas

An antenna, which comprises a reflecting screen with simple radiating elements mounted over it, in a broadside configuration, is generally termed a panel antenna. An array may comprise one or more panels connected together.

Typical panels use full-wavelength dipoles, half-wave dipoles, or slots as radiating elements (Fig. 3-3). They have several advantages over Yagi-Uda antennas:

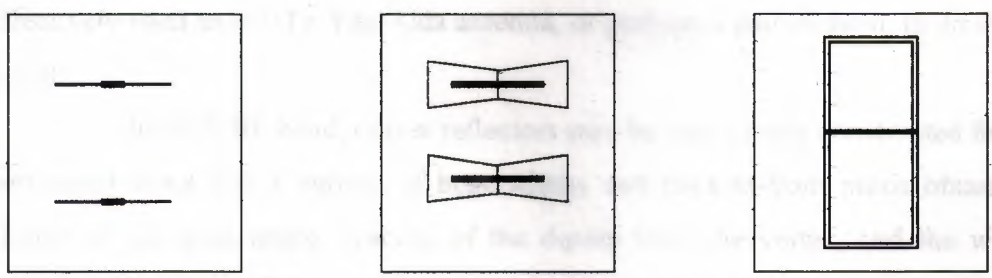
1 More constant gain, radiation patterns, and VSWR over a wide bandwidth-up to an octave.

2 More compact physical construction-the phase center is maintained closer to the axis of the supporting structure, providing better control of the azimuth radiation pattern.

3 Very low coupling to the mounting structure.

4 Low side lobes and rear lobes.

Panel antennas for frequencies in the UHF band lend themselves to printed-circuit design methods, as the radiating structures, feed lines, and matching system may all be produced by stripline techniques. At lower frequencies the radiating elements are often mounted at voltage minimum points using conducting supports, so a strong, rigid construction can be produced. A really solidly built but lightweight panel for a military



(a) **(b)** **(c)**

Figure 3-3 Panel antennas. (a) Two full-wave dipole elements. (b) Two batwing slot elements. (C) Skeleton-slot elements.

Application is shown in Fig. 3-4a. Here an all-welded aluminum frame and a skeleton-slot radiator are used so that the antenna will resist rough use in the field.

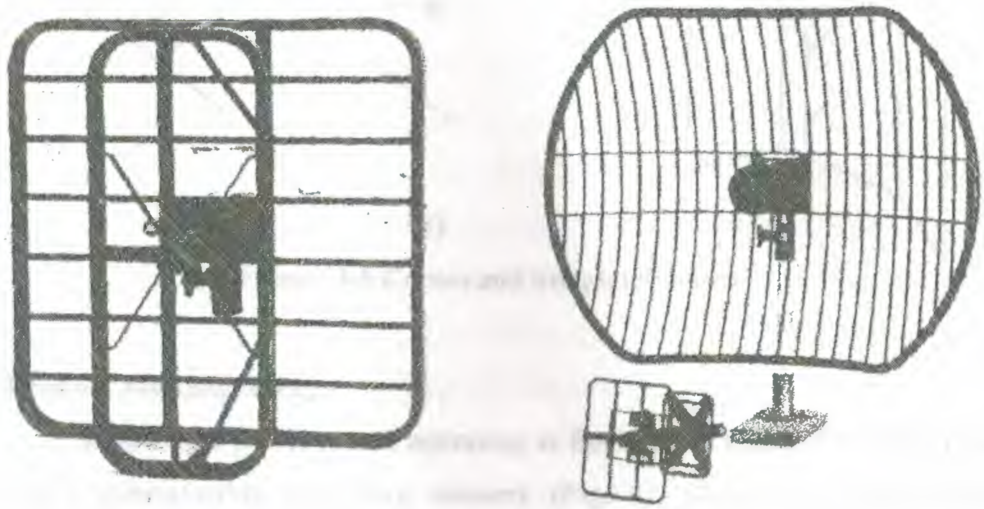


Figure 3-4 Robustly constructed antennas for military use. (a) Skeleton-slot-fed panel (225 - 400 MHz). (b) Grid paraboloid (610-1850 MHz).

3.2.5 Corner Reflectors

Well-designed corner-reflector antennas are capable of providing high gain and low sidelobe levels, but below 100 MHz they are mechanically cumbersome. Before using a corner reflector, make sure that the same amount of material could not be more effectively used to build a Yagi-Uda antenna, or perhaps a pair of them, to do the job even better.

In the UHF band, corner reflectors may be very simply constructed from solid or perforated sheet and a variety of beamwidths and back-to-front ratios obtained by the choice of the apex angle, spacing of the dipole from the vertex, and the width of the reflector. The apex of the corner is sometimes modified to form a trough (Fig.3-5). The provision of multiple dipoles extends the antenna aperture and increases the available gain.

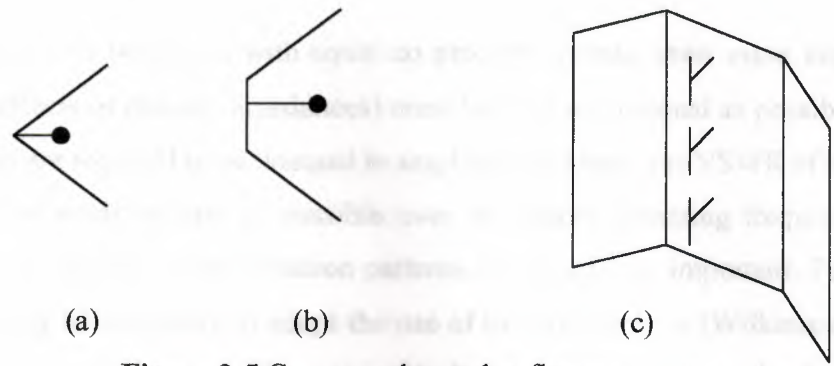


Figure 3-5 Corner and trough reflectors.

3.2.6 Feeding Multiple Arrays

Simple low-power arrays operating at frequencies below 500 MHz is usually fed using a coaxial-cable branching network (Fig3-6). Stripline power dividers are attractive for applications above about 200 MHz and can be designed to provide arbitrary power division ratios and any required number of ports; they provide a high level of reproducibility in volume production and can be designed using readily available computer software. If an array is to operate at high mean input power, it may be necessary to use large-diameter fabricated coaxial transformers, which will generally be terminated by EIA flange connections.

It is important to consider the effects of the nonideal reflection coefficient of real Antennas on the way in which power will divide at each junction in an array feed network.

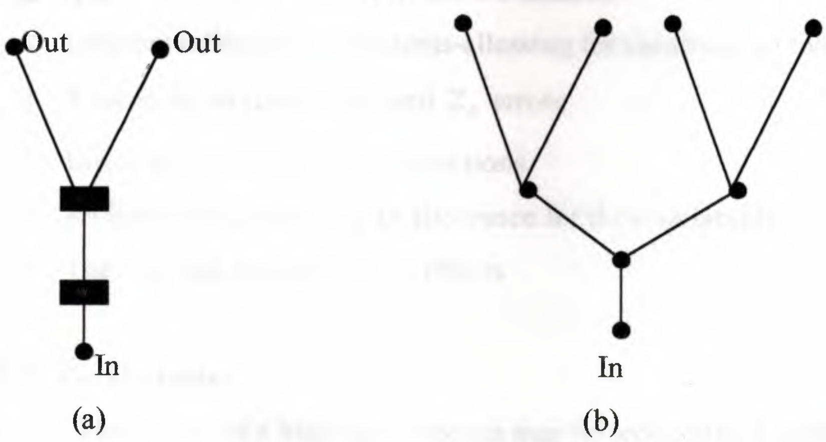


Figure 3-6 Simple branching feeder systems. (a) Two-way. (b) Four-way.

When elements are to be driven with equal co phased currents, their input impedances (including the effects of mutual impedances) must be as close to equal as possible; where element currents are required to be unequal in amplitude or phase, the VSWR of individual elements must be made as low as possible over the whole operating frequency band, especially if close control of the radiation patterns of the array is important. For critical applications it may be necessary to adopt the use of hybrid junctions (Wilkinson or other types); these reduce, the error in the ratio of radiating currents where the impedances presented at the junction are unequal. The use of suitable network-analysis software will allow the designer to explore the impact of element reflection on the nominal element currents and on the performance of the array.

For applications in which the achievement of stringently defined radiation patterns is essential, the designer will begin by selecting a suitable current distribution using one of the established techniques for array design. Having chosen the form of the elements and distribution system, the designer should then compile a budget of possible phase and amplitude errors, identifying each separate cause of error and assigning a value to. it (in general it will be possible to assign an amplitude with some certainty, but it will not be possible to define the phase of the error, at least over any appreciable bandwidth). The confidence with which the prescribed radiation pattern is likely to be achieved can then be investigated using a Monte Carlo technique. If the required confidence is not obtained, the design can be revised. The analysis should include:

1. Element reflection coefficients-allowing for construction tolerances
2. Transmission-line length and Z_0 errors
3. Errors in power division at junctions
4. Radome reflections and an allowance for their variability
5. Thermal and environmental effects

3.2.7 Paraboloids

The design of a high-gain antenna may be reduced to a problem of illuminating the aperture necessary to develop the specified radiation patterns and gain. The size of the aperture is determined only by the gain required, whatever type of elements is used to fill it. As the cost of the feed system and the radiating elements doubles for each extra

3-dB gain, a stage is reached at which it becomes attractive to use a single radiating element, to illuminate a reflector, which occupies the whole of the necessary antenna aperture. The design task is reduced to choosing the size and shape of the reflector and specifying the radiation pattern of the illuminating antenna. If the antenna aperture is incompletely filled or its illumination is nonuniform, the gain, which is, realized decreases. The ratio of the achieved gain to the gain obtainable from the same aperture when it is uniformly illuminated by lossless elements is termed the aperture efficiency of the antenna. In a receiving context, this quantity represents the proportion of the power incident on the aperture, which is delivered to a matched load at the terminals of the antenna.

