FUNDAMENTALS OF RADIATION

SINGLE-ELEMENT ANTENNAS

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STUDY SCHEDULE NO. 23

For each study step, read the assigned pages first at your usual speed. 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 for that step. Study each other step in this same way.

☐ 1. Electromagnetic Waves .... Pages 1-7

Here you will learn how energy can be sent through space from a transmitting antenna to a receiving antenna. The fundamentals of electromagnetic waves, and how "standing waves" of voltage and current are produced in a wire one-half wavelength long or longer, are also discussed. Answer Lesson Questions 1 and 2.

☐ 2. The Radiation of Radio Waves .... Pages 8-10

In this section you will study why energy is radiated, and how the receiving antenna intercepts the radiated wave. Answer Lesson Question 3.

☐ 3. The Hertz Antenna .... Pages 10-19

This section tells about the properties of the Hertz antenna, and how to connect it to a transmitter. The radiation patterns of Hertz antennas and how the earth affects these radiation patterns are discussed. Answer Lesson Questions 4, 5, and 6.

☐ 4. The Marconi Antenna .... Pages 20-24

This type of antenna is frequently used in standard broadcast transmitters. Its operation, feeding, loading, and radiation patterns are compared to the Hertz antenna. Typical broadcast antennas are analyzed. Answer Lesson Questions 7, 8, and 9.

☐ 5. Special Transmitting Antennas .... Pages 24-28

In television and f.m. broadcasting, special types of antennas must be used. These are discussed in this section.

☐ 6. Receiving Antennas .... Pages 28-36

Here you will learn why different types of receiving antennas are used, and how radio waves are sent through space. Such terms as ground waves, skip distance, and polarization are explained. Typical receiving antennas, including all-wave and noise-reducing systems, are studied. Answer Lesson Question 10.

☐ 7. Start Studying the Next Lesson.

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FUNDAMENTALS OF RADIATION
SINGLE-ELEMENT ANTENNAS

Electromagnetic Waves

ANTENNA systems, used at both transmitting and receiving points, have a very pronounced effect upon the efficiency and reliability of communication. A good receiving antenna, for instance, sometimes may make the difference between good reception and no reception at all! Likewise, an efficient transmitting antenna may permit the use of a very low carrier power for a given field strength at a certain distance, whereas a poor antenna may require a power increase of several-fold.

To understand how any antenna performs, it is necessary to know something about the behavior of electromagnetic waves in space. Let us see how radio waves travel, and the simple laws they must follow in going from transmitter to receiver.

WHAT IS A WAVE?

We have all seen waves on a river or a pond. At any given point, the water is alternately rising and falling in such a way as to give the appearance of traveling horizontally as well.

This illusion of sideways travel arises from the timing of the up and down motion. When the water is at the top of its excursion, as at point a in Fig. 1, it is not quite at the top at point b, although it is rising. Water at point c has already passed its peak and has begun to fall.

At some instant later, the water at point b will be at its peak, while the water at point a will have started to drop. At point c, of course, the water will be down even farther than it was.

In this manner, the crest of the wave moves forward, although the water does not. Thus it is the *disturbance pattern* that travels forward, and not the water itself. This type of motion caused by a disturbance is called "wave motion."

How Frequency, Velocity, and Wavelength Are Related. The water level changes by going through complete *cycles* of rise and fall, over and over again, at a constant rate. If we count so many crests (or troughs) each minute, we may say the water

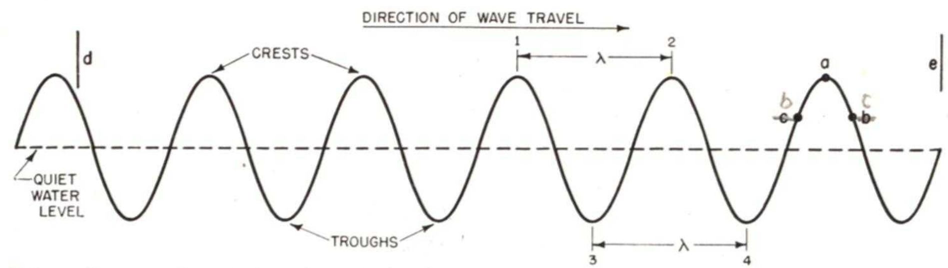


FIG. 1. Diagram showing how the pattern of displacement of a water wave may move steadily from left to right, while the water itself moves only up and down.

wave has a *frequency* of so many cycles per minute. The exact frequency, of course, will depend upon the nature of the source causing the disturbance.

If we were to go to one side of the river and inspect several waves at once, we would see that the crests of two successive waves are separated by a definite distance. In Fig. 1, this is the distance 1-2, or 3-4. This crest-to-crest or trough-to-trough distance is called a *wavelength,* and is always the same for a fixed frequency. We can measure this distance in feet, inches, meters, or any other convenient unit of length.

Finally, the speed, or *velocity,* with which the wave disturbance travels over the water surface can be determined by watching one particular crest to see how fast it moves along. Thus, we can measure the time required for one crest to move over a known distance, such as point d to point e in Fig. 1.

Since the wave travels exactly one wavelength in one complete cycle of rise and fall, we can say simply that the *velocity in feet per second is equal to the distance of one wavelength in feet multiplied by the number of cycles per second.* This is usually written in mathematical symbols as:

$$v = \lambda f$$

where v is the velocity, f is the frequency, and the Greek letter, "lambda" (λ), represents the wavelength.

► The wavelength is one of the most important features of a wave motion. For instance, if we turn the equation around we read:

$$\lambda = v/f$$

and we can see that the wavelength not only depends upon the frequency of oscillation, but also on the velocity with which the wave is propagated. This is true of all types of waves.

RADIO WAVES ALONG WIRES

Electromagnetic waves, or radio waves, will not only radiate into space, as we shall see later, but also they can be made to travel along guiding wires.

Suppose we have a long wire, and we attach a high-frequency generator or oscillator to one end of it. Remember, that electric energy cannot travel instantaneously, so let us observe what happens as the wave travels along the wire. In Fig. 2A, the wave is shown progressing toward the wire end. We can think of this wave as an alternate crowding together and thinning out of electrons at negative and positive peaks.

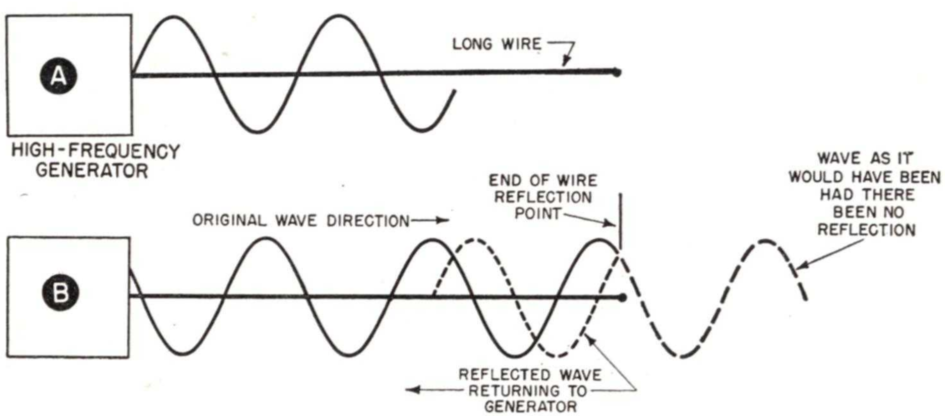


FIG. 2. Illustrating how electric waves on a wire can be reflected by the wire end. This also occurs when there is any sudden change in the wire impedance.

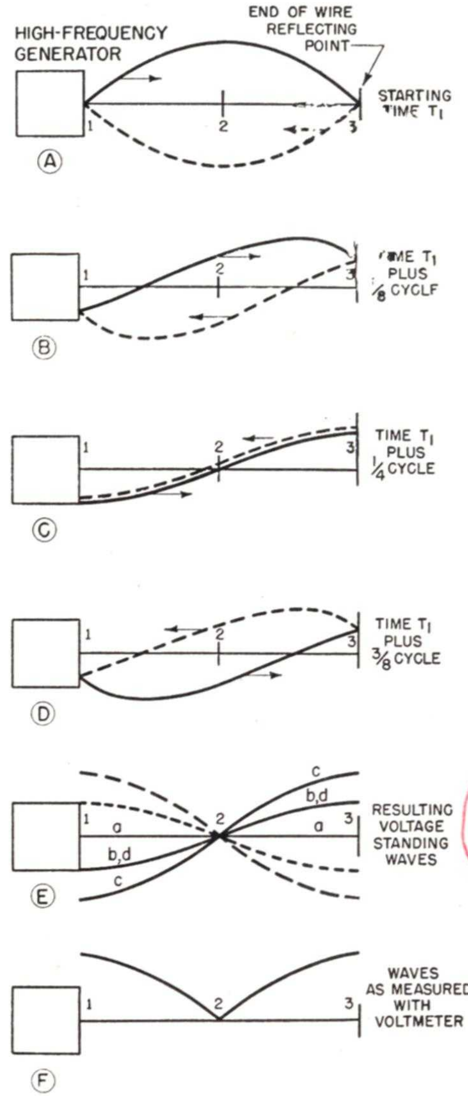


FIG. 3. Showing the manner in which original and reflected waves, traveling in opposite directions, add together to produce standing voltage waves, and how these voltage waves appear when measured with a voltmeter.

► Now what happens when the wave reaches the end of the wire? Since there is no more conducting material in which the electrons can flow, they tend to "pile up," thereby building up full voltage at the wire end. But more important, *the electrons are reflected by the sudden end of the conductor, and the wave begins to travel back the other way* just as water waves are reflected by the river bank.

This reflecting action is illustrated in Fig. 2B. The original wave is drawn in heavy line, and the reflected wave, as it has been forced to turn around and proceed back down the line to return to the generator, is shown in dotted lines. Note the complete reversal of direction. Had there been no wire end, and hence no reflection, the wave would have proceeded as shown in the dashed line to the right of the reflection point.

► This reflection of electric energy is characteristic of all wires, lines, and cables in which there is a sudden break or change of impedance.

Voltage Standing Waves. Let us suppose that we trim the long wire in Fig. 2 so that when voltage of a definite frequency is being fed into the wire by the oscillator we have a *negative drop* of voltage just beginning at the source end, as a *positive rise* is arriving simultaneously at the other end or reflection point. In other words, we have trimmed or cut off the long wire until it is *exactly one-half a wavelength long.*

This particular adjustment is illustrated in Fig. 3A. The heavy line shows the voltage distribution along the wire at a certain instant, when a wave is traveling to the right, and the dotted line indicates the accompanying reflected wave returning to the generator.

An eighth of a cycle later, the original wave will have traveled to the right one-eighth of a wavelength, and the reflected wave will have moved to the left the same distance. This gives the distribution shown in Fig. 3B.

Still another eighth cycle later, the two waves will have moved in opposite directions to give the picture in Fig. 3C. And finally, three-eighths of a cycle after Fig. 3A, we have the relation given in Fig. 3D.

This plotting of voltage distribution can be carried on for a complete cycle, after which the patterns repeat themselves, over and over again.

But what is the actual effective voltage along the wire as these two waves travel in opposite directions? The resultant voltage at any point on the wire is equal to the combined effects of the original and the reflected waves. Let us see what the sum of these voltage waves can be.

First, let us add together the two voltage waves of Fig. 3A. Everywhere that the original wave is positive, the reflected wave is negative. Conversely, wherever the original wave is negative, the reflected wave is positive. We find then, that these two waves tend to cancel each other, and we have the effective voltage reduced to zero all along the wire for this particular instant. This condition is represented by the zero voltage straight line a in Fig. 3E.

If we next take the waves for an eighth cycle later as in Fig. 3B, and add them together, we get the following as shown in curve b of Fig. 3E:

At point 1, both waves are slightly negative, and they add together to give a moderate negative voltage. At point 2, the original wave is positive, but the reflected wave is negative and equal in value so that the resultant voltage is reduced to zero. At point 3, both waves are positive. The resultant voltage, therefore, is equal to their sum, and is also positive.

In a similar way we can add the waves of Figs. 3C and 3D to get the curves c and d of Fig. 3E.

Furthermore, if we drew curves for *all conditions* throughout a complete oscillator cycle, we would also have the dotted curves shown in the same figure.

Curves b and d in Fig. 3E are identical, because the two components, the original wave and the reflected wave, are the same. Notice, however, that the reflected wave in 3B is the same as the original wave of 3D. Likewise the original wave of 3B is the same as the reflected wave of 3D. The sum of the reflected waves and the original waves in either case is the same.

► The peculiar voltage distribution of Fig. 3E is a very important phenomenon. Note that although this particular voltage pattern is caused by two waves traveling in opposite directions, the pattern itself remains stationary. Only the instantaneous voltages change their values, pulsing positively and negatively in time with the frequency of the generator supplying the energy. Because of their behavior, these voltage patterns on a wire are called "standing waves."

Voltage Loops and Nodes. Note that at points 1 and 3, the voltage reaches a higher value than at any other point along the wire. These points, at which maximum voltage is developed, are called "voltage loops"; they always occur exactly one-half wavelength apart.

Notice, also, that at point 2 the voltage is always zero. This zero voltage point is called a "voltage node."

