# The ABCs of HF Antennas

*Beginning hams, take heart!*

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Antennas can be a very confusing and often frustrating subject to understand, particularly for the newly licensed radio amateur. Entire books—quite a few of them, in fact—have been written on the subject of antennas over the years. Much of what we call *antenna theory* is often very difficult to visualize, partly because of the way it has been traditionally presented, and partly because it's often somewhat foreign to our normal view of the ways things work. This sometimes makes it hard for those in our hobby who aren't engineers to acquire a clear view of what is an admittedly complex subject. What I'm hoping to do here is to summarize some of the more *practical* information that you'll *most* need to know to make decisions on which antenna configuration might work best for you, without your having to sift through all of the available volumes right away.

I'll try to keep the discussion centered on antennas used in the HF bands—those below 30 MHz—with only brief references made to their VHF and UHF counterparts as needed for comparison, because the end use of antennas above 30 MHz can be very different from those used in the bands below 30 MHz. VHF/UHF antennas normally presume primarily line-of-sight communications and antennas of relatively small size. As a result, VHF/UHF antennas are pretty well standardized and normally don't present the same degree of installation problems that HF antennas present, since they can normally be easily installed on the smallest of urban lots. HF antennas, by contrast, are generally intended for use under ionospheric skip conditions and their installation should keep that objective in mind. They can also become very large physically as the frequency of operation goes lower, especially down at 1.8 MHz (160 meters). This often makes installation of an HF antenna in an urban environment "a challenge of compromises" on the part of the average amateur. It's therefore probably less confusing to keep these two ranges of ham antennas distinctly separate. These reasons will become even more apparent as we progress.

### A single best?

To begin, perhaps it's best to be honest and say that there is no single best HF antenna for everyone; that's one reason why there are so many variations, I suppose. Just as there is no best automobile for everyone, there are many models and style categories to choose from. And like an automobile, the antenna that's *best* for you will depend in large part upon your own finances, the overall size that you can reasonably accommodate and the end result that you realistically hope to achieve—like the choice of an automobile or of many other products.

### The Utopian antenna

We've all looked for that Utopian antenna, one that will cover all frequencies of interest, perhaps provide us with some gain and present a favorable angle of radiation, under all conditions. Unfortunately, like Utopia, it's not been discovered yet! In fact, books like the *ARRL Antenna Book* are as thick as they are because of the wide variety of possible antennas, and various refinements to them, that our fellow hams have experimented with over the years. It's also a book well worth your reading time after your exposure to the basics.

Instead of searching for something that doesn't yet exist, let's take a look at what does, and how it might apply to your individual circumstances. That's the key factor—your particular, individual circumstances. Each of us has practical limitations—some more so than others—on how much antenna wire, aluminum element tubing or tower structure we can put up, and still keep peace within our own family and in the neighborhood in general. This may be the most important factor in your final decision.

### The two basic types

If you boil it down, there are two basic HF antenna types, but there are numerous variations on these two types, the classic half-wave horizontal wire dipole and the almost-as-classic ground-mounted, quarter-wave vertical, normally made of aluminum tubing. All others are ultimately based on these two design configurations. Also, try to keep this in mind: Any resonant antenna must be at least an electrical one-half-wavelength long, it can be longer, but not shorter. There are methods of making the physical length of an antenna shorter using coils, while maintaining the correct electrical length; these are often seen on both horizontal and vertical commercial amateur antenna designs. The minimum electrical one-half-wavelength requirement, however, must still be met. How is a quarter-wave vertical possible, then?

