The Aerial Performers of the Radio Circuits

Basic Amateur Radio. Part 1: Antennas are as different as the hams who use them. This two-part series will bring you a measure of expertise on this all-important subject.

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The first thing to be said about antennas is that they are *different*. Not only are they different from all other types of equipment in Amateur Radio stations, but they also differ greatly among themselves. True, as far as genetic makeup is concerned, they all belong to the same family. They are all employed in the same line of work. However, they vary widely in appearance, and they differ in such individual characteristics as efficiency, attention to gains and losses, and ability to adjust to change.

The *lifestyle* of antennas is different from that of most other Amateur Radio components. Unlike receivers and transmitters, the vast majority of antennas do not live out their lives in the comfortable security of ham shacks but instead are subjected to all the perils of outdoor existence. They face struggles with burdens of snow and ice and can get corroded by salt and grime. Strong winds can make them fall flat on their baluns; squirrels can chew their support ropes to shreds. For all sorts of reasons, change is their lot. An antenna's life is not an easy one.

Antennas require installation, and here, too, is a difference. Other equipment can be bought or built, plugged in to a source of power, and be on its way. With antennas it's rarely that easy. Antennas must be installed by a process involving problems (expected and unexpected), decisions and work. This is particularly true of hf (high-frequency, 3-30 MHz) antennas, the kind we will primarily consider in this article.

In addition to *being different,* antennas *make a difference*. They can make the difference between a signal that really gets out and one that really doesn't; between a signal that lets you keep schedules, make radio friends, provide solid copy to a listening world — and one that, on the other hand, hides timidly below the noise level. As far as antenna work is concerned, each amateur is in competition with himself as well as with others, and the slogan of antenna-minded persons is forever the same as that of 4-H youth: "To Make the Best Better."

Prime Candidates for Discussion

Antennas are one of the leading subjects for amateur discussions on and off the air. One reason for the wide differences of opinion is that an antenna that works well for one amateur may not work equally well for another. Also, antennas cannot usually be adjusted or performance-tested on the bench. Other equipment can be checked, component by component, in the shack. Antennas must be tested *on the air*. They must be worked on *in place* ("place" being, perhaps, a precarious spot 50 feet or more above the ground), or they must be taken down, adjusted, and again be put up and tested on the air. They are repaired and improved by experimentation, by consultation, by guess and by gosh, or by something more explicit thrown in.

Much has been written about antennas. The latest edition of the *ARRL Antenna Book* contains 329 pages on the subject, and many other books and articles deal with antenna design, construction and experimentation.

What Antennas Are and What They Do

The study of antennas involves a mixture of fact and theory; a mixture of the tangible and the intangible. On the one hand, antennas are tangible, material objects with physical proportions which can be measured. They are made of metal, usually in the form of wire or tubing. Metal, in general, is a good conductor of electrical currents, and practically all metallic objects can be made to radiate a signal. How effectively they do this radiating, however, is something that varies tremendously. How any antenna manages to do it at all is another matter, one which takes us out of the world of material things and into the world of theory. This world of theory is inhabited by electromagnetic waves of various lengths (light, heat, X-ray, radio), all of them traveling through free space at the speed of approximately 300,000 kilometers (186,000 miles) per second. Among these waves we find our Amateur Radio signals — combinations of electrical and magnetic energy sent at radio frequencies from our transmitters to our antennas and from our antennas into the atmosphere and space.

As radio waves move into the atmosphere, their wavelength and frequency remain essentially the same as they were when they left the transmitting antenna, but their *field strength* (volts per meter) varies inversely with the distance from the antenna. This means that at twice the distance away from the antenna, the field

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strength of the wave is only half as much. At the same time, the *power* per unit area of the radiated wave falls off inversely as the *square of the distance* from the transmitting antenna, so that at twice the distance the power density (watts per square meter) is only *one-fourth* as much as it was originally. Remember that as the wave moves away from the transmitting antenna it becomes weaker the farther it goes.