In Fig. 3E, we have the voltage standing wave pattern as it really exists. That is, in curve c, for example, if the voltage loop at point 1 is positive at one instant, then the voltage loop at point 3 is negative. In other words, the loops are 180° out of phase. If we were to measure the voltage along the wire with an a.c. voltmeter, we would not obtain this particular pattern. All voltages would be recorded as positive, since the voltmeter cannot make allowance for phase. Voltmeter readings then, will give a voltage standing wave pattern like that in Fig. 3F. Nevertheless, this is still a useful pattern, and the loops are still one-half wavelength apart. In fact, ultra-high-frequency waves are measured in precisely this manner.

Current Standing Waves. By using the same method of drawing original and reflected waves, we can also outline the current standing wave pattern. There is, however, one important difference. There is no current at the end of the long wire. To make the end current zero, we find it necessary to *invert* the phase of the reflected wave. In other words, if the original current arriving at the end is positive, the reflected current must be negative, and vice versa. This is reasonable, for the current entering the end of the wire must be equal, and opposite, to that current leaving the same point.

The current standing wave pattern for a wire of one-half wavelength long appears in Fig. 4. Compare this to the voltage standing wave in Fig. 3E.

► It is important to note that the positions of nodes and loops have been interchanged. For instance, at the ends of the wire, points 1 and 3, we have *voltage loops* and *current nodes;* also, in the center at point 2, we find a *voltage node* and a *current loop.*

Whenever we have standing waves along a wire, it is always true that *at every point where there is maximum voltage, we will find near-zero current; conversely, at those points of zero voltage, the current will have its maximum value.*

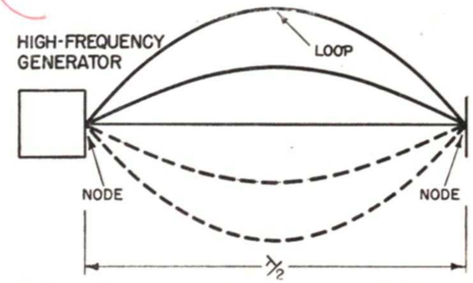


FIG. 4. Current standing waves on a half-wave wire showing the "loop" of maximum current at the center, and the zero current or "nodes" at each end.

Length of Resonant Wires. When we trimmed the long wire to set up the standing waves of Figs. 3E and 4, we actually "tuned" the wire to resonate at the frequency of the oscillator. We could have realized the same standing wave patterns by leaving the wire as it was, and adjusting the frequency of the oscillator until exactly one-half a wave reached across the entire line.

To what length must we cut a wire to make it resonant for a given frequency? When we were discussing water waves, you will remember, we found that a wavelength was equal to the wave velocity divided by the frequency, or

$$\lambda = v/f$$

Since radio waves travel along a wire with very nearly the velocity of light, or 300,000,000 meters per second, the length in meters of a *full-wave-*

length wire would be 300,000,000 divided by the frequency in cycles per second. Thus, for a frequency of 1500 kilocycles, the length of a full-wave wire would be:

$$\lambda = \frac{300,000,000}{1,500,000} = 200 \text{ meters}$$

and, of course, a *half-wave* wire would be exactly one-half this value, or 100 meters long. (When the frequency is given in megacycles, divide 300 by the frequency in megacycles rather than convert the frequency to cycles per second.)

► Notice that a wire 100 meters long is a half-wavelength long at 1500 kc. (1.5 mc.), but at 3 mc. the same length of wire is one wavelength long. Likewise, at 6 mc. it is 2 wavelengths long.

Resonance Effects. After standing waves have been set up in a long wire as in Figs. 3E and 4, we find that at point 1 where the oscillator is delivering its energy, that the voltage is very high, but the current, theoretically, is zero. This means that the end of the wire presents a very high impedance to the oscillator, and very little current can flow into the line. Nevertheless, at point 2 the current can be quite high.

► This is exactly the behavior of a parallel-tuned circuit, which at resonance draws very little generator current because of its high impedance, yet has a heavy circulating "tank" current. We can expect then, that *a half-wavelength of wire will act exactly as a parallel resonant circuit.*

The resonant line differs from the parallel resonant circuit, however, in that it is resonant at more than one frequency. For instance, if we take the line we have trimmed, and increase the oscillator frequency to twice its former value, thereby cutting the wavelength in half, we find that a *full-wave* standing wave pattern is developed along the wire as in Fig. 5. The heavy line outlines the maximum voltage values; the dotted line represents the maximum values of current along the wire. As before, we have voltage loops and current nodes at the wire ends, and very high impedance is presented to the oscillator. We have, however, one additional loop and node for both current and voltage.

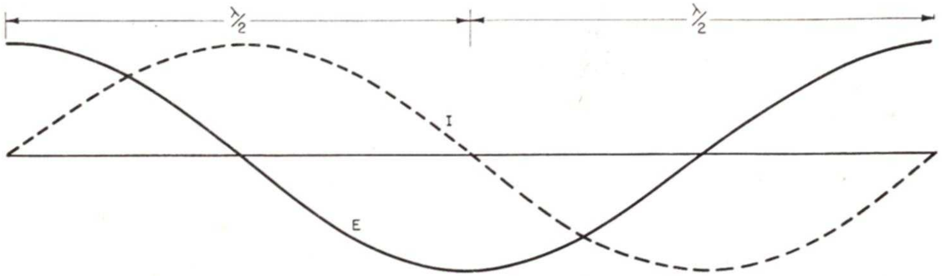


FIG. 5. Current and voltage standing waves along a full-wave wire.

We could carry the experiment still further by increasing the oscillator frequency to 3 or 4 times its original value for a single half-wave, and thereby developing standing waves of 3/2 wavelength or 2 full-waves, respectively. In doing this, we would find that the long wire acts as a parallel circuit for all multiples of the lowest half-wave frequency.

► In all cases, however, the oscillator

will be delivering power into a voltage loop and a current node. This particular method of feeding a wire at a high-voltage, low-current point is commonly called "voltage feed."

Instead of feeding energy to a long wire at its end, it is possible to set up standing waves by breaking the line at any point and inserting the oscillator, or generator, in series with the line. In Fig. 6, the oscillator is shown inserted in the center of a half-wave line. As shown by the voltage and current curves, the oscillator is feeding into a current loop and voltage node. We see, therefore, that the oscillator is working into an extremely low resistance, and must deliver very high current at a very small voltage. Nevertheless, the voltage at each of the wire ends still reaches a high value.

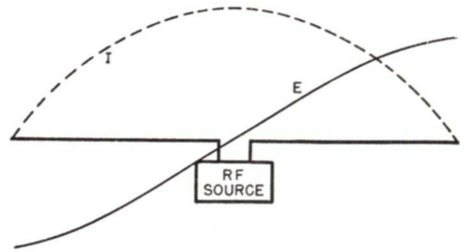


FIG. 6. Standing waves set up on a half-wave line by current-feeding at a low-impedance current loop.

Here again, we have the line behaving as a resonant circuit; but this time it resembles a *series-tuned* circuit which presents a very low external impedance, drawing a heavy current at low voltage, yet developing very high voltage across its components.

► This manner of feeding energy into a resonant line at a high-current, low-voltage point is called "current feed."

Impedance of a Resonant Wire. From Ohm's Law we know that the impedance in a circuit is equal to the voltage divided by the current. This also applies to resonant lines. For a resonant wire, the impedance at any point along the wire is equal to the voltage divided by the current at the same point.

In Fig. 7, the voltage distribution on a half-wave line is shown as the heavy line E, and the current distribution as the dotted line I. If at every point we divide the E values by the corresponding I values, we will obtain an impedance curve such as the dashed curve, Z.

Curve Z is the impedance variation along a resonant line that has *no losses*. Notice the impedance is zero at the current loop, but theoretically extends to infinity at the current nodes. In actual wires, this is never quite realized, for all lines have some losses. Nevertheless, the impedance along a resonant line quite commonly changes by a factor of several thousand times.

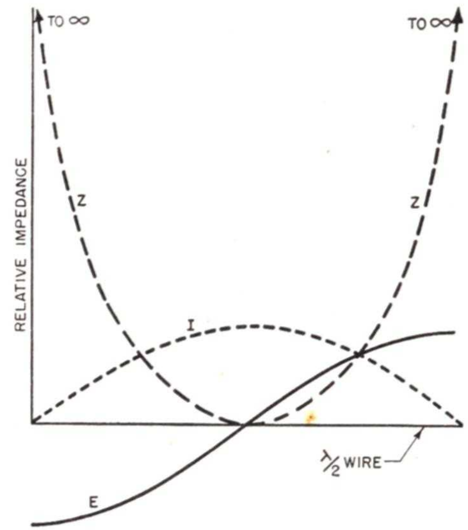


FIG. 7. The impedance at any given point along a resonant wire is equal to the voltage divided by the current at that point.

The Radiation of Radio Waves

Up to this time, we have considered only standing waves along a wire, and the peculiar voltage, current, and impedance values we may find along the wire. We will discover, however, that in order to maintain the standing waves, we must supply a continuous amount of energy, for some of the energy leaves the wire and radiates into space. The radio energy travels in space instead of on a wire. Let us see how this comes about, and how we can use this useful fact.

WAVES IN SPACE

In order to understand how radio energy is radiated into space, let us review some basic electrical considerations.

Electric and Magnetic Fields Around a Wire. In any of our voltage standing wave patterns for a half-

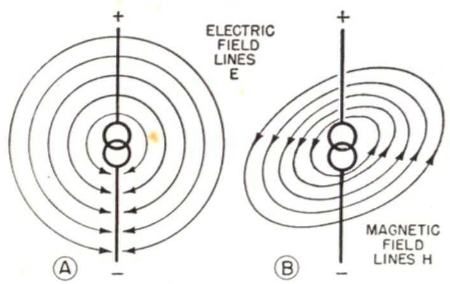


FIG. 8. The electric and magnetic field lines surrounding a resonant current-carrying conductor in free space.

wave line, we noticed that the two voltage loops at the wire ends were 180° out of phase, and were, therefore, of opposite polarity at any instant. Because of this, a half-wave wire often is called a "dipole."

In such a dipole, these regions of opposite voltage generate an electric field in space outside the wire just as two condenser plates of opposite polarity produce an electric field between them. In Fig. 8A is shown a half-wave wire, or dipole, being current-fed at its center. At any given instant, when the top and bottom of the wire have reached their maximum positive and negative potentials, the electric field lines E bow out from top to bottom in much the same manner as shown in the figure.

In addition, since the wire also has current flowing along its length, a magnetic field is generated around the wire just as with any other current-carrying conductor. The magnetic field lines H are represented in Fig. 8B.

If the frequency of the oscillator should happen to be very low, both magnetic and electric fields around the wire would start from zero, and gradually expand to their maximum values in one direction, drop again to zero, expand again with the direction of the field lines reversed, then collapse again to zero. This is repeated, over and over again, for every alternating current cycle of the generator.

► If we gradually increase the frequency of the generator, we find that both the electric and the magnetic field begin to behave in an unusual manner. As the frequency is increased, the fields find it more and more difficult to collapse fast enough to keep up with the rapidly changing wire current. In other words, these field lines behave as though they had inertia, and show a tendency to resist any sudden change in their intensity.

Let us look at Fig. 9. In A, we have the top of the dipole at the start of a

cycle becoming more and more positive, and the lines of the electric field correspondingly increasing in intensity. At B, the potential difference between top and bottom of the dipole has reached its highest value. The accompanying electric field also has expanded to its maximum intensity.

In Fig. 9C, we find that the potential between the dipole ends is beginning to diminish. The electric field lines, however, do not follow readily, new field near the wire forces outward the old field which has not previously collapsed.

A similar action takes place in the magnetic field around the dipole. Although we have not shown it here, each magnetic field finds it difficult to collapse with sufficient speed, and is, therefore, snapped off and pushed outward by the following fast-growing new field of the opposite polarity.

We may visualize the field lines leav-

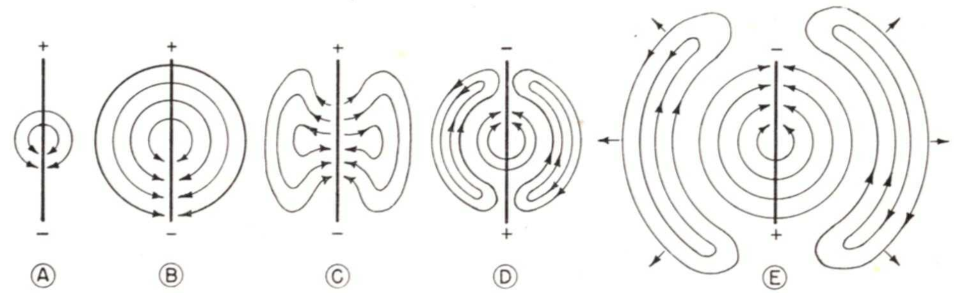


FIG. 9. The electric field is pushed into space by the next field of opposite polarity. The action of the magnetic field at right angles to the electric field (not shown) is the same.

and tend to distort themselves into a doughnut-shape. Since the electric field is present at all points around the wire, the field lines in the figure actually represent only a cross-section of the complete field.