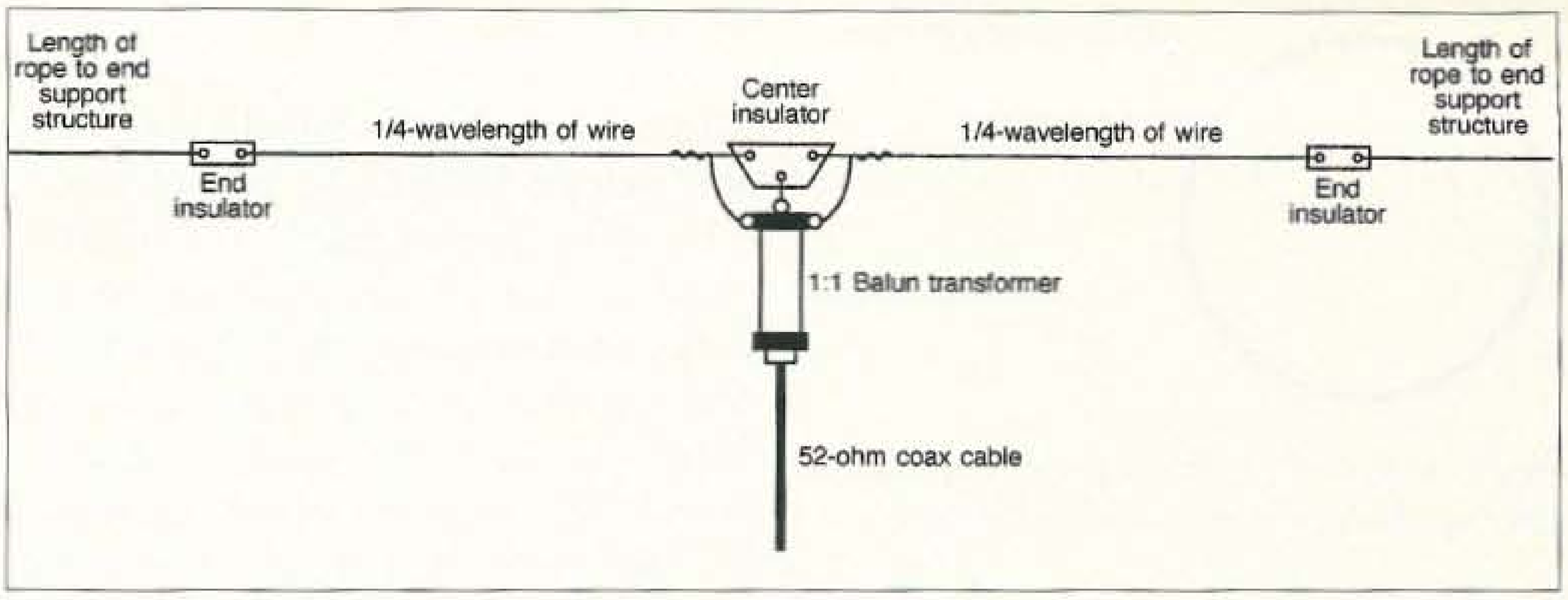


*Fig. 2. Half-wave horizontal dipole, viewed from the side. Each wire element is 1/4-wavelength long, separated at the center by an insulator and connected to the coax cable via a 1:1 balun.*

### The horizontal dipole

The half-wave horizontal dipole, most often made simply of wire, is well-suited for the HF amateur bands below 30 MHz, producing a pattern that resembles the symbol for infinity when viewed from either of its ends (**Fig. 1**). It's the classical center-fed wire dipole antenna strung between two opposite supports, with 1/4-wavelength of wire on each side of a center insulator (**Fig. 2**). This type of antenna can be fed with coaxial cable at that center insulator—most often using a 1:1 balun—with a balanced feedpoint impedance of roughly 75 ohms. It can also be fed with open-wire transmission line—via a balanced output antenna matching unit—for operation over a number of non-resonant frequencies. Though not as efficient as when it's operating as a truly resonant antenna, this scheme works because the losses in the higher-impedance, open-wire transmission line are very low at these frequencies, whereas the losses in a low impedance coaxial cable would be excessive and perhaps even damaging to the radio or to the coaxial cable itself.

Horizontal half-wave wire antennas have been used ever since the very beginning of practical radio communications, and continue to be widely utilized by hams and some commercial shortwave installations to this day. Anything that's been proven by the test of time is worthy of your consideration. The biggest problem for most people seems to be in the ability to put one up high enough for the lowest of the HF frequencies. I'll get more into that a bit later. The other problem is in how to center-feed an antenna of this type and to have the transmission line drop down fairly close to where your equipment is located. That may be one reason why the backyard "radio shack" became popular in the early days of wireless communications, and still is in many parts of the world. The shack ended up where the transmission line drooped down from the dipole's center—that and the fact that the very early radio gear was definitely not "XYL-friendly" and was often best left out in the yard!

