Here is a down-to-earth, non-engineering level description of what basic wire antennas are, methods of coupling to them, and some interesting possibilities when using them.

Wire Antennas: A Primer

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Editor's note: The author, now a Silent Key, was a frequent CQ contributor and the author of Electronic Communications, a standard engineering textbook published in multiple editions between 1959 and 1991. We present this article with the author's original hand-drawn illustrations.

What is a dipole? Since the beginning of amateur radio, one of the basic horizontal wire antennas has been the dipole. It is a wire cut to a half-wavelength (1/2-wave) for the middle of the band of frequencies on which it is to be used. A 1/2-wave wire allows electrons to oscillate back and forth along it most easily at its resonant frequency length.

"Dipole" can be considered to mean the shortest antenna that can have only two different maximum voltage polarities. When one end is at a maximum positive polarity, the other end will be at a maximum negative, with zero polarity in the middle. If it is a little too long or too short, the true maximum voltage cannot be developed on the wire. If a radio frequency (RF) AC voltage drives enough negative electrons to produce a 500-volt negative charge at one end of a dipole, the other end, having now lost that number of electrons, becomes 500-volt positive.

An important question for the radio amateur is: To what length should a dipole antenna be cut? The 160-meter band, which is 1.8 to 2.0 MHz, is our only medium frequency (MF) band. MF means 0.3 to 3 MHz. Our other 10 high frequency (HF) bands are between 3 and 30 MHz. The length of a dipole in feet for any of these bands can be determined if the desired frequency of operation is known in megahertz (MHz). The formula is:

Dipole length in feet = 468/MHz

This formula includes the required shortening to ±95% of a dipole's length factor because of its two capacitive "end effects." When there are two or more dipole wires connected in series, any added dipoles should all be computed by a no-end-effects-shortening formula, or:

Second or other dipoles in feet = 492/MHz

All of the answers obtained will be the operating length of the wire between the holes in the two end insulators. Add 3 or 4 inches of wire at each end to go through the insulator holes and come back to be twisted back around the dipole wire. If an antenna has to be low or erected near metal objects, shortening it a little might help its operation.

Let's assume a dipole should be a 1/4-wave above its "effective ground level." And what is that? A good effective ground level would be the surface of a salt-water-soaked soil, or marsh, extending out many wavelengths in all directions under the antenna. If the soil is dry and possibly sandy or rocky, the effective ground level may be one to several feet below the surface. The effective ground level at a station usually depends on how wet or dry the soil happens to be that day. You can see we may be playing with rubbery numbers when talking about antennas.

Small length variations will probably not affect how well an antenna seems to radiate and receive. Antenna theory can be an exact science for any given frequency, but just getting close to the correct length for a mid-band dipole for our relatively wide amateur bands may be all that a ham needs to worry about. If he (or she) uses an antenna tuner, that can correct for most slightly incorrect dipole lengths, heights, etc.

It is generally agreed that doubling the height of a dipole above ground level almost doubles its effectiveness for both transmitting and receiving. So tall poles, towers, and trees look pretty good to radio amateurs — but unfortunately not to the people who make the laws on allowable antenna heights and antenna placements in cities and other places.

A Dipole Antenna

The antenna in *Figure 1* is an 80-meter band, 1/2-wave dipole, cut for some frequency in the "CW" (**C**ontinuous-strength **W**ave) part of that band, let's say for 3.550 MHz. By using the formula:

length = 468 /3.55 = ±131.8 ft long

If the antenna happens to be cut a foot long or short, it should still work fine, even if an antenna tuner is not used. Most transceivers today have an internal output "Tune" button that corrects small values of incorrect inductive or capacitive reactance (detuning) exhibited by the antenna.

A dipole for the 80-m "radiotelephone" ('phone) band, let's say 3.900 MHz, should be:

length = 468/3.9 = ±120 ft long

It's interesting that either of these dipoles will work quite well over the whole CW and phone parts of the bands if open-wire feeders and an antenna tuner are used, as described later.

A dipole wire cut apart in the center becomes two 1/4-wave wires. If such a dipole is fed RF at its center by some kind of a 2-wire RF "transmission" or "feed" line, it will be a "balanced" dipole. The open middle ends can be said to have a "radiation resistance," or a "center feed-point impedance" of ±73 ohms to RF AC. This "feeder impedance" is abbreviated as "Z_f" ("Z" for impedance and "f" for feeder or feedpoint).

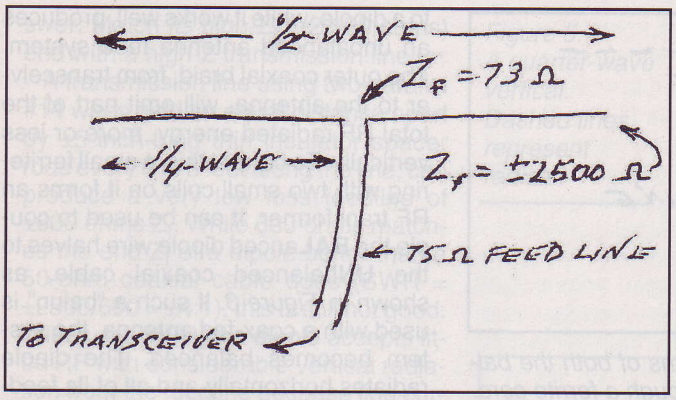


Figure 1. Basic dipole lengths and impedances. The high Z_f, or feedpoint impedance, is at the ends of the dipole. (All illustrations are hand-drawn originals by the author)

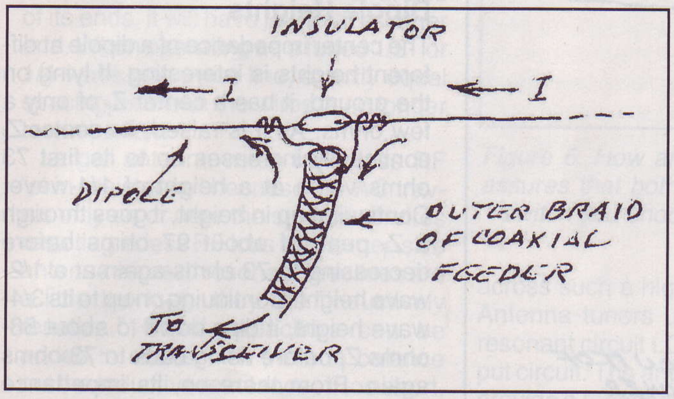


Figure 2. Connecting a coaxial feeder to a dipole.