In the VHF and UHF bands, a reflector may be made of solid sheet, perforated sheet, wire netting, or a series of parallel curved rods. As the wavelength is large, the mechanical tolerance of the reflector surface is not very demanding, and various methods of approximating the true surface required are possible. Table 3-2 indicates some of the combinations of techniques currently in use and illustrates the diversity of the methods, which are successful for various purposes.

Frequency MHz	**Diameter M**	**f/d ratio**	**Construction**	**Feed type**
200	10.0	0.5	Mesh paraboloid	4-element Yagi-uda
700	3.0	0.25	Solid skin	Dipole and reflector
900	7.0	0.4	Perforated steel sheet	Horn
610-960	1.2	0.25	Grid of rods	Slot and reflector
1500	2.4	0.25	Solid skin	Dipole and disk
1350-2500	1.1	0.25	Grid of rods	Slot and reflector

TABLE 3-2 Typical Paraboloid-Antenna Configurations

Grid paraboloids are attractive to produce because the curvature of all the rods is exactly the same; only their length varies across the antenna. A typical example is shown in Fig. 3-4b. The main deficiency of grid paraboloids is the leakage of energy through the surface, restricting the front-to-back ratio, which can be achieved. For example, at 1500

MHz a front-to-back ratio of -30 dB is a typical limit. If a greater front-to-back ratio is needed, it may be possible to adopt an offset geometry. Alternatively, the reflector bars can be extended in depth, or an orthodox continuous skin of solid or perforated sheet can be used in place of the grid; the consequent increase in weight and wind-loaded area must be accepted as a necessary penalty for improved electrical performance. A mathematical treatment of grid reflectors appears.

Radomes are frequently fitted to feeds or complete antennas in order to reduce the effects of wind and snow. They may be made from fiberglass or in the form of a tensioned membrane across the front of the antenna. In severe climates it is possible to heat a radome with a set of embedded wires, but this method can be applied only to a plane-polarized antenna.

Point-to-point links using tropospheric-scatter propagation require extremely high antenna gains and generally use a reflector, which is an offset part of a full paraboloidal surface constructed from mesh or perforated sheet. Illumination is provided by a horn supported at the focal point by a separate tower.

3.3 Base-Station Antennas

3.3.1 Simple Low-Gain Antennas

The simplest types of base-station antennas will provide truly omnidirectional azimuth coverage only when mounted in a clear position on top of a tower. Figure 3-7 shows standard configurations for ground-plane and coaxial dipole antennas and demonstrates that these forms are closely related. They are cheap and simple to construct and may be made to handle high power. Exact dimensions must be determined by experiment, as the stray inductance and capacitance associated with the feed-point insulator cannot be neglected. The use of a folded feed system can provide useful mechanical support and gives better control over the antenna impedance (both the relative diameter of the feed and grounded conductors and the point of their interconnection can be varied). The satisfactory operational bandwidth of the coaxial dipole *d* depends critically on the charactenstic impedance Z_0, of the lower coaxial section formed by the feed line (radius *r)* inside the skirt (radius *R).* If this section has too small a Z_0, radiating currents will flow on the outside of the feeder line unless the skirt length is exactly $\lambda / 4$. The impedance, gain, and radiation pattern of the antenna then becomes critically dependent on the positioning of the feed line on the tower, severely limiting the useful bandwidth of the antenna.

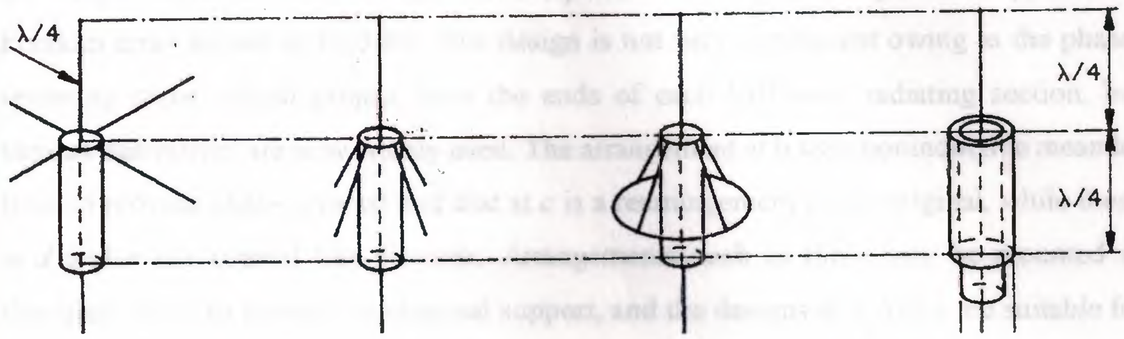


Figure 3-7 Low-gain base-station antennas. (a) Standard ground plane with radials. (b) Ground plane with sloping radials. (C) Ground plane with closed ring. (d) Coaxial Dipole.

3.3.2 Discone Antennas

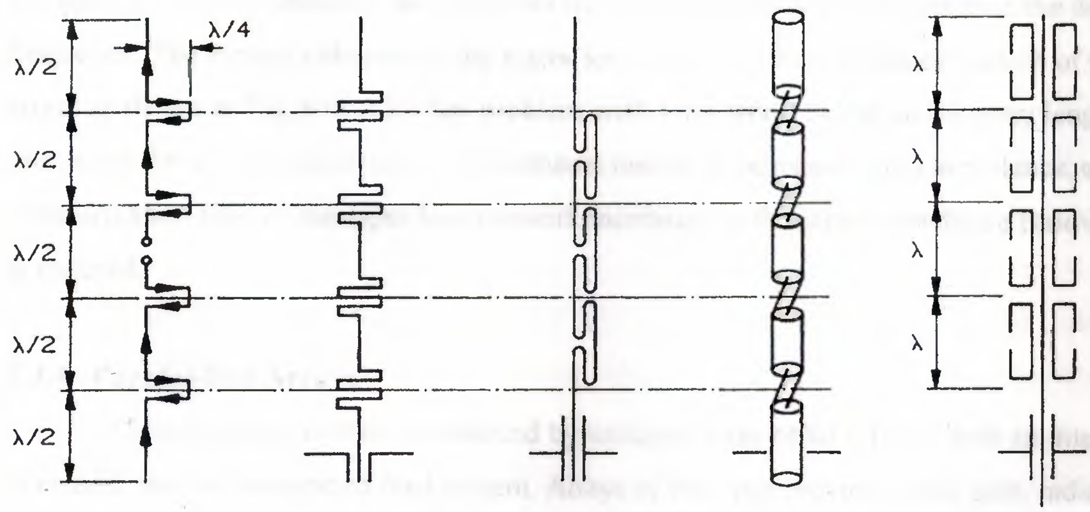
The discone and its variants are the most commonly used low-gain wideband base-station antennas. The useful lower frequency limit occurs when the cone is a little less than $\lambda / 4$ high, but the upper frequency limit is determined almost entirely by the accuracy with which the conical geometry is maintained near the feed point at the apex of the cone.

Discones may be made with either the disk or the cone uppermost. The support for the upper part of the antenna usually takes the form of low-loss dielectric pillars or a thin-walled dielectric cylinder, fitted well outside the critical feed region.

Variants of the basic discone use biconical forms in place of the conventional cone and replace the disk by a cone with a large apex angle. At the lower end of the VHF band the antennas may be mounted at ground level, so a minimal skeleton disk, which couples to the ground, may be used if some loss of efficiency and the propagation effects associated with a low antenna elevation can be accepted.

3.3.3 Collinear Arrays

The ground plane and coaxial dipole have about the same gain as a half-wavelength dipole. When more gain is needed, the most popular omnidirectional antennas are simple collinear arrays of half-wave dipoles. The original array of this type is the Franklin array shown in Fig3-8a. This design is not very convenient owing to the phase-reversing stubs, which project from the ends of each half-wave radiating section, but various derivatives are now widely used. The arrangement at b uses noninductive meander lines to provide phase reversal and that at *c* is a rearrangement of the original, while those at *d* and *e* use coaxial line sections. Arrangements such as these may be mounted in fiberglass tubes to provide mechanical support, and the designs at b And c are suitable for production by printed-circuit techniques.



(a) (b) (c) (d) (c)

Figure 3-8 Collinear dipole arrays. (a) Franklin array. (b) Array with meander-line phase reversal. (c) Array with transposed coaxial sections. (d) and (e) Alternative coaxial forms.

In each of these arrangements, the elements are connected in series; an input-matching section transforms the input impedance of the lower section, which may be $\lambda/2$ or $\lambda/4$ long, to 50 Ω. A set of quarter-wavelength radial elements or a quarter-wavelength choke is used to suppress currents on the outside of the feeder cable. The gain available from these arrays is limited by two factors:

1. There is mechanical instability in a very long antenna with a small vertical beam width.
2. The available excitation current diminishes away from the feed as a result of the power lost by radiation from the array.

The practical upper limit of useful gain is about 10 dBi.

In the case of the coaxial-line designs, each section is shorter than a free-space half wavelength so that the correct phase shift is obtained inside the section. The examples shown would typically provide a gain of 9 dBi at the design frequency. The useful bandwidth of these antennas is inherently narrow because of the phase error between successive radiating sections, which occurs when the frequency is changed from the design frequency. The typical behavior of the major lobes of the vertical radiation pattern of these arrays is shown in Fig 3-9. A further problem with long arrays is that as the array length is increased, the series connection of the elements results in increased input impedance, as the transformation ratio of the input feed network increases, so the input impedance bandwidth is reduced.

3.3.4 Parallel-Fed Arrays

Much greater control is obtained by using an array of fat dipoles with an internal, branched, parallel-connected feed system. Arrays of this type provide stable gain, radiation patterns, and input VSWR over wide bandwidths. A well-optimized eight-element array is able to provide acceptable gain (10 dBi) patterns and input impedance over the entire 225- to 400-MHz communications band.

