CHAPTER 4

ANTENNAS

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. State the basic principles of antenna radiation and list the parts of an antenna.
2. Explain current and voltage distribution on an antenna.
3. Describe how electromagnetic energy is radiated from an antenna.
4. Explain polarization, gain, and radiation resistance characteristics of an antenna.
5. Describe the theory of operation of half- wave and quarter-wave antennas.
6. List the various array antennas.
7. Describe the directional array antennas presented and explain the basic operation of each.
8. Identify various special antennas presented, such as long-wire, V, rhombic, turnstile, ground-plane, and corner-reflector; describe the operation of each.
9. List safety precautions when working aloft and around antennas.

INTRODUCTION

If you had been around in the early days of electronics, you would have considered an ANTENNA (AERIAL) to be little more than a piece of wire strung between two trees or upright poles. In those days, technicians assumed that longer antennas automatically provided better reception than shorter antennas. They also believed that a mysterious MEDIUM filled all space, and that an antenna used this medium to send and receive its energy. These two assumptions have since been discarded. Modern antennas have evolved to the point that highly directional, specially designed antennas are used to relay worldwide communications in space through the use of satellites and Earth station antennas (fig. 4-1). Present transmission theories are based on the assumption that space itself is the only medium necessary to propagate (transmit) radio energy.

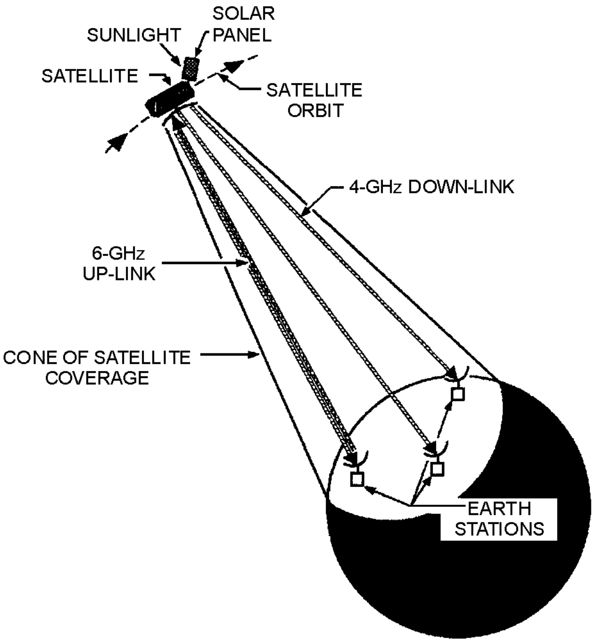


Figure 4-1.—Satellite/earth station communications system.

A tremendous amount of knowledge and information has been gained about the design of antennas and radio-wave propagation. Still, many old-time technicians will tell you that when it comes to designing the length of an antenna, the best procedure is to perform all calculations and try out the antenna. If it doesn't work right, use a cut-and-try method until it does. Fortunately, enough information has been collected over the last few decades that it is now possible to predict the behavior of antennas. This chapter will discuss and explain the basic design and operation of antennas.

PRINCIPLES OF ANTENNA RADIATION

After an rf signal has been generated in a transmitter, some means must be used to radiate this signal through space to a receiver. The device that does this job is the antenna. The transmitter signal energy is sent into space by a TRANSMITTING ANTENNA; the rf signal is then picked up from space by a RECEIVING ANTENNA.

The rf energy is transmitted into space in the form of an electromagnetic field. As the traveling electromagnetic field arrives at the receiving antenna, a voltage is induced into the antenna (a conductor). The rf voltages induced into the receiving antenna are then passed into the receiver and converted back into the transmitted rf information.

The design of the antenna system is very important in a transmitting station. The antenna must be able to radiate efficiently so the power supplied by the transmitter is not wasted. An efficient transmitting antenna must have exact dimensions. The dimensions are determined by the transmitting frequencies. The dimensions of the receiving antenna are not critical for relatively low radio frequencies. However, as the frequency of the signal being received increases, the design and installation of the receiving antenna become more critical. An example of this is a television receiving antenna. If you raise it a few more inches from the ground or give a slight turn in direction, you can change a snowy blur into a clear picture.

The conventional antenna is a conductor, or system of conductors, that radiates or intercepts electromagnetic wave energy. An ideal antenna has a definite length and a uniform diameter, and is completely isolated in space. However, this ideal antenna is not realistic. Many factors make the design of an antenna for a communications system a more complex problem than you would expect. These factors include the height of the radiator above the earth, the conductivity of the earth below it, and the shape and dimensions of the antenna. All of these factors affect the radiated-field pattern of the antenna in space. Another problem in antenna design is that the radiation pattern of the antenna must be directed between certain angles in a horizontal or vertical plane, or both.

Most practical transmitting antennas are divided into two basic classifications, HERTZ (half-wave) ANTENNAS and MARCONI (quarter-wave) ANTENNAS. Hertz antennas are generally installed some distance above the ground and are positioned to radiate either vertically or horizontally. Marconi antennas operate with one end grounded and are mounted perpendicular to the Earth or to a surface acting as a ground. Hertz antennas are generally used for frequencies above 2 megahertz. Marconi antennas are used for frequencies below 2 megahertz and may be used at higher frequencies in certain applications.

A complete antenna system consists of three parts: (1) The COUPLING DEVICE, (2) the FEEDER, and (3) the ANTENNA, as shown in figure 4-2. The coupling device (coupling coil) connects the transmitter to the feeder. The feeder is a transmission line that carries energy to the antenna. The antenna radiates this energy into space.

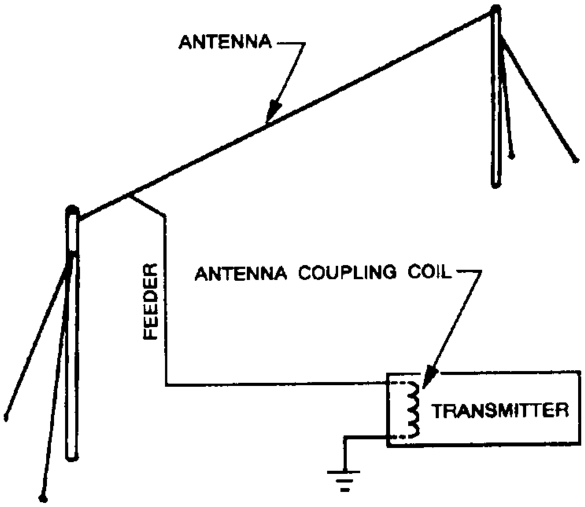


Figure 4-2.—Typical antenna system.

The factors that determine the type, size, and shape of the antenna are (1) the frequency of operation of the transmitter, (2) the amount of power to be radiated, and (3) the general direction of the receiving set. Typical antennas are shown in figure 4-3.

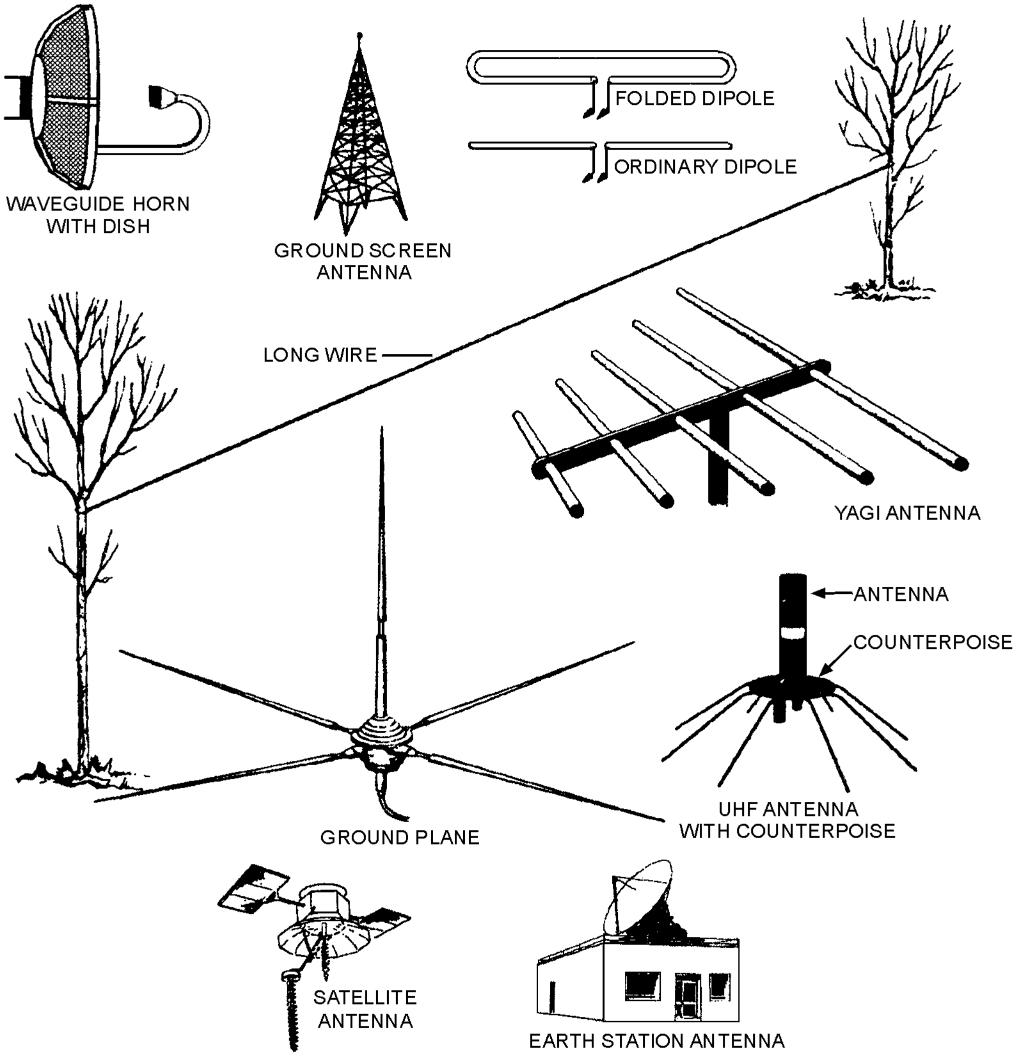


Figure 4-3.—Typical antennas.

CURRENT AND VOLTAGE DISTRIBUTION ON AN ANTENNA

A current flowing in a wire whose length is properly related to the rf produces an electro magnetic field. This field is radiated from the wire and is set free in space. We will discuss how these waves are set free later in this chapter. Remember, the principles of radiation of electromagnetic energy are based on two laws:

1. A MOVING ELECTRIC FIELD CREATES A MAGNETIC (H) FIELD.
2. A MOVING MAGNETIC FIELD CREATES AN ELECTRIC (E) FIELD.

In space, these two fields will be in phase and perpendicular to each other at any given time. Although a conductor is usually considered present when a moving electric or magnetic field is mentioned, the laws that govern these fields say nothing about a conductor. Therefore, these laws hold true whether a conductor is present or not.

Figure 4-4 shows the current and voltage distribution on a half-wave (Hertz) antenna. In view A, a piece of wire is cut in half and attached to the terminals of a high-frequency ac generator. The frequency of the generator is set so that each half of the wire is 1/4 wavelength of the output. The result is a common type of antenna known as a DIPOLE.

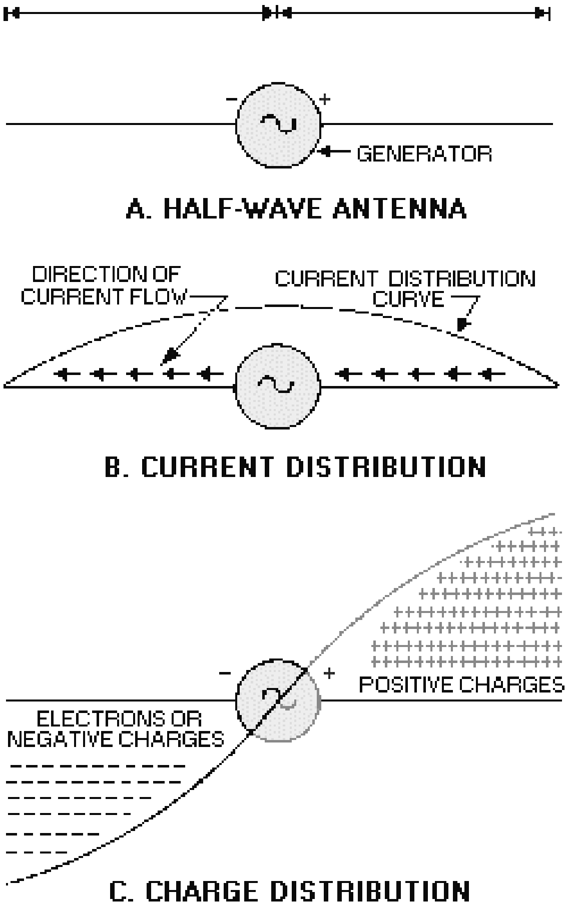


Figure 4-4.—Current and voltage distribution on an antenna.

At a given time the right side of the generator is positive and the left side negative. Remember that like charges repel. Because of this, electrons will flow away from the negative terminal as far as possible, but will be attracted to the positive terminal. View B shows the direction and distribution of electron flow. The distribution curve shows that most current flows in the center and none flows at the ends. The current distribution over the antenna will always be the same no matter how much or how little current is flowing. However, current at any given point on the antenna will vary directly with the amount of voltage developed by the generator.

One-quarter cycle after electrons have begun to flow, the generator will develop its maximum voltage and the current will decrease to 0. At that time the condition shown in view C will exist. No current will be flowing, but a maximum number of electrons will be at the left end of the line and a minimum number at the right end. The charge distribution view C along the wire will vary as the voltage of the generator varies. Therefore, you may draw the following conclusions:

1. A current flows in the antenna with an amplitude that varies with the generator voltage.
2. A sinusoidal distribution of charge exists on the antenna. Every 1/2 cycle, the charges reverse polarity.
3. The sinusoidal variation in charge magnitude lags the sinusoidal variation in current by 1/4 cycle.

Q1. What are the two basic classifications of antennas?

Q2. What are the three parts of a complete antenna system?

Q3. What three factors determine the type, size, and shape of an antenna?

RADIATION OF ELECTROMAGNETIC ENERGY

The electromagnetic radiation from an antenna is made up of two components, the E field and the H field. We discussed these fields in chapters 1 and 2. The two fields occur 90 degrees out of phase with each other. These fields add and produce a single electromagnetic field. The total energy in the radiated wave remains constant in space except for some absorption of energy by the Earth. However, as the wave advances, the energy spreads out over a greater area and, at any given point, decreases as the distance increases.

Various factors in the antenna circuit affect the radiation of these waves. In figure 4-5, for example, if an alternating current is applied at the A end of the length of wire from A to B, the wave will travel along the wire until it reaches the B end. Since the B end is free, an open circuit exists and the wave cannot travel farther. This is a point of high impedance. The wave bounces back (reflects) from this point of high impedance and travels toward the starting point, where it is again reflected. The energy of the wave would be gradually dissipated by the resistance of the wire of this back-and-forth motion (oscillation); however, each time it reaches the starting point, the wave is reinforced by an amount sufficient to replace the energy lost. This results in continuous oscillations of energy along the wire and a high voltage at the A end of the wire. These oscillations are applied to the antenna at a rate equal to the frequency of the rf voltage.

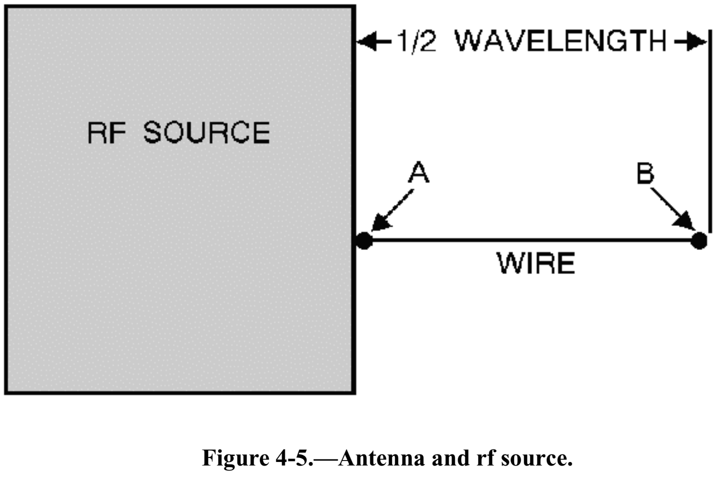


Figure 4-5.—Antenna and rf source.

These impulses must be properly timed to sustain oscillations in the antenna. The rate at which the waves travel along the wire is constant at approximately 300,000,000 meters per second. The length of the antenna must be such that a wave will travel from one end to the other and back again during the period of 1 cycle of the rf voltage. Remember, the distance a wave travels during the period of 1 cycle is known as the wavelength and is found by dividing the rate of travel by the frequency.

Look at the current and voltage (charge) distribution on the antenna in figure 4-6. A maximum movement of electrons is in the center of the antenna at all times; therefore, the center of the antenna is at a low impedance. This condition is called a STANDING WAVE of current. The points of high current and high voltage are known as current and voltage LOOPS. The points of minimum current and minimum voltage are known as current and voltage NODES. View A shows a current loop and current nodes. View B shows voltage loops and a voltage node. View C shows the resultant voltage and current loops and nodes. The presence of standing waves describes the condition of resonance in an antenna. At resonance the waves travel back and forth in the antenna reinforcing each other and the electromagnetic waves are transmitted into space at maximum radiation. When the antenna is not at resonance, the waves tend to cancel each other and lose energy in the form of heat.

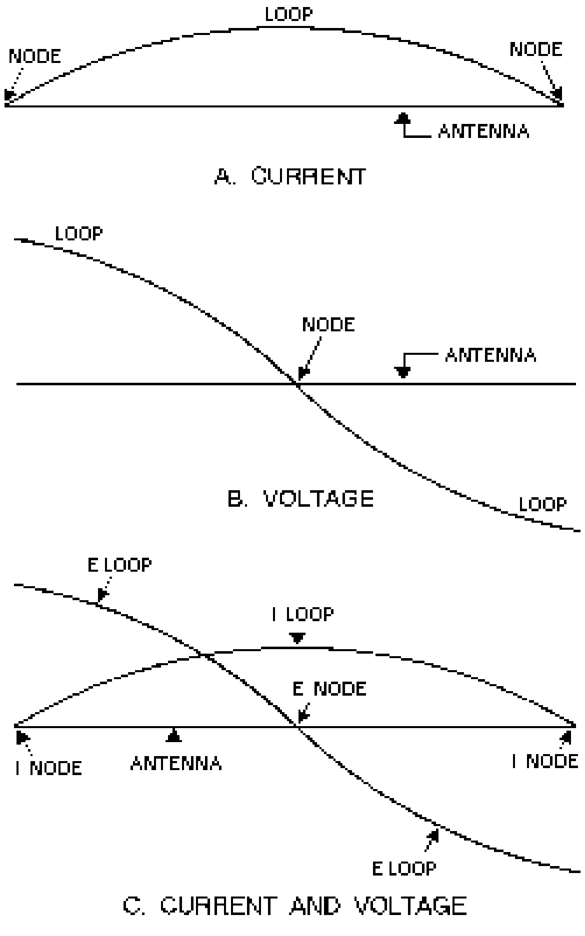


Figure 4-6.—Standing waves of voltage and current on an antenna.

Q4. If a wave travels exactly the length of an antenna from one end to the other and back during the period of 1 cycle, what is the length of the antenna?

Q5. What is the term used to identify the points of high current and high voltage on an antenna?

Q6. What is the term used to identify the points of minimum current and minimum voltage on an antenna?

ANTENNA CHARACTERISTICS

You can define an antenna as a conductor or group of conductors used either for radiating electromagnetic energy into space or for collecting it from space. Electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into space. On the receiving end, electromagnetic energy is converted into electrical energy by the antenna and is fed into the receiver.

Fortunately, separate antennas seldom are required for both transmitting and receiving rf energy. Any antenna can transfer energy from space to its input receiver with the same efficiency that it transfers energy from the transmitter into space. Of course, this is assuming that the same frequency is used in both cases. This property of interchangeability of the same antenna for transmitting and receiving is known as antenna RECIPROCITY. Antenna reciprocity is possible because antenna characteristics are essentially the same for sending and receiving electromagnetic energy.

RECIPROCITY OF ANTENNAS

In general, the various properties of an antenna apply equally, regardless of whether you use the antenna for transmitting or receiving. The more efficient a certain antenna is for transmitting, the more efficient it will be for receiving on the same frequency. Likewise, the directive properties of a given antenna also will be the same whether it is used for transmitting or receiving.

Assume, for example, that a certain antenna used with a transmitter radiates a maximum amount of energy at right angles to the axis of the antenna, as shown in figure 4-7, view A. Note the minimum amount of radiation along the axis of the antenna. Now, if this same antenna were used as a receiving antenna, as shown in view B, it would receive best in the same directions in which it produced maximum radiation; that is, at right angles to the axis of the antenna.

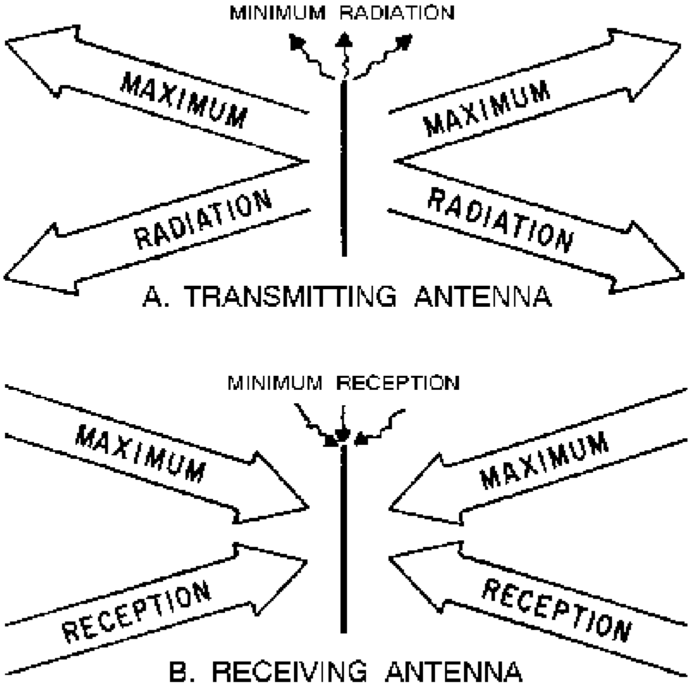


Figure 4-7.—Reciprocity of antennas.

ANTENNA GAIN

Another characteristic of a given antenna that remains the same whether the antenna is used for transmitting or receiving is GAIN. Some antennas are highly directional that is, more energy is propagated in certain directions than in others. The ratio between the amount of energy propagated in these directions compared to the energy that would be propagated if the antenna were not directional is known as its gain. When a transmitting antenna with a certain gain is used as a receiving antenna, it will also have the same gain for receiving.

POLARIZATION

Let's review polarization briefly. In chapter 2 you learned that the radiation field is composed of electric and magnetic lines of force. These lines of force are always at right angles to each other. Their intensities rise and fall together, reaching their maximums 90 degrees apart. The electric field determines the direction of polarization of the wave. In a vertically polarized wave, the electric lines of force lie in a vertical direction. In a horizontally polarized wave, the electric lines of force lie in a horizontal direction. Circular polarization has the electric lines of force rotating through 360 degrees with every cycle of rf energy.

The electric field was chosen as the reference field because the intensity of the wave is usually measured in terms of the electric field intensity (volts, millivolts, or microvolts per meter). When a single-wire antenna is used to extract energy from a passing radio wave, maximum pickup will result when the antenna is oriented in the same direction as the electric field. Thus a vertical antenna is used for the efficient reception of vertically polarized waves, and a horizontal antenna is used for the reception of horizontally polarized waves. In some cases the orientation of the electric field does not remain constant.

Instead, the field rotates as the wave travels through space. Under these conditions both horizontal and vertical components of the field exist and the wave is said to have an elliptical polarization.

Q7. The various properties of a transmitting antenna can apply equally to the same antenna when it is used as a receiving antenna. What term is used for this property?

Q8. The direction of what field is used to designate the polarization of a wave?