The center of a dipole has a low Z_f, but the ends always have a high Z_f, a value of let's say ±2,500 ohms, but it may vary considerably due to length, wire thickness, ground material, etc.

High Z points are also points of high RF voltages and little current. Low Z points carry higher currents because all oscillating electrons have to go through these points and voltage values will be low. So a dipole antenna wire could theoretically be thinner at its ends and thicker at its center, but it is usually a simple bare copper wire having a wire gauge of #10 to #16. (A thinner lacquer insulated #22 gauge wire might be used if it is supposed to be "hidden"!) If the wire is insulated, it works fine, but if the insulation is solid plastic, in a few years it will dry out, begin to peel, hang down, and some of it may drop off, making the antenna's appearance pretty crummy.

Rotary dipoles for higher frequency bands, or the elements of beam antennas, usually use aluminum or some other metal tubing. The wider diameter and greater surface area may suggest slightly shorter computed lengths. This is usually disregarded, but the diameters are usually reduced as the ends are approached to reduce tubing weight and physical drooping.

If the two middle ends of a dipole are connected to a 2-parallel-wire transmission line having an inductance-to-capacitance ratio that produces a 73-ohm Z_f, the antenna and the transmission line impedances will match at the antenna feed point. This allows RF energy to transfer between feedline and the antenna with essentially no loss.

But amateurs often use a 50-ohm transmission line rather than 73 ohms. Why? The modern manufacturers of amateur radio equipment usually design their output/input circuits to have a ±50-ohm impedance, for good reasons. A horizontal dipole has a center Z_f of ±73 ohms; the common vertical 1/4-wave antenna has a base Z_f of ±36.5 ohms; and beam antennas usually have 50-ohm Z_f inputs. A transceiver's 50-ohm Z_f output/input is about halfway between horizontal and vertical antenna center impedances, and is a match for beam antennas. The difference in operation between 73 and 50 ohms, or between 50 and 36.5 ohms, is not too much, particularly with modern transceivers having an internal reactive correcting circuit that tunes the antenna to operate with a minimum SWR (below).

Coaxial Cables

Trying to produce a 2-parallel-wire 50- or 73-ohm transmission line with its wires held apart the required small fraction of an inch to allow them to provide the desired impedance along the whole line's length is not too practical, particularly in wet weather. This why 50-ohm Z_f "coaxial" cable transmission lines are usually used. The center wire of a coaxial cable would be connected to one of the two 1/4-wave wires of a dipole, as shown in *Figure 2*. The outer metallic conductor of coax is a tubing-like copper braid around the thick-insulation covered center wire. This outer braid would be connected to the other 1/4-wave wire. A small strain insulator should be used between the two dipole wires.

If RF AC power feeds from a transceiver's 50-ohm Z_f output fitting into the end of a 50-ohm coaxial cable and then into the 73-ohm antenna, energy will couple transceiver-to-transmission line-to-antenna with some loss of radiated energy from the dipole, but now some of the RF energy will be radiated from the more or less vertical coax cable's outer braid.

Long coaxial lines have greater losses due to the energy absorbed by the resistance present in the internal insulating material. Also, the higher the frequency of the RF, the greater the losses in coaxial cables. However, they can be cut to *any length*, assuming the impedances at both ends match reasonably well. The open end of a coax cable where it is connected to the antenna must be coated with some type of waterproofing and insulating substance.

The arrows shown on the dipole's RF radiating flat top in *Figure 2* indicate that at this particular moment, RF current is flowing in the same direction in both of the 1/4-wave wires, but it will be running in the opposite direction in the feedline (Remember, RF is an alternating current). A half-cycle later, the flat top RF currents will both be flowing in the opposite direction, reversing all polarities. Since the two 1/4-wave flat-top currents are flowing in the same direction, they radiate as a single 1/2-wave dipole.

If the 80-meter antenna in *Figure 1* is used on 40-meters, each half of the dipole is now one 1/2-wave in length, providing high Z_f to any low Z_f 50-ohm coaxial feeder. The two 1/2-wave wires will now accept very little power to be radiated as a transmitted signal, although the outer braid of the coaxial cable will now be radiating some RF energy.

SWR

RF feedline energy recognizes any mismatched antenna impedance connection when it comes up to it. Some or most of its energy will be reflected back down the transmission line to the source (all of it in the case of a short circuit at the antenna feedpoint end) and "standing waves" of voltage or current are developed on the transmission line.

The ratio of the high-to-low voltages (or currents) along the line develops a "standing-wave ratio" (SWR) value that

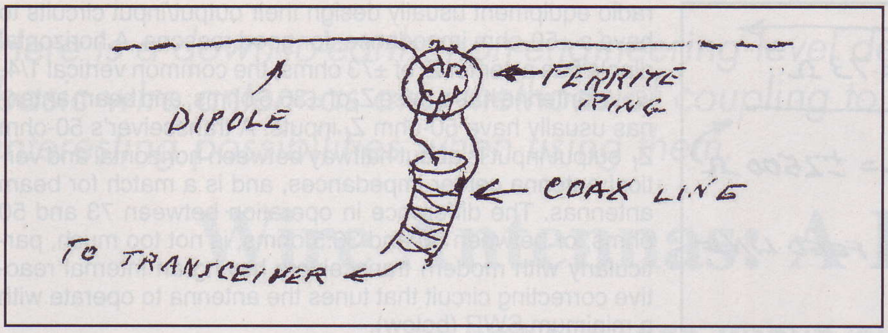


Figure 3. One form of a balun involves wrapping several turns of both the balanced antenna wire and the unbalanced coaxial feedline through a ferrite core.