Radio waves spread out from different types of antennas in characteristically different patterns. Excluding the effect of nearby objects, the shape of the pattern depends primarily on the kind of antenna and its height above ground. From most vertical antennas, radio waves leave more or less in the shape of a horizontal doughnut. No one has actually *seen* them leave in this shape, but we can accept this fact in theory because measurements taken of the radiated field show equal strength in all horizontal directions. Illustrations of radio-wave patterns and types of antennas producing them can be seen in the *ARRL Radio Amateur's Handbook*, the *ARRL Antenna Book,* and numerous other publications.

Before we go on to discuss types of antennas, let's consider a source of confusion that stems from our use of common names in referring to our radio bands. The common amateur band names (40 meters, 80 meters, etc.) are *approximations,* not precise wavelengths for the different bands. But the names have great practical value as far as ease of communication, time-saving and brain-saving are concerned.

The FCC has allocated — in accordance with International Telecommunication Union (ITU) regulations — certain groups or segments of the radio spectrum for amateur use. Each allocated group includes many individual frequencies and some groups include more frequencies than others. For example, the so-called 40-meter amateur band includes all frequencies from 7000 kHz to 7300 kHz. The 10-meter amateur band is much broader, including frequencies from 28.0 MHz to 29.7 MHz.

Antennas are constructed so that their physical length corresponds in some way to the theoretical wavelength of the bands for which they were designed, and so we designate them quarter-wave (1/4 λ), half-wave (1/2 λ), five-eighth-wave (5/8 λ), full-wave, etc., antennas. (The Greek letter lambda, λ, is commonly used in scientific work to indicate wavelength.) These physical antenna lengths, however, do not correspond exactly to the theoretical wavelengths, which are based on the velocity of the waves in free space — 300,000,000 meters per second, as indicated by

Wavelength in meters =

$$\frac{300{,}000{,}000}{\text{freq. in Hz}} \text{ or }$$

$$\frac{300}{\text{freq. in MHz}} \qquad \text{(Eq. 1)}$$

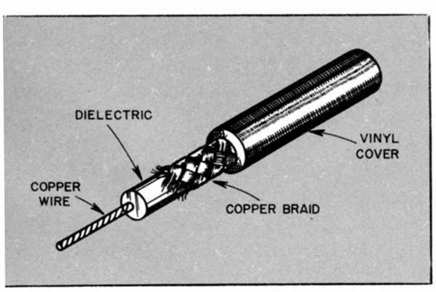
When a wave is traveling in a conductor such as an antenna, rather than in free space, it travels at a slightly slower speed and the antenna needs to be shorter than its free-space wavelength would indicate. These practical formulas

$$\text{length (ft)} = \frac{468}{\text{freq. (MHz)}}$$

$$\text{length (m)} = \frac{143}{\text{freq. (MHz)}} \qquad \text{(Eq. 2)}$$

automatically take care of this difference in length for the most-common horizontal antenna used by amateurs — the half-wave dipole. Don't confuse these two very important formulas: Eq. 1 is used for calculating wavelength (in meters). Eq. 2 is used for determining the physical length (in feet) of a half-wave wire dipole antenna.

Fig. 1 — Coaxial cable is the feed line used by most radio amateurs.



A Look at Transmission Lines

The transmission line is the life line linking the receiver and transmitter to the antenna. There are three kinds in general use in Amateur Radio: *coax, open wire* and *twin-lead.*

The purpose of any feed line is to transport as much energy as possible from the transmitter to the antenna or from the antenna to the receiver, but under certain conditions the line can "lose" much of the energy it is supposed to be transporting. A very small amount of energy is lost from even the best feed line — typically, about one or two percent per 100 feet of open-wire line at frequencies of 3-30 MHz — but we are talking here about more than that very small amount. If, for example, a coax line has been damaged or was made of inferior material to begin with, or if it is not properly matched electrically to the antenna, it can lose energy. A good grade of coax is a good investment. A poor-grade, "lossy" length of coax can drain away your hard-earned radio-frequency energy in a distance of just a few feet.

