BEHAVIOR OF RADIO WAVES AND RECEIVING ANTENNAS

33FR-2

NATIONAL RADIO INSTITUTE
ESTABLISHED 1914
WASHINGTON, D. C.

STUDY SCHEDULE No. 33

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions specified for that step. Study each other step in this same way.

1. Introduction; Radio Waves; Radiation Patterns of Transmitting Antennas; Vertical and Horizontal Polarization . . . . Pages 1-6

   Components of a Radio Wave; How Radio Waves Are Produced; Wavelength; Wavelength of an Antenna; Frequency-Wavelength Relationship; Field Intensity Surveys; How Radiation Patterns Are Secured; Action of a Receiving Antenna; Polarization of Radio Waves. Answer Lesson Questions 1, 2 and 3.

2. The Ground Wave; Television Receiving Antenna Problems; Sky Waves; The Kennelly-Heaviside Layer; Peculiarities of Sky Wave Reception . . . . Pages 6-13

   Facts about ground waves; vertical and horizontal receiving antennas; multiple paths of television signals; Beam Characteristics of Ultra-High-Frequency Waves; the Kennelly-Heaviside Layer; Refraction of Radio Waves; Progressive Refraction; E, F_1 and F_2 Layers; Long-Distance Reception; Polarization of Sky Waves; Fading; Skip Distance; Selective Attenuation. Answer Lesson Questions 4 and 5.

3. Receiving Antenna Problems; Directivity of Receiving Antennas . . . . Pages 13-18

   Three factors in selecting and installing a receiving antenna; four factors affecting directional characteristics of receiving antennas; Current and Voltage Distribution of Half-Wave Doublet Antennas; Current and Voltage Distribution of Grounded Vertical Antennas; Directional Characteristics; Radiation Patterns for Receiving Antennas; summary of receiving antenna installation rules. Answer Lesson Questions 6 and 7.

4. Coupling the Antenna to the Receiver; Transmission lines; Noise Reduction . . . . Pages 18-24

   Signal-transferring problems; Voltage Feed For a Doublet Antenna; Current Feed; Antenna Resistance and Impedance; Surge Impedance of Transmission Lines; Typical Surge Impedance Values; noise problems; how noise-reducing antenna systems work; Noise-Reducing Loop Antenna. Answer Lesson Questions 8, 9 and 10.

5. All-Wave Antennas; Variable-Directivity Antennas . . . . Pages 24-29

   Types of All-Wave Antennas Commonly Used; Multiple Doublet Antennas; Single All-Wave Doublets; Use of Counterpoise for Noise Reduction; antennas with controllable directional characteristics.

6. Mail your Answers for this Lesson to N.R.I. for Grading.

7. Start Studying the Next Lesson.

FM8M149 1949 Edition Printed in U.S.A.

Behavior of Radio Waves and Receiving Antennas

Introduction

THE extremely high sensitivity of modern radio receivers has made many servicemen somewhat careless with the installation of receiving antennas. In addition to feeding strong signals from desired stations into a receiver, a good receiving antenna must also have a ***high signal-to-noise ratio,*** if station programs are to be heard with a minimum of interfering noises. The introduction and rapid acceptance of all-wave receivers brought added responsibilities to the serviceman, along with puzzling questions concerning the peculiarities of radio waves at various frequencies.

In order to answer these highly practical questions and solve the receiving antenna problems which occur in service work, you must first understand what radio waves are, how they behave, how a receiving antenna can be made to intercept a maximum of radiated energy, and how intercepted signals can be fed to a receiver with highest possible efficiency. All this information will be given you in this lesson.

Radio Waves

Components of a Radio Wave. Whenever electrons flow through a conductor, *both an electric field and a magnetic field will always be produced.* (Of course, either field can exist by itself if no electron motion is involved; an electric field exists alone between two electrically charged bodies, while a magnetic field exists around a permanent magnet.) Furthermore, whenever electrons *change* their speed of travel through a conductor or oscillate back and forth, the result is a *moving* electric field and a *moving* magnetic field which together are known as an *electromagnetic field.* If the electrons are oscillating back and forth at a high enough rate (at a high frequency), the electromagnetic field will travel off into space at the speed of light (186,000 miles per second), giving what is known as an *electromagnetic wave* or a *radio wave.* A radio wave, therefore, has two components: *1. The electric field component; 2. The magnetic field component.*

How Radio Waves Are Produced. A study of the fields in the vicinity of a typical transmitting antenna such as that shown in Fig. *1A* will give you a good idea of how radio waves are radiated into space. This is a *doublet antenna,* for it is broken at its center and the two sections are fed with an oscillating electron flow produced by a radio transmitter; it is also known as a *di-pole antenna.** Suppose that the transmitter polarity at one instant of time is as indicated in Fig. *1A;* electron flow will then be in the directions indicated by arrows *i,* making the upper end of the doublet negative and the lower end positive. We can consider the circuit between the two halves of the antenna to be completed through space, for

---

*Although you will find the terms "doublet antenna" and "di-pole antenna" used interchangeably in many cases, the following definitions are accepted by most radio engineers: *A doublet antenna* is fed at its center, and its two sections are essentially equal in length and are in the same straight line; a doublet antenna may or may not be at resonance for the frequency of the signal fed to it. *A di-pole antenna* is to the radio physicist a theoretically perfect antenna having uniform current throughout its length and with ends having opposite polarity; to the practical radio man a di-pole antenna has *essentially* uniform current throughout its length, is *not* at resonance with the signal frequency fed to it, has ends with opposite polarity, and may be fed anywhere along its length.

these halves form a condenser having the surrounding air as a dielectric. A *displacement current* (the equivalent of an electron movement) flows from the negative half of the antenna through space to the positive half.

To simplify our study, we can neglect the transmitter connection and consider this antenna as a single length of wire in space, having the polarity shown in Fig. *1B* when electron flow *i* is upward as indicated; this antenna wire can be thought of as a source which is feeding power into space. The polarity will reverse from instant to instant of time in step with reversals in electron flow through the wire.

When electron flow through a doublet antenna is in the direction shown in Fig. *1B*, a *magnetic* field will encircle the wire and will act in the direction shown in Fig. *1C;* this magnetic field is usually designated by the letter *H*. At the same time an electric field having the direction shown in Fig. *1D* will be set up in space by the oppositely charged halves of the antenna; this electric field is usually designated by the letter *E*. At any point in space, the electric and magnetic fields (*E* and *H*) produced by an energized antenna *will always be at right angles to each other.*

A continuously oscillating (alternating) electron flow in a doublet antenna produces in the vicinity of the antenna an electromagnetic field; the relative intensities of the electric and magnetic components of this field at various distances away from the antenna at one instant of time are shown in Fig. *1E*. At point *1,* for example, there is an electric field component E_1 which is acting upward parallel to the antenna (in the plane of this page), and a magnetic field component H_1 which is at right angles to the electric field (towards you, at right angles to this page). The arrow lines E_1 and H_1 are intended to show the relative strengths of the electric and magnetic fields at point *1,* and the directions in which these fields act; these arrow lines *do not* represent the paths of electric and magnetic fields, for these paths are shown in Figs. *1C* and *1D*. Each other point in Fig. *1E,* such as *2, 3, 4, 5, 6, 7* and *8,* will likewise have its electromagnetic field with an electric component *E* and a magnetic component *H;* note that between points *4* and *8* there is a reversal in the directions of the components, with *E* now acting downward in the plane of the paper and *H* acting away from you perpendicular to the paper. The electromagnetic field is traveling away from the transmitting antenna in all directions, at the speed of light; both the electric and the magnetic components of this field are always acting *at right angles to this direction of travel.*

A portion of the electromagnetic field produced by a transmitting antenna acts as if it were permanently associated with the antenna and were staying in its immediate vicinity; this portion is known as the *induction field.* The other part of the electromagnetic field, known as the *radiation field,* the *electromagnetic wave* or the *radio wave,* breaks away from the antenna and travels outward through space. Insofar as energy is concerned, the *E* and *H* components of the radiation field or radio wave are always equal to each other at a distance from a transmitting antenna (in the region of the radiation field); close to the antenna, in the region of the induction field, the *E* component may be considerably greater than the *H* component. We will consider only the radiation field (radio wave) for the remainder of this lesson unless otherwise indicated, since the induction field ordinarily exists only for a few hundred feet away from the antenna.

Wavelength. During the time required for one complete cycle of the alternating current flowing through the

antenna in Fig. *1E*, the electromagnetic wave will travel from point *0* to point *8*, and both the electric field *E* and the magnetic field *H* at any point will also go through one complete sine wave cycle. The distance between point *0* and *8* is known as *one wavelength.*

When engineers study radio waves in space, they ordinarily consider only one component (usually the electric field component *E*), and consequently they think of a radio wave as having the simple sine wave form shown in Fig. *1F*. The distance between the extremities of one complete cycle of this wave is therefore one wavelength. Fractions of a cycle are called fractions of a wavelength; half a cycle is thus half a wavelength or simply a half-wave, and 1½ cycles are 1½ wavelengths or 3/2 waves.

The next important fact for you to recognize is that *a wavelength is a different value* (in feet or in meters) *at each frequency*. Doubling the frequency means that we get twice as many alternations or cycles of the radio wave into a given distance, and each cycle or wave will therefore be only one-half as long; Fig. *1G* illustrates this clearly. The higher the frequency of a radio wave, the shorter will be the length of one complete wave or cycle.

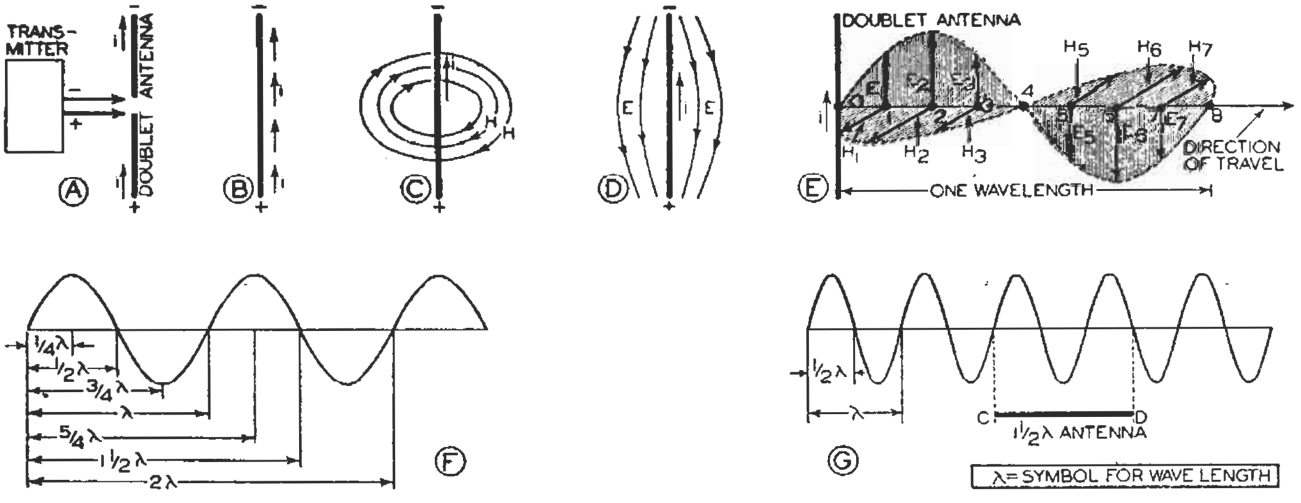


FIG. 1. These diagrams show the first steps in the formation of a radio wave by a simple doublet antenna which is fed by a transmitter. Electron flow *i* through the antenna wire in the direction shown produces a magnetic field *H* and an electric field *E*, both of which travel away from the antenna at the speed of light.

Wavelength of an Antenna. The characteristics of a receiving antenna depend to a great extent upon its length with respect to the wavelength of the signal being picked up. For this reason, it is common practice to describe an antenna as being "so many" wavelengths long for a particular signal frequency. When a radio signal produces a half-sine-wave distribution of current along a receiving antenna, we know that the antenna is half as long as one wavelength of that particular signal, and we say that the antenna is *one-half wavelength long.*

We could easily determine the wavelength of an antenna at a particular frequency by drawing the radio wave and the antenna on the same line at the same scale, and simply counting the number of cycles covered by the antenna. Figure *1G* illustrates this; line *CD*, which represents an antenna drawn to scale, covers 1½ cycles and consequently we have a 3/2-wave antenna at this particular signal frequency. It is generally more convenient to figure out this information than to secure it graphically, however; simply divide the length of the antenna by the wavelength of the signal (using the same units of length), and the result will be the wavelength of the antenna

Example: Antenna length is 100 feet;

signal wavelength is 200 feet; 100 ÷ 200 = ½, and consequently we have a half-wave antenna in this example.

