HOW TV ANTENNAS WORK

Finish

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STUDY SCHEDULE No. 59

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

☐ **1. Introduction .... Pages 1-2**

You learn here what basic requirements a television antenna must meet.

☐ **2. Behavior of TV Signals .... Pages 2-7**

This section contains a discussion of the transmission and reflection characteristics of v.h.f. waves. You learn, among other things, why reflections may cause ghosts and why TV waves are horizontally polarized.

☐ **3. Types of TV Antennas .... Pages 8-29**

In this section, you learn the characteristics of all types of antennas commonly used for the reception of TV signals.

☐ **4. Transmission Lines .... Pages 29-36**

Here you learn what the three common types of transmission lines are, how they operate as carriers of r.f. current, why it is important to match their impedances to the receiver and antenna impedances, and how such matches can be made.

☐ **5. Answer Lesson Questions and Mail Your Answers to NRI for Grading.**

☐ **6. Start studying the next Lesson.**

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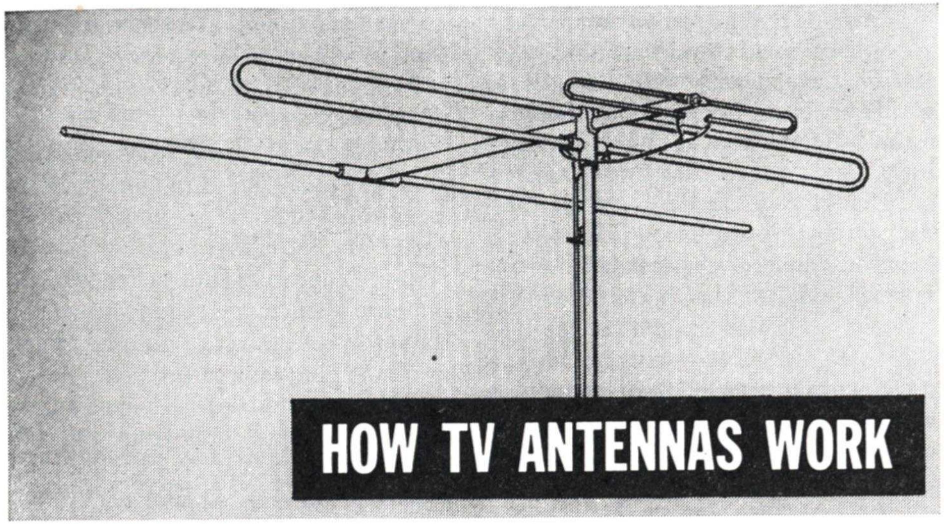


HOW TV ANTENNAS WORK

ANTENNAS are once again important to the radio man. Just as every AM broadcast radio receiver once required a good antenna to bring in a signal, so now do television receivers require good antennas—sometimes even very elaborate ones.

By radio AM broadcasting standards, the signal strength in the service area of a television transmitter is extremely high. However, the transmitted signal covers such an extremely wide frequency range—almost 6 megacycles — that a television receiver must tune very broadly to accept it. Consequently, it cannot have as much amplification as a regular broadcast-band receiver does. This means that a relatively strong signal must be fed into the receiver from the antenna for the set to work properly; as a result, it is usually necessary to have an antenna that will be as efficient as possible in picking up signals.

As a matter of fact, in a great many cases, the success or failure of a television receiver installation depends largely on the type of antenna equipment that is used and on the location at which the antenna is installed. In a relatively few locations that are close to television transmitters, there is usually enough signal strength so that a simple antenna will work satisfactorily. In general, however, it is best to be very careful to choose the right antenna and install it properly if the customer is to get a satisfactory picture. No matter how expensive or well built a television receiver is, it will not work well unless the antenna gives it a satisfactory signal.

Let's see what requirements a television antenna must meet.

BASIC REQUIREMENTS

As you know, two frequency bands are now assigned to television. The low-frequency band extends from 54 to 88 megacycles, and the high-frequency band extends from 174 to 216 megacycles; the frequencies between the two bands are assigned to f.m. stations and to other services. (A third band in the u.h.f. region between 480 and 920 mc. may soon be opened to television.) The large metropolitan areas usually have at least two stations in each band. Locations that are less thickly populated may have only one or two stations, both of which may or may not be in the same band.

Naturally, the owner of a television set wants to pick up every station he can reasonably expect to get. If he lives where stations transmit in both bands, he will want to receive both bands, or at least those portions of them containing the local stations. An antenna installation for such a location, therefore, must have a frequency response that is broad enough to cover all the desired channels. Usually the signal strength in such a metropolitan area is great enough so that the antenna gain is not the major consideration; however, the gain should be as uniform as possible over all the frequencies covered.

On the other hand, there are many locations at which it is barely possible to receive just one station. Wide frequency response is not as desirable in an antenna for such locations as is high gain.

Sometimes it is desirable to pick up the frequencies between the two bands, sometimes not. If a television set is designed for f.m. reception also, of course its antenna should pick up the f.m. frequencies. If the set is not designed for f.m., however, it is desirable to have the antenna reject the frequencies in the f.m. band to prevent the possibility that image reception will cause interference between f.m. signals and television signals in the receiver.

In many locations, the television antenna must be directional in its reception—that is, it must receive better in one direction than in the others. The usual reason for wanting directivity in a television antenna is that it helps prevent "ghosts," which are multiple pictures produced on the face of the picture tube when an antenna picks up signals from a station over different paths. We shall discuss ghosts in more detail later on.

A television antenna that is to be mounted outside must be proof against corrosion and must be mechanically strong enough to stand winds and storms. It should also be so constructed that it is relatively easy to mount and to orient in the desired position.

Before we can say much about television antennas, it would be well for us to go further into the subject of the behavior of television signals. This will make it easier to understand the operation of the antenna as it receives the signals.

Behavior of TV Signals

As you know, radio waves transmitted at broadcast frequencies either travel along the ground or bounce back and forth between the ground and the Kennelly-Heaviside layer. The former are called "ground waves," the latter, "sky waves." The very-high-frequency signals used in television, however, behave differently. They act more like light beams, the resemblance becoming more pronounced as the frequency is increased. By this, we mean that they are transmitted in relatively straight lines outward from the transmitting antenna: they do not bend around hills or other obstructions as do the AM broadcasting waves, nor are they reflected from the Kennelly-Heaviside layer as sky waves are. Therefore, television signals are often considered to be "line of sight"—which would mean, if it were strictly true, that you could not receive television signals at any point unless you could see the transmitting antenna from the location of the receiving antenna. (As we shall show a little later, this is not quite true.)

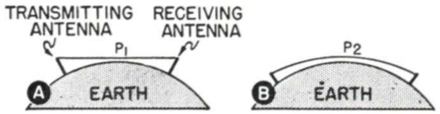


FIG. 1. The slight refraction of TV signals in air permits reception to be had over distances that are longer than the line-of-sight path.

As a result of this characteristic of television signals, the distance over which a television signal can be received is severely limited. The distance at which dependable reception can be obtained depends, of course, upon the height of the transmitting and receiving antennas; however, television broadcasts from the tower of the highest building in the world, the Empire State Building in the city of New York, can usually be picked up reliably only within a radius of about 60 miles.

An illustration of a true line-of-sight signal is shown in Fig. 1A. As you can see, the signals from the transmitter travel in a straight line, P_1; those that pass the receiving antenna continue on out into space and never return to earth. Notice that if either the transmitting or the receiving antenna were slightly less elevated, the curve of the earth would interrupt the optical line of sight between them and thus prevent reception of the signals at the receiving antenna.

As it happens, however, there is a certain amount of refraction (bending) of v.h.f. radio signals in the air. As a result of this bending, television signals can travel slightly farther than they could if they were strictly line of sight. This is illustrated in Fig. 1B, where P_2 is the curved path actually taken by the signals. Comparing the length of P_2 with that of P_1, you can readily see that the curved path permits signals to be received over a greater distance. The actual increase in receiving distance is not proportionally as great as is shown here, because the curve of the earth has been greatly exaggerated in these drawings. However, the increase in receiving distance caused by the refraction of v.h.f. signals is appreciable.

The chart in Fig. 2 provides a convenient way to determine the line-of-sight distance between the two antennas. Assuming normal transmission strength and an average good TV receiver, reception within this area should be highly acceptable. Actually, reasonably reliable reception can be had beyond these figures for reasons we have just explained.

To use this chart, mark off the height of the transmitting antenna in feet on the left-hand scale and the height of the receiving antenna in feet on the right-hand scale. Lay a ruler or other straight edge across the two marked points. The point where the ruler intercepts the center scale shows

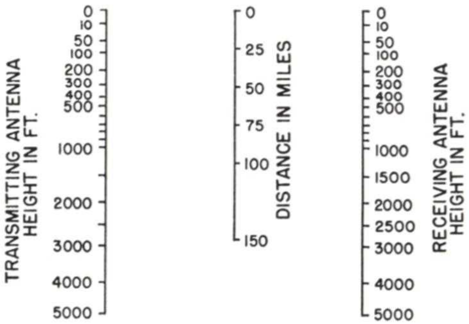


FIG. 2. Chart for determining the maximum line-of-sight distance between two antennas.

the distance in miles over which line-of-sight reception is possible.

If the area on which the transmitting antenna is erected is at the same height above sea level as the area on which the receiving antenna is erected, you should use the height above ground of the two antennas in computing the line-of-sight distance. Suppose, for example, that the transmitting tower is 400 feet tall, that the receiving antenna is 50 feet above the ground, and that the ground level at both locations is the same with respect to sea level. If you lay out these two distances on the chart and lay a ruler between them, you will find that the line-of-sight distance between them is 38 miles.

If there is a difference in the average height above sea level between the two areas at which the antennas are erected, this difference should be added to the height of the antenna at the higher location. Suppose, for example, that the transmitting antenna is 400 feet high and is on a hill that is 225 feet higher than the level of the area on which the receiving antenna is erected. The transmitting antenna should now be considered to have an effective height of 625 feet. Laying out this height on the left-hand scale and 50 feet on the right-hand scale, you'll find that the line-of-sight distance is now increased to 45 miles.

Conversely, if the receiving antenna is on a hill, its effective height should be increased by the relative height of the hill in computing the corrected line-of-sight distance. There is one limitation that must be placed on this increase in effective height, however. The height of the hill or other elevation can be added to the antenna height only if the area around the other antenna (the one that is not on a hill) is free of obstructions in the line-of-sight direction for a certain distance.

For example, suppose the transmitting antenna is on a hill. For there to be an increase in its effective height, the area around the *receiving* antenna must be clear in the line-of-sight direction. To find out how far it must be clear, lay the ruler from 0 on the transmitting antenna scale to 50 (the height of the receiving antenna) on the receiving antenna scale. The center scale then shows a distance of 10 miles, which is the distance from the receiving antenna in the line-of-sight direction (that is, along a line between the two antennas) in which there must be no obstructions.

If the receiving antenna is on a hill and the transmitting antenna is not, you can find the distance from the transmitting antenna that will have to be clear by laying a ruler between 400 (the height of the transmitting antenna) on the transmitting-antenna scale and zero on the receiving-antenna scale. This will give a distance of 28 miles.

If there are any obstacles between the two antennas, they will usually prevent reception if their width along the line-of-sight path is greater than one-half wavelength of the transmitted wave. If the width of the obstacle is less than a half wavelength, it will not interfere with the reception; the waves will bend around the obstacle and continue as though nothing were in the way.

REFLECTIONS

The waves used to transmit television signals can be reflected from a conductive material. If they strike a building, for example, they will be reflected from the metallic structure of the building just as a light beam would be reflected from a mirror, with the angle of reflection being the same as the angle of incidence. (Some prefer to consider that the metallic structure of the building in such a case acts as an antenna that absorbs the waves and reradiates them. Whichever explanation you prefer, the effect is the same; the radio waves take on a new direction after striking the building.)

This re-direction of television signals by conductors (or by natural objects containing conductive materials, such as hills) is sometimes helpful and sometimes extremely annoying for the man attempting to erect a receiving antenna. It is helpful in those cases in which it permits television reception at points where it would be impossible to receive signals without its aid. Suppose, for example, that there is a large building between the transmitter and the location at which you're attempting to install a television antenna. If you cannot get the receiving antenna above the obstructing building, direct reception of television signals will be impossible. It may well be, however, that signals will be reflected from some other building and reach the receiving antenna along an indirect path. As a matter of fact, this is a very common occurrence in installations made in large cities.

An example of another location at which a reflected signal is very helpful is shown in Fig. 3. Here the receiving antenna is located in a deep valley. As far as the direct signal from the transmitter is concerned, the antenna receives nothing. However, the water tower on the hill at the left of this figure is in the line of the direct signal, and since it is metallic, it reflects the signal (or picks it up and reradiates it, if you prefer) down into the valley to the receiving antenna.