► In Fig. 9D, the alternating current in the wire has passed through zero and begun to flow in the opposite direction, thereby making the top of the dipole negative, instead of positive. This gives rise to a new electric field of opposite polarity. The old electric field lines in C, however, have not yet had time to collapse, and they are simply snapped off. The new field, growing near the wire, now pushes the old field outward in every direction at the speed of light as illustrated in Fig. 9E. This process is repeated, over and over again, with each alternating current cycle. Each

ing a dipole as a series of expanding bubbles, one inside the other; the radius of each bubble increasing with the velocity of light. These magnetic and electric fields that fly off into space constitute what we call an "electromagnetic wave."

Plane Waves. In Figs. 8 and 9, the electric field lines E, and the magnetic field lines H, are always at right angles to each other. Close to the radiator, the lines have considerable curvature. As they leave the wire, and radiate into space, these circular lines expand in diameter at a very rapid rate. If we could see an electromagnetic wave coming toward us from a dipole some distance away, the bubbles would be so large that when we examined a small part of a bubble surface the electric and magnetic field lines would appear flat. Under these circumstances we say the electromagnetic wave is a "plane wave."

In Fig. 10 is shown how a small section of a plane wave would appear. The heavy vertical lines represent the electric field; the dotted lines indicate the accompanying magnetic field at an

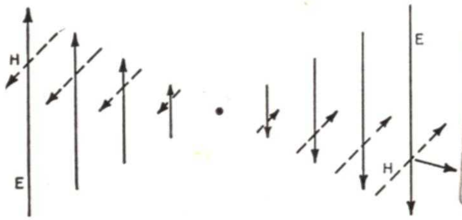


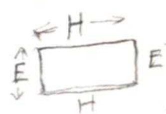
FIG. 10. An imaginary electromagnetic plane wave moving from left to right in which the electric and magnetic field lines are at right angles to each other and to the direction of wave travel.

angle of 90°. The entire wave is traveling to the right in the direction of the arrow. Electromagnetic, or radio waves, are "transverse" waves because the direction of both the E and H fields is at right angles to the direction of travel.

Wave Polarization. In Fig. 10 the electric lines E are drawn vertically. This is commonly called a "vertically polarized" plane wave. Waves of this type are radiated by a vertical wire.

If, instead, the electric lines E had been horizontal, and the magnetic lines H vertical, we would have a "horizontally polarized" plane wave. A horizontal wire radiates horizontally polarized waves.

► Now that we have observed that a long wire operates as a radiator of electromagnetic waves, it is obvious that such wires can be used as transmitting antennas. Let us see then, how these wires can be made into efficient antenna systems, and what forms these systems may take.



The Hertz Antenna

The simplest type of transmitting antenna is called the Hertz antenna, for the German scientist who first used it. It consists merely of an *ungrounded* length of wire which is fed with radio-frequency current at one of its resonant frequencies. We see then, that any of the long wires with standing waves on them, as shown in Figs. 3, 5, and 6, are Hertz antennas.

Hertz antennas may be voltage-fed at a high-impedance voltage loop as in Figs. 3 and 5; or they may be current-fed at a low-impedance voltage node as shown in Fig. 6. The current and voltage standing wave patterns, in any case, will always be the same. It is possible, also, to operate a Hertz antenna with any number of half-wave standing waves along its length. The most elementary form, however, is that in which the wire is cut to a single half-wave length, so in this particular case, the Hertz antenna is called a dipole.

POWER RADIATED FROM AN ANTENNA

As we pointed out earlier, the impedance along a dipole varies theoretically, from zero at a current loop to infinity at a voltage loop. See Fig. 7. But this is for standing waves on a wire that has *no radiation or I^2R losses.*

Radiation Resistance. Radiation losses modify somewhat the impedance variation along a dipole. In a practical, well-isolated antenna, the impedance at a current loop (the center of the antenna in the case of a half-wave radiator) instead of zero, is approximately 72 ohms. The impedance at a voltage loop, instead of reaching infinity, will usually be somewhere between 1000 and 50,000 ohms, the exact value depending upon the nearness of surrounding conducting objects and the ground. *The impedance of a radiating antenna at the point where power is fed to it is called the "radiation resistance" of the antenna. If a resistance, the ohmic value of which is equal to the radiation resistance, were connected to the end of the transmission line in place of the antenna, it would dissipate as much power as the antenna.*

For this reason, the transmitter and the transmission line to the antenna must be designed to work into this "radiation resistance." Generally, an antenna is fed at a current loop (maximum) which, in the case of a half-wave antenna, is at the center of the antenna. In this case, the "radiation resistance" is about 72 ohms.

How the Power Input to an Antenna Is Calculated. In determining the power delivered to a transmitting antenna, the radiation resistance can be considered just as real as though it were an actual resistor. For example, by following Ohm's Law, we can multiply the square of the antenna current at a given point by the effective radiation resistance at the same point, and determine the true power being dissipated by the antenna.

To illustrate, if we have a current of 5 amperes flowing in an antenna resistance of 500 ohms, the power being absorbed by the antenna is:

$$\text{Power} = I^2 R = 5^2 \times 500 = 25 \times 500 = 12{,}500 \text{ watts or } 12.5 \text{ kilowatts.}$$

If we should substitute a fixed resistor of 500 ohms for the antenna, we would find that the same power of 12.5 kilowatts would be delivered to the resistor.

► The power to an antenna is equal to the *square* of the current multiplied by the radiation resistance. If the antenna current in the previous example were 15 amperes (*3* times the former value) the power would increase to *9* times its former value, that is, 112.5 kilowatts.

Efficiency of an Antenna. No antenna, however, is 100% efficient. Any antenna, in addition to its radiation resistance, also has ohmic resistance in its conducting wire.

The efficiency of any antenna is the ratio of radiated energy to the total energy supplied by the transmitter. Since the same antenna current flows in both radiation and ohmic resistances, efficiency may be expressed as the ratio of radiation resistance to the total resistance of the antenna system. In good antennas, this figure may easily approach 90% to 95%.

REMOTE FEED TO A HERTZ ANTENNA

It is desirable to construct an antenna in a well-isolated, clear space where it is free from absorbing objects; often it is impractical to connect the transmitter, or oscillator, directly to the antenna. Some system of remote feed, therefore, must be used.

Tuned Feeders. If we connect the transmitter to the antenna by means of a pair of parallel wires a half-wave-length long, as shown in Fig. 11, we find that the transmitter delivers the same power as it did before. We now have standing waves on the "tuned feeder" line as shown, with both the antenna and the transmitter operating

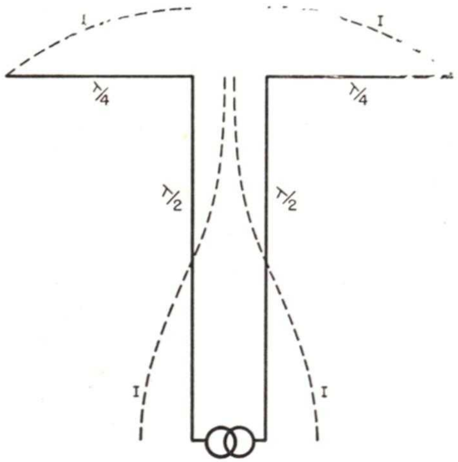


FIG. 11. Half-wave tuned feeders current-feed a remote antenna by presenting current loops at both the antenna and the transmitter.

at low-impedance current loops. This is a current-feed system.

As current loops always occur exactly one-half wavelength apart, the tuned feeders can be any convenient whole number of half-waves in length.

Actually, there is some radiation from the parallel feeders, but since these wires are very close together, the radiation from one feeder wire tends to cancel the radiation from the other feeder wire. In this way, almost all radiation still occurs in the open antenna at the end of the transmission line. Except for slight losses in the line, the effect of this feed system is exactly the same as though the transmitter were connected directly in series with the antenna itself.

In practice, the tuned feeders are seldom cut to exact lengths; instead, they are cut to some convenient length, and tuned coupling circuits as in Figs. 12A or 12B are used to feed in energy from the transmitter tank. If the lines are shorter than one-half wavelength long, the parallel-tuned coupling circuit in Fig. 12A increases their apparent electrical length. If they are longer than one-half a wavelength long, the series-tuned circuit in Fig. 12B effectively shortens them. Adjusting the variable condensers in each case brings the combined coil-condenser feeder-antenna system to resonance.

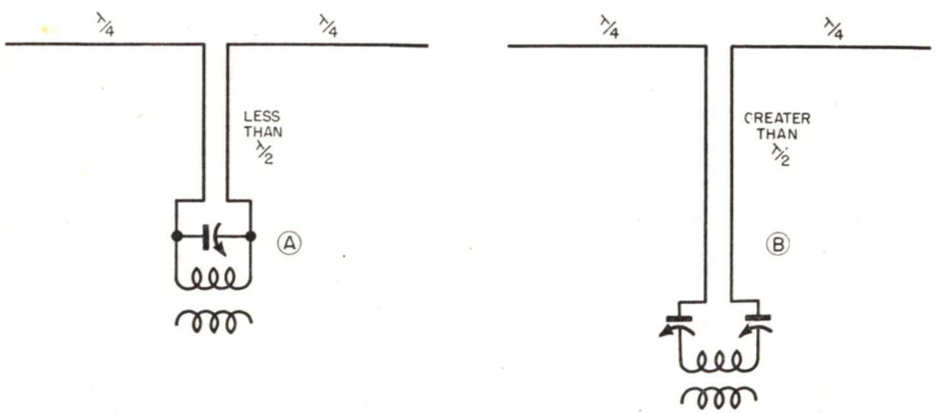


FIG. 12. For feeders that are too short, the electrical length can be increased by parallel tuning as in A. Series tuning, shown in B, is used to "shorten" feeders cut too long.

Tuned feeders can be used in the same manner to make a voltage-feed system. In Fig. 13 is shown the familiar "zeppelin" antenna, so called because it was first used on lighter-than-air craft. In this instance, the ideal length of the feeders is one-quarter wavelength or some *odd* multiple thereof.

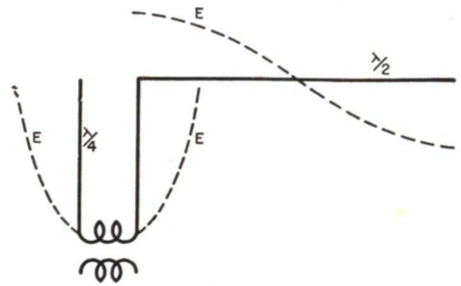


FIG. 13. The "Zepp" antenna is voltage fed.

This insures that a voltage loop on the feeder wires is connected to a corresponding voltage loop at the antenna. As before, with feeders not quite the correct length, either series- or parallel-tuned coupling networks can be used.

Untuned Feeders. If we attempted to use tuned feeders with the antenna separated from the transmitter by a comparatively long distance, we would probably find the line losses intolerably high. There is a considerable amount of energy lost at every current loop where the current is extremely high. Increasing the number of current loops, therefore, rapidly increases the line losses. In addition, although radiation from a short tuned line is slight, if the line should be too long, the stray radiation might increase to such a point that the radiation pattern of the antenna itself might be affected, resulting in strong signals where they are not wanted, and thus leading to unnecessary interference as well as to a waste of power in the tuned feeder lines.

We previously discovered, in our study of audio-frequency transmission lines, that if the line is terminated in its characteristic impedance, not only do we obtain a maximum transfer of power, but also there is no reflection of energy from the end of the line. It follows then, that *if we can terminate a high-frequency line with an apparent resistance exactly equal to its characteristic impedance,* no wave reflection will occur at the antenna termination, and *no standing waves will be set up along the feeder line.* Our transmission line, then, can be any length, and tuning will not be necessary.

Since a half-wave antenna has a radiation resistance of approximately 72 ohms, we can current-feed it by attaching a 72-ohm twisted-pair line as in Fig. 14. By proper choice of wire

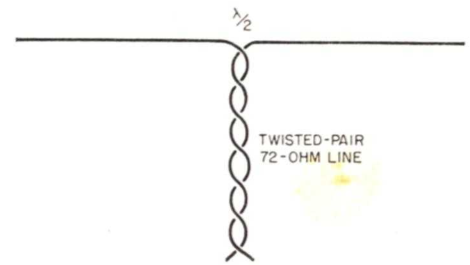


FIG. 14. A 72-ohm twisted-pair line can be connected directly to the center of a half-wave antenna without mismatch loss.

size and insulation thickness, the twisted-pair line is made to have a characteristic impedance of 72 ohms.

If we want to use a 600-ohm open-wire line instead of a 72-ohm twisted-pair, we can match the antenna impedance to the higher line impedance by means of a transformer, as shown in Fig. 15.

In general, however, it is difficult to build a radio-frequency transformer that does not require tuning, so a simpler and more efficient method is to "fan out" the line so that it can be connected to the proper points on the antenna which have a higher impedance as illustrated in Fig. 16. This particular method of connecting an untuned line is called "delta feed." The gradual spreading out of the line wires is necessary to prevent any *sudden* changes in line impedance which would cause re-

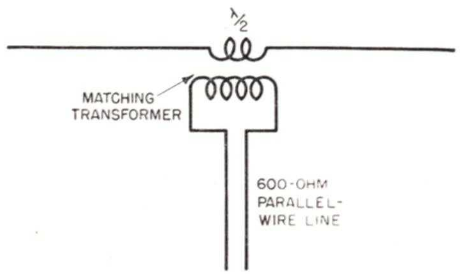


FIG. 15. A 600-ohm line can be made to appear as 72 ohms to the antenna by using an impedance-matching transformer.

flections and consequent standing waves on the line. Notice that the ends of the wire connect to the 600-ohm points of the radiating antenna, and that there is no spacer in the center of the antenna.