*Frequency - **Wavelength** Relationship.* Oftentimes the frequency of a radio wave rather than the wavelength is known. The preceding section indicates that there is a definite relationship between frequency and wavelength; this relationship is based upon the fact that an electromagnetic wave *in space* always travels at the same speed, approximately 300,000,000 meters per second or 186,000 miles per second (this is also the speed at which light travels through space). The following formula gives the relationship between the speed, frequency and wavelength of a radio wave in space:

Wavelength in meters multiplied by frequency in cycles per second always equals 300,000,000.*

Figure *1E* shows only one of the many possible paths for radio waves away from the antenna. There will be many other paths in all directions. When a radio wave travels along the ground directly to the receiving antenna, it is known as a *ground wave.* When a radio wave travels up into the sky and is then bent back to the receiving antenna, it is known as a *sky wave.* Both the ground wave and the sky wave must be considered when studying problems involving the transmission and reception of radio signals.

Radiation Patterns of Transmitting Antennas

It is a well-known fact that radio stations which are intended to serve a local area, such as broadcast band stations in this country, use antennas which radiate signals having maximum intensity *along the ground.* Stations which must send messages or programs to far-distant receiving points use antennas which direct radio waves skyward, for it is now known that there is a layer in the upper atmosphere which will bend the sky wave back to earth again at a point considerably distant from the station. Commercial short-wave stations in transoceanic use, amateur radio stations, and short-wave stations which transmit entertainment programs to far-distant countries all use antennas which are carefully designed to produce the strongest possible sky wave.

Field Intensity Surveys. Careful measurements must be made of the amount of energy radiated in each direction (north, south, east and west) from a transmitting station in order tc determine whether an antenna is giving adequate coverage of the desired local service area or is radiating satisfactory signals to desired distant points, as the case may be. It is customary to measure the energy in the electrical component *E* of the radio wave; the results are expressed in terms of microvolts per meter, millivolts per meter or volts per meter, with these units expressing the voltage existing between two points which are exactly one meter apart in space at the location where the signal intensity is measured. These field intensity units also correspond to the voltage which would be measured between the ends

---

*When dealing with antennas it is usually more convenient to speak in terms of wavelength than frequency. If either the frequency or the wavelength of a radio wave is known, you can easily determine the missing value. It is common practice to let f represent frequency *in cycles per second* and λ (Greek letter lambda) represent wavelength *in meters;* the above formula then becomes $\lambda \times f = 300{,}000{,}000$.

To find frequency when wavelength is known, use this variation: $f = 300{,}000{,}000 \div \lambda$. Example: If wavelength is 5 meters, what is the frequency? Answer: $f = 300{,}000{,}000 \div 5 = 60{,}000{,}000$ cycles or 60 megacycles.

To find wavelength when frequency is known, use this variation: $\lambda = 300{,}000{,}000 \div f$. Example: If frequency is 1,500 kc., what is the wavelength? Answer $\lambda = 300{,}000{,}000 \div 1{,}500{,}000$, or 200 meters.

To get wavelength in feet, multiply the wavelength in meters by 3.28 (roughly 3¼).

of a true di-pole antenna exactly one meter long, erected at the receiving location being checked. Measurements are usually made with a loop receiving antenna, and the readings are converted by means of higher mathematics to equivalent values for a true di-pole antenna. The final values are plotted on a graph to give what is known as the *radiation pattern* of a transmitting antenna.

How Radiation Patterns Are Secured. If an engineer wants to know how well the ground wave is getting out in various directions from a broadcast station antenna, he might take suitable field intensity measuring equipment first to a position P_1, which is two miles due east of the antenna, place his pick-up antenna at the angle and direction which give maximum signal, and make the first measurement; he could then travel in a two-mile-radius circle around the antenna and make measurements at positions P_2, P_3, P_4, etc., in Fig. *2A*, which are NE, N, NW, W, etc., from the antenna along this circle (any other convenient radius could just as well be used).

An alternative procedure involves selecting convenient positions each two miles away, regardless of their direction from the transmitting antenna, and measuring the angle θ (see Fig. *2A*) between a line to the antenna and a line running due east from the antenna. After measurements have been made for a sufficient number of points, the engineer draws a diagram similar to that in Fig. *2A*, with radial lines running from the antenna location to each point at which a measurement was made. Along line A-P_1, starting from A, he plots the signal intensity measured at point P_1, using any convenient scale (he might let one inch represent 10 millivolts per meter). The length of line AE_1 then represents the field intensity measured at point P_1, two miles due east of the antenna. The same procedure is repeated for each other radial line, and a smooth curve is drawn through the various points. This curve is the *horizontal radiation pattern;* it indicates the approximate signal intensity in millivolts per meter which can be expected at a point two miles from the transmitting antenna at any angle with the due east line, eliminating the need for making measurements at all angles. The particular pattern shown in Fig. *2A* indicates that practically no energy is being radiated along the ground in the NW, W and SW directions, and that almost uniform energy is being radiated in the N, NE, E, SE, and S directions.

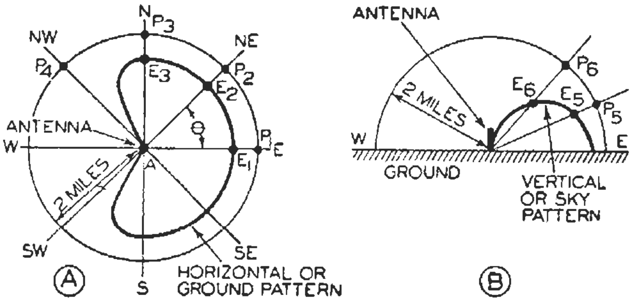


FIG. 2. Horizontal and vertical radiation patterns for a directional transmitting antenna.

Similar information concerning sky wave radiation can be obtained by making measurements from an airplane or blimp. An example of a pattern secured for a flight due east and west over an antenna is shown in Fig. *2B*. This radiation pattern indicates that signal intensity is a maximum along the ground, but that considerable energy is being radiated into the sky in the form of a sky wave.

Vertical and Horizontal Polarization

Action of a Receiving Antenna. A short straight antenna will pick up a maximum signal when it is *parallel* to the electric lines of force associated with a radio wave, as indicated in Fig. *3A*. Free electrons in the antenna wire move back and forth along the wire in step with changes in the direction and intensity of the electric lines of force, with the result that an alternating current is sent down to the receiver. When the antenna is at right angles to the electric lines of force, the electrons will oscillate from side to side across the wire, and no current will flow to the receiver.

You can also visualize the action of a receiving antenna by considering the magnetic lines of force, which are at right angles to the antenna. These magnetic lines, moving through space at the speed of light, cut across the receiving antenna and induce in it a radio frequency voltage which is proportional to the number of lines which cut the antenna per unit of time. This voltage in turn forces a current down the antenna lead-in wire to the receiver.

Polarization of Radio Waves. When the electric lines of force associated with a radio wave are perpendicular to the ground, as indicated in Fig. *3B*, they are said to be *vertically polarized.* When the electric lines of force associated with a radio wave are parallel to the ground, as indicated in Fig. *3C*, they are said to be *horizontally polarized.* The magnetic lines of force associated with a radio wave are also polarized, but we can neglect them when considering the effectiveness of various receiving antennas.

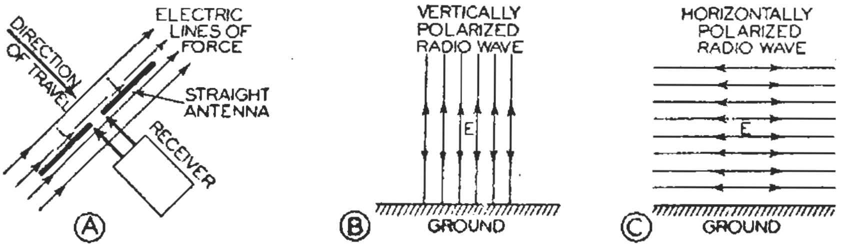


FIG. 3. The electric field E associated with a radio wave may have any angle whatsoever with respect to ground when it arrives at a receiving antenna, and this angle will have an important effect upon signal pick-up by a given antenna. When E is perpendicular to the ground, we say that the radio wave is vertically polarized; when E is parallel to the ground, the radio wave is horizontally polarized.

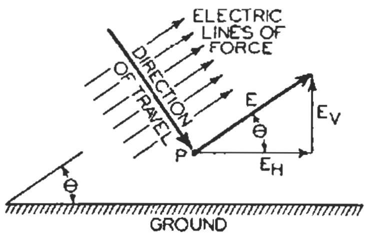


FIG. 4. An electric field arriving at the angle θ to ground may be considered equal to a vertically polarized component E_V acting with a horizontally polarized component E_H.

The electric lines of force associated with a sky wave seldom have perfect vertical or horizontal polarization; they are usually at an angle with the ground, somewhat as shown in Fig. *4*. Here the radio wave is traveling toward the ground after reflection from the sky. The intensity and direction of the electric field at point *P* (above the ground on this path of travel) can be represented by the arrow line *E*. This arrow line can be considered to have two components; a vertical component E_V and a horizontal component E_H, as shown in Fig. *4*. To secure a maximum signal at location *P*, you would have to place a straight doublet antenna in the direction indicated by *E*. A vertical antenna would only pick up a signal corresponding to the length of E_V, and a horizontal antenna would in this case give but slightly more signal pick-up corresponding to the length of E_H.

The Ground Wave

The transmitting antennas used by broadcast stations for local coverage are generally of the vertical type, for these can be designed to radiate considerable energy along the ground and at the same time keep the sky wave at a low enough intensity to avoid interference betwen ground and sky waves within the service area of the station. The electric lines of force produced by an energized vertical antenna are essentially parallel to the antenna when near the surface of the earth, and hence are very nearly vertically polarized. We might conclude that for maximum signal pick-up at the receiving location, the receiving antenna should be of the vertical type, but we know that the majority of receiving antennas are actually horizontal.

There are several reasons why a

horizontal antenna is more satisfactory for receiving purposes. First of all, high vertical antennas are expensive and difficult to erect, making them unsuited for the average home. Secondly, electric lines of force bend forward as they move away from the antenna, as indicated in Fig. *5B*, due to the presence of the ground; one engineer describes this phenomenon by saying "the radio waves are pushed forward with their feet dragging on the ground." Another reason is this: Radio waves which travel over hilly or mountainous country or near tall steel buildings are reflected enough to change their angle of polarization and their direction of travel. At a reasonably distant receiving location such as that shown in Fig. *5A*, there is invariably a large enough horizontal component E_H (Fig. *5B*) to excite a horizontal antenna.

There is still another good reason for making receiving antennas horizontal. Electrical devices which cause man-made interference produce far more vertically polarized electric lines of force than horizontally polarized lines, and since these interference-producing devices are close to the receiver location, they would induce strong signals in a vertical receiving antenna. A horizontal antenna picks up a minimum of noise signals and still intercepts enough of the signal from a local transmitting antenna to give a satisfactorily high signal-to-noise ratio. In most cases, a horizontal antenna gives better reception of sky waves than does a vertical antenna.

Ground waves radiated by either a broadcast or short-wave station will follow the earth until they are totally absorbed or are too weak to affect receiving antennas. Only by increasing the amount of power radiated by the transmitting antenna can stronger ground waves and more distant reception of ground waves be secured. All reception at points outside the range of ground waves will be due to sky waves reflected back to earth by a layer in the upper atmosphere. These sky waves are absorbed very little by the atmosphere, and consequently will often be reflected back to points thousands of miles away from the station with surprisingly high signal strength.

Television Receiving Antenna Problems

At the carrier frequencies used in modern television systems, automobile ignition systems and electrical devices having sparking contacts can cause considerable interference. It is highly desirable to use a horizontal receiving antenna in order to keep out these vertically polarized interference signals. Television transmitting antennas are usually designed to radiate horizontally polarized radio waves, for these will be picked up with maximum efficiency by a horizontal receiving antenna and will therefore give a maximum signal-to-noise ratio.

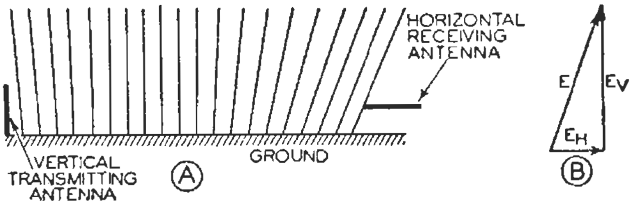


FIG. 5. Vertically polarized electric lines of force produced by a vertical transmitting antenna gradually change their angle with the ground as they travel away from the antenna.