In such cases, reflected signals are certainly helpful. Suppose, however, that the location at which you are installing a receiving antenna is such that you get a perfectly good signal directly from the transmitter but that you also get one or more reflected signals from the same station that traveled over different paths to reach the receiving antenna. Such a state of affairs is illustrated in Fig. 4. As you can see by examining this figure, the direct wave from the transmitter to the receiver travels through a considerably shorter distance than do any of the waves reflected from the various buildings to the receiver.

Radio waves, even though they travel at the speed of light (186,000 miles per second), require a measurable length of time to get from one point to another. Therefore, the reflected waves will arrive at the receiving antenna a short time later than the direct wave, the time difference depending on the relative lengths of the paths. A radio wave traveling at the speed of light moves at the rate of 985 feet per microsecond (a microsecond is a millionth of a second), so a wave that travels over a path that is approximately a thousand feet longer than the direct path would arrive at the receiving antenna a microsecond later than does the direct wave.

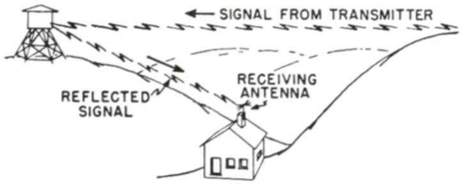


FIG. 3. How a reflected signal may give reception at a location not reached by the direct signal.

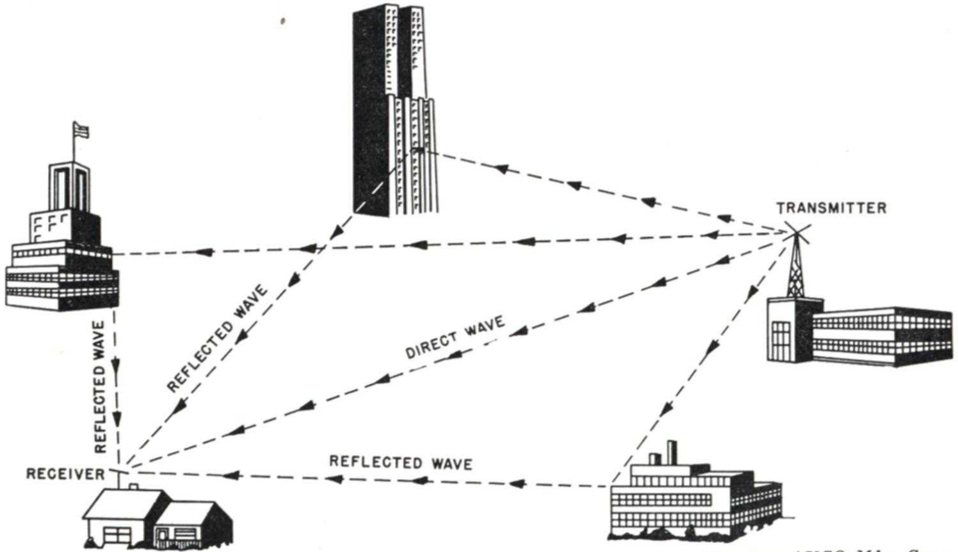
This sounds like a very small interval of time, but its effect on a television receiver is quite appreciable.

The scanning beam of a 10-inch picture tube travels across the face of the tube at the rate of .133 inch per microsecond. Therefore, a reflected wave that reaches the receiving antenna one microsecond later than the direct wave produces a picture on the tube face that is .133 inch (or a little more than 1/8 inch) to the right of the picture produced by the direct wave. If you were looking at the tube, you would see the basic picture—that is, the one produced by the direct wave—on which would be superimposed another image of the same picture that was shifted about 1/8 inch to the right. The effect would be quite noticeable and rather distressing.

A multiple image of this sort is called a ghost. It is possible for there to be several ghosts if there are several reflecting paths—in fact, there can be one for each path. It is not necessary for the time difference between the direct and the reflected signal to be as great as a microsecond to produce a noticeable ghost: if the reflected wave arrives .19 microsecond later than the direct wave, the effect will be quite apparent. A time difference of .19 microsecond means that the reflected wave has traveled .19 times 985 (the number of feet per microsecond that a wave travels) or 187 feet farther than the direct wave. As a matter of fact, a path difference of as little as 70 feet will produce a blurring of the right-hand edge of the picture, although no distinct ghost will be produced.

Ghosts are always injurious to the quality of the received picture. The injury may be only slight if the strength of the reflected signal is low. If the reflected signal is as strong as the direct signal, however, the picture quality may be rather poor. If many ghosts are received, the effect may be to produce gray outlines of the picture rather than distinctly separate images.

The only way that ghosts caused by multiple reception can be eliminated is to orient the antenna so that it picks up only one signal. This usually means that the antenna must be rather directive—that is, it must receive much better in one direction than in others. We shall learn more about this later on.



Courtesy AVCO Mfg. Corp.

FIG. 4. How reflected signals can cause multi-path reception, which may produce ghosts.

We pointed out earlier that differences in path length between direct and reflected waves cause differences in the time of arrival of signals at the antenna, with the result that ghosts are produced. Any other effect that causes a time delay between the application of two signals to the receiver will also produce ghosts. For example, ghosting is sometimes also caused by reflections within the transmission line that connects the antenna to the receiver. Suppose that a 100-foot transmission line connects the antenna to the receiver. Suppose, too, that all of the signal sent down the transmission line to the receiver does not enter the receiver, but that part of it is instead reflected back up the transmission line to the antenna and then reflected down the line again to the receiver. (We shall describe the cause of such reflections later.) If this happens, the part of the signal that went up and down the line will have traveled 200 feet more than did the signal that went straight down the line to the receiver. As we said before, a path difference of this length can cause an appreciable effect on the picture on the t.c.r. tube.

POLARIZATION OF TV SIGNALS

As you know, a radio wave consists of an electric field and a magnetic field that are at right angles to one another. In radio and television work, we usually consider only the electric field when we are discussing the direction of the wave. Furthermore, we generally deal with a "plane-polarized" form of this field—that is, one that lies all in one plane, which may be at any angle to the earth's surface.

You know from earlier Lessons that a voltage is induced in an antenna when it is in an electric field. If the antenna is in the same plane as the field, the voltage induced in it is a maximum; if it is at some angle with respect to the plane of the field, less voltage is induced in the antenna. Therefore, we get the maximum efficiency from an antenna if we orient it so that it is in the same plane as the electric field of the radio wave.

Television signals are transmitted so that the electric lines of force of the wave are horizontal with respect to the earth's surface. For this reason, television signals are said to be "horizontally polarized." There are several reasons for using horizontal polarization, chief of which is that most noise signals are vertically polarized. Therefore, a horizontal antenna will pick up television signals most efficiently, and, at the same time, will pick up noise signals poorly. For this reason, television antennas are almost always mounted horizontally.

Now, let's learn something about the basic antennas that are used to receive television signals.

Types of TV Antennas

Before we start to discuss actual television antennas, we should review the subject of radiation patterns, which you studied earlier in your Course. The radiation pattern of an antenna is an important part of the description of the antenna, so it is worth while to take a moment to refresh your memory on the subject.

Briefly, the radiation pattern of an antenna is a graph that shows how well the antenna receives from each direction in any given plane. Since television signals are horizontally polarized, the radiation patterns we are going to show in this Lesson will be the patterns for the horizontal plane. In other words, each pattern we give will show how well the antenna for which it is drawn picks up horizontally polarized television signals coming from any direction.

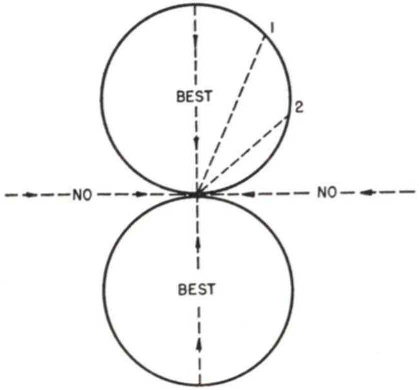


FIG. 5. The common figure-8 radiation pattern.

A very common radiation pattern, usually called a figure-8 pattern because of its shape, is shown in Fig. 5. For the sake of clarity, we have not shown the antenna that possesses this pattern; usually, however, it is drawn in to show the orientation of the pattern with respect to the antenna.

To understand the meaning of this plot, imagine that you draw a straight line from point A in any direction. The length of this line between point A and the point where the line hits either circle is a measure of the receiving ability of the antenna for television signals coming along that line. As you can see, it is possible to draw a straight line from A in such a way that it does not strike either circle. This means that the antenna will not pick up signals from that direction at all. Lines drawn in other directions from A will be of varying length when they intersect the edge of the circle. In each case, the length of the line will show how well the antenna picks up from that direction; the longer a given line is, the better the antenna pickup will be for a signal coming along the direction of the line. For example, a signal coming from the direction of point 1 will be picked up better than will be one coming from the direction of point 2.

Although the parts of the radiation pattern in this example are circles, it is perfectly possible—in fact, much more common—for them to have other and less regular shapes. Whatever its shape, each part of a radiation pattern is called a "lobe."

Now let's discuss each of the major kinds of television receiving antennas, starting with the dipole.

DIPOLE

The dipole antenna consists of two cylindrical metal rods mounted so that they are in line with one another but not in contact (Fig. 6A). As you learned earlier in your Course, an antenna of this sort acts as if it consisted of many small elements of inductance and capacity connected as shown in Fig. 6B.

An exact mathematical analysis of the behavior of a dipole is both difficult and complicated. Fortunately, it is not necessary to make such an analysis for our purposes. As a practical matter, we can consider a dipole (or any receiving antenna, for that matter) to be a generator having an impedance Z_A, as shown in Fig. 6C. Of course, the energy furnished by this "generator" is actually induced in it by the television signal, so it has the characteristics of the received signal.

The impedance Z_A of the antenna depends upon the length of the antenna with respect to the wavelength (λ) of the signal being received. If the antenna is exactly half a wavelength ($\lambda/2$) long, its impedance is approximately 73 ohms; if it is a wavelength (λ) long, its impedance is approximately 2000 ohms; and if it is 3/2 wavelengths ($3\lambda/2$) long, its impedance is approximately 90 ohms. In each of these cases, the impedance is a pure resistance. If the wavelength of the received signal is such that the antenna is between $\lambda/2$ and λ long, its impedance is a combination of inductance and resistance having a value between 73 and 2000 ohms; if it is between λ and $3\lambda/2$ long, its impedance is a combination of capacity and resistance having a value between 2000 and 90 ohms. (Incidentally, the easiest way to determine the length in inches of one half wave in free space at the desired frequency is to divide 5900 by the frequency in megacycles.)

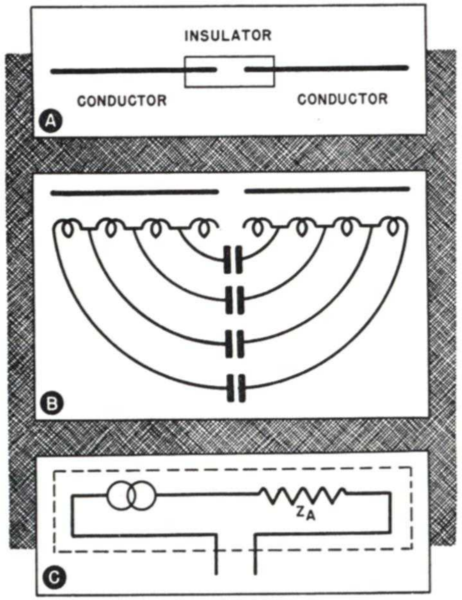


FIG. 6. A dipole antenna and its electrical equivalents.

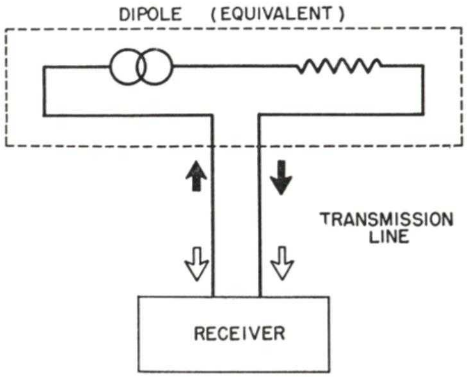


FIG. 7. A two-conductor transmission line passes signal currents (black arrows) from the dipole to the receiver but tends to cancel signals picked up by the line itself (white arrows).

A dipole antenna is connected to a receiver through a 2-conductor transmission line, as shown in Fig. 7. As the black arrows in this figure show, the flow of signal current through the two conductors of this line is in opposite directions at any instant.

Because the two conductors are closely spaced, however, any currents that flow in them because of direct pickup of a television signal by the line itself are in the same direction in each at any instant, as shown by the white arrows. These latter currents flow through the antenna transformer of the receiver in opposite directions and cancel. Therefore, they produce no effect at the input of the set. Thus, the television signal delivered to the set is picked up only by the dipole; the length of the transmission line theoretically does not affect the signal pickup. There are practical reasons for keeping the transmission line as short as possible, however. We shall discuss these later in this Lesson.