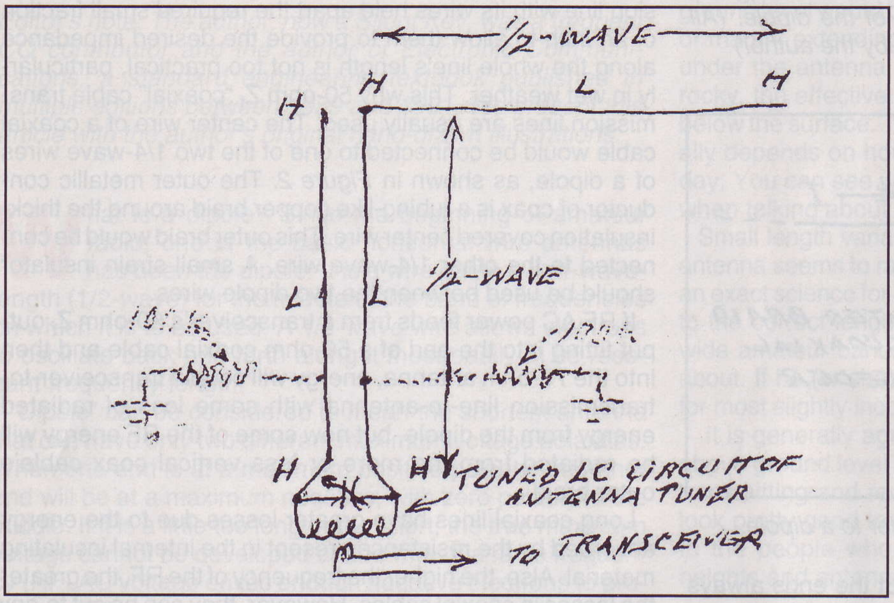


Figure 4. A half-wave open-wire feed line coupled to the end of a dipole. See text for discussion of the LC tuning circuit and the two 100k resistors to ground shown in dashed lines.

can be shown on a "reflectometer" connected in the transmission line. The greater the impedance mismatch, the higher the SWR and the less transmission of energy to the antenna. An example would be trying to feed the high-Z_f of ±2,500 ohms at the end of a dipole with a 50-ohm coax line, a ±2500/50 mismatch, and an SWR of ±50:1. Although an SWR of 2:1 may reduce energy transmission and antenna radiation somewhat, as the SWR increases over 3:1, the antenna no longer wants to accept much RF power, so RF radiation decreases as the SWR increases.

In the cases of matching a 50-ohm transceiver and coax line to the center of a dipole, the differences in impedances may be 73/50 for an SWR of ±1.46:1. When a vertical antenna base is coupled to a 50-ohm line, the SWR will be 50/36 or ±1.4:1. Neither of these is near the perfect 1:1 SWR ratio, but both are close enough. Note that the greater value is always divided by the lesser. An internal reactance-correcting circuit can bring the SWR to 1:1.

No matter how high the SWR, there will always be some radiation and reception with any antenna. The greater the SWR in a coax cable, the greater the transmitting loss will be because signals will be reflecting back and forth in the coax due to the mismatch, losing energy on each reflection. It is interesting that the reception of RF signals with a high SWR will be much better than will be its transmission of RF power. Tuning a transceiver's antenna improperly makes this quite evident — with almost no transmission of RF there are usually fairly strong received signals.

The Balun

When using a coaxial-fed dipole, there can never be equal capacitances between the right and left halves of the dipole to both the inner and outer coaxial conductors. Simple coaxial coupling to a dipole, while it works well, produces an unbalanced antenna feed system. The outer coaxial braid, from transceiver to the antenna, will emit part of the total RF radiated energy, more or less vertically. To correct this, a small ferrite-ring with two small coils on it forms an RF transformer. It can be used to couple the **BAL**anced dipole wire halves to the **UN**balanced coaxial cable, as shown in *Figure 3*. If such a "balun" is used with a coax-fed antenna, the system becomes balanced. The dipole radiates horizontally and all of its feedline RF waves are kept inside its coax cable. There are several different types of baluns, and some may be more frequency-sensitive than others.

Dipole Heights

The center impedance of a dipole at different heights is interesting. If lying on the ground, it has a center Z_f of only a few ohms. As it is raised, its center Z_f continually increases up to its first 73 ohms value at a height of 1/4-wave. Continuing up in height, it goes through a Z_f peak of about 97 ohms before decreasing to 73 ohms again at a 1/2-wave height. Continuing on up to its 3/4-wave height, it dips down to about 58-ohms Z_f before rising back to 73 ohms again. From there on, its impedance peaks and dips vary less and less above and below 73 ohms every 1/4-wave in until above about 3 wavelengths in height, its Z_f remains essentially constant at 73 ohms. All this can make matching the Z_f of a dipole to a feedline very interesting.

Harmonic Transmission

Center-fed dipoles can also operate on their *odd* harmonic frequencies. For example, a 7-MHz band dipole also works on its third harmonic, in the 21-MHz amateur band. The 7-MHz dipole is now working as three 1/2-wave dipoles connected in series. The low-Z_f center point of the middle dipole may now be a little higher than 73 ohms, but the mismatch may not be all that important, particularly if a balun is used. (Other harmonics of frequencies in the 3.5-to-4 MHz and the 7-to 7.3-MHz bands also fall into other HF ham bands.)

Coaxial feed can be used to any point that is 1/4-wave from either end of any multiple-1/2-wave long antenna wire, or to the center of any of its 1/2-wave sections.

Open-Wire Transmission Lines

How can a dipole be made to accept power efficiently if it is fed at its high-impedance (high-voltage) end? Answer: Match its high-Z_f (±2,500 ohms) end with a high-Z transmission line.

A transmission line using two parallel #14 wires held an equal distance apart by ±5-inch-long thin insulator spacer rods every 3 to 5 feet along the line, can produce a very low loss feedline of ±600 ohms Z_f. While 600 ohms matches the end Z_f of a dipole better than a 50-ohm coaxial cable does (SWR = ±2500/600 = ±4:1), this is still not good. With a 4:1 SWR, the dipole accepts little RF with considerable vertical radiation from the feedline because line current maximums do not line up to cancel.