Television signals may reach a receiving antenna in a city location over two or more different paths. This multiple transmission effect is due to reflection of waves from buildings, bridges and other steel structures, and may give two or more images superimposed on each other due to slight differences in the times of arrival of the signals over the various paths. This secondary or ghost image effect can be minimized by erecting the horizontal doublet receiving antenna as high as possible and in a direction which gives maximum reception of either the direct wave or the reflected wave, but not both. When there are two television stations in a locality, a doublet antenna must necessarily be in a position which gives a satisfactory compromise between signals arriving from the two directions. An alternative procedure involves the use of two doublets at right angles to each other and crossed at their centers, with the system oriented to give best possible pick-up from both stations.

Beam Characteristics of Ultra-High-Frequency Waves. Ultra-high-frequency (u.h.f.) radio waves such as are used in modern television systems are above 40 megacycles. These u.h.f. waves behave like beams of light, in that they travel in essentially straight lines from the transmitting antenna. This means that if the transmitting antenna is not visible from the top of the receiving antenna on a clear day, signals will in all probability not be received. With antennas at ordinary heights on level ground, the curvature of the earth definitely restricts the coverage of a given station. This is illustrated in exaggerated form in Fig. *6A;* increasing the distance between the two antennas would make the radio waves pass over the top of the receiving antenna without affecting it, for these u.h.f. waves cannot bend around the earth. Television broadcasts from the tower of the highest building in the world, the Empire State Building in New York City, can normally be picked up only within a radius of about sixty miles of the transmitting station. Occasionally, reception at greater distances is possible because of a peculiar distribution of moisture in the air which bends ultra-high-frequency sky waves back to the earth at more distant locations. In Fig. *6B,* for example, reception of signals over the direct path marked P_1 would be blocked by the earth, but under certain conditions the sky waves might be bent back to the lower atmosphere, taking path P_2 to the receiving antenna. In general, however, sky wave reception at ultra-high frequencies is unreliable.

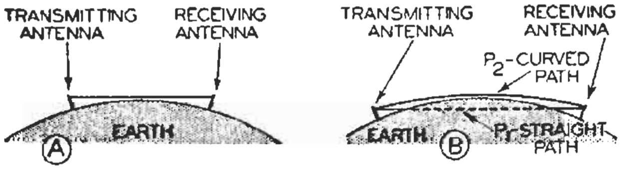


FIG. 6. Radio waves at ultra-high frequencies travel in essentially straight lines, limiting the reliable range of reception of television programs to line-of-sight distances.

Sky Waves;
The Kennelly-Heaviside Layer

Before Marconi in 1901 succeeded in transmitting a radio message from England to the North American Continent, scientists generally believed that all radio reception was by means of ground waves, and that long-distance transmission was impossible because of the absorption of energy by the ground. The success of Marconi proved this theory false, and many new theories were advanced to explain the amazing long-distance transmission of signals. Kennelly in America and Heaviside in England simultaneously presented the explanation that there are electron layers in the sky which act like any conductive layer in reflecting and bending electromagnetic waves. These theories have been proved correct, and today we speak of this wave-bending layer in the atmosphere as the Kennelly-Heaviside layer. The reason for the existence of this layer is usually explained in the following manner: The surface of the earth is surrounded by air, which thins out (becomes rarefied) away from the earth. Under the action of ultra-violet rays of light from the sun, this rarefied air becomes ionized, with the result that a layer made up of free electrons, positive ions and negative ions is formed high above the earth.

A radio wave passing into the Kennelly-Heaviside layer will impart some of its energy to the free electrons in the layer, setting them into vibration. The velocity of vibration will be the least at the highest frequencies, for even an electron has a certain amount of mass which prevents large amplitudes of vibration at high frequencies. The mass of the electron makes it act as a reactance, so its velocity is 90° out of phase with the velocity of the radio wave. The oscillating electrons in the layer produce a new radio wave which acts with the original wave. This combining of velocities which are 90° out of phase results in an apparent speeding up of the radio wave when it hits the electron layer.

Radio waves at low radio frequencies cause the electrons in the layer to vibrate with great amplitude. These electrons collide with air particles, giving up their energy and liberating ions and more electrons. In this way a portion of the energy in the original radio wave is lost in the Kennelly-Heaviside layer; the loss may amount to as much as 30% and occurs chiefly at the lower levels, where there are more ions of air to absorb energy.

Refraction of Radio Waves. Let us assume that the Kennelly-Heaviside layer has a uniform distribution of electrons and that the electric lines of force associated with a radio wave are moving toward it at the angle shown in Fig. *7A*. As the radio wave enters the layer, portion *y* encounters electrons first and speeds up. The result is a bending of the electric lines of force and of the radio wave path itself; this bending of the path of travel is always down toward the earth. Scientists refer to this phenomenon as *refraction* rather than as bending.

Progressive Refraction. The electron density (number of electrons per unit volume) in the Kennelly-Heaviside layer is greater in the upper regions than in the lower regions. We would naturally expect this, since the upper portion of the layer is closer to the sun and is consequently subject to greater ionization. A radio wave entering the Kennelly-Heaviside layer at an angle encounters regions of increasingly greater electron density, and consequently undergoes increasingly greater refraction or bending; this phenomenon is known as *progressive refraction.* It is quite possible for the bending to progress to the point where the radio wave travels horizontally with respect to the earth, then actually bends back toward the earth in the manner shown in Fig. *7B*.

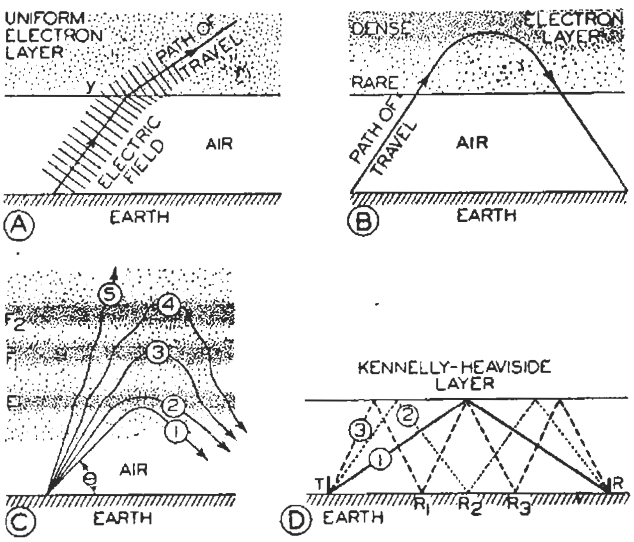


FIG. 7. These diagrams show how sky waves can be refracted (bent) back toward the earth by the Kennelly-Heaviside layer in the upper atmosphere.

E, F_1 and F_2 Layers. Actually, the Kennelly-Heaviside layer is not as simple as is shown in Fig. *7B*. The action of the sun upon the upper atmosphere is such as to produce three separate layers, one above the other. If we were able to measure electron densities, starting from the earth and going vertically upward, we would find that for the first thirty to forty-five miles there would be a negligible number of electrons. Continuing upward, the electron density would increase to the first maximum value at a height of about sixty miles, then gradually decrease. Higher up still, electron density would increase again and reach another maximum at about 125 miles. Farther up we would pass through another region of gradually decreasing and then increasing electron density until we reached the third and final maximum-density level at about two hundred miles up. Above this level the electron density decreases to a negligible value, for at this height in the stratosphere there is almost a total vacuum, and little ionization can occur. These three maximum-density layers are known as the E, F_1 and F_2 layers respectively.

The E layer is nearest the earth and is fairly constant in height; the F_2 layer is highest and may vary in height from 150 miles to 225 miles. This highest layer is most affected by the sun and hence it varies greatly in height and electron density from day to night, from summer to winter, and with conditions on the sun such as sun spots (solar eruptions). The F_2 layer also varies with latitude, and may be higher or lower around the equator than it is in the north temperate zone or at either pole. Oftentimes the F_1 (middle layer) and F_2 layers will merge to form what is called an F layer. Less often, the E layer will separate into two layers, with one being known as the normal E layer and the other as the *sporadic* E layer.

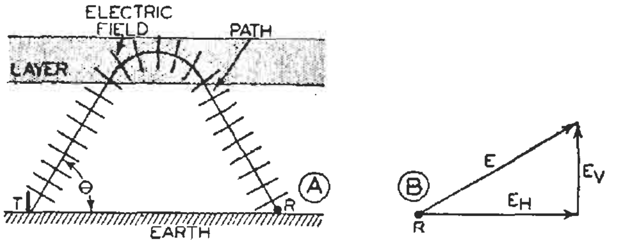


FIG. 8. Effect of the Kennelly-Heaviside layer upon the polarization of a sky wave.

A sky wave may be refracted back to earth by the lower portion of the E layer, as shown by path *1* in Fig. *7C;* on the other hand, it may be refracted by the upper part of the E layer as in path *2*, may pass completely through the E layer and be refracted by the F_1 and F_2 layers as shown by paths *3* and *4*, or may pass completely through all three layers as in path *5* and be lost in interplanetary space. As a rule, the longer wavelengths (broadcast band and longer wavelengths) are refracted by the E and F_1 layers, and shorter wavelengths are refracted by the F_1 and F_2 layers. The extremely short waves (ultra-high frequencies) pass through all three layers, and hence are not ordinarily received.

The angle θ in Fig. *7C* (the angle between the sky wave and the earth) has a vital effect upon the path taken by the sky wave; the greater this angle, the more chance there is for the wave to get through the E layer and be refracted by the higher layers. A sky wave radiated at a high angle will be bent back to earth closer to the transmitting station than a wave radiated at a low angle and refracted by a lower layer. This statement is illustrated in Fig. *7D;* radiation of the sky wave at the largest angle, along path ***3*, results in** reception at point R_1, which is near to station T. Radiation at a low angle, along path *1*, gives reception at point R, which is a considerable distance from the station. Of course, the ground wave will be received in the immediate vicinity of the station in all cases.

Long-Distance Reception. The Kennelly-Heaviside layer makes possible long-distance reception of signals from low-power radio stations, for this layer bends radio waves back to the earth at points far beyond the range of reliable ground wave reception. These sky waves will be reflected skyward again by the earth, and will oftentimes be refracted by the Kennelly-Heaviside layer and reflected by the earth one or more additional times. Each path from earth to sky and back again is called a *hop*. Signals from station T in Fig. *7D* may reach receiving point R in 1, 2 or 3 hops, as illustrated by paths *1*, *2* and *3* respectively in Fig. *7D*. As a rule, signals on the longer wavelengths are sent with fewer hops than those on the shorter wavelengths. The best wavelength to use for communication between two given points depends considerably upon the conditions in the electron layers. The number of hops is controlled by the angle at which the sky wave leaves the station; the ideal number of hops at any time depends upon conditions in the upper layers. Where reliable transmission is essential, the same message is oftentimes broadcast simultaneously on several different wavelengths, each reflecting from a different layer and giving a different number of hops.

Peculiarities of Sky Wave Reception

Polarization of Sky Waves. If we analyze the electric field produced at receiving point R by the sky wave from station T in Fig. *8A,* we find that it has a vertical component E_V and a horizontal component E_H, as shown in Fig. *8B.* When θ (the angle of radiation) is more than 45°, the E_H component will be the stronger, and a horizontal receiving antenna will give better signal pick-up than a vertical antenna. When a radio wave travels a long distance with a single refraction from the Kennelly-Heaviside layer, θ may be less than 45°; the vertical component of the electric field will then predominate, and a vertical antenna will give better signal pick-up provided there is no man-made interference near the receiver. When interference is present, a horizontal antenna is invariably more satisfactory, for the horizontal component E_H of a sky wave is usually strong enough to give a high signal-to-noise ratio.

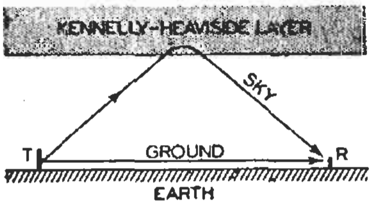


Fig. 9. This diagram shows why fading sometimes occurs within 50 miles of a broadcast station.

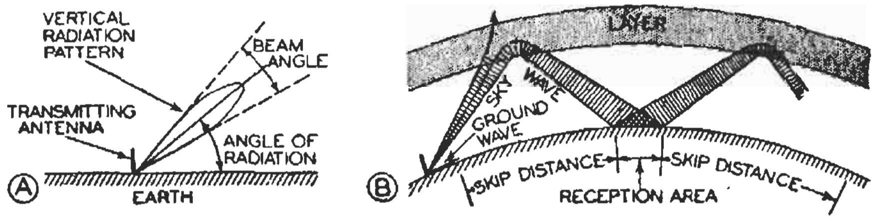


Fig. 10. Long-distance communication via short-wave radio depends entirely upon sky waves. The transmitter engineer chooses operating conditions which will make the sky wave come back to earth at the desired reception area.