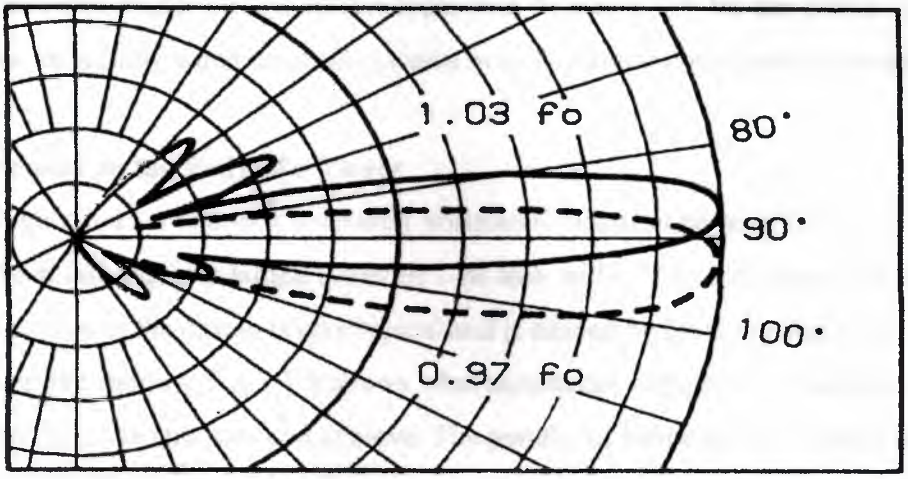


Figure 3-9 Vertical radiation pattern of a typical end fed array.

3.3.5 Dipoles on a Pole

Much ingenuity has been applied to the design of simple wide-band high-gain omnidirectional antennas. A simple offset pole-mounted array is shown in Fig.3-l0a. This will provide about 10-dBi gain in the forward direction but typically only 4 dBi rearward, depending on the pole diameter and the spacing between the dipole and the pole axis. An attempt to avoid this problem is shown in Fig.3-lob, but this type of antenna has distorted vertical radiation patterns caused by the phase shifts, which result from the displacement of the dipoles; gain is also reduced to about 6 dBi for the four-element array shown.

The solution in Fig.3-l0c, in which dipoles are placed in pairs and are cophased, is more satisfactory, as the phase center of each tier is concentric with the supporting pole. However, the antenna is relatively expensive, as eight dipoles provide only 6-dB gain over a single dipole.

One possibility is to use the in-line stacked array in Fig.3-l0a and place the base station toward the edge of the service area. The rearward illumination may be improved if the spacing between the dipoles and the pole is optimized for the pole size and frequency to be used.

Analytical solution to the azimuth pattern is available, and simple computer programs provide results in good agreement with measurements. When designing the feed networks for multielement arrays of this type, take care to allow for the effects of mutual impedances, especially when unequal currents or nonsymmetric geometries are used.

3.3.6 Antennas on the Body of a Tower

Figure 3-11 a shows a measured horizontal radiation pattern for a simple dipole mounted from one leg of a lattice tower of 2-rn face width. The distortion of the circular azimuthal pattern of the dipole is very typical and is caused by blocking and reflection from the structure. By contrast, Fig.3-1lb shows what an antenna comprising three dipole panels mounted on the same structure can achieve. The penalty of adopting this improved solution lies in the cost of the more complex antenna, so before an optimum design can be arrived at, the value of the improved service must be assessed.

The horizontal radiation pattern of a complete panel array is usually predicted from measured complex radiation-pattern data for a single panel, using a suitable computer program.

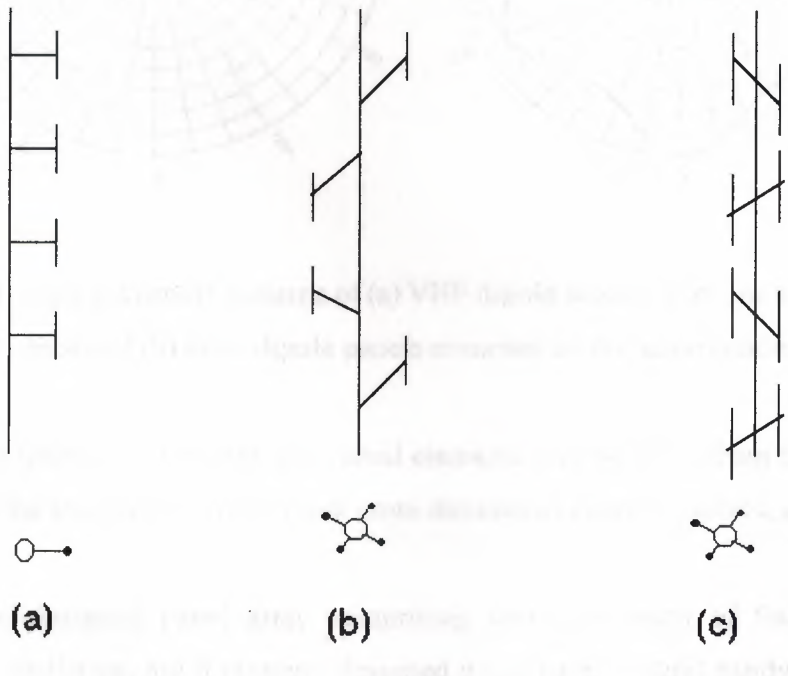


Figure 3-10 Pole-mounted dipoles. (a) In line. (b) Four dipoles spaced around a pole. (c) Eight dipoles spaced around a pole.

For each azimuth bearing, the angle from each panel axis is found, and the relative field in that direction is obtained. The radiated phase is computed from the excitation phases and physical offsets of the phase centers of the individual panels.

Depending on the cross-sectional size of the structure, the most omni directional coverage may be produced with all panels driven with the same phase or by a phase rotation around the structure; for example, on a square tower the element current phases would then be 0^0, 90^0, 180^0, and 270^0.

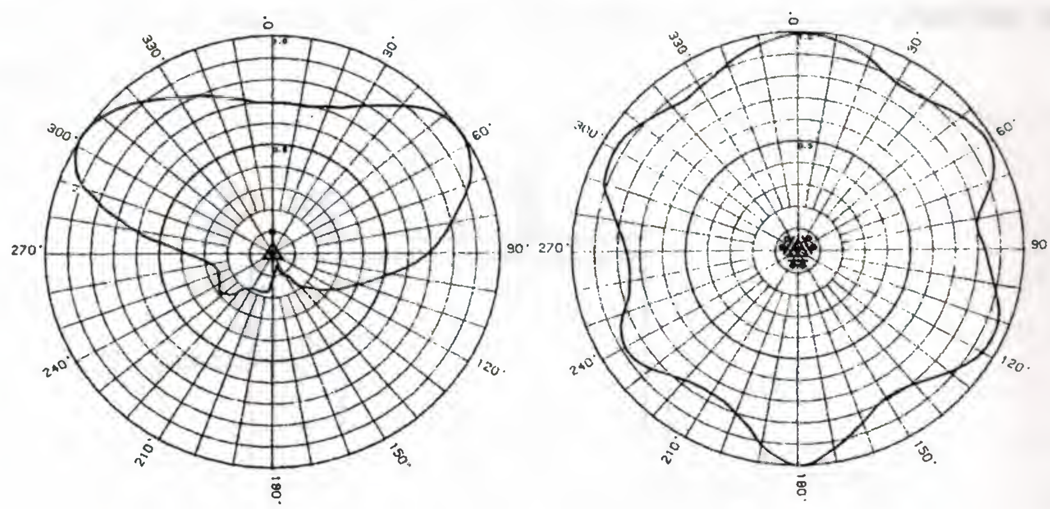


Figure 3-11 Typical azimuth patterns of (a) VHF dipole mounted off one leg of a triangular mast and (b) three dipole panels mounted on the same structure.

When phase rotation is used, the individual elements may be offset from the centerlines of the faces of the structure to give a more omni directional azimuth pattern, as in Fig. 3-12.

A well-designed panel array comprising four tiers, each of four panels, is an expensive installation, but if properly designed it can have a useful bandwidth of as much as 25 percent. This allows several user services to be combined into the same antenna, each user having access to a very omnidirectional high-gain antenna.

Groups of panels may be arranged and fed to produce an azimuth pattern, which is tailored to the arbitrary requirements of the service area or to provide nulls which are necessary to meet cochannel protection objectives.

VHF/UHF base-station antennas are sometimes situated on the bodies of large towers, perhaps up to 10 m (30 ft) in diameter. It is not economically possible to provide smooth omnidirectional coverage from such a large structure. However, by the use of some lateral thinking, it may be possible to make a virtue out of a necessity. It is often possible to provide solid coverage of an arc 270^0 try using two channels, overlapping coverage only in the region of greatest traffic. (If the station operator can guarantee the rearward null, the frequency planner may benefit and the operator may get two channels where they matter most.)

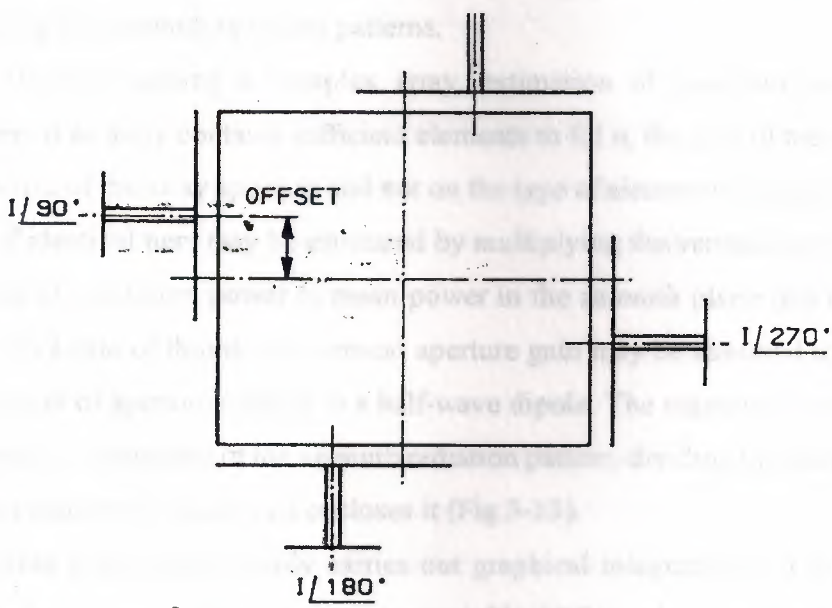


Figure 3-12 Plan arrangement of an omni directional panel array on a large tower.