Q9. If a wave's electric lines of force rotate through 360 degrees with every cycle of rf energy, what is the polarization of this wave?

Polarization Requirements for Various Frequencies

Ground-wave transmission is widely used at medium and low frequencies. Horizontal polarization cannot be used at these frequencies because the electric lines of force are parallel to and touch the earth. Since the earth acts as a fairly good conductor at low frequencies, it would short out the horizontal electric lines of force and prevent the radio wave from traveling very far. Vertical electric lines of force, on the other hand, are bothered very little by the earth. Therefore vertical polarization is used for ground-wave transmission, allowing the radio wave to travel a considerable distance along the ground surface with minimum attenuation.

Sky-wave transmission is used at high frequencies. Either horizontal or vertical polarization can be used with sky-wave transmission because the sky wave arrives at the receiving antenna elliptically polarized. This is the result of the wave traveling obliquely through the Earth's magnetic field and striking the ionosphere. The radio wave is given a twisting motion as it strikes the ionosphere. Its orientation continues to change because of the unstable nature of the ionosphere. The relative amplitudes and phase differences between the horizontal and vertical components of the received wave also change. Therefore, the transmitting and receiving antennas can be mounted either horizontally or vertically.

Although either horizontally or vertically polarized antennas can be used for high frequencies, horizontally polarized antennas have certain advantages and are therefore preferred. One advantage is that vertically polarized interference signals, such as those produced by automobile ignition systems and electrical appliances, are minimized by horizontal polarization. Also, less absorption of radiated energy by buildings or wiring occurs when these antennas are used. Another advantage is that support structures for these antennas are of more convenient size than those for vertically polarized antennas.

For frequencies in the vhf or uhf range, either horizontal or vertical polarization is satisfactory. These radio waves travel directly from the transmitting antenna to the receiving antenna without entering the ionosphere. The original polarization produced at the transmitting antenna is maintained throughout the entire travel of the wave to the receiver. Therefore, if a horizontally polarized antenna is used for transmitting, a horizontally polarized antenna must be used for receiving. The requirements would be the same for a vertical transmitting and receiving antenna system.

For satellite communications, parallel frequencies can be used without interference by using polarized radiation. The system setup is shown in figure 4-8. One pair of satellite antennas is vertically polarized and another pair is horizontally polarized. Either vertically or horizontally polarized transmissions are received by the respective antenna and retransmitted in the same polarization. For example, transmissions may be made in the 3.7 to 3.74 GHz range on the vertical polarization path and in the 3.72 to 3.76 GHz range on the horizontal polarization path without adjacent frequency (co-channel) interference.

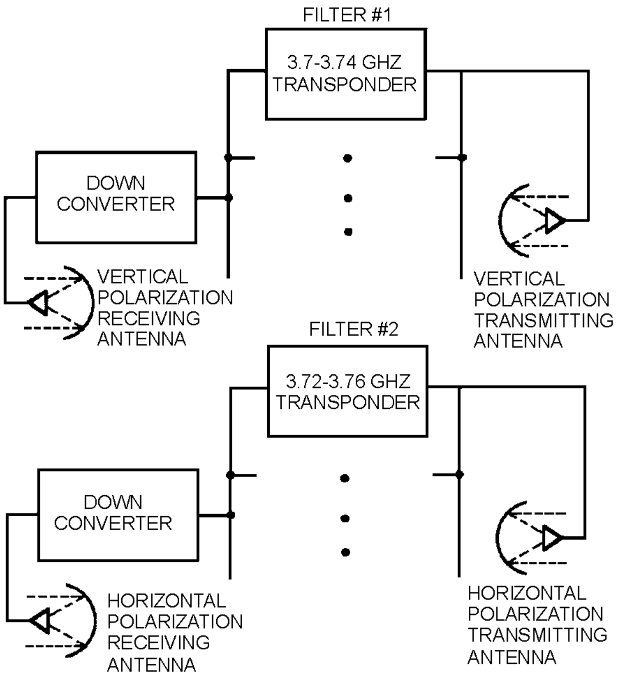


Figure 4-8.—Satellite transmissions using polarized radiation.

Advantages of Vertical Polarization

Simple vertical antennas can be used to provide OMNIDIRECTIONAL (all directions) communication. This is an advantage when communications must take place from a moving vehicle.

In some overland communications, such as in vehicular installations, antenna heights are limited to 3 meters (10 feet) or less. In such instances vertical polarization results in a stronger receiver signal than does horizontal polarization at frequencies up to about 50 megahertz. From approximately 50 to 100 megahertz, vertical polarization results in a slightly stronger signal than does horizontal polarization with antennas at the same height. Above 100 megahertz, the difference in signal strength is negligible.

For transmission over bodies of water, vertical polarization is much better than horizontal polarization for antennas at the lower heights. As the frequency increases, the minimum antenna height decreases. At 30 megahertz, vertical polarization is better for antenna heights below about 91 meters (300 feet); at 85 megahertz, antenna heights below 15 meters (50 feet); and still lower heights at the high frequencies. Therefore, at ordinary antenna mast heights of 12 meters (40 feet), vertical polarization is advantageous for frequencies less than about 100 megahertz.

Radiation is somewhat less affected by reflections from aircraft flying over the transmission path when vertical polarization is used instead of horizontal polarization. With horizontal polarization, such reflections cause variations in received signal strength. This factor is important in locations where aircraft traffic is heavy.

When vertical polarization is used, less interference is produced or picked up because of strong vhf and uhf broadcast transmissions (television and fm). This is because vhf and uhf transmissions use horizontal polarization. This factor is important when an antenna must be located in an urban area having several television and fm broadcast stations.

Advantages of Horizontal Polarization

A simple horizontal antenna is bi-directional. This characteristic is useful when you desire to minimize interference from certain directions. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized.

When antennas are located near dense forests or among buildings, horizontally polarized waves suffer lower losses than vertically polarized waves, especially above 100 megahertz. Small changes in antenna locations do not cause large variations in the field intensity of horizontally polarized waves. When vertical polarization is used, a change of only a few meters in the antenna location may have a considerable effect on the received signal strength. This is the result of interference patterns that produce standing waves in space when spurious reflections from trees or buildings occur.

When simple antennas are used, the transmission line, which is usually vertical, is less affected by a horizontally mounted antenna. When the antenna is mounted at right angles to the transmission line and horizontal polarization is used, the line is kept out of the direct field of the antenna. As a result, the radiation pattern and electrical characteristics of the antenna are practically unaffected by the presence of the vertical transmission line.

Q10. What type of polarization should be used at medium and low frequencies?

Q11. What is an advantage of using horizontal polarization at high frequencies?

Q12. What type of polarization should be used if an antenna is mounted on a moving vehicle at frequencies below 50 megahertz?

RADIATION RESISTANCE

Radiated energy is the useful part of the transmitter's signal. However, it represents as much of a loss to the antenna as the energy lost in heating the antenna wire. In either case, the dissipated power is equal to I^2R. In the case of heat losses, the R is real resistance. In the case of radiation, R is an assumed resistance; if this resistance were actually present, it would dissipate the same amount of power that the antenna takes to radiate the energy. This assumed resistance is referred to as the RADIATION RESISTANCE.

Radiation resistance varies at different points on the antenna. This resistance is always measured at a current loop. For the antenna in free space, that is, entirely removed from any objects that might affect its operation, the radiation resistance is 73 ohms. A practical antenna located over a ground plane may have any value of radiation resistance from 0 to approximately 100 ohms. The exact value of radiation resistance depends on the height of the antenna above the ground. For most half-wave wire antennas, the radiation resistance is about 65 ohms. It will usually vary between 55 and 600 ohms for antennas constructed of rod or tubing. The actual value of radiation resistance, so long as it is 50 ohms or more, has little effect on the radiation efficiency of the antenna. This is because the ohmic resistance is about 1 ohm for conductors of large diameter. The ohmic resistance does not become important until the radiation resistance drops to a value less than 10 ohms. This may be the case when several antennas are coupled together.

RADIATION TYPES AND PATTERNS

The energy radiated from an antenna forms a field having a definite RADIATION PATTERN. A radiation pattern is a plot of the radiated energy from an antenna. This energy is measured at various angles at a constant distance from the antenna. The shape of this pattern depends on the type of antenna used. In this section, we will introduce the basic types of radiation (isotropic and anisotropic) and their radiation patterns.

Isotropic Radiation

Some antenna sources radiate energy equally in all directions. Radiation of this type is known as ISOTROPIC RADIATION. We all know the Sun radiates energy in all directions. The energy radiated from the Sun measured at any fixed distance and from any angle will be approximately the same. Assume that a measuring device is moved around the Sun and stopped at the points indicated in figure 4-9 to make a measurement of the amount of radiation. At any point around the circle, the distance from the measuring device to the Sun is the same. The measured radiation will also be the same. The Sun is therefore considered an isotropic radiator.

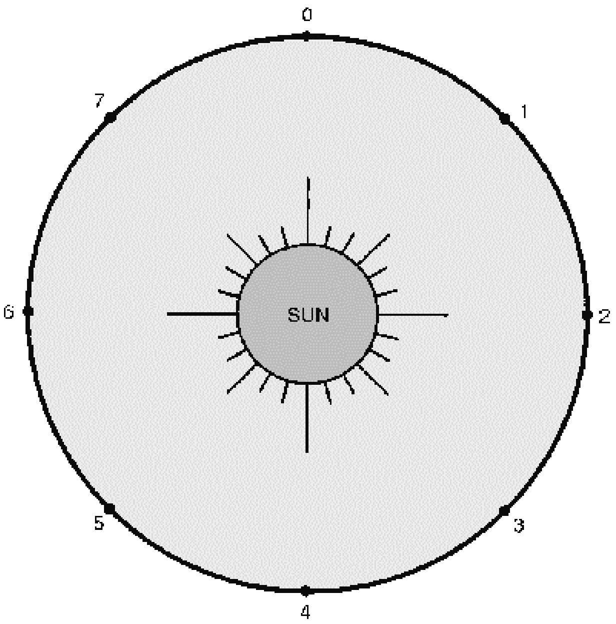
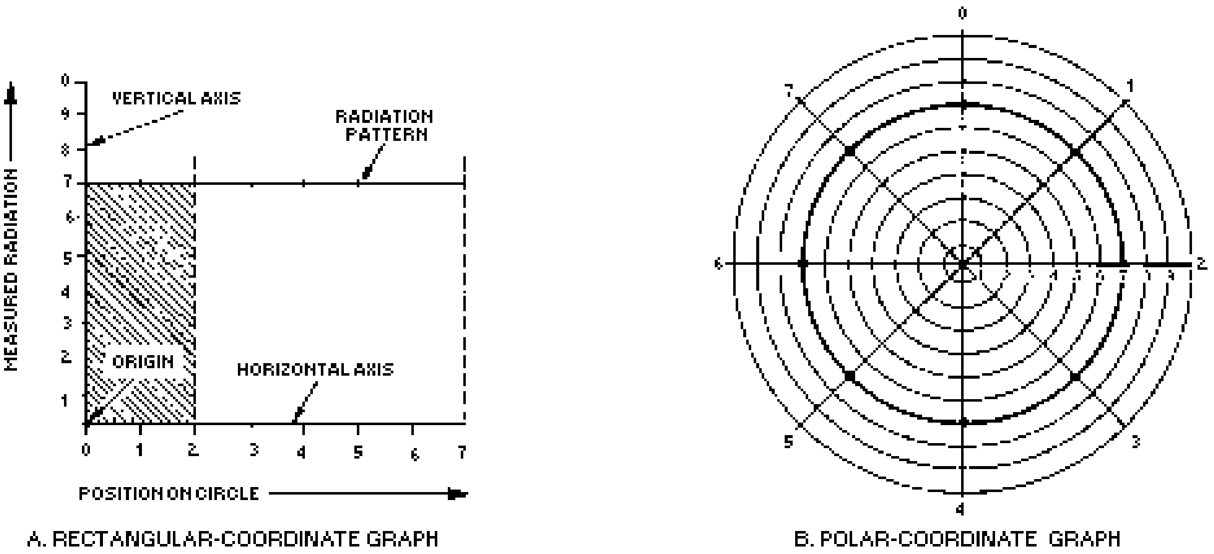


Figure 4-9.—Isotropic radiator.

To plot this pattern, we will assume that the radiation is measured on a scale of 0 to 10 units and that the measured amount of radiation is 7 units at all points. We will then plot our measurements on two different types of graphs, rectangular- and polar-coordinate graphs. The RECTANGULAR-COORDINATE GRAPH of the measured radiation, shown in view A of figure 4-10, is a straight line plotted against positions along the circle. View B shows the POLAR-COORDINATE GRAPH for the same isotropic source.



A. RECTANGULAR-COORDINATE GRAPH

B. POLAR-COORDINATE GRAPH

Figure 4-10.—Comparison of rectangular- and polar-coordinate graphs for an isotropic source.

In the rectangular-coordinate graph, points are located by projection from a pair of stationary, perpendicular axes. In the polar-coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric, equally-spaced circles. The horizontal axis on the rectangular-coordinate graph corresponds to the circles on the polar-coordinate graph. The vertical axis on the rectangular-coordinate graph corresponds to the rotating axis (radius) on the polar-coordinate graph.

Rectangular-Coordinate Pattern

Look at view A of figure 4-10. The numbered positions around the circle are laid out on the HORIZONTAL AXIS of the graph from 0 to 7 units. The measured radiation is laid out on the VERTICAL AXIS of the graph from 0 to 10 units. The units on both axes are chosen so the pattern occupies a convenient part of the graph.

The horizontal and vertical axes are at a right angle to each other. The point where the axes cross each other is known as the ORIGIN. In this case, the origin is 0 on both axes. Now, assume that a radiation value of 7 units view B is measured at position 2. From position 2 on the horizontal axis, a dotted line is projected upwards that runs parallel to the vertical axis. From position 7 on the vertical axis, a line is projected to the right that runs parallel to the horizontal axis. The point where the two lines cross (INTERCEPT) represents a value of 7 radiation units at position 2. This is the only point on the graph that can represent this value.

As you can see from the figure, the lines used to plot the point form a rectangle. For this reason, this type of plot is called a *rectangular-coordinate graph*. A new rectangle is formed for each different point plotted. In this example, the points plotted lie in a straight line extending from 7 units on the vertical scale to the projection of position 7 on the horizontal scale. This is the characteristic pattern in rectangular coordinates of an isotropic source of radiation.

Polar-Coordinate Pattern

The polar-coordinate graph has proved to be of great use in studying radiation patterns. Compare views A and B of figure 4-10. Note the great difference in the shape of the radiation pattern when it is transferred from the rectangular-coordinate graph in view A to the polar-coordinate graph in view B. The scale of radiation values used in both graphs is identical, and the measurements taken are both the same. However, the shape of the pattern is drastically different.

Look at view B of figure 4-10 and assume that the center of the concentric circles is the Sun. Assume that a radius is drawn from the Sun (center of the circle) to position 0 of the circle. When you move to position 1, the radius moves to position 1; when you move to position 2, the radius also moves to position 2, and so on.

The positions where a measurement was taken are marked as 0 through 7 on the graph. Note how the position of the radius indicates the actual direction from the source at which the measurement was taken. This is a distinct advantage over the rectangular-coordinate graph in which the position is indicated along a straight-line axis and has no physical relation to the actual direction of measurement. Now that we have a way to indicate the *direction* of measurement, we must devise a way to indicate the *magnitude* of the radiation.

Notice that the rotating axis is always drawn from the center of the graph to some position on the edge of the graph. As the axis moves toward the edge of the graph, it passes through a set of equally-spaced, concentric circles. In this example view B, they are numbered successively from 1 to 10 from the center out. These circles are used to indicate the magnitude of the radiation.

The advantages of the polar-coordinate graph are immediately evident. The source, which is at the center of the observation circles, is also at the center of the graph. By looking at a polar-coordinate plot of a radiation pattern, you can immediately see the direction and strength of radiation put out by the source. Therefore, the polar-coordinate graph is more useful than the rectangular-coordinate graph in plotting radiation patterns.

Anisotropic Radiation

Most radiators emit (radiate) stronger radiation in one direction than in another. A radiator such as this is referred to as ANISOTROPIC. An example of an anisotropic radiator is an ordinary flashlight. The beam of the flashlight lights only a portion of the space surrounding it. If a circle is drawn with the flashlight as the center, as shown in view B of figure 4-11, the radiated light can be measured at different positions around the circle. Again, as with the isotropic radiator, all positions are the same distance from the center, but at different angles. However, in this illustration the radiated light is measured at 16 different positions on the circle.

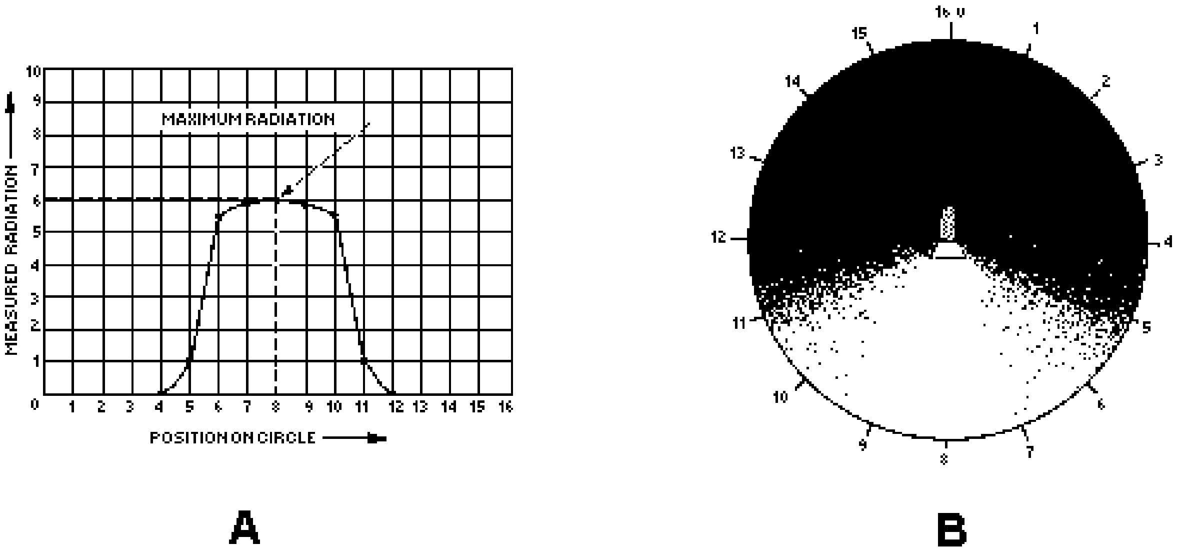


Figure 4-11.—Anisotropic radiator.

Directly behind the flashlight (position 0) the radiation measured is minimum. Accordingly, a 0 value is assigned to this position in the rectangular-coordinate graph (fig. 4-11, view A). This radiation remains at minimum until position 4 is reached. Between positions 4 and 6, the measuring device enters the flashlight beam. You can see this transition from darkness to brightness easily in view B. Radiation is fairly constant between positions 6 and 10. Maximum brightness occurs at position 8, which is directly in the path of the flashlight beam. From positions 10 to 12, the measuring device leaves the flashlight beam and the radiation measurement falls off sharply. At position 13 the radiation is again at 0 and stays at this value back to position 0.

Radiation from a light source and radiation from an antenna are both forms of electromagnetic waves. Therefore, the measurement of radiation of an antenna follows the same basic procedure as that just described for the Sun and the flashlight. Before proceeding further with the study of antenna patterns, you should be sure you understand the methods used to graph the measured radiation (magnitude of the radiation). Study the rectangular- and polar-coordinate systems of plotting presented in the following section.

Q13. What is the radiation resistance of a half-wave antenna in free space?

Q14. A radiating source that radiates energy stronger in one direction than another is known as what type of radiator?

Q15. A radiating source that radiates energy equally in all directions is known as what type of radiator?

Q16. A flashlight is an example of what type of radiator?

In figure 4-11, view A, the radiation pattern of the flashlight is graphed in rectangular coordinates. The illustration of the flashlight beam in view B clearly indicates the shape of the flashlight beam. This is not evident in the radiation pattern plotted on the rectangular-coordinate graph. Now look at figure 4-12. The radiation pattern shown in this figure looks very much like the actual flashlight beam. The pattern in figure 4-12 is plotted using the same values as those of figure 4-11, view A, but is drawn using polar coordinates.

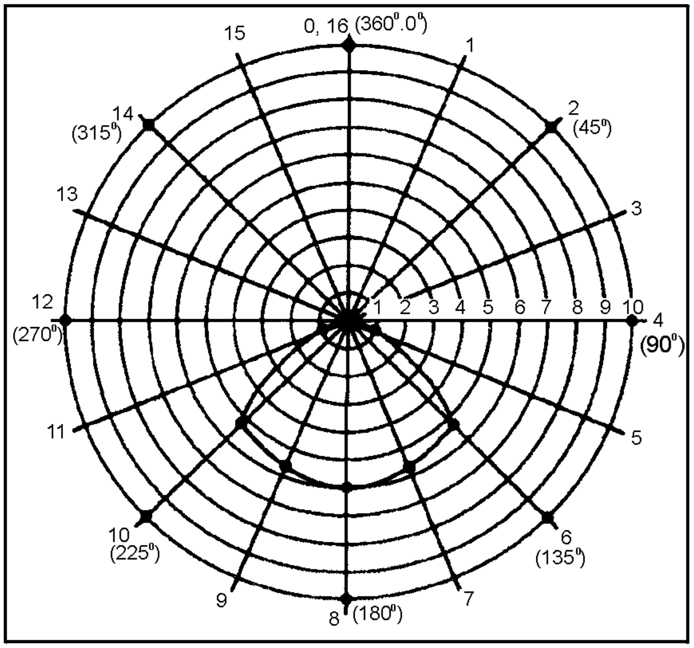


Figure 4-12.—Polar-coordinate graph for anisotropic radiator.

The positions marked off on the two polar-coordinate graphs in figures 4-10 and 4-12 were selected and numbered arbitrarily. However, a standard method allows the positions around a source to be marked off so that one radiation pattern can easily be compared with another. This method is based on the fact that a circle has a radius of 360 degrees. The radius extending vertically from the center (position 0 in figure 4-10) is designated 0 degrees. At position 4 the radius is at a right angle to the 0-degree radius. Accordingly, the radius at position 4 is marked 90 degrees, position 8 is 180 degrees, position 12 is 270 degrees, and position 16 is 360 degrees. The various radii drawn on the graph are all marked according to the angle each radius makes with the reference radius at 0 degrees.

The radiation pattern in figure 4-12 is obtained by using the same procedure that was used for (figure 4-10, view B). The radiation measured at positions 1, 2, 3, and 4 is 0. Position 5 measures approximately 1 unit. This is marked on the graph and the rotating radius moves to position 6. At this position a reading of 5.5 units is taken. As before, this point is marked on the graph. The procedure is repeated around the circle and a reading is obtained from positions 6 through 11. At position 12 no radiation is indicated, and this continues on to position 16.

The polar-coordinate graph now shows a definite area enclosed by the radiation pattern. This pattern indicates the general direction of radiation from the source. The enclosed area is called a LOBE. Outside of this area, minimum radiation is emitted in any direction. For example, at position 2 the radiation is 0. Such a point is called a NULL. In real situations, some radiation is usually transmitted in all directions. Therefore, a null is used to indicate directions of minimum radiation. The pattern of figure 4-12 shows one lobe and one continuous null.

ANTENNA LOADING

You will sometimes want to use one antenna system for transmitting and receiving on several different frequencies. Since the antenna must always be in resonance with the applied frequency, you may need to either physically or electrically lengthen or shorten the antenna.

Except for trailing-wire antennas used in aircraft installations (which may be lengthened or shortened), physically lengthening the antenna is not very practical. But you can achieve the same result by changing the electrical length of the antenna. To change the electrical length, you can insert either an inductor or a capacitor in series with the antenna. This is shown in figure 4-13, views A and B. Changing the electrical length by this method is known as LUMPED-IMPEDANCE TUNING, or LOADING. The electrical length of any antenna wire can be increased or decreased by loading. If the antenna is too short for the wavelength being used, it is resonant at a higher frequency than that at which it is being excited. Therefore, it offers a capacitive reactance at the excitation frequency. This capacitive reactance can be compensated for by introducing a lumped-inductive reactance, as shown in view A. Similarly, if the antenna is too long for the transmitting frequency, it offers an inductive reactance. Inductive reactance can be compensated for by introducing a lumped-capacitive reactance, as shown in view B. An antenna without loading is represented in view C.