Radiation Patterns. The radiation pattern of a dipole that is $\lambda/2$ long with respect to the received signal is shown in Fig. 8A. As you can see, this is the figure-8 pattern we discussed earlier. We have drawn in the dipole to show its orientation with respect to the pattern.

This figure shows that there is no pickup off the ends of the dipole and maximum pickup at right angles to it. The fact that both halves of the pattern are the same size shows that the antenna picks up equally well from the front and the back.

Engineers measure the pickup of any antenna by comparing it to that of a simple dipole of this sort. Therefore, the maximum pickup of this antenna, which is indicated by the lines drawn from the center of the dipole to the farthest part of the pattern, is assigned the value 1.

The "dimple" in the radiation pattern shown by the dotted lines in Fig. 8A shows what happens if the wavelength of the received signal is somewhat shorter than that for which the dipole was cut. Notice that reception at right angles to the dipole becomes worse.

If the wavelength of the received signal is twice that for which the dipole was cut (that is, if the dipole is λ long for the received signal), the antenna has the radiation pattern shown in Fig. 8B. This pattern has four elongated lobes, which are at the angles shown with respect to the dipole. There is no pickup off the ends or directly front or back from the dipole as far as signals of this wavelength are concerned.

The two small dotted lobes at right angles to the dipole in this figure show how the radiation pattern begins to change for signals of still shorter wavelength. As the wavelength of the received signal becomes shorter, with the dipole remaining the same physical length, new lobes begin to appear at right angles to the dipole. When the wavelength of the received signal becomes so short that the dipole is $3\lambda/2$ long, the radiation pattern has the shape shown in Fig. 8C. Notice that the reception at right angles to the dipole is as good as it is for a half-wave dipole and that the reception at angles of 42° from the dipole is even better: the center line of each of these side lobes has a value of 1.4, meaning that pickup in these directions is 1.4 times as great as the maximum pickup of a half-wave dipole in its most favored directions. In other words, the pickup in the directions of the side lobes is about 2 db greater than the pickup at right angles to a half-wave dipole.

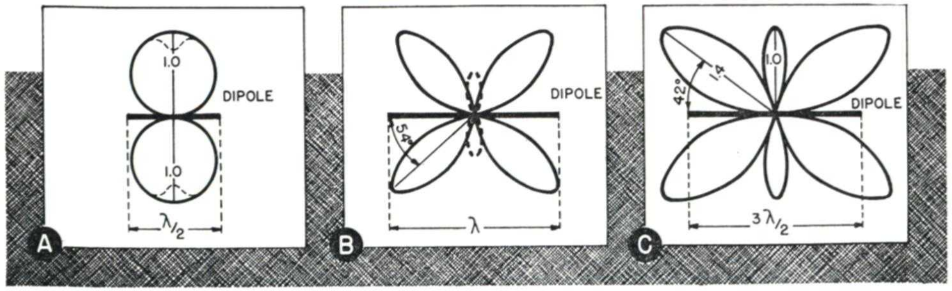


FIG. 8. In these illustrations of the radiation patterns of a dipole as a half-wave, full-wave, and three-half-wave antenna, the dipole remains the same physical length, but the frequency of the signal it is receiving changes.

Remember, each dipole shown in Fig. 8 is the same length in terms of inches. Its length in terms of wavelengths increases only because the wavelength of the received signal decreases.

If the wavelength of the received signal becomes even shorter, more lobes will appear in the radiation pattern; each time the dipole becomes $\lambda/2$ longer, one more lobe will be produced on each side of the antenna.

If a dipole is used to pick up signals for which it is less than $\lambda/2$ long, its radiation pattern is a figure 8, just as it is for $\lambda/2$ operation. However, the lobes of the pattern are somewhat smaller than are those of $\lambda/2$ pattern, which means that the amount of pickup is less but that the directions of best pickup are the same.

Because of the distribution of the frequencies assigned to television stations, we are chiefly interested in the operation of dipoles when they are shorter than $\lambda/2$, exactly $\lambda/2$, or $3\lambda/2$ long. A dipole cut to be $\lambda/2$ long for channel 2 (54-60 mc.) will be only about $3\lambda/4$ long for channel 6 (82-88 mc.) and approximately $3\lambda/2$ long for channel 7 (174-180 mc.). It will be λ long somewhere in the region between the two television bands, which is assigned to other services. In fact, a dipole that is cut to be $\lambda/2$ long for any low-band channel will be more than λ long for any high-band channel.

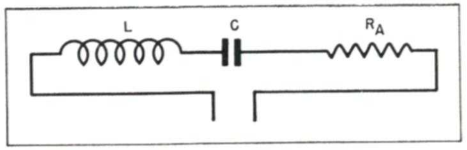


FIG. 9. A dipole can be considered to be a resonant circuit.

This relationship between the wavelengths of the lower and upper bands is the reason why it is often possible to use a single antenna to get reception on both bands even with transmitters in different locations. If we use a dipole cut for the low band and find it possible to orient it so that its center lobe is toward the low-band stations and its side lobes are toward the high-band stations, signals from both can be received efficiently. In the city of Washington, D. C., for example, there are many locations where it is possible to receive all four local stations (which operate on channels 4, 5, 7, and 9) with a single dipole.

Now that you are familiar with the basic television antenna, the simple dipole, we can proceed to study more complex kinds. Before we do, however, let us mention one thing more. We said earlier that a dipole could be considered to be a generator having an internal impedance Z_A. It is also possible, and sometimes much more convenient, to consider it to be a series resonant circuit with an inductance L, a capacity C, and a resistance R_A, as shown in Fig. 9. The values of L and C are such that the circuit is resonant at the frequency for which the antenna is $\lambda/2$ long. In the rest of this Lesson, we shall consider an antenna to be either a resonant circuit or a generator, whichever is the better as a means of making it easier for you to understand the action of a particular antenna.

FOLDED DIPOLE

A common form of television antenna known as the folded dipole is shown in Fig. 10. It consists of a single rod or tube that is bent into the shape shown. In use, the antenna is mounted in a vertical plane with its long sides parallel to the earth and with the unbroken long side on top. The transmission line is connected to the two ends of the antenna as shown.

Such an antenna has the same radiation pattern as does a simple dipole that is half as long as the perimeter of the folded dipole. For example, a dipole cut for channel 2 (54 to 50 mc.) will be about 8.2 feet long. A folded dipole made by bending a rod 16.4 feet long will have the same radiation pattern at the channel 2 frequencies; in fact, as far as the radiation pattern is concerned, we can consider the two to be the same thing at all frequencies. In other words, the two will resonate to the same frequency and have identical radiation patterns.

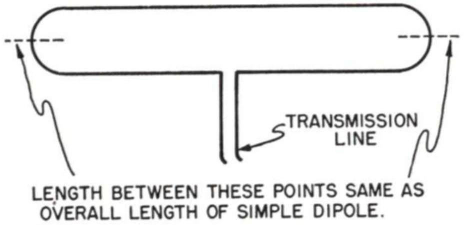


FIG. 10. A folded dipole antenna.

We can, therefore, find out all we want to know about the radiation pattern of any folded dipole by studying the pattern of a simple dipole that is resonant to the same frequency, meaning one that is half as long as the perimeter of the folded dipole. Or, if we wish to make a folded dipole that will have the same radiation pattern as a particular simple dipole, we can do so by making it out of a rod that is twice as long as the simple dipole.

You may wonder why we should bother to use a folded dipole, since we can always find a simple dipole that will be its equal as far as radiation pattern is concerned. There are two reasons: first, the folded dipole has a higher impedance than a simple dipole has at resonance; and second, the folded dipole has a somewhat broader frequency response than its equivalent simple dipole has.

The impedance of a folded dipole depends upon the spacing between its two long sides. The usual kind is made with a spacing of about λ/64, which gives it an impedance of approximately 300 ohms—4 times as great as that of a simple dipole—at resonance. As it happens, 300 ohms is the impedance of one very commonly used kind of transmission line; therefore, a folded dipole can be perfectly impedance-matched to such a line for the frequency to which the dipole is resonant.

We shall discuss the importance of impedance matching at length a little farther along in this Lesson, but right now we might point out that a proper impedance match between the antenna and the line permits a maximum transfer of power from the antenna to the line. (You are already familiar with the fact that a maximum transfer of power from a source to a load occurs when the two have the same impedance; in this case, we can consider the antenna to be a source and the transmission line to be a load.) This means that a folded dipole will deliver a stronger signal to a receiver than a simple dipole will, even though the amount of signal each picks up is the same, if a 300-ohm transmission line is used with each. (There is also a kind of transmission line that has a 72-ohm impedance and therefore matches a simple dipole perfectly; however, as you will learn later in this Lesson, there are often reasons for preferring a 300-ohm line even when the antenna is a simple dipole.)

We mentioned earlier that the impedance of a simple dipole depends upon the frequency of the incoming signal, since it is this frequency that determines whether the antenna will be λ/2, λ, 3λ/2, or some other length. At frequencies above resonance the impedance of a dipole increases rather rapidly. The impedance of a folded dipole also depends upon the frequency of the incoming signal; over a fairly wide range of frequencies above resonance, however, its impedance does not change as much as that of a simple dipole does. In other words, the impedance of a folded dipole is more nearly constant than that of a simple dipole over a range of frequencies above resonance.

To see what the practical effect of this fact is, suppose that we have a simple dipole and a folded dipole, each of which is perfectly matched to its own transmission line. With respect to the amount of signal power delivered to a receiver, these two antennas will be the same at their resonant frequency. At frequencies above resonance, the impedances of each will change; consequently, neither will be perfectly matched to its transmission line, and the amount of power each will deliver to a receiver will therefore decrease. Since the relative impedance change of the dipole will be greater than that of the folded dipole, however, the mismatch between the dipole and its line will be greater. For this reason, the power that the dipole will deliver to a receiver will decrease faster at off-resonance frequencies. Over a range of frequencies above resonance, therefore, a folded dipole will furnish more power to a receiver than a simple dipole will.

For this reason, engineers say that a folded dipole has a wider frequency response than a dipole has. This does not mean that the folded dipole picks up over a wider range than a simple dipole does—their pickup is the same at all frequencies, since they have the same radiation patterns. What it does mean is that a folded dipole and its transmission line will deliver more power to a receiver than a dipole and its transmission line will over a range of above-resonance frequencies.

This effect does not hold at all frequencies, because the impedance of a folded dipole rises very sharply at frequencies near twice its resonant frequency — that is, at frequencies where it is approximately equal to a λ antenna. As we saw earlier, however, λ antennas are not particularly important in television, because the frequency for which a lowband antenna is λ long occurs in the band between the two television bands.

At 3 times its resonant frequency (that is, at a frequency for which it is the equivalent of a 3λ/2 antenna), a folded dipole has an impedance of about 400 ohms. It has a somewhat wider response than a simple dipole at frequencies greater than this, though the effect is not as marked as it is at frequencies close to resonance.

F.M. RECEPTION

Many television sets are designed to be f.m. receivers also. The antenna used with such a set must be able to pick up signals in the f.m. band (88-108 mc.) as well as those in the television bands. From what we said earlier, a dipole cut to be $\lambda/2$ long for channel 2 is between $3\lambda/4$ and λ long for signals in the f.m. band. This means that its impedance is high, and, consequently, there is a considerable mismatch between the antenna and the transmission line at these frequencies.

Fortunately, however, an f.m. set can be made to be much more sensitive than a television receiver is. In spite of this mismatch and consequent loss of power, therefore, the f.m. section of an f.m.-television set can generally be operated even by an antenna that is cut for channel 2. For this reason, it is usually possible to use the same antenna for both television and f.m. reception.

DIPOLES WITH PARASITIC ELEMENTS

A parasitic element is a metal rod or wire that is mounted near an antenna for the purpose of changing the antenna's radiation pattern. Such an element is not connected to the transmission line, which is the reason why it is called parasitic. It produces an effect on the radiation pattern of the antenna because it picks up the signal and re-radiates it, changing its phase in the process. This re-radiated signal is then picked up by the antenna. The antenna therefore has two signals induced in it, one the original signal and the other the signal re-radiated from the parasitic element; these two may add to produce a stronger combined signal or partially cancel to produce a weaker one, depending on the phase relationship between them. As a result, the radiation pattern of a dipole (or a folded dipole; remember, the two have the same radiation patterns) that has a parasitic element mounted near it is different from that of a dipole alone.

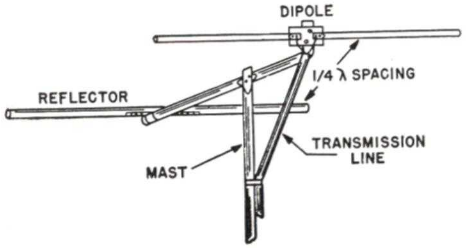


FIG. 11. A plain dipole with reflector.

