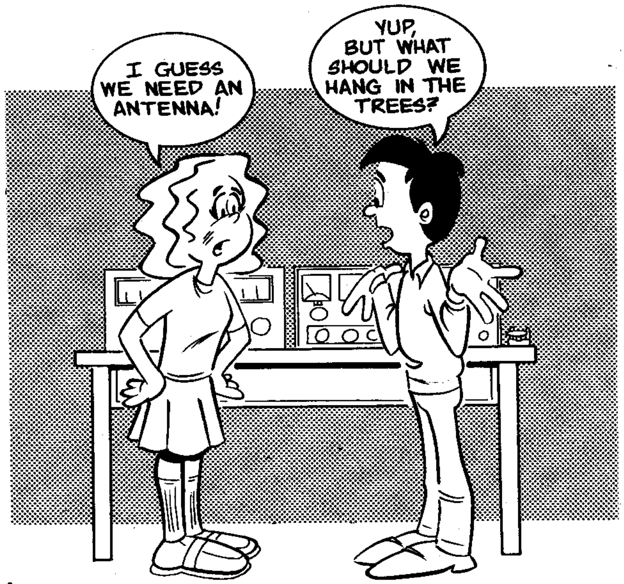
• *First Steps In Radio*

# Radio Antennas and How They Operate




## *Part 9:* No amateur station can operate without an antenna. How do you pick the best type for your needs and budget? There's no simple answer, but learning their pros and cons is a good first step.

By Doug DeMaw,* W1FB

Have you strung up your "Aunt-Enna" yet? That term is sometimes used in jest to describe an antenna. But, there are less humorous names for antennas, such as *aerials* or *radiators*. The term aerial is somewhat out of style, but some old-timers still use the word on the air. You will also become aware of other antenna names as you listen to amateurs talking. For example, you might run across such words as vertical, Yagi (multielement directional antenna), rhombic (large wire antenna that is diamond shaped), and long wire.

Whatever style of antenna you select, and despite what it may be called, you will need an antenna for your ham radio station. In fact, you may eventually have several antennas on your property for communicating on various frequencies and over a variety of distances.

Most beginners start with just one antenna, but as their quest for long-distance communication (DX) increases they may add new and better antennas. Even if you don't anticipate being licensed in the near future, you will still need an antenna for shortwave listening, and for reception of W1AW code-practice sessions.[1]

### Match Your Antenna

I've known a number of new hams who thought they could get on the air with a random length of wire at whatever height they could manage. Grave disappointment often followed. I have even known some Novices who gave up on Amateur Radio because "nobody answers my CQs." (The term CQ means "calling any radio amateur," and it is sent on CW or voice with the station call letters to let other hams know that we are seeking a QSO, or "contact.") These amateurs received no responses to their CQs because they had ineffective antennas, and thereby were transmitting weak signals.

The first rule for a suitable antenna is that it be *matched* to the transmitter and receiver. What does this mean? Well, our station equipment has a specific characteristic antenna-terminal impedance, generally 50 ohms. Few antennas exhibit a 50-ohm impedance without some type of adjustment or impedance-matching circuit (known also as a "matching network"). The objective is to make the antenna feed point become the same impedance as that of the station equipment. If this is not done, maximum power transfer between the transmitter and the antenna will not occur. Similarly, the received signals will be weaker than normal if the impedances are not matched. Many commercial devices are available for matching purposes. They are called Transmatches, antenna tuners or antenna couplers. In some types of systems, they can be used to match an antenna to a transmitter while in others they are used to "fool" a transmitter into thinking it is operating into a proper impedance, or *load*. This does not correct the mismatched condition at the antenna, but it does permit the transmitter to operate at full rated power without problems. From this we can establish as rule number 1 that the antenna should be matched to the feed line,