3.3.7 Special-Purpose Arrays

For applications in which the largest possible coverage must be obtained, the azimuth radiation pattern of the antenna must be shaped to concentrate the transmitted power in the area to be served, for example, an airway, harbor, or railroad track. Energy radiated in other directions is wasted and is a potential cause of interference to others.

Antennas with cardioidal azimuth radiation patterns are useful for a wide range of applications.

Simple two-element arrays (dipole plus passive reflector) or dipoles mounted off the face of a tower may be adequate, but a wider range of patterns is available if two driven dipoles are mounted on a single supporting boom and excited with suitably chosen currents and phases.

When a signal must be laid down over an arbitrarily shaped area of terrain, Yagi-Uda arrays may be arranged as at Fig. 27-2f and g. Due allowance must be made for the separation of the phase centers of the antennas when computing the radiation patterns. As an approximate guide, the phase center of a Yagi-Uda antenna lies one-third of the way along the director array, measured from the driven element.

Further tiers of antennas may be used to increase the gain of the system without modifying the azimuth radiation patterns.

When designing a complex array, estimation of gain can present a confusing problem. If an array contains sufficient elements to fill it, the gain of the array depends only on the size of the array aperture and not on the type of elements chosen. The gain of a filled array of identical tiers may be estimated by multiplying the vertical aperture power gain by the ratio of maximum power to mean power in the azimuth plane (the maximum-to-mean ratio). As a rule of thumb, the vertical aperture gain may be assumed to be 1.15 times per wavelength of aperture relative to a half-wave dipole. The maximum-to-mean ratio may be obtained by integration of the azimuth radiation pattern, dividing the area of the pattern into the area of a circle, which just encloses it (Fig.3-13).

Using a planimeter easily carries out graphical integration, but it is quite simple to write an integration routine for a programmable pocket calculator. Once an array has been selected, its horizontal and vertical radiation patterns may be computed and used to predict the array gain more accurately.

The growth of cellular telephone systems has created a demand for high-gain base-station antennas with well-controlled pattern characteristics to permit intensive frequency reuse. The standard directional antenna for this application is an extended corner reflector array in which a long reflector is excited by an array of collinear dipole elements.

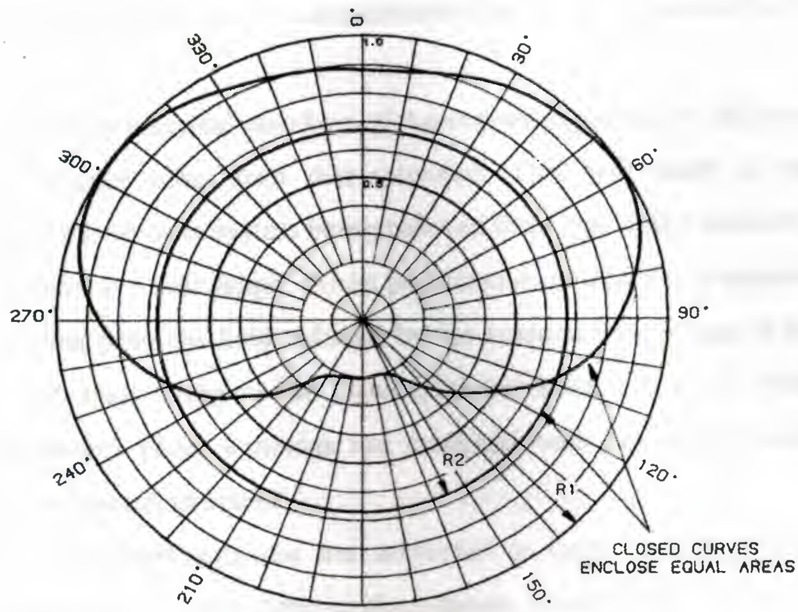


Figure 3-13 The maximum-to-mean ratio of an azimuth radiation pattern.

3.4 System Considerations

3.4.1 Mounting Arrangements

When mounting any antenna, it is important not to impair its performance by the influence of the supporting structure. The inevitable effect of the supporting structure on the radiation pattern of a dipole. This effect is accompanied by a modification of the input impedance, which may be unwelcome if a low VSWR is needed. In any critical application the change of the radiation patterns and gain must be taken into account when estimating system performance. Impedance matching of the antenna must be undertaken in the final mounting position or a simulation of it.

If Yagi-Uda arrays are mounted with their elements close to a conducting structure, they too will suffer changes of radiation patterns and impedance. The effects will be greatest if tower members pass through the antenna, as they do when an array is mounted on clamps fitted at the center of the cross boom. If at all possible, when an array is center-mounted, the member to which it is clamped should tie at right angles to the elements of the array.

Currents induced in diagonal members of the supporting structure will cause reradiation in polarization planes other than that intended. This will result in the cross-polar discrimination of the antenna system being reduced from that which would be measured on an isolated antenna at a test range. When polarization protection is important, the tower should be screened from the field radiated by the antenna with a cage of bars spaced not more than $\lambda/10$ apart, lying in the plane of polarization. (A square mesh is used for circular polarization.) Panel antennas are designed with an integral screen to reduce coupling to the mounting structure.

Long end-mounted antennas are subjected to large bending forces and turning moments at their support points. Staying the antenna, using nylon, can reduce these forces or polyester ropes for the purpose to avoid degrading its electrical characteristics.

In severe environments antennas may be provided with radomes or protective paints. It is very important that the antennas be tested and set up with these measures already applied, especially if the operating frequency is in the UHF band.

3.4.2 Coupling

A further consideration when planning a new antenna installation on an existing structure is the coupling, which will exist between different antennas. When a transmitting antenna is mounted close to a receiving antenna, problems, which can arise, include:

1. Radiation of spurious signals (including broadband noise) from the transmitter.
2. Blocking or desensitization of the receiver.
3. Generation of cross-modulation effects by the receiver.
4. Radiation of spurious signals (intermodulation products and harmonics) due to nonlinear connections in the transmitting antenna or generation of spurious signals and cross-modulation effects caused by the same mechanism in the receiving antenna.

The last of these problems must be avoided by good antenna design-avoiding any rubbing, unbounded joints. The other effects depend critically on the isolation between the antennas and on parameters of the transmitters and receivers; their manufacturers should specify these parameters.

The isolation between two antennas may be predicted from Fig.3-14 or from standard propagation formulas. Antenna isolations may be increased by using larger spacings between them or by using arrays of two or more antennas spaced to provide each with a radiation-pattern null in the direction of the other.

An alternative method of increasing the isolation between the antenna-system inputs is to insert filters. If a suitable filter can be constructed, the antenna isolation may be reduced until, in the limit, a single antenna is used with all equipment, transmitters and receivers, coupled to it through filters. When receivers are connected to a common antenna, the signal from the antenna is usually amplified before being divided by a hybrid network. The number of services which use a single antenna can be extended to six or more, provided adequate spacings are maintained between the frequencies allocated to different users. The whole system is expensive, but the cost may be justified if the antenna itself is large or if tower space is limited.

3.4.3 Coverage

In free-space conditions the intensity of a radio wave diminishes as the distance from the transmitter increases in accordance with the inverse-square law. Terrestrial links are not usually in free-space conditions, and the field diminishes more rapidly with distance.

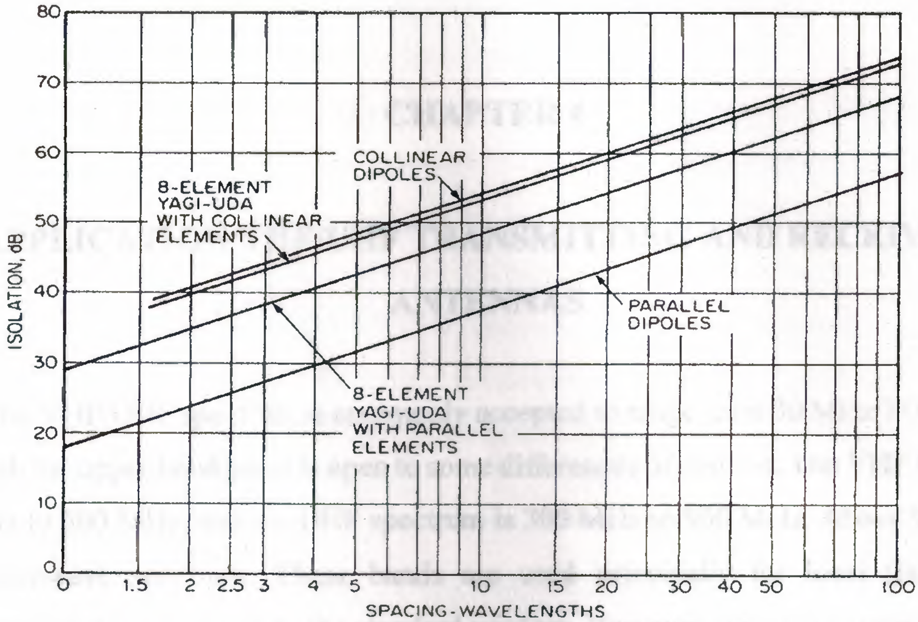


Figure 3-14 Typical isolations between Yagi-Uda antennas.