For maximum signal pick-up with a doublet antenna at R in Fig. *8A,* the antenna wire should of course coincide with the electric lines of force nearest point R in this diagram; amateur and commercial antenna systems are sometimes tilted to take advantage of this fact, but for home entertainment purposes it is impractical and unnecessary to provide means for tilting the antenna to a new angle each time a new distant station is tuned in.

Fading. For signals below 3 megacycles in frequency, the sky wave is refracted and bent back to the ground almost immediately after its entrance into the lowest electron layer (the E layer). If there is an appreciable amount of high-angle radiation (sky waves) from the station, receiving antennas about fifty miles away from the station will pick up the ground wave directly and the sky wave after refraction, as indicated in Fig. *9.* The sky wave, traveling a considerably longer distance, may arrive *in phase with* the ground wave, in which case there is reinforcement and maximum signal pick-up; more likely, the two waves will be partially or completely *out of phase,* giving partial or complete cancellation of the signal. The phase relationship may vary from instant to instant, causing fading, for the Kennelly-Heaviside layer sometimes shifts up and down slightly. Briefly, then, sky waves cause fading at receiving locations near the limits of reliable ground wave reception from a given station because the phase relationship between the sky and ground waves changes continually due to refraction of the sky wave by the rapidly - shifting Kennelly - Heaviside layer, giving partial or complete cancellation of the ground wave.

If the shifts which cause fading occur in less than one-tenth of a second, the a.v.c. system in the average receiver will not be able to compensate for them and the variations in signal strength will be annoyingly noticeable at the receiver loudspeaker. Even when fading takes place at a slow rate, the automatic changes in receiver gain may result in noticeable alternate periods of clear and noisy reception.

Fading is generally less severe during the daytime. The Kennelly-Heaviside layer is then so dense that radio waves at broadcast band frequencies are almost completely absorbed as they enter the lower regions of the layer. Fading at distances of from 40 to 60 miles away from a broadcast station can be kept at a minimum by designing the transmitting antenna to radiate most of its energy along the ground; vertical antennas which are about ⅝ wavelength high are best suited for this purpose.

Skip Distance. At frequencies of from 3 to 30 megacycles, the sky wave is used almost exclusively for communication purposes. The transmitting antenna is in this case designed to radiate most of its signal into the sky, and may have a vertical radiation pattern like that in Fig. *10A*. Notice that maximum signal intensity occurs at a definite *angle of radiation* with the ground, and that radiation is concentrated over a definite angular distance which is known as the *beam angle*. There may be enough radiation along the ground in a case like this to provide adequate reception for distances of perhaps ten miles away from the station, but most of the energy is radiated into the sky, where it is either bent back to the earth or lost through absorption. This type of radiation pattern for a transmitting antenna provides reception over a more or less restricted area at a great distance away from the station; the distance and the area both depend upon the width of the beam, the angle of radiation, the frequency of transmission and upon conditions in the Kennelly-Heaviside layer. The distance between the maximum limit of ground wave reception and the closest point at which the sky wave returns to earth is commonly known as the *skip distance* (see Fig. *10B*). Different frequencies must be used for each distance covered, and frequency must be changed at night to compensate for the shift in the height of the electron layers and the resulting change in the skip distance, as each frequency is acted upon differently by the layers. As a general rule, high transmitting frequencies are best for daylight and lower frequencies are better for night transmission. Furthermore, radio transmission is better in winter than in summer, for in winter there is less absorption of signals by the electron layers.

Selective Attenuation. We must not overlook the fact that the transmission of voice and music is accomplished by sending a number of side-band frequencies along with an r.f. carrier. Each side frequency is acted upon by the Kennelly-Heaviside layer in a slightly different manner, and consequently the various frequencies may take various paths back to the earth or may be attenuated differing amounts. The result is that side frequencies in the received signal may have a different strength relationship to the carrier frequency than they had at the transmitting station, causing amplitude distortion in the demodulated audio signal; this cannot be corrected in the receiver. Since conditions in the Kennelly-Heaviside layer fluctuate quite rapidly, reception may be distorted severely at one moment and may become clear in the next instant, particularly when the receiver is located near the boundary between a skip area and a reception area.

Receiving Antenna Problems

Even though a transmitting station is designed to "lay down" a strong signal in a definite receiving area, part or all of this energy will be wasted unless the receiving antenna is properly designed. Three important factors are involved in the selection and installation of a receiving antenna:

1. That portion of the antenna which intercepts the electric and magnetic components of the radio wave must have *maximum possible signal pick-up.* This involves consideration of the directional properties of the antenna, the polarization of radio waves from favorite stations, and the frequency range over which signals are to be picked up.
2. The signal energy picked up by the antenna must be transferred to the receiver with a minimum of loss over the desired range of carrier frequencies. This involves matching the transmission line impedance to the impedance of the antenna and to the impedance of the receiver input, *to secure maximum transfer of energy from the antenna to the receiver.*
3. There should be a *maximum signal-to-noise ratio* at the receiver input. This is usually secured by designing the antenna system so it will accept a minimum of noise signals.

Directivity of Receiving Antennas

The directional characteristics of a receiving antenna system depend upon a number of important factors: 1. The current and voltage distribution along the antenna; 2. The position of the antenna with respect to ground; 3. The position of the pick-up section with respect to other elements of the antenna, if the system is made up of more than one wire; 4. The electrical characteristics of the ground near the antenna.*

Current and Voltage Distribution of Half-Wave Doublet Antennas. A single straight half-wave doublet antenna like that in Fig. *11A,* located in free space (away from the influence of the earth and other objects) and fed with energy either by a direct connection to a transmitter or by radiation of power through space from a distant transmitter, acts like a number of small elements of inductance and capacity connected together in the manner shown in Fig. *11B.* If a.c. power is fed into the center in the case of a half-wave doublet transmitting antenna, the current encounters small elements of inductance which serve to choke it and reduce its value, and for each inductance there is an elemental capacitive path which draws off a portion of the antenna current and brings it to a corresponding point on the other half-section of the antenna. The result is that the r.f. signal current is the greatest *at the center* of a half-wave receiving antenna, and gradually drops to zero as it approaches the extreme ends. Across each elemental inductance there will be a voltage drop due to current flow through it, and those elements nearest the center will naturally have the highest voltage drops. The result is that the r.f. voltage *with respect to the center of the antenna* increases rapidly as we move outward from the center, then increases more gradually to a maximum value at the ends; furthermore,

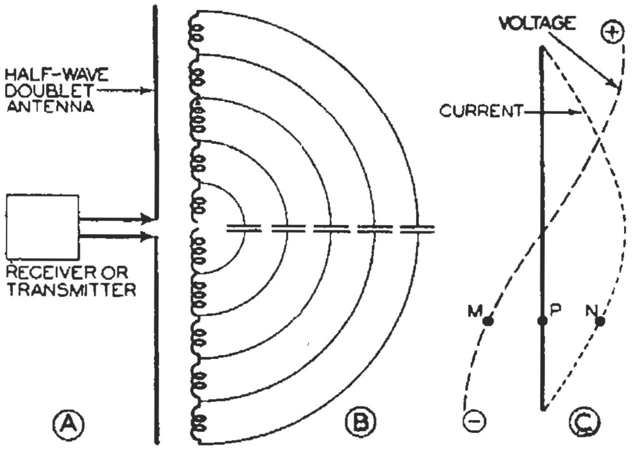


FIG. 11. Characteristics of a simple half-wave transmitting or receiving antenna in free space.

---

*Items *3* and *4* are not covered in this lesson since they are ordinarily neglected when designing and installing antennas for home radio receivers. These factors are extremely important in connection with amateur and commercial receiving antennas and with television receiving antennas, and are taken up in advanced lessons dealing with these subjects.

the ends will be opposite in polarity at any instant and will reverse in polarity *once for each cycle.* The curves in Fig. *11C* show this current and voltage distribution; they tell, for example, that the effective (r.m.s.) value of the r.f. current at point *P* is proportional to the distance *NP,* and the r.m.s. value of voltage at point *P* is proportional to the distance *MP.* Notice that both curves are sinusoidal (having a sine wave shape), with maximum current at the center and maximum voltage at the ends. (Since the center of the antenna has zero voltage, it may be considered at ground potential and all voltages measured with respect to the center rather than to ground.)

This half-sine-wave distribution of current and voltage will be obtained for any doublet transmitting or receiving antenna in free space whenever the length of the antenna wire is equal to one-half the wavelength of the signal. This condition can occur at only one signal frequency; at that frequency the antenna radiates or picks up a maximum signal, and is said to be *at resonance.*

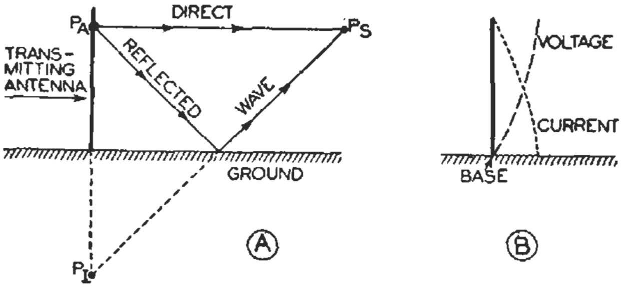


FIG. 12. Characteristics of a grounded vertical quarter-wave antenna. A perfectly conductive ground is assumed.

The essential requirement of a resonant receiving antenna is that it act as a pure resistive source. This requirement can be met by making the antenna one-half wavelength long or some multiple of a half wavelength (2, 3, 4, 5, etc., times as long). An antenna which is not a multiple of one-half wavelength for a particular radio wave will have either an inductive reactance or a capacitive reactance which raises its impedance and reduces the amount of current which can be delivered to the receiver. It is possible to introduce either capacity or inductance in the antenna circuit in order to cancel out the existing reactance; this *tunes* the antenna to resonance, making it purely resistive and giving at its ends the zero-current, maximum-voltage condition which results in maximum signal pickup.

Current and Voltage Distribution of Grounded Vertical Antennas. If a vertical antenna is grounded at one end, it will be at resonance when only ¼ wavelength long, for the earth serves to duplicate the effect of the other ¼ wavelength. A quarter-wave grounded vertical antenna is shown in Fig. *12A;* a receiving antenna at point P_S in space will receive a radio wave directly from point P_A on the transmitting antenna, and will receive another radio wave directly from point P_A by reflection from the ground. This reflected wave appears to come from a point P_I which is located the same distance below the surface of the earth as P_A is above the earth. In the language of radio engineers, we have an *image antenna* in the ground; although it is a purely imaginary structure, the observed effects are exactly the same as if it were present.

The current and voltage distribution curves for a grounded quarter-wave vertical antenna are shown in Fig. *12B;* note that current is zero and voltage a maximum at the upper end of the antenna, just as with a half-wave antenna. (Remember that these curves indicate r.m.s. values; the current and voltage at each point along the antenna are varying in a sine wave manner at the signal frequency.) A grounded vertical antenna is at resonance whenever its height is some odd multiple of ¼ wavelength; it can therefore be $\lambda/4$ (λ is the symbol for one wavelength), $3/4\lambda$, $5/4\lambda$, etc. An untuned vertical antenna (an antenna whose height at a particular signal frequency is not a multiple of $\lambda/4$) can be tuned to resonance, making it purely resistive and giving maximum signal pick-up at that signal frequency, by adding either a coil or a condenser in series.

Typical resonant receiving antennas are shown in Fig. *13;* current distribution curves for these are shown in dotted lines. At *A, B* and *C* are grounded $\lambda/4$ antennas, while at *D* and *E* are ungrounded $\lambda/2$ antennas; in each case the free ends have zero current. A receiving antenna which is at resonance when straight will remain at resonance even though a part of it is bent at an angle. A resonant half-wave antenna for reception at 49 meters should be 49 ÷ 2, or 24.5 meters (81 feet) long. A grounded quarter-wave antenna which is to be resonant at this same wavelength should be about 40.5 feet long.

A quarter-wave antenna which is resonant at 98 meters will be a half-wave antenna for signals at 49 meters and will be a full-wave antenna for signals at 24.5 meters. At wavelengths other than these values we can secure signal pick-up approaching that of a resonant antenna by introducing into the antenna system a condenser which will tune it to a lower wavelength, or by inserting a coil which will tune it to a longer wavelength. This practice is used quite often, especially when the antenna does not have the correct length for resonance at a desired frequency. For example, if an 81-foot length of wire is needed for a center-fed half-wave antenna and only 61 feet of room is available, the surplus 20 feet of wire can be wound in two coils of equal size, and one placed in series with each section of the antenna, near the center.