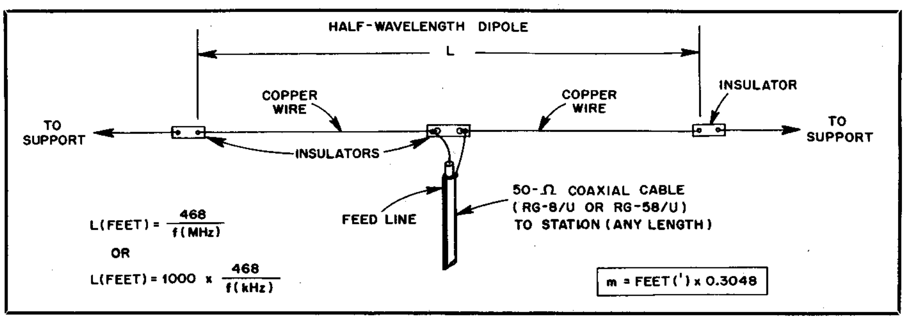



Fig. 1 — Details of a dipole antenna that is ½-wavelength long electrically. This is often a new amateur's first antenna.

[1]Notes appear on page 34.

*ARRL Contributing Editor, P.O. Box 250, Luther, MI 49656 transmitter and receiver for best results.

Some antennas need no matching device to work correctly with the station equipment. A popular example is the dipole antenna (also called a "doublet" by some hams). If cut to the proper length, it will exhibit an impedance that is close to 50 ohms. All that we need to do is connect it to the station gear through a length of 50-ohm coaxial cable. Fig. 1 illustrates this style of antenna. It is perhaps the most common "first antenna" for new amateurs. The overall length is ½ wavelength at the favored operating frequency.

For example, suppose you are a Novice and want to start operating in the 80-meter Novice band (3700 to 3750 kHz). You would want to cut the antenna for the center of that band (3725 kHz). Using the formula in Fig. 1 you would have a length (L) of 125.63 feet, or 125 feet 7½ inches.[2] The feed line would be connected at the exact center of the wire, as shown.

A common variation of this antenna is shown in Fig. 2. What we have here is a drooping dipole, or "inverted V." The formula for length is the same as for the antenna of Fig. 1. The inverted V needs only one high support (for the center), which makes it simpler to erect. If we cut our dipoles to the operating frequency, they are said to be "resonant," and this is desirable. When an antenna is resonant, the feed point looks like a pure resistance to the feed line. If it is not resonant, we will encounter a component known as "reactance," and it can make our antenna difficult to match to the feed line. Ideally, the reactance should be tuned out or canceled by means of a matching circuit. A detailed description of reactance can be found in *The ARRL Antenna Book.*

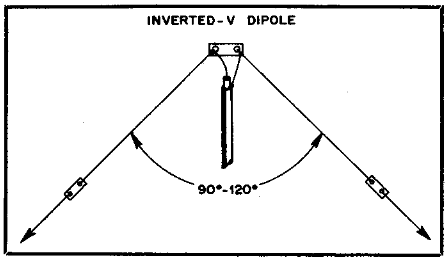



Fig. 2 — A variation of the dipole in Fig. 1. Only one supporting structure is needed for this antenna.

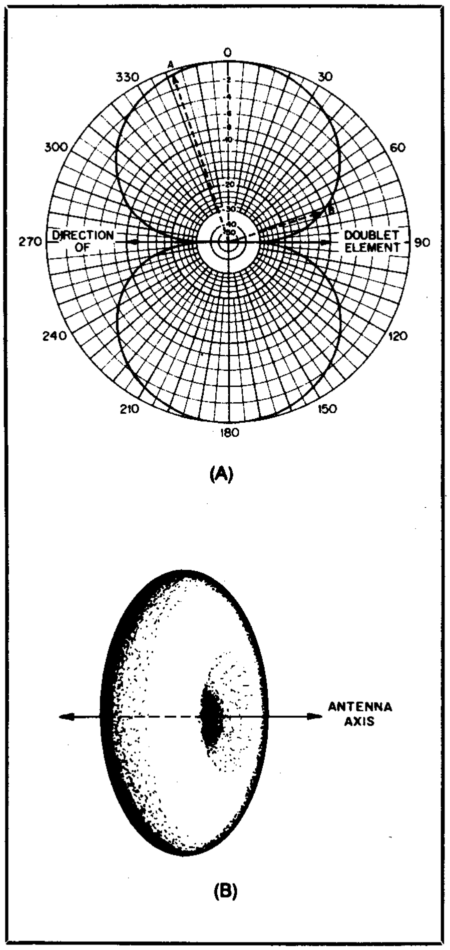



Fig. 3 — At A, the figure-8 pattern of a dipole that is ½ wavelength or greater above ground. If one could see the energy being radiated, it would have the doughnut shape at B.