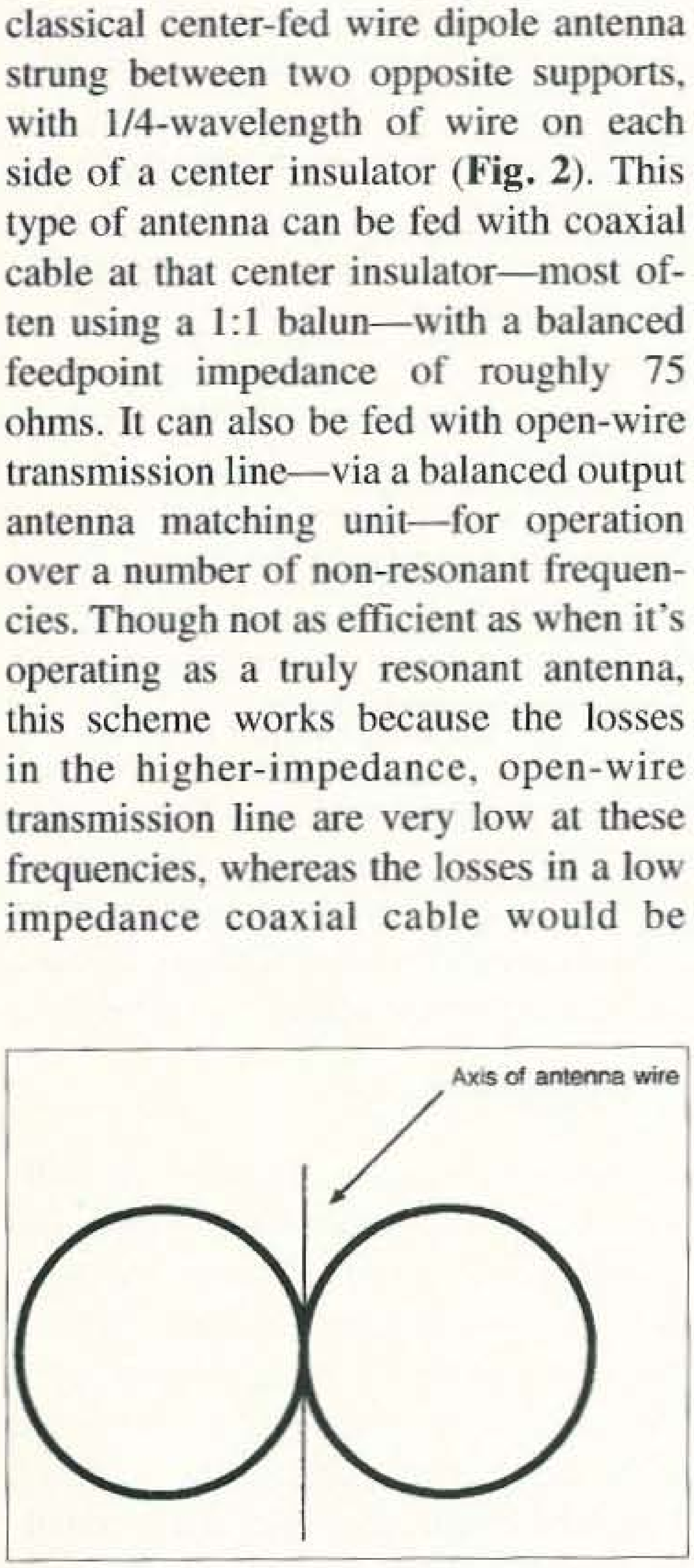


*Fig. 1. Idealized radiation pattern of a half-wave horizontal dipole antenna, as viewed from directly above.*

### The quarter-wave vertical

The quarter-wave aluminum-tubing vertical antenna (**Fig. 3**) is the next most popular—and probably next oldest—form of transmitting and receiving antenna, and is also used by amateur radio operators and commercial broadcasters the world over. It will produce a basically circular radiation pattern when birds-eye-viewed from the very tip, looking downward (**Fig. 4**). It's typically fed at its base—very near the ground—with the shield of the coaxial cable going to the ground system directly, while the center conductor is connected to the above-ground vertical element. This represents a feedpoint impedance of about 35 ohms unbalanced, so it's also compatible with low-impedance coaxial cable transmission line.