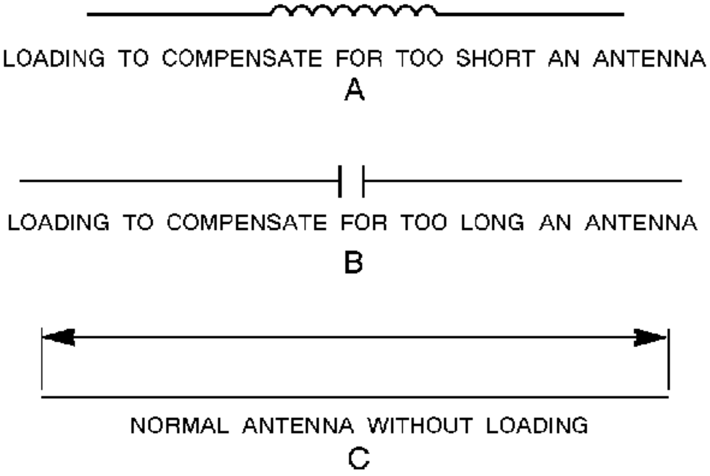


Figure 4-13.—Electrically equal antenna.

BASIC ANTENNAS

Before you look at the various types of antennas, consider the relationship between the wavelength at which the antenna is being operated and the actual length of the antenna. An antenna does not necessarily radiate or receive more energy when it is made longer. Specific dimensions must be used for efficient antenna operation.

Nearly all antennas have been developed from two basic types, the Hertz and the Marconi. The basic Hertz antenna is 1/2 wavelength long at the operating frequency and is insulated from ground. It is often called a DIPOLE or a DOUBLET. The basic Marconi antenna is 1/4 wavelength long and is either grounded at one end or connected to a network of wires called a COUNTERPOISE. The ground or counterpoise provides the equivalent of an additional 1/4 wavelength, which is required for the antenna to resonate.

HALF-WAVE ANTENNAS

A half-wave antenna (referred to as a dipole, Hertz, or doublet) consists of two lengths of wire rod, or tubing, each 1/4 wavelength long at a certain frequency. It is the basic unit from which many complex antennas are constructed. The half-wave antenna operates independently of ground; therefore, it may be installed far above the surface of the Earth or other absorbing bodies. For a dipole, the current is maximum at the center and minimum at the ends. Voltage is minimum at the center and maximum at the ends, as was shown in figure 4-6.

Radiation Patterns

In the following discussion, the term DIPOLE is used to mean the basic half-wave antenna. The term DOUBLET is used to indicate an antenna that is very short compared with the wavelength of the operating frequency. Physically, it has the same shape as the dipole.

RADIATION PATTERN OF A DOUBLET.—The doublet is the simplest form of a practical antenna. Its radiation pattern can be plotted like the radiation pattern of the flashlight (fig. 4-12). Figure 4-14 shows the development of vertical and horizontal patterns for a doublet. This in NOT a picture of the radiation, but three-dimensional views of the pattern itself. In three views the pattern resembles a doughnut. From the dimensions in these views, two types of polar-coordinate patterns can be drawn, horizontal and vertical. The HORIZONTAL PATTERN view A is derived from the solid pattern view C by slicing it horizontally. This produces view B, which is converted to the polar coordinates seen in view A. The horizontal pattern illustrates that the radiation is constant in any direction along the horizontal plane.

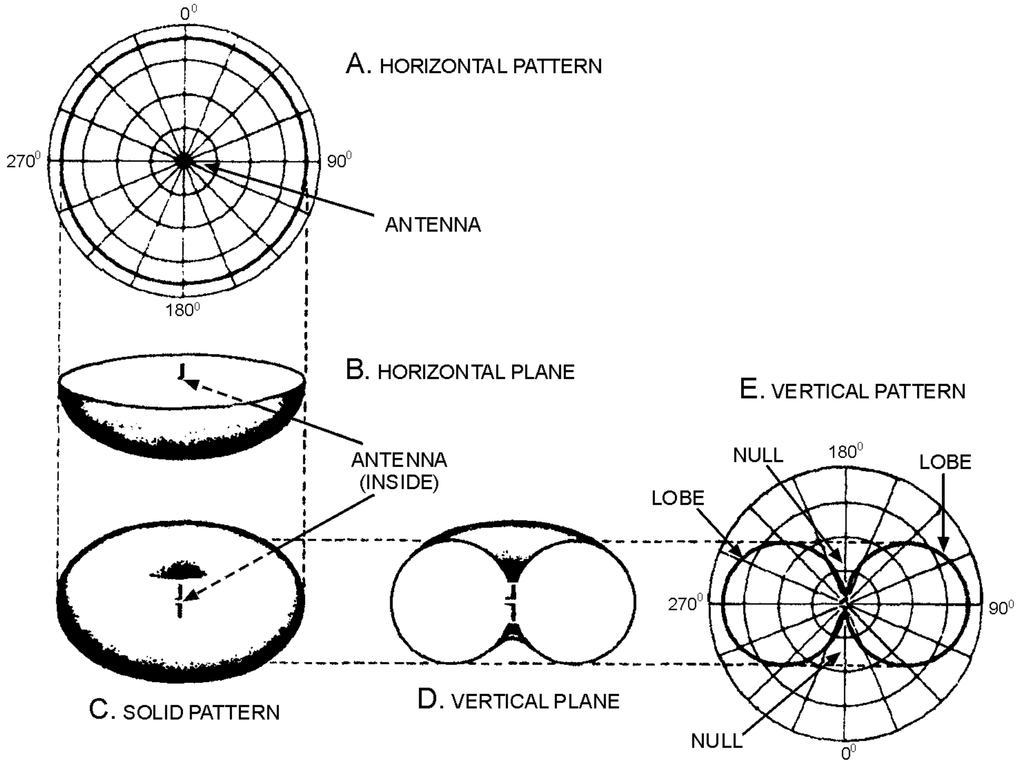


Figure 4-14.—Development of vertical and horizontal patterns.

A VERTICAL PATTERN view E is obtained from the drawing of the vertical plane view D of the radiation pattern view C. The radiation pattern view C is sliced in half along a vertical plane through the antenna. This produces the vertical plane pattern in view D. Note how the vertical plane in view D of the radiation pattern differs from the horizontal plane in view B. The vertical pattern view E exhibits two lobes and two nulls. The difference between the two patterns is caused by two facts: (1) no radiation is emitted from the ends of the doublet; and (2) maximum radiation comes from the doublet in a direction perpendicular to the antenna axis. This type of radiation pattern is both NONDIRECTIONAL (in a horizontal plane) and DIRECTIONAL (in a vertical plane).

From a practical viewpoint, the doublet antenna can be mounted either vertically or horizontally. The doublet shown in figure 4-14 is mounted vertically, and the radiated energy spreads out about the antenna in every direction in the horizontal plane. Since ordinarily the horizontal plane is the useful plane, this arrangement is termed NONDIRECTIONAL. The directional characteristics of the antenna in other planes is ignored. If the doublet were mounted horizontally, it would have the effect of turning the pattern on edge, reversing the patterns given in figure 4-14. The antenna would then be directional in the horizontal plane. The terms "directional" and "nondirectional" are used for convenience in describing specific radiation patterns. A complete description always involves a figure in three dimensions, as in the radiation pattern of figure 4-14.

Q17. What terms are often used to describe basic half-wave antennas?

Q18. If a basic half-wave antenna is mounted vertically, what type of radiation pattern will be produced?

Q19. In which plane will the half-wave antenna be operating if it is mounted horizontally?

RADIATION PATTERN OF A DIPOLE.—The radiation pattern of a dipole (fig. 4-15) is similar to that of the doublet (fig. 4-14). Increasing the length of the doublet to 1/2 wavelength has the effect of flattening out the radiation pattern. The radiation pattern in the horizontal plane of a dipole is a larger circle than that of the doublet. The vertical-radiation pattern lobes are no longer circular. They are flattened out and the radiation intensity is greater.

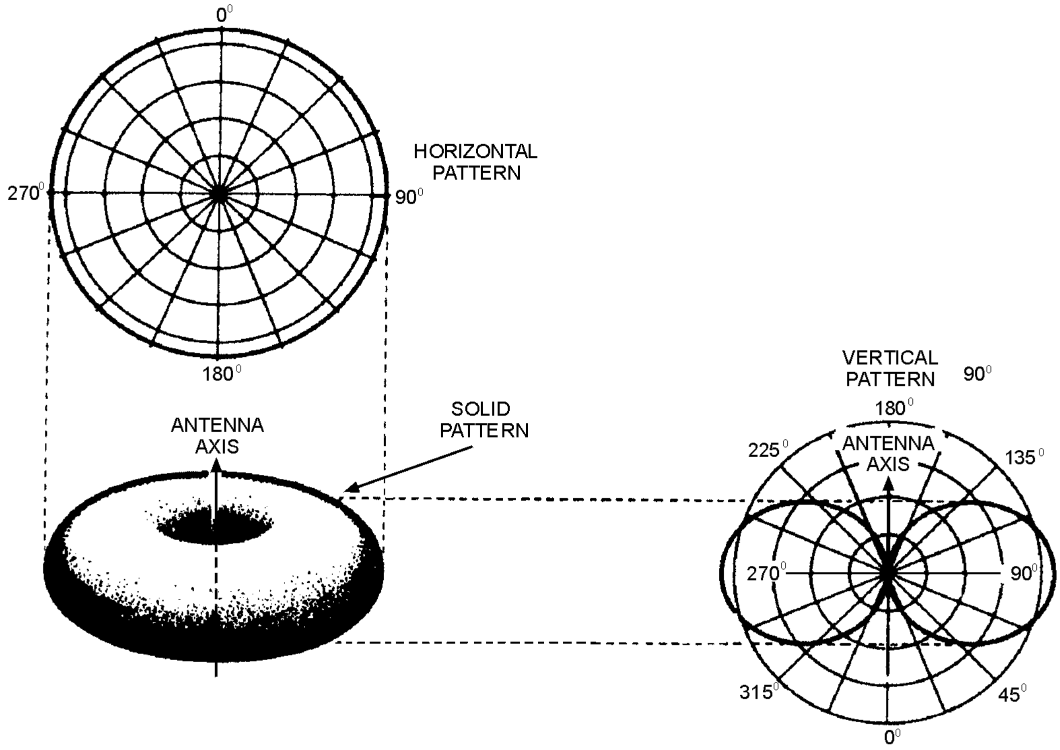


Figure 4-15.—Radiation pattern of a dipole.

Methods of Feeding Energy to an Antenna

Voltage and current distribution for the half-wave antenna (shown in figure 4-16) is the same as that for the antenna discussed earlier in this chapter. A point closely related to the voltage and current distribution on an antenna is the method of feeding the transmitter output to the antenna. The simplest method of feeding energy to the half-wave antenna is to connect one end through a capacitor to the final output stage of the transmitter. This method is often called the END-FEED or VOLTAGE-FEED method. In this method the antenna is fed at a point of high voltage (the end).

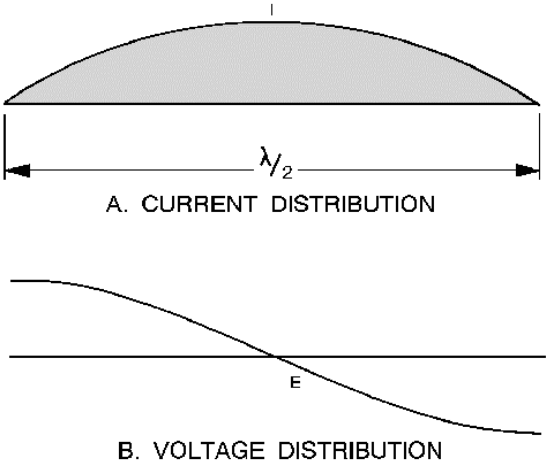


Figure 4-16.—Standing waves of current and voltage.

Energy may also be fed to the half-wave antenna by dividing the antenna at its center and connecting the transmission line from the final transmitter output stage to the two center ends of the halved antenna. Since the antenna is now being fed at the center (a point of low voltage and high current), this type of feed is known as the CENTER-FEED or CURRENT-FEED method. The point of feed is important in determining the type of transmission line to be used.

QUARTER-WAVE ANTENNAS

As you have studied in the previous sections, a 1/2 wavelength antenna is the shortest antenna that can be used in free space. If we cut a half-wave antenna in half and then ground one end, we will have a grounded quarter-wave antenna. This antenna will resonate at the same frequency as the ungrounded half-wave antenna. Such an antenna is referred to as a QUARTER-WAVE or Marconi antenna. Quarter-wave antennas are widely used in the military. Most mobile transmitting and receiving antennas (fig. 4-17) are quarter-wave antennas.

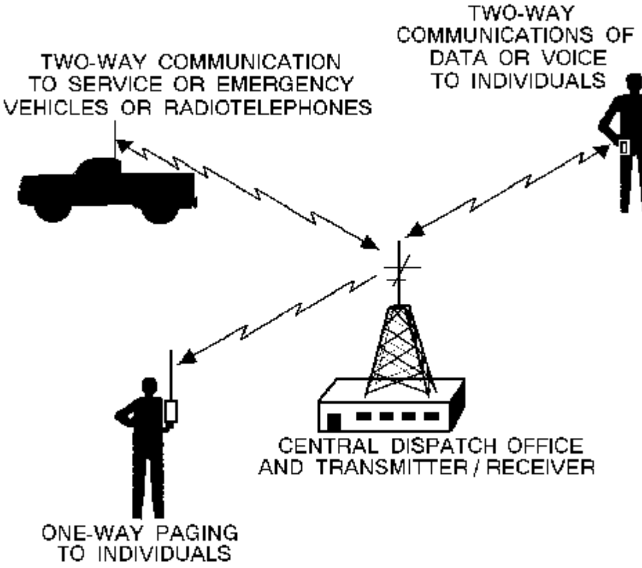


Figure 4-17.—Mobile antennas.

As stated above, a grounded quarter-wave antenna will resonate at the same frequency as an ungrounded half-wave antenna. This is because ground has high conductivity and acts as an electrical mirror image. This characteristic provides the missing half of the antenna, as shown in the bottom part of figure 4-18. In other words, the grounded quarter-wave antenna acts as if another quarter-wave were actually down in the earth.

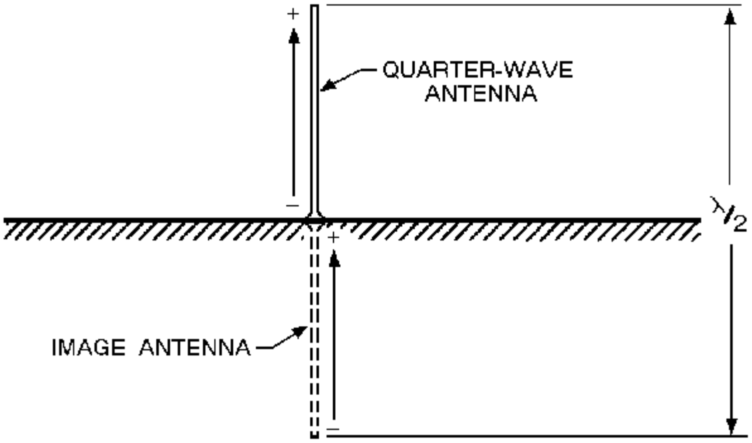


Figure 4-18.—Grounded quarter-wave antenna image.

Characteristics of Quarter-Wave Antennas

The grounded end of the quarter-wave antenna has a low input impedance and has low voltage and high current at the input end, as shown in figure 4-18. The ungrounded end has a high impedance, which causes high voltage and low current. The directional characteristics of a grounded quarter-wave antenna are the same as those of a half-wave antenna in free space.

As explained earlier, ground losses affect radiation patterns and cause high signal losses for some frequencies. Such losses may be greatly reduced if a perfectly conducting ground is provided in the vicinity of the antenna. This is the purpose of a GROUND SCREEN (figure 4-19, view A) and COUNTERPOISE view B.

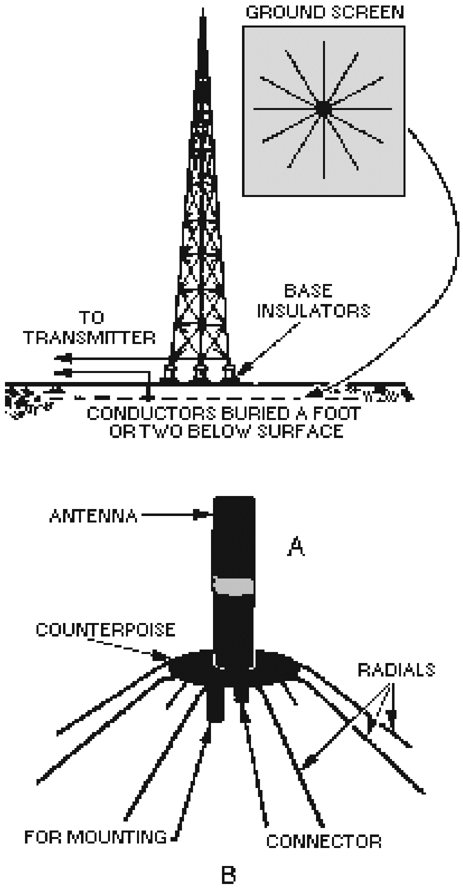


Figure 4-19.—Groundscreen and counterpoise.

The ground screen in view A is composed of a series of conductors buried 1 or 2 feet (0.3 to 0.6 meter) below the surface of the earth and arranged in a radial pattern. These conductors reduce losses in the ground in the immediate vicinity of the antenna. Such a radial system of conductors is usually 1/2 wavelength in diameter.

A counterpoise view B is used when easy access to the base of the antenna is necessary. It is also used when the earth is not a good conducting surface, such as ground that is sandy or solid rock. The counterpoise serves the same purpose as the ground screen but it is usually elevated above the earth. No specific dimensions are necessary in the construction of a counterpoise nor is the number of wires particularly critical. A practical counterpoise may be assembled from a large screen of chicken wire or some similar material. This screen may be placed on the ground, but better results are obtained if it is placed a few feet above the ground.

Q20. Since the radiation pattern of a dipole is similar to that of a doublet, what will happen to the pattern if the length of the doublet is increased?

Q21. What is the simplest method of feeding power to the half-wave antenna?

Q22. What is the radiation pattern of a quarter-wave antenna?

Q23. Describe the physical arrangement of a ground screen.

FOLDED DIPOLE

The use of parasitic elements and various stacking arrangements causes a reduction in the radiation resistance of a center-fed, half-wave antenna. Under these conditions obtaining a proper impedance match between the radiator and the transmission line is often difficult. A convenient method of overcoming these difficulties is to use a FOLDED DIPOLE in place of the center-fed radiator. (See views A and B of figure 4-20).

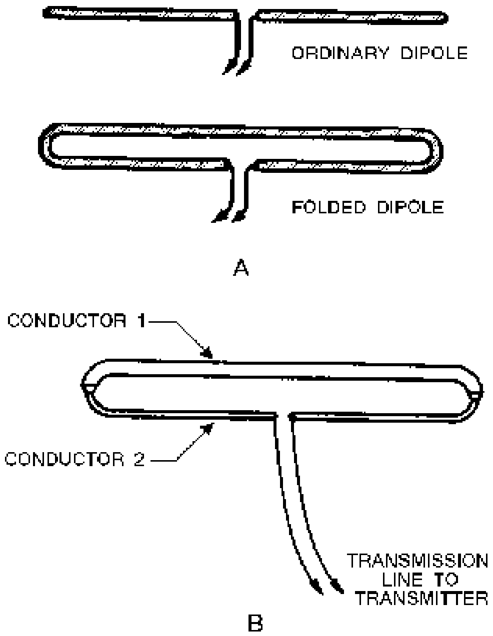


Figure 4-20.—Folded-dipole antennas.

A FOLDED DIPOLE is an ordinary half-wave antenna that has one or more additional conductors connected across its ends. Additional conductors are mounted parallel to the dipole elements at a distance equal to a very small fraction of a wavelength. Spacing of several inches is common.

The feed-point impedance can be further increased by using three or four properly spaced parallel conductors. Standard feed-line SPREADERS are used to maintain this spacing when required. In any folded dipole, the increase of impedance is the square of the number of conductors used in the radiator. Thus, a three-wire dipole has nine times (3^2) the feed-point impedance of a simple center-fed dipole. A second method of stepping up the impedance of a folded dipole is to use two conductors with different radii, as shown in view B.

The directional characteristics of a folded dipole are the same as those of a simple dipole. However, the reactance of a folded dipole varies much more slowly as the frequency is varied from resonance. Because of this the folded dipole can be used over a much wider frequency range than is possible with a simple dipole.

Q24. What is the difference in the amount of impedance between a three-wire dipole and a simple center-fed dipole?

Q25. Which has a wider frequency range, a simple dipole or a folded dipole?

ARRAY ANTENNAS

An array antenna is a special arrangement of basic antenna components involving new factors and concepts. Before you begin studying about arrays, you need to study some new terminology.

DEFINITION OF TERMS

An array antenna is made up of more than one ELEMENT, but the basic element is generally the dipole. Sometimes the basic element is made longer or shorter than a half-wave, but the deviation usually is not great.

A DRIVEN element is similar to the dipole you have been studying and is connected directly to the transmission line. It obtains its power directly from the transmitter or, as a receiving antenna, it delivers the received energy directly to the receiver. A PARASITIC ELEMENT is located near the driven element from which it gets its power. It is placed close enough to the driven element to permit coupling.

A parasitic element is sometimes placed so it will produce maximum radiation (during transmission) from its associated driver. When it operates to reinforce energy coming from the driver toward itself, the parasitic element is referred to as a DIRECTOR. If a parasitic element is placed so it causes maximum energy radiation in a direction away from itself and toward the driven element, that parasitic element is called a REFLECTOR.

If all of the elements in an array are driven, the array is referred to as a DRIVEN ARRAY (sometimes as a CONNECTED ARRAY). If one or more elements are parasitic, the entire system usually is considered to be a PARASITIC ARRAY.

MULTIELEMENT ARRAYS frequently are classified according to their directivity. A BIDIRECTIONAL ARRAY radiates in opposite directions along the line of maximum radiation. A UNIDIRECTIONAL ARRAY radiates in only one general direction.

Arrays can be described with respect to their radiation patterns and the types of elements of which they are made. However, you will find it useful to identify them by the physical placement of the elements and the direction of radiation with respect to these elements. Generally speaking, the term BROADSIDE ARRAY designates an array in which the direction of maximum radiation is perpendicular to the plane containing these elements. In actual practice, this term is confined to those arrays in which the elements themselves are also broadside, or parallel, with respect to each other.

A COLLINEAR ARRAY is one in which all the elements lie in a straight line with no radiation at the ends of the array. The direction of maximum radiation is perpendicular to the axis of the elements.

An END-FIRE ARRAY is one in which the principal direction of radiation is along the plane of the array and perpendicular to the elements. Radiation is from the end of the array, which is the reason this arrangement is referred to as an end-fire array.

Sometimes a system uses the characteristics of more than one of the three types mentioned. For instance, some of the elements may be collinear while others may be parallel. Such an arrangement is often referred to as a COMBINATION ARRAY or an ARRAY OF ARRAYS. Since maximum radiation occurs at right angles to the plane of the array, the term broadside array is also used.

The FRONT-TO-BACK RATIO is the ratio of the energy radiated in the principal direction compared to the energy radiated in the opposite direction for a given antenna.

PHASING

Various reflected and refracted components of the propagated wave create effects of reinforcement and cancellation. At certain distant points from the transmitter, some of the wave components meet in space. Reception at these points is either impaired or improved. If the different components arrive at a given point in the same phase, they add, making a stronger signal available. If they arrive out of phase, they cancel, reducing the signal strength.