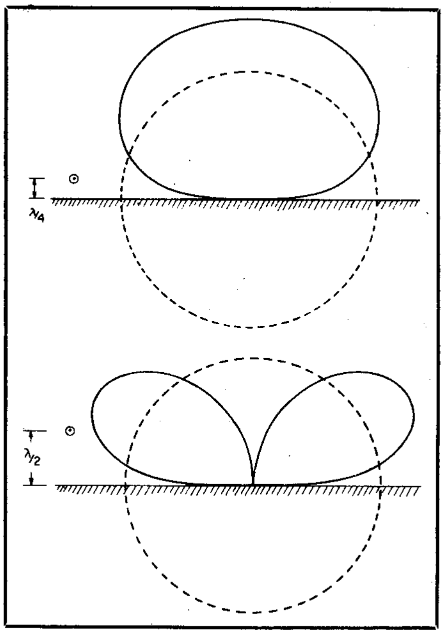



Fig. 4 — Illustrations of the radiation angles of two antenna heights (¼ and ½ wavelength). The dotted lines show what the pattern would be if there was no ground reflection under the dipoles.

**What's a Dipole?**

What are the characteristics of a dipole antenna? One feature is that it will radiate a figure-8 pattern (bidirectional) if it is approximately ½ wavelength or greater above ground (see Fig. 3). The lower the height above ground, the more omnidirectional it becomes. The feed impedance will vary with the height above ground, and may be as high as 100 ohms or as low as 25 ohms. In either extreme, most transmitters will work satisfactorily over these feed-impedance ranges.

It is seldom practical to erect an 80-meter dipole ½ wavelength or more above ground, for this would require support poles of approximately 130 feet! Most hams settle for whatever height is convenient, and good close-range (out to a few hundred miles) communications are common with 80-meter dipole heights of, say, 25 feet. As we mentioned earlier, low heights will cause the antenna to radiate equally well in all directions, since the figure-8 pattern tends to vanish. In general, the lower the height, the shorter the effective communications distance (depending on propagation conditions).

There is still another consideration when we deal with antenna height: a trait known as "radiation angle." It has a relationship to the angle, respective to the horizon, at which the radiation occurs. The lower the radiation angle, the greater the distance our signals can span. A dipole that is high above ground is best for low-angle work when seeking DX. On the other hand, if our dipole is quite close to ground, it will radiate a high-angle signal (almost straight up), which is good only for relatively close range, and without directional traits. We can learn from this that many factors affect dipole-antenna performance. These rules apply to all antennas erected in the horizontal format above ground.

Finally, a dipole antenna has limitations. It is good for just one amateur band when it is fed with coaxial cable. Also, it may cover only a part of an amateur band before a mismatch occurs. This phenomenon is known as "antenna bandwidth." Special broadband antennas have been designed to minimize this undesirable condition.

One way to avoid this problem is to use what is called a multiband dipole. Not only can we deal with the limited bandwidth by tuning the feed line, we can operate on many amateur bands with a single dipole erected as shown in Fig. 1 or 2. The main difference is in the type of feed line we use, plus the addition of a matching circuit in the radio room.

Fig. 5 illustrates two antennas that can be used in this manner. The antenna at A is capable of performing well from 160 through 10 meters if it is elevated well above ground and is not near conductive objects such as power or phone lines and metal structures. (All antennas work better if these conditions are observed.)

The characteristic impedance of the balanced feed line is not critical if it is in a range from 300 to 600 ohms. TV ribbon line can be used also if it is of high quality.