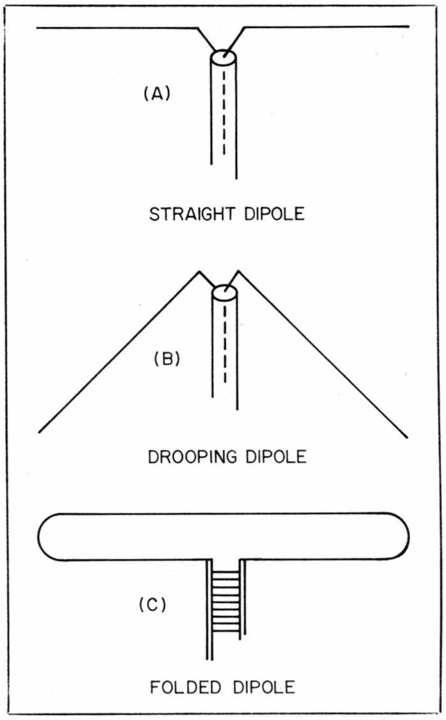


Fig. 2 — The dipole antenna is a favorite with beginners. Most antennas can be considered to be some form of dipole.

Kinds of Antennas

In this section we will describe, very briefly, five of the most common kinds of antennas used by amateurs. Any of these types can be *monoband* antennas, designed for operation on only one band, or *multiband,* designed for operation on several bands. Multibanders often make use of *traps* — not traps which catch and hold radio waves, as their name might imply, but rather traps which act as electrical gates, letting energy through on some bands and keeping energy out on other bands.

The Dipole

The dipole antenna is a favorite with beginners. It is a fundamental type of antenna and most antennas can be considered to be some form of dipole, even though their dipole ancestry may not be guessed from their appearance.

Dipole antennas are constructed of two equal-length pieces of metal, usually wire. For the half-wave dipole, the most common type, each of the two pieces is one-quarter wavelength long; the total length, therefore, is a half wavelength for the band being used. The less common full-wave and 1.28-wave dipoles yield a stronger signal for both sending and receiving, but they require more space than do shorter length ones. They may also require provision for "matching impedances," and are frequently fed with

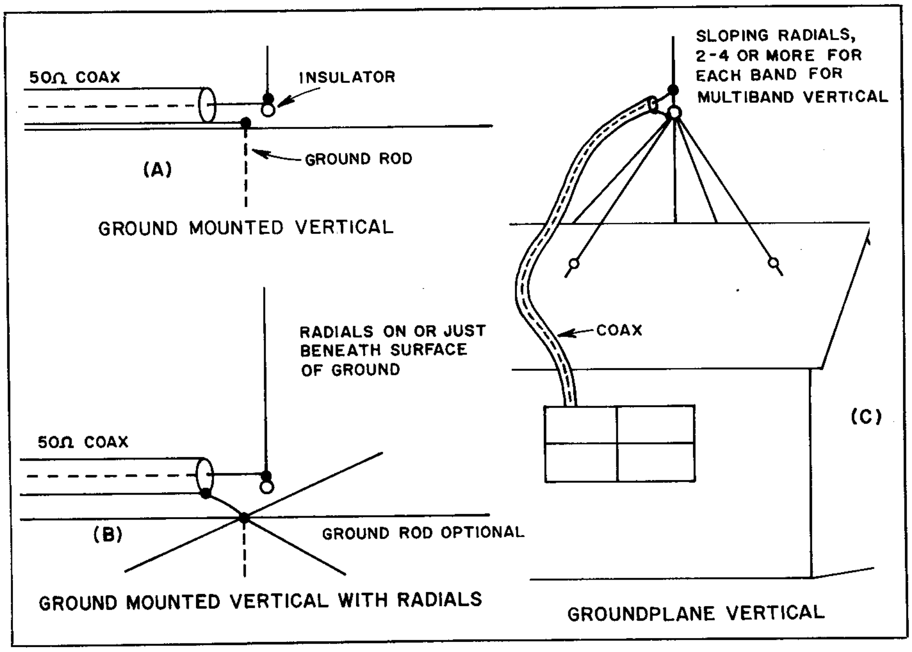


Fig. 3 — Three common methods for mounting quarter-wave vertical antennas.

open-wire feed line. (See the *ARRL Radio Amateur's Handbook* and *The ARRL Antenna Book,* for discussion of impedance matching.)