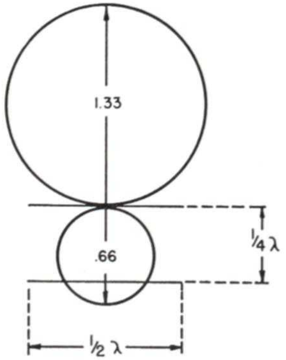


FIG. 12. The radiation pattern for a dipole and reflector of the dimensions shown.

The effect of a parasitic element on the radiation pattern of a dipole depends upon the length of the element (in terms of wavelength), its spacing from the dipole (also in terms of wavelength), and the frequency of the incoming signal. It is possible to get almost any desired pattern by choosing the proper element or combination of elements.

One common use of a parasitic element is shown in Fig. 11. Here an element called a "reflector" is placed parallel to the dipole in the horizontal plane. The reflector is about 5% longer than the dipole. The spacing between the dipole and the reflector is usually $\lambda/4$ at the frequency for which the dipole is resonant, though sometimes spacings as close as $.15\ \lambda$ are used.

The radiation pattern at the resonant frequency for a dipole and reflector spaced $\lambda/4$ apart is shown in Fig. 12. As you can see, the addition of the reflector increases the pickup of the dipole considerably on one side and decreases it considerably on the other, the decrease being on the reflector side of the combination. If the spacing between them were less than $\lambda/4$, the forward lobe would be even longer and somewhat narrower, and the backward lobe (the lobe on the reflector side of the antenna) would be smaller.

Fig. 13 shows the radiation pattern for the combination when it is operating at 3 times the resonant frequency (that is, when the dipole is a $3\lambda/2$ antenna). Notice that the spacing between the antenna and the reflector is now $3\ \lambda/4$. This is explained by the fact that the spacing between them is fixed at $\lambda/4$ when the antenna is erected; since the wavelength is only ⅓ the original wavelength when the antenna is operating at 3 times the resonant frequency, the spacing, which is fixed in terms of inches, becomes 3 times as great in terms of wavelength.

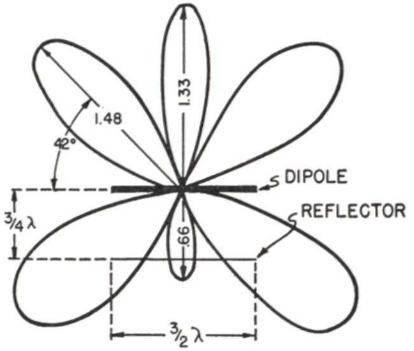


FIG. 13. The radiation pattern of a dipole and reflector operating as a three-half-wave antenna.

As you can see, the center forward lobe is considerably larger and the center backward lobe is considerably smaller than they are in the radiation pattern of a dipole alone. The side lobes, however, are very nearly the same size as they are in the dipole pattern.

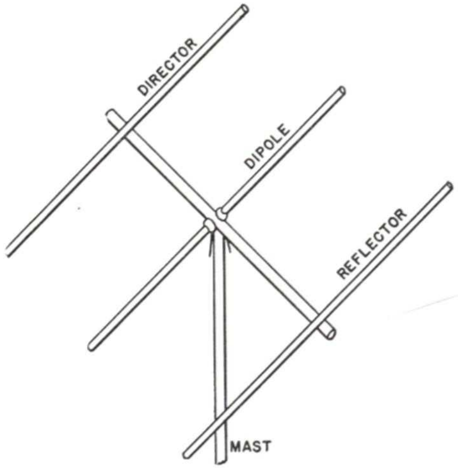


FIG. 14. A dipole with director and reflector.

Since the combination of a dipole and a reflector picks up much better in one direction than in another, particularly at the resonant frequency, it is said to be a "directional" antenna. The combination can be made even more directional by adding another parasitic element on the opposite side of the dipole from the reflector and parallel to both of them (see Fig. 14). This element, which is called a "director," is about 4% shorter than the dipole and is spaced $\lambda/4$ or less from it. The radiation pattern for a director-dipole-reflector combination at the resonant frequency is shown in Fig. 15. Notice that the addition of the director lengthens and narrows the forward lobe and shortens the backward lobe.

The impedance of a dipole is decreased to about 60 ohms by the addition of parasitic elements spaced $\lambda/4$ from it. Its impedance can be brought back to about 72 ohms by reducing the spacing to something less than $\lambda/4$.

The increased forward pickup caused by adding parasitic elements to a dipole makes the combination very useful in areas that are some distance from a television station. However, such antennas are also very frequently used in areas where the signal strength is high; here, their decreased backward pickup is the characteristic that makes them desirable. In a location where there are strong reflected signals that cause ghosts in the picture, a properly oriented parasitic array may be able to pick out the desired signal and ignore the reflected one, thus eliminating the ghosts. We shall go into this matter at greater length in another Lesson.

Unfortunately, the increased directivity and antenna gain produced by the use of parasitic elements are accompanied by a decreased broadness in response. This is generally true of any directional antenna array, although some are worse than others in this respect. Some directional antennas have frequency responses so narrow that they will not pick up equally all the frequencies in a 6-mc. television signal. This fact, of course, rules such antennas out for television use, no matter what their other characteristics may be.

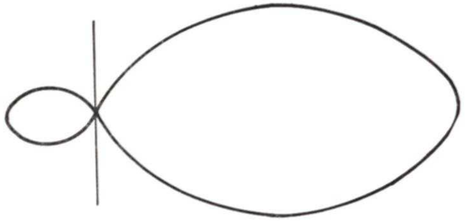


FIG. 15. Radiation pattern of a dipole with reflector and director.

MULTIPLE-CHANNEL RECEPTION

The antennas you have studied so far are the basic ones used in areas where the signal strength is high. There are several other kinds, which we shall discuss in a moment, but the great majority of installations use a dipole or a folded dipole, with or without parasitic elements.

Naturally, the demand for television sets is greatest where television offers the greatest variety of entertainment; therefore, most receivers are located in areas where there are two or more stations. For such receivers, it is necessary to erect an antenna that will pick up all the available stations and preferably pick them up equally well.

How complex such an antenna must be depends on the location. Many things must be taken into account, such as the signal strength in the area where the set is, the relative directions of the stations from the set, whether or not reflected signals are present at the location, the sensitivity of the set, how much electrical noise there is at the point where the installation is to be made: all these play a part in determining what antenna will be satisfactory. We shall study all these factors and several others in this and succeeding Lessons.

Generally speaking, the practice among servicemen making initial installations of sets is to use the simplest and least expensive antenna that will give reasonably good results. As a result, most set installers attempt first to use a dipole or a dipole with a reflector to pick up all the available stations. Very often it turns out that even a simple dipole will give adequate reception on both the low and high bands if the signal strength at the location is high.

We shall go into the question of selecting the proper antenna at some length in a later Lesson, so we shall not devote much time to it here. However, we shall give one example of conditions under which a dipole can be used to receive several stations.

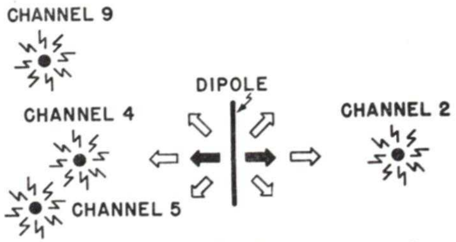


FIG. 16. How a dipole can be used to receive several stations.

This example is pictured in Fig. 16. Notice that there are four stations shown: one on channel 2, one on 4, one on 5, and one on 9. The black arrows show the directions of the major lobes of the antenna radiation pattern for $\lambda/2$ operation, and the white arrows show the major lobes for $3\,\lambda/2$ operation.

If the dipole shown in this example is cut to be a $\lambda/2$ antenna for the channel 4 frequency, it will be about a $3\,\lambda/2$ antenna for channel 9. Therefore, in the location shown, it will have a major lobe pointing toward the channel 4 station and another pointing toward the channel 9 station. There will also be a major lobe pointing toward the channel 2 station: remember, an antenna operating at a frequency less than that for which it is a $\lambda/2$ antenna has a radiation pattern that has the same shape as its $\lambda/2$ pattern, although the lobes are smaller. Finally, since the antenna is $\lambda/2$ long for channel 4, it is reasonably close to being a $\lambda/2$ antenna for channel 5; the channel 5 station will therefore be picked up also, though perhaps not quite as strongly as the others.

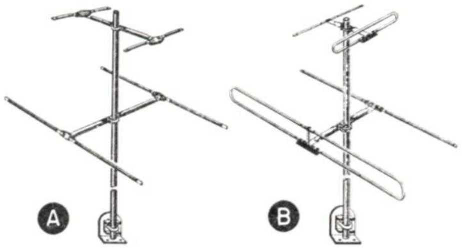
Notice that a reflector could not be used with this antenna because one station is on the opposite side of the antenna from the others. The effect of a reflector, as you saw earlier, is to reduce the pickup on its side of the antenna very strongly. If we used a reflector on the channel 2 side of the antenna in this example, therefore, the channel 2 station would not be picked up if it were at some distance from the receiver. If all the stations were on the same side of the antenna, however, the use of a reflector might well result in improved pickup of all of them.

A simple dipole could be used in this example, but a folded dipole would probably be a better choice. The reason is that the channel 5 station is being picked up mostly because it is fairly near the frequency for which the antenna is cut. Since a folded dipole has a somewhat wider frequency response than a simple dipole has, the former would probably give better reception of the channel 5 station. Then, too, we would get a better impedance match to a 300-ohm line if we were to use a folded dipole, with the result that the signal applied to the receiver would be better for all stations.

Of course, stations are not always located so conveniently with respect to the major lobes of the radiation pattern of a dipole antenna. If both low-band and high-band stations are to be picked up, a dipole will not be very satisfactory unless it can be oriented so that it will pick up the low-band stations as a $\lambda/2$ antenna and pick up the high-band stations as a $3\,\lambda/2$ antenna. It often turns out that such an orientation is impossible, particularly if a station on channel 11, 12, or 13 is to be picked up—

stations up at this end of the high band are harder to pick up than are those operating at lower frequencies.

One way to solve this problem is to use two antennas, one that will be a $\lambda/2$ antenna for the low band and one that will be a $\lambda/2$ antenna for the high band. Fig. 17 shows two common forms of such antennas in which a single mast is used to support both. The one shown in Fig. 17A consists of two simple dipoles and reflectors; the one in Fig. 17B is exactly the same except that the antenna elements are folded dipoles.

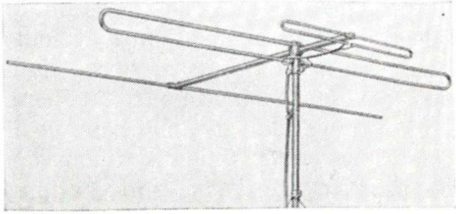


Courtesy JFD Mfg. Co., Inc.

FIG. 17. Examples of two-band antennas.

In most installations, these antennas are connected to the same transmission line. A few sets have an input designed to accept two transmission lines; when an antenna combination of this sort is used with one of these sets, separate transmission lines are run from the antennas to the set. A switch within the set automatically connects the proper line and antenna to the input circuit when the channel selector switch is turned.

When both antennas are connected to the same line, interaction between them is prevented by connecting them with a piece of transmission line that is $\lambda/4$ long at the frequency to which the low-band antenna is resonant; you will learn later in this Lesson what the effect of such a line is. In some locations, this method of isolating the two antennas is not effective: signals picked up by one of the elements are re-radiated and picked up by the other, with the result that ghosts are formed in the picture. Sometimes re-orientation of one of the elements or relocation of the whole antenna will prevent this from happening. If not, some other form of antenna must be used.



Courtesy American Phenolic Corp.

FIG. 18. Another form of two-band antenna.

Because of its wider frequency response, the folded-dipole form of this antenna combination shown in Fig. 17B is usually preferred to the simple-dipole kind shown in Fig. 17A. Both kinds are very common, however.

One feature of both these antennas is that the high-band and low-band sections can be oriented in different directions if it is desirable to do so.

Antennas like these are almost invariably equipped with reflectors, which, of course, makes them unidirectional in their pickup. If it is necessary to use bidirectional antennas at some location, the reflectors can be removed without much difficulty. Their response will be affected somewhat if this is done, because the impedances of the antennas will change, but the effect on the performance of the antennas caused by this change will not be great.

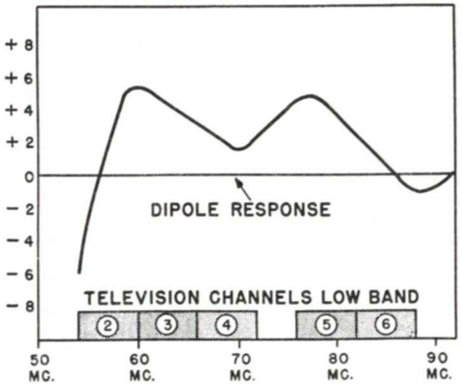


FIG. 19. How the response of the antenna shown in Fig. 18 compares with that of a dipole over the low band.