The losses in any transmission line will increase as the length of the line is increased. The untuned line, however, because it has no standing waves and consequent power-wasting current loops, will usually be much more efficient than the tuned transmission line. In use, the untuned line has very nearly a constant current throughout its length; the current being slightly lower at the terminating end because of power losses in the line.

In addition to the methods already discussed, many other ways of matching an untuned transmission line to the antenna have been devised. In one particular example, a short tuned line is used as a transformer to provide any desired impedance match between the antenna and an untuned long line. A more detailed description will be given in a later Lesson.

RADIATION PATTERNS OF HERTZ ANTENNAS

The Free-Space Dipole. So far, we have discussed the manner in which standing waves may be set up along a transmitting antenna wire and how these standing waves are instrumental in generating electromagnetic waves which travel outward through space. We have no reason to expect, however, that an equal amount of energy will be propagated in all directions. In just what directions will the radio wave energy be concentrated as it leaves the transmitting antenna?

Suppose that we have a half-wave Hertz antenna (a dipole) suspended with its length pointing north and

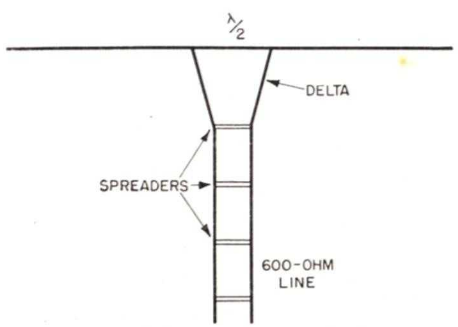


FIG. 16. The delta feed matches the line to the antenna by spreading the feeders and attaching them at the 600-ohm impedance points of the antenna.

south, and parallel to the earth's surface. Let us say, also, that the antenna is so far above the ground and other conducting bodies that there will be little effect upon the radiation. We will have then, a *horizontal* dipole in *free*

space, a basic reference antenna.

Now if we take a field-strength meter, which is a receiver calibrated in terms of the field strength of the signal being received, and walk around the antenna, taking measurements as we go, we can determine the relative radiation in all directions. Let us assume that as we go around the antenna, we keep some constant distance away, one mile for instance, from the center

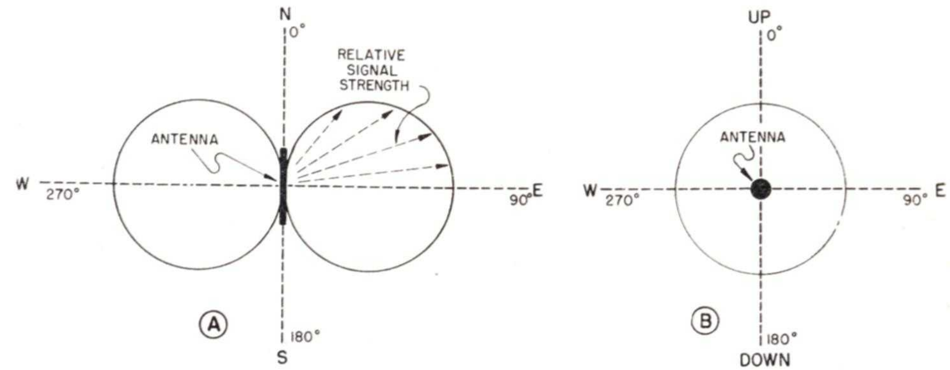


FIG. 17. In A, the horizontal plane radiation pattern for a horizontal half-wave antenna in free space resembles a figure-eight. The vertical plane pattern in B, is a perfect circle.

of the antenna, making a circle with a radius of one mile, having the antenna for a center.

The field-strength measurements we take under these circumstances show accurately the variation in radiation for different angles about the horizontal antenna. If we plot these readings, making the distance of each plotted point from the center of the graph proportional to the observed field strength for each angular position, we obtain a pattern as in Fig. 17A.

Since we have taken our measurements in a *horizontal plane,* this pattern represents the radiation of the dipole in a horizontal plane.

Note that the curve does not mean that the radio waves go out to a certain point and then stop. Theoretically, the waves keep going indefinitely. The distance from any point on the curve to the antenna center, does, however, represent the relative amount of energy being propagated in that particular direction.

It is important to note that there is zero radiation along the north-south length of the antenna, and that the points of maximum radiation, commonly called "lobes," occur at right angles to the antenna. This is characteristic of all half-wave antennas, and is brought about because the maximum electromagnetic radiation is perpendicular to the direction of current flow in the dipole.

Fig. 17A represents the radiation of a horizontal dipole in a *horizontal plane.* We could obtain another radiation pattern if we were to fly under, around, over, down, and below the antenna, always keeping a fixed distance away, and taking measurements as we went. Since in this case we would be taking field-strength readings as we traveled in an up-and-down, or vertical plane, the pattern we obtained would represent the radiation in a *vertical* *plane*. The antenna always looks the same from any vertical position, and since the radiation remains constant, our graph can be plotted as before, forming a perfect circle. This is illustrated in Fig. 17B.

By studying the graphs of Figs. 17A and 17B, which show the horizontal and vertical plane radiation, respectively, we can see that the *three-dimensional* radiation pattern of an isolated dipole looks like a gigantic doughnut with

3/2 wavelengths long, or 2 wavelengths long?

Let us take the full-wavelength antenna first. Since it is exactly two half-waves long, we can consider it as the combination of two dipoles, or half-wave antennas, in series. Refer to Fig. 5, which shows the standing wave pattern on such a full-wave antenna. We can assume that the right half of the antenna is one dipole, and that the left half is a second dipole.

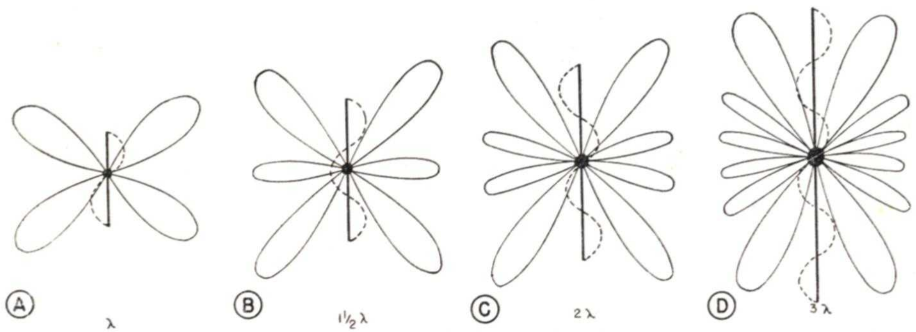


FIG. 18. Polar radiation patterns in the vertical plane (thin solid lines), and current distribution curves (thin dotted lines) for vertical antennas of various lengths in free space are shown here. You will observe that increasing the antenna length causes more of the energy to be radiated toward (but never along) the directions in which the antenna is pointing.

the antenna running directly through a very small hole.

Had we used a *vertical* antenna instead of a *horizontal* one, the vertical and horizontal plane radiation patterns would have been interchanged; Fig. 17A would have become the vertical plane pattern, and Fig. 17B the horizontal plane pattern. In any case, the radiation patterns for a dipole in free space are always the same *with respect to the antenna itself*.

Directional Patterns of Multi-Wave Antennas. We have considered, so far, the radiation pattern of a single half-wave antenna or dipole only. What sort of pattern can we obtain if we set up standing waves on free-space antennas of a full wavelength long,

There is no reason to assume that the radiation from either of these twin dipoles will be any different from the patterns shown for a single dipole in Figs. 17A and 17B. As a matter of fact, the action is identical. There is, however, one important point we cannot overlook. Notice that the current and voltage in the right half of the antenna in Fig. 5 are exactly 180° out of phase with the current and voltage in the left half. We have, therefore, two dipoles excited 180° out of phase.

We should expect then, as we take radiation measurements around a full-wave antenna, that at some points the radiation from one effective dipole will aid and increase the radiation from the other dipole; while at other points,

the two radiation fields will be out of phase and hence cancel each other. As a matter of fact, it is obvious that directly broadside to the radiation from the right half of the antenna will be exactly equal and opposite to that from the left half. In other words, at right angles to the antenna wire, there will be no radiation at all.

This is exactly what happens. Suppose we suspend, horizontally, a full-wave antenna in free space—the *horizontal* radiation pattern appears as in Fig. 18A. Note that new zero radiation

HOW THE GROUND AFFECTS A HERTZ ANTENNA

Up to this point, we have considered the theoretical performance of the Hertz antenna when it is located in isolated free space, entirely removed from any effects of the ground. Obviously, it is impossible to realize this condition. In practice, the antenna is always near the earth, which has a very definite effect upon the antenna characteristics and behavior.

To some extent, all objects reflect radio waves. A large sheet of low-resist-

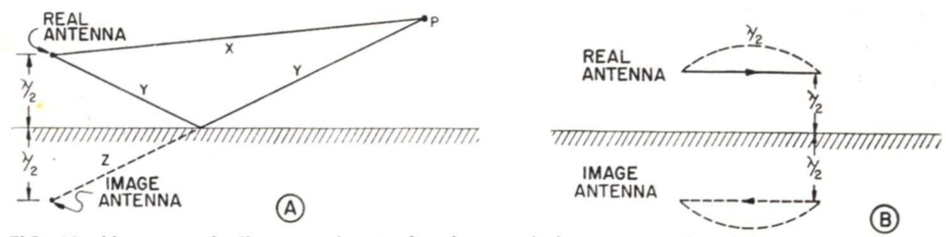


FIG. 19. How ground effects can be simulated correctly by assuming that the reflected waves are radiated by a fictitious image antenna below the ground surface.

points or "nulls" now occur directly broadside to the antenna. Notice also, that we now have four lobes instead of two, and these have moved toward the ends of the wire.

Similarly, if we consider the antenna of 3/2 wavelengths as three dipoles, and the antenna of 2 full-wavelengths as four dipoles, the aiding and canceling interference from each additional dipole element will result in more and more complex radiation patterns. Not only will the lobes of maximum radiation be shifted nearer and nearer the direction of the antenna itself, but numerous minor lobes of lower radiation intensity will develop also. The horizontal radiation patterns for horizontal free-space antennas 3/2, 2, and 3 wavelengths in length are shown in Figs. 18B, 18C, and 18D.

ance metal reflects radio waves in exactly the same way that a mirror reflects light waves. In most circumstances, as far as the reflection of radio waves is concerned, moist ground of high conductivity can be considered as a very large sheet of metal. If we have an antenna of any sort which is directly over low-resistance, moist earth, we can expect that some of the energy radiated by the antenna will strike the ground and be reflected at a new angle. This results in a distortion of the radiation pattern as well as in an apparent change in antenna radiation resistance.

The "Image" for a Horizontal Hertz Antenna. Let us suppose that we have a horizontal Hertz half-wave antenna suspended exactly a half-wavelength above the ground. Fig. 19A shows a cross-sectional view of how we would see the antenna "end-on," or looking down its length.

Since a half-wave antenna radiates most of its energy broadside, there is little radiation toward and away from us, and most of the radio wave energy will be directed up, down, right, and left.

► We can see that radiation may be received at any remote receiving point P, directly along path X. However, radio waves may strike the ground along path Y, be reflected, and also reach the same point P. This is exactly the same phenomenon we have when light is reflected by a mirror. As far as point P is concerned, the radiation coming over path Y looks exactly as though it had traveled over the dotted path Z, after being generated by the "image" antenna located one-half wavelength below the earth's surface. Theoretically, it is possible to realize an identical radiation field at point P

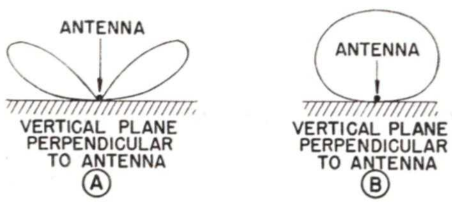


FIG. 20. How ground reflection changes the radiation pattern of a horizontal antenna.

if we ignore the reflection of radiated waves, and instead, consider the effects of additional radiation from an image antenna below ground.

Actually, such an image antenna does not exist, for radio waves themselves do not penetrate the earth very deeply. The use of such fictitious images, however, is very convenient, and with them it is possible to predict just what antenna behavior can be expected under different circumstances.

For correct results, we must assume that the instantaneous direction of current flow in the image antenna is 180° out of phase with that in the real antenna. This is illustrated in Fig. 19B which shows a broadside view of the real and the image antenna located a half-wavelength above and below the ground surface respectively.

How Changes in the Radiation Pattern Occur. When the resultant radiation arrives at any point P, as in Fig. 19A, it is equal to the sum of the direct and the reflected waves, and we find that at some points the two waves add together, and at other points they cancel, depending upon the relative phases of each wave. This results in a very decided change in the effective radiation pattern. The radiation in a vertical plane for a half-wave horizontal antenna, a half-wavelength above the ground, is shown in Fig. 20A. Compare this with the radiation of such an antenna in free space as in Fig. 17B.

As the depth below ground of the image antenna will always be equal to the real antenna height above ground, the effect of the image will be different for various antenna heights above ground. Thus, the vertical radiation pattern for a half-wave horizontal antenna just ¼ wave above the ground will look like Fig. 20B. Compare this, also, with the free-space pattern in Fig. 17B.