The antenna of Fig. 5B is known as an end-fed Zepp. It got its name from the type of antennas that were used on Zeppelins

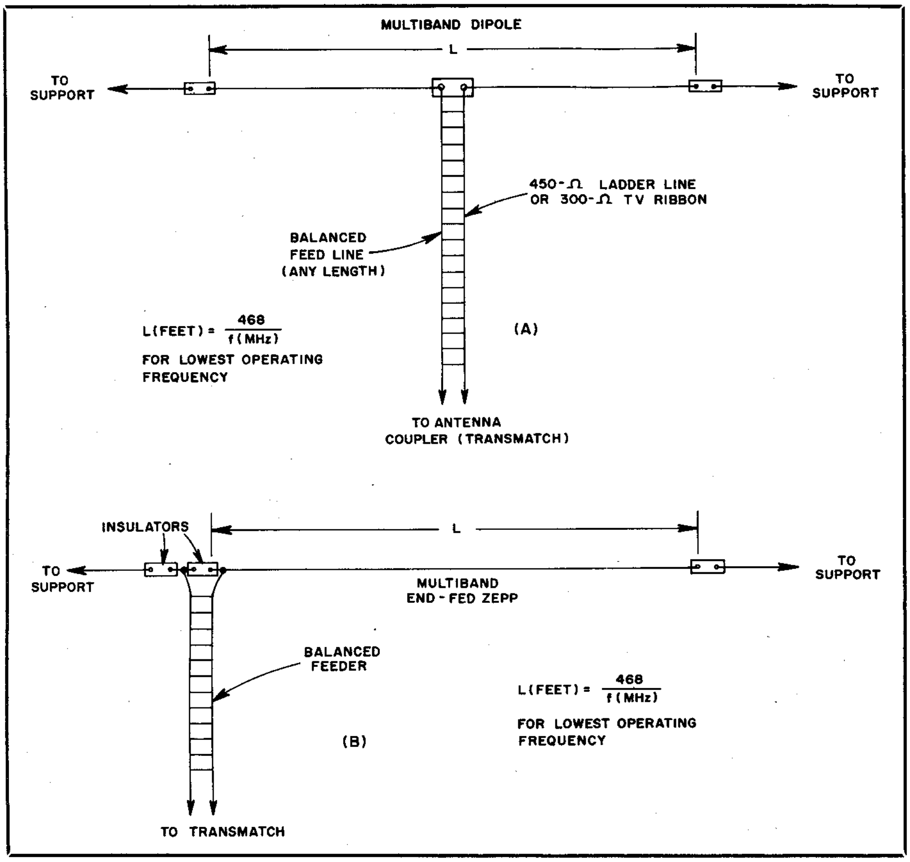



Fig. 5 — Two versions of the ½-wave wire antenna. In each example, the wire is cut to an electrical ½ wavelength in accordance with the formula in Fig. 1, using the lowest anticipated operating frequency in the calculation. A Transmatch is used to match the feed line to the station equipment.

many years ago. It is not as desirable an antenna as is the one at A of Fig. 5, but it will serve well for multiband use. The center-fed multiband antenna of Fig. 5A is probably the best choice for beginners in terms of cost versus complexity and performance.

All of the antennas we have discussed thus far are horizontally polarized. This means the radiated energy is *parallel* to the earth in the direction of the lines of force. A vertically polarized antenna has electric lines that are *perpendicular* to the earth. For close-range work (signals not reflected off the ionospheric layers), the antenna at each end of the communication circuit should be of the same polarization — vertical to vertical, or horizontal to horizontal. Horizontally polarized signals travel only very short distances over ground at HF, while vertically polarized waves can propagate long distances along the ground. Both work fine at VHF and UHF. A substantial signal loss will result if a polarization mismatch exists — vertical to horizontal antennas. For skywave (skip) communications, the polarization match is not significant because the signals that bounce off the ionosphere become somewhat "tumbled" and may arrive back at earth with various polarization traits.

## Should You Go Vertical?

Antennas for use on automobiles are almost always of the vertical type. They offer low radiation angles and are simple to install. For line-of-sight VHF communications to amateur repeaters, it is necessary that the repeater antenna also be vertically polarized to prevent signal-path loss from polarization mismatch of the transmitted waves.

Many amateur fixed-location stations also have vertical antennas for HF-band use. They require very little physical space and are good low-angle radiators for DX operation. Some vertical antennas are designed for single-band use, while others contain "traps," which permit them to be used on many bands. These traps contain a coil and capacitor in parallel, thus forming a tuned (resonant) circuit for the band of interest. The trap serves to divorce electrically the portion of the antenna beyond (above) the trap. Dipole antennas can be built along the same principles to allow multiband use.