Several forms of the dipole antenna are in use. In addition to the *straight dipole* form (Fig. 2A), and the *drooping dipole* with wires drooping at an angle to form an inverted V (Fig. 2B), we occasionally see a *folded dipole* with the wire doubled back on itself, as in Figure 2C. The maximum radiation from a dipole is at right angles to the direction of the wires. Minimum radiation is off the ends of the wires.

The majority of dipoles are center fed, with energy from the transmitter entering at midpoint through a transmission line or feed line. [Note: Practical information on the construction and installation of a simple, coax-fed, half-wave dipole will be given in Part 2 of this series.]

The Vertical

Vertical antennas are commonly 1/4-, 1/2- or 5/8-λ long, with the 1/4-λ vertical being most often used by amateurs. Like the longer length dipoles, the taller verticals yield a stronger signal for both transmitting and receiving. But they, too, require more space, a fact that must be taken into consideration. Not that there is usually any shortage of space in the upward direction, but guy ropes are needed to keep taller verticals in position and prevent them, when hit by a strong wind, from suddenly finding themselves horizontal junk instead of vertical antennas.

There is an interesting electrical phenomenon and behavioral oddity common to all verticals — a *nonphysical mirror image* which appears, ghost-like, in the ground directly below the antenna whenever a signal is being transmitted or received. This mirror image forms the other half of the vertical and makes it into what is basically a "vertical dipole."

When we stand in front of a flat mirror and direct the beam from a flashlight toward it, the light in the mirror seems to come from a point as far back of the mirror's surface as we are standing in front of it, and the quality of the mirror determines, to a large extent, the quality and strength of the image we are seeing. An antenna's mirror image is an *electrical* one, with the ground acting as a mirror, and the conductive quality of the ground largely determining the strength of the mirror image. Excluding the effect of nearby surrounding objects, the mirror image and the height of the antenna, for the most part, determine the radiation pattern of the antenna's radiated wave.

The quarter-wave vertical is usually constructed and installed in one of three different ways:

1) As shown in Fig. 3A, the antenna is set on an insulator of some kind (a glass bottle, for example) placed on the ground. If it is coax fed, the copper wire in the center of the coax is connected directly to the quarter-wavelength-long aluminum tubing, or to some other radiating element such as a vertical wire or tower. The copper braid of the coax is connected to a metal ground rod pushed into the ground near the antenna base. This is the least efficient of the three methods we are discussing. (Efficiency is the amount of power radiated from the antenna compared to the amount of antenna input power.

2) The antenna is again mounted on the ground and fed by coax, but in addition has a group of copper wires called *radials* extending out from the base of the antenna as spokes of a wheel. These radials — the more the better — add *conductivity* to the ground. They can be laid out directly on the ground or placed underground at a very shallow depth, just deep enough to protect them from physical damage but not so deep as to put "lossy" ground between them and the vertical portion of the antenna (Fig. 3B). By tradition, each radial is 1/4 λ long. But if you can't fit 1/4-λ radials into the space you have available, a denser network of shorter ones or a mixture of shorter and longer ones may be the best way to go.

3) The most efficient of the three methods is to mount the antenna high above the ground, away from all energy-absorbing objects, including the ground itself. In this installation, a circle of three to five radials, each 1/4-λ long, extends out from the base as in method 2, but because they are up high they form an artificial ground or *groundplane.* This antenna is referred to as a *groundplane vertical* (Fig. 3C).

Table 1 gives a comparison of the most common horizontal dipole and vertical antennas.