CHAPTER 4

APPLICATION VHF/UHF TRANSMITTING AND RECEIVING ANTENNAS

The VHF/UHF spectrum is commonly accepted to range from 30 MHz TO 900 MHz, although the upper breakpoint is open to some differences of opinion. The VHF spectrum is 30 MHz to 300 MHz, and the UHF spectrum is 300 MHz to 900 MHz. Above 900 MHz is the microwave spectrum. These bands are used principally for local (line-of-sight) communications, according to the standard wisdom. However, with the advent of OSCAR satellites, the possibility of long-distance direct communications is a reality for VHF/UHF operators. In addition, packet radio is becoming common; this means indirect long distance possibilities through networking. For the low end of the VHF spectrum (e.g., 6-meter amateur band), long-distance communications are a relatively common occurrence.

In many respects, the low-VHF region is much like the 10-meter amateur band and 11-meter Citizen's Band: skip is not an infrequent occurrence. Many years ago, I recall an event where such skip caused many a local police officer to skip a heart beat. In those days, our police department operated on 38.17 MHz, which is between the 6-meter and 10-meter amateur bands. They received an emergency broadcast concerning a bank robbery at a certain Wilson Boulevard address. After a race to the county line, they discovered that the reported address would be outside of the county... and in fact did not exist even in the neighboring county (a number was skipped). The problem was traced to a police department in a southwest city that also had a Wilson Boulevard, and for them the alarm was real.

The principal difference between the lower frequencies and the VHF/UHF spectrum is that the wavelengths are shorter in the VHF/UHF region. Consider the fact that the wavelengths for these bands range from 10 meters to 1 meter for the VHF region, and from 1 meter to 33 centimeters for the UHF region. Most antenna designs are based on because bandwidth is a function of length/diameter ratio for many classes of antenna, broad banding an antenna in the VHF/UHF region is relatively easy. If, say,

25-mm (i.e., 1-inch) aluminum tubing is used to make a quarter-wavelength vertical, then the approximate L / D ratio is 790 in the 8-meter band, to be wider than the HF bands. and 20 in the 2-meter band. This feature is fortunate, because the VHF/UHF bands.

Another point to make is that many of the mechanical chores of antenna design and construction become easier for VHF/UHF antennas. One good example is the delta impedance matching scheme. At 80-meters, the delta-match dimensions are approximately 36 x43 feet, and at 2 meters they are 9.5 x 12 inches. Clearly, delta matching is a bit more practical for most users at VHF than at HF.

4.1 Types of antennas usable for VHF/UHF

The concept (VHF/UHF antenna) is only partially valid because virtually all forms of antenna can be used at HF, MW, and VHF/UHF. The main limitations that distinguish supposedly VHF/UHF designs from others are mechanical: there are some things that are simply much easier to accomplish with small antennas. Besides the delta match mentioned previously, there is the ease of construction for multi-element antennas. A 14-element 20-meter beam would be a wonderful thing to have in a QRM-laden DX pile-up, but is simply too impractical for all but a few users because of its size. If you look on embassy rooftops around the world you will see many-element Yagi and log periodic HF antennas supported on massive towers . And some of them use a standard Size 25 tower (common for amateur use) as the antenna boom! A 14-element 80-/75-meter Yagi approaches impossibility. But at 2 meters, one person, in one hand, can carry a 14-element Yagi beam antenna unless the wind is acting up.

4.2 Lower band antennas on VHF/UHF

The antenna farm consisted of a 14-element 2-meter beam, a three-element tri-band HF beam (10-15-20 meters), and a five-band (80-10 meters) trap dipole. All of the coaxial cables came into the station through a wall; they were kept disconnected, and shorted out, when not in use because of the senior Red Cross official's concern over lightning.

One night, attempting to connect the 2-meter beam to the Gonset (gooney box) 2-meter AM transceiver; John accidentally used the cable from the five-band trap dipole instead.

We worked a lot of stations that contest weekend, and scored lots of points. Later, we discovered the error, and asked a more technically competent adult (we were teenagers), He then gave us a lesson in longwire antenna theory. A good longwire is many wavelengths long. Consider that a half-wave antenna on
2-meters is (80 m/2 m), 40 wavelengths shorter than an 80-meter half-wave antenna. Thus, the 80-meter antenna, counting foreshortening of physical lengths because the traps, was on the order of 35 to 38 wavelengths long on 2-meters. We had a highly directional, but multi-lobed pattern.

Similarly, 40- to 10-meter and 80- to 10-meter trap verticals are often usable on VHF/UHF frequencies without any adjustments. Similarly, Citizens Band 11-meter antennas, many of which are %-wavelength (18-feet high), will sometimes work on VHF frequencies. Check the VSWR of an HF antenna on 2 meters with a reliable VHF/UHF VSWR meter (or RF watt-meter) to discover the truth about any particular antenna. Always use the low-power setting on the transmitter to limit damage in cases where the specific antenna is not usable on a specific frequency.

The lesson to be learned is that antennas are often usable on much higher than the design frequency, even though useless on nearby bands. Care must be exercised when initially checking out the antenna, but that is not an inordinate difficulty.

4.3 VHF/UHF antenna impedance matching

The VHF/UHF antenna is no more or less immune from the need for impedance matching than lower frequency antennas. However, some methods are easier (coax BALUNs, delta match, etc.) and others become either difficult or impossible. An example of the latter case is the tuned LC impedance matching network. At 6 meters, and even to some limited extent 2 meters, inductor and capacitor LC networks can be used. But above 2 meters other methods are more reasonable. We can, however, mimmick the LC tuner by using strip line components, but that approach is not always suited to amateur needs.

The BALUN transformer makes an impedance transformation between Balanced and UNbalanced impedances. Although both 1:1 and 4:1 impedance ratios are possible, the 4:1 ratio is most commonly used for VHF/UHF antenna work. At lower frequencies it is easy to build broadband transformer BALUNs, but these become more of a problem at VHF and above.

For the VHF/UHF frequencies, a 4:1 impedance ratio coaxial BALUN (Fig. 4-1A) is normally used. Two sections of identical coaxial cable are needed. One section (A) has a convenient length to reach between the antenna and the transmitter. Its characteristic impedance is Z_0. The other section (B) is a half-wavelength long at the center of the frequency range of interest. The physical length is found from:

$$L = \frac{5904V}{F_{MHz}} \quad \text{inches} \tag{4-1}$$

Where:

L is the cable length in inches

F_{MHz} is the operating frequency in megahertz

V is the velocity factor of the coaxial cable

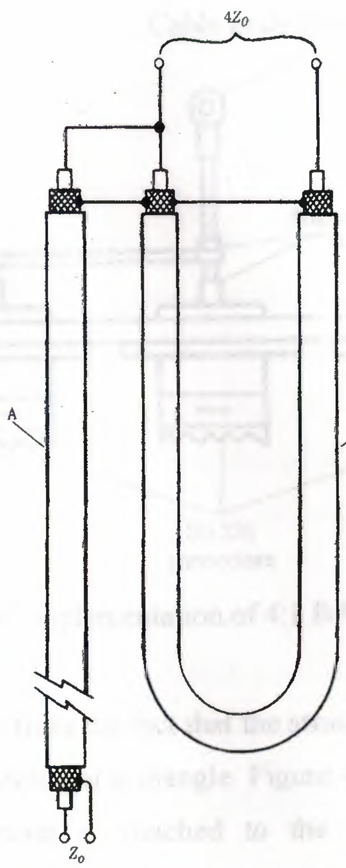


Figure 4-lA coaxial 4:1 BALUN transformer.

The velocity factors of common coaxial cables are shown in the table.

Coaxial cable velocity factors

Regular Polyethylene	0.66
Polyethylene Foam	0.80
Teflon	0.72

A mechanical method of joining the coaxial cables is shown in Fig. 4-lB.This arrangement has the effect of shorting together the shields of the three ends of coaxial cable. The center conductors are connected in the manner shown. This method is used especially where a mounting bracket is available on the antenna. The lengths of coaxial cable need PL-259 coax connectors installed in order to use this method .

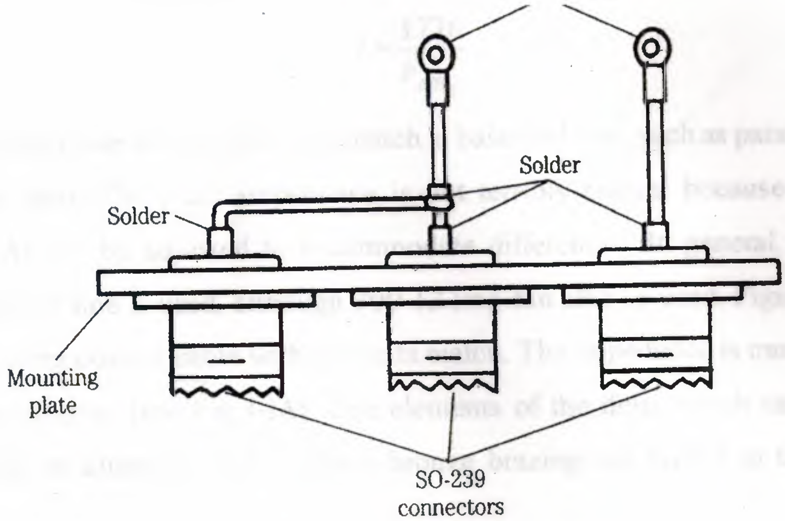


Figure 4-1B Practical implementation of 4:1 BALUN using connectors.