Directional Characteristics. Although the shape of a receiving antenna has little effect upon resonant conditions, shape does affect the directional characteristics of an antenna. If an antenna is short in comparison to the wavelength of the signals which it picks up (most of the antennas used for 500 to 1,500 kc. broadcast band reception are in this class), best signal pick-up is secured when the electric lines of force associated with the radio wave arrive *parallel* to the antenna wire. Thus, the vertical portion of a short antenna will respond best to vertically polarized electric fields, and the horizontal portion of a short antenna will receive horizontally polarized waves best. Only short antennas (shorter than one-quarter wavelength of the radio wave which is intercepted) have these properties, for they are acted upon directly by the electric field and are not greatly influenced by surrounding objects or by the ground.

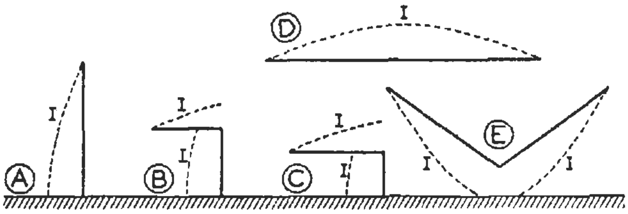


FIG. 13. These curves show that current distribution *I* along a quarter-wave or half-wave antenna is essentially independent of the shape of the antenna.

Radiation Patterns for Receiving Antennas. When the length of an antenna is one-fourth the wavelength of the signal picked up (or is longer than ¼ wavelength), special patterns must be used to show the directional characteristics. These patterns are called *radiation patterns* because they are usually secured by making measurements while the antenna in question is connected to a transmitter and is radiating signals, but each pattern applies to a particular antenna *regardless of whether it is used for transmitting or receiving purposes.* A horizontal radiation pattern for a receiving antenna indicates the effectiveness of signal pick-up in any direction along the ground. A vertical radiation pattern for a receiving antenna indicates the effectiveness of signal pick-up at various angles to the ground in one vertical plane passing through the center of the antenna system.

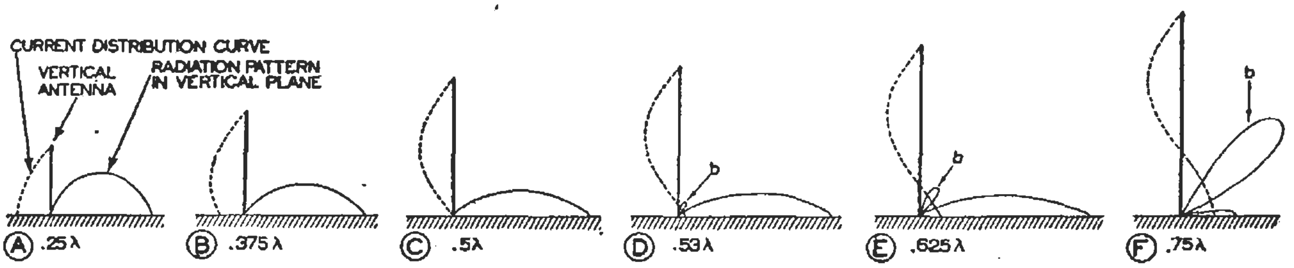


Fig. 14. Current distribution curves (dotted lines) and vertical radiation patterns (thin solid lines) at one particular frequency for grounded vertical antennas having various physical lengths.

In Fig. *14A* is shown the radiation pattern in a vertical plane for a grounded vertical $\lambda/4$ antenna; this pattern will be the same for vertical planes in all directions (north, east, south or west) for this particular antenna and height. As antenna height is increased above $\lambda/4$ the radiation pattern flattens out, indicating improved pick-up of the ground wave, as shown at *B, C, D* and *E* in Fig. *14*. When antenna height becomes more than $\lambda/2$ (.5λ), a lobe or ear directed up into the sky begins to form, however; this indicates that the antenna is beginning to favor reception of sky waves. If the height of the antenna is increased beyond .75λ, only sky waves will be received effectively. Remember that these patterns are for grounded vertical antennas; when a vertical antenna is elevated above the ground, the patterns become quite different.

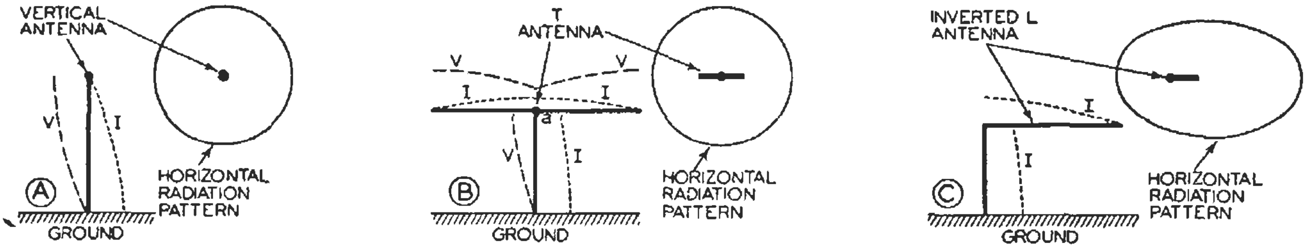


Fig. 15. Horizontal radiation patterns for grounded vertical, T and inverted L types of antennas.

The horizontal radiation pattern for a quarter-wave grounded vertical antenna is shown in Fig. *15A*. This pattern indicates that a vertical antenna receives ground waves equally well from all directions along the surface of the earth. When a grounded vertical antenna is shorter than $\lambda/4$, the center of a horizontal wire can be connected to the top of the vertical antenna to form the T antenna shown in Fig. *15B;* this does not affect the horizontal radiation pattern, but it does serve as a load which helps to tune the antenna to resonance. The current distribution curves show that currents are zero at the ends of the horizontal portion and increase gradually up to point *a*, where the two currents combine to flow down the vertical portion of the antenna These currents are equal for a symmetrical T antenna, and since they flow in opposite directions toward point *a* in Fig. *15B* they do not alter the non-directional characteristics of the vertical portion. The T-type antenna is particularly desirable when it is impractical to erect a sufficiently high vertical antenna to give resonance. Resonant conditions produced by the antenna itself always give better signal pick-up than resonance produced by inserting coils or condensers.

A vertical antenna shorter than $\lambda/4$

can be increased in effective length by connecting to its top a single horizontal wire as shown in Fig. *15C*, giving an inverted L antenna. The horizontal portion serves to load the vertical portion; if its length is properly chosen, it will tune the antenna system to resonance at one desired signal frequency, giving maximum possible current at the receiver. Radio waves arriving from the direction in which the horizontal section is pointing are favored, giving a slightly directional radiation pattern in the horizontal plane, as shown in Fig. *15C*. The natural wavelength of an L or T type antenna is determined by measuring from the ground to the end of the longest horizontal section.

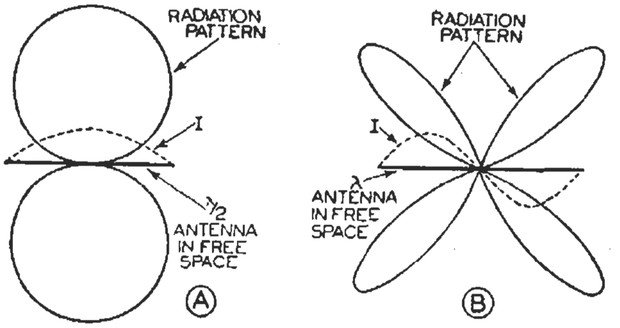


FIG. 16. Radiation patterns for λ/2 and λ antennas in free space. The patterns are the same for all planes passing lengthwise through the antennas.

The radiation pattern of a theoretically perfect half-wave antenna in free space will be the same in any plane passing through the antenna wire and will be a figure-of-eight pattern as shown in Fig. *16A*. A three-dimensional radiation pattern, showing the pick-up characteristics in all directions, would appear like a round "doughnut," with the antenna wire running through the doughnut hole. The outstanding fact about a λ/2 antenna in free space is that it receives best from its sides, and has practically no signal pick-up from its ends. Practical doublet antennas have somewhat similar directional characteristics, and consequently should be kept broadside to a station from which maximum signal pick-up is desired.

The radiation pattern for a full-wave (λ) antenna in free space, shown in Fig. *16B*, resembles somewhat a four-leaf clover, indicating that best reception is restricted to four narrow beams, and that there is no reception either from the ends (in the plane of the antenna) or from the sides (at right angles to the antenna). More and more of these lobes appear in the radiation pattern as antenna length is increased in multiples of λ/2, with the lobes becoming longer and narrower; antennas longer than λ/2 are therefore unsuited for general reception in all directions.

It is practically impossible to erect a horizontal doublet receiving antenna which is high enough above the ground so it will act as if it were in free space. The average radio receiver owner would have difficulty in erecting a horizontal antenna which is higher than about 50 feet above the ground (about 15 meters). This would make the antenna λ/4 above the ground for a 60-meter wave. The radiation patterns in two vertical planes at right angles to each other for a λ/2 horizontal doublet antenna mounted a distance of λ/4 above the ground are shown in Fig. *17A*. These patterns tell us that sky wave reception is good and is essentially the same in all directions. The patterns might lead you to expect poor

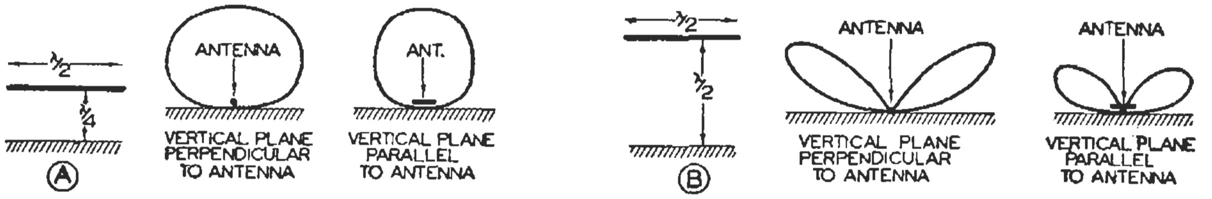


FIG. 17. Radiation patterns for a horizontal half-wave doublet antenna located one-fourth wavelength (*A*) and one-half wavelength (*B*) above a perfectly conducting ground.

ground wave reception, but ground waves are usually tilted sufficiently to induce ample voltage in an antenna of this type, giving quite good ground wave reception also. When the half-wave doublet antenna in Fig. *17A* is raised another ¼ wavelength, making it ½ wavelength above the ground, a decidedly directional radiation characteristic is obtained, as indicated in Fig. *17B*. Sky waves coming in at a reasonable angle (the usual condition for these waves) are picked up quite well, but waves arriving at high or low angles of elevation are poorly received. An antenna such as this would not be good for reception of signals broadcast by an airplane flying overhead, nor for reception of ground wave signals unless they were well tilted.

The angle at which maximum energy reaches a receiving antenna is the same as the angle at which maximum energy leaves the transmitting antenna. In other words, if a given transmitting antenna radiates maximum energy into the sky at a definite angle of elevation, maximum pick-up of signals from that antenna will be obtained with a receiving antenna which has maximum pick-up at that same angle of elevation.

Conclusion. Keep the following facts in mind when installing receiving antennas:

1. A simple antenna having a pick-up portion which is $\lambda/4$ meters long or less and in one straight line gives best reception of radio waves whose electrical lines of force are parallel to the pick-up wire.
2. Horizontal doublet antennas having pick-up sections with a total length of $\lambda/2$ or less give best pick-up of signals arriving broadside to the antenna, but give fairly good pick-up from other directions as well at normal antenna heights above ground.

Coupling The Antenna To The Receiver

Now that we have seen how the pick-up portion of an antenna can be made to produce maximum voltage and maximum current for a given radio wave, we are ready to consider how maximum signal can be transferred from the antenna to the radio receiver. For antennas less than a quarter-wave long, the solution is quite simple, involving merely a direct connection as shown in Fig. *18*. The entire length of the antenna system will pick up signals, and consequently length *b-c* must be added to length *a-b* when determining the operating wavelength of the system. For a $\lambda/4$ system, the current will be a maximum at the ground end; if the receiver is connected close to ground, maximum current will flow through primary coil *P* and will induce the greatest possible voltage in secondary coil *S*. A long ground wire between receiver and ground moves the primary coil to a point where current is less, reducing the efficiency of the antenna; furthermore, an excessively long ground wire picks up noise and thus lowers the signal-to-noise ratio. Keep the ground wire as short as possible, and increase the length of the antenna itself up to ¼ wavelength if maximum pick-up is required at a given wavelength.