Radiation Pattern

Effects similar to those described in the preceding paragraph can be produced at the transmitting point itself. Consider the antennas shown in figure 4-21, views A and B. View A shows an unobstructed view of the radiation pattern of a single dipole. In view B two dipoles, shown as points 1 and 2, are perpendicular to the plane of the page. They are spaced 1/4 wavelength apart at the operating frequency. The radiation pattern from either antenna 1 or 2, operating alone, would be uniform in all directions in this plane, as shown in view A. Suppose that current is being fed to both antennas from the same transmitter in such a way that the current fed to antenna 2 lags the current in antenna 1 by 90 degrees. Energy radiating from antenna 1 toward receiving location X will reach antenna 2 after 1/4 cycle of operation. The energy from both antennas will add, and propagation toward X will be strong.

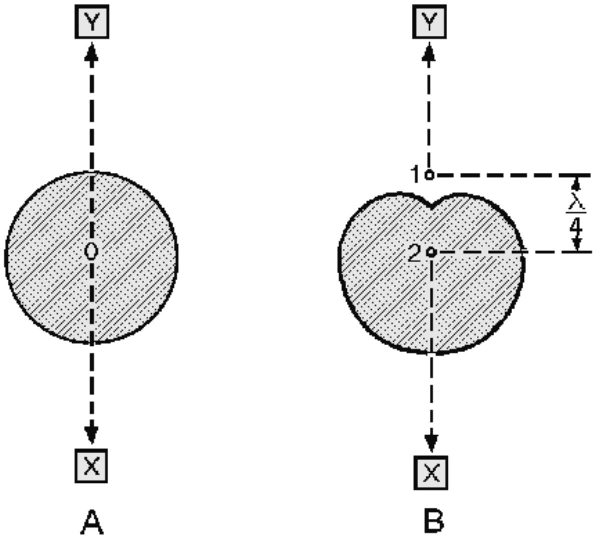


Figure 4-21.—Phasing of antenna in free space.

Radiation from antenna 2 toward receiving location Y will reach antenna 1 after 1/4 cycle. The energy in antenna 1 was 1/4 cycle behind that of antenna 2 to begin with; therefore, the radiation from antenna 1 toward receiving point Y will be exactly 180 degrees out of phase with that of antenna 2. As a result, the radiation fields will cancel and there will be no radiation toward Y.

At receiving points away from the line of radiation, phase differences occur between 0 and 180 degrees, producing varying amounts of energy in that direction. The overall effect is shown by the radiation pattern shown in view B. The physical phase relationship caused by the 1/4-wavelength spacing between the two elements, as well as the phase of the currents in the elements, has acted to change the radiation pattern of the individual antennas.

Stub Phasing

In the case just discussed, the currents fed to the two antennas from the same transmitter were 90 degrees out of phase. Sections of transmission line, called STUBS, are frequently used for this purpose. These stubs can be adjusted to produce any desired phase relationship between connected elements.

When two collinear half-wave elements are connected directly so their currents are in the same phase, the effect is the same as that of a full-wave antenna, as shown in figure 4-22, view A. The current in the first 1/2 wavelength is exactly 180 degrees out of phase with that in the second 1/2 wavelength. This is the opposite of the desired condition. In the illustration, arrows are used to indicate the direction of current flow in the antenna. (Using arrows is a convenient means of determining the phase on more complicated arrays.)

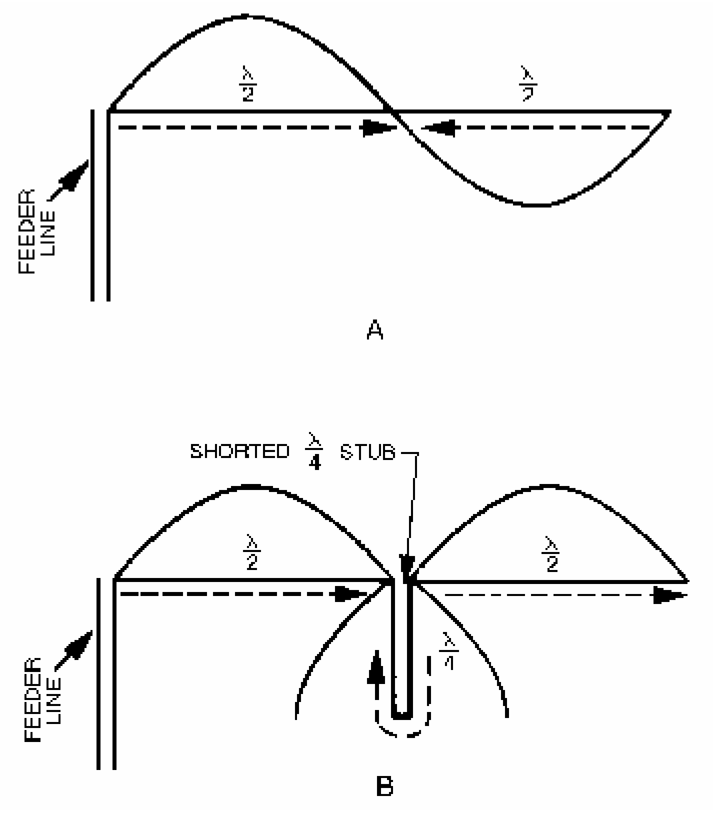


Figure 4-22.—Phasing of connected elements.

When the two elements are connected by a shorted 1/4-wavelength stub, as shown in view B, current travels down one side of the stub and up the other. It travels a distance of a 1/2 wavelength in the stub itself. As a result, the current moves through 1/2 cycle of change. When the current reaches the second element, it is in the desired phase. Since the current on one side of the stub is equal and opposite to the current on the other side, the fields produced here cancel and no radiation is transmitted from the stub itself.

DIRECTIVITY

The DIRECTIVITY of an antenna or an array can be determined by looking at its radiation pattern. In an array propagating a given amount of energy, more radiation takes place in certain directions than in others. The elements in the array can be altered in such a way that they change the pattern and distribute it more uniformly in all directions. The elements can be considered as a group of antennas fed from a common source and facing different directions. On the other hand, the elements could be arranged so that the radiation would be focused in a single direction. With no increase in power from the transmitter, the amount of radiation in a given direction would be greater. Since the input power has no increase, this increased directivity is achieved at the expense of gain in other directions.

Directivity and Interference

In many applications, sharp directivity is desirable although no need exists for added gain. Examine the physical disposition of the units shown in figure 4-23. Transmitters 1 and 2 are sending information to receivers 1 and 2, respectively, along the paths shown by the solid arrows. The distance between transmitter 1 and receiver 1 or between transmitter 2 and receiver 2 is short and does not require high-power transmission. The antennas of the transmitters propagate well in all directions. However, receiver 1 picks up some of the signals from transmitter 2, and receiver 2 picks up some of the signals from transmitter 1, as shown by the broken arrows. This effect is emphasized if the receiving antennas intercept energy equally well in all directions.

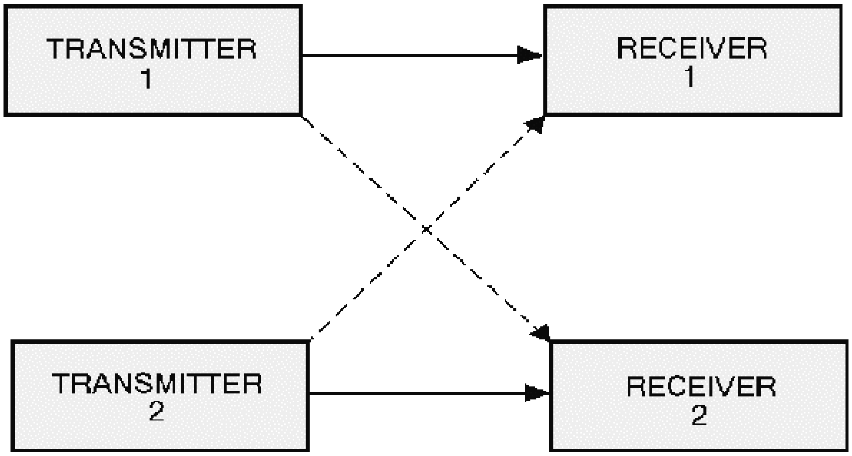


Figure 4-23.—Directivity and interference.

The use of highly directional arrays as radiators from the transmitters tends to solve the problem. The signals are beamed along the paths of the solid arrows and provide very low radiation along the paths of the broken arrows. Further improvement along these lines is obtained by the use of narrowly directed arrays as receiving antennas. The effect of this arrangement is to select the desired signal while discriminating against all other signals. This same approach can be used to overcome other types of radiated interference. In such cases, preventing radiation in certain directions is more important than producing greater gain in other directions.

Look at the differences between the field patterns of the single-element antenna and the array, as illustrated in figure 4-24. View A shows the relative field-strength pattern for a horizontally polarized single antenna. View B shows the horizontal-radiation pattern for an array. The antenna in view A radiates fairly efficiently in the desired direction toward receiving point X. It radiates equally as efficiently toward Y, although no radiation is desired in this direction. The antenna in view B radiates strongly to point X, but very little in the direction of point Y, which results in more satisfactory operation.

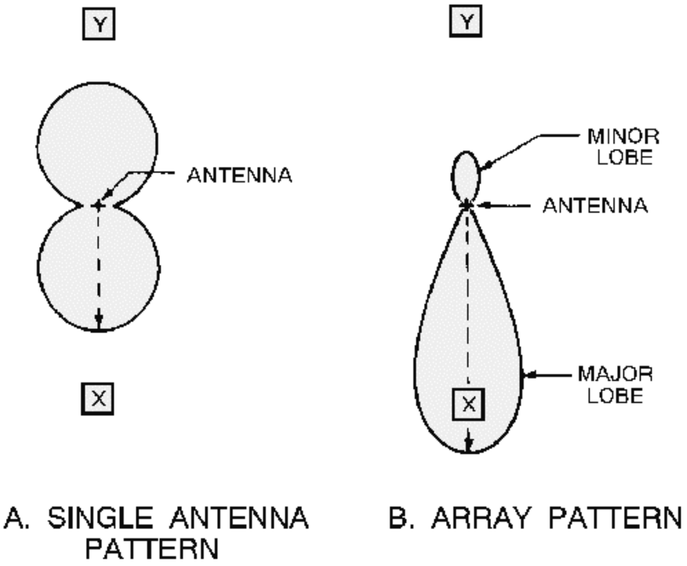


Figure 4-24.—Single antenna versus array.

Major and Minor Lobes

The pattern shown in figure 4-24, view B, has radiation concentrated in two lobes. The radiation intensity in one lobe is considerably stronger than in the other. The lobe toward point X is called a MAJOR LOBE; the other is a MINOR LOBE. Since the complex radiation patterns associated with arrays frequently contain several lobes of varying intensity, you should learn to use appropriate terminology. In general, major lobes are those in which the greatest amount of radiation occurs. Minor lobes are those in which the radiation intensity is least.

Q26. What is the purpose of antenna stubs?

Q27. What is the primary difference between the major and minor lobes of a radiation pattern?

DIRECTIONAL ARRAYS

You have already learned about radiation patterns and directivity of radiation. These topics are important to you because using an antenna with an improper radiation pattern or with the wrong directivity will decrease the overall performance of the system. In the following paragraphs, we discuss in more detail the various types of directional antenna arrays mentioned briefly in the "definition of terms" paragraph above.

Collinear Array

The pattern radiated by the collinear array is similar to that produced by a single dipole. The addition of the second radiator, however, tends to intensify the pattern. Compare the radiation pattern of the dipole (view A of figure 4-25) and the two-element antenna in view B. You will see that each pattern consists of two major lobes in opposite directions along the same axis, QQ1. There is little or no radiation along the

PP1 axis. QQ1 represents the line of maximum propagation. You can see that radiation is stronger with an added element. The pattern in view B is sharper, or more directive, than that in view A. This means that the gain along the line of maximum energy propagation is increased and the beam width is decreased. As more elements are added, the effect is heightened, as shown in view C. Unimportant minor lobes are generated as more elements are added.

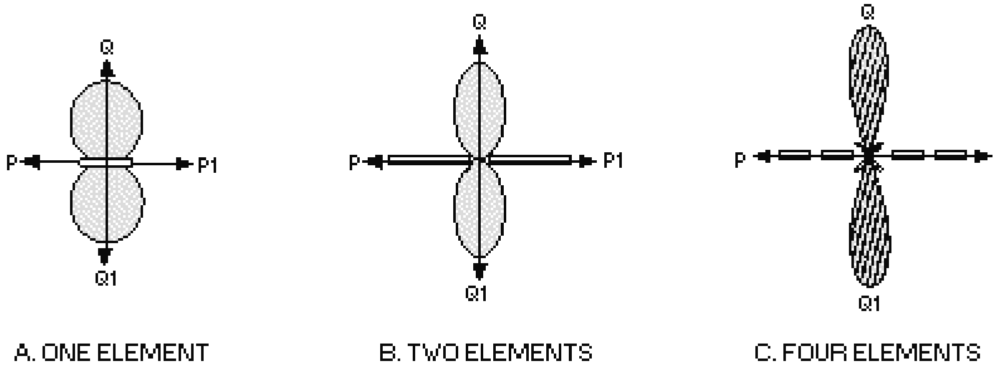


Figure 4-25.—Single half-wave antenna versus two half-wave antennas in phase.

More than four elements are seldom used because accumulated losses cause the elements farther from the point of feeding to have less current than the nearer ones. This introduces an unbalanced condition in the system and impairs its efficiency. Space limitations often are another reason for restricting the number of elements. Since this type of array is in a single line, rather than in a vertically stacked arrangement, the use of too many elements results in an antenna several wavelengths long.

RADIATION PATTERN.—The characteristic radiation pattern of a given array is obtained at the frequency or band of frequencies at which the system is resonant. The gain and directivity characteristics are lost when the antenna is not used at or near this frequency and the array tunes too sharply. A collinear antenna is more effective than an end-fire array when used off its tuned frequency. This feature is considered when transmission or reception is to be over a wide frequency band. When more than two elements are used, this advantage largely disappears.

LENGTH AND PHASING.—Although the 1/2 wavelength is the basis for the collinear element, you will find that greater lengths are often used. Effective arrays of this type have been constructed in which the elements are 0.7 and even 0.8 wavelength long. This type of array provides efficient operation at more than one frequency or over a wider frequency range. Whatever length is decided upon, all of the elements in a particular array should closely adhere to that length. If elements of different lengths are combined, current phasing and distribution are changed, throwing the system out of balance and seriously affecting the radiation pattern.

Q28. What is the maximum number of elements ordinarily used in a collinear array?

Q29. Why is the number of elements used in a collinear array limited?

Q30. How can the frequency range of a collinear array be increased?

Q31. How is directivity of a collinear array affected when the number of elements is increased?

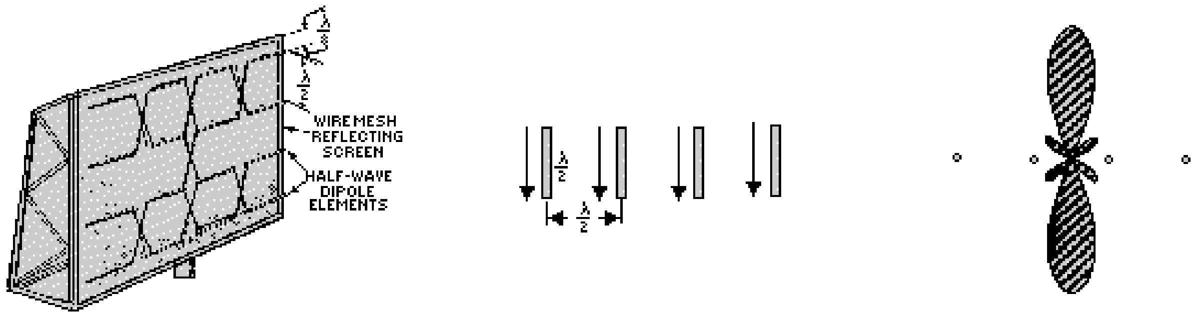
SPACING.—The lower relative efficiency of collinear arrays of many elements, compared with other multi-element arrays, relates directly to spacing and mutual impedance effects. Mutual impedance is an important factor to be considered when any two elements are parallel and are spaced so that considerable coupling is between them. There is very little mutual impedance between collinear sections. Where impedance does exist, it is caused by the coupling between the ends of adjacent elements. Placing the ends of elements close together is frequently necessary because of construction problems, especially where long lengths of wire are involved.

The effects of spacing and the advantages of proper spacing can be demonstrated by some practical examples. A collinear array consisting of two half-wave elements with 1/4-wavelength spacing between centers has a gain of 1.8 dB. If the ends of these same dipoles are separated so that the distance from center to center is 3/4 wavelengths and they are driven from the same source, the gain increases to approximately 2.9 dB.

A three-dipole array with negligible spacing between elements gives a gain of 3.3 dB. In other words, when two elements are used with wider spacing, the gain obtained is approximately equal to the gain obtainable from three elements with close spacing. The spacing of this array permits simpler construction, since only two dipoles are used. It also allows the antenna to occupy less space. Construction problems usually dictate small-array spacing.

Broadside Arrays

A broadside array is shown in figure 4-26, view A. Physically, it looks somewhat like a ladder. When the array and the elements in it are polarized horizontally, it looks like an upright ladder. When the array is polarized vertically, it looks like a ladder lying on one side (view B). View C is an illustration of the radiation pattern of a broadside array. Horizontally polarized arrays using more than two elements are not common. This is because the requirement that the bottom of the array be a significant distance above the earth presents construction problems. Compared with collinear arrays, broadside arrays tune sharply, but lose efficiency rapidly when not operated on the frequencies for which they are designed.



A. ARRAY

B. SIDE VIEW OF ARRAY

C. TOP VIEW OF ARRAY

Figure 4-26.—Typical broadside array.

RADIATION PATTERN.—Figure 4-27 shows an end view of two parallel half-wave antennas (A and B) operating in the same phase and located 1/2 wavelength apart. At a point (P) far removed from the antennas, the antennas appear as a single point. Energy radiating toward P from antenna A starts out in phase with the energy radiating from antenna B in the same direction. Propagation from each antenna travels over the same distance to point P, arriving there in phase. The antennas reinforce each other in this direction, making a strong signal available at P. Field strength measured at P is greater than it would be if the total power supplied to both antennas had been fed to a single dipole. Radiation toward point P1 is built up in the same manner.

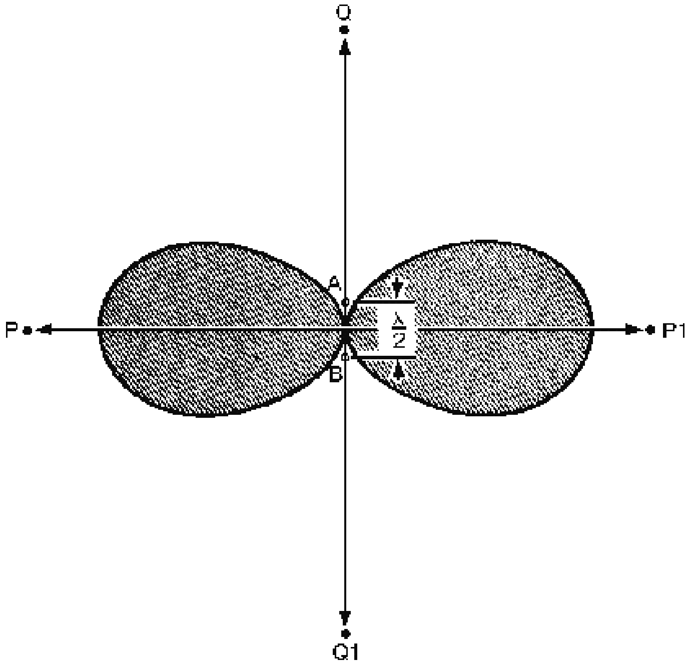


Figure 4-27.—Parallel elements in phase.

Next consider a wavefront traveling toward point Q from antenna B. By the time it reaches antenna A, 1/2 wavelength away, 1/2 cycle has elapsed. Therefore energy from antenna B meets the energy from antenna A 180 degrees out of phase. As a result, the energy moving toward point Q from the two sources cancels. In a like manner, radiation from antenna A traveling toward point Q1 meets and cancels the radiation in the same direction from antenna B. As a result, little propagation takes place in either direction along the QQ1 axis. Most of the energy is concentrated in both directions along the PP1 axis. When both antenna elements are fed from the same source, the result is the basic broadside array.

When more than two elements are used in a broadside arrangement, they are all parallel and in the same plane, as shown in figure 4-26, view B. Current phase, indicated by the arrows, must be the same for all elements. The radiation pattern shown in figure 4-26, view C, is always bi-directional. This pattern is sharper than the one shown in figure 4-27 because of the additional two elements. Directivity and gain depend on the number of elements and the spacing between them.

GAIN AND DIRECTIVITY.—The physical disposition of dipoles operated broadside to each other allows for much greater coupling between them than can occur between collinear elements. Moving the parallel antenna elements closer together or farther apart affects the actual impedance of the entire array and the overall radiation resistance as well. As the spacing between broadside elements increases, the effect on the radiation pattern is a sharpening of the major lobes. When the array consists of only two dipoles spaced exactly 1/2 wavelength apart, no minor lobes are generated at all. Increasing the distance between the elements beyond that point, however, tends to throw off the phase relationship between the original current in one element and the current induced in it by the other element. The result is that, although the major lobes are sharpened, minor lobes are introduced, even with two elements. These, however, are not large enough to be of concern.

If you add the same number of elements to both a broadside array and a collinear array, the gain of the broadside array will be greater. Reduced radiation resistance resulting from the efficient coupling between dipoles accounts for most of this gain. However, certain practical factors limit the number of elements that may be used. The construction problem increases with the number of elements, especially when they are polarized horizontally.

Q32. What is the primary cause of broadside arrays losing efficiency when not operating at their designed frequency?

Q33. When more than two elements are used in a broadside array, how are the elements arranged?

Q34. As the spacing between elements in a broadside array increases, what is the effect on the major lobes?

End-Fire Arrays

An end-fire array looks similar to a broadside array. The ladder-like appearance is characteristic of both (fig. 4-28, view A). The currents in the elements of the end-fire array, however, are usually 180 degrees out of phase with each other as indicated by the arrows. The construction of the end-fire array is like that of a ladder lying on its side (elements horizontal). The dipoles in an end-fire array are closer together (1/8-wavelength to 1/4 -wavelength spacing) than they are for a broadside array.

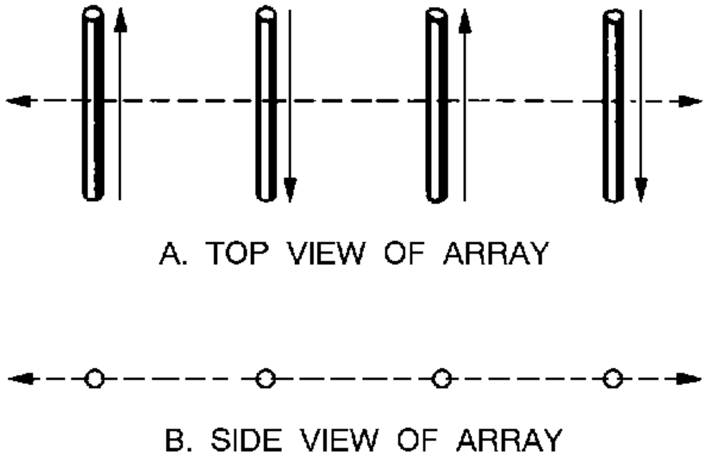


Figure 4-28.—Typical end-fire array.

Closer spacing between elements permits compactness of construction. For this reason an end-fire array is preferred to other arrays when high gain or sharp directivity is desired in a confined space. However, the close coupling creates certain disadvantages. Radiation resistance is extremely low, sometimes as low as 10 ohms, making antenna losses greater. The end-fire array is confined to a single frequency. With changes in climatic or atmospheric conditions, the danger of detuning exists.

RADIATION PATTERN.—The radiation pattern for a pair of parallel half-wave elements fed 180 degrees out of phase is shown in figure 4-29, view A. The elements shown are spaced 1/2 wavelength apart. In practice, smaller spacings are used. Radiation from elements L and M traveling toward point P begins 180 degrees out of phase. Moving the same distance over approximately parallel paths, the respective wavefronts from these elements remain 180 degrees out of phase. In other words, maximum cancellation takes place in the direction of P. The same condition is true for the opposite direction (toward P1). The P to P1 axis is the line of least radiation for the end-fire array.