The delta match gets its name from the fact that the structure of the matching element has the shape of the Greek letter delta, or a triangle. Figure 4-2A shows the basic delta match scheme. The matching element is attached to the driven element of the antenna (symmetrically, about the center point of the antenna). The width (A) of the delta match is given by:

$$L = \frac{1416}{F_{MHz}} \text{ inches} \tag{4-2}$$

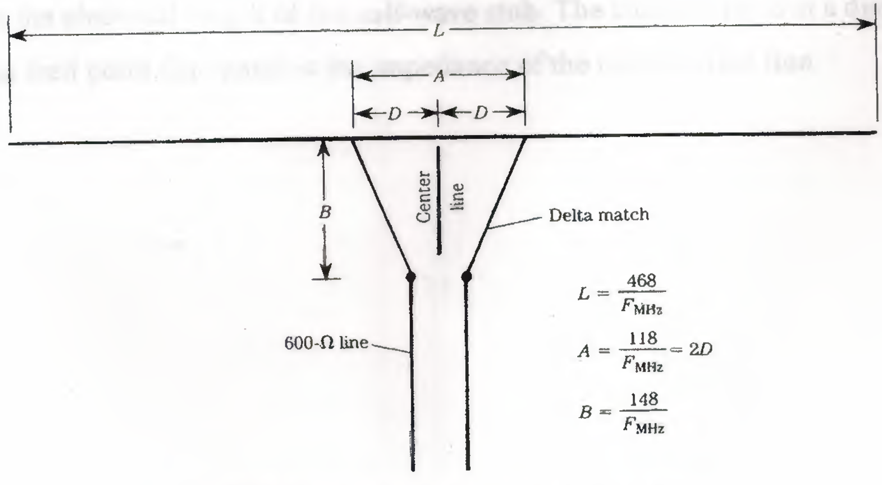


Figure 4-2A Delta feed matching system.

While the height of the match (B) is:

$$L = \frac{1776}{F_{MHz}} \qquad (4\text{-}3)$$

The transmission line feeding the delta match is balanced line, such as parallel transmission line or twin lead. The exact impedance is not terribly critical because the dimensions (especially A) can be adjusted to accommodate differences. In general, however, either 450-fl or 600-12 line is used, although 300-12 line can also be used. Figure 4-2B shows a method for using coaxial cable with the delta match. The impedance is transformed in a 4:1 BALUN transformer (see Fig.4-lA). The elements of the delta match can be made from brass, copper, or aluminum tubing, or a bronze brazing rod bolted to the main radiator element.

A stub-matching system is shown in Fig.4-3. In this case, the impedance transformation is accomplished although a half-wavelength shorted stub of transmission line. The exact impedance of the line is not very critical, and is found from:

$$Z_0 = 276 \text{ LOG}_{10} \frac{2S}{d} \qquad (4\text{-}4)$$

The matching stub section is made from metal elements such as tubing, wire, or rods (all three are practical at VHF/UHF frequencies). For a 3/16 inch rod, the spacing is approximately 2.56-inches to make a 450 Ω transmission line. A sliding short cir-cult is used to set the electrical length of the half-wave stub. The stub is tapped at a distance from the antenna feed point that matches the impedance of the transmission line.

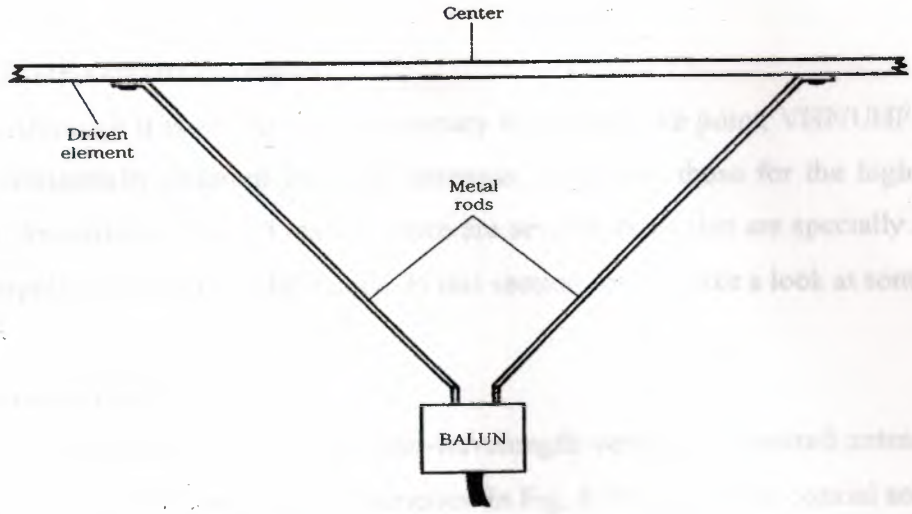


Figure 4-2B Practical VHF delta match.

In the example shown, the transmission line is coaxial cable, so a 4:1 BALUN transformer is used between the stub and the transmission line. The two adjustments to make in this system are: 1) the distance of the short from the feedpoint, and 2) the distance of the transmission line tap point from the feedpoint. Both are adjusted for minimum VSWR.

The gamma match is basically a half delta match, and operates according to similar principles (Fig 4-4). The shield (outer conductor) of the coaxial cable is connected to the center point of the radiator element. The center conductor of the coaxial cable series feeds the gamma element through a variable capacitor.

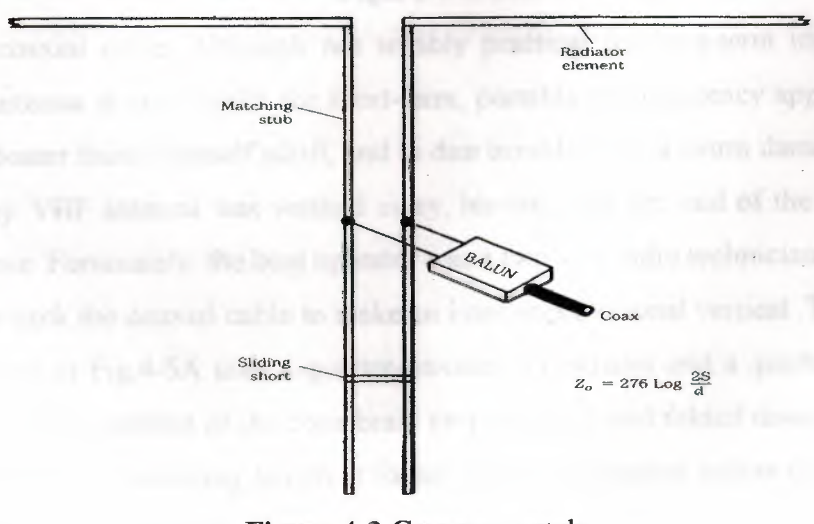


Figure 4-3 Gamma match

4.4 VHF/UHF antenna examples

Although it is probably not necessary to reiterate the point, VHF/UHF antennas are not substantially different from HF antennas, especially those for the higher bands. However, for various practical reasons there are several forms that are specially stilted, or at least popular, in the VHF/UHF bands. In this section we will take a look at some of them

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4.4.1 coaxial vertical

The coaxial vertical is **a** quarter-wavelength vertically polarized antenna that is popular on VHF/UHF. There are two varieties. In Fig. 4-5A we see the coaxial antenna

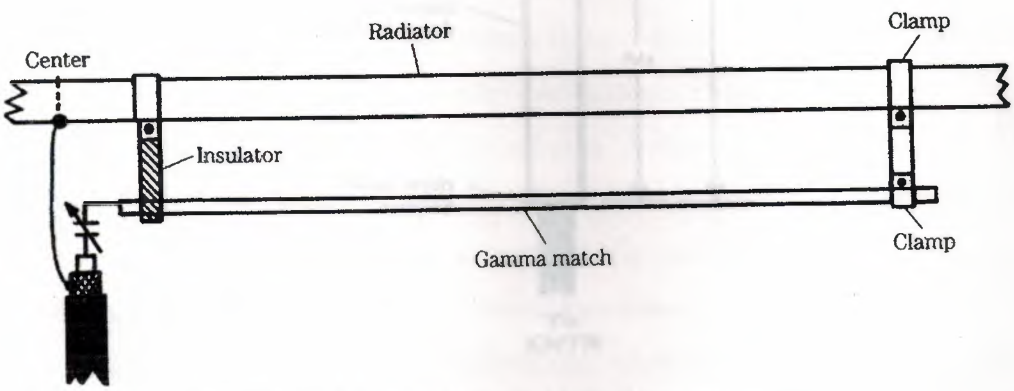

Figure 4-4 Stub matching.

made with coaxial cable. Although not terribly practical for long-term installation, the coax-coax antenna is very useful for short-term, portable or emergency applications. For example, a boater found himself adrift, and in dire trouble, after a storm damaged the boat. The mast-top VHF antenna was washed away, leaving only the end of the coaxial cable dangling loose. Fortunately, the boat operator was a two-way radio technician, and he knew how to strip back the coaxial cable to make an impromptu coaxial vertical .The coax-coax antenna shown in Fig.4-5A uses a quarter-wavelength radiator and a quarter-wavelength sleeve. The sleeve consists of the coax braid stripped back and folded down the length of the coax cable. The maximum length is found from the equation below (actual length is trimmed from this maximum).

$$L = \frac{2952\,V}{F_{MHz}} \text{ inches} \quad (4\text{-}5)$$

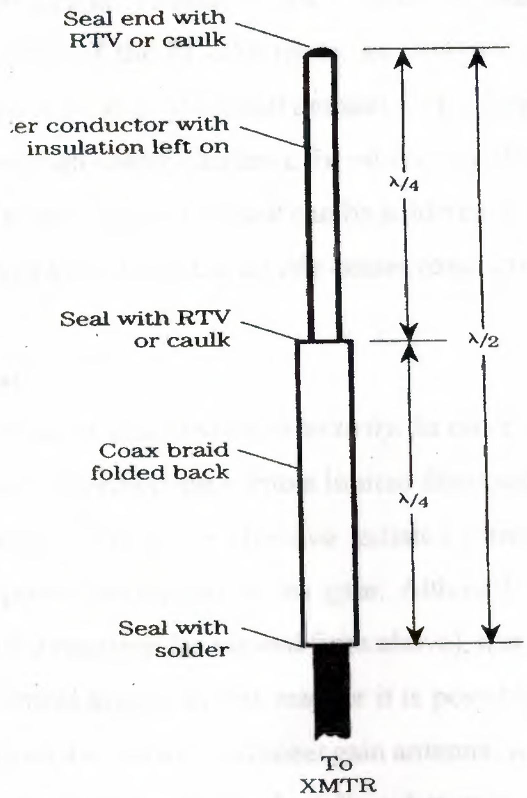

Figure 4-5A Coaxial vertical based on coaxial cable.