You've probably noticed that the two feedpoint impedances that I've mentioned so far—75 ohms for a horizontal dipole and 35 ohms for a ground-mounted vertical—are slightly different from the 52-ohm coaxial cable that most hams traditionally use. These differences are too small to be of any real significance at these frequencies, representing a mismatch of about 1.5 to 1, and thus won't present a problem from a practical standpoint. They're also simply approximations of what a real-life antenna's feedpoint impedance might actually be; it can vary quite a bit. Additionally, it's generally considered best

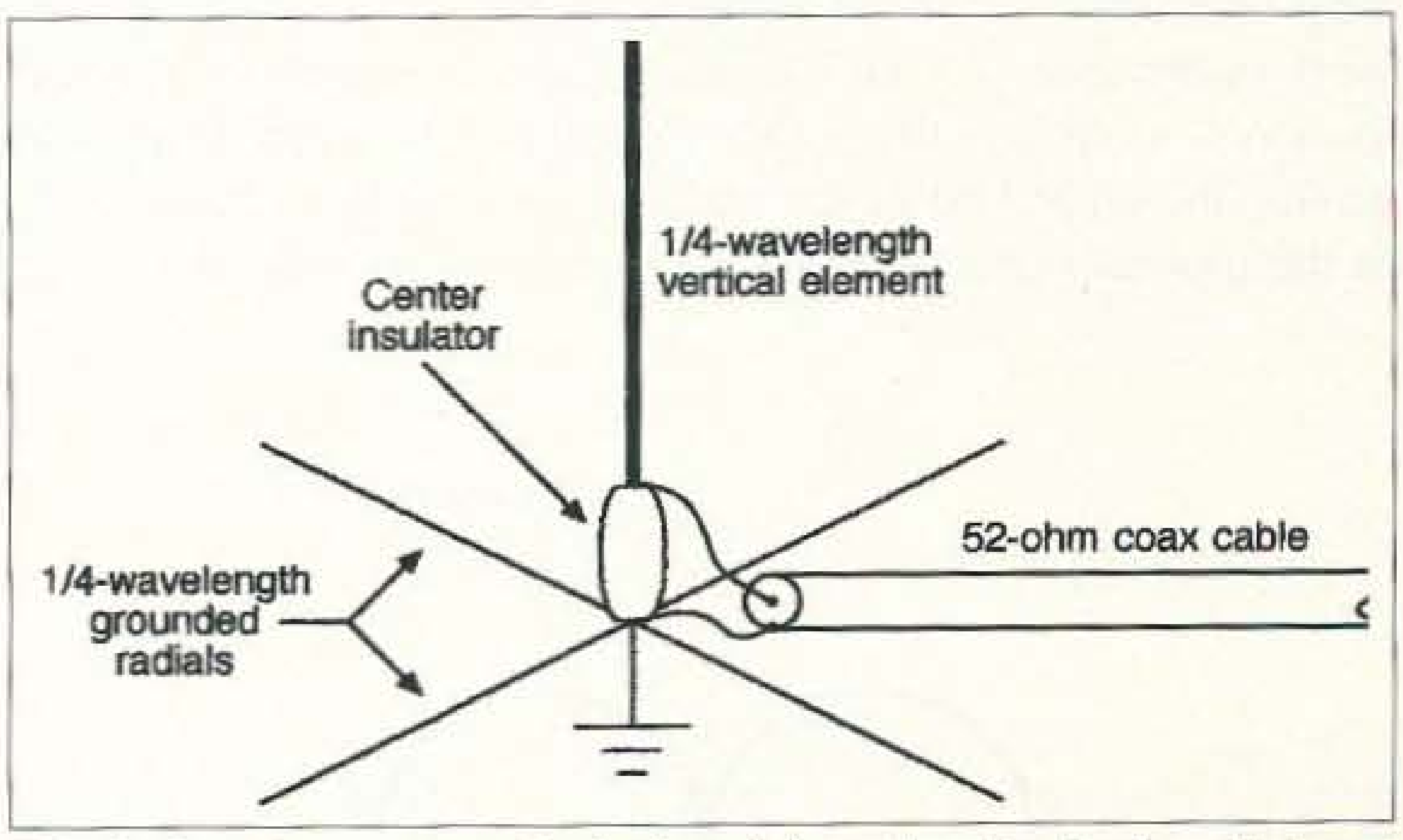


*Fig. 3. Quarter-wave vertical, viewed from the side. Each radial, and the main vertical element, is 1/4-wavelength long. The center conductor of the coax is connected directly to the vertical element and the shield of the coax to ground.*