Cutting such an "open-wire transmission line" to a *1/2-wavelength* produces high-Z_f at both ends. When cut to a *1/4-wavelength*, if it sees a high Z_f at one of its ends, it will have low Z_f at its other end. When operating as a tuned 1/2- or 1/4-wave open-wire line, exactly equal spacing between the wires is no longer too important.

Larger antenna wires have less RF "skin resistance" because RF AC travels only on or near the surface of wires resulting in less RF loss with larger-size antenna wires. If resonant feedlines are a little too long, they are "inductively reactive." Small capacitors can be added in series with them to balance out the inductive reactance. If too short, they are "capacitively reactive" and small tapped coils can be added in series with them to balance out the capacitive reactance.

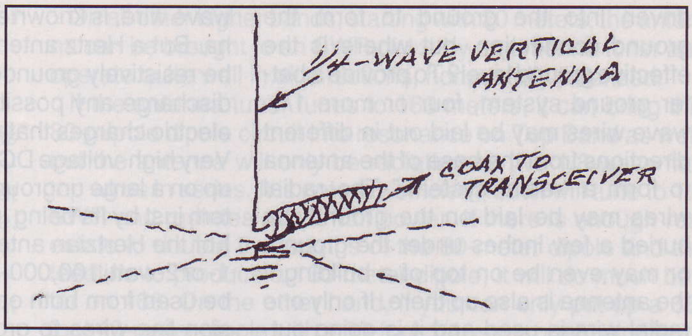
Coaxial cables can also be used as tuned lines. They must be cut to ±0.66 of the 468/MHz or 492/MHz values, making them more or less single-band dipoles.

Coupling Open-Wire Lines

Suppose the high-Z_f end of a dipole is connected to one end of a *1/4-wave* open-wire transmission line. The transmission line sees the dipole's high-Z end so it assumes a high-Z value there. A 1/4-wave down the line, its impedance will now be a low-Z value and provides a reasonable match to a 50-ohm Z_f transceiver antenna fitting.

If a *1/2-wave* long open-wire transmission line is attached to the high-Z_f end of a dipole (see *Figure 4*), it will repeat its high-Z value at the transceiver end. This length requires a high-Z antenna tuner between the feeder's high-Z_f value and the low-Z_f transceiver antenna fitting. What makes up a high-Z circuit? A parallel coil and capacitor (LC) circuit tuned to the operating frequency is one example of a high-Z resonant circuit. A high-Z_f transmission line's wires can be connected directly

Figure 5. A quarter-wave vertical. Dashed lines represent radials.



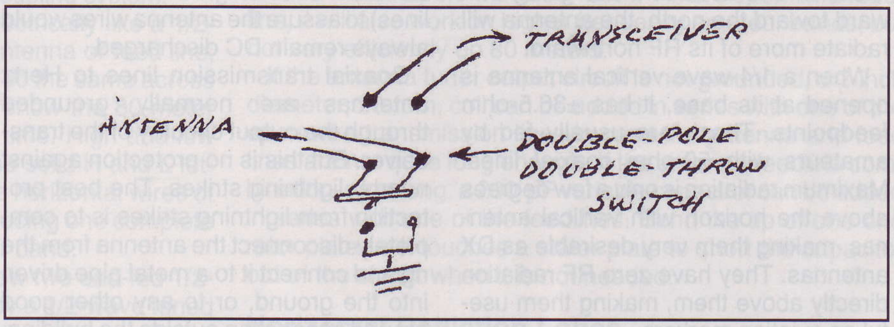


Figure 6. How an antenna grounding switch is connected. The DPDT switch assures that both antenna leads are grounded. You need to be sure that the switch you choose can handle the maximum power you will be transmitting.

across such a high-Z tuned LC circuit. Antenna tuners usually have parallel resonant circuit LC circuits as their output circuit. The antenna tuner must also provide a reasonably good match to the low-Z_f transceiver antenna fitting. This could be by using a few-turns low-impedance "link coupling" coil coupled into or coiled around the center turns of the tuner's LC circuit, as indicated. When the tuner is tuned to the operating frequency, the transmission line will see high-Z matches at both of its ends and the dipole will radiate RF energy efficiently. Antenna tuners use more involved 50-ohm impedance coupling circuits. The impedance values are shown in capital letters.

When center-feeding a dipole, the maximum radiation is at 90 degrees from the wire direction. When end-feeding a dipole, the maximum radiation direction is slightly more in line with the wire and away from the feedpoint. The longer the antenna, the more exaggerated this effect becomes.

If a 1/2-wave open-wire tuned line can couple an end-fed dipole to a high-Z antenna tuner, couldn't a 1/2-wave-long single wire (high Z_f at both ends) couple energy to the end of the dipole? It could. But with a 2-wire tuned open transmission line, the currents in the two parallel wires are equal but *opposite* in direction, canceling RF radiation from them. The only radiation is from the dipole. With a single 1/2-wave wire feeding the end of a dipole, both the 1-wire feeder and the antenna will now radiate energy. Half of the power will be radiated by the horizontal dipole and half by the essentially vertical one-wire 1/2-wave feedline. Two such series connected 1/2-wave resonant wires form a "full-wave" antenna. An interesting thing about this antenna is that when RF current is going outward from the antenna tuner, at the same time, the RF current will be going inward on the horizontal dipole. A half cycle later, both currents reverse.

Different Types of Dipoles

There are several different antenna designs used by amateurs that are each variations on the basic 1/2-wave dipole. We'll take a look at the most common ones, starting with one that — at first glance — doesn't seem to either be a 1/2-wave antenna or a dipole.

The Quarter-Wave Vertical Antenna

A common amateur antenna is a metal pole or wire 1/4-wavelength long, with its bottom end grounded (see *Figure 5*). It is actually half of a vertical dipole, with the earth operating as the other 1/4-wave element to make it a resonant 1/2-wave circuit. Actually, the earth operates as an almost infinite number of 1/4-, 3/4-, 5/4- etc. wave elements extending outward in all directions.

Making a good RF ground connection for a vertical antenna can be difficult. An 8-foot, copper-clad iron pipe is often driven into the ground to form the ground connection, but where is the effective ground level? To provide a better ground system, four or more 1/4-wave wires may be laid out in different directions from the base of the antenna to form a "radial system." The radial wires may be laid on the ground, be buried a few inches under the ground, or may even be on top of a building if the antenna is also up there. If only one radial wire is used and it is going outward toward the north, the antenna will radiate more of its RF northward.