The vertical antenna radiates equally in all directions and is, therefore, an omnidirectional antenna. A ½-wavelength dipole can be erected vertically to produce the same results. Most vertical antennas are 1/4 or 5/8 wavelength long. They can be thought of as one half of a dipole. The missing half is in the earth and is called the "image half."

Fig. 6B shows how this can be envisioned. The dashed lines represent the image half of the dipole. For this to take place, we must create a ground system for use with the vertical antenna. A number of wires can be extended outward to form a circle from the base of the vertical antenna to form a ground screen. These wires may be buried in the soil, or they may lie on the ground. The more ground screen or *radial* wires used the better. But, most antenna engineers agree that 120 radials, each ¼-wavelength long, represent a reasonably good ground system for vertical antennas. However, many hams report satisfactory results when using as few as six

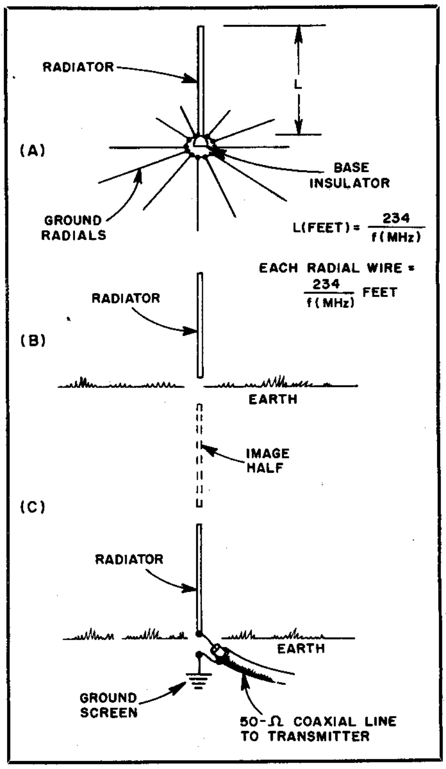



Fig. 6 — Many amateurs use vertical antennas. These radiate a vertically polarized wave, are effective over long distances, and have an omnidirectional radiation pattern (like a doughnut, with the radiator at the center). A ground screen or ground radials are needed to provide the missing half of the system, and to provide a reflective surface for the wave. Illustration B shows how the image half of the dipole appears in the earth under the radiator, making the system function as a vertical dipole. The feed line is connected as shown at C, with the shield braid of the coaxial cable connected to earth ground and the ground screen, while the center conductor of the cable attaches to the lower end of the radiator. The feed impedance is typically 30 ohms or less, so many hams insert a matching device to elevate the feed impedance to 50 ohms.