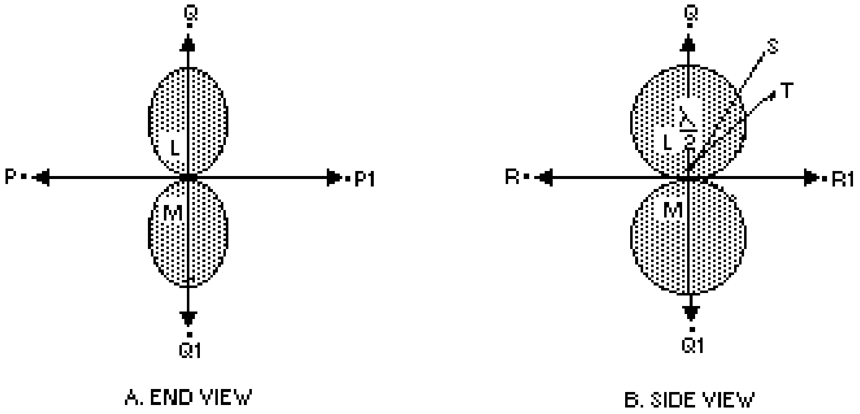


Figure 4-29.—Parallel elements 180 degrees out of phase.

Consider what happens along the QQ1 axis. Energy radiating from element M toward Q reaches element L in about 1/2 cycle (180 degrees) after it leaves its source. Since element L was fed 180 degrees out of phase with element M, the wavefronts are now in the same phase and are both moving toward Q reinforcing each other. Similar reinforcement occurs along the same axis toward Q1. This simultaneous movement towards Q and Q1 develops a bi-directional pattern. This is not always true in end-fire operation. Another application of the end-fire principle is one in which the elements are spaced 1/4 wavelength apart and phased 90 degrees from each other to produce a unidirectional pattern.

In figure 4-29, view A, elements A and B are perpendicular to the plane represented by the page; therefore, only the ends of the antennas appear. In view B the antennas are rotated a quarter of a circle in space around the QQ1 axis so that they are seen in the plane of the elements themselves. Therefore, the PP1 axis, now perpendicular to the page, is not seen as a line. The RR1 axis, now seen as a line, is perpendicular to the PP1 axis as well as to the QQ1 axis. The end-fire array is directional in this plane also, although not quite as sharply. The reason for the greater broadness of the lobes can be seen by following the path of energy radiating from the midpoint of element B toward point S in view B. This energy passes the A element at one end after traveling slightly more than the perpendicular distance between the dipoles. Energy, therefore, does not combine in exact phase toward point S. Although maximum radiation cannot take place in this direction, energy from the two sources combines closely enough in phase to produce considerable reinforcement. A similar situation exists for wavefronts traveling toward T. However, the wider angle from Q to T produces a greater phase difference and results in a decrease in the strength of the combined wave.

Directivity occurs from either one or both ends of the end-fire array, along the axis of the array, as shown by the broken arrows in figure 4-28, view A; hence, the term *end-fire* is used.

The major lobe or lobes occur along the axis of the array. The pattern is sharper in the plane that is at right angles to the plane containing the elements (figure 4-29, view A). If the elements are not exact half-wave dipoles, operation is not significantly affected. However, because of the required balance of phase relationships and critical feeding, the array must be symmetrical. Folded dipoles, such as the one shown in figure 4-20, view A, are used frequently because the impedance at their terminals is higher. This is an effective way of avoiding excessive antenna losses. Another expedient to reduce losses is the use of tubular elements of wide diameter.

GAIN AND DIRECTIVITY.—In end-fire arrays, directivity increases with the addition of more elements and with spacings approaching the optimum. The directive pattern for a two-element, bi-directional system is illustrated in figure 4-29. View A shows radiation along the array axis in a plane perpendicular to the dipoles, and view B shows radiation along the array axis in the plane of the elements. These patterns were developed with a 180-degree phase difference between the elements. Additional elements introduce small, minor lobes.

With a 90-degree phase difference in the energy fed to a pair of end-fire elements spaced approximately 1/4 wavelength apart, unidirectional radiation can be obtained. The pattern perpendicular to the plane of the two elements is shown in figure 4-30, view A. The pattern shown in view B, taken in the same plane, is for a six-element array with 90-degree phasing between adjacent elements. Since both patterns show relative gain only, the increase in gain produced by the six-element array is not evident. End-fire arrays are the only unidirectional arrays wholly made up of driven elements.

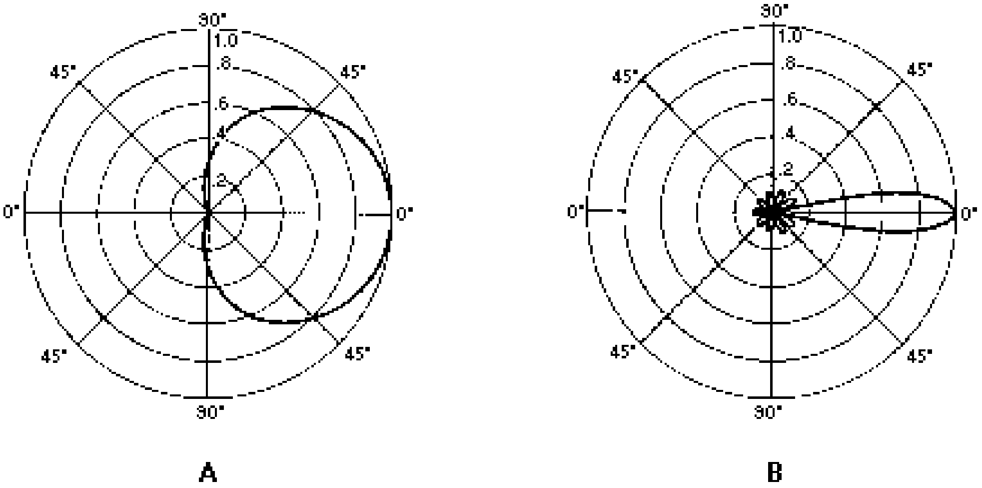


Figure 4-30.—Unidirectional end-fire arrays.

Q35. What are some disadvantages of the end-fire array?

Q36. Where does the major lobe in the end-fire array occur?

Q37. To maintain the required balance of phase relationships and critical feeding, how must the end-fire array be constructed?

Parasitic Arrays

If a small light bulb were placed in the center of a large room, the illumination would be very poor. However, if a reflector were placed behind the bulb, the space in front of the reflector would be brighter and the space behind the reflector would be dimmer. The light rays would be concentrated. Also, if a lens were placed in front of the bulb, the light would be even more concentrated and a very bright spot would appear on the wall in front of the lens. A flashlight is a practical combination of the small bulb, the reflector, and the lens. The energy from an antenna can be reflected and concentrated in a similar manner.

Although we do not usually discuss the gain of a flashlight, we can continue the comparison of an antenna and a flashlight to explain the meaning of antenna gain. Suppose the spot on the wall in front of the flashlight becomes 10 times brighter than it was when only the open bulb was used. The lens and reflector have then produced a 10-fold gain in light. For antennas, the simple half-wave antenna corresponds to the open bulb in the flashlight. Suppose an antenna system concentrates the radio waves so that at a particular point the field strength is 10 times more than it would be at the same distance from a half-wave antenna. The antenna system is then said to have a gain of 10.

Parasitic arrays represent another method of achieving high antenna gains. A parasitic array consists of one or more parasitic elements placed in parallel with each other and, in most cases, at the same line-of-sight level. The parasitic element is fed inductively by radiated energy coming from the driven element connected to the transmitter. It is in NO way connected directly to the driven element.

When the parasitic element is placed so that it radiates away from the driven element, the element is a director. When the parasitic element is placed so that it radiates toward the driven element, the parasitic element is a reflector.

The directivity pattern resulting from the action of parasitic elements depends on two factors. These are (1) the tuning, determined by the length of the parasitic element; and (2) the spacing between the parasitic and driven elements. To a lesser degree, it also depends on the diameter of the parasitic element, since diameter has an effect on tuning.

OPERATION.—When a parasitic element is placed a fraction of a wavelength away from the driven element and is of approximately resonant length, it will re-radiate the energy it intercepts. The parasitic element is effectively a tuned circuit coupled to the driven element, much as the two windings of a transformer are coupled together. The radiated energy from the driven element causes a voltage to be developed in the parasitic element, which, in turn, sets up a magnetic field. This magnetic field extends over to the driven element, which then has a voltage induced in it. The magnitude and phase of the induced voltage depend on the length of the parasitic element and the spacing between the elements. In actual practice the length and spacing are arranged so that the phase and magnitude of the induced voltage cause a unidirectional, horizontal-radiation pattern and an increase in gain.

In the parasitic array in figure 4-31, view A, the parasitic and driven elements are spaced 1/4 wavelength apart. The radiated signal coming from the driven element strikes the parasitic element after 1/4 cycle. The voltage developed in the parasitic element is 180 degrees out of phase with that of the driven element. This is because of the distance traveled (90 degrees) and because the induced current lags the inducing flux by 90 degrees (90 + 90 = 180 degrees). The magnetic field set up by the parasitic element induces a voltage in the driven element 1/4 cycle later because the spacing between the elements is 1/4 wavelength. This induced voltage is in phase with that in the driven element and causes an increase in radiation in the direction indicated in figure 4-31, view A. Since the direction of the radiated energy is stronger in the direction away from the parasitic element (toward the driven element), the parasitic element is called a reflector. The radiation pattern as it would appear if you were looking down on the antenna is shown in view B. The pattern as it would look if viewed from the ends of the elements is shown in view C.

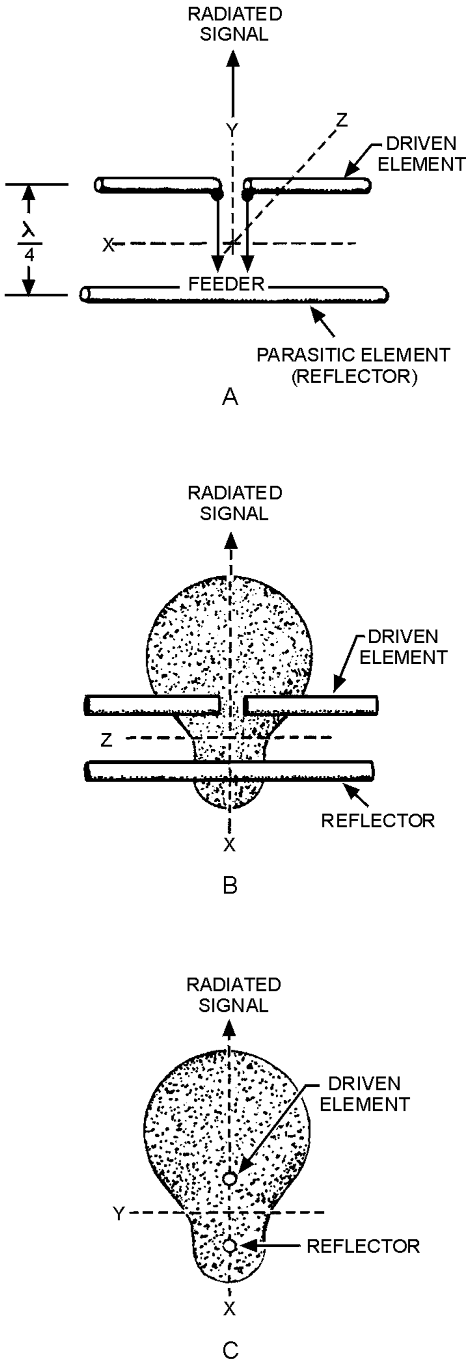


Figure 4-31.—Patterns obtained using a reflector with proper spacing.

Because the voltage induced in the reflector is 180 degrees out of phase with the signal produced at the driven element, a reduction in signal strength exists behind the reflector. Since the magnitude of an induced voltage never quite equals that of the inducing voltage, even in very closely coupled circuits, the energy behind the reflector (minor lobe) is not reduced to 0.

The spacing between the reflector and the driven element can be reduced to about 15 percent of a wavelength. The parasitic element must be made electrically inductive before it will act as a reflector. If this element is made about 5 percent longer than 1/2 wavelength, it will act as a reflector when the spacing is 15 percent of a wavelength.

Changing the spacing and length can change the radiation pattern so that maximum radiation is on the same side of the driven element as the parasitic element. In this instance the parasitic element is called a director.

Combining a reflector and a director with the driven element causes a decrease in back radiation and an increase in directivity. This combination results in the two main advantages of a parasitic array—unidirectivity and increased gain. If the parasitic array is rotated, it can pick up or transmit in different directions because of the reduction of transmitted energy in all but the desired direction. An antenna of this type is called a ROTARY ARRAY. Size for size, both the gain and directivity of parasitic arrays are greater than those of driven arrays. The disadvantage of parasitic arrays is that their adjustment is critical and they do not operate over a wide frequency range.

GAIN AND DIRECTIVITY.—Changing the spacing between either the director or the reflector and the driven element results in a change in the radiation pattern. More gain and directivity are obtained by changing the length of the parasitic elements.

The FRONT-TO-BACK RATIO of an array is the proportion of energy radiated in the principal direction of radiation to the energy radiated in the opposite direction. A high front-to-back ratio is desirable because this means that a minimum amount of energy is radiated in the undesired direction. Since completely suppressing all such radiation is impossible, an infinite ratio cannot be achieved. In actual practice, however, rather high values can be attained. Usually the length and spacing of the parasitic elements are adjusted so that a maximum front-to-back ratio is obtained, rather than maximum gain in the desired direction.

Q38. What two factors determine the directivity pattern of the parasitic array?

Q39. What two main advantages of a parasitic array can be obtained by combining a reflector and a director with the driven element?

Q40. The parasitic array can be rotated to receive or transmit in different directions. What is the name given to such an antenna?

Q41. What are the disadvantages of the parasitic array?

Multielement Parasitic Array

A MULTIELEMENT PARASITIC array is one that contains two or more parasitic elements with the driven element. If the array contains two parasitic elements (a reflector and a director) in addition to the driven element, it is usually known as a THREE-ELEMENT ARRAY. If three parasitic elements are used, the array is known as a FOUR-ELEMENT ARRAY, and so on. Generally speaking, if more parasitic elements are added to a three-element array, each added element is a director. The field behind a reflector is so small that additional reflectors would have little effect on the overall radiation pattern. In radar, from one to five directors are used.

CONSTRUCTION.—The parasitic elements of a multi-element parasitic array usually are positioned as shown in figure 4-32, views A and B. Proper spacings and lengths are determined experimentally. A folded dipole (view B) is often used as the driven element to obtain greater values of radiation resistance.

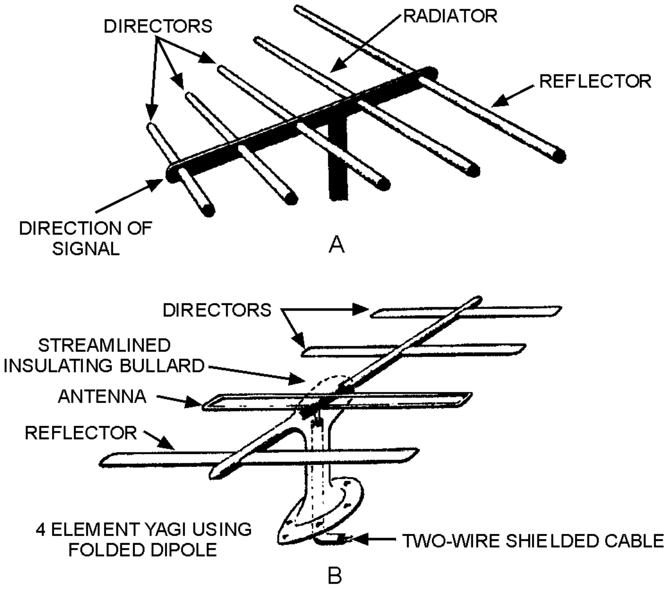


Figure 4-32.—Yagi antenna.

YAGI ANTENNAS.—An example of a multielement parasitic array is the YAGI ANTENNA (figure 4-32, views A and B). The spacings between the elements are not uniform. The radiation from the different elements arrives in phase in the forward direction, but out of phase by various amounts in the other directions.

The director and the reflector in the Yagi antenna are usually welded to a conducting rod or tube at their centers. This support does not interfere with the operation of the antenna. Since the driven element is center-fed, it is not welded to the supporting rod. The center impedance can be increased by using a folded dipole as the driven element.

The Yagi antenna shown in figure 4-32, view A, has three directors. In general, the greater number of parasitic elements used, the greater the gain. However, a greater number of such elements causes the array to have a narrower frequency response as well as a narrower beamwidth. Therefore, proper adjustment of the antenna is critical. The gain does not increase directly with the number of elements used. For example, a three-element Yagi array has a relative power gain of 5 dB. Adding another director results in a 2 dB increase. Additional directors have less and less effect.

A typical Yagi array used for receiving and transmitting energy is shown with a support frame in figure 4-33. This antenna is used by the military services. It operates at frequencies of from 12 to 50 megahertz and consists of two separate arrays (one high-frequency and one low-frequency antenna array) mounted on one frame. The various elements are indicated in the figure. The high-frequency (hf) array consists of one reflector, one driven element, and two directors; the low-frequency (lf) array has the same arrangement with one less director. The lengths of the elements in the high-frequency array are shorter than those in the low-frequency array. The physical lengths of the elements in the individual arrays are equal, but the electrical lengths can be varied by means of the tuning stubs at the center of the elements. The array can be rotated in any desired direction by a remotely controlled, electrically driven, antenna rotator.

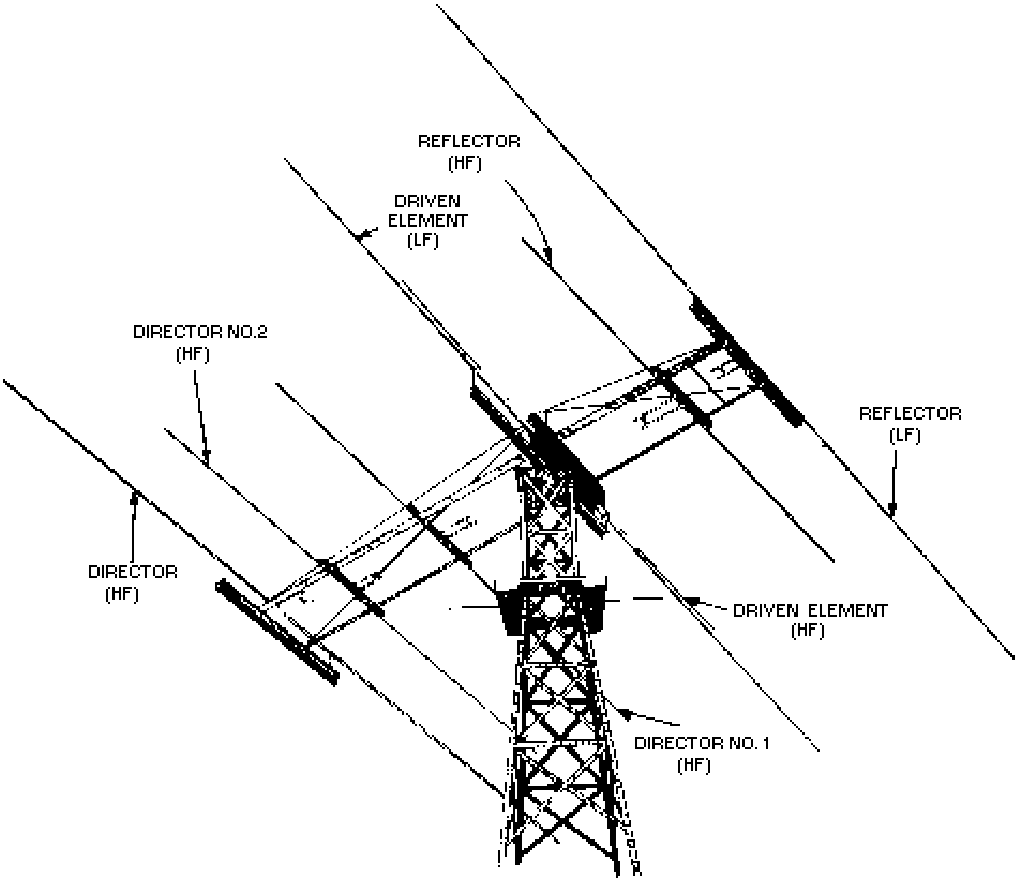


Figure 4-33.—A typical parasitic array used for transmitting and receiving.

Q42. What is the advantage of adding parasitic elements to a Yagi array?

Q43. The Yagi antenna is an example of what type of array?

SPECIAL ANTENNAS

In this section we will cover some special communications and radar antennas. Some of these antennas we touch on briefly since they are covered thoroughly in other courses.

Previously discussed antennas operate with standing waves of current and voltage along the wires. This section deals principally with antenna systems in which the current is practically uniform in all parts of the antenna. In its basic form, such an antenna consists of a single wire grounded at the far end through a resistor. The resistor has a value equal to the characteristic impedance of the antenna. This termination, just as in the case of an ordinary transmission line, eliminates standing waves. The current, therefore, decreases uniformly along the wire as the terminated end is approached. This decrease is caused by the loss of energy through radiation. The energy remaining at the end of the antenna is dissipated in the terminating resistor. For such an antenna to be a good radiator, its length must be fairly long. Also, the wire must not be too close to the ground. The return path through the ground will cause cancellation of the radiation. If the wire is sufficiently long, it will be practically nonresonant over a wide range of operating frequencies.

LONG-WIRE ANTENNA

A LONG-WIRE ANTENNA is an antenna that is a wavelength or longer at the operating frequency. In general, the gain achieved with long-wire antennas is not as great as the gain obtained from the multielement arrays studied in the previous section. But the long-wire antenna has advantages of its own. The construction of long-wire antennas is simple, both electrically and mechanically, with no particularly critical dimensions or adjustments. The long-wire antenna will work well and give satisfactory gain and directivity over a frequency range up to twice the value for which it was cut. In addition, it will accept power and radiate it efficiently on any frequency for which its overall length is not less than approximately 1/2 wavelength. Another factor is that long-wire antennas have directional patterns that are sharp in both the horizontal and vertical planes. Also, they tend to concentrate the radiation at the low vertical angles. Another type of long-wire antenna is the BEVERAGE ANTENNA, also called a WAVE ANTENNA. It is a horizontal, long-wire antenna designed especially for the reception and transmission of low-frequency, vertically polarized ground waves. It consists of a single wire, two or more wavelengths long, supported 3 to 6 meters above the ground, and terminated in its characteristic impedance, as shown in figure 4-34.

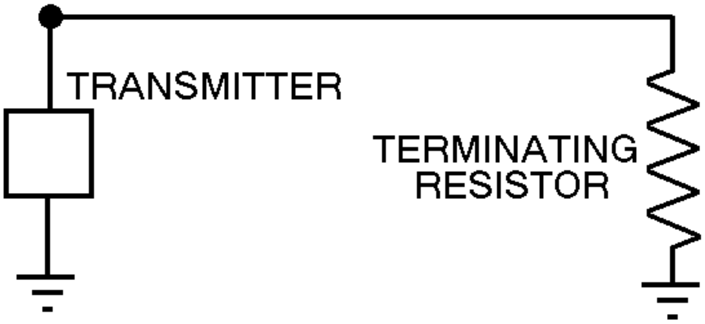


Figure 4-34.—Beverage antenna.

Q44. To radiate power efficiently, a long-wire antenna must have what minimum overall length?

Q45. What is another name for the Beverage antenna?

V ANTENNA

A V ANTENNA is a bi-directional antenna used widely in military and commercial communications. It consists of two conductors arranged to form a V. Each conductor is fed with currents of opposite polarity.