The Resistance of an Antenna Depends on Its Height. With any antenna, some of the energy that is radiated directly toward the ground is reflected and returned promptly to the antenna, where it is absorbed. This causes a secondary current to flow, which may aid or reduce the original flow of current, depending upon the relative phase of the two currents. *The net effect is that the radiation resistance of the antenna is changed.*

Because the phase of the reflected wave depends upon the antenna height, the apparent antenna resistance also will depend upon the antenna height. In general, the radiation resistance of a horizontal antenna is near zero for very low heights, increases to a maximum of about 100 ohms for a height of 1/3 wavelength, and then varies slightly above and below the theoretical value of 72 ohms for further increases in height.

The Image of a Vertical Antenna. The effects of ground reflection can be just as pronounced with a vertical antenna as with a horizontal one. A half-wave vertical antenna with its center located a half-wavelength above the ground is illustrated in Fig. 21A. Just as before, the energy at any point P is the sum of waves arriving over the direct path X and the reflection path Y. Here, too, an image antenna can be used for correct results.

It is important to note, however, that the direction of instantaneous current flow in the image of a vertical antenna is *in phase* with the direction of instantaneous current flow in the real antenna and *not* reversed or 180° out of phase, as was the case for the horizontal antenna.

The radiation pattern for the antenna in Fig. 21A is shown in Fig. 21B. Although this is similar to the radiation of a half-wave antenna in free space, as pictured in Fig. 17A, notice that the lobes are much narrower, and only one-half of each exists, for it is meaningless to speak of radiation within the ground.

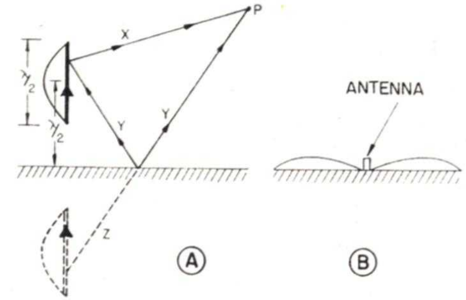


FIG. 21. An image antenna can be used with a vertical antenna to determine ground reflection effects. Note, however, that the two respective antenna currents are not reversed but are in phase. When the center of a vertical half-wave antenna is a half-wave above ground, as shown in A, it gives the vertical plane radiation pattern pictured in B.

The Marconi Antenna

We have noticed that the ground reflection has a very pronounced effect upon the operation of a Hertz antenna, but what happens if we do not insulate an antenna from ground, but actually connect it to ground through the driving generator?

Let us look at Fig. 22. Here we have, not a half-wave wire, but a *quarter-wave wire* attached directly to ground through the generator, or transmitter.

► After drawing in the image antenna, as shown by the dashed lines, we find we have the exact equivalent of a *half-wave* antenna, even though we have only one-quarter wavelength of wire—the other half of the antenna is made up of a fictitious image antenna that does not exist.

The current distribution along a grounded quarter-wave antenna is shown by the dotted lines. The vertical plane radiation pattern from this antenna is exactly one-half the vertical plane radiation from a free-space dipole. See the heavy line curve in Fig. 22B. If we imagine radiation traveling through the earth, the radiation pattern would be completed, as shown by the dotted curve. Compare this figure with that in Fig. 17A.

► A grounded antenna of this type is called a "Marconi quarter-wave antenna," for the Italian inventor who first made use of it. In general, antennas that are operated against the ground, are called Marconi antennas. Notice that the basic Hertz antenna is one-half a wavelength long, and the basic Marconi antenna is one-quarter of a wavelength long and operates against ground.

RADIATION PATTERNS FOR MARCONI ANTENNAS

The radiation pattern in Fig. 22A is not desirable for broadcast purposes. Although a great deal of energy is concentrated along the ground surface, a substantial amount of radiation is directed into the sky, and hence is wasted and lost.

We find, however, that if we increase the antenna to more than one-quarter wavelength long, the radiation pattern is considerably improved.

If, for instance, we use grounded vertical antennas of 0.375, 0.5, and 0.53 wavelengths in length, we will get the vertical plane radiation patterns shown in Figs. 23A, 23B, and 23C. It is apparent that increasing the antenna length correspondingly increases the radiation very close to the ground. Although the patterns are drawn to the right of the antennas only, we should remember that these patterns are present on *all* sides of the vertical radiators.

We cannot continue to benefit by increasing the antenna length indefinitely, however. Notice the small minor lobe b, which has begun to appear in Fig. 23C. If we make the antenna 0.625 or 0.75 wavelengths long, as shown in Figs. 23D and 23E, the ground surface radiation begins to decrease, and the minor lobe grows into a major lobe, thus indicating that most of the radiated energy is being sent into the sky.

For broadcast purposes, the antenna length of 0.53 wavelength in Fig. 23C is the best compromise. This antenna has very nearly the maximum ground radiation, while the minor lobe b, is not large enough to be objectionable. A great many broadcast-station antennas are constructed like this.

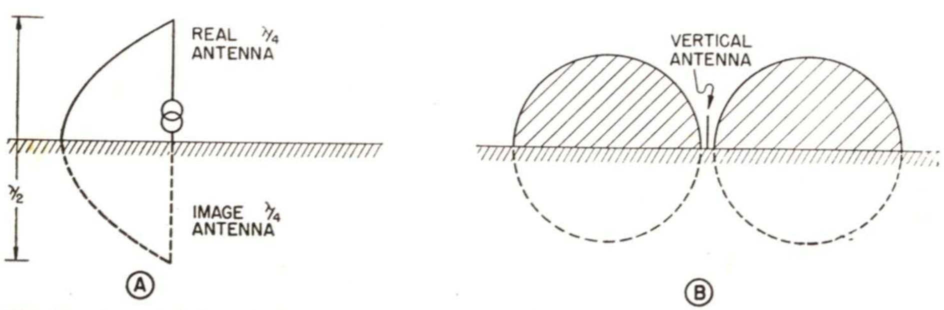


FIG. 22. A grounded vertical quarter-wave Marconi antenna together with its image appears as a complete half-wave radiator as shown in A. The vertical plane radiation pattern from such an antenna is shown in B.

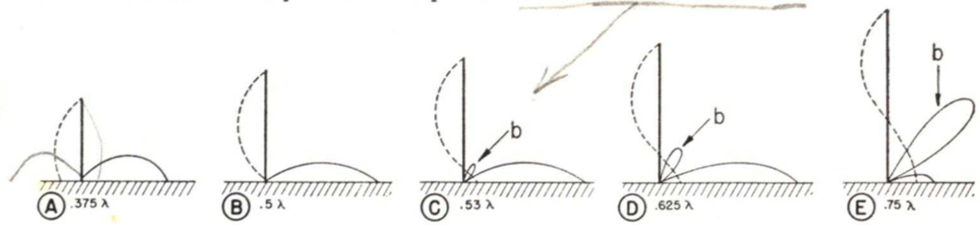


FIG. 23. Current distribution curves (dotted lines) and vertical radiation patterns (thin solid lines) at one particular frequency for grounded vertical antennas having various physical lengths.

LOADING AND REMOTE FEED TO A MARCONI ANTENNA

Feeding a Marconi antenna from a transmission line is very similar to current-feeding a Hertz antenna. With the Marconi antenna, however, one side of the transmission line must be grounded.

As with the Hertz antenna, a transformer can be used to match the transmission-line impedance to the radiation-resistance of the Marconi antenna. This arrangement is shown in Fig. 24A.

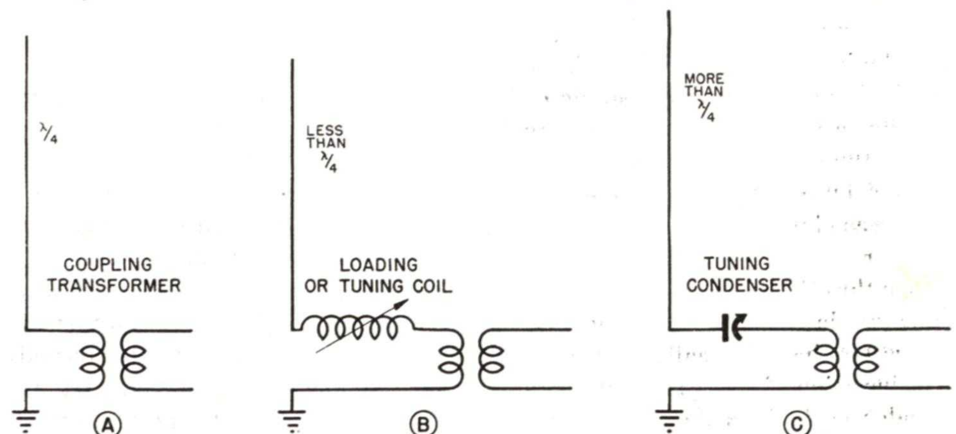


FIG. 24. Antennas that are too short or too long can be tuned to resonance by the insertion of a series-loading coil or a tuning condenser.

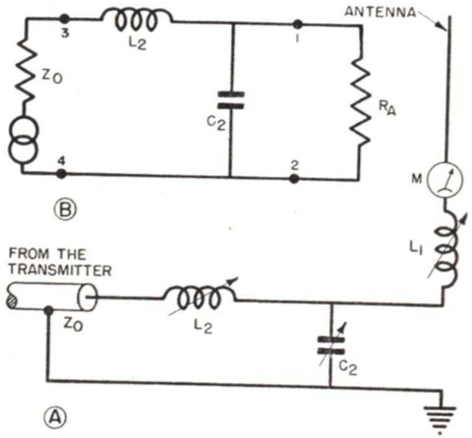


FIG. 25. In A is shown the actual circuit, and in B the equivalent circuit of a coupling network used to match a low-impedance concentric transmission line to a high-impedance antenna.

In general, a quarter-wave Marconi will not have a radiation resistance of 72 ohms, but only one-half this amount, or 36 ohms, since half the effective antenna is in the ground as represented by the antenna image.

If the antenna is not exactly one-quarter wavelength long, it is not resonant, and no standing waves can be developed at the desired frequency without tuning.

If the antenna is shorter than one-quarter wavelength, its electrical length can be increased by the insertion of a variable inductance, or "loading coil," as shown in Fig. 24B. This effectively tunes the antenna to resonance so that only a pure resistance is presented to the secondary of the coupling transformer.

On the other hand, antennas that are greater in length than one-quarter wave can be electrically shortened by the insertion of a series variable tuning condenser. This is shown in Fig. 24C.

Coupling Networks. When using Marconi antennas close to one-half wavelength long, a current node will be very close to the base. Thus the base impedance may be so high, that the simple schemes in Fig. 24 cannot be used to match the antenna to a low-impedance transmission line. In such cases, it is necessary to use some sort of impedance-matching network.

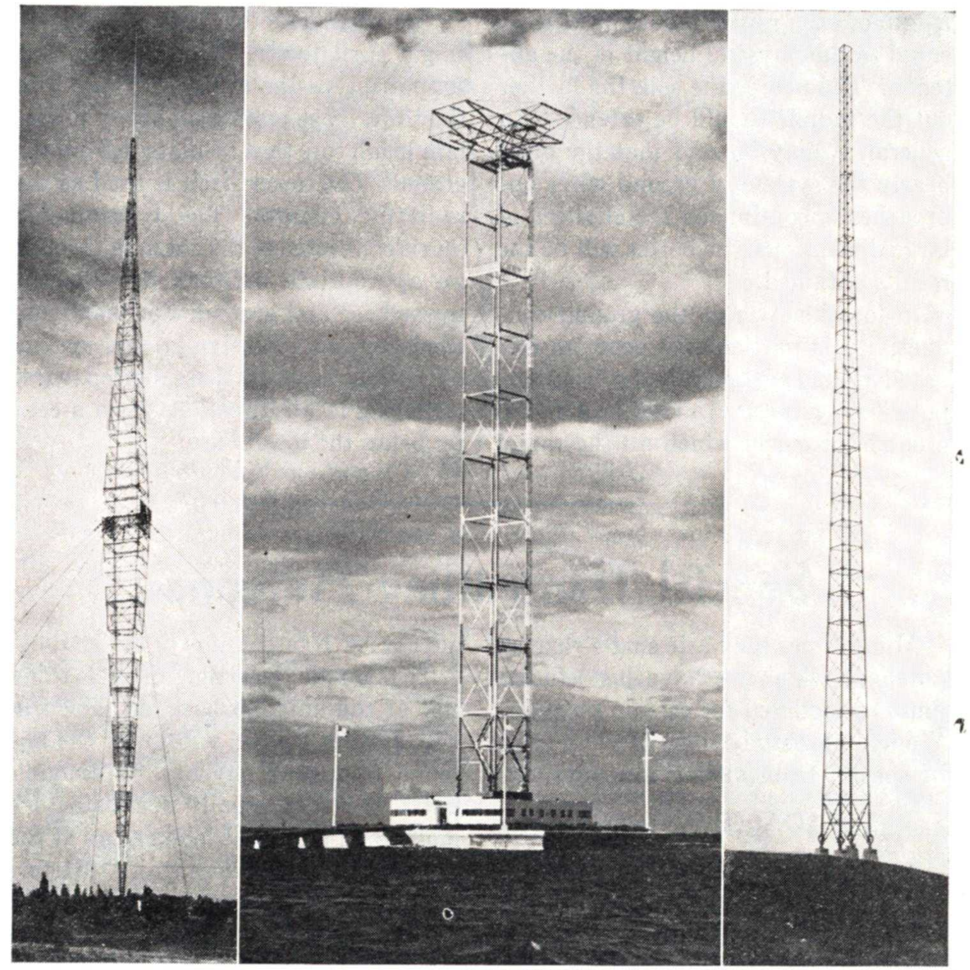
A simple impedance-matching network is given in Fig. 25A. The loading coil L_1 is used to tune the antenna to resonance; in some cases, this inductance may be replaced by a variable capacity. The coupling network consisting of the variable capacitor C_2, and the variable inductance L_2, appears as a parallel resonant circuit when looked at from the antenna terminals. (The coil L_2 is in parallel with C_2 if the characteristic impedance Z_0 of the low-impedance concentric transmission line is considered as closing the circuit.) We have the equivalent circuit of this network in Fig. 25B where the apparent antenna resistance R_A is shunted across the parallel-tuned circuit, while the line impedance Z_0 is effectively in series with the coil. Notice that L_1 is not shown in the equivalent circuit, because R_A represents the combined effects of the antenna and its loading coil L_1.