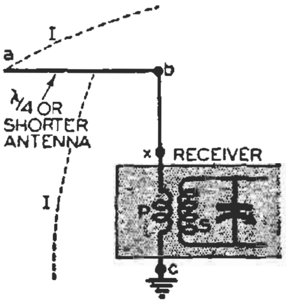


FIG. 18. Direct connection of an inverted L antenna to a receiver.

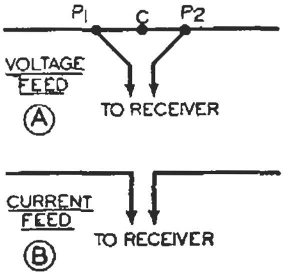


FIG. 19. Feed methods for a doublet receiving antenna.

A $\lambda/4$ antenna for best reception of a 1,500 kc. (200-meter) signal should be 50 meters (165 feet) long. This length is rarely attained in the average receiving antenna, but a coil can be inserted in the lead-in wire (at point *x* in Fig. *18*) to offset this lack of length. On short-wave bands, however,

even a 50-foot antenna is too long for $\lambda/4$ operation. When an antenna is only slightly longer than $\lambda/4$ (not more than about ⅜ wavelength long), the excessive length can be offset by inserting a variable condenser at point x and adjusting for maximum signal pick-up from the desired station (this tunes the antenna to resonance, making it equivalent to a $\lambda/4$ antenna at that station frequency). Tuning of an antenna complicates the operation of a receiver, so it is customary to design the primary coil so it will make the average broadcast antenna tune approximately to the broadcast band wavelengths, and provide means for reducing the size of this coil on short wave bands.

Voltage Feed For a Doublet Antenna. With a doublet antenna, it is quite possible to connect two wires (a transmission line) to points which are equally spaced on each side of the center, as shown in Fig. *19A,* in order to transfer to the receiver a portion of the r.f. voltage which is developed by the antenna. The voltages at P_1 and P_2 are opposite in polarity at any instant of time (see Fig. *11C*), and hence the voltage between P_1 and C will always add to that between P_2 and C. This connection is commonly referred to as a *voltage feed* to the receiver.

Current Feed. When a doublet antenna is cut at its center and two wires are used to connect the cut ends to the receiver, we have what is known as *current feed* to the receiver. Antenna current flows along one half of the pick-up section, down one lead-in wire to the receiver, through the antenna coil of the receiver, up through the other lead-in wire, and finally out over the other half of the pick-up section. Since current in a $\lambda/2$ or shorter antenna is a maximum at the center, this connection gives maximum current through the antenna coil of the receiver. Current feed is widely used with **antennas for all types of receivers.**

A $\lambda/2$ antenna which is designed for 80 meters will be a full-wave antenna at 40 meters, a $3/2\lambda$ antenna at 30 meters, and a 2λ antenna at 20 meters. Let us see if an antenna like this will work effectively at all three wavelengths with current feed. Figure *20* shows the current distribution for these four operating conditions; these curves show that current is a maximum at the center only for operation as a $\lambda/2$ or $3/2\lambda$ antenna. Current at the center is zero for λ or 2λ operation, which means that a current feed at the center will theoretically give no signal transfer to the receiver under these conditions; it would be necessary to move the tap to an off-center point of maximum current in order to secure efficient signal pick-up. This explains why a single $\lambda/2$ antenna which is used for all-wave reception and has a current feed connection to the receiver will give excellent results at certain frequencies and will be very inefficient at other frequencies.

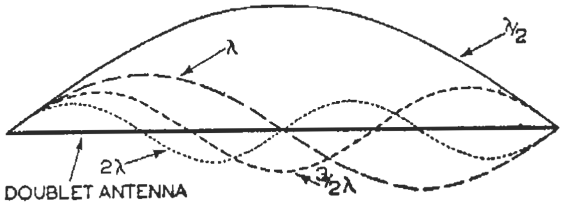


FIG. 20. Current distribution curves for $\lambda/2$, λ, $3/2\lambda$, and 2λ operation of a doublet antenna.

Transmission Lines

Antenna Resistance and Impedance. Any antenna which is tuned to resonance will act as a resistance source of r.f. signals; at the center of a $\lambda/2$ antenna this a.c. resistance will be about 72 ohms. For a grounded $\lambda/4$ antenna, the a.c. resistance at the ground (measured between the antenna lead-in wire and the ground wire) will be about 36 ohms. A voltage-fed $\lambda/2$ antenna will have a resistance considerably higher than 72 ohms; if the transmission line connections are made near the ends of the antenna, this resistance may be as high as 5,000 ohms. At off-resonant conditions, reactive components are added to these resistance values, making the impedance of an untuned antenna quite high.

Surge Impedance of Transmission Lines. Any two-wire transmission line is a combination of elemental resistances, inductances and capacities arranged as shown in Fig. *21A*. At low audio frequencies the inductances and capacities have a negligible reactive effect and the line simply has a d.c. resistance distributed along its length due to the resistance of the wire itself. At radio frequencies, however, the elemental inductances and capacities have much more effect upon the characteristics of the line than do the elemental resistances, and we can for practical purposes neglect entirely the presence of these resistances. The values of these elemental inductances and capacities control one extremely important characteristic rating of a transmission line—its *surge impedance,* usually designated as Z_0*. The inductance values are determined by the diameter of the transmission line wires and the spacing between them; the capacity values are determined by the diameter of the wires, the spacing between the wires, and by the nature of the dielectric materials between the two wires. Neither the frequency of the radio signal nor the length of the line ordinarily has any effect whatsoever upon the inductance and capacity values. This means that the surge impedance of a transmission line depends only upon the construction of a unit length of a transmission line, and is the same for any length of line and for any frequency. Increasing the distance between the two line wires will increase the surge impedance; reducing the diameter of the wires will increase the surge impedance; the use of a dielectric material which increases the capacity between the two wires will reduce the surge impedance.

If we were to measure the impedance between the input terminals of an extremely long (infinitely long) transmission line, we would get a value which is equal to the surge impedance of that line. Furthermore, this impedance would be purely resistive, for the large numbers of elemental inductances and capacities distributed over this infinitely long line make it act as a broadly tuned resonant circuit having the same impedance at all frequencies. This fact is illustrated in Fig. *21B*.

If we were to measure the input impedance of a practical transmission line (seldom more than one or two wavelengths long in radio work), we would probably get a value considerably different from the surge impedance of the line; actually the value of impedance which we measure would depend upon the length of the line and upon how it was terminated (the nature of the load at the output end of the line). It is possible to compute the input impedance of a transmission line having any length and any type of load at its output end, but the mathematical procedure involved is highly complicated and for all practical receiving antenna purposes is quite unnecessary.

We are not concerned with this input impedance of a practical transmission line, because there is a simple way to make this input impedance equal to the surge impedance of the transmission line. If the output end of a transmission line is terminated in a load having an impedance exactly equal to the surge impedance of the transmission line, the input impedance of that

---

*This impedance is also known as the *characteristic impedance* of a transmission line; "characteristic impedance" is a more readily understood term, but "surge impedance" is the term more widely used. The value of this impedance depends upon the ratio of elemental inductance to elemental capacitance.

transmission line will then be equal to the surge impedance of that line regardless of its length; this is illustrated in Fig. *21C*. If the input end of this line is now connected to a signal source having an impedance equal to the surge impedance of the transmission line, the impedance at each end of the transmission line will be equal to the surge impedance Z_0 regardless of the length of the line. This phenomenon is widely used in the design of transmission lines for connecting receiving antennas to receivers, for it simplifies construction considerably and gives at each end of the transmission line an impedance match which results in maximum transfer of power from the antenna to the receiver.

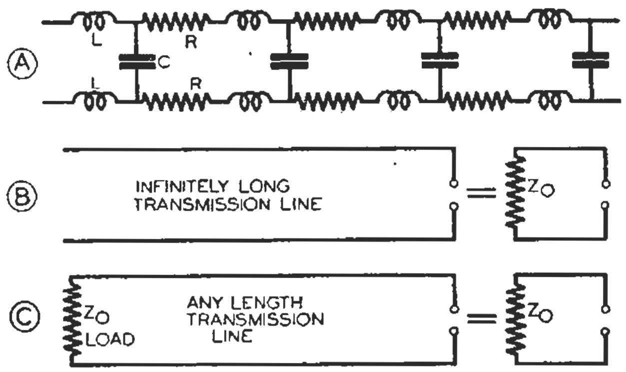


FIG. 21. **Important facts concerning the behavior of transmission lines.**

Typical Surge Impedance Values. A transmission line made up of two No. 18 wires spaced 2 inches apart will have a surge impedance of about 560 ohms. Two No. 10 wires separated by 2 inches have a surge impedance of about 440 ohms. No. 18 and No. 10 wires separated by 3 inches will have surge impedances of 610 ohms and 480 ohms respectively. These so-called "open" transmission lines are rarely used with receiving antennas, but are widely used with transmitter installations. When two No. 18 rubber-covered wires are twisted together or when one rubber-covered wire is placed inside a braided metallic covering, the surge impedance Z_0 will range between 70 and 150 ohms; by careful design, this impedance can be made equal to 72 ohms, making it possible to couple a current-fed $\lambda/2$ antenna directly to the transmission line, securing a perfect impedance match and maximum transfer of power from the antenna to the transmission line. If the receiver is made to serve as a 72-ohm load on the other end of this line, we will have maximum transfer of power from the antenna to the receiver regardless of the length of the transmission line.

It is not essential that a 72-ohm transmission line be used for maximum transfer of power. An r.f. impedance-matching transformer, usually called an *antenna transformer,* can be used at the antenna to match the antenna impedance to the surge impedance of the transmission line regardless of what their respective values may be, thereby securing maximum transfer of energy. Another impedance-matching transformer can be used at the receiver end to match the receiver input impedance to the transmission line surge impedance. When a receiver is designed for use with a definite antenna system, the first r.f. transformer in the receiver is designed to match the surge impedance of the transmission line, eliminating the need for a separate matching transformer.

Noise Reduction

It is useless to erect an antenna which will deliver a strong carrier signal to a receiver if this signal is "blanketed" by local man-made interference noise which is also picked up by the antenna. As a general rule, man-made interference produces electric fields which are *perpendicular* to the ground, just like the fields produced by a vertical transmitting antenna. If a horizontal antenna with a vertical down lead is used for reception, most of the interference noise will be picked up by the down lead; very little will be picked up by the horizontal section.

The chief problem in securing a noise-reducing antenna is that of preventing the down lead or transmission line from picking up noise signals.

With a doublet antenna, the transmission line inherently rejects noise signals. The two down leads of the transmission line are normally twisted together in the manner shown in Fig. *22A*, so that very little electric field can exist between adjacent wires in the transmission line. Any noise voltages which are induced in these vertical wires cause currents to flow in the same direction in both wires at any instant of time. Noise currents therefore flow in opposite directions through the primary of the receiver transformer to the center tap and then to ground; as long as these two noise currents are balanced, they cannot produce any flux in the receiver transformer. Some noise signals may be picked up by the entire antenna system acting as a vertical mast; an electrostatic shield is usually placed between the primary and secondary windings of the receiver input transformer to prevent these noise signals from being transferred to the secondary winding.

The antenna and receiver transformers in Fig. *22A* can give a perfect impedance match at only one frequency; the tuning action can, however, be made sufficiently broad by means of tight coupling in the transformers to give satisfactory reception over a wide range of frequencies.

Noise-reducing antenna systems for the 500 kc. to 1,500 kc. broadcast band are invariably of the single-wire horizontal type; a typical noise-reducing broadcast antenna is shown in Fig. *22B*. Since limitations of space in the vicinity of the average home would normally prevent the use of a horizontal pick-up section which is $\lambda/4$ meters in length, a more reasonable length of from 50 to 100 feet is usually employed, and the primary of the antenna transformer is designed to bring this length up to $\lambda/4$ for the highest frequency which the antenna is to pick up. The transmission line in this case is a single insulated wire surrounded by a flexible metal loom or shield; this shield is connected to the ground terminal of the receiver. A twisted 2-wire transmission line may be used if proper ground connections are made at the receiver, and the transmission line is properly connected to the antenna transformer. For maximum reduction of noise and the most favorable distribution of current in the antenna, the shielding metal loom must be grounded near the antenna, either to a vent pipe, to the grounded metal roof of the building, or to a grounded gutter. Additional grounding of the shield at several points is optional, but should be done whenever the transmission line runs conveniently near a grounded object. This type of noise-reducing antenna may also be designed for all-wave reception.