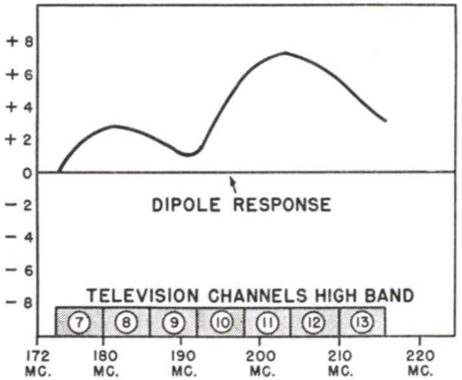


FIG. 20. How the response of the antenna shown in Fig. 18 compares with that of a dipole over the high band.

A somewhat different version of the antenna shown in Fig. 17B is illustrated in Fig. 18. This is a widely used antenna. Here the high- and low-band antennas as well as the low-band reflector are in the same horizontal plane; the low-band folded dipole is the reflector for the high-band antenna.

Fig. 19 shows how the pickup of this antenna compares with that of a standard dipole on the low band from 58 to 88 mc. For each channel, the pickup of a folded $\lambda/2$ dipole tuned to that channel is taken as the standard. The curve shows how many db up or down the pickup of the antenna is for each channel, using this standard value as 0 db. Thus, the pickup of the antenna is greater than that of the standard dipole at all frequencies for which the curve is above the 0 db line.

As you can see from Fig. 19, the antenna has a greater pickup than a standard dipole over most of the low band, but its pickup is less than that of the standard dipole at the extreme ends of the band.

Fig. 20 shows how the pickup of this antenna compares with that of a standard dipole over the high band. As you can see, the pickup of the antenna is better than that of the standard dipole at all points in this band and is considerably better around channel 11.

The radiation patterns for this antenna at low-band frequencies and high-band frequencies are shown in Fig. 21. Since the backward lobes are quite small, this antenna is very much one-directional; in fact, it cannot be used unless all the stations it is to pick up lie in the same general di-

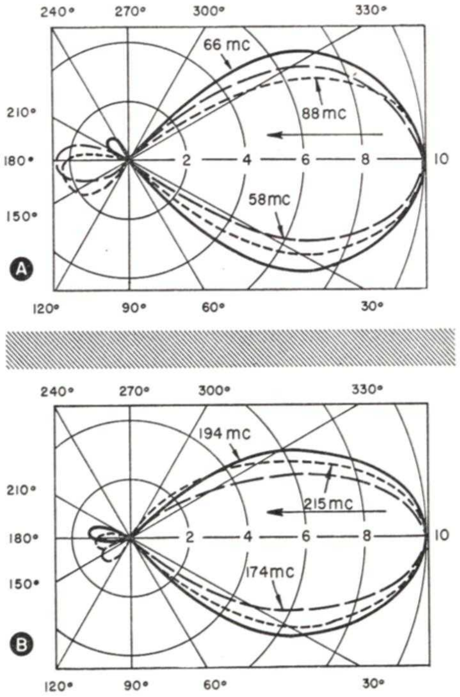


FIG. 21. The radiation patterns of the antenna shown in Fig. 18 for the low and high bands.

rection from the receiver. Of course, it is always possible to use two or more of these antennas, orienting each for one station or group of stations, or to use an antenna rotator to point the antenna at the particular station wanted at the moment. (An antenna rotator is a small, slow-speed, reversible motor that is coupled to the antenna mast in such a way that rotation of the motor will turn the antenna. The direction and amount of rotation of the motor are controlled by a switch or some other control device at the receiver location. Thus, the person operating the set can easily orient the antenna to improve the reception. Antenna rotators will be described more fully in a later Lesson.)

Rather than use combined antennas of the kind we have described, you can erect completely separate antennas for the high band and the low band, mounting them some distance apart to prevent interaction between them and running separate lines to the set. Unless the set is equipped to switch automatically from one line to the other, however, it will be necessary to bring the lines to a low-capacity switch that can be used to connect the desired line to the set.

Most commercially manufactured high-low antennas are cut so that each antenna resonates near the middle of the band for which it is used. Each will then provide reasonably good coverage over its band. If there is only one station in each band in your vicinity, you can get better reception by using antennas cut specifically for those stations. Some manufacturers offer "custom-made" antennas of this sort. If the signal strength in the area is high, however, antennas that resonate near the middle of each band will usually be perfectly satisfactory.

As a matter of fact, almost any form of dipole antenna is reasonably satisfactory in a location where the signal strength is high. An elaborate antenna is needed in such a location only if reflected signals that cause ghosts in the picture are present. Such ghosts can often be eliminated, as you learned earlier, by using a directional antenna that does not pick up the reflected signals.

Antennas for areas where the signal strength is low are another matter. In such areas, it is necessary to use antennas that are as efficient as they can be made. We shall describe such antennas in a few moments. Before we do, however, let us discuss a few unusual kinds that have been developed to give broad-band response.

BROAD-BAND ANTENNAS

It has been found that an effective way to broaden the frequency response of a dipole antenna is to increase the diameter of the poles. (This is the reason why a folded dipole has a broader response than a dipole; effectively, its poles are thicker.) Fig. 22 shows several designs of thick-pole antennas that have rather wide frequency response. The one shown in Fig. 22A is like an ordinary dipole except that the diameter of the poles is many times greater. The one shown in Fig. 22B has conical poles, and that shown in Fig. 22C has spheroidal ones. These three are shown as though they were made of sheet metal; however, approximately the same response can be secured by replacing their solid surfaces with taut wires run lengthwise. The example in Fig. 22D shows how the antenna in Fig. 22A would look if such a replacement were made.

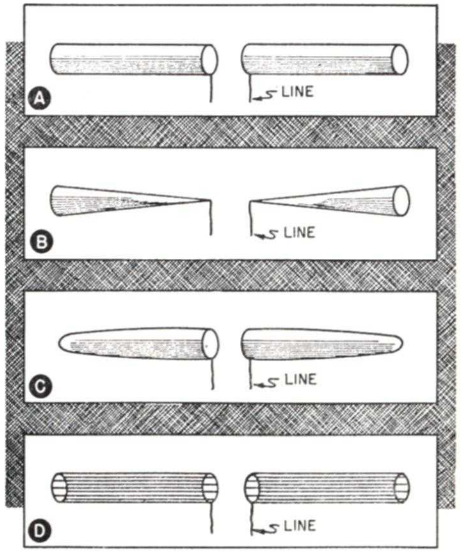


FIG. 22. Forms of broad-band antennas.

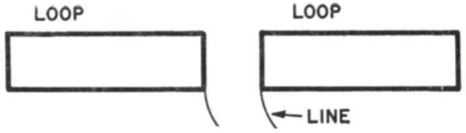


FIG. 23. Another kind of broad-band antenna.

These antennas, although they work well, are seldom used and are not commercially available. The reason is that they are not suitable for outdoor mounting, because they can easily be damaged by a strong wind or by the formation of ice upon them. The kind shown in Fig. 22D would not be subject to damage of this sort as much as the others would be, but it would have the disadvantage of whistling as the wind went through it. In addition, and perhaps more important, it would be difficult to make one of these that would be mechanically strong.

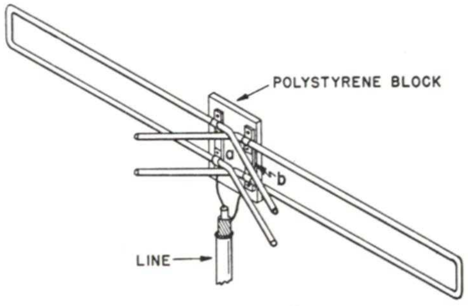


FIG. 24. The bat-wing antenna, a variant of the one shown in Fig. 23.

Another way in which a dipole can be made to have a wider frequency response is shown in Fig. 23. Here, as you can see, the rods of a simple dipole have been replaced by rectangular loops. This produces much the same effect as increasing the diameter of the rods does.

A commercial variation of this antenna, known as the "bat wing," is shown in Fig. 24. In this form, each half of the antenna consists of a rectangular loop that is bent about one-quarter of the distance from its open end and is bridged across by a metal strap near the bend. The two long closed sections thus formed make up an antenna like the one shown in Fig. 23, which has a frequency response that covers the entire low-frequency television band plus the f.m. band. The two short open-ended sections make up a wide-band dipole antenna that provides reception over the entire high-frequency band. Since the transmission line is connected to the bridging straps, the low-band and high-band antennas are effectively connected in parallel to the line. The impedance of the combination is approximately 72 ohms over a wide frequency range.

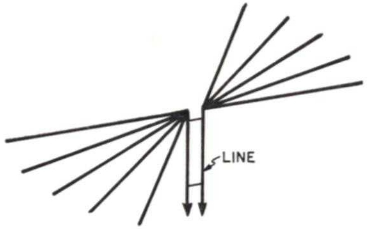


FIG. 25. The di-fan antenna, which has a broad-band response. All the antenna elements shown are in the same horizontal plane.

Another form of wide-band antenna is shown in Fig. 25. This consists of two V-shaped sections, each made up of five rods of equal length. It is mounted so that all the rods are in a horizontal plane. This antenna has an impedance of about 300 ohms over a wide frequency range, and offers good reception over the two television bands and the f.m. band.

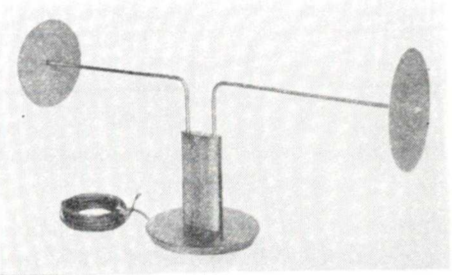
INDOOR AND WINDOW ANTENNAS

Many television installations are made in apartment houses where outside antennas are not permitted. In such cases, indoor or window antennas must be used.

An indoor antenna is not usually as satisfactory as an outdoor one. For one thing, the incoming signal is attenuated by having to pass through the structural materials of the building to reach the antenna. This attenuation may be severe if the building has a steel framework; in fact, it may be impossible to get enough of a signal for satisfactory operation if the building has much steel in its walls.

Courtesy Technical Appliance Corp.

FIG. 26. A widely used form of indoor antenna.



Courtesy RCA

FIG. 27. Another form of indoor antenna.

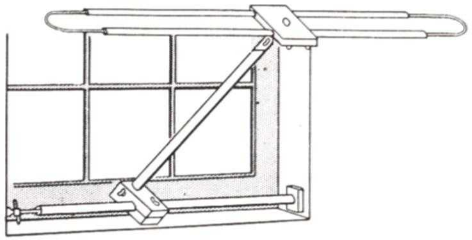
Another handicap under which the indoor antenna labors is that its length is restricted by the fact that it is used inside a home. The usual low-band antenna is too big to keep in the average living room, which is where an indoor antenna is generally placed. Therefore, antennas that are shorter than λ/2 for the lower channels must be used. The radiation patterns of such antennas, you will recall, have shorter lobes than λ/2 antennas, meaning that they do not pick up as well.

Finally, there is usually no possibility of using any kind of directive array for an indoor antenna, because such arrays require far too much space. Therefore, it may be difficult or impossible to eliminate reflections in an indoor installation.

In spite of these handicaps, an indoor antenna will often give good results in an area where the signal strength is high. An antenna like that shown in Fig. 26 has proved to be satisfactory in many installations. This antenna consists of two telescoped metal rods secured to a base through a pivot. These rods are electrically insulated from each other and are connected to the two leads of a transmission line. The angle between the two rods can be changed at will, and the length of the rods can be easily changed by pulling out the telescopic sections. The whole antenna can be rotated simply by picking it up and turning it.

The effective length of this antenna depends on the distance between the tips of the two rods. Thus, lengthening the rods or increasing the angle between them makes the antenna resonant to a lower frequency, and shortening the rods or decreasing the angle between them makes it resonant to a higher frequency. Usually it is necessary to adjust either the length or the angle when the set is tuned from one station to another.

Another kind of indoor antenna is shown in Fig. 27. This antenna, as you can see, is a dipole having a large metal disk mounted at the end of each rod. The effect of these disks is to increase the capacity of the antenna. As a result, such an antenna can be considerably shorter physically than a simple dipole that resonates to the same frequency. In addition, its response is somewhat broader than that of a simple dipole.



Courtesy Insuline Corp. of America

FIG. 28. A form of adjustable indoor antenna.

A window antenna often gives better results than an indoor antenna, particularly when it can be placed in a window that is on the same side of the building as is the transmitter. A typical window antenna is shown in Fig. 28. As you can see, it is a folded dipole that is mounted on a very short mast. At the other end of the mast is a cross bar that can be secured to the window frame, usually by extending the end of the bar to wedge it across the frame.