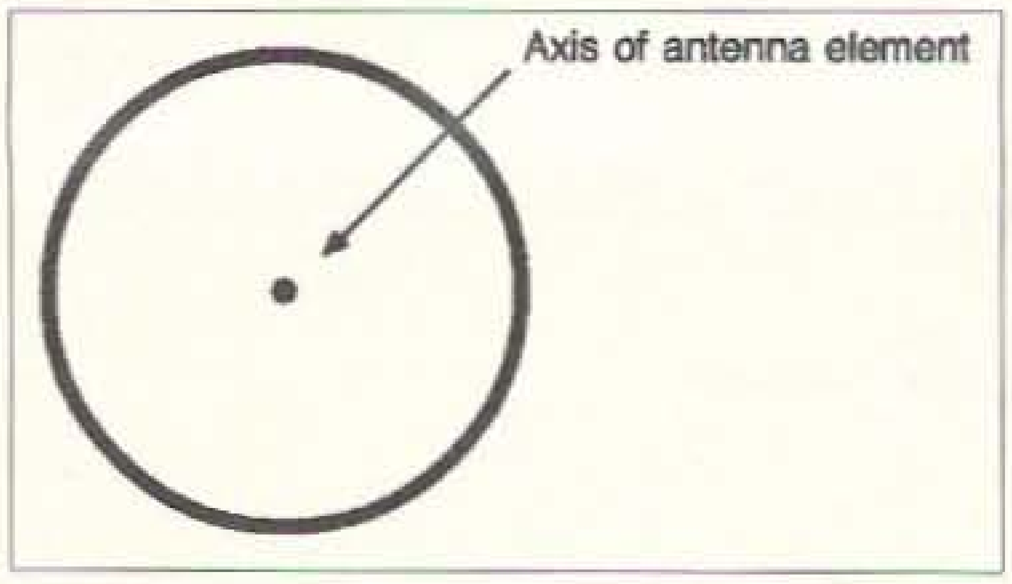


*Fig. 4. Idealized radiation pattern of a 1/4-wave vertical, viewed from directly above.*

practice to use a balun—balanced to unbalanced—RF transformer when feeding any naturally balanced antenna, such as a horizontal dipole (**Fig. 5**). It aids in keeping RF currents off the outside of the coaxial cable's shield when feeding such a balanced antenna. If the outside shield of the coaxial cable is allowed to become part of the radiating system—as it may be without a balun—power can be wasted in ineffective transmission line radiation. Also, any existing TVI and RFI conditions might be aggravated and interference pick-up from household appliances during receive might be increased. It's easy to tell if an antenna is balanced or not; if one side of the antenna's transmission line connection point is not grounded, then it's usually considered a balanced antenna.