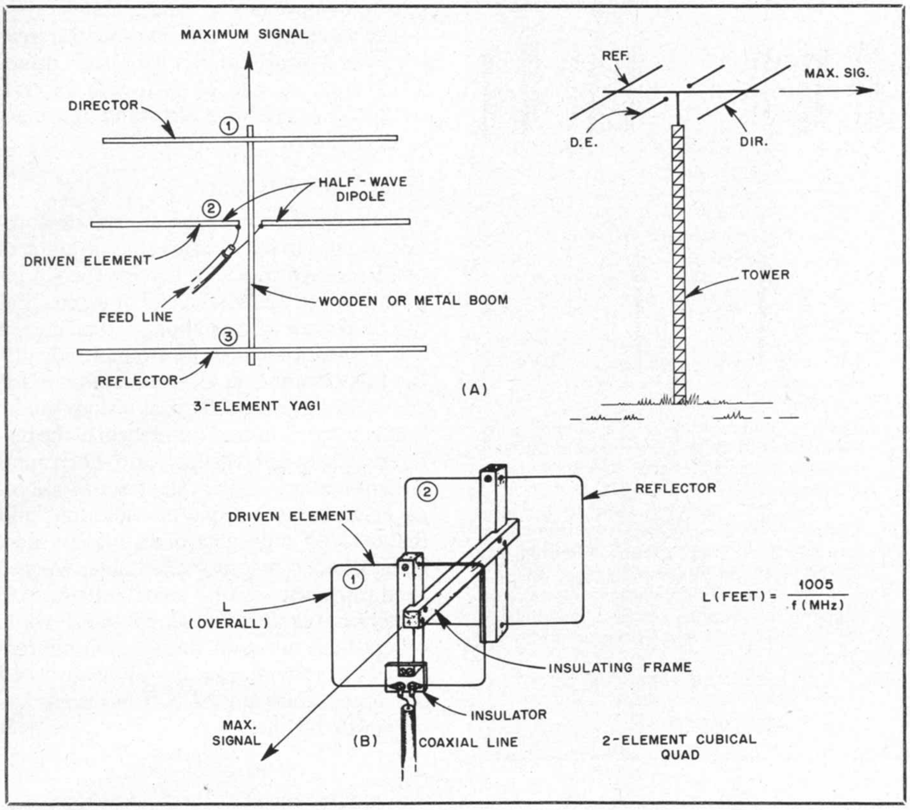



Fig. 7 — Examples of popular directional gain antennas (beam antennas). At A is a Yagi antenna with a reflector, a driven element and a director. Antenna B is a cubical quad type with two elements (reflector and driven element). Both antennas may have additional directors to increase the gain, but only one reflector is used with beam antennas.

ground radials. It depends on the ground conductivity in a given region.

### Directional Gain Antennas

Many antennas have what is known as gain. Increased gain means an increase in effective signal power. If we were to replace a dipole antenna (no gain) with a 10-dB gain antenna, the effect would be the same as raising the transmitter power from 100 to 1000 W! It can be seen, therefore, that antennas with gain offer advantages for certain types of operation. Most of the popular gain antennas are also *directional,* and are erected so they can be rotated. This rotation is necessary if we are to maximize our signal power in a given direction. The directionality helps us two ways, during transmit *and* receive. Rotatable TV and FM antennas are good examples of gain types of directional antennas. These are called *beam* antennas because the signal is beamed in a particular direction, as is the case with a beam of light.

In its basic form, a beam antenna consists of a radiator (driven element) and a reflector. However, directors may also be added to increase the overall antenna gain. The two most popular forms of beam antennas are the Yagi-Uda (usually called "Yagi") and the cubical-quad antenna. Both types are shown in Fig. 7. Illustration A is a three-element Yagi antenna. The driven element (2) is a ½-wavelength dipole. The reflector (3) acts as a mirror (as with a light source) to direct the energy forward. It has a length approximately 5% greater than that of element 2. The director (1) further enhances the forward radiation of the signal. It is roughly 5% shorter than element 2. As this antenna is rotated away from the station at the other end of the communication circuit, the signal becomes weaker and weaker, and there may be several deep nulls in the response during rotation. This can work to our advantage in reducing interference from other stations and noise sources.

**Need a Copy of This Article or a Previous Installment?**

Although each issue of *QST* is protected by copyright, we would like to make it as easy as possible for readers to obtain copies of each installment of First Steps in Radio. Provided that copies are made *for the personal use of an individual, or of a Novice class,* ARRL hereby grants permission for photocopies to be made of any article in this series. If your club plans to teach a Novice class, feel free to make a sufficient number of copies for students' personal use. If you are missing one or more installments, back issues are available for $2.75 apiece from the Circulation Department, ARRL Hq., 225 Main St., Newington, CT 06111.

The cubical-quad antenna of Fig. 7B uses full-wavelength loop elements. A two-element version is shown. The reflector (2) is 5% greater in perimeter than is the driven element (1). Both antennas provide horizontal polarization, as shown. By rotating either of them 90 degrees on its axis, we can obtain vertical polarization. In other words, if antenna B of Fig. 7 had the feed terminals on the side rather than the bottom, it would have been rotated 90 degrees.

The spacing between the elements of either beam antenna will usually vary from a ¼ wavelength to somewhat less than a ¼ wavelength. The spacing chosen depends on the design objectives, which include feed impedance, forward gain and rejection off the rear of the antenna. Additional director elements can be added to these antennas to improve the gain and effective antenna bandwidth. Yagi beam antennas seldom present a 50-ohm impedance. Therefore, it is common practice to include some type of matching device at the feed point so 50- or 75-ohm coaxial cable can be used for the feed line. Antenna traps can be installed in the Yagi elements for multiband operation. Generally, the three bands concerned are 20, 15 and 10 meters. A three-band Yagi is referred to as a "tribander." Although there are numerous gain types of beam antennas, only the Yagi and the cubical quad have been treated here. *The ARRL Antenna Book* (recommended reading) describes most of the antennas used by radio amateurs, and their theory of operation. The book also explains various matching circuits.