It is a characteristic of the parallel resonant circuit that a high resistance *across* it has the same effect as a small resistance *in series* with it. The resistance that can be seen by looking into the terminals 1-2 is inversely proportional to the resistance Z_0. Likewise, the resistance that can be seen by looking into the terminals 3-4 is inversely proportional to the resistance R_A. We can see then, that by proper adjustment of L_2 and C_2, the impedance of the network at 3-4 can be made to match the line impedance Z_0, and at the same time the network impedance at 1-2 can be adjusted to equal R_A. Under these circumstances we have perfect impedance matching, and a maximum amount of power is delivered into the antenna.

Special Ground Systems. In studying the effect of antenna images, and particularly with the grounded Marconi antenna, we have assumed that the conductivity of the ground was high, and that radio wave reflection at the surface occurred without loss. Unfortunately, this is not always true.

In regions where the soil is dry or sandy, the soil resistance to high-frequency currents may be excessively high. In such cases, the efficiency of any antenna system may be sharply reduced.

One method of reducing losses in a



Center illustration: Courtesy Columbia Broadcasting System

On the left a vertical antenna (guyed type) at Station WLW in Cincinnati, with tuning extension at top. In the center is shown an example of a top-loaded antenna used by WCBS in New York City. At the right is a self-supporting 154-foot high vertical antenna of WWSW, located in Pittsburgh, Penna.

poor ground is to make an artificial ground system. This is done by burying in trenches, 12 to 18 inches deep, a large number of bare copper wires that extend away from the antenna in all directions, like the spokes of a wheel. These buried ground wires are commonly known as "radials."

Measurements have shown that the longer the radials, the greater will be the signal strength along the ground for a given transmitter power. The length of each radial should be at least equal to the physical height of the antenna. The poorer the soil, the farther out the radials should be extended. In general, it may be said that the more nearly the system of ground wires approaches a continuous metal sheet of large dimensions, the better will be the results obtained.

In locations where the ground conductivity is particularly poor, an elevated ground system called a "counterpoise" may be used. This is a radial ground system in which all the radial wires are on insulated supports about eight feet above the earth. The wires are all connected together directly under the antenna, and this junction serves as the ground connection.

► Almost all modern broadcast stations use some form of vertical Marconi antenna that may be anywhere from 0.25 to about 0.54 wavelengths in height. As shown in Fig. 23, this type of antenna gives the best extended coverage with a minimum of sky wave.

The usual practice is to construct a single steel tower, of either the self-supporting or the guy-wire type, with the tower base resting on heavy porcelain insulators that insulate it from the ground. The tower itself is used as the radiating element. The transmission line is connected to the antenna through an appropriate network between the tower base and ground. For maximum efficiency, an extensive ground system of radials is used, these buried wires radiating in all directions from a center below the tower base.

Special Transmitting Antennas

Many times the basic single element antennas which we have just studied must be modified for certain purposes. We will now study some of these types of special transmitting antennas.

TOP-LOADED ANTENNAS

In some cases, it is either physically impossible or economically impractical to erect a vertical broadcast antenna that is the proper theoretical height for a desired radiation pattern. In such circumstances, a shorter antenna is constructed, and the resonant frequency is brought down by loading.

The simple insertion of a loading coil at the antenna base, as shown in Fig. 24B, of course, will lower the antenna frequency any desired amount, but this is not usually a satisfactory method. If a current loop occurs at the antenna base, as it does with a quarter-wave Marconi antenna, for example, more power may be wasted in heating the coil than will be radiated by the relatively short antenna. In addition, since the loop of maximum current occurs in the coil and not on the open

antenna, a desirable radiation pattern cannot be obtained.

Let us look at Fig. 26A. This is an ordinary vertical quarter-wave Marconi antenna with a current distribution shown as I. Since the radiation from each small element of any antenna is proportional to the current in that element, it is obvious that the bottom two-thirds of the antenna is responsible for more than about 80% of the total antenna radiation!

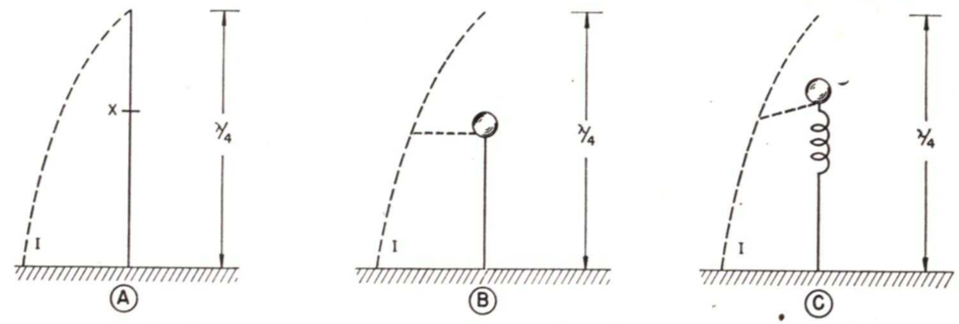


FIG. 26. Top-loading by adding capacity to the top of a short antenna can make the current distribution of the base the same as that for a true quarter-wave wire.

A better method of loading is to cut the antenna at point X and attach some device which gives the appearance at the bottom of the antenna that the top section is still present.

This is easily done by attaching a large metal ball, or disk, to point X, thus increasing the capacity to ground, and maintaining proper current flow. This is illustrated in Fig. 26B. The dashed line shows the shape of the resulting current standing wave; the dotted line indicates the pattern as it would have been had the antenna been completed.

Such a method of increasing the apparent length of a short antenna is called "top-loading."

Still better results from top-loading can be realized if a loading coil is inserted in series between the shortened antenna and the capacity ball, or disk, as shown in Fig. 26C.

This latter arrangement is one of the most efficient means of using a short antenna. Not only is the coil located near a current node so that the losses are small, but approximately two-thirds of the current loop is still developed along the antenna wire so that good radiation is the result.

By means of top-loading, an antenna of only 0.375 wavelength long can be made to behave like one of 0.53 wavelength long, thus changing the radiation pattern from that of Fig. 23A to the more desirable radiation pattern shown in Fig. 23C.

LONG-WIRE ANTENNAS

For special purposes, such as point-to-point communication, horizontal Marconi antennas are sometimes used. Referring to the radiation pattern of a long Hertz antenna in Fig. 18D, you will notice that the radiation lobes occur very near, but not quite in line with, the antenna wire itself. The longer the antenna is made, the more nearly the radiation approaches the direction of the wire. A long horizontal wire above ground has similar radiation characteristics, and offers advantages when extreme directivity is desired.

Practical directive antennas made up of several long wires operating to-

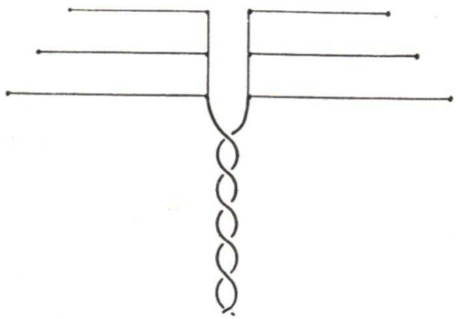


FIG. 27. Three dipoles in parallel, each of different length and resonant frequency, make up one type of broad-band antenna.

gether have been designed. These will be discussed in a later Lesson on antennas of more than one element.

BROAD-BAND ANTENNAS

Up to this point, we have discussed antennas that are either self-resonant, or that can be tuned to resonance at a single definite frequency. Nevertheless, for ordinary broadcast transmission, these antennas are sufficiently broad in tuning to accept all the side bands which are separated from the carrier wave by only a small percentage of the carrier frequency.

In f.m. or television broadcasting at ultra-high frequencies, the extremely wide frequency band gives rise to side band frequencies that are comparatively widely separated from the carrier frequency. When a sharply resonant antenna is used for a wide band of frequencies, the antenna discriminates against the more remote side band frequencies, resulting in a frequency-distorted audio-output signal, even though there is no frequency distortion in the low-frequency amplifier of the transmitter or receiver. Also, since the antenna is not a pure resistance at the side band frequencies for which it is not resonant, an impedance match between the antenna and an untuned transmission line can no longer be obtained. This may result in standing waves being set up on the transmission line, and losses in general greatly increased.

It is imperative then, for efficient radiation of a wide band of frequencies, that some form of broad-band antenna be used.

The Multiple-Dipole Antenna. One method for making an ultra-high-frequency antenna system that is resonant over a wide band is to connect in parallel several dipoles of different lengths,

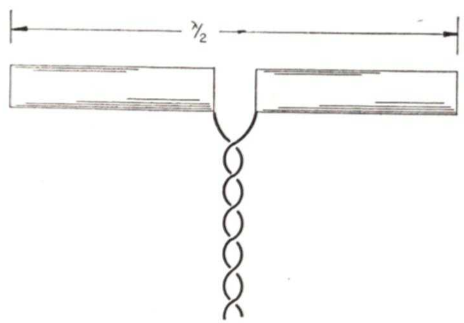


FIG. 28. Broad-banding is accomplished in the "stove-pipe" antenna by making the dipole conductors of large diameter.

and feed them with a common transmission line. Such a system is shown in Fig. 27.

The dipoles, however, do not operate entirely independently of each other, and such an arrangement is not always satisfactory.

The Stove-Pipe Antenna. A better method for broadening antenna response is to make the conductor of large copper pipe or tubing rather than of wire with a small diameter. For a dipole, this structure resembles two "stove-pipes" placed end to end as pictured in Fig. 28.

Increasing the conductor's diameter in an antenna does not affect the radiation resistance. It does, however, in-

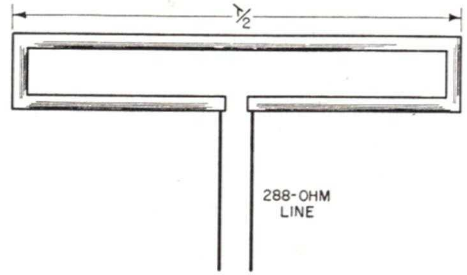


FIG. 29. The "folded dipole" is not only broad-band because of the large-diameter conductors, but it also has a built-in impedance step-up of 4 to 1 to match a high-impedance line.

crease the antenna capacity and reduce the inductance so that the effective Q of the antenna is lowered, and the resonance curve correspondingly widened.*

Another way of looking at it is to assume that not only can antenna current flow straight down the length of each conductor, but also it can spiral around the conductor as it goes, thus finding a longer path, and hence, other frequencies of resonance.

The Folded Dipole. A very useful arrangement of two stove-pipe dipoles is given in Fig. 29. Here we have two dipoles connected in parallel, but the transmission line feeds power to only one of them. This arrangement is known as the "folded dipole."

If the two dipoles are of equal diameter, equal currents will flow in them. The transmission line, however, supplies only one-half the total antenna current. For the power to the antenna to remain the same, the voltage applied to the transmission line must be doubled. *The effective resistance of the antenna* (which is E/I) *is 4 times the value that it was before the dipole was folded.* The 72-ohm dipoles, therefore, have the effect of an impedance of 288 ohms. We have then, not only broad-banding but impedance matching at the same time!

Furthermore, the relative currents in each dipole depend upon the respective diameters of the conductors, and by proper choice of conductor size we can design this type of antenna to serve as an impedance-matching transformer for almost any desired impedance ratio, that is, it does not always have to be 4 to *1*.

The Bi-Cone Antenna. Another variation of the stove-pipe antenna is

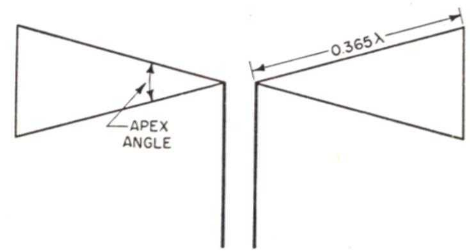


FIG. 30. The impedance of the "bi-cone" broad-band antenna can be changed by varying the apex angle of its metal cones.

shown in Fig. 30. Here the pipes have been replaced by metal cones. This is known as the "bi-cone" or "hour-glass" antenna.