When a 1/4-wave vertical antenna is opened at its base, it has ±36.5-ohm feedpoints. These are usually fed by amateurs with 50-ohm coaxial lines. Maximum radiation is only a few degrees above the horizon with vertical antennas, making them very desirable as DX antennas. They have zero RF radiation directly above them, making them useful as aviation markers.

Marconi Antennas

Any antenna using the earth or ground to make it resonate properly is known as a "Marconi" antenna. It may be a 1/4-wave vertical or a horizontal antenna some odd multiple of a 1/4-wave long, although an exact length may not be too important if an antenna tuner is used at the transmitter end. Shipboard radiotelegraph low-frequency (90-160 kHz) Marconi antennas were usually made as long as possible with loading coils added to them. A 90-kHz 1/4-wave *ship* station antenna should be: **468/2, or 234/.09 = ±2600 ft**, or **±0.5 mile long** — on a ship? A whole lot of loading coil inductance was needed between the transmitter and a ship's ±250-foot antenna wire to make it work like a 1/4-wave Marconi antenna.

An old-time amateur method of coupling the near end of a 1/4-wave, single-wire Marconi antenna to a transmitter output was to push a two- or three-turn link coupling coil into the nearest-to-ground-potential turns of a transmitter's output LC circuit. The farther this link was pushed into the coil, the tighter the coupling was to the antenna circuit. The free end of the link coil might be either grounded or be connected to a variable capacitor or inductor to ground for best antenna tuning. Today, antenna tuners are usually used to couple Marconi antennas to transceivers.

Hertz Antennas

Any antenna that does not depend on the ground or earth to make it resonant, such as a dipole or any multiple of a 1/2-wave wire, is known as a "Hertz" antenna. But a Hertz antenna should always be resistively grounded in some way to discharge any possible high DC static electric charges that may build up on it. Very high-voltage DC charges can build up on a large ungrounded antenna system just by its being in the atmosphere. For the Hertzian antenna in *Figure 4*, a 1- or 2-watt, 100,000-ohm resistor could be used from both open-wire transmission line wires to ground (see dashed lines) to assure the antenna wires would always remain DC discharged.

Coaxial transmission lines to Hertz antennas are normally grounded through the output circuitry of the transceiver. But this is no protection against nearby lightning strikes. The best protection from lightning strikes is to completely disconnect the antenna from the rig and connect it to a metal pipe driven into the ground, or to any other good ground connection outside the building. An antenna grounding switch is shown in *Figure 6*.

Windom Dipoles

A single #14 copper wire alone in air is said to have a self-impedance of ±500 ohms. Such a single wire can be used as a transmission line if it is connected to a ±500-ohm point on a dipole, usually ±14% out from its center (or to a similar point on a vertical antenna) and then to a similar Z_f point above ground on an antenna tuner. This is known as a "windom" antenna. How much vertical radiation it also puts out depends on the length of the feeder wire. One thing about this antenna, at all frequencies other than the computed one, it probably tunes as a top-loaded vertical antenna on any band with an antenna tuner. The operator may never know how it is working. Windom antennas can also use a parallel 2-wire feeder to cancel radiation from the feedline if the off-center impedance opened point equals the impedance of the feedline.

Zepp Antennas

A dipole fed at one end with a tuned open-wire transmission line is known as a "Zepp" antenna. In the early 1900s, when gas-filled, lighter-than-air dirigibles flew the skies of the world, such zeppelins (named after Ferdinand von Zeppelin) dropped this type of antenna out of the radio-operating cabin while in flight. A fairly heavy insulator attached to its end kept the antenna and its transmission line taut and more-or-less straight horizontally. Your author communicated with the Graf Zeppelin by CW on 500 kHz from his passenger ship while the Graf Zeppelin was flying near Spain in the mid 1930s. Incidentally, his first ham antenna in 1931 was a 40-meter Zepp (but is now a 40-meter double Zepp). Today, blimps seen flying above football fields use small VHF or UHF antennas to send TV and audio signals to their local ground stations.

A vertical VHF dipole with a 1/4-wave open-wire transmission line attached to the bottom end of the dipole forms a "J antenna." The two bottom open-wire transmission line ends can be connected directly to a coaxial cable and to a transceiver. Or, the two open-wire line ends and a coax cable shield may be connected together with the cable's internal lead going up a short distance to a 50-ohm point above the shorted parts on either of the transmission wires, usually through a small capacitor. J-antennas are popular "omnidirectional" (all directions) VHF or UHF vertical Zepp antennas with the transmission line coupled to the transceiver through a long coaxial cable,

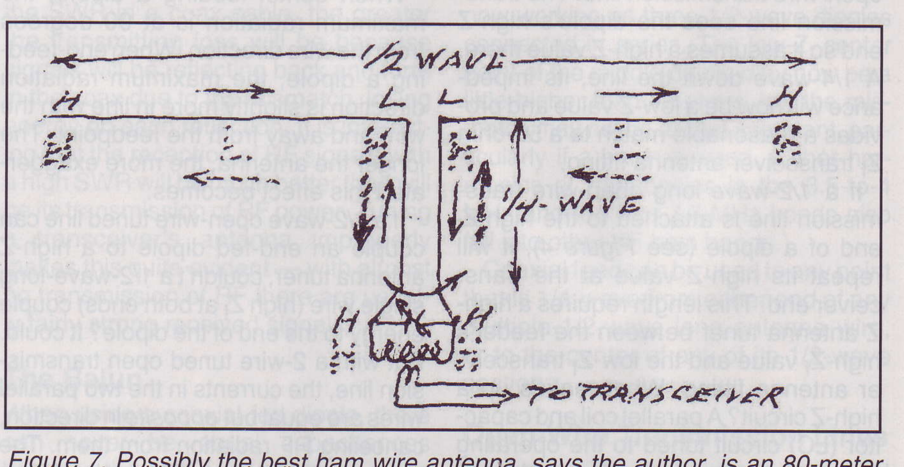


Figure 7. Possibly the best ham wire antenna, says the author, is an 80-meter dipole fed with open-wire line and an antenna tuner. See text for discussion of the dotted letters and the arrows indicating direction of current flow.

allowing the little antenna to be mounted high enough for good radiation and reception.