The antenna is mounted by suspending it from above using a short piece of string, twine, or fishing line. From a practical point of view, the only problem with this form of antenna is that it tends to deteriorate after a few rainstorms. Sealing the end, and the break between the sleeve and the radiator, with either silicone RTV or bathtub caulk .A more permanent method of construction is shown in Fig.4-5B can reduce this effect.

The sleeve is a piece of copper or brass tubing (pipe) about 1-inch in diameter. An end cap is fitted over the end, and sweat soldered into place. The solder is not intended to acid mechanical strength, but rather to prevent weathering from destroying the electrical contact between the two pieces. An SO-239 coaxial connector is mounted on the end cap.

The coax is connected to the S0-239 inside of the pipe, which means making the connection before mounting the end cap.

The radiator element is a small piece of tubing (or brazing rod) soldered to the center conductor of a PL-259 coaxial connector. An insulator is used to prevent the rod from shorting to the outer shell of the PL-259 (note: an insulator salvaged from the smaller variety of banana plug can be shaved a small amount with a fine file and made to fit inside the PL-259. It allows enough center clearance for ~4-inch or i46-inch brass tubing).

Alternatively, the radiator element can be soldered to a banana plug. The normal sized banana plug happens to fit into the female center conductor of the 80-239.

4.4.2 collinear vertical

Gain in antennas is provided by *directivity*. In other words, by taking the power radiated by the antenna, and projecting it into a limited direction, we obtain the appearance of higher radiated power. In fact, the effective radiated power (ERP) of the antenna is merely its feedpoint power multiplied by its gain. Although most antenna patterns are shown in the horizontal dimension (as viewed from above), it is also possible to obtain gain by compressing the vertical aspect. In this manner it is possible to have a vertical antenna that produces gain. Figure 4-6 shows a collinear gain antenna, with vertical polarization and a horizontally omnidirectional pattern. Incidentally, when mounted horizontally the pattern becomes bi-directional.

The collinear antenna shown in Fig.4-6 is basically a pair of stacked collinear arrays. Each array consists of a quarter-wavelength section (A) and a half-wavelength section (C) separated by a quarter-wavelength phase reversing stub (B). The phase reversal stub preserves in-phase excitation for the outer element (referenced to the inner element).

The feedpoint is between the two elements of the array (i.e., between the A sections). The coaxial-cable impedance is transformed by a 4:1 BALUN transformer (see Fig.4-lA). Alternatively, 3OO Ω twin lead can be used for the transmission line. If this alternative is used, then the use of UHF shielded twin lead is highly recommended. If the transmitter lacks the balanced output needed to feed twin lead, then use a BALUN at the input end of the twin lead (i.e., right at the transmitter).

4.4.3 Yagi antennas

The Yagi beam antenna is a highly directional gain antenna, and is used both in HF and VHF/UHF systems. The antenna is relatively easy to build at VHF/UHF.

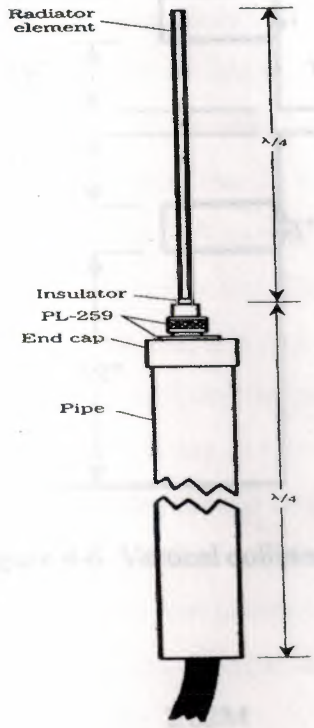

Figure 4-5B Tubing coaxial vertical.

In fact , it is easier than for HF systems. The basic Yagi was covered in chapter 12, so we will only show examples of practical VHF devices. A 6-meter Yagi antenna is shown in Fig.4-7. This particular antenna is a four element model. The reflector and directors can be mounted directly to a metallic boom, because they are merely parasitic. The driven element, however, must be insulated from the metal boom.

The driven element shown in Fig.4-7 is a folded dipole. While this is common practice at VHF, because it tends to broadband the antenna, it is not strictly necessary. The dimensions of the driven element are found from Eq.4-4. Set the equation equal to 300 Ω, select the diameter of the tubing from commercially available sources, and then calculate the spacing.

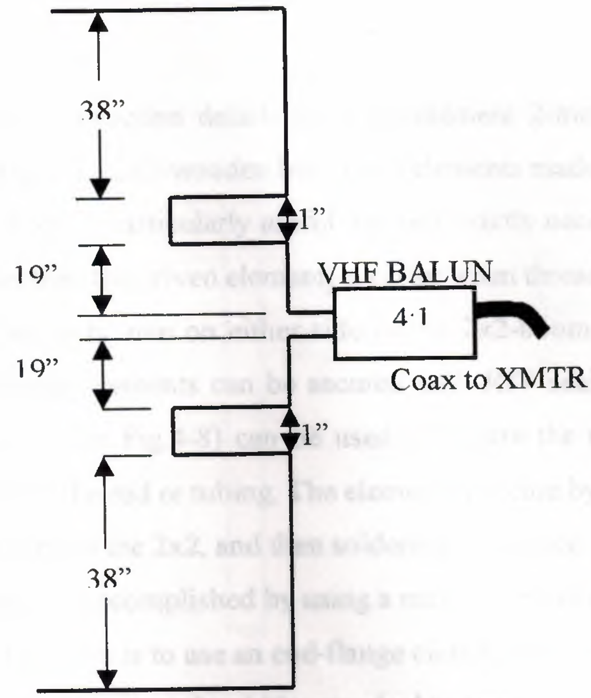

Figure 4-6 Vertical collinear antenna

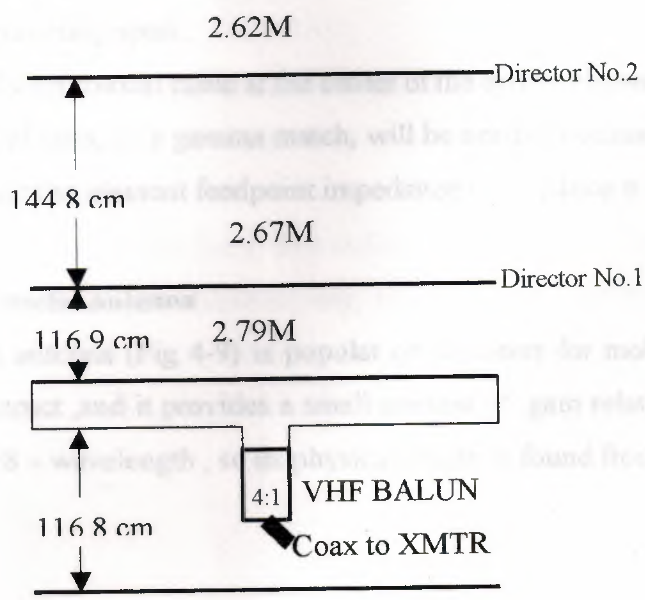

Figure 4-7 Six-meter beam.

4.4.4: Two-meter yagi

The Figure 4-8 shows the construction details for a six-element 2-meter Yagi beam antenna. This antenna is built using a 2x2-wooden boom and elements made of either brass or copper rod. Threaded brass rod is particularly useful, but not strictly necessary. The job of securing the elements (other than the driven element) is easier when threaded rod is used, because it allows a pair of hex nuts, one on either side of the 2x2-boom, to be used to secure the element. Non-threaded elements can be secured with *RTV* sealing a press-fit. Alternatively, tie wires (see inset to Fig.4-8) can be used to secure the rods. A hole is drilled through the 2 x 2 to admit the rod or tubing. The element is secure by wrapping a tie wire around the rod on either side of the 2x2, and then soldering it in place.

Mounting of the antenna is accomplished by using a mast secured to the boom with an appropriate clamp. One alternative is to use an end-flange clamp, such as are sometimes used to support pole lamps, etc. The mast should be attached to the boom at the center of gravity, which is also known as the *balance point.* If you try to balance the antenna in one hand unsupported, there is one (and only one) point at which it is balanced (and won't fall). Attach the mast hardware at, or near, this point in order to prevent normal gravitational torques from tearing the mounting apart .

The antenna is fed with coaxial cable at the center of the driven element. Ordinarily, either a matching section of coax, or a gamma match, will be needed because the effect of parasitic elements on the driven element feedpoint impedance is to reduce it .