The V is formed at such an angle that the main lobes reinforce along the line bisecting the V and make a very effective directional antenna (see figure 4-35). Connecting the two-wire feed line to the apex of the V and exciting the two sides of the V 180 degrees out of phase cause the lobes to add along the line of the bisector and to cancel in other directions, as shown in figure 4-36. The lobes are designated 1, 2, 3, and 4 on leg AA', and 5, 6, 7, and 8 on leg BB'. When the proper angle between AA' and BB' is chosen, lobes 1 and 4 have the same direction and combine with lobes 7 and 6, respectively. This combination of two major lobes from each leg results in the formation of two stronger lobes, which lie along an imaginary line bisecting the enclosed angle. Lobes 2, 3, 5, and 8 tend to cancel each other, as do the smaller lobes, which are approximately at right angles to the wire legs of the V. The resultant waveform pattern is shown at the right of the V antenna in figure 4-36.

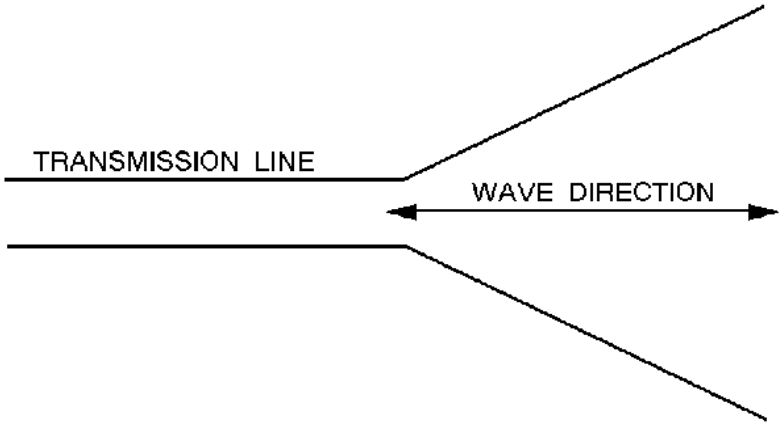


Figure 4-35.—Basic V antenna.

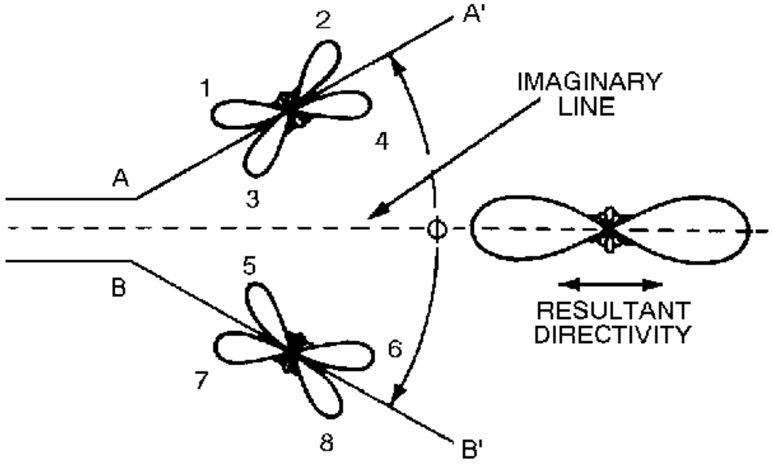
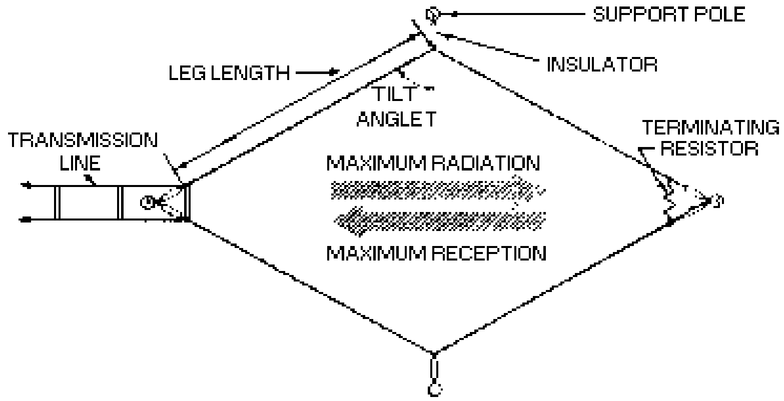


Figure 4-36.—Formation of directional radiation pattern from a resonant V antenna.

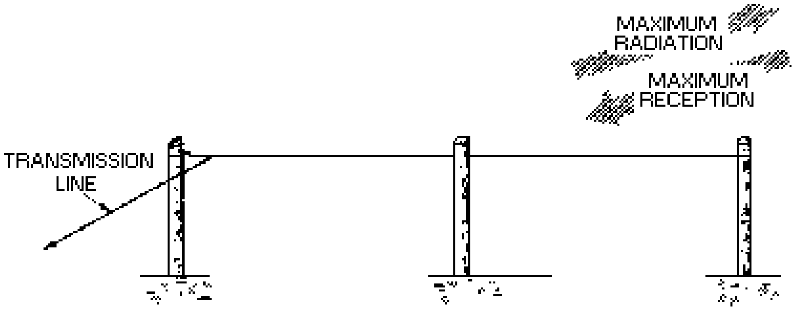
Q46. What is the polarity of the currents that feed the V antenna?

RHOMBIC ANTENNA

The highest development of the long-wire antenna is the RHOMBIC ANTENNA (see figure 4-37). It consists of four conductors joined to form a rhombus, or diamond shape. The antenna is placed end to end and terminated by a noninductive resistor to produce a uni-directional pattern. A rhombic antenna can be made of two obtuse-angle V antennas that are placed side by side, erected in a horizontal plane, and terminated so the antenna is nonresonant and unidirectional.



A. TOP VIEW



B. SIDE VIEW

Figure 4-37.—Basic rhombic antenna.

The rhombic antenna is WIDELY used for long-distance, high-frequency transmission and reception. It is one of the most popular fixed-station antennas because it is very useful in point-to-point communications.

Advantages

The rhombic antenna is useful over a wide frequency range. Although some changes in gain, directivity, and characteristic impedance do occur with a change in operating frequency, these changes are small enough to be neglected.

The rhombic antenna is much easier to construct and maintain than other antennas of comparable gain and directivity. Only four supporting poles of common heights from 15 to 20 meters are needed for the antenna.

The rhombic antenna also has the advantage of being noncritical as far as operation and adjustment are concerned. This is because of the broad frequency characteristics of the antenna.

Still another advantage is that the voltages present on the antenna are much lower than those produced by the same input power on a resonant antenna. This is particularly important when high transmitter powers are used or when high-altitude operation is required.

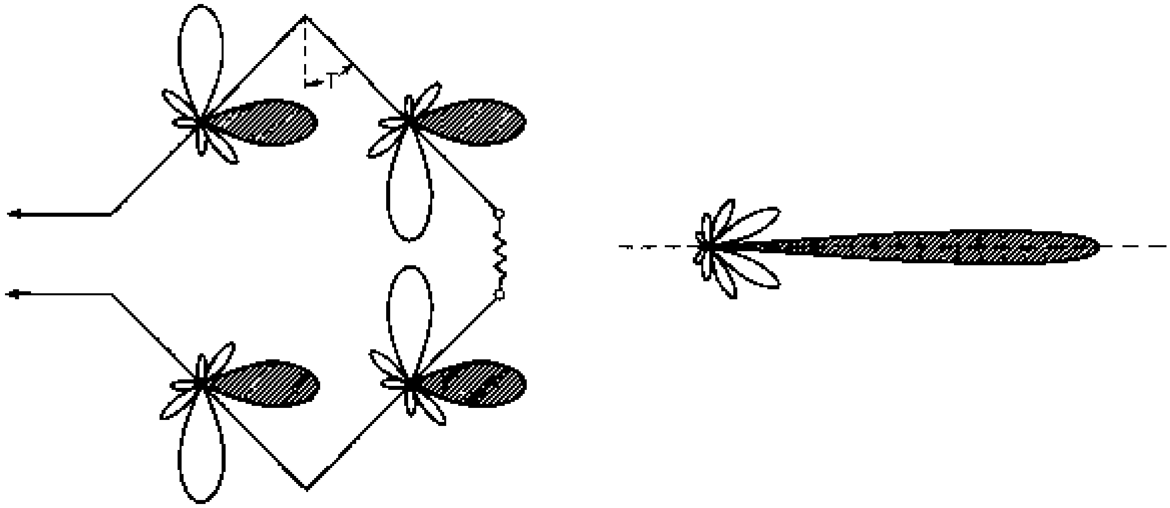
Disadvantages

The rhombic antenna is not without its disadvantages. The principal one is that a fairly large antenna site is required for its erection. Each leg is made at least 1 or 2 wavelengths long at the lowest operating frequency. When increased gain and directivity are required, legs of from 8 to 12 wavelengths are used. These requirements mean that high-frequency rhombic antennas have wires of several hundred feet in length. Therefore, they are used only when a large plot of land is available.

Another disadvantage is that the horizontal and vertical patterns depend on each other. If a rhombic antenna is made to have a narrow horizontal beam, the beam is also lower in the vertical direction. Therefore, obtaining high vertical-angle radiation is impossible except with a very broad horizontal pattern and low gain. Rhombic antennas are used, however, for long-distance sky wave coverage at the high frequencies. Under these conditions low vertical angles of radiation (less than 20 degrees) are desirable. With the rhombic antenna, a considerable amount of the input power is dissipated uselessly in the terminating resistor. However, this resistor is necessary to make the antenna unidirectional. The great gain of the antenna more than makes up for this loss.

Radiation Patterns

Figure 4-38 shows the individual radiation patterns produced by the four legs of the rhombic antenna and the resultant radiation pattern. The principle of operation is the same as for the V and the half-rhombic antennas.



A. INDIVIDUAL RADIATION PATTERNS

B. RESULTANT RADIATION PATTERNS

Figure 4-38.—Formation of a rhombic antenna beam.

Terminating Resistor

The terminating resistor plays an important part in the operation of the rhombic antenna. Upon it depend the unidirectivity of the antenna and the lack of resonance effects. An antenna should be properly terminated so it will have a constant impedance at its input. Terminating the antenna properly will also allow it to be operated over a wide frequency range without the necessity for changing the coupling adjustments at the transmitter. Discrimination against signals coming from the rear is of great importance for reception. The reduction of back radiation is perhaps of lesser importance for transmission. When an antenna is terminated with resistance, the energy that would be radiated backward is absorbed in the resistor.

Q47. What is the main disadvantage of the rhombic antenna?

TURNSTILE ANTENNA

The TURNSTILE ANTENNA is one of the many types that has been developed primarily for omnidirectional vhf communications. The basic turnstile consists of two horizontal half-wave antennas mounted at right angles to each other in the same horizontal plane. When these two antennas are excited with equal currents 90 degrees out of phase, the typical figure-eight patterns of the two antennas merge to produce the nearly circular pattern shown in figure 4-39, view A. Pairs of such antennas are frequently stacked, as shown in figure 4-40. Each pair is called a BAY. In figure 4-40 two bays are used and are spaced 1/2 wavelength apart, and the corresponding elements are excited in phase. These conditions cause a part of the vertical radiation from each bay to cancel that of the other bay. This results in a decrease in energy radiated at high vertical angles and increases the energy radiated in the horizontal plane. Stacking a number of bays can alter the vertical radiation pattern, causing a substantial gain in a horizontal direction without altering the overall horizontal directivity pattern. Figure 4-39, view B, compares the circular vertical radiation pattern of a single-bay turnstile with the sharp pattern of a four-bay turnstile array. A three-dimensional radiation pattern of a four-bay turnstile antenna is shown in figure 4-39, view C.

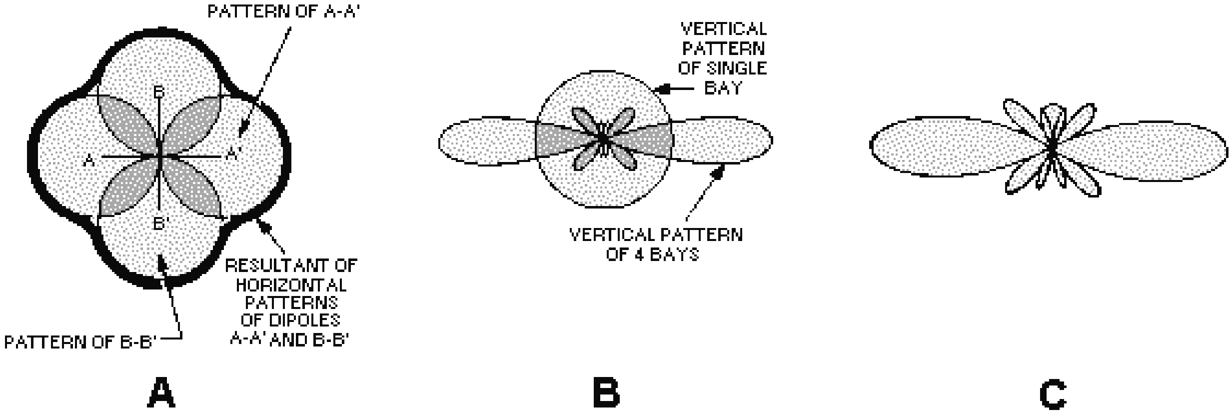


Figure 4-39.—Turnstile antenna radiation pattern.

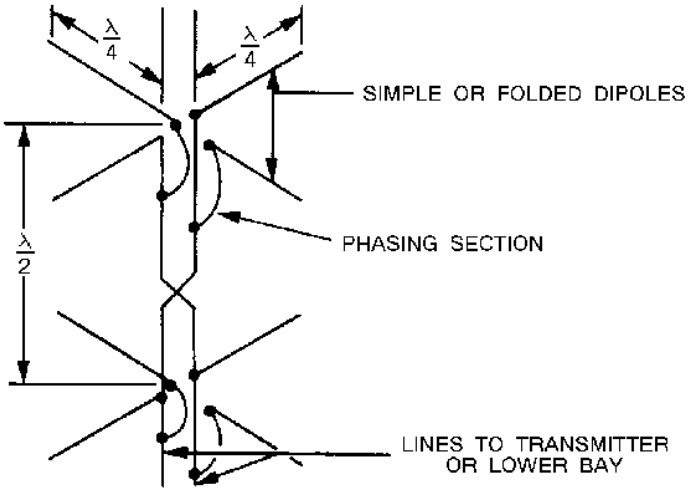


Figure 4-40.—Stacked turnstile antennas.

GROUND-PLANE ANTENNA

A vertical quarter-wave antenna several wavelengths above ground produces a high angle of radiation that is very undesirable at vhf and uhf frequencies. The most common means of producing a low angle of radiation from such an antenna is to work the radiator against a simulated ground called a GROUND PLANE. A simulated ground may be made from a large metal sheet or several wires or rods radiating from the base of the radiator. An antenna so constructed is known as a GROUND-PLANE ANTENNA. Two ground-plane antennas are shown in figure 4-41, views A and B.

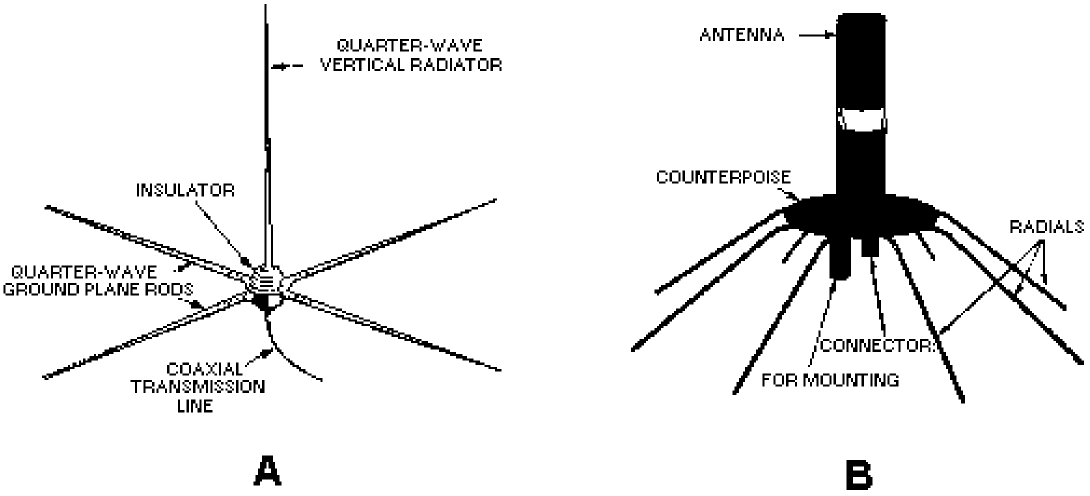


Figure 4-41.—Ground-plane antennas.

CORNER REFLECTOR

When a unidirectional radiation pattern is desired, it can be obtained by the use of a corner reflector with a half-wave dipole. A CORNER-REFLECTOR ANTENNA is a half-wave radiator with a reflector. The reflector consists of two flat metal surfaces meeting at an angle immediately behind the radiator. In other words, the radiator is set in the plane of a line bisecting the corner angle formed by the reflector sheets. The construction of a corner reflector is shown in figure 4-42. Corner-reflector antennas are mounted with the radiator and the reflector in the horizontal position when horizontal polarization is desired. In such cases the radiation pattern is very narrow in the vertical plane, with maximum signal being radiated in line with the bisector of the corner angle. The directivity in the horizontal plane is approximately the same as for any half-wave radiator having a single-rod type reflector behind it. If the antenna is mounted with the radiator and the corner reflector in the vertical position, as shown in view A, maximum radiation is produced in a very narrow horizontal beam. Radiation in a vertical plane will be the same as for a similar radiator with a single-rod type reflector behind it.

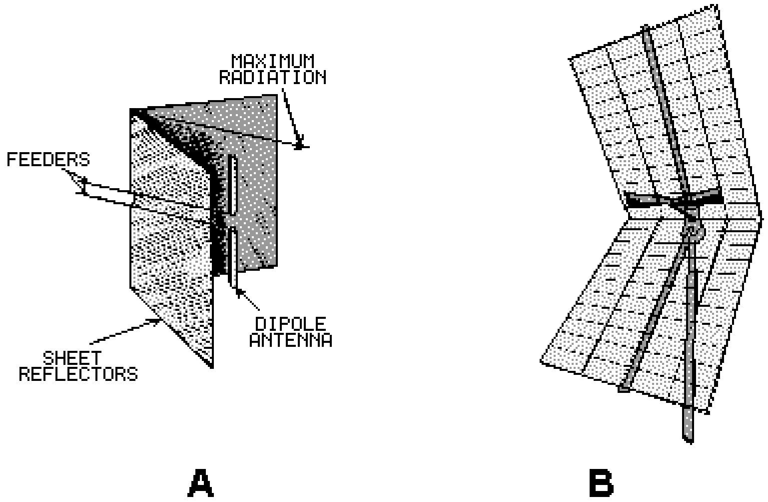


Figure 4-42.—Corner-reflector antennas.

Q48. What is the primary reason for the development of the turnstile antenna?

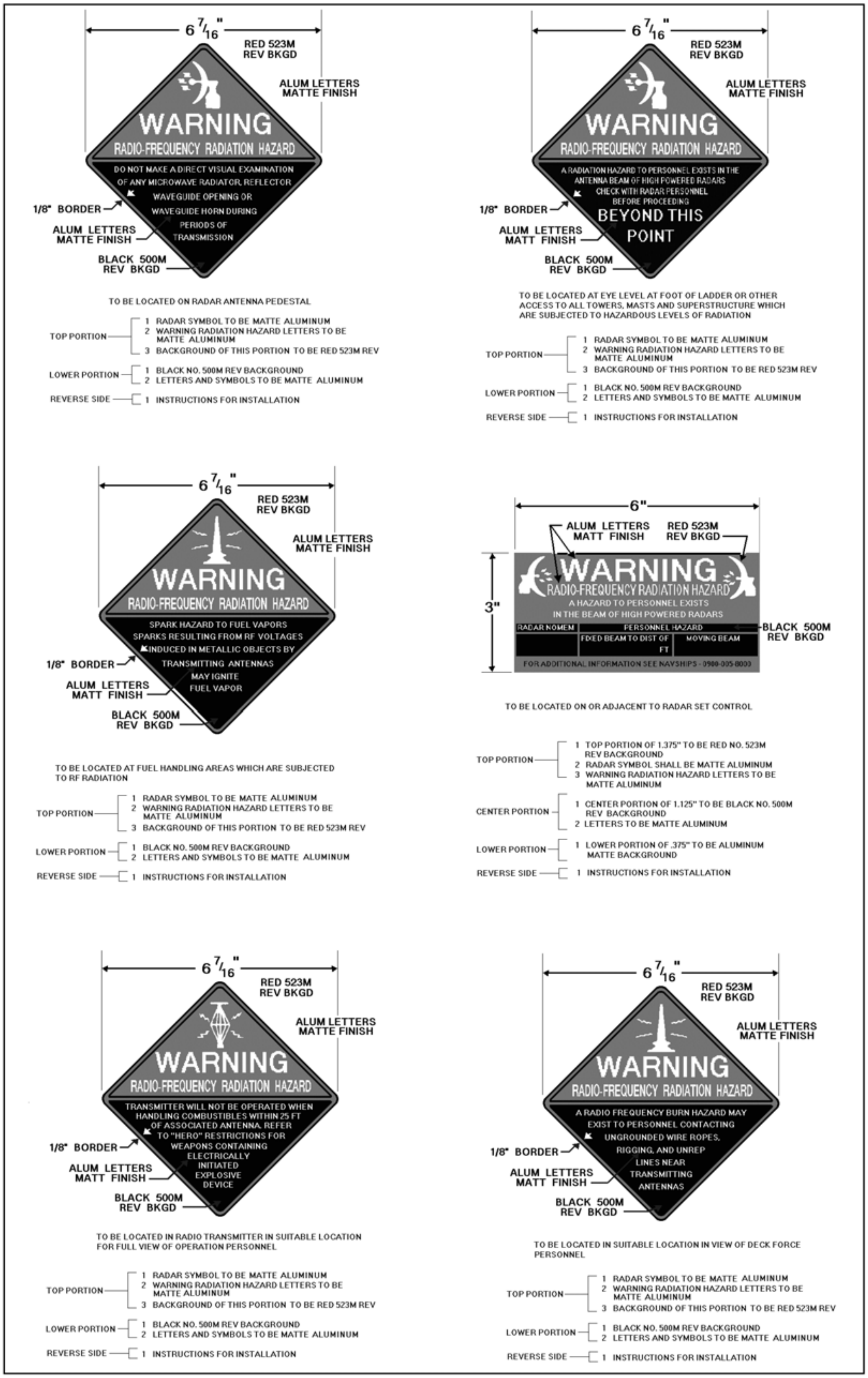
RF SAFETY PRECAUTIONS

Although electromagnetic radiation from transmission lines and antennas is usually of insufficient strength to electrocute personnel, it can lead to other accidents and compound injuries. Voltages may be induced in ungrounded metal objects, such as wire guys, wire cable (hawser), hand rails, or ladders. If you come in contact with these objects, you could receive a shock or rf burn. This shock can cause you to jump or fall into nearby mechanical equipment or, when working aloft, to fall from an elevated work area. Take care to ensure that all transmission lines or antennas are deenergized before working near or on them.

Either check or have someone check all guys, cables, rails, and ladders around your work area for rf shock dangers. Use working aloft "chits" and safety harnesses for your own safety. Signing a "working aloft chit" signifies that all equipment is in a nonradiating status. The person who signs the chit should ensure that no rf danger exists in areas where you or other personnel will be working.

Nearby ships or parked aircraft are another source of rf energy that you must consider when you check a work area for safety. Combustible materials can be ignited and cause severe fires from arcs or heat generated by rf energy. Also, rf radiation can detonate ordnance devices by inducing currents in the internal wiring of the devices or in the external test equipment or leads connected to them.

<u>**ALWAYS**</u> obey rf radiation warning signs and keep a safe distance from radiating antennas. The six types of warning signs for rf radiation hazards are shown in figure 4-43.