The Yagi

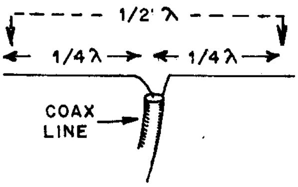
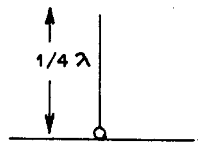
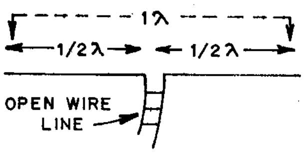
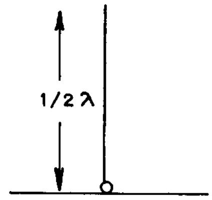
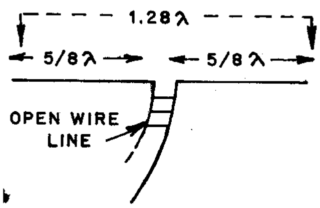
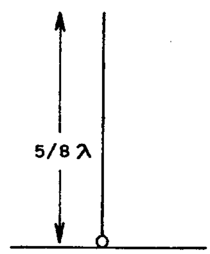
When we consider the Yagi antenna, we move into a group called *beam* antennas. Most beam antennas, including Yagis, are unidirectional, having the strength of their radiated energy primarily concentrated in one direction at the expense of other directions, somewhat similar to the beam from a flashlight.

Yagis, the most popular of the beam antennas, are commonly horizontal dipoles with parasitic elements. The elements are called "parasitic" because they have no direct *electrical* connection to the transmitter or the receiver but instead are coupled (electromagnetically) to an element which *is* coupled directly (by a feed line) to the transmitter or receiver.

Normally, all of the Yagi elements are made of aluminum tubing. One element, a half-wave dipole called the *driven element,* is attached to the transmission line and receives energy from the transmitter. The parasitic elements are called *directors* and *reflectors.* All elements are placed on a horizontal support called a *boom* and are spaced at selected distances from each other — the reflector on one side of the driven element and the director on the other side. The reflector is about three to five percent longer than the driven element; the director is similarly shorter. The dimensions of these elements, as well as the spacing between them, must be carefully worked out if the antenna is to give its best performance.

The three-element Yagi is shown in Fig. 4. Yagis usually have only one reflector but can have as many directors as desired. Since the Yagi is normally rotatable, the beam can be pointed (with the director or directors in front) in a desired direction to

Table 1
Comparison of the Most Common Horizontal Dipole and Vertical Antennas.

Horizontal Dipoles		*Verticals*	
 1/2-wave dipole	Usually fed with coax transmission line.	 1/4-wave vertical	Usually fed with coax transmission line at base of antenna.
 Full-wave dipole commonly called double zepp or two half-waves in phase.	Usually fed with open-wire transmission line through antenna tuner at transmitter. Has about 2 dB gain over 1/2-wave dipole.	 1/2-wave vertical	Usually fed with coax to a matching circuit at base of vertical. Has about 2 dB gain over 1/4-wave vertical.
 1.28-wave dipole commonly called extended double zepp	Usually fed with open-wire line through an antenna tuner at the transmitter. Has about 3 dB gain over 1/2-wave dipole.	 5/8-wave vertical	Usually fed with coax to matching circuit at base of vertical. Has about 3 dB gain over 1/4-wave vertical.

Note: The terms "gain" and "dB" (decibels) will be discussed in part 2 of this article.

transmit or receive maximum signal strength. The antenna can be monoband or multiband, depending on its construction.

The Quad

Elements of the quad antenna are basically folded dipoles (see Fig. 2C) pulled out into a square shape. The quad is a rotatable beam antenna, usually consisting of at least two four-sided continuous loops — the antenna elements. These loops, spaced at selected distances from each other, are placed on a horizontal support, the boom. The driven element is directly coupled to the transmitter by a feed line, and a reflector is parasitically (electromagnetically) coupled to the driven element. In addition, many quads have one or more directors which are also parasitic, and you will hear amateurs say they have two-element, three-element, or four-element quads. These elements, each of which has four sides approximately a quarter-wavelength long (thus making up a complete wavelength for a desired band), can be placed on the boom as squares (Fig. 5A) or as "square diamonds" (Fig. 5B) in a plane perpendicular to the ground. Seen from even a short distance away, all the elements look alike, although the reflector is slightly larger than the driven element, and the directors are slightly smaller. *Spreaders*, usually made of bamboo or fiberglass, support the loops and hold them in place. The loops may be very large — an element for a 20-meter quad, for example, is about 17 feet on each of the four sides of the continuous wire loop.