The slant-length of each cone, as indicated, is usually made 0.365 of a wavelength for the center frequency of the broad band. The antenna resist-

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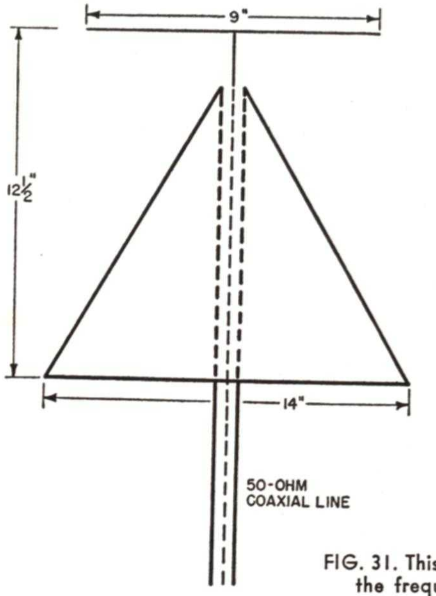
*$Q = \frac{\omega L}{R}$ where L is the effective inductance of the radiator.



ance can be varied by changing the apex angle of each cone. An apex angle of 12° gives a resistance of 900 ohms; a 30° apex angle gives 300 ohms.

The Discone Antenna. A modification of the bi-cone antenna is made by replacing one of the cones with a metal disc. This is illustrated in Fig. 31.

This particular "discone" antenna presents a satisfactory match to the 50-ohm feed line over the frequency band of 250-1000 megacycles per second. The radiation pattern, however, is constant up to 600 megacycles only. Above this frequency, radiation in an upward direction becomes excessive.

FIG. 31. This "discone" antenna matches the 50-ohm line over the frequency band 250-1000 megacycles per second.

Receiving Antennas

In the earlier part of this Lesson, we found that a long wire, on which standing waves are being generated, can lose some of its energy in the form of radio waves radiating into space. This same long wire can absorb energy from a passing electromagnetic wave causing a current to flow along the wire.

But what causes this current? If we look back at Fig. 10, we can see why this action is so. In the first place, if the electromagnetic wave, in passing to the right, flows over our long wire so that the electric lines are parallel to the wire, a potential difference will be built up between the two ends of the wire and, of course, a current will flow along the wire.

The magnetic field lines also cut the wire at an angle of 90°, and from our study of voltage induction, we know that this, too, will induce an e.m.f. Thus we can think of the generation of voltage between the ends of the wire as being caused by the action of either the electric or the magnetic field.

It follows then, that any antenna that performs well as a transmitting antenna, will perform well as a receiving antenna. This statement can be carried further by saying that the individual radiation patterns for transmitting and receiving will be identical.

In order to decide which is the best type of receiving antenna, we must first find out what happens to a radio wave after it leaves the transmitting antenna.

THE GROUND WAVE

Turning back to Fig. 23C, we notice that broadcast-station antennas are deliberately designed to concentrate the wave radiation along the surface of the ground. Radio waves that travel close to the ground are called "ground waves." They are used extensively for coverage of a relatively short distance.

How the Polarization of a Ground Wave Is Changed. In most cases, the conductivity of the ground is not as high as we would like it to be, and a great deal of the wave energy is lost in the ground, and is dissipated as heat. Furthermore, the velocity of radio waves in the earth is not as great as it is in free space. Vertically polarized waves are emitted by a vertical antenna, but as these waves travel along the earth's surface, the wave front begins to lean over as shown in Fig. 32A. It is as though the wave were "dragging its feet." The net result is that a tilted, not a true vertical wave, arrives at the distant receiving antenna. As shown in Fig. 32B, the tilted wave can be considered equivalent to two component waves, one with vertical polarization, the other with horizontal polarization. In other words, because of ground effects, the ground wave has changed its polarization.

Judging from this figure, it is obvious that we can use either a horizontal or a vertical antenna to receive the ground waves, since we have components of both vertical and horizontal polarization. We have not, however, considered the subject of man-made noise and interference.

Polarization of Interference. When we studied the radiation from a low horizontal wire we found that most of the energy was directed upward. See Fig. 20B. This is true because the antenna image has a current flow that is 180° out of phase with that in the real antenna, resulting in a cancellation of all the r.f. radiation along the ground.

If we consider an electric power line as an antenna, we find that, because of its image, most of the spurious noise signals arising along the line are radiated directly upward.

► As a consequence, in a power line, automobile, or other noise-producing source, parts of which are vertical and parts horizontal, only the *vertical* parts will be instrumental in radiating noise energy along the ground. *Man-made interference, therefore, is predominantly vertically polarized.*

After considering this fact, it seems

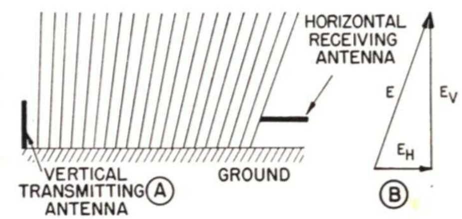


FIG. 32. Vertically polarized electric lines of force produced by a vertical transmitting antenna gradually change their angle with the ground as they travel away from the antenna.

wise to choose a horizontal antenna, since we can use either a horizontal or a vertical antenna as shown in Fig. 32. In so doing, we will not only receive the desired signals just as well, but we will discriminate against the vertically polarized noise and interference waves, and reduce their effects as much as possible. In general, we find that a horizontal antenna gives the best signal-to-noise ratio of any simple antenna that it is possible to construct.

THE SKY WAVE

The ground wave, as illustrated in Fig. 23D, is not useful for long-distance transmission, because it is constantly attenuated and absorbed by the ground itself, by hills, buildings, trees, and any other similar obstacle.

For coverage of long distances, such as in point-to-point communication, most of the radio wave energy must be radiated into the sky. This is pictured in Fig. 23E. Radiation so directed is commonly called a "sky wave."

But how does the energy return to the earth so that it can be picked up by the desired receiving station? As we shall see, the radio waves are reflected in the upper atmosphere and then directed earthward again to the desired point. Let us see how this takes place.

The Kennelly - Heaviside Layer. Far above the earth, where the air is very thin, ultra-violet rays from the sun ionize the remaining air particles in much the same manner that gas in a neon sign is ionized. These ionized regions occur at various heights, and are called "Kennelly-Heaviside layer" for its co-discoverers.

An interesting property of ionized air is that a radio wave can travel within it with greater velocity than it can in ordinary air. Hence, a radio wave leaving the earth at a certain angle, as in Fig. 33A, will be bent sharply as it enters a uniformly ionized region.

The Kennelly-Heaviside layer, however, is not uniformly ionized. It may consist of several alternate layers of rare and dense ionization. This means that as the radio wave enters a layer, it first meets only rare ionization when it is bent but little; but as it progresses deeper and deeper into the layer, it meets denser and denser ionization, and the refraction, or bending, is increased.

Under favorable conditions, the radio wave may be completely turned around and directed back to the earth. This is shown in Fig. 33B. Although the action is refraction, or bending, the results are exactly the same as they would be if the radio wave had been reflected.

The Skip Distance. At the point where the refracted wave strikes the earth, good reception can be realized. The exact distance between this point and the transmitter, commonly called the "skip distance," depends upon the frequency of transmission, the height of the Kennelly-Heaviside layer, and the angle with which the wave leaves the transmitting antenna.

Normally, if the wave strikes the refracting layers at a nearly perpendicular angle, it is not refracted at all, but simply penetrates the ionized regions and is lost. Thus, only waves striking the layer at less than a critical angle are reflected. This means that there is always a *minimum* skip distance, and if the ground wave does not

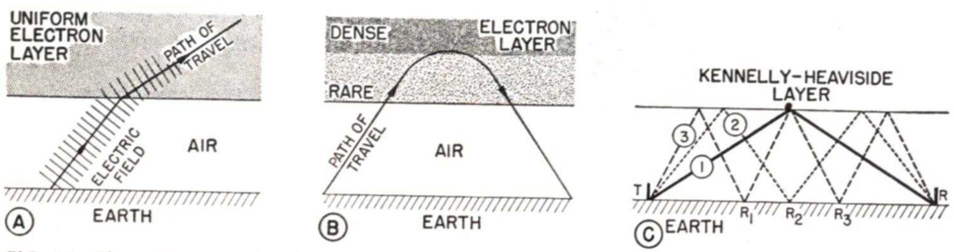


FIG. 33. These diagrams show how sky waves can be refracted (bent) back toward the earth by the Kennelly-Heaviside layer in the upper atmosphere.

extend into the area, there will be no reception at all between the area where the ground wave is effective, and the area where the skip signal can be received.

It is possible, too, to have more than one skip, because the earth may reflect the returning wave and direct it back into the Kennelly-Heaviside layer to be refracted once more, this process may occur over and over again. Thus, as shown in Fig. 33C, the transmitter T may be heard at the receiver R by waves traveling over three different paths. Along path 1 we have only one refraction. Along path 2 we have two refractions from the Kennelly-Heaviside layer, and one reflection from the earth. This results in another reception point R_2. Similarly, along path 3 we have three skips, giving reception at points R_1 and R_3 as well.

Because the sun's ionizing action is greatest during the summer, the Kennelly-Heaviside layer is closer to the earth during this season, and the average usable skip distances are much shorter than they are during the winter. For the same reason, skip distances at night are always longer than those in the daytime.

► Nevertheless, since skip distances also change with frequency, it is often possible for a transmitter engineer to choose an appropriate operating frequency, and thus radiate a usable signal into almost any receiving area at any time.

Fading. In addition to its daily and yearly variations, the Kennelly-Heaviside layer also seems to change its level slightly from moment to moment, thus causing the fading that we so often notice in long-distance reception.

Fading may be the result of one or more of the three causes listed below:

1. A slight change in the height of the ionized layers may cause the wave to "hop over" the receiver, or to come to the earth between the receiver and the transmitter. In either case, the actual field intensity of the wave is diminished. Obviously, nothing can be done about this type of fading.

2. A change in the refracting layers may alter the wave polarization. Thus, if an antenna is more responsive to vertically polarized waves, and the wave suddenly becomes predominantly horizontally polarized, the apparent signal intensity will drop.

Point-to-point communication systems sometimes use a "diversity antenna" to overcome this trouble. This means that two antennas, one vertical and one horizontal, are used for the same receiver. A special automatic device constantly selects the antenna giving the greater signal strength, and connects it to the receiver.

3. A receiver, located near the outer edge of the ground wave coverage area of a broadcast station, for example, can receive both a ground wave and a sky wave at the same time. The resulting signal will depend upon the relative phase of these two waves. At one moment the sky wave may be *in phase* with the ground wave and give a very loud signal. At the next moment the Kennelly-Heaviside layer may change slightly and the sky wave will be 180° *out of phase* with the ground wave. In this case, the signals tend to cancel each other, and very weak or garbled reception may be the result. The only way to minimize this type of fading is to eliminate either the sky wave or the ground wave, and retain only the desired one. For this reason, local

broadcast stations are interested in keeping the sky-wave radiation as small as possible.

Sky Wave Polarization. We can expect that, even though a sky wave may be vertically or horizontally polarized when it leaves the transmitting antenna, by the time it is refracted and returned to the earth at the receiver, it may have any type of polarization. Exact polarization will depend, to a great extent, upon the maximum radiation angle of the transmitting antenna.

► In general, there is sufficient horizontal polarization in a sky wave for satisfactory use of a horizontal receiving antenna. As shown before, the horizontal form also is particularly desirable in locations where man-made interference is a problem.

RECEIVING ANTENNA TYPES

We have found that a horizontal antenna is usually preferable for reception of both ground and sky waves; now let us see the different forms that such an antenna can take.

The L and T Antennas. The simplest horizontal antenna is a horizontal wire suspended between two suitable supports such as a house and a tree, or two antenna masts.

If the lead-in to the receiver is attached at one end of the horizontal wire, we have an inverted "L antenna."

The lead-in also may be attached at the wire center, in which case the antenna becomes a "T."

The best results are obtained with an L or a T antenna when it is tuned by making the combined length of the wire and the lead-in either one-quarter wavelength, or some *odd* multiple of a quarter-wavelength long. When the lead-in is attached to the low-impedance antenna coil of the receiver and thence to ground, a current loop occurs directly at the receiver, and a maximum input signal is obtained. Refer to Fig. 22A. It is apparent that antennas of this type are actually quarter-wave resonant Marconi antennas.

In cramped spaces where it is impossible to suspend the proper length of wire in one straight line, an L or a T antenna can be constructed by folding the wire at an angle of 90° in one or more places. Such folding, of course, reduces antenna efficiency somewhat, but the results will be much better than when a short, non-resonant wire is used.

The Noise-Reducing Antenna. In locations where ignition noise, powerline sputter, and other interference is intense, the L or T antenna ordinarily is not satisfactory, because the lead-in wire is more or less vertical, and acts as a vertical antenna that readily picks up the vertically polarized waves of man-made interference. To reduce interference noises, it is, therefore, necessary to use some form of noise-reducing antenna.

The simplest form of noise-reducing antenna is a Hertz half-wave wire, a horizontal dipole or "doublet," with a twisted-pair lead-in wire as shown in Fig. 34.

The twisted-pair lead-in is a transmission line, so for maximum efficiency, a transformer is used at the antenna to match the antenna resistance to the impedance of the line (if, of course, the antenna resistance is not equal to the line impedance), and at the receiver another transformer is used to match the line impedance to that of the receiver input terminals.