### The ground radial system

Getting back to our HF vertical antenna installation, the active metal-tubing portion of a vertical antenna must be insulated from the ground mounting support and all quarter-wave verticals must have an effective ground plane beneath them. The ground plane is actually the other *half* of the antenna. Remember when I said that all antennas must be at least a half-wavelength long? Well, in the case of what we call a quarter-wave vertical, the other quarter-wave—the other *half* of the antenna—is in the ground plane beneath it. It's also sometimes called the phantom or *image* antenna. So a quarter-wave vertical isn't really a quarter-wavelength long; the other quarter-wave is the ground plane, and a good ground plane is absolutely essential. That ground plane can be the roof of an automobile, the hull of a metal ship, the fuselage of an airplane, a wire radial system or very conductive earth ground itself. Generally speaking, unless the antenna is over a salt marsh, the earth itself is an unpredictable and too often a variable ground plane. This variable other half of the antenna can represent substantial losses when left unaddressed.

Metallic radials—which can often simply be copper electrical house wires—are the most reliable, predictable and lowest-loss choice for a ground plane radial system in normal installations. If you intend to use a ground-mounted, quarter-wave vertical antenna for your station, don't forget to include the time, labor and expense of an adequate radial system into your initial considerations. Many have tried to circumvent that requirement, but few have been successful! Most of the tuning and other end performance problems associated with backyard, ground-mounted verticals can be traced to inadequate radial systems.

Taking a hint from the commercial AM broadcasters may be one of the best examples. A typical commercial AM broadcast station tower—which can be either a quarter-wave or a five-eighths-wave vertical—will have one quarter-wave-length radial, usually made of heavy copper strap, for every three compass degrees around the tower. That's 120 full-length quarter-wave radials emanating from the base of the tower in bicycle-wheel-spoke fashion. At the low-end of the AM broadcast band, each radial can be over 400 feet long, but it's the only way for the broadcaster to be sure of good stability in the tower's feedpoint impedance, along with the very least amount in ground losses—which represents energy lost in simply heating ground. Rarely will hams go to those extremes in installing a ground radial system, but it does illustrate the importance of a good radial system if you expect consistently predictable results, which commercial broadcasters must. Normally, ground soil conductivity is just too variable for professional installations. I'm often curious if hams are really aware of this when I hear folks talking about the "simplicity" of installing a quarter-wave, ground-mounted vertical. I have to believe that most really aren't. A well-installed vertical is not an easy job. Wide variations in feedpoint impedance and antenna effectiveness are almost inevitable without a well-laid-out radial system. Tossing up a vertical is easy; putting in a ground radial system for the HF bands is not!