A Multi-Band Antenna

Possibly the best wire antenna for all HF amateur bands is shown in *Figure 7*. It does require an antenna tuner. It is a center-fed (CF) 1/2-wave 80-meter dipole. It might be ±130 feet long with a 1/4-wave ±65-foot long open-wire transmission line. On 80 meters, it has low Z_f at its center. Moving down the 1/4-wave feeder, the open-wire line presents a high-Z to the antenna tuner. Coupling the antenna tuner to the transceiver might be by link coupling or some other low-Z coupling system.

The tuner's resonant LC circuit acts electrically like a 1/2-wave dipole. Every 1/2 wave along an antenna or feed line, the RF voltages reverse polarity, so they do the same across the tuner's LC circuit. The solid arrows show the 80-meter RF currents present at some particular time. High and low voltage and Z_f points are indicated by the solid H and L letters. The currents in both of the 1/4-wave horizontal wires of the dipole are in the same direction, producing one complete 1/2-wave dipole radiator on the 80-meter band.

On the 40-meter band, the flat top is now two end-fed 1/2-wave dipoles coupled to the transmitter by a 1/2-wave tuned feedline. The dipoles, feeders, and the antenna tuner all have high-Z_f points at their connections. The high and low voltage and Z_f points are now indicated by *dashed H and L letters*. On the 40-meter band, this is two separate Zepp-fed dipoles, or a "double-Zepp."

As a 40-meter double-Zepp, the current in the left dipole might be going left, as shown by the *dashed* arrow. The current then reverses and goes downward in the left-hand feeder. It reverses again across the resonant LC circuit. It reverses yet again to go upward on the right-hand feedline, and finally reverses to leftward on the right-hand dipole. So, the two 1/2-wave dipole flat-top currents are going in the same direction, or are radiating "in phase." They are now radiating twice as much power at exactly right angles to the wires of both dipoles. This is a power gain of two times, or 3 dB, in this direction. This is actually a 2-element wire-type beam antenna. Because the currents in the two feeder wires are in opposite directions, radiation from them is zero.

The next higher frequency amateur band is the 30 meters, a U.S. no-'phone band from 10.1 to 10.15 MHz. Here, each antenna radiating section is ± 0.75-waves long, or three 1/2-waves long. An antenna tuner will tune it to a 1:1 SWR. It is now an "extended double-Zepp." It radiates 1/3 of its power at 90° from the antenna wire and 2/3 of its power in two other directions at about 50° from the antenna wire.

On all other higher bands, starting with 20 meters, the antenna can be brought to an SWR of 1:1 by an antenna tuner and operate quite well in all directions, horizontally polarized.

If the antenna tuner tunes to 160 meters, it can bring this 80-mipole dipole circuit into resonance on Top Band as well, but the antenna will only be radiating as two 1/8-wave flat-top wires in series. It is not very efficient, but it will tune to 1:1 SWR and radiates about half power. If there is enough real estate to double the lengths of the 80-meter dipole and the feedline to produce a 160-meter dipole, it will do much better on 160. On the other hand, if you can only put up a 66-foot 40-meter dipole with a 33-foot 1/4-wave open-wire feedline, it will also work on higher frequency amateur bands, but not very efficiently on 80 meters.

If the antenna tuner output circuit is not grounded, a 2-inch diameter, 20-turn, coil can be added in series with one of the open-wire transmission lines in case the antenna and feed lines are not quite long enough. If the antenna/feedline combination is too long, a 200-pF variable capacitor can be added in series with one of the feedlines. Bend the tip of one end rotor plate so it touches a stator plate to short the capacitor out of the circuit when it is not needed.

Horizontal Radiation Lobes

The RF "radiation pattern" or "lobe" of a north/south dipole wire in outer space, seen end-on, is outward in all directions (*Figure 8a*), and is a circular lobe. It is picturing the relative radiation in all possible directions.

When looking down on a N/S dipole, the radiation lobes to both its E and W sides appear as slightly elongated circles (*Figure 8b*), with maximum horizontal radiation at 90° from the wire. This is picturing the total radiation as RF current flows from one end of a dipole to the other end.

If near earth, a horizontal dipole radiates equal RF in all directions at right angles to the wire. Some of the downward radiation may warm the earth a bit, but much of it may be reflected upward at many angles by the earth and may then be re-reflected downward by the ionosphere.

With the 40-meter double-Zepp, the radiation lobe at 90° from the wire would be twice as long as when it was used as a single 80-meter dipole. Since there is no more power being

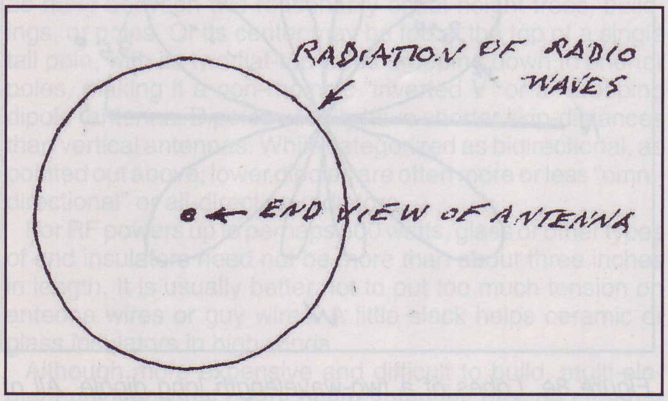


Figure 8a. Circular lobe of the horizontal radiation of a dipole antenna, looking at it from the end of the wire.