4.4.5 5/8 wavelength 2-meter antenna

The 5/8 –wavelength antenna (Fig 4-9) is popular on 2-meters for mobile operation because it is easy to construct ,and it provides a small amount of gain relative to dipole . The radiator element is 5/8 – wavelength , so its physical length is found from:

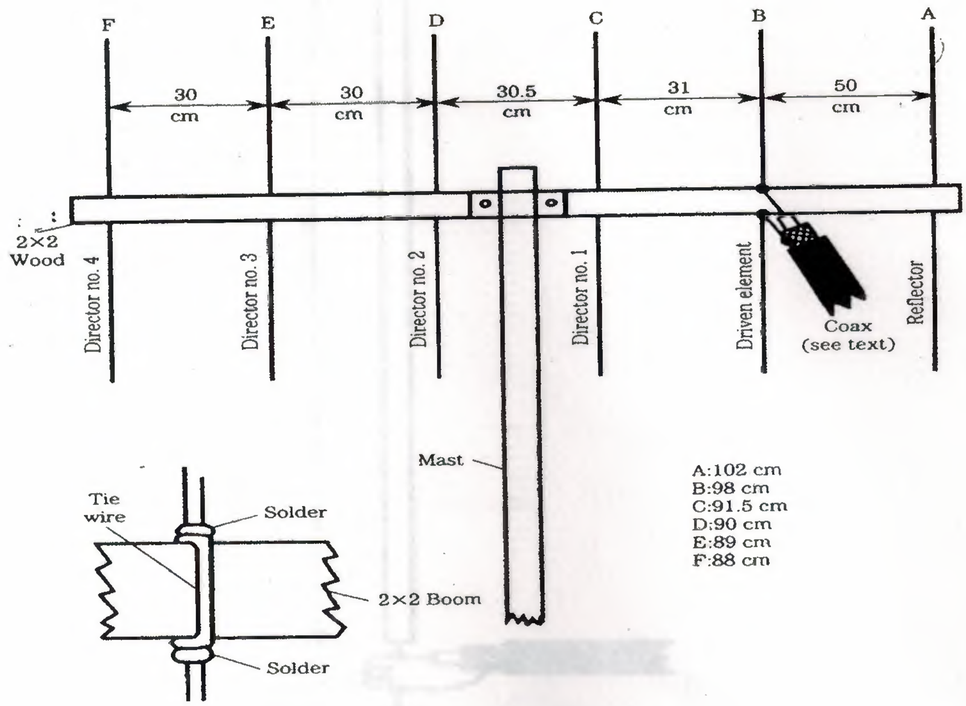

Figure 4-8 Two –meter vertical beam

$$L=\frac{7380}{F_{MHz}} \quad \text{inches} \tag{4-6}$$

The 5/8-wavelength antenna is not a good match to any of the common forms of coaxial cables. Either a matching section of cable, or an inductor match, is normally used. In Fig4-9 an inductor match is used. The matching coil consists of 2 to 3 turns of wire, wound over a ¼-inch o.d. form, ¼-inch long. The radiator element can be tubing, brazing rod, or a length of heavy piano wire. Alternatively, for low-power systems, it can be a telescoping antenna that is bought as a replacement for portable radios or televisions. These antennas have the advantage of being capable of being adjusted to resonance without the need for cutting .

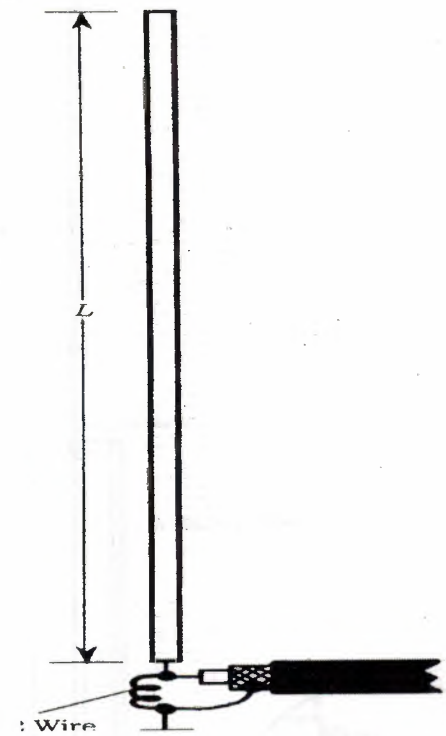

Figure 4-9 wavelength two-meter antenna.

4.4.6 J-pole antennas

The J-pole antenna is another popular form of vertical on the VHF bands. It can be used at almost any frequency, although the example shown in Fig.4-10 is for 2-meters. The antenna radiator is %-wavelength long, so its dimension is found from:

$$L= \frac{8838}{F_{MH_Z}} \quad \text{inches} \tag{4-7}$$

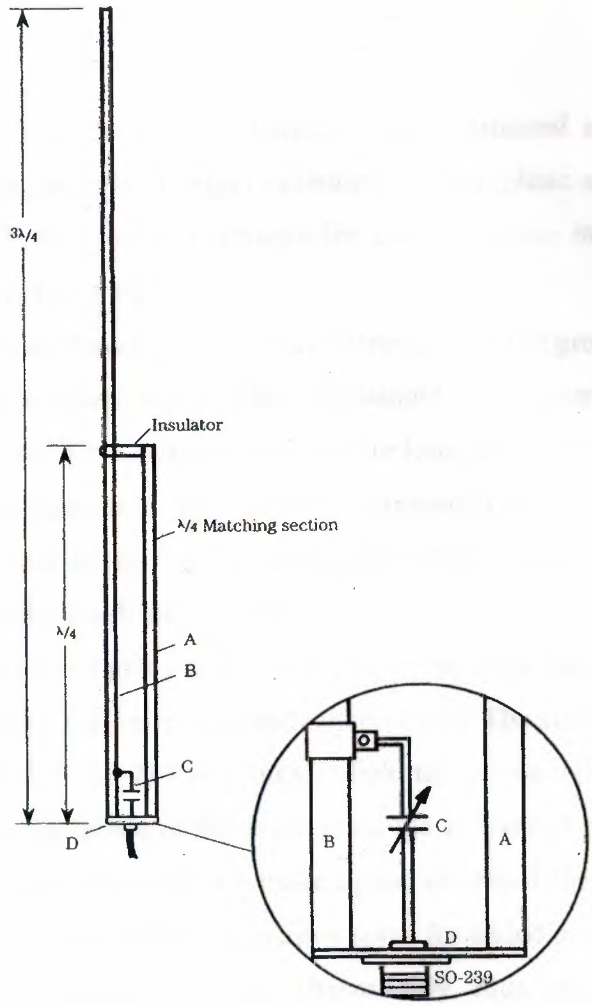

Figure 4-10 J-pole antenna.

And the quarter-wavelength matching section length from:

$$L = \frac{2952}{F_{MH_z}} \tag{4-8}$$

Taken together the matching section and the radiator form a parallel transmission line with *a* characteristic impedance that is four times the coaxial cable impedance. If 50 Ω coax is used; and the elements are made from 0.5 inch o.d. pipe, then *a* spacing of 1.5-inches will yield an impedance of about 200 Ω). Impedance matching is accomplished by a gamma match consisting of a 25-pF variable capacitor, connected by a clamp to the radiator, about 6 inches (experiment with placement) above the base.

4.4.7 Ground plane

The ground plane antenna is a vertical radiator situated above an artificial RF ground consisting of quarter-wavelength radiators. Ground plane antennas can be either 1/4-wavelength or 5/8-wavelength (although for the latter case impedance matching is needed—see the previous example).

Figure 4-11 shows how to construct an extremely simple ground-plane antenna for 2-meters and above. The construction is too lightweight for 6-meter antennas (in general), because the element lengths on 6-meter antennas are long enough to make their weight too great for this type of construction. The base of the antenna is a single 80-239 chassis type coaxial connector. Be sure to use the type that requires four small machine screws to hold it to the chassis, and not the single nut variety.

The radiator element is a piece of 3/16-inch or 4-mm brass tubing. This tubing can be bought at hobby stores that sell airplanes and other models. The sizes quoted just happen to fit over the center pin of an 80-239 with only a slight tap from a lightweight hammer-and I do mean slight tap. If the inside of the tubing and the connector pm are pre-tinned with solder, then sweat soldering the joint will make a good electrical connection that is resistant to weathering. Cover the joint with clear lacquer spray for added protection.

The radials are also made of tubing. Alternatively, rods can also be used for this purpose. At least four radials are needed for a proper antenna (only one shown in Fig. 4-11). This number is optimum because they are attached to the 80-239 mounting holes, and there are only four holes. Flatten one end of the radial, and drill a small hole in the center of the flattened area. Mount the radial to the S0-239 using small hardware (4-40, etc.).
The 80-239 can be attached to a metal L-bracket. While it is easy to fabricate such a bracket, it is also possible to buy suitable brackets in any well-equipped hardware store. While shopping at one do-it-yourself type of store, I found several reasonable candidate brackets.

The bracket is attached to a length of 2x2 lumber that serves as the mast .

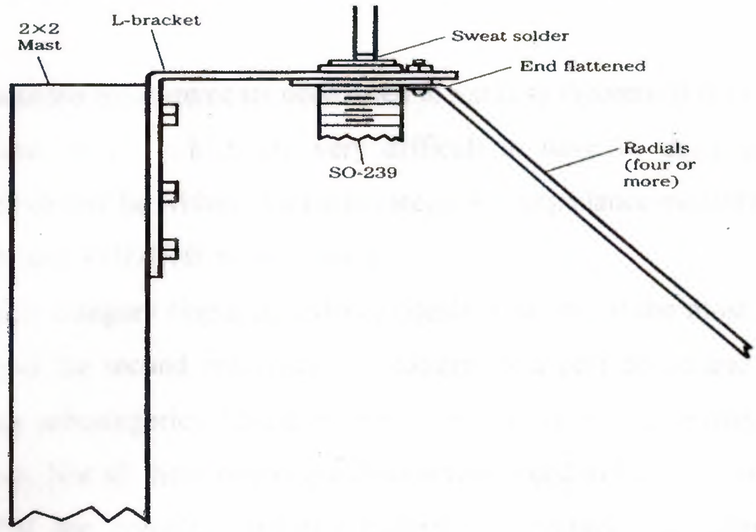

Figure 4-11 Small VHF ground plane construction.

CONCLUSION

The antenna measurements need often to validate theoretical data, and sometimes to determine some values, which are very difficult to have by calculation. The antenna measurements almost lie within two basic categories: impedance measurements and pattern measurements and VHF/UHF measurements.

The first category (input impedance) deals with one of the most important antenna parameters, and the second one (radiation pattern) is a very broad and equally important one with many subcategories. Measurements of efficiency and noise may also be desired in some instances. Not all these possible measurements need to be made in every situation. It is seldom that the complete antenna pattern is measured, including side lobes and polarization characteristics in all directions, often, at the higher frequencies it can be assumed the antenna ohmic losses are negligible, and therefore the radiation efficiency factor need not be measured.

Especially at the higher frequencies where directional antennas are often used. In this project, we learned the selection of antennas to perform various tasks, together with aspects of reliability, sitting, and economics. And we presented the application of the VHF and UHF antennas, we learned about the VHF and UHF transmitting and receiving antenna, and we had some experiences for the VHF and UHF antennas showing the output and the input.

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