Such an antenna has a response like that of any other folded dipole. The ends of the one shown in Fig. 28 can be extended to make the antenna resonate to a lower frequency if desired; this is usually done, if at all, only when the antenna is first installed, since it is inconvenient to change the length thereafter.

As we said, it is usually better to install a window antenna on the side of the building that faces the transmitter. However, it is often possible to pick up an adequate signal on the other side of the building also if other buildings or objects reflect the signal toward that side of the building.

Many other forms of indoor and window antennas have been developed. Generally speaking, there is little to recommend one kind over another. The only way to tell whether a particular kind will be satisfactory in a particular location is to try it there.

We have discussed the basic antennas used in locations where the signal strength is fairly high. Now, let's see what kinds of antennas can be used in locations that are on the fringe of the reception area.

STACKED ARRAYS

In areas where the signal strength is low or the surrounding electrical noise is high, the signal-to-noise ratio of the voltage applied to the input of a television set is important. This ratio, as you learned earlier in your studies of radio, shows how strong the signal voltage is in comparison to the noise voltage. Any noise voltage of the proper frequency that is applied to the input of a set will be amplified just as the signal voltage is. Consequently, there will be considerable noise in the output of a set if the signal-to-noise ratio of the voltage applied to the input is low.

The noise-reducing feature of the f.m. audio system may keep such noise from being annoyingly audible. It is always visible, however, because it creates lines or snow in the picture; in fact, the picture may be largely obscured if the noise level is high. Therefore, it is always desirable to have a high signal-to-noise ratio in the voltage that is applied to the input of the set.

The only way to get a high signal-to-noise ratio at the input is to have the antenna pick up considerably more signal than noise. If the antenna is at some suburban or country location where the signal strength and the noise level are both low, the antenna must have a great deal of gain so that it will pick up a good signal. In this case, it does not usually matter whether the antenna is also able to reject noise. If, on the other hand, it is in some city location where both the signal and the noise level are high, the antenna must be able to reject noise; if it is able to do so, its gain is a matter of secondary importance.

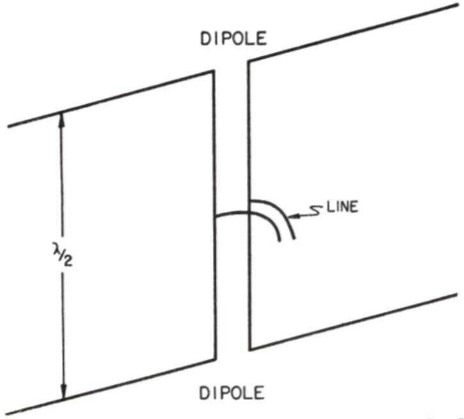
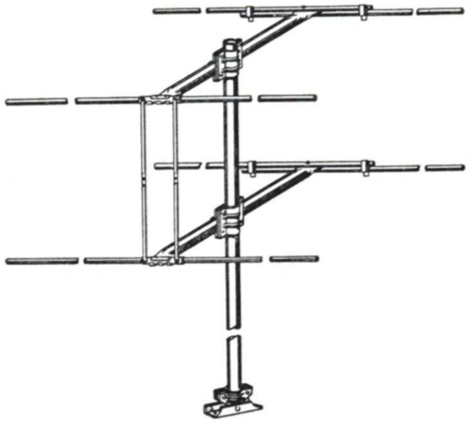


FIG. 29. A simple two-dipole stacked array.

Stacked arrays have become popular for both kinds of installations because they provide good gain and good noise rejection at the same time. A simple stacked array is shown in Fig. 29. This consists of two identical dipoles stacked one above the other and spaced λ/2 apart for the frequency to which they are resonant. The two are connected in parallel by lines connected to their inner ends as shown. The transmission line is connected to the midpoint of the lines that connect the two antennas. Since they are in parallel, their net impedance is always half that of one alone; at resonance, it is 36 ohms.

The increased signal pickup of such an antenna is explained by the fact that there are two of them. Their spacing is what makes them able to reject noise. Any noise coming from above or below induces a voltage in each antenna. Since the two are spaced λ/2 or 180 electrical degrees apart vertically, the noise voltages induced in them are 180° out of phase; therefore, such voltages cancel when they arrive at the point where both are applied to the transmission line.



Courtesy Technical Appliance Corp.

FIG. 30. A "lazy H" stacked array.

The noise rejection and the pickup of this stacked array can both be improved by adding a reflector to each element, as shown in Fig. 30. (This array is often called a "lazy H," because it looks like two letter H's lying on their sides.) The pickup is increased thereby just as it is when a reflector is added to a single dipole. The noise rejection is increased because signals coming from the backward or reflector side of the array are reduced, and any noise they contain is reduced likewise. The reflectors have little effect on noise coming from below or above the array, however.

FIG. 31. A stacked array of dipoles, directors, and reflectors.

The impedance of this array at resonance is 30 ohms.

The signal pickup can be still further increased by adding a director to each element as shown in Fig. 31. The director has much the same effect as it does when it is used with a single dipole. Adding it to the array has little effect on the noise pickup, except that it narrows the horizontal angle from which the antenna picks up. This may result in a reduction in noise pickup if the antenna can be oriented so that the desired signal is received but the noise is not. If the source of noise lies in the same general direction as the desired station, however, orientation of the antenna will not help in reducing the noise pickup.

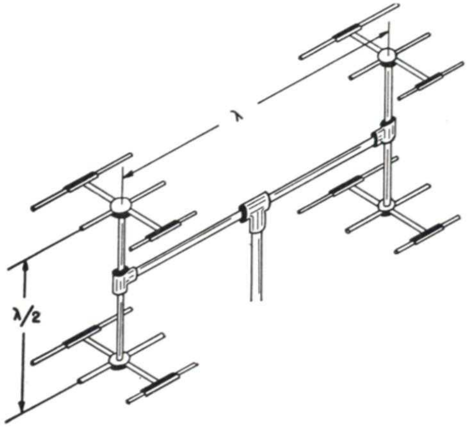
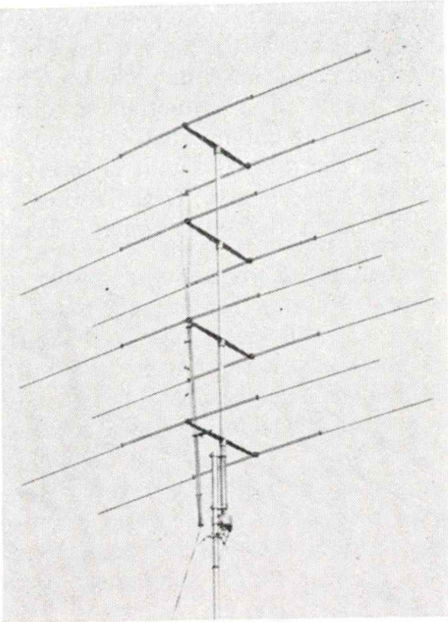


FIG. 32. A combination of stacked arrays.

If further increases in pickup are needed to make reception satisfactory, more elaborate antenna arrangements can be used. One of these is shown in Fig. 32. Here we have two stacked arrays like those in Fig. 31 that are mounted side by side a distance λ apart. This array has a gain of 11 db over a simple dipole and a horizontal pickup angle of only 28°. Since a gain of 6 db represents a doubling of the voltage, you can see that this particular array will deliver almost 4 times the voltage to the transmission line that a simple λ/2 dipole would. All four dipoles used in this array are connected in parallel; the impedance of the array is therefore ¼ the impedance of the individual dipoles.

It is also possible to stack more antenna arrays vertically. One of the



Courtesy LaPointe Plascomold Corp.

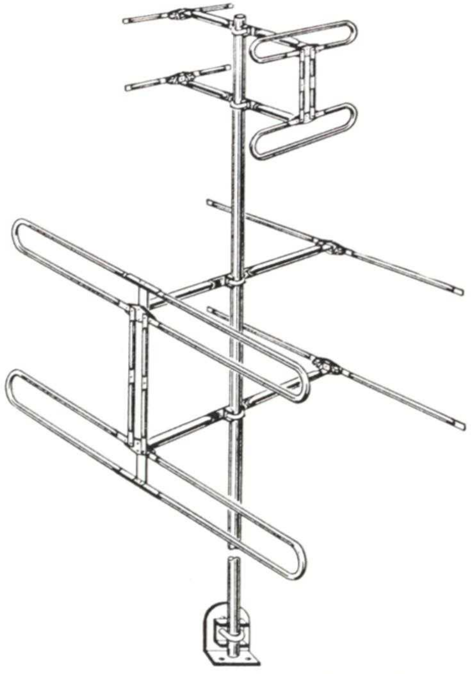
FIG. 33. A four-bay stacked array.

most complex of these arrangements that is now in use is shown in Fig. 33. This antenna, which is known as a 4-bay stacked array, consists of four dipoles and reflectors stacked vertically. A feature of this antenna is that the dipoles are connected to parallel rods (called Q sections) as well as to the transmission line. The impedances of the dipoles can be adjusted by sliding shorting bars along these sections; this makes it possible to match the impedance of the array to that of the transmission line.

Antenna Height. When an antenna is installed at a location that is a considerable distance from a transmitter, it must be gotten as high in the air as possible. We have mentioned this fact before, but it is important enough to bear repeating. The receiving antenna must be high enough to be on a line of sight from the transmitting antenna, or at any rate only slightly below a line-of-sight path (as you learned earlier in this Lesson, there is a small amount of bending of v.h.f. signals in the atmosphere). Remember, an antenna cannot manufacture a signal; no matter how efficient it is, it must be placed in a portion of space through which a signal passes if it is to pick up the signal.

Therefore, the use of a high-gain antenna is not the only procedure that must be followed to get reception in fringe areas. Some means must also be found to mount the antenna high in the air.

Band Widths. In general, we can say that the band width an antenna can pick up becomes more restricted as the antenna becomes more complex. Thus, it is possible to make simple stacked arrays like those in Figs. 29 and 30 pick up over the whole low or high band, particularly if folded dipoles are used instead of the simple dipoles shown, whereas the complex array shown in Fig. 32 can be used for only one station. If you want to pick up more than one station in a location where it is necessary to use an array of the latter kind, you must use a separate one for each station.



Courtesy JFD Mfg. Co., Inc.

FIG. 34. Low-band and high-band stacked arrays mounted on the same mast.

If both low- and high-band stations are to be picked up in a location where it is possible to use antennas of the kind shown in Figs. 29 and 30, you can use a stacked low-band and a stacked high-band array on the same mast, as shown in Fig. 34. The kind of all-band antenna shown earlier in Fig. 18 can also be stacked with consequent improvement in pickup and in signal-to-noise ratio.

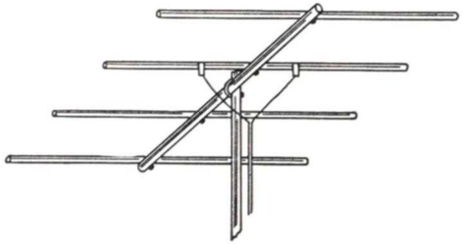


FIG. 35. A Yagi antenna.

YAGI ANTENNA

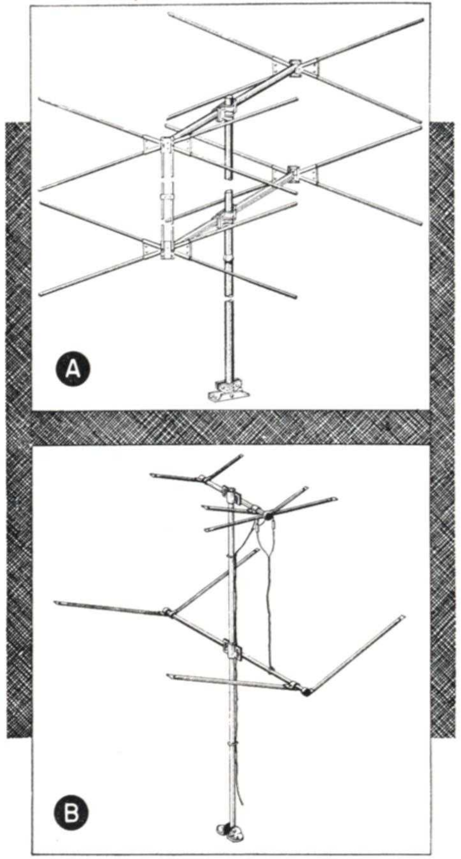
The Yagi antenna (named after its Japanese inventor) shown in Fig. 35 is useful in fringe reception areas because of its extremely high gain. This antenna consists of a dipole, a reflector, and either 2 or 3 directors. The dipole in this antenna differs from others we have described in that it is made of one rod, rather than a pair of rods. The two leads of the transmission line are connected to this rod at points equidistant from the center of the rod. At first glance, it would appear that the transmission line is shorted when it is connected to a rod in this manner; actually, however, because of the distributed capacity and inductance of the rod, there is an impedance between the two leads of the transmission line.