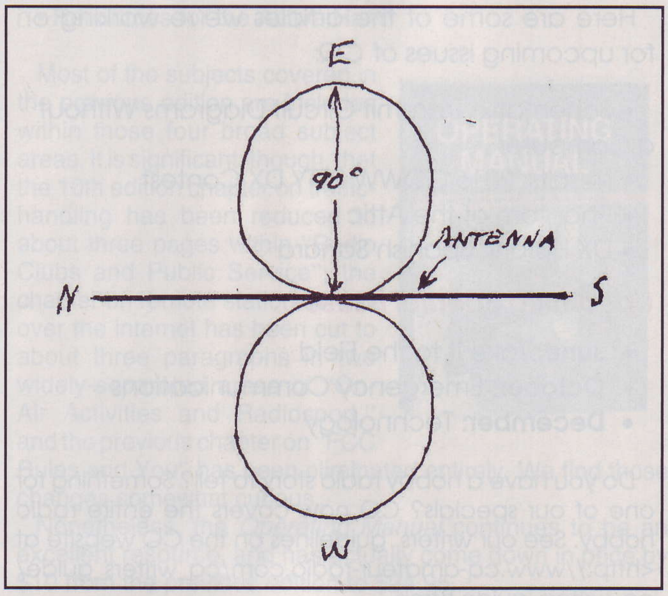


Figure 8b. Horizontal lobes of a dipole with a north/south orientation, looking down from above.

transmitted, its radiation lobe width (a picturing of its total radiated energy) would be reduced from the nearly 90° of a single dipole to about 45°. Actual lobe shapes may be changed by antenna heights, nearby structures, trees, nearby wires, metal poles, etc.

The radiation pattern of a full-wave N/S antenna (two dipoles long) looking down on it in outer space is shown as four major lobes, all roughly 50° from the antenna, with maximum lobe widths of about 40° (*Figure 8c*). Note that the two dipole lobes cancel each other because the currents in them will always be in opposite directions, resulting in zero 90° radiation. With a 100-watt transmitter, the total power radiated by a dipole, a double Zepp, a full-wave antenna, etc. will all be the same, but different amounts of the RF power will be radiated in the different lobe directions. In between lobes are directions of theoretically zero radiation, called "nulls."

The radiation from an antenna that is 1.5 wavelengths long (3 dipoles long, such as the 30-meter extended double-Zepp antenna) in outer space is shown in *Figure 8d*. Its middle 1/2-wave section is developing two lobes at 90° from the antenna. The other two dipoles produce four lobes like a full-wave antenna, but at about 40° from the antenna, with six lobes and six nulls.

The radiation of two full-waves in phase (as an 80-meter dipole on 20-meters) is shown in *Figure 8e*. Its beaming effect develops four longer and slimmer main lobes at about 35° from the wire. Since four currents are cancelling each other, there is no lobe at 90° from the wire.

If a receiver is in a null direction between two lobes or off the end of an antenna there should be no RF transmitted to the receiver. However, the ionosphere, up 200 or so miles, is in constant motion and provides many constantly billowing reflective surfaces. Any RF signals striking them are reflected or refracted in many directions. So there will always be RF energy reflected or refracted to points on earth in unexpected places. This is why signals are heard in null directions and why signals may sometimes be heard in the expected skip zone of a station.

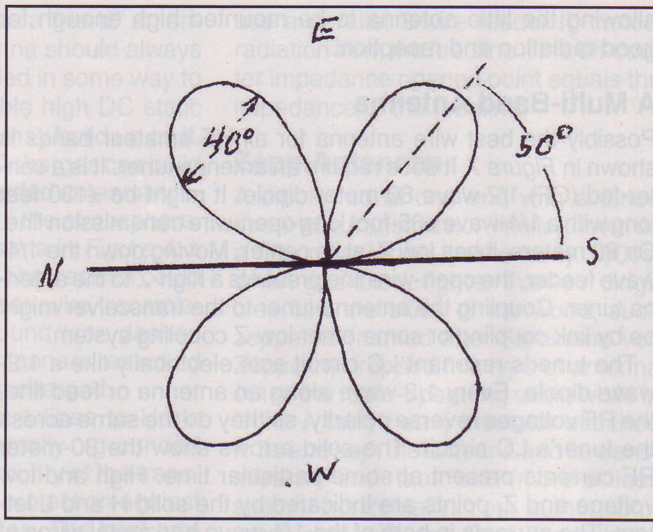


Figure 8c. Lobes of a full-wave antenna, also oriented north-south.

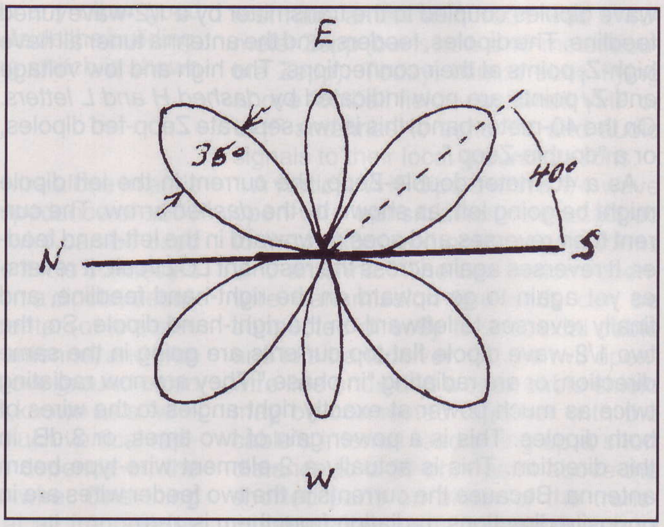


Figure 8d. Lobes of an antenna that is three half-wavelengths long.

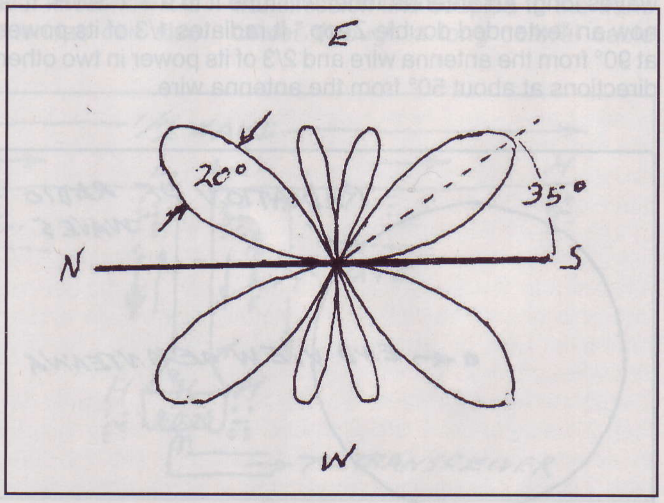


Figure 8e. Lobes of a two-wavelength long dipole. All of these may exist on the same physical antenna (see Figure 7), depending on the frequency band in use at the time.