Although the lead-in picks up noise signals, these noise currents flow in *opposite* directions through the primary of the input transformer of the receiver, to the center tap and then to ground, as shown by the dotted arrows in Fig. 34. If the line and the transformer windings are properly balanced, the two noise currents cancel each other, and no noise is heard in the receiver.

On the other hand, desired signal currents, as indicated by the solid arrows, after being fed into the line by the antenna, actually flow in the *same direction* through the input transformer winding. Desired signal voltages, therefore, are induced in the transformer secondary winding, and thence fed to the receiver.

The electrostatic shield, or Faraday screen, between the primary and secondary windings of the input transformer, is used to prevent noise voltages from being fed to the receiver directly through the capacity between the windings. It does not, however, interfere with the desired magnetic coupling between the transformer primary and secondary.

Instead of the twisted-pair lead-in, almost any type of transmission line can be used in a noise-reducing antenna. A particularly good installation is made with a completely-shielded concentric cable. The noise-reducing action is exactly the same as before.

All-Wave Antennas. Just as with transmitting antennas, a receiving antenna will not perform very well at frequencies greatly different from its resonant frequency. The doublet in Fig. 34, therefore, will not be efficient at frequencies for which it is not approximately one-half a wavelength of its electrical resonant length.

For modern receivers that operate over a number of wave bands, it is necessary to employ some sort of all-wave antenna if the best possible reception at all frequencies is to be realized.

One of the simplest wide-band antennas is the "spider web" illustrated in Fig. 35. It consists of three half-wave doublets, each of different length, all attached to the same twisted-pair transmission line. Doublet A_1 is resonant for the shortest wavelength; A_3 for the longest wavelength, and A_2 for the intermediate wavelength. Coils L_A are loading coils serving to increase the effective length of doublet A_3.

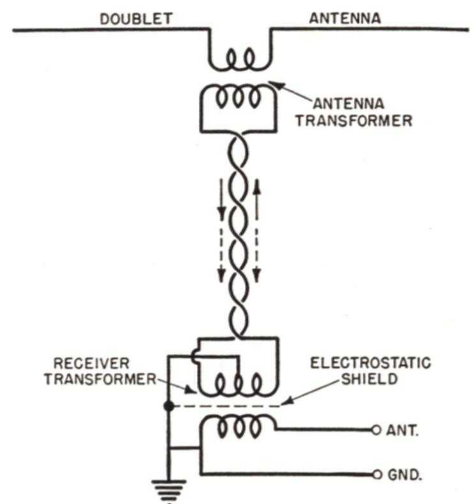


FIG. 34. A simple noise-reducing antenna.

Although these three doublets work best at their own individual resonant frequencies, they are sufficiently broad to give adequate pickup at the in-between frequencies.

Because a twisted-pair line and a balanced input transformer are used, this all-wave antenna is also a noise-reducing antenna when used on the short-wave bands.

When used in the standard broadcast band, the signal pickup of the doublets is low. Nevertheless, because at broadcast frequencies the reactance of coil Ch is very small, and that of condenser C is very large, all the doublets plus the entire length of the transmission line behave as a T antenna. This particular antenna, therefore, does not have the noise reduction feature when it is used in the broadcast band.

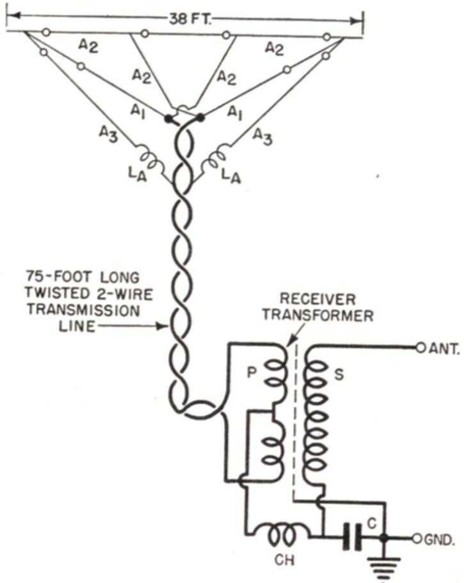


FIG. 35. All-wave noise-reducing antenna made up of three doublets. Because of its general resemblance to the web of a spider, this RCA-Victor product is commonly known as a "spider-web" antenna.

Many other types of all-wave antennas have been devised. Almost all of these give a fair response over a wide band because they are made up of lengths or sections which are resonant at separate frequencies throughout the short-wave bands. The customary built-in noise-reduction action, also, is realized in very much the same manner as for the antennas in Figs. 34 and 35.

The Loop Antenna. In the early part of this Lesson we mentioned that an electromagnetic wave, upon passing through a coil of wire, would induce an e.m.f. in the coil. How does this come about?

Suppose we have a one-turn loop of wire sitting upright, as shown in Fig. 36, and that a radio wave with vertical polarization is traveling to the loop from the right.

When the lines of the electric field, which actually represent a potential difference in space, strike the side x

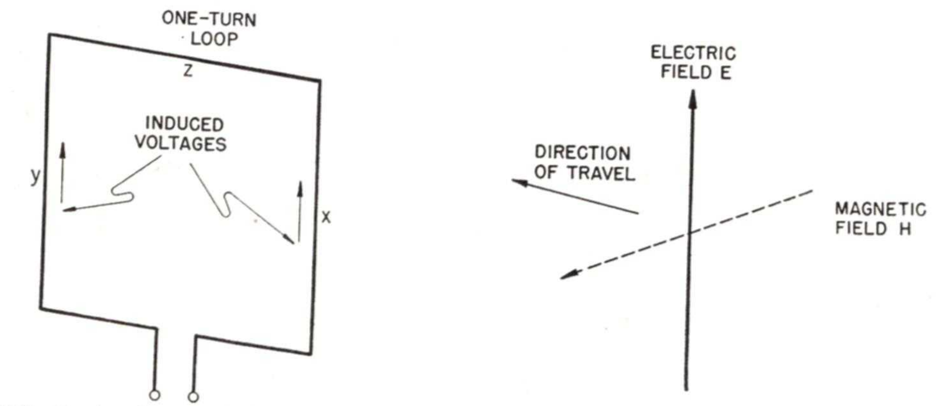


FIG. 36. A radio wave induces an e.m.f. in each side of a wire loop, and these voltages will cancel each other unless there is a difference in the time that a radio wave intercepts the two sides of the loop. For this reason, maximum signal is received when the top edge of the loop z is pointed toward the signal source.

of the loop, a potential difference is established between the top and the bottom of side x and a current will flow in the loop.

It is just as convenient and also correct to consider the lines of the magnetic field as cutting across side x at right angles, thus generating an e.m.f. which causes the current flow in the loop.

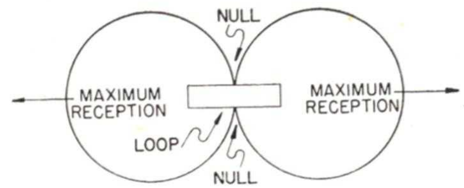


FIG. 37. Reception pattern in the horizontal plane for a vertical loop antenna. Note the extremely sharp nulls which make it useful for direction-finding.

But note that in either case, a *very small fraction of a second later* the same radio wave will also induce an equal voltage in the opposite side of the loop marked y. It is important that the voltage in side y is exactly opposite in direction (or polarity) to the voltage in side x. This means that the two voltages tend to cancel each other, and the resulting voltage in the loop will be a voltage that is equal to the *instantaneous difference* between the separate voltages in the opposite sides of the loop.

In other words, if the loop is turned so that the radio wave strikes one side before it strikes the other, the voltage in one side will occur at a later time than it will in the other side, hence, the two voltages will be out of phase, and a substantial voltage will be developed at the loop terminals.

If on the other hand, the loop is rotated so that it is broadside to the radio wave, equal but opposite voltages will be induced in each side of the loop *at the same time*, and the voltage developed at the terminals will be zero.

This means that a loop of wire, used as an antenna, will have very sharp directional characteristics. In fact, if we use a many-turn vertical loop, which is a loop antenna, we can expect its reception pattern in the horizontal plane to be very much like that shown in Fig. 37. Notice that when a radio wave strikes the flat face of the loop, the reception theoretically is zero. These points of zero output voltage are called voltage "nulls." Only when one edge of the loop is pointed toward the distant transmitter is the induced voltage a maximum.

Since the voltage developed in a loop antenna depends upon the time difference, or phase, of the two currents in opposite sides of the loop, the farther apart these sides are separated, and the greater the area of the loop, the more efficiently the loop will perform.

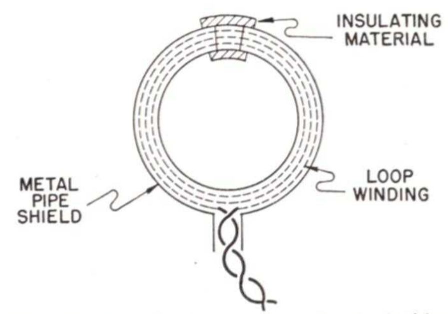
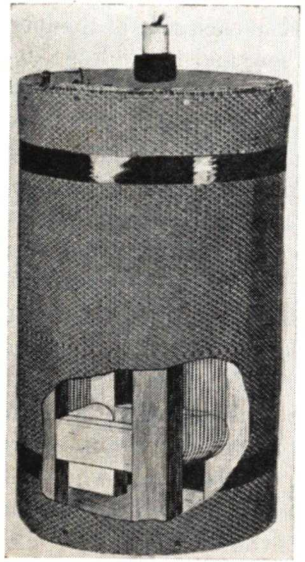
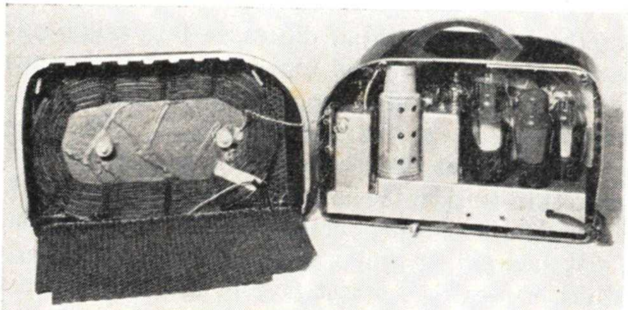


FIG. 38. A method of electrostatically shielding a loop antenna for radiomarine or aircraft use.

Uses of the Shielded Loop. The loop antenna is used extensively in radio direction-finder equipment and in the radio-compass, because of its extremely sharp directional characteristics. In actual use, however, the nulls of a loop will not be sufficiently sharp





Courtesy General Electric Co.

FIG. 39 (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.

FIG. 40 (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 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.

and the voltage will not drop to zero at these points unless the loop is electrostatically shielded, because in addition to the loop effect, the loop will also act as a short antenna in much the same manner as a flat sheet of metal would.

In radiomarine and aircraft use, loop antennas are usually shielded by placing them in a ring of metal pipe as shown in Fig. 38. Note, however, that the metal does not entirely enclose the loop wires, but is broken at one point, the covering being completed by some insulating material. If this were not done, the loop would be shorted, and no signals could be received.

The loop antenna, at best, is an inefficient affair, and under no circumstances will it perform as well as an outside antenna. With modern, high-gain broadcast receivers, however, the low signal voltage is no great handicap, and many manufacturers now produce receivers with built-in loops that do not require an outside antenna. Names such as "Wavemagnet" and "Beamascope" are really trade names for simple loop antennas. Two such examples are illustrated in Figs. 39 and 40. These loops, too, are electrostatically shielded by a Faraday screen made up of space-wound copper wires. In such broadcast-receiver use it is often possible to reduce interference noises by rotating the loop so that a null coincides with the direction of arrival of man-made interference.

Lesson Questions

Be sure to number your Answer Sheet 23RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. If a wire is one-half wavelength long for 1100 kilocycles, for what frequency will it be a full wavelength long?

2. What is the length in meters of a wire that is a half wavelength long for a frequency of 3 megacycles?

3. For a horizontally polarized plane wave, are the *magnetic* lines: 1, horizontal; or 2, vertical?

4. At what point in the antenna is the radiation resistance measured?

5. What power is dissipated by an antenna having a radiation resistance of 200 ohms, and a feed current of 4 amperes?

6. If the current in a transmitting antenna is doubled, how much is the radiated power changed?

7. What is the essential difference between a Hertz antenna and a Marconi antenna?

8. In a vertical Marconi antenna for standard broadcast transmission, what electrical length will give the best ground coverage and the least sky wave lobe?

9. How can a short Marconi antenna be lengthened to $\frac{\lambda}{4}$?

10. What phenomenon gives long-distance transmission when high-frequency radio carriers are used?

SMILE

When you give a smile, you give something that is priceless yet costs nothing. Nobody can buy, beg, borrow, or steal your smile, because it is of no value unless you give it away in friendly greeting.

A smile takes but a moment, but its effects sometimes last forever. A smile creates happiness among friends, brings sunshine to the sad, and promotes valuable good will in business.

You don't feel like smiling? Then force yourself to smile. Whistle, hum a tune or sing softly—act as if you were already happy, and the smile will come. A happy smile comes from happy thoughts, not outward conditions.

It isn't what you are or where you are or what you are doing that makes you happy or unhappy—*it's what you think about it.* You'll find just as many happy faces among Chinese coolies sweating in the rice paddies for ten cents a day as you will among any similar-size group of business presidents in this country.

Smile!

J. E. SMITH