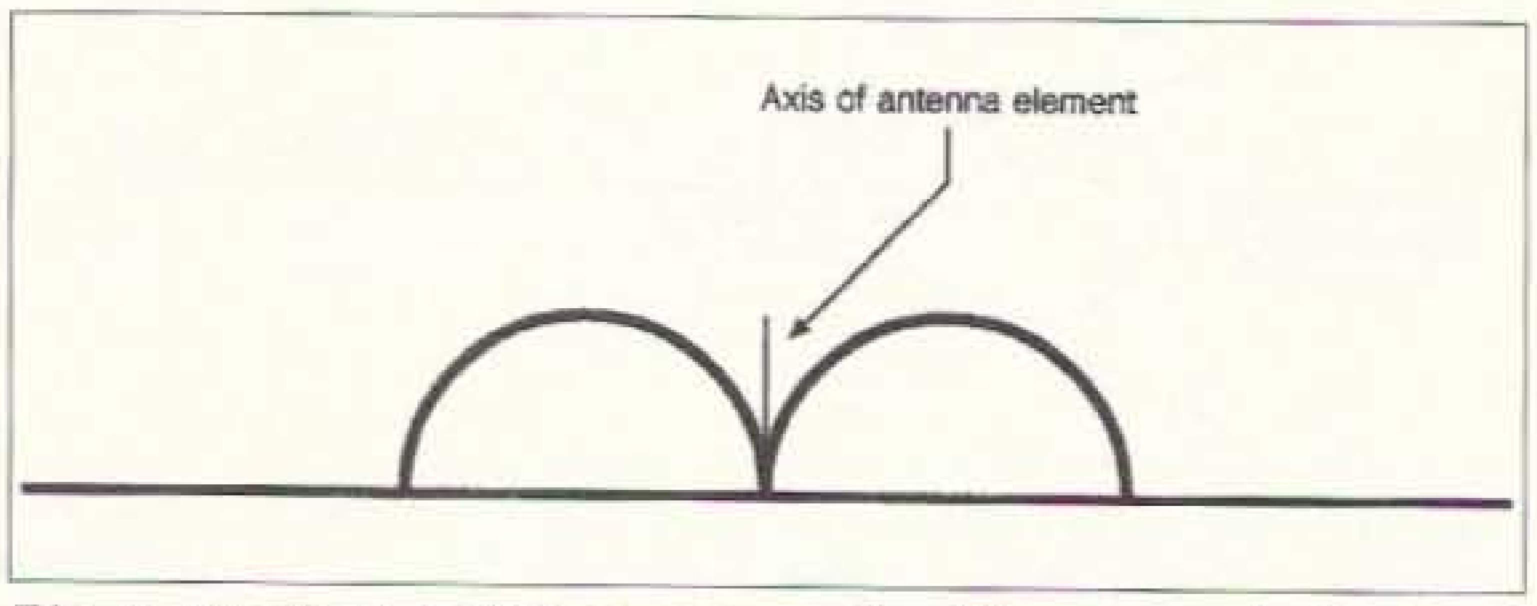


*Fig. 5. Idealized radiation pattern of a 1/4-wave vertical, viewed from the side.*

### Less-than-ideal installations

Of course, if you can't achieve the ideal, and very few can, you can still install a compromise radial system and make many rewarding contacts; just don't be too surprised when results change with soil conductivity during wet and dry weather, or between sizzling-hot summer and freezing winter conditions. Different soil compositions can also play a role in the results you'll experience. There's been a good deal written about this subject, so you can find much more in the literature if you have the desire to learn more before installing a ground-mounted, quarter-wave vertical antenna for the HF ham bands. In general, however, the more radials, the better. If you put in as many radials as your property and other considerations permit, you'll know that you've done all that you can and you'll just have to work around whatever variations might result. Few of us live in an open field, with only antenna considerations to be addressed, like commercial broadcasting stations do.

### 50 MHz and above

A brief diversion at this point: At VHF and UHF frequencies, an effective ground plane is easily achieved with four or more drooping radials, right at the above-ground vertical antenna support itself, or from the metallic structure of the car or other vehicle, in the case of a mobile installation. VHF/UHF antennas are also often greater than one-quarter-wavelength, or even one-half-wavelength today; five-eighths-wave and multiple five-eighths-wave vertical antennas are common, because of the potential gain that they offer by way of the more desirable vertically-compressed pattern possible with these longer antennas (**Fig. 6**). At VHF and UHF frequencies, the nearly impossible ideal situations that we face in the HF bands disappear completely because of the smaller sizes of antennas and their complementary radials at these frequencies. Instead, feedline loss considerations and height above average terrain become the dominant factors. The highest quality coaxial cable that you can afford and the greatest structurally-safe height that you can manage for a VHF/UHF installation are the keys to best performance at these frequencies.

### Angle of radiation explored

Returning once again to the HF ham bands, we should address the subject of *angle of radiation*. This gets just a bit complex, and perhaps somewhat difficult to visualize, but it's important to have some acquaintance with the subject nonetheless. I'll be simplifying it as much as possible, so again, if you would like to delve deeper into it, there are references as to how to achieve to optimum angles of radiation in most of the antenna books.

The angle of radiation from an antenna within the amateur HF bands—those frequencies under 30 MHz—is important because it will be one determining factor in how far your signal can be expected to skip in the first, and subsequent, bounces off the ionosphere. Just like a ball bouncing off the cushion of a pool table, the angle at which your radio signal strikes the ionosphere will determine the equal, but opposite, angle that it's reflected back from the ionosphere—in general. This, in turn, normally determines how far the skip distance will be. I've said "in general" and "normally," because there are other factors involved, some of which we can't always predict, but this is the mechanism that we usually assume to be true.

In general, the lower the angle at which your radio signal's main lobe strikes the ionosphere, the greater your expected skip distance will usually be.