The nulls of a handheld 1/2-wave VHF receiving dipole or a loop antenna can be used as relatively sharp directional indicators of hidden transmitters a short distance away. Lobe peaks are never very sharp directional indicators.

A horizontal N/S dipole wire always radiates horizontally polarized signals at right angles to the wire, or E and W. It also has vertical radiation lobes. For heights up to almost 1/8-wave, most of the radiation is upward. At 1/4-wave height, the radiation is some upward but more outward. When 1/2-wave high, the lobes are all outward at ±30° with nothing upward. At 3/4-wave, its upward lobe is greater than the outward lobes. At 1-wave high, there is only outward with nothing upward. For all 1/2-wave heights above on full wavelength, there is nothing going upward. In between is both upward and outward, with the upwards lessening as height increases.

The E/W lobes of a horizontal N/S antenna, being partially outward, will be radiating to some extent in both northerly and southerly directions. The ionosphere can reflect and refract these waves down to distant stations in both N and S areas and actually provide reasonable strength signals in these directions — off the ends of the antenna — and in supposedly null directions! A full-wave N-S antenna wire radiates even more RF in line with the antenna wire, producing quite strong N-S distant received signals as well as in the expected major lobe directions. The ionosphere reflects or refracts some additional signals down to earth in these directions.

Theoretically, at a short distance, a vertical antenna should pick up no signal from a horizontal antenna and vice versa. Actually, a horizontally radiated wave begins to lose its radiated angle. After a few miles a vertical antenna may pick up horizontally transmitted waves quite well due to reflected signals from the ionosphere.

Erecting Dipoles

A dipole operated at a 1/4-wave height above effective ground level, or any multiple of 1/4-wave, provides a 73-ohm center impedance value to its transmission line. If not at exactly 1/4-wavelength in height, it may have some other center impedance value. Actually, a dipole at about 0.2 wave and again at about 0.6-wave heights has a center impedance of close to 50 ohms and matches a 50-ohm coaxial cable nicely.

If operating at less than a 1/4-wave height, much of its RF downward radiated energy is reflected upward by the ground and may be re-reflected right back down again by the ionosphere. As a result, the higher a horizontal antenna is the better it will be for long distance DX. If lowered, its reflected signals may provide better and stronger shorter distance reflected signals.

A wire dipole is fairly simple to put up and work with. It can be hung between two reasonably equal height trees, buildings, or poles. Or its center may be fed at the top of a single tall pole, with its two flat-top wires dropping down to shorter poles, making it a non-rhombic "inverted V" or a "drooping dipole" antenna. Dipoles usually have shorter skip-distances than vertical antennas. While categorized as bidirectional, as pointed out above, lower dipoles are often more or less "omni-directional" or all-direction radiators.

For RF powers up to perhaps 500 watts, glass or other types of end insulators need not be more than about three inches in length. It is usually better not to put too much tension on antenna wires or guy wires. A little slack helps ceramic or glass insulators in high winds.

Although more expensive and difficult to build, multi-element unidirectional rotary beam antennas provide stronger transmitted and received signals in the direction they are pointed. But that's another story.

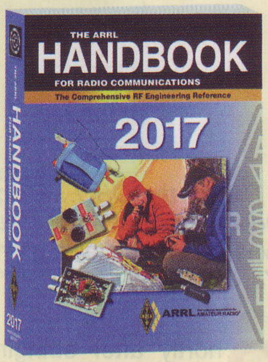
what's new

ARRL Handbook and Operating Manual

The 2017 *ARRL Handbook for Radio Communications* and the 11th edition of the *ARRL Operating Manual* are now available. As we have said in the past, these two references should be in every ham's library and refreshed every so often as technology and operating modes progress.

The ARRL Handbook

As always, the *Handbook* covers the basics of RF communication technology, including the fundamentals of electronic theory, design principles and more. New additions for 2017 include "A Revised Approach to Measuring Crystal Parameters" and "Updated Details on the Placement of Filter Stubs" for the engineers among us, plus more practical segments on "Decoding Fox-1 Satellite Telemetry," "A 30, 17 and 12-Meter Antenna Project" and "A Raspberry Pi Network Server/Client for Antenna Rotators." The book includes a CD with all the text and illustrations from the print edition as well as software, PC board templates and more. The hardcover *Handbook* sells for $59.95; the softcover edition is $49.95.

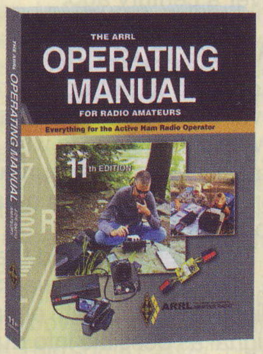


ARRL Operating Manual

The first thing we noticed about the 11th edition of the *ARRL Operating Manual for Radio Amateurs* was that it appeared to be thinner than the 10th edition, and indeed, it is nearly 100 pages shorter. The contents have been completely reorganized, with 14 specifically-focused chapters in the 2012 edition changed to four broadly-focused chapters in the new book:

- Basic Station and Operating Techniques
- Radio Clubs and Public Service
- On-Air Activities and Radiosport
- Resources for the Active Ham

Most of the subjects covered in the previous edition are included within those four broad subject areas. It is significant, though, that the 10th edition chapter on traffic-handling has been reduced to about three pages within "Radio Clubs and Public Service"; the chapter on remote station control over the internet has been cut to about three paragraphs in two widely-separated areas of "On-Air Activities and Radiosport," and the previous chapter on "FCC Rules and You" has been eliminated entirely. We find those changes somewhat curious.



Nonetheless, the *Operating Manual* continues to be an excellent resource, and has actually come down in price by $10 from the previous edition to $24.95.

Both books are available from ARRL, 225 Main St., Newington, CT 06111, <www.arrl.org>, or from any number of ham radio retailers.