Quads can be constructed as monoband (Fig. 5A) or multiband (Fig. 5B).

Fig. 4 — Three-element monoband Yagi consists of a driven element and two parasitic elements.

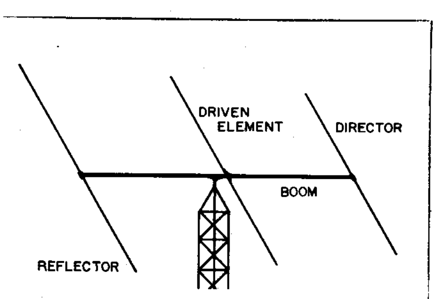
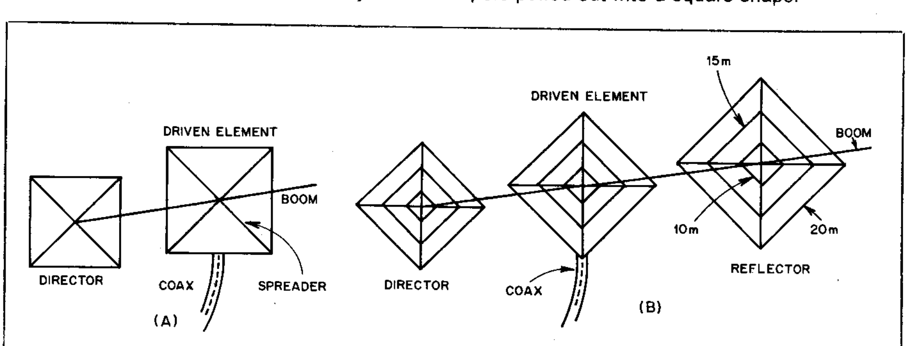


Fig. 5 — The quad antenna is basically a folded dipole pulled out into a square shape.



Multiband quads employ concentric loops for the various bands, with the band having the longest wavelength and therefore the largest loop on the outside and the others nested in the center (Fig. 5B).

Yagis and quads are the two most popular beam antennas, and amateurs can endlessly compare their relative merits. Yagis, according to those who prefer them, are (1) easier to construct and install, (2) less prone to receive damage from ice storms or strong winds, and (3) have a more attractive appearance. On the other hand, amateurs who prefer quads say they (1) are better for multiband operation, (2) possess greater "gain" for equal boom lengths, and (3) are easier to adjust since there is less interaction between elements, element spacing is less critical, and they are more broad-banded than Yagis.

The Longwire

The simplest antenna mechanically and electrically is just what its name implies, a long wire, with emphasis on the "long." Any piece of wire can be made to radiate or receive a signal, but an antenna does not deserve the name "longwire" unless it meets one important requirement: It must be more than one wavelength long for the band or bands being used and, if possible, should be several wavelengths long. A "random length" of wire can be called a longwire antenna, but the wavelength should still be taken into consideration. In general, the longer the wire, the stronger the radiation in certain directions. (Note: In most cases, longwire antennas require the use of an antenna matching unit, such as a Transmatch or "Match Box" to make possible the most efficient transfer of power from transmitter to antenna. See *The Radio Amateur's Handbook* for descriptions of these units.) Longwire antennas are usually at least one or more wavelengths long, using the lowest desired frequency band (which has the longest wavelength) to determine the length of the wire. They can be single wires (a type popular with beginners) or they can be constructed of wires combined in a number of ways, such as in the so-called V beam and the rhombic, which are more sophisticated longwire antennas.

There they are: five general types of antennas, each one with its subtypes — the straight, drooping and folded *dipoles;* the quarter-, half- and other-wave *verticals;* the *Yagis* and *quads,* each with varying numbers of elements and the *longwires* — simple and compound. Within each subtype, if we could but see them, are millions of individual antennas, all alike in some ways; all different in others. All of them are engaged, with varying degrees of succcess, in sending our radio signals out into all parts of the world. All of them leave us filled with amazement at their aerial performances, and always wondering — but never quite sure — just what their next act may be.