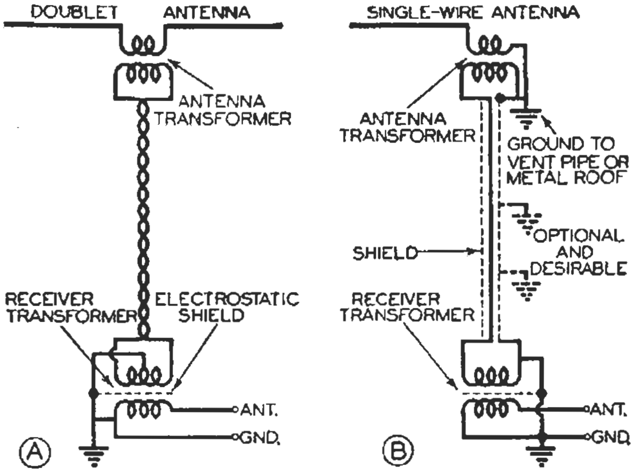
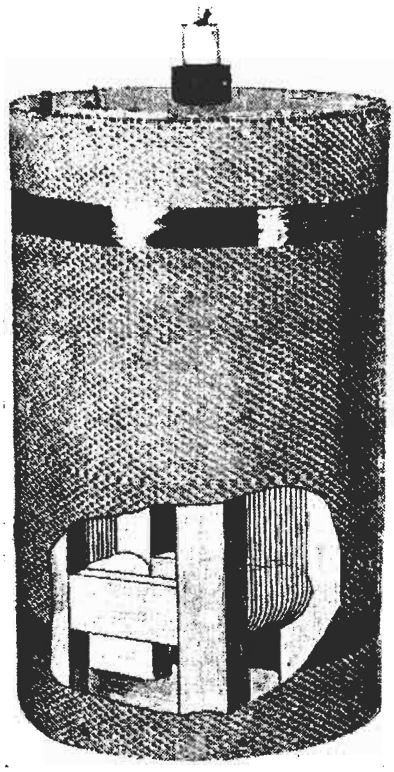


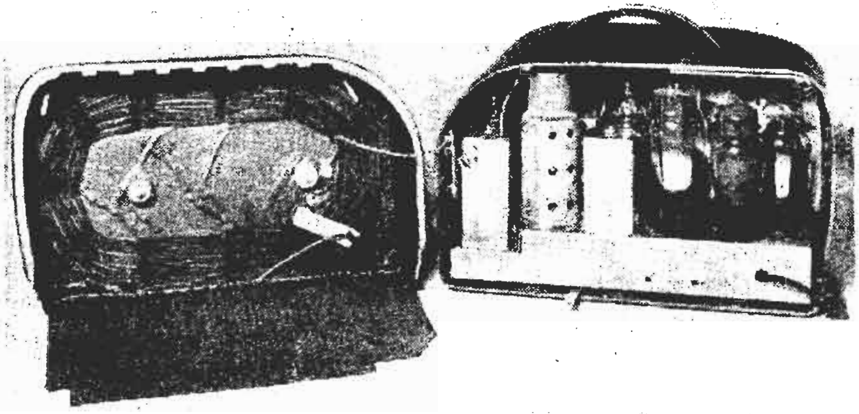
FIG. 22. Two types of noise-reducing antennas.

Even though the vertical lead-in wires of an antenna system are carefully shielded against man-made noise fields, there is still a possibility that noise will be picked up by the antenna system. This is due to the fact that the electric fields produced by man-made interference may not always be exactly perpendicular to the earth; if they are slanted any appreciable amount and extend an appreciable distance above the ground, they will induce noise voltages in the horizontal pick-up wires. When a noise-reducing antenna system fails to give a satisfactory signal-to-noise ratio, the usual procedure is to *change the position of the horizontal pick-up portion of the antenna,* such as by increasing its height, changing its direction, or moving it to a location farther away from the source of noise.

Noise-Reducing Loop Antenna. Another solution to the problem of noise interference is the use of a shielded loop antenna which is built right into the cabinet of a radio receiver. To understand how this shielded loop can reduce noise signals, we must first consider the relative strengths of the electric and magnetic fields associated with radio waves. At points outside of the induction field produced by a transmitting antenna or source of noise interference, the electric and magnetic fields associated with the radiation field (the radio wave) are essentially equal. Close to the source, however, the electric component *E* is much greater than the magnetic component *H;* in fact, *E* may be as much as 70 times stronger than *H.* Noise interference sources are generally so close to the receiver that the vertically-polarized electric component *E* of the noise is much stronger than the magnetic component of noise, whereas the *E* and *H* components of the desired radio signals are equal. If we can remove the electric component *E* of both the noise signals and the radio signals, depending upon magnetic components only for reception, we will then have eliminated the noise almost completely without impairing reception of the desired radio signal. The chief purpose of the grounded Faraday shield which surrounds some types of built-in loop antennas is therefore to prevent *electric components of both station and noise signals from affecting the receiver.*

~~One~~ commercial version of this shielded loop arrangement is shown in Fig. 23. The Faraday shield is in the form of a closed cylinder with sheet metal discs covering the top and bottom faces and with the sides covered with a coarse woven material in which the vertical threads are wire and the





Courtesy General Electric Co.

FIG. 23 (Left). Typical shielded loop antenna (General Electric Beamascope) designed for installation inside a console model home radio receiver. Part of the Faraday shield is cut away to show the loop winding and its wood frame inside. This unit is rotated to a position of minimum noise pick-up at the time the receiver is installed in a home.

Courtesy Zenith Radio Corp.

Above: A compact shielded loop antenna mounted at the rear of this 5-tube superheterodyne table model receiver (Zenith Wavemagnet) eliminates the need for antenna and ground connections. The flat loop is wound on a spider-web type coil form, and is mounted between two flat shields woven with vertical copper wires and horizontal insulating cords. All shield wires are connected together at the bottom and grounded to the receiver chassis.

horizontal threads are non-conducting fiber. Every vertical wire makes contact with the top metal disc, but only one of these vertical wires makes electrical contact with the bottom disc; this construction eliminates closed circuits in the vicinity of the loop, giving maximum pick-up by the loop of the magnetic component of radio signals. The shield is grounded, and consequently all signal and noise currents induced in its vertical wires by the *E* components are led off to ground without affecting the receiver. The well-known directional characteristics of a loop are utilized to give additional noise rejection; the loop is rotated for minimum noise, so its line of minimum pick-up is in the direction of the noise source. No external antenna or ground connections are necessary when one of these shielded loops is installed, but an outdoor antenna can be connected to the loop or in place of it if distant reception is desired. A loop of this type can be built right into the cabinet of a radio receiver, and can be tuned over the entire broadcast band by a main tuning condenser section which is adjusted to track with the oscillator; this tuning to resonance for each station increases the sensitivity of the loop very greatly.

All-Wave Antennas

Either horizontal doublet antennas or single-wire horizontal antennas with end feed may be used for all-wave reception. The doublet is ordinarily preferred, for its balanced two-wire transmission line gives inherent rejection of vertically-polarized noise signals. Both types of all-wave antennas favor slightly the reception of signals from certain directions, but these directional characteristics can ordinarily be neglected when installing an all-wave antenna for the average radio listener. It is far more important to place the horizontal pick-up section of the antenna *at right angles* to a nearby power line, in order to secure rejection of horizontally-polarized power line noise signals.

Types of All-Wave Antennas Commonly Used. Three distinct types of antenna systems are in common use for all-wave reception over the entire range from about 18 meters (16.5 megacycles) to 545 meters (550 kc.). These are:

1. An antenna system made up of two or more doublet antennas, each tuned to a different wave-length. With the customary broadness of tuning in doublet antennas, fairly uniform pick-up is obtained over the desired range. A typical system might employ three half-wave doublets, tuned respectively to 16, 25 and 49 meters.

2. A system employing a single horizontal doublet antenna cut at its exact center for current feed, and with a length which will keep it less than a full-wave antenna at any frequency in the range to be received. For example, if the receiver is to go down to 18 meters, a 50-foot horizontal doublet can be used, for it will be a full-wave antenna at about 15 meters and will have sufficient current at its center at 18 meters. At 30 meters this antenna would become a $\lambda/2$ unit; at all longer wavelengths it will be shorter than $\lambda/2$, and will have maximum current at its center even though the current is gradually reduced due to off-resonant conditions as wavelength is increased.

3. A system employing a single horizontal wire having a properly grounded antenna transformer at one end for current feed, and with a length which will keep the effective pick-up portion of the system less than a half-wave long at any frequency in the range to be received. For example, if the shortest wavelength at which reception is desired is 18 meters, a 25-foot horizontal wire would very likely be used (this would be a half-wave antenna at 15 meters).

An all-wave doublet antenna gives maximum pick-up at a frequency which makes it $\lambda/2$. Pick-up decreases gradually above $\lambda/2$, for the current at the center of the antenna goes down. At λ operation the current at the center is zero, and there is practically no signal pick-up. Above λ, pick-up increases again to a maximum at $3/2\lambda$, then drops to zero again at 2 λ. All this means that a doublet antenna will pick up stations having frequencies higher than that for λ operation, but reception will be erratic due to the highly directional and continually changing radiation patterns and to the dead spots in reception which occur at λ, 2λ, 3λ, 4λ, etc., operation.

A single-wire antenna acts in much the same way above its efficient operating length of $\lambda/4$; there will be dead spots in reception at $\lambda/2$, λ, $3/2\lambda$, 2λ, $5/2\lambda$, etc., for these operating lengths give zero current at the antenna transformer. Pick-up will be good at $\lambda/4$, $3/4\lambda$, $5/4\lambda$, $7/4\lambda$, etc., for these operating lengths give high currents at the antenna transformer.

Multiple Doublet Antennas. A typical all-wave doublet antenna system employing three doublet antennas is shown in Fig. *24*. Doublet A_1 serves for the shortest wavelength, A_3 for the longest wavelength and A_2 for the intermediate wavelength. (Coils L_A serve merely to increase the effective length of doublet A_3, improving reception at about 50 meters.) Although these three antennas work best at their own resonant wavelengths, they are sufficiently broad to give adequate pick-up at in-between wavelengths. The connections between one or more of the doublets and the transmission line are transposed, as is done for A_1 and A_2 in Fig. *24*, so that the signal voltages in the various doublets will add and give maximum transmission line current.

Whenever the wavelength of a desired radio signal is such as to give resonance for one of the doublet antennas in this system, the antenna impedance will be that of a normal doublet, which is 72 ohms. Since the transmission line is designed to have a surge impedance of about 72 ohms, a good match between the antenna and the transmission line is secured at resonant frequencies. When the desired signal does not give resonance for any one of the doublets, the impedance of the antenna will be much higher than 72 ohms, but there is one interesting characteristic of a transmission line which can be used to counteract this mismatch: A practical transmission line (only a few wavelengths long) has a high input impedance whenever its length is some multiple of $\lambda/2$ meters for a particular signal. By making the length of the transmission line a multiple of $\lambda/2$ for wavelengths in between the natural resonant frequencies of the three doublets, efficient transfer of signals from the antenna to the transmission line is obtained at in-between wavelengths as well. Whenever the manufacturer of an all-wave antenna specifies that the transmission line supplied with the system must not be cut, and that if too short it should be lengthened in equal lengths of a definite number of feet, you can be sure that the purpose is improvement of match at off-resonant frequencies.

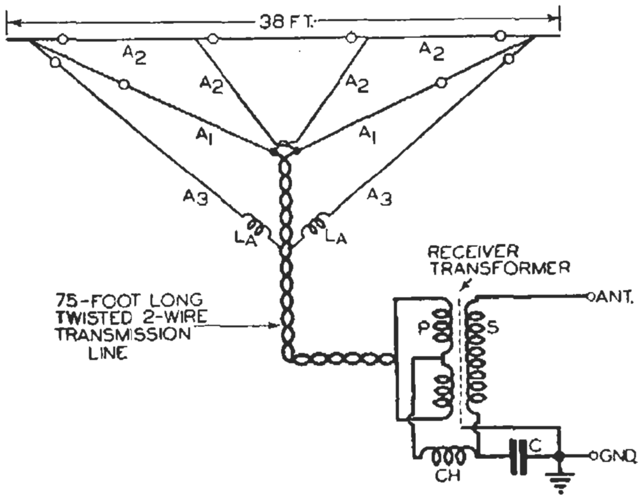


FIG. 24. All-wave noise-reducing antenna made up of three doublets. Because of its general resemblance to the web of a spider, this RCA-Victor product is commonly known as a spider-web antenna.

With proper design it is possible to build a multiple-doublet all-wave antenna which is reasonably effective at all wavelengths between the lowest and highest natural wavelengths of the doublets employed. Response at wavelengths below this range can be obtained by adding shorter doublets. Fairly satisfactory response will be obtained at wavelengths above this range since all of the doublets will then be shorter than $\lambda/2$, and will have a maximum current at their centers. At broadcast band wavelengths, however, this maximum current becomes quite low even for the longest doublet; to offset this, the special receiver coupling transformer shown in Fig. *24* is employed to convert the entire antenna system into a T antenna for broadcast band reception.