The spacings of the reflector and the directors from the dipole are very critical, as is also the spacing between the ends of the transmission line leads. The reflector and director spacings are determined by the manufacturer of the antenna on an experimental basis. The transmission line spacing is found when the antenna is erected, by moving the ends of the leads together or apart until the best picture is secured on the set to which the antenna is connected. The connections between the line and the dipole are usually made with movable clips to make this adjustment easier.

This antenna has a forward gain of 11 db and a very narrow horizontal pickup angle. As you would expect, it also has a very limited band width; as a matter of fact, it can be used for only one station. When you order such an antenna, therefore, you must specify the station it is to be used for, since the spacings between the elements and the lengths of the elements differ for every channel.

NON-HORIZONTAL ANTENNAS

In suburban and country locations where the noise is low and increased signal pickup is the main thing wanted from an antenna, the antennas shown in Figs. 36A and B can sometimes be used. The theory behind these anten-



Top illustration Courtesy Technical Appliance Corp., bottom illustration Courtesy Premax Products

FIG. 36. Antennas designed to pick up both horizontally and vertically polarized signals.

nas is that the television signals, although originally transmitted with horizontal polarization, will be partially vertically polarized by the time they have travelled a long distance, because of reflections and other effects. In other words, the television signal at remote locations will have both a horizontal and a vertical component. A horizontal antenna will pick up a vertically polarized wave only slightly, and, conversely, a vertical antenna will pick up a horizontally polarized wave only slightly; however, antennas like those shown in Fig. 36 will pick up signals of either polarization. Therefore, they will give greater pickup than a purely horizontal antenna will when the signal contains both horizontal and vertical components.

However, such antennas will also pick up noise (which is usually vertically polarized) better than a horizontal antenna will. They are therefore not suitable for use in noisy locations.

RHOMBIC ANTENNA

If there is enough space available at the location of the set, a rhombic antenna (an example of which is shown in Fig. 37) can be used to get extremely high gain over a wide band. This antenna is made of two long wires strung in a diamond shape parallel to the ground. One end of each wire is connected to a non-inductive resistor; the transmission line is connected to the other end of each.

This antenna is unidirectional, receiving best from the end to which the terminating resistance is connected. The single lobe of its radiation pattern, which is extremely narrow, is lined up with the long axis of the diamond. Because of the narrowness of the pattern, this antenna must be very carefully oriented.

The efficiency of the rhombic increases as the leg length (measured in wavelengths) increases. The legs should be at least 2 λ long for the lowest-frequency station to be received, and preferably more.

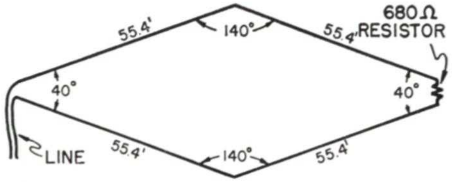


FIG. 37. A rhombic or diamond antenna has a very sharp radiation pattern. It should be oriented so that the resistor end of the antenna will point directly at the desired station.

The chief elements to be considered in the design of a rhombic are the leg lengths and the angles between the legs. If these are properly selected, a rhombic antenna can be made to cover the entire television spectrum at high gain. The design shown in Fig. 37 offers this wide coverage with voltage gains of up to 20 db over a half-wave dipole for the high band.

A rhombic should be strung as high as possible, since its performance improves as its height is increased.

As you can see from the figure, the rhombic requires a great deal of space. An area about 105 feet long and 40 feet wide is needed to erect the antenna shown.

The impedance of a properly designed rhombic antenna is always the same as that of its terminating resistor. In the design shown in Fig. 37, this is 680 ohms. This can be matched reasonably well by a 600-ohm line, which can readily be matched to a 300-ohm receiver through a matching transformer.

Although 600-ohm line is not commercially available, you can make it yourself of two pieces of No. 12 wire spaced 6″ apart (center to center) by insulators. A 2-to-1 matching transformer can be bought or can be made by winding a primary of 29 turns over a ½-inch plastic core form and winding a secondary of 17.5 turns over the center of the primary. Both the primary and secondary windings should be close wound.

Transmission Lines

The lead-in used to connect an antenna to a television set is called a transmission line. Three types of these lines—coaxial, twin-lead, and shielded twin-lead lines—are in use. We shall first learn the physical characteristics of these lines, then study their electrical operation as carriers of r.f. current.

Like any conductors, transmission lines have distributed inductance and capacity. A line therefore has impedance when it is carrying r.f. current. In television, we are concerned with the "characteristic" or "surge" impedance of a line, which is the input impedance of an infinitely long section of that particular line. This characteristic impedance is determined by the physical construction of the line and by the electrical properties of the material used in it.

Other important properties of a transmission line are its attenuation, which is usually stated in db per 100 feet for signals of various frequencies, and its ability to reject interference. We shall discuss each of these factors in the following descriptions of the three main types of television transmission lines.

Coaxial Line. The coaxial line, shown in Fig. 38, consists of a wire surrounded coaxially by a tube of flexible metal braid that is spaced evenly from the wire by insulating material. The center wire and the outer braid (which is covered with waterproof insulation) are the two conductors of this line.

FIG. 38. A typical coaxial transmission line.

The diameter of the wire, the distance between the wire and the braid, and the dielectric constant of the insulating material determine the impedance of a coaxial line. The kind commonly used in television installations has an impedance of 72 ohms. Its attenuation is 2.2 db at 40 mc., 3.75 db at 100 mc., and 5.6 db at 200 mc. per 100-ft. length.

FIG. 39. An unshielded twin-lead transmission line.

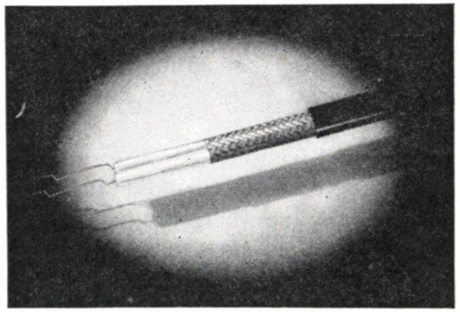
When coaxial line is used, the metal braid is grounded at the receiver. It therefore acts as a shield around the central wire, reducing interference pickup very considerably. Because of this ground connection, the line should be used only with a set having an unbalanced input.

Twin-Lead Line. The twin-lead line, shown in Fig. 39, consists of two flexible wires molded into a flat ribbon of plastic insulating material. The impedance of the line depends upon the diameters of the wires, the spacing between them, and the dielectric constant of the insulation. The kind most commonly used in television installations has an impedance of 300 ohms, although 150-ohm and 72-ohm twin-lead line can also be obtained.

The 300-ohm type has an attenuation of 1.1 db at 40 mc., 2.1 db at 100 mc., and 3.6 db at 200 mc. per 100-foot length. As you can see, its attenuation is far less than that of coaxial cable, a factor that can be very important in an installation made where the signal strength is low. It does not have as much ability to reject noise pickup as coaxial line has, however.

Shielded Twin-Lead Line. If it were made in the conventional manner, a 300-ohm shielded twin-lead line would have to be extremely large in diameter, because the shield would have to be spaced far away from the conductors to reduce the capacity between them. However, a new type of shielded twin-lead line, shown in Fig. 40, is reasonably small and yet has an impedance of 300 ohms.

The two conductors used in this line are crimped into a series of sawtooth sections. In manufacture, a tube of polyethylene (a plastic insulator) is extruded around each of these conductors. Each conductor touches the tube in which it is encased only at the points of the sawtooth; otherwise, the conductor is surrounded only by air. The effect of this construction is to reduce the capacity between the two conductors and the capacity between the conductors and the shield, because air has a lower dielectric constant than has any other insulator. The line can therefore have a 300-ohm impedance and yet be reasonably small in cross-sectional diameter.



Courtesy Federal Tel. and Radio Corp.

FIG. 40. A shielded 300-ohm twin-lead transmission line.

The two conductors in their polyethylene tubes are enclosed in a shield of flexible braid, which is in turn enclosed in a thermoplastic insulating jacket. This shield is grounded when the line is installed and therefore permits the line to have as good interference rejection as coaxial line.

The attenuation of this line is 2.4 db at 50 mc., 3.4 db at 100 mc., and 4.6 db at 200 mc, per 100-foot length—slightly less than that of 72-ohm coaxial cable.

Now that we have learned what practical transmission lines are like, let's learn how they operate when r.f. flows through them.

LINE REFLECTIONS

We mentioned earlier that the three important characteristics of a transmission line are its ability to reject interference, its attenuation, and its surge impedance. What effect the first two of these have on our choice of a transmission line can be stated simply. Generally speaking, we want there to be as little attenuation in the transmission line as possible. All other factors being equal, therefore, unshielded twin-lead line is the best one to choose for an installation. If interference is a problem, however, a shielded line must be used in spite of its greater attenuation.

Now, let us see why the impedance of a line is important.

The job of a transmission line is to deliver a signal to a load. It can do so efficiently only if the load is resistive and has an ohmic value equal to the surge impedance of the line. If the load has reactance, or if its resistance is not equal to the impedance of the line, a phenomenon known as "reflection" occurs: part of the signal that comes along the line to the load is returned, or reflected, back to the line.

To see what effect such a reflection has in a practical case, let's suppose we have a 72-ohm line connected to the input of a set that has a 300-ohm input impedance. (As you learned in an earlier Lesson, sets have input impedances of 72 ohms, 300 ohms, or both.) Suppose, too, that the line is connected to a folded dipole that has an impedance of 300 ohms.

A signal picked up by the antenna is fed into the line and travels down it to the set. Because the line and the set have different impedances (that is, their impedances are not matched), only part of the signal is fed into the set; the rest is reflected back into the line. This reflected signal travels back up the line to the antenna. Because of the mismatch between the antenna and line impedances, part of this reflected signal is reflected again; it travels back down the line and again appears at the input of the set.

If the line is 50 feet long, the part of the signal that has been reflected twice has traveled 100 feet farther than did the part of the signal that was fed into the set at the time of the first reflection. (For convenience in reference, let's call the former the reflected signal and the latter the original signal.) Because of this difference in path length, the reflected signal will be slightly out of phase with the original signal; since both are applied to the input of the set, this phase difference will cause blurring of the picture. In other words, line reflections caused by mismatches of impedance at the ends of the line produce exactly the same effect as that produced by multipath reception. Severe ghosting can be produced by such mismatching, because it is perfectly possible for a strong signal to be reflected up and down the line several times, thus causing several out-of-phase signals to be applied to the input of the set.

Such reflections cannot occur if the impedance of the transmission line matches the input impedance of the set, because then all the signal that comes down the line will be absorbed by the set. If there is a proper impedance match at this end of the line, it does not matter whether there is a match between the antenna and the line as far as reflections are concerned. Therefore, one important thing to remember about a transmission line is that *its impedance must match the input impedance of the set with which it is used.*

Fortunately, this is not a difficult requirement to meet. As you learned earlier in your Course, all modern sets have input impedances of 72 ohms, 300 ohms, or both. Since both 72-ohm and 300-ohm lines are available, it is always possible to secure an impedance match between the line and the set.

Of course, it may happen that a set having a 300-ohm input impedance is to be installed in a location where an antenna having a 72-ohm line is already installed. In such a case, a matching transformer or a resistor network can be used to match the set and the line (or a new line can be installed). We shall discuss such problems in a later Lesson on antenna installations.

ANTENNA MATCHING

Whether or not the antenna impedance is matched to that of the line is not important as far as reflections are concerned, as we just pointed out. However, the lack of an impedance match will have an effect on the transfer of the signal from the antenna to the line.

We mentioned earlier that the antenna can be considered to be a generator and the transmission line its load. You know from previous studies that the greatest transfer of power between a generator and its load occurs when the two are matched in impedance. Therefore, an impedance mismatch between the antenna and the line will give less than a maximum transfer of signal power from the antenna to the line.

As far as the antenna is concerned, a line that is properly matched in impedance at the receiver end will be an infinite line — that is, its actual impedance will be equal to its surge impedance at all frequencies. Therefore, we could be sure of getting a maximum transfer of signal at all frequencies if we could match the impedance of the antenna to that of a properly terminated line at all frequencies.

Unfortunately, this cannot be done. As you learned earlier in this Lesson, the impedance of an antenna depends upon the frequency of the received signal. An antenna can be made to have a fixed impedance for one frequency but not for all. Even a wide-band antenna will vary rather considerably in impedance over the television bands.

Fortunately, this fact seldom causes any problems in the metropolitan areas where most installations are made. There the signal strength is almost invariably high enough so that part of the pick-up signal can be wasted without affecting reception. In such areas, usually the only impedance match of importance is that between the line and the set; as long as this match is made, it does not matter much whether the line and the antenna are matched. If they are not, part of the signal will be wasted, but there will still be enough to operate the set satisfactorily in most cases.