TO BE LOCATED ON RADAR ANTENNA PEDESTAL

TOP PORTION
1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1 BLACK NO. 500M REV BACKGROUND
2 LETTERS AND SYMBOLS TO BE MATTE ALUMINUM

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

TO BE LOCATED AT EYE LEVEL AT FOOT OF LADDER OR OTHER ACCESS TO ALL TOWERS, MASTS AND SUPERSTRUCTURE WHICH ARE SUBJECTED TO HAZARDOUS LEVELS OF RADIATION

TOP PORTION
1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1 BLACK NO. 500M REV BACKGROUND
2 LETTERS AND SYMBOLS TO BE MATTE ALUMINUM

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

TO BE LOCATED AT FUEL HANDLING AREAS WHICH ARE SUBJECTED TO RF RADIATION

TOP PORTION
1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1 BLACK NO. 500M REV BACKGROUND
2 LETTERS AND SYMBOLS TO BE MATTE ALUMINUM

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

TO BE LOCATED ON OR ADJACENT TO RADAR SET CONTROL

TOP PORTION
1 TOP PORTION OF 1.375" TO BE RED NO. 523M REV BACKGROUND
2 RADAR SYMBOL SHALL BE MATTE ALUMINUM
3 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM

CENTER PORTION
1 CENTER PORTION OF 1.125" TO BE BLACK NO. 500M REV BACKGROUND
2 LETTERS TO BE MATTE ALUMINUM

LOWER PORTION
1 LOWER PORTION OF .375" TO BE ALUMINUM MATTE BACKGROUND

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

TO BE LOCATED IN RADIO TRANSMITTER IN SUITABLE LOCATION FOR FULL VIEW OF OPERATION PERSONNEL

TOP PORTION
1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1 BLACK NO. 500M REV BACKGROUND
2 LETTERS AND SYMBOLS TO BE MATTE ALUMINUM

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

TO BE LOCATED IN SUITABLE LOCATION IN VIEW OF DECK FORCE PERSONNEL

TOP PORTION
1 RADAR SYMBOL TO BE MATTE ALUMINUM
2 WARNING RADIATION HAZARD LETTERS TO BE MATTE ALUMINUM
3 BACKGROUND OF THIS PORTION TO BE RED 523M REV

LOWER PORTION
1 BLACK NO. 500M REV BACKGROUND
2 LETTERS AND SYMBOLS TO BE MATTE ALUMINUM

REVERSE SIDE
1 INSTRUCTIONS FOR INSTALLATION

Figure 4-43.—Examples of rf radiation warning signs.

RF BURNS

Close or direct contact with rf transmission lines or antennas may result in rf burns. These are usually deep, penetrating, third-degree burns. To heal properly, these burns must heal from the inside to the skin's surface. To prevent infection, you must give proper attention to all rf burns, including the small "pinhole" burns. Petrolatum gauze can be used to cover these burns temporarily, before the injured person reports to medical facilities for further treatment.

DIELECTRIC HEATING

DIELECTRIC HEATING is the heating of an insulating material by placing it in a high-frequency electric field. The heat results from internal losses during the rapid reversal of polarization of molecules in the dielectric material.

In the case of a human in an rf field, the body acts as a dielectric. If the power in the rf field exceeds 10 milliwatts per centimeter, a person in that field will have a noticeable rise in body temperature. The eyes are highly susceptible to dielectric heating. For this reason, you should not look directly into devices radiating rf energy. The vital organs of the body also are susceptible to dielectric heating. For your own safety, you must NOT stand directly in the path of rf radiating devices.

PRECAUTIONS WHEN WORKING ALOFT

When radio or radar antennas are energized by transmitters, you must not go aloft unless advance tests show that little or no danger exists. A casualty can occur from even a small spark drawn from a charged piece of metal or rigging. Although the spark itself may be harmless, the "surprise" may cause you to let go of the antenna involuntarily and you may fall. There is also a shock hazard if nearby antennas are energized.

Rotating antennas also might cause you to fall when you are working aloft. Motor safety switches controlling the motion of rotating antennas must be tagged and locked open before you go aloft near such antennas.

When working near a stack, you should draw and wear the recommended oxygen breathing apparatus. Among other toxic substances, stack gas contains carbon monoxide. Carbon monoxide is too unstable to build up to a high concentration in the open, but prolonged exposure to even small quantities is dangerous.

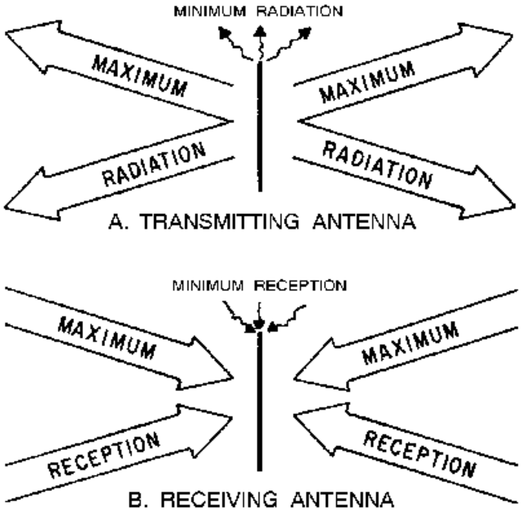
SUMMARY

This chapter has presented information on the various types of antennas. The information that follows summarizes the important points of this chapter.

An **ANTENNA** is a conductor, or system of conductors, that radiates or receives energy in the form of electromagnetic waves.

HERTZ (half-wave) and **MARCONI** (quarter-wave) are the two basic classifications of antennas.

RECIPROCITY of antennas means that the various properties of the antenna apply equally to transmitting and receiving.

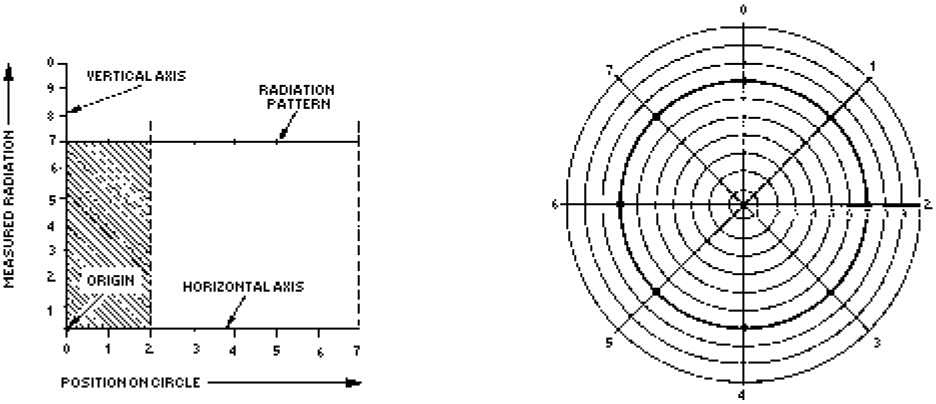


A. TRANSMITTING ANTENNA

B. RECEIVING ANTENNA

RADIATION RESISTANCE is the amount of resistance which, if inserted in place of the antenna, would consume the same amount of power that is actually radiated by the antenna.

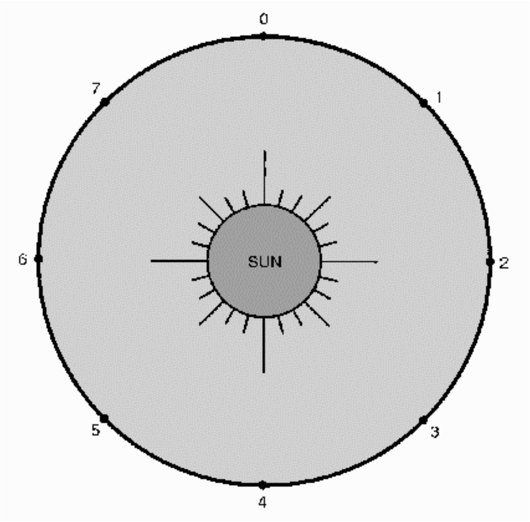
RADIATION PATTERNS can be plotted on a rectangular- or polar-coordinate graph. These patterns are a measurement of the energy leaving an antenna.



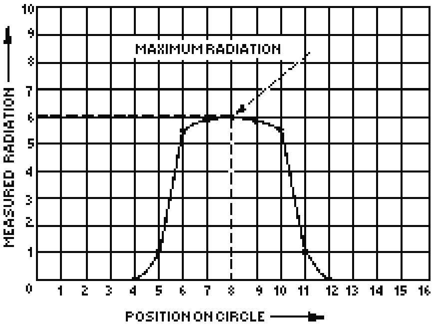
A. RECTANGULAR-COORDINATE GRAPH

B. POLAR-COORDINATE GRAPH

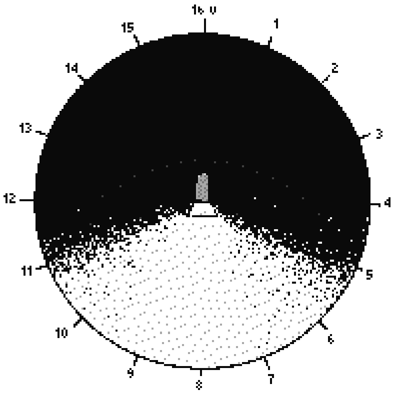
An **ISOTROPIC RADIATOR** radiates energy equally in all directions.



An **ANISOTROPIC RADIATOR** radiates energy directionally.



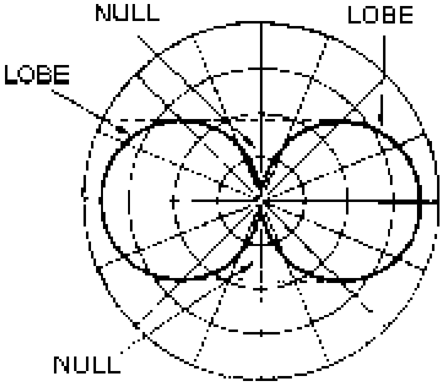
A



B

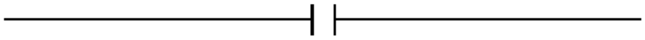
A **LOBE** is the area of a radiation pattern that is covered by radiation.

A **NULL** is the area of a radiation pattern that has minimum radiation.

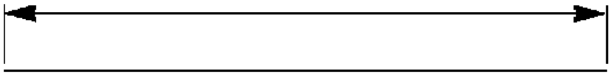


ANTENNA LOADING is the method used to change the electrical length of an antenna. This keeps the antenna in resonance with the applied frequency. It is accomplished by inserting a variable inductor or capacitor in series with the antenna.

LOADING TO COMPENSATE FOR TOO SHORT AN ANTENNA
A

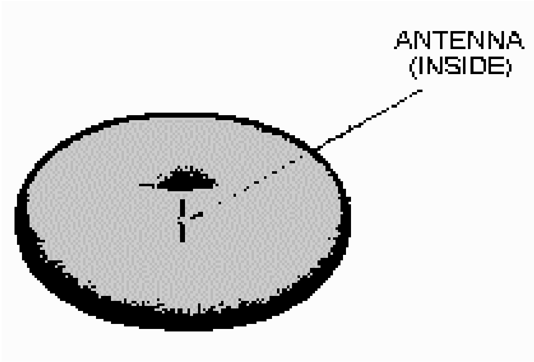


LOADING TO COMPENSATE FOR TOO LONG AN ANTENNA
B

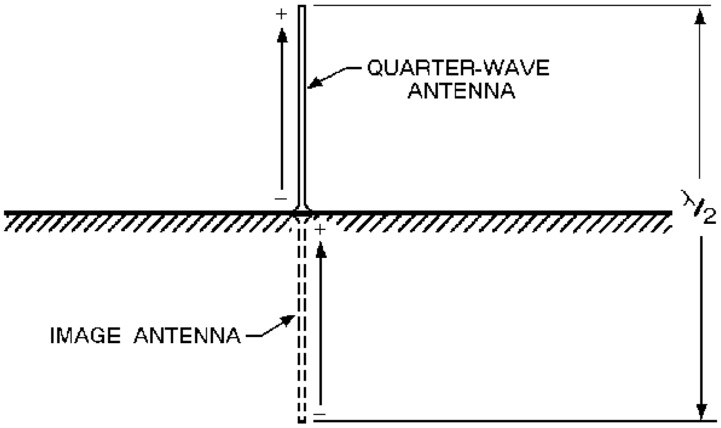


NORMAL ANTENNA WITHOUT LOADING
C

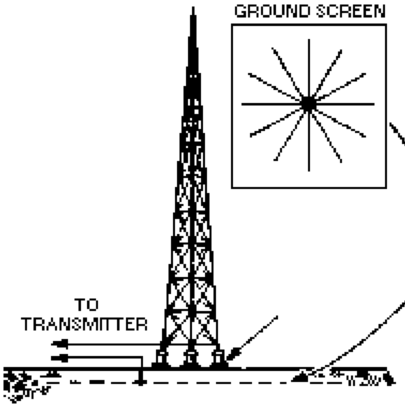
A **HALF-WAVE ANTENNA (Hertz)** consists of two lengths of rod or tubing, each a quarter-wave long at a certain frequency, which radiates a doughnut pattern.

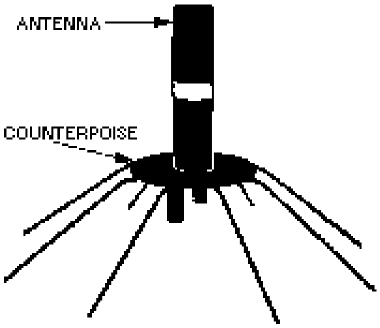


A **QUARTER-WAVE ANTENNA (Marconi)** is a half-wave antenna cut in half with one end grounded. The ground furnishes the missing half of the antenna.



The **GROUND SCREEN** and the **COUNTERPOISE** are used to reduce losses caused by the ground in the immediate vicinity of the antenna. The ground screen is buried below the surface of the earth. The counterpoise is installed above the ground.





The **FOLDED DIPOLE** consists of a dipole radiator, which is connected in parallel at its ends to a half-wave radiator.

AN **ARRAY** is a combination of half-wave elements operating together as a single antenna. It provides more gain and greater directivity than single element antennas.

A **DRIVEN ARRAY** derives its power directly from the source.

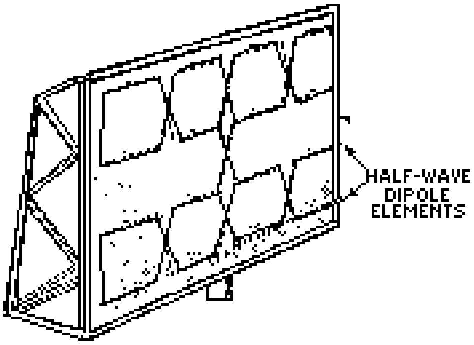
A **PARASITIC ARRAY** derives its power by coupling the energy from other elements of the antenna.

The **BIDIRECTIONAL ARRAY** radiates energy equally in two opposing directions.

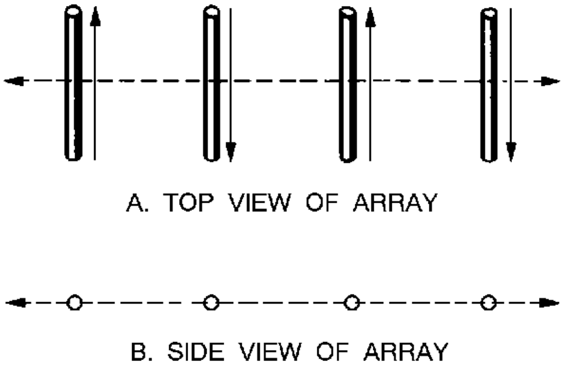
The **UNIDIRECTIONAL ARRAY** radiates energy efficiently in a single direction.

The **COLLINEAR ARRAY** has elements in a straight line. Maximum radiation occurs at right angles to this line.

The **BROADSIDE ARRAY** has elements parallel and in the same plane. Maximum radiation develops in the plane at right angles to the plane of the elements.



The **END-FIRE ARRAY** has elements parallel to each other and in the same plane. Maximum radiation occurs along the axis of the array.

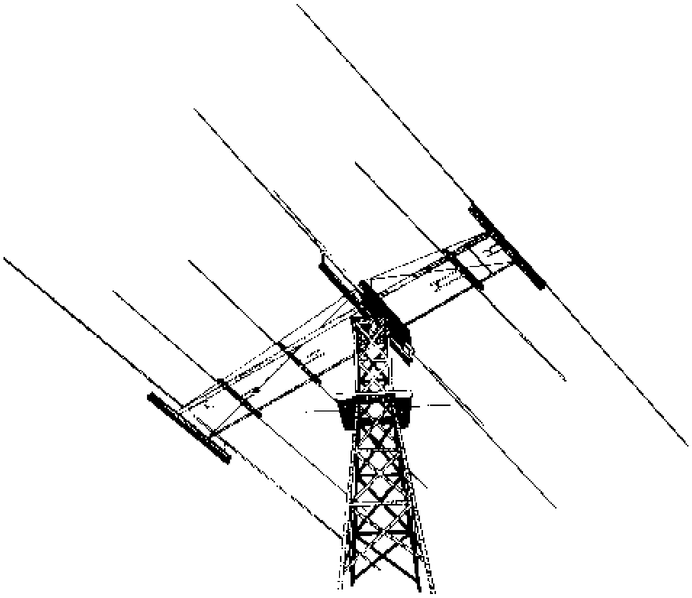


MATCHING STUBS are used between elements to maintain current in the proper phase.

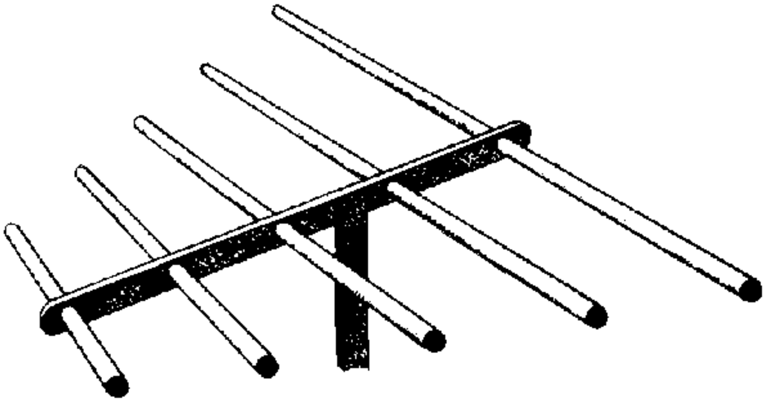
The **GAIN OF A COLLINEAR ANTENNA** is greatest when the elements are spaced from 0.4 to 0.5 wavelength apart or when the number of elements is increased.

The **OPTIMUM GAIN OF A BROADSIDE ARRAY** is obtained when the elements are spaced 0.65 wavelength apart.

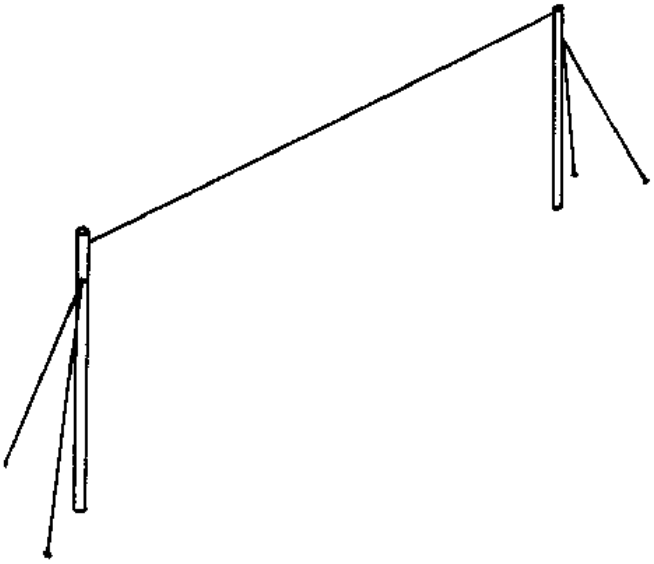
A **PARASITIC ARRAY** consists of one or more parasitic elements with a driven element. The amount of power gain and directivity depends on the lengths of the parasitic elements and the spacing between them.



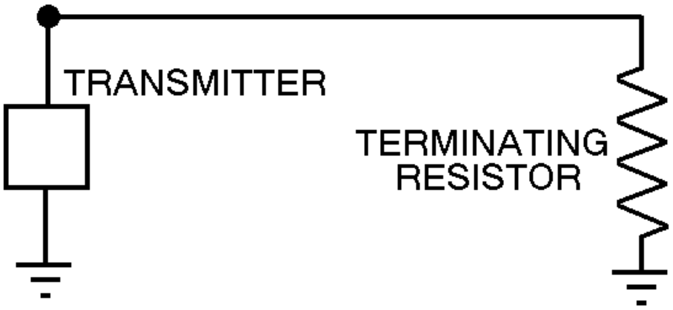
MULTIELEMENT ARRAYS, such as the YAGI, have a narrow frequency response as well as a narrow beamwidth.



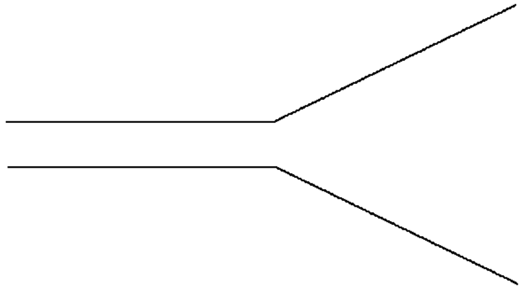
A **LONG-WIRE ANTENNA** is an antenna that is a wavelength or more long at the operating frequency. These antennas have directive patterns that are sharp in both the horizontal and vertical planes.



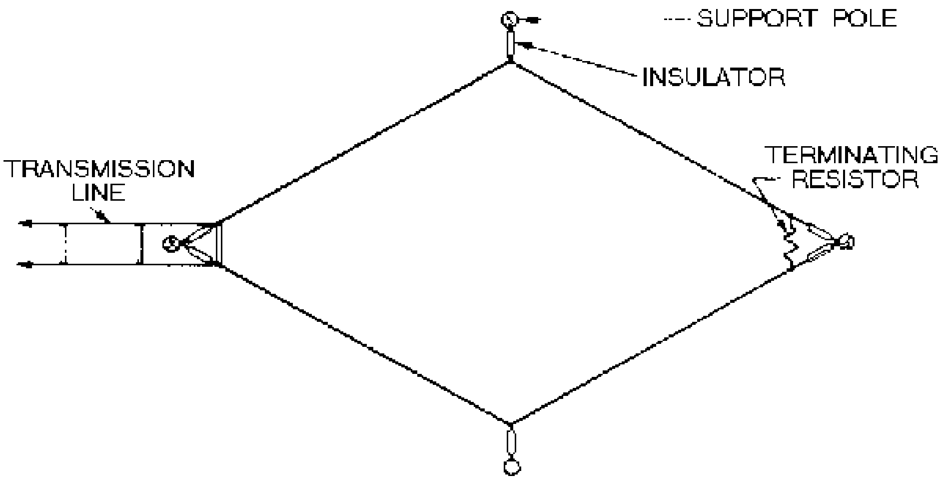
BEVERAGE ANTENNAS consist of a single wire that is two or more wavelengths long.



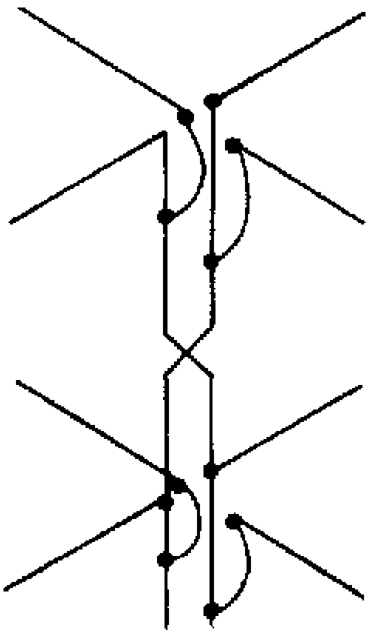
A **V ANTENNA** is a bi-directional antenna consisting of two horizontal, long wires arranged to form a V.



The **RHOMBIC ANTENNA** uses four conductors joined to form a rhombus shape. This antenna has a wide frequency range, is easy to construct and maintain, and is noncritical as far as operation and adjustment are concerned.



The **TURNSTILE ANTENNA** consists of two horizontal, half-wire antennas mounted at right angles to each other.



ANSWERS TO QUESTIONS Q1. THROUGH Q48.

A1. Half-wave (Hertz) and quarter-wave (Marconi).

A2. Coupling device, feeder, and antenna.

A3. Frequency of operation of the transmitter, amount of power to be radiated, and general direction of the receiving set.