Observe that the midpoint of primary winding *P* is connected to ground through choke coil *CH* and condenser *C*. At broadcast band frequencies, very little signal current is fed to the transmission line by the doublets; the entire system acts as a T antenna, and signal currents which are picked up by the transmission line flow down both transmission line wires in the same direction to the center tap of *P*, then through *CH* (which has a low reactance at broadcast frequencies), through secondary winding *S* to the antenna terminal of the receiver, and through the receiver input coil to ground. Condenser *C* has such a high reactance at low frequencies that it acts essentially as an open circuit. When an all-wave doublet antenna system is converted to a T antenna in this manner, the system of course loses the noise-reducing and directional properties of a doublet.

Single All-Wave Doublets. An antenna arrangement which gives satisfactory reception on short-wave bands and which automatically converts to a T type antenna at broadcast frequencies without losing its noise-reducing properties and without sacrificing an impedance match is shown in schematic form in Fig. *25A*. This system employs a single doublet antenna; it may be center-fed, in which case both sides of the horizontal doublet will be equal in length, or it may be fed from an off-center point, in which case the sides of the doublet will be unequal in length.

This unique system employs two transformers at the antenna and two at the receiver. At high frequencies, condensers C_1 and C_2 become so low in reactance that they short out coils L_9-L_{10} and L_{11}-L_{12}, making the two right-hand transformers ineffective at high frequencies; the transmission line circuit therefore takes the form shown in Fig. *25B* at high frequencies (at short wavelengths). As you can see, this is a conventional doublet arrangement; if its length is $\lambda/2$ or less, current will flow along the entire antenna in the same direction at any instant of time. This current will flow through L_1 and L_2 in the same direction, inducing voltages in L_3 and L_4 which add together and cause current to flow down transmission line T_1 and up transmission line T_2 at one instant. The result is current flow through L_5 and L_6 in the same direction at any instant, inducing in L_7 a voltage which is applied to the input of the receiver. The

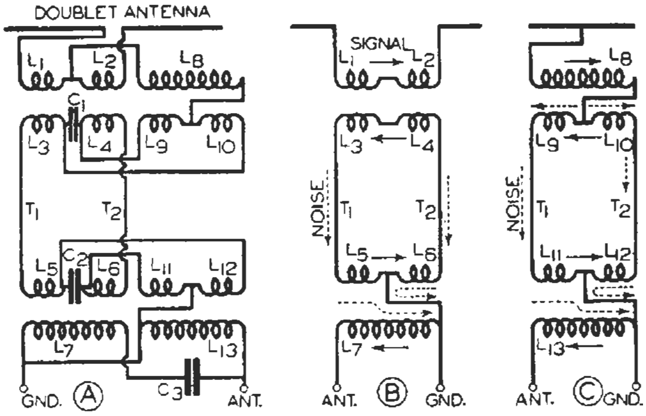


FIG. 25. Taco all-wave noise-reducing antenna system, made by Technical Appliance Corp. Actual circuit is shown at *A*; the effective circuit for short-wave bands is at *B*, while the effective circuit for the broadcast band is at *C*. Dotted arrows show directions of noise currents at one instant of time; solid arrows show directions of desired signal currents at one instant of time.

transformers used in this system provide the desired broad impedance match for efficient transfer of power over a wide range of high frequencies. Noise currents flow through leads T_1 and T_2 in the same directions, then in opposite directions through L_5 and L_6 to their common terminal and to ground, so no noise signal voltages are induced in L_7.

At broadcast band frequencies, condensers C_1 and C_2 have high reactances, and hence have no shorting effect upon secondary windings L_9-L_{10} and L_{11}-L_{12}. Furthermore, at these low frequencies coil elements L_1, L_2, L_3, L_4, L_5, L_6 and L_7 have negligible inductive reactance and may be neglected, giving in effect the circuit shown in Fig. *25C*. Condenser C_3 in Fig. *25A* has a high reactance at broadcast band frequencies, and serves to prevent L_7 from shorting L_{13}. Again we find that noise signals picked up by the vertical down leads T_1 and T_2 are cancelled out at the receiver end of the transmission line (in primary windings L_{11} and L_{12}). The entire down lead system acts as a vertical or T antenna, with the flat top section serving merely as a load which produces a larger r.f. current at the point along the antenna to which coil L_8 is connected. This current flows down through L_8, then divides to flow through L_9 and L_{10} and through L_{11} and L_{12} to the mid-point and then to ground, as shown by the dotted line arrows. This is normal current distribution for a T type antenna, but of course it does not feed the receiver. The flow of antenna current through winding L_8 serves to induce voltages in L_9 and L_{10} which act in the same direction and serve to circulate a signal current through the entire transmission line circuit. This current flows through windings L_{11} and L_{12} in the same direction, inducing a strong radio signal voltage in L_{13}. This winding in turn feeds the voltage to the receiver.

Use of Counterpoise for Noise Reduction. Another arrangement of a single doublet antenna which gives satisfactory signal pick-up along with noise reduction on all bands is that which employs a counterpoise for picking up strong noise signals. These noise signals are fed through the receiver input circuit in such a way that they "buck out" or cancel the usual noise signals, giving essentially noise-free reception on bands in which the doublet is acting as a T.

The circuit diagram of a typical antenna-counterpoise installation on a three-band receiver is given in Fig. *26A*. Each band has a separate receiver matching transformer as a part of the receiver preselector (an antenna system like this can be used only with receivers designed especially for it). For short-wave reception, band-changing switch SW_1 is at position *C*, and we have a normal noise-reducing doublet antenna with L_1-L_2 serving as the receiver matching transformer. Condenser C_5 provides a path from the mid-point of L_1 to ground for noise signals, and 1-megohm resistor R_{26} allows static charges picked up by the antenna to leak off to ground gradually without causing noise.

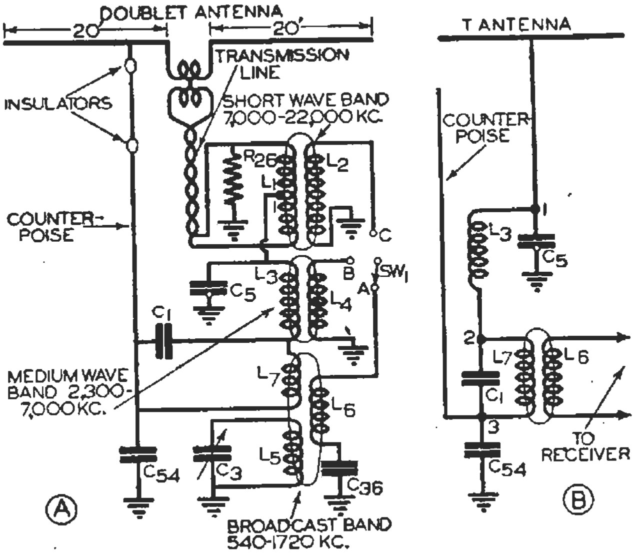


FIG. 26. All-wave noise-reducing antenna system employing a counterpoise (RCA-Victor Master Antenna as used with RCA-Victor model 99K receiver).

For broadcast band reception, switch SW_1 is at position *A*, and we have T antenna action. To simplify an analysis of the antenna system under these conditions, we can redraw the circuit as in Fig. *26B* to include only those parts which are effective during broadcast band reception. The length of the counterpoise is 10 feet longer than half the length of the transmission line, and consequently this lower portion of the transmission line (adjacent to the counterpoise) will pick up essentially the same amount of station and noise signals as the counterpoise. The upper portion of the transmission line is ordinarily quite high above the ground, out of the region of strong noise signals, but it will pick up and feed down through the transmission line a certain amount of noise along with the station signals. Let us trace the path taken by the noise signal currents, neglecting station signals for the time being.

Noise signals picked up by the T antenna will come down to point *1* in Fig. *26B* (corresponding to point *1* at the center tap of L_1 in Fig. *26A*); some will go through C_5 to ground, and the remainder will go through coil L_3 to point *2*. Again the noise currents divide, with some going through L_7 in a downward direction to point *3*, and others going through C_1 directly to point *3*. From here the noise currents either go to ground through condenser C_{54} or take a return path up the counterpoise to the T antenna again. Noise signal currents coming down the counterpoise divide at point *3*, with some going to ground through C_{54}, some going directly to point *2* through C_1, and some going through L_7 in the opposite direction to that taken by the T antenna noise currents. From point *2* these counterpoise noise currents go through L_3 to point *1*, from which some go to ground through C_5 and others take the return path up the T antenna and over to the counterpoise. By adjusting the value of trimmer condenser C_5, the division of the counterpoise and T antenna noise currents throughout this circuit can be made such that the noise currents sent through L_7 by the two pick-up systems will be exactly equal and opposite, and will therefore "buck out" or cancel each other.

In securing cancellation of noise signals in this manner, we also secure cancellation of any station signals which are picked up by the lower portion of the T antenna. This makes only the upper portion of the transmission line available for picking up signals of broadcast band stations; coil L_3 and condenser C_1 serve to compensate for this short effective pick-up length, to compensate for the detuning effect of C_5 and to equalize the amount of energy transferred to L_6 at different broadcast band wavelengths.

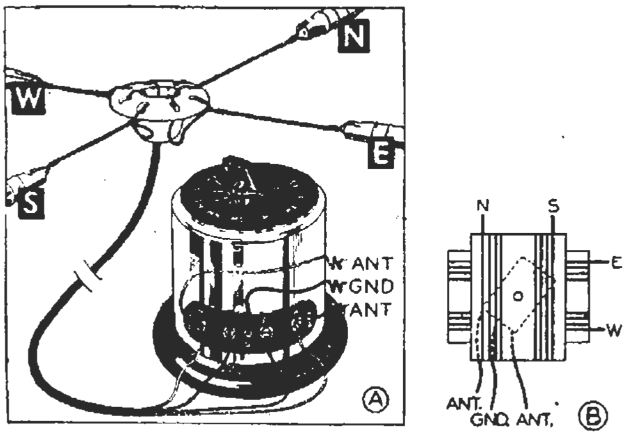


FIG. 27. Taco variable-directivity short-wave antenna, with a selector control which gives the same effect upon directional characteristics as would rotation of a single doublet antenna.

Variable-Directivity Antennas

A short-wave antenna system which is designed to have controllable directional characteristics is shown in Fig. *27A*. Two doublet antennas, each 60 feet long, are located at right angles to each other. At 37 meters they become $\lambda/2$ doublets and have maximum pick-up. At wavelengths longer than 37 meters they are less than λ/2 but still have maximum current at the center and give quite satisfactory signal pick-up. For wavelengths less than 37 meters they may become λ, 3/2λ, 2λ, etc., antennas, with clover-shaped radiation patterns which make the directional adjustment more critical. Each doublet has a two-wire transmission line going to its own coil at the receiver end; the two coils are mounted at right angles to each other as shown in Fig. *27B*, with a third coil mounted in their center in such a way that it can be rotated for maximum coupling with either of the stationary coils or for any intermediate amount of coupling with both coils. In this way it is possible to control the direction from which maximum signal pick-up is secured. The performance is essentially the same as that of the rotatable beam antennas used by amateur radio enthusiasts and by commercial short-wave stations for long-distance radio communication.

TEST QUESTIONS

Be sure to number your Answer Sheet 33FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In addition to feeding strong signals from desired stations into a receiver, what other characteristic must a good receiving antenna have?
   A high signal to noise ratio
2. What two components does a radio wave have? The electric field component + the magnetic field component
3. When a radio signal produces a half-sine-wave distribution of current along a receiving antenna, how many wavelengths long is the antenna?
   ½ wavelength long.
4. What natural condition in space makes long-distance radio communication possible? The fact that sky waves are reflected back toward the earth by the Kennelly-Heaviside layer
5. Describe briefly how sky waves cause fading at receiving locations near the limits of reliable ground wave reception from a given station.
   P 11
6. At what point along a half-wave receiving antenna is r.f. signal current at maximum? The center
7. What information is given by the horizontal radiation pattern of a receiving antenna?
   P 15
8. Why is an antenna transformer sometimes used to connect an antenna to a transmission line? To match the antenna impedance to the surge impedance of the transmission line.
9. What change would you make in a noise-reducing antenna installation if it failed to give a satisfactory signal-to-noise ratio? Change the position of the horizontal pick-up section of the antenna
10. What is the chief purpose of the grounded Faraday shield which surrounds some types of built-in loop antennas?
    P 23