As a matter of fact, the antenna and the transmission line are often deliberately mismatched in areas of high signal strength where there are several stations. The purpose of doing so is to make reception fairly uniform over a wide band. If a 300-ohm line is used with a 72-ohm dipole, for example, there will be a 4-to-1 mismatch at the frequency for which the dipole is cut. This will cause a loss of signal for that station; since the signal strength is high, however, this loss is not serious. At higher frequencies, where the dipole does not pick up as well, its impedance will increase. The impedance match between the antenna and the line will therefore improve, and the consequent improvement in signal transfer from the antenna to the line will partially compensate for the reduced response of the antenna.

This effect can be produced, by the way, only if the impedance of the antenna at resonance is lower than that of the line. The reverse of this condition (having the line lower than the antenna in impedance) will not produce any helpful effect, because the impedance of an antenna always rises at off-resonance frequencies; therefore, the mismatch between the line and the antenna will get worse as the frequency increases.

In fringe areas, where every bit of signal is needed, the match between the antenna and the line becomes very important. In this respect, it is fortunate that it is usually necessary to use a separate antenna for each station in such areas, because each antenna and line can then be matched individually for a particular frequency. As we just pointed out, this is the only way in which a perfect match can be secured.

Fringe area reception generally calls for the use of stacked arrays, which, as you learned earlier, have relatively low impedances. If the particular array to be used does not have the same impedance as does the input of the set, obviously no line can match them both. In such a case, the easiest solution is to select a line that will match either the set or the antenna and then to create a match between the line and the other component of the system.

The more common practice is to select a line that will match the set (since it is always possible to make this match) and then find some way to make the line match the antenna also.

Matching Section. An impedance match between an antenna and a line can be secured by connecting the one to the other through a $\lambda/4$ section of line having a characteristic impedance intermediate between the two impedances that are to be matched. Such a connecting line is called a matching section. The characteristic impedance it must have can be calculated from the formula:

$$Z_{MS} = \sqrt{Z_A \times Z_{TL}}$$

where Z_{MS} is the impedance of the matching section, Z_A is the impedance of the antenna, and Z_{TL} is the impedance of the transmission line. Applying this formula to the problem of matching, say, a 72-ohm antenna and a 300-ohm line, we find that the matching section must have an impedance of $\sqrt{72 \times 300}$, which is approximately 147 ohms. Therefore, a $\lambda/4$ length of 150-ohm line (which is a commercially available item) will serve as a matching section in this case. Of course, it will be a matching section for only one frequency, since it will not be $\lambda/4$ long at any other frequency.

Another method of matching an antenna and a line is to use what is known as a "matching stub." To understand the action of this device, we must learn something about the electrical characteristics of $\lambda/4$ and $\lambda/2$ lines.

QUARTER-WAVE AND HALF-WAVE LINES

To determine the characteristics of a piece of transmission line, we could connect it to a source of r.f. energy and measure the r.m.s. values of the r.f. voltages and currents found at various points along the line. We could then determine the impedance at each point along the line; if we plotted this impedance against the length of line, we could get a picture of how the line works. Fig. 41 shows the results we would get if we did this for four special cases that are of particular interest.

Fig. 41A shows how the impedance varies along a $\lambda/4$ line that is open at both ends. We shall speak of the left-hand end of each of these plots as being the source end, because this is the end to which the source of r.f. energy would have to be coupled to get these plots. Notice that the impedance is zero at the source end and high at the other end (which we shall call the load end). In other words, a $\lambda/4$ section of open line will appear to be a short circuit to a source connected to one end of the line.

When a $\lambda/4$ line is shorted at its load end (Fig. 41B), exactly the opposite result is produced: the impedance is high at the source end and zero at the shorted end. Thus, a $\lambda/4$ line shorted at the load end appears to be an open circuit at the source end.

A similar plot for an open $\lambda/2$ line (Fig. 41C) shows that its impedance is high at both ends and low in the middle. Finally, a plot for a $\lambda/2$ line that is shorted at one end (Fig. 41D) shows that its impedance is low at both ends and high in the middle.

An easy way to keep these facts in mind is to remember that a $\lambda/4$ line inverts its load whereas a $\lambda/2$ line repeats its load. If the load end of a $\lambda/4$ line is open, its source end appears shorted, and vice versa. The source end of a $\lambda/2$ line, on the other hand, always has the same impedance as the load end has.

All these facts about the performance of $\lambda/4$ and $\lambda/2$ lines will prove useful to you in your later studies of television. We have already seen one use that is made of the properties of a $\lambda/4$ line: we learned earlier that a high-band and a low-band antenna are electrically isolated by connecting them with a length of transmission line that is $\lambda/4$ long at the frequency for which the low-band antenna is cut. This isolates the two antennas at low frequencies because the high-band antenna acts practically as a short for these frequencies. Since a shorted $\lambda/4$ line has a high impedance at its other end, the high-band antenna appears as a high impedance across the low-band antenna, and therefore has very little effect on it. At high frequencies, the $\lambda/4$ isolating section is simply an extension of the transmission line as far as its effect on the high-band antenna is concerned. Since the low-band antenna has high impedance at these frequencies, it can be considered to be simply a high-impedance load across the line.

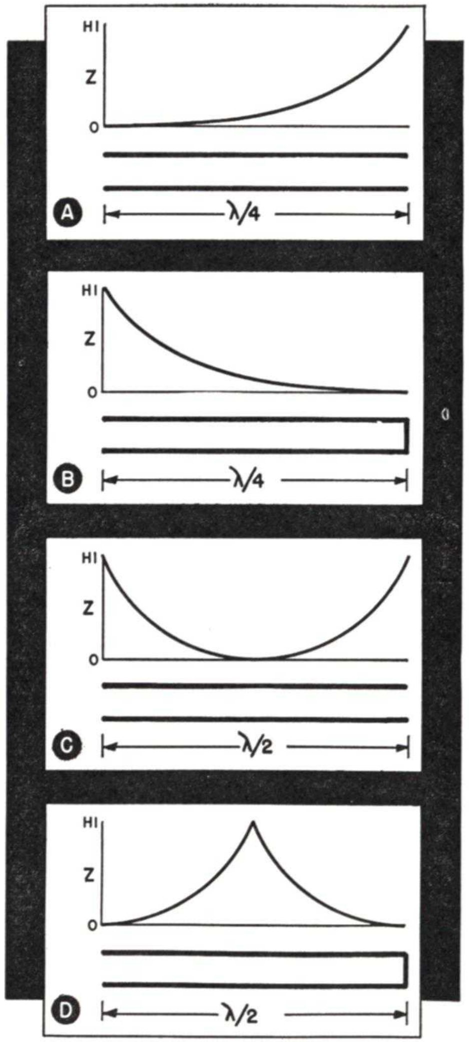


FIG. 41. The characteristics of quarter-wave and half-wave lines.

At the moment, we are particularly concerned with the operation of a shorted $\lambda/4$ line when it is used to match an antenna to a transmission line. When it is used for this purpose, a shorted $\lambda/4$ line is called a "matching stub" (the name coming from the fact that only a short stub of a line is used).

To take a practical example, let's say we want to use a matching stub to match a 300-ohm line to a 30-ohm antenna. (The antenna shown earlier in Fig. 30 has an impedance of 30 ohms.) Fig. 42 shows the connections that will permit this match to be made. As you can see, the transmission line is connected to the open end of the matching stub and the antenna is connected to the stub a distance d from its shorted end. Let's see why these connections produce the match we want.

As we just pointed out, the impedance of a matching stub is very high at its open end. When we connect the 300-ohm line to this end of the stub, we are effectively connecting the low impedance of the line and the high impedance of the stub in parallel; consequently, the impedance at the point of connection becomes 300 ohms (since the impedance of a parallel combination of a high and a low impedance is, for all practical purposes, that of the low impedance). Therefore, the impedance of the matching stub now varies from zero at its shorted end to 300 ohms at the point of connection to the line. Somewhere between these two ends of the stub is a point where its impedance is exactly 30 ohms; it is to this point that the 30-ohm antenna is connected. The impedance of the antenna is therefore perfectly matched.

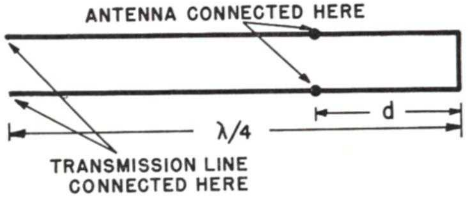


FIG. 42. How a matching stub works.

A matching stub can be used in this manner to match any antenna to any line. If the impedance of the line is lower than that of the antenna, the open end of the matching stub must be connected to the antenna; the impedance of the stub will then vary from zero to the same impedance as the antenna, and the line can be matched to the combination by connecting it to the stub at the proper point.

What the proper point is depends on the ratio of the impedances of the antenna and the line. Table I shows the points of connection for various impedance ratios. In this table, Z_1 is the higher impedance and Z_2 the lower impedance. For instance, if we have a 300-ohm line and a 30-ohm

TABLE I

Stub Connections for Various Impedance Ratios

Z_2/Z_1	d*	Z_2/Z_1	d*
0.05	14	0.55	53
0.10	20	0.60	56
0.15	25	0.65	59
0.20	30	0.70	63
0.25	34	0.75	67
0.30	37	0.80	70
0.35	41	0.85	75
0.40	44	0.90	80
0.45	47	0.95	90
0.50	50	1.00	100

* % of length from shorted end

antenna, Z_1 is 300 ohms and Z_2 is 30 ohms. The ratio Z_2/Z_1 is therefore 30/300 or 0.10. From the table, you can see that for this ratio of impedances, the antenna should be connected to the matching stub at a distance from the shorted end equal to 20% of the length of the stub. If the ratio of impedances were, say, 0.45, the point of connection should be 47% of the length of the stub, and so on. In all cases, these distances are from the shorted end of the stub.

Obviously, it is mechanically more difficult to tap in on a matching stub than it is to use a matching section between the transmission line and the antenna. However, the matching stub has the advantage of being usable no matter what the impedances of the antenna and the line may be, whereas the matching section can be used only if the square root of the product of the impedances of the two is equal to the impedance of some available line. For example, if a section of line were to be used to match a 30-ohm antenna and a 72-ohm line, it would have to have an impedance of $\sqrt{30 \times 72}$, or approximately 46.5 ohms — and no commercially available line has this impedance.

Remember, neither of these matching methods will provide a match at more than one frequency, because a matching section or a matching stub will be $\lambda/4$ long at only one frequency.

Looking Ahead. You have now studied the theory of operation of TV antennas and transmission lines. In a future Lesson, you will learn how to select the antenna and the transmission line for a particular installation and how to make the installation.

Lesson Questions

Be sure to number your Answer Sheet 59RH-3.

Place your Student Number on every Answer Sheet.

***Send in your set of answers for this Lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Why is it possible to receive TV carrier signals somewhat beyond the line-of-sight distance even though they are not reflected from the Kennelly-Heaviside layer?
2. If the heights above sea level of a transmitting antenna and a receiving antenna are 800 feet and 50 feet respectively, what is the maximum line-of-sight distance between the two?
3. If a reflected signal travels several hundred feet farther than a direct signal and both reach the same antenna, what will be the effect on the picture?
4. What is the impedance of a plain dipole of (a) $\lambda/2$, (b) λ, and (c) $3\lambda/2$ length?
5. A dipole cut to be $\lambda/2$ for channel 2 receives that channel best from a direction perpendicular to its length. At what angle from the dipole will it receive best on channel 7, for which it is $3\ \lambda/2$ long?
6. Is it more important to match the impedance of the transmission line to that of the receiver or that of the antenna, and why?
7. What length of transmission line should be used to connect a high-band to a low-band antenna to prevent interaction between them?
8. How does the active (or driven) element in a Yagi antenna differ from that of an array consisting of an ordinary dipole with reflectors and directors?
9. What should be the impedance of the transmission line connected to a folded dipole if maximum power transfer is wanted?
10. Suppose a shorted $\lambda/4$ matching stub is to be used to match a 300-ohm line and a 50-ohm antenna. Should the open end of the stub be connected to the line or to the antenna?

Be sure to fill out a Lesson Label and send it along with your answers.

SHOULD YOU DEPEND ON LUCK?

Accident—chance—luck—have very little bearing upon the production of any great result or true success in life. Of course, there have been many discoveries and accomplishments which may *seem* to be the result of "luck."

For instance: Newton "discovered" the law of gravity by watching an apple fall from a tree. Galileo "invented" the telescope after hearing of a toy constructed by a spectacle-maker. Brown "invented" the suspension bridge after watching a spider throw its web.

But these discoveries and inventions were made by men *trained* to take advantage of what they observed. Thousands of *untrained* men had seen the same things and paid no attention.

The new discoveries in Radio—Television—Electronics will be made by men *trained to take advantage of what they observe.*

J. E. Smith