A4. One-half the wavelength.

A5. Current and voltage loops.

A6. Current and voltage nodes.

A7. Reciprocity of antennas.

A8. Electric (E) field.

A9. Circular polarization.

A10. Vertical polarization.

A11. Less interference is experienced by man-made noise sources.

A12. Vertical polarization.

A13. 73 ohms.

A14. Anisotropic radiator.

A15. Isotropic radiator.

A16. Anisotropic radiator.

A17. Dipole, doublet and Hertz.

A18. Nondirectional.

A19. Vertical plane.

A20. The pattern would flatten.

A21. To connect one end through a capacitor to the final output stage of the transmitter.

A22. A circular radiation pattern in the horizontal plane, or same as a half wave.

A23. It is composed of a series of conductors arranged in a radial pattern and buried 1 to 2 feet below the ground.

A24. Nine times the feed-point impedance.

A25. Folded dipole.

A26. To produce desired phase relationship between connected elements.

A27. Major lobes have the greatest amount of radiation.

A28. Four.

A29. As more elements are added, an unbalanced condition in the system occurs which impairs efficiency.

A30. By increasing the lengths of the elements of the array.

A31. Directivity increases.

A32. Lower radiation resistance.

A33. Parallel and in the same plane.

A34. They sharpen.

A35. Extremely low radiation resistance, confined to one frequency, and affected by atmospheric conditions.

A36. Along the major axis

A37. Symmetrically.

A38. Length of the parasitic element (tuning) and spacing between the parasitic and driven elements.

A39. Increased gain and directivity.

A40. Rotary array.

A41. Their adjustment is critical and they do not operate over a wide frequency range.

A42. Increased gain.

A43. Multielement parasitic array.

A44. One-half wavelength.

A45. Wave antenna.

A46. Opposite.

A47. It requires a large antenna site.

A48. For omnidirectional vhf communications.

APPENDIX I

GLOSSARY

ABSORPTION—(1) Absorbing light waves. Does not allow any reflection or refraction. (2) Atmospheric absorption of rf energy with no reflection or refraction (adversely affects long distance communications).

ACOUSTICS—The science of sound.

AMPLITUDE—The portion of a cycle measured from a reference line to a maximum value above (or to a maximum value below) the line.

ANGLE OF INCIDENCE—The angle between the incident wave and the normal.

ANGLE OF REFLECTION—The angle between the reflected wave and the normal.

ANGLE OF REFRACTION—The angle between the normal and the path of a wave through the second medium.

ANGSTROM UNIT—The unit used to define the wavelength of light waves.

ANISOTROPIC—The property of a radiator to emit strong radiation in one direction.

ANTENNA—A conductor or set of conductors used either to radiate rf energy into space or to collect rf energy from space.

ARRAY OF ARRAYS—Same as COMBINATION ARRAY.

BAY—Part of an antenna array.

BEVERAGE ANTENNA—A horizontal, longwire antenna designed for reception and transmission of low-frequency, vertically polarized ground waves.

BIDIRECTIONAL ARRAY—An array that radiates in opposite directions along the line of maximum radiation.

BROADSIDE ARRAY—An array in which the direction of maximum radiation is perpendicular to the plane containing the elements.

CENTER-FEED METHOD—Connecting the center of an antenna to a transmission line, which is then connected to the final (output) stage of the transmitter.

CHARACTERISTIC IMPEDANCE—The ratio of voltage to current at any given point on a transmission line. Represented by a value of impedance.

COAXIAL LINE—A type of transmission line that contains two concentric conductors.

COLLINEAR ARRAY—An array with all the elements in a straight line. Maximum radiation is perpendicular to the axis of the elements.

COMBINATION ARRAY—An array system that uses the characteristics of more than one array.

COMPLEMENTARY (SECONDARY) COLORS OF LIGHT—The colors of light produced when two of the primaries are mixed in overlapping beams of light. The complementary colors of light are magenta, yellow, and cyan.

COMPLEX WAVE—A wave produced by combining two or more pure tones at the same time.

COMPRESSION WAVES—Longitudinal waves that have been compressed (made more dense) as they move away from the source.

CONDUCTANCE—The opposite of resistance in transmission lines. The minute amount of resistance that is present in the insulator of a transmission line.

CONNECTED ARRAY—Another term for DRIVEN ARRAY.

COPPER LOSSES—The I^2R loss in a conductor caused by the current flow through the resistance of the conductor.

CORNER-REFLECTOR ANTENNA—A half-wave antenna with a reflector consisting of two flat metal surfaces meeting at an angle behind the radiator.

COUNTERPOISE—A network of wire that is connected to a quarter-wave antenna at one end and provides the equivalent of an additional 1/4 wavelength.

COUPLING DEVICE—A coupling coil that connects the transmitter to the feeder.

CREST (TOP)—The peak of the positive alternation (maximum value above the line) of a wave.

CRITICAL ANGLE—The maximum angle at which radio waves can be transmitted and still be refracted back to earth.

CRITICAL FREQUENCY—The maximum frequency at which a radio wave can be transmitted vertically and still be refracted back to earth.

CURRENT-FEED METHOD—Same as CENTER-FEED METHOD.

CURRENT STANDING-WAVE RATIO (ISWR)—The ratio of maximum to minimum current along a transmission line.

CYCLE—One complete alternation of a sine wave that has a maximum value above and a maximum value below the reference line.

DAMPING—Reduction of energy by absorption.

DENSITY—(1) The compactness of a substance. (2) Mass per unit volume.

DETECTOR—The device that responds to a wave or disturbance.

DIELECTRIC HEATING—The heating of an insulating material by placing it in a high frequency electric field.

DIELECTRIC LOSSES—The losses resulting from the heating effect on the dielectric material between conductors.

DIFFRACTION—The bending of the paths of waves when the waves meet some form of obstruction.

DIFFUSION—The scattering of reflected light waves (beams) from an object, such as white paper.

DIPOLE—A common type of half-wave antenna made from a straight piece of wire cut in half. Each half operates at a quarter wavelength of the output.

DIRECTIONAL—Radiation that varies with direction.

DIRECTOR—The parasitic element of an array that reinforces energy coming from the driver toward itself.

DIRECTIVITY—The property of an array that causes more radiation to take place in certain directions than in others.

DISPERSION—The refraction of light waves that causes the different frequencies to bend at slightly different angles.

DISTRIBUTED CONSTANTS—The constants of inductance, capacitance, and resistance in a transmission line. The constants are spread along the entire length of the line and cannot be distinguished separately.

DOPPLER EFFECT—The apparent change in frequency or pitch when a sound source moves either toward or away from a listener.

DOUBLET—Another name for the dipole antenna.

DRIVEN ARRAY—An array in which all of the elements are driven.

DRIVEN ELEMENT—An element of an antenna (transmitting or receiving) that is connected directly to the transmission line.

ECHO—The reflection of the original sound wave as it bounces off a distant surface.

ELASTICITY—The ability of a substance to return to its original state.

ELECTROMAGNETIC FIELD—The combination of an electric (E) field and a magnetic (H) field.

ELECTROMAGNETIC INTERFERENCE—Man-made or natural interference that degrades the quality of reception of radio waves.

ELECTROMAGNETIC RADIATION—The radiation of radio waves into space.

ELECTRIC (E) FIELD—The field produced as a result of a voltage charge on a conductor or antenna.

ELEMENT—A part of an antenna that can be either an active radiator or a parasitic radiator.

END-FEED METHOD—Connecting one end of an antenna through a capacitor to the final output stage of a transmitter.

END-FIRE ARRAY—An array in which the direction of radiation is parallel to the axis of the array.

FADING—Variations in signal strength by atmospheric conditions.

FEEDER—A transmission line that carries energy to the antenna.

FLAT LINE—A transmission line that has no standing waves. This line requires no special tuning device to transfer maximum power.

FLEXIBLE COAXIAL LINE—A coaxial line made with a flexible inner conductor insulated from the outer conductor by a solid, continuous insulating material.

FOLDED DIPOLE—An ordinary half-wave antenna (dipole) that has one or more additional conductors connected across the ends parallel to each other.

FOUR-ELEMENT ARRAY—An array with three parasitic elements and one driven element.

FREE-SPACE LOSS—The loss of energy of a radio wave because of the spreading of the wavefront as it travels from the transmitter.

FREQUENCY—The number of cycles that occur in one second. Usually expressed in hertz.

FREQUENCY DIVERSITY—Transmitting (and receiving) of radio waves on two different frequencies simultaneously.

FRONT-TO-BACK RATIO—The ratio of the energy radiated in the principal direction to the energy radiated in the opposite direction.

FUNDAMENTAL FREQUENCY—The basic frequency or first harmonic frequency.

GAIN—The ratio between the amount of energy propagated from an antenna that is directional to the energy from the same antenna that would be propagated if the antenna were not directional.

GENERATOR END—See INPUT END.

GROUND PLANE—The portion of a groundplane antenna that acts as ground.

GROUND-PLANE ANTENNA—A type of antenna that uses a ground plane as a simulated ground to produce low-angle radiation.

GROUND REFLECTION LOSS—The loss of rf energy each time a radio wave is reflected from the Earth's surface.

GROUND SCREEN—A series of conductors buried below the surface of the earth and arranged in a radial pattern. Used to reduce losses in the ground.

GROUND WAVES—Radio waves that travel near the surface of the Earth.

HALF-WAVE DIPOLE ANTENNA—An antenna consisting of two rods (1/4 wavelength each) in a straight line, that radiates electromagnetic energy.

HARMONIC—A frequency that is a whole number multiple of a smaller base frequency.

HERTZ ANTENNA—A half-wave antenna installed some distance above ground and positioned either vertically or horizontally.

HORIZONTAL AXIS—On a graph, the straight line axis plotted from left to right.

HORIZONTAL PATTERN—The part of a radiation pattern that is radiated in all directions along the horizontal plane.

HORIZONTALLY POLARIZED—Waves that are radiated with their E field component parallel to the Earth's surface.

INCIDENT WAVE—(1) The wave that strikes the surface of a medium. (2) The wave that travels from the sending end to the receiving end of a transmission line.

INDUCTION FIELD—The electromagnetic field produced about an antenna when current and voltage are present on the same antenna.

INDUCTION LOSSES—The losses that occur when the electromagnetic field around a conductor cuts through a nearby metallic object and induces a current into that object.

INFRASONIC (SUBSONIC)—Sounds below 15 hertz.

INPUT END—The end of a two-wire transmission line that is connected to a source.

INPUT IMPEDANCE—The impedance presented to the transmitter by the transmission line and its load.

INTENSITY (OF SOUND)—The measurement of the amplitude of sound energy. Sometimes mistakenly called loudness.

INTERCEPT—The point where two lines drawn on a graph cross each other.

INTERFERENCE—Any disturbance that produces an undesirable response or degrades a wave.

IONOSPHERE—The most important region of the atmosphere extending from 31 miles to 250 miles above the earth. Contains four cloud-like layers that affect radio waves.

IONOSPHERIC STORMS—Disturbances in the earth's magnetic field that make communications practical only at lower frequencies.

IONIZATION—The process of upsetting electrical neutrality.

ISOTROPIC RADIATION—The radiation of energy equally in all directions.

LEAKAGE CURRENT—The small amount of current that flows between the conductors of a transmission line through the dielectric.

LIGHT RAYS—Straight lines that represent light waves emitting from a source.

LOAD END—See OUTPUT END.

LOADING—See LUMPED-IMPEDANCE TUNING.

LOBE—An area of a radiation pattern plotted on a polar-coordinate graph that represents maximum radiation.

LONG-WIRE ANTENNA—An antenna that is a wavelength or more long at its operating frequency.

LONGITUDINAL WAVES—Waves in which the disturbance (back and forth motion) takes place in the direction of propagation. Sometimes called compression waves.

LOOP—The curves of a standing wave or antenna that represent amplitude of current or voltage.

LOWEST USABLE FREQUENCY—The minimum operating frequency that can be used for communications between two points.

LUMPED CONSTANTS—The properties of inductance, capacitance, and resistance in a transmission line.

LUMPED-IMPEDANCE TUNING—The insertion of an inductor or capacitor in series with an antenna to lengthen or shorten the antenna electrically.

MAGNETIC (H) FIELD—The field produced when current flows through a conductor or antenna.

MAJOR LOBE—The lobe in which the greatest amount of radiation occurs.

MARCONI ANTENNA—A quarter-wave antenna oriented perpendicular to the earth and operated with one end grounded.

MAXIMUM USABLE FREQUENCY— Maximum frequency that can be used for communications between two locations for a given time of day and a given angle of incidence.

MEDIUM—The substance through which a wave travels from one point to the next. Air, water, wood, etc., are examples of a medium.

MINOR LOBE—The lobe in which the radiation intensity is less than a major lobe.

MULTIELEMENT ARRAY—An array consisting of one or more arrays and classified as to directivity.

MULTIELEMENT PARASITIC ARRAY— An array that contains two or more parasitic elements and a driven element.

MULTIPATH—The multiple paths a radio wave may follow between transmitter and receiver.

NATURAL HORIZON—The line-of-sight horizon.

NEGATIVE ALTERNATION—The portion of a sine wave below the reference line.

NODE—The fixed minimum points of voltage or current on a standing wave or antenna.

NOISE (OF SOUND)—An unwanted disturbance caused by spurious waves that originate from man-made or natural sources.

NONDIRECTIONAL—See OMNIDIRECTIONAL.

NONLUMINOUS BODIES—Objects that either reflect or diffuse light that falls upon them.

NONRESONANT LINE—A transmission line that has no standing waves of current or voltage.

NORMAL—The imaginary line perpendicular to the point at which the incident wave strikes the reflecting surface. Also called the perpendicular.

NULL—On a polar-coordinate graph, the area that represents minimum or 0 radiation.

OMNIDIRECTIONAL—Transmitting in all directions.

OPAQUE—A type of substance that does not transmit any light rays.

OPEN-ENDED LINE—A transmission line that has an infinitely large terminating impedance.

OPTIMUM WORKING FREQUENCY—The most practical operating frequency that can be used with the least amount of problems; roughly 85 percent of the maximum usable frequency.

ORIGIN—The point on a graph where the vertical and horizontal axes cross each other.

OUTPUT END—The end of a transmission line that is opposite the source.

OUTPUT IMPEDANCE—The impedance presented to the load by the transmission line and its source.

PARALLEL RESONANT CIRCUIT—A circuit that acts as a high impedance at resonance.

PARALLEL-WIRE—A type of transmission line consisting of two parallel wires.

PARASITIC ARRAY—An array that has one or more parasitic elements.

PARASITIC ELEMENT—The passive element of an antenna array that is connected to neither the transmission line nor the driven element.

PERIOD—The amount of time required for completion of one full cycle.

PITCH—A term used to describe the frequency of a sound heard by the human ear.

PLANE OF POLARIZATION—The plane (vertical or horizontal) with respect to the earth in which the E field propagates.

POINT OF ZERO DISPLACEMENT—See REFERENCE LINE.

POLAR-COORDINATE GRAPH—A graph whose axes consist of a series of circles with a common center and a rotating radius extending from the center of the concentric circles.

POSITIVE ALTERNATION—The portion of a sine wave above the reference line.

POWER LOSS—The heat loss in a conductor as current flows through it.

POWER STANDING-WAVE RATIO (PSWR)—The ratio of the square of the maximum and minimum voltages of a transmission line.

PRIMARY COLORS (OF LIGHT)—The three primary colors of light (red, green, and blue), from which all other colors may be derived.

PRISM—A triangular-shaped glass that refracts and disperses light waves into component wavelengths.

PROPAGATION—Waves traveling through a medium.

QUALITY (OF SOUND)—The factor that distinguishes tones of pitch and loudness.

QUARTER-WAVE ANTENNA—Same as the Marconi antenna.

RADIATION FIELD—The electromagnetic field that detaches itself from an antenna and travels through space.

RADIATION LOSSES—The losses that occur when magnetic lines of force about a conductor are projected into space as radiation and are not returned to the conductor as the cycle alternates.

RADIATION PATTERN—A plot of the radiated energy from an antenna.

RADIATION RESISTANCE—The resistance, which if inserted in place of an antenna, would consume the same amount of power as that radiated by the antenna.

RADIO FREQUENCIES—Electromagnetic frequencies that fall between 3 kilohertz and 300 gigahertz and are used for radio communications.

RADIO HORIZON—The boundary beyond the natural horizon in which radio waves cannot be propagated over the earth's surface.

RADIO WAVE—(1) A form of radiant energy that can neither be seen nor felt. (2) An electromagnetic wave generated by a transmitter.

RAREFIED WAVE—A longitudinal wave that has been expanded or rarefied (made less dense) as it moves away from the source.

RECEIVER—The object that responds to a wave or disturbance. Same as detector.

RECEIVING ANTENNA—The device used to pick up an rf signal from space.

RECEIVING END—See OUTPUT END.

RECIPROCITY—The property of interchangeability of the same antenna for transmitting and receiving.

RECTANGULAR-COORDINATE GRAPH—A graph in which straight-line axes (horizontal and vertical) are perpendicular.

REFERENCE LINE—The position a particle of matter would occupy if it were not disturbed by wave motion.

REFLECTED WAVE—(1) The wave that reflects back from a medium. (2) Waves traveling from the load back to the generator on a transmission line. (3) The wave moving back to the sending end of a transmission line after reflection has occurred.

REFLECTION WAVES—Waves that are neither transmitted nor absorbed, but are reflected from the surface of the medium they encounter.

REFLECTOR—The parasitic element of an array that causes maximum energy radiation in a direction toward the driven element.

REFRACTION—The changing of direction as a wave leaves one medium and enters another medium of a different density.

RERADIATION—The reception and retransmission of radio waves caused by turbulence in the troposphere.

RESONANCE—The condition produced when the frequency of vibrations are the same as the natural frequency (of a cavity). The vibrations reinforce each other.

RESONANT LINE—A transmission line that has standing waves of current and voltage.

REST POSITION—See REFERENCE LINE.

REVERBERATION—The multiple reflections of sound waves.

RHOMBIC ANTENNA—A diamond-shaped antenna used widely for long-distance, high-frequency transmission and reception.

RIGID COAXIAL LINE—A coxial line consisting of a central, insulated wire (inner conductor) mounted inside a tubular outer conductor.

SCATTER ANGLE—The angle at which the receiving antenna must be aimed to capture the scattered energy of tropospheric scatter.

SELF-INDUCTION—The phenomenon caused by the expanding and collapsing fields of an electron which encircles other electrons and retards the movement of the encircled electrons.

SELF-LUMINOUS BODIES—Objects that produce their own light.

SENDING END—See INPUT END.

SERIES RESONANT CIRCUIT—A circuit that acts as a low impedance at resonance.

SHIELDED PAIR—A line consisting of parallel conductors separated from each other and surrounded by a solid dielectric.

SHORT-CIRCUITED LINE—A transmission line that has a terminating impedance equal to 0.

SINK—See OUTPUT END.

SKIN EFFECT—The flow of ac current near the surface of a conductor at rf frequencies.

SKIP DISTANCE—The distance from a transmitter to the point where the sky wave is first returned to earth.

SKIP ZONE—A zone of silence between the point where the ground wave becomes too weak for reception and the point where the sky wave is first returned to earth.

SKY WAVES—Radio waves reflected back to earth from the ionosphere.

SONIC—Pertaining to sounds capable of being heard by the human ear.

SOURCE—(1) The object that produces waves or disturbance. (2) The name given to the end of a two-wire transmission line that is connected to a source.

SPACE DIVERSITY—Reception of radio waves by two or more antennas spaced some distance apart.

SPACE WAVE—A radio wave that travels directly from the transmitter to the receiver and remains in the troposphere.

SPECTRUM—(1) The entire range of electromagnetic waves. (2) VISIBLE. The range of electromagnetic waves that stimulate the sense of sight. (3) ELECTROMAGNETIC. The entire range of electromagnetic waves arranged in order of their frequencies.

SPORADIC E LAYER—Irregular cloud-like patches of unusually high ionization. Often forms at heights near the normal E layer.

SPREADER—Insulator used with transmission lines and antennas to keep the parallel wires separated.

STANDING WAVE—The distribution of voltage and current formed by the incident and reflected waves which have minimum and maximum points on a resultant wave that appears to stand still.

STANDING-WAVE RATIO (SWR)—The ratio of the maximum (voltage, current) to the minimum (voltage, current) of a transmission line. Measures the perfection of the termination of the line.

STRATOSPHERE—Located between the troposphere and the ionosphere. Has little effect on radio waves.

STUB—Short section of a transmission line used to match the impedance of a transmission line to an antenna. Can also be used to produce desired phase relationships between connected elements of an antenna.

SUDDEN IONOSPHERIC DISTURBANCE—An irregular ionospheric disturbance that can totally blank out hf radio communications.

SUPERSONIC—Speed greater than the speed of sound.

SURFACE WAVE—A radio wave that travels along the contours of the earth, thereby being highly attenuated.

TEMPERATURE INVERSION—The condition in which warm air is formed above a layer of cool air that is near the earth's surface.

THREE-ELEMENT ARRAY—An array with two parasitic elements (reflector and director) and a driven element.

TONES—Musical sounds.

TRANSLUCENT—A type of substance, such as frosted glass, through which some light rays can pass but through which objects cannot be seen clearly.

TRANSMISSION LINE—A device designed to guide electrical energy from one point to another.

TRANSMITTING ANTENNA—The device used to send the transmitted signal energy into space.

TRANSPARENT—A type of substance, such as glass, that transmits almost all of the light waves that fall upon it.

TRANSMISSION MEDIUMS—The various types of lines and waveguides used as transmission lines.

TRANSMITTER END—See INPUT END.

TRANSVERSE WAVE MOTION—The up and down motion of a wave as the wave moves outward.

TROPOSPHERE—The portion of the atmosphere closest to the earth's surface, where all weather phenomena take place.

TROPOSPHERIC SCATTER—The propagation of radio waves in the troposphere by means of scatter.

TROUGH (BOTTOM)—The peak of the negative alternation (maximum value below the line).

TUNED LINE—Another name for the resonant line. This line uses tuning devices to eliminate the reactance and to transfer maximum power from the source to the line.

TURNSTILE ANTENNA—A type of antenna used in vhf communications that is omnidirectional and consists of two horizontal half-wave antennas mounted at right angles to each other in the same horizontal plane.

TWISTED PAIR—A line consisting of two insulated wires twisted together to form a flexible line without the use of spacers.

TWO-WIRE OPEN LINE—A parallel line consisting of two wires that are generally spaced from 2 to 6 inches apart by insulating spacers.

TWO-WIRE RIBBON (TWIN LEAD)—A parallel line similar to a two-wire open line except that uniform spacing is assured by embedding the two wires in a low-loss dielectric.

ULTRASONIC—Sounds above 20,000 hertz.

UNIDIRECTIONAL ARRAY—An array that radiates in only one general direction.

UNTUNED LINE—Another name for the flat or nonresonant line.

V ANTENNA—A bi-directional antenna, shaped like a V, which is widely used for communications.

VELOCITY—The rate at which a disturbance travels through a medium.

VERTICAL AXIS—On a graph, the straight line axis oriented from bottom to top.

VERTICAL PATTERN—The part of a radiation pattern that is radiated in the vertical plane.

VERTICALLY POLARIZED—Waves radiated with the E field component perpendicular to the earth's surface.

VOLTAGE-FEED METHOD—Same as END FEED METHOD.

VOLTAGE STANDING-WAVE RATIO (VSWR)—The ratio of maximum to minimum voltage of a transmission line.

WAVE ANTENNA—Same as BEVERAGE ANTENNA.

WAVE MOTION—A recurring disturbance advancing through space with or without the use of a physical medium.

WAVE TRAIN—A continuous series of waves with the same amplitude and wavelength.

WAVEFRONT—A small section of an expanding sphere of electromagnetic radiation, perpendicular to the direction of travel of the energy.

WAVEGUIDE—A hollow metal tube used as a transmission line to guide energy from one point to another.

WAVELENGTH—(1) The distance in space occupied by 1 cycle of a radio wave at any given instant. (2) The distance a disturbance travels during one period of vibration.

YAGI ANTENNA—A multielement parasitic array. Elements lie in the same plane as those of the end-fire array.

MODULE 10 INDEX