### Feeding Your Antenna

We've learned that most antennas can be used with feed lines of any convenient length. We need to be aware, however, that all feed lines have some loss, and certain ones are worse than others. And, the longer our feed line, the greater the loss. Open-wire ladder line is the least lossy, while coaxial cable of small diameter is the worst. The small coaxial lines are RG-58/U and RG-59/U types. Larger-diameter cable, RG-8/U and RG-11/U, is better. The higher the operating frequency, the greater the line losses per 100 feet of cable. So, it is conceivable that with a certain line loss our 100-W signal might diminish to 30 or 40 W by the time it reached the antenna — especially at VHF and higher! The same loss is experienced in the receive mode. Therefore, we should always try to keep the feed line as short as we can.

The larger conductors are best for antennas to keep losses down and to enhance the strength (physical) of the system. For wire antennas, it is wise to use no. 10 through no. 14 conductor sizes, likewise with the wire elements of cubical quads. For Yagi antennas, it is normal practice to use aluminum tubing for the elements. Small Yagi antennas, of the kind used at VHF and higher, may contain aluminum rods for the elements. All insulators should be of high-quality material, such as ceramic, steatite, Plexiglas®, high-dielectric plastic compounds or fiberglass.

The gauge of wire used in ground screens is not as critical. Smaller wire, such as no. 20 through 26, can be used with success, but heavy-gauge wire will stand up longer to corrosion.

## What You've Learned

It may seem that I left a great deal unsaid. I did, but only because this installment of First Steps in Radio is meant as an introduction to the principle of antennas. Entire books are written about antennas, and still a great many details are omitted. It is for this reason that I have recommended *The ARRL Antenna Book* as a study guide.

It is important that we recognize the difference between vertical and horizontal antenna polarization, the effect of antenna height on the angle of radiation, and that the feed impedance of an antenna must be matched to that of the feed line. We also need to remember that some antennas are directional and capable of gain, while others have no gain and are omnidirectional or bidirectional. If you've absorbed this much, then our article this month has been worthwhile.

### Glossary

antenna — a device made of conducting material for sending transmitter signals, or for receiving them.
antenna coupler — a device consisting of coils and capacitors that can be adjusted to provide an impedance match between a transmitter and an antenna, or between a transmitter and an antenna feed line.
antenna tuner — same as an antenna coupler.
dipole — an antenna that is ½ wavelength overall and is fed at the electrical center.
director — an electrical element of a gain type of antenna, such as a Yagi.
gain — the ability of a circuit to enhance the amplitude of an ac or RF signal.
ground screen — an artificial earth ground consisting of conductive material, such as wire or screen.
image antenna — a nonphysical part of an antenna system that exists in the earth under the antenna.
ionosphere — the outer layers of the earth's atmosphere, with some electron and ion content.
load — a device that is capable of receiving power.
long wire — a straight wire antenna that is 1 wavelength or greater overall.
matched — a condition in which two identical impedances are joined.
matching network — see antenna coupler.
multiband — the property of a circuit or antenna to function on several frequency bands.
polarization — vertical or horizontal lines of force, respective to antenna radiation. Circular polarization is also possible.
radial wires — the wires in a ground screen that extend radially from the base of an antenna.
radiation angle — the angle, respective to earth, that an antenna field leaves an antenna.
radiator — the portion of an antenna system to which the power is applied; also known as the driven element in some antennas.
reflector — a conductor in a multielement gain type of antenna; it acts as an RF mirror to direct the signal forward past the driven element.
Transmatch — a matching network designed mainly for matching the transmission line (feed line) to the transmitter; similar to an antenna coupler or tuner.
trap — a resonant, parallel-tuned circuit placed in an antenna element to isolate portions of the element from other element sections.
Yagi — a type of directional gain antenna, named after the co-inventor, Hidetsugu Yagi, a Japanese engineer.

**Notes**

[1] Check *QST* for a schedule of W1AW code-practice transmissions at various speeds.

[2] mm = in × 25.4; m = ft × 0.3048.