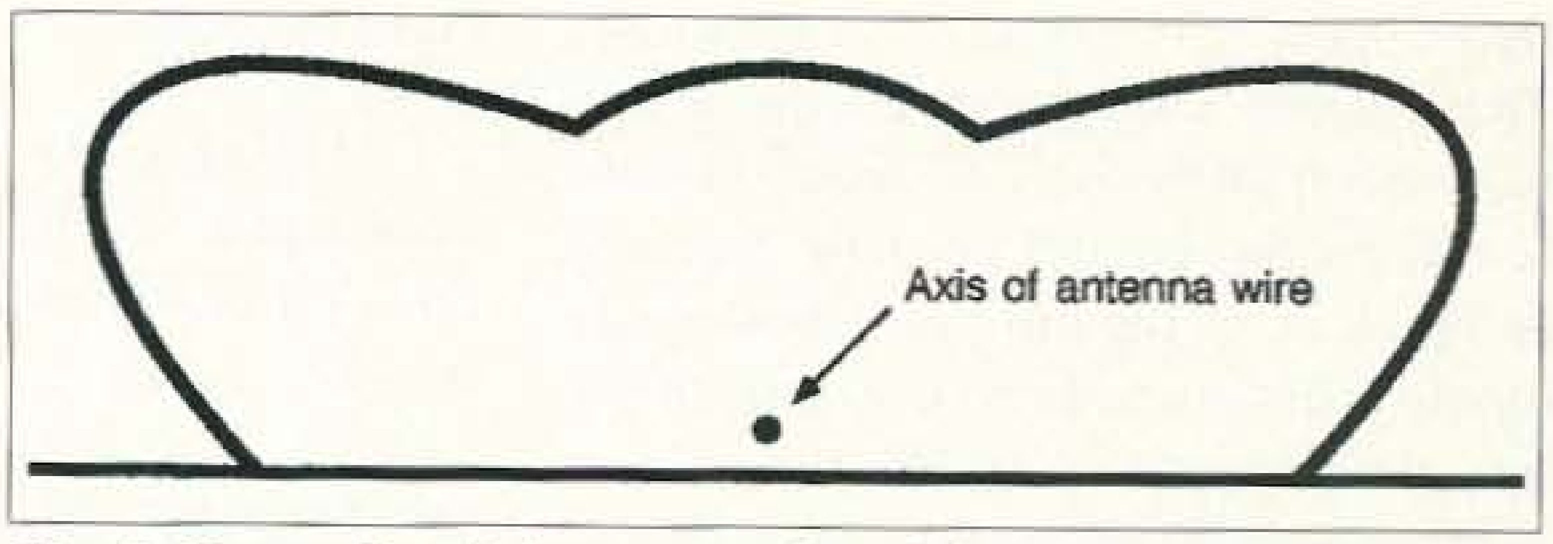


*Fig. 7. Expected radiation pattern for a 1/2-wave horizontal wire-dipole antenna, mounted 1/2 wavelength above average ground soil composition, viewed from one end of the antenna wire's axis.*

Antenna patterns can be complex—they're usually not the simple, clean-looking patterns shown in basic textbooks. An antenna can have a main or major lobe, plus numerous minor lobes and side lobes. This is especially true of an HF horizontal antenna mounted fairly close to the ground or close to other nearby conducting objects (**Fig. 7**). "Fairly close" usually means within a half wavelength of another conducting object.

Keeping a horizontal antenna at least a half-wavelength away from other influencing factors can be a formidable task in the average home-installation when you consider that it's 66 feet at 40 meters, 33 feet at 20 meters and even 16 feet at 10 meters!

### How high is up?

Antenna books also tell us that horizontal antennas should be at least a certain height above the ground to produce the optimum angle of radiation that we'd like to expect on a particular frequency band. By the way, that optimum angle of radiation varies with the band in question, but those heights work out to be at least 45 feet high for a 40-meter antenna, 40 feet up for the 20-meter band and 35 feet high at 10 meters. It's generally agreed that heights of 40 to 70 feet are good compromise elevations for reasonably predictable long-distance work on the bulk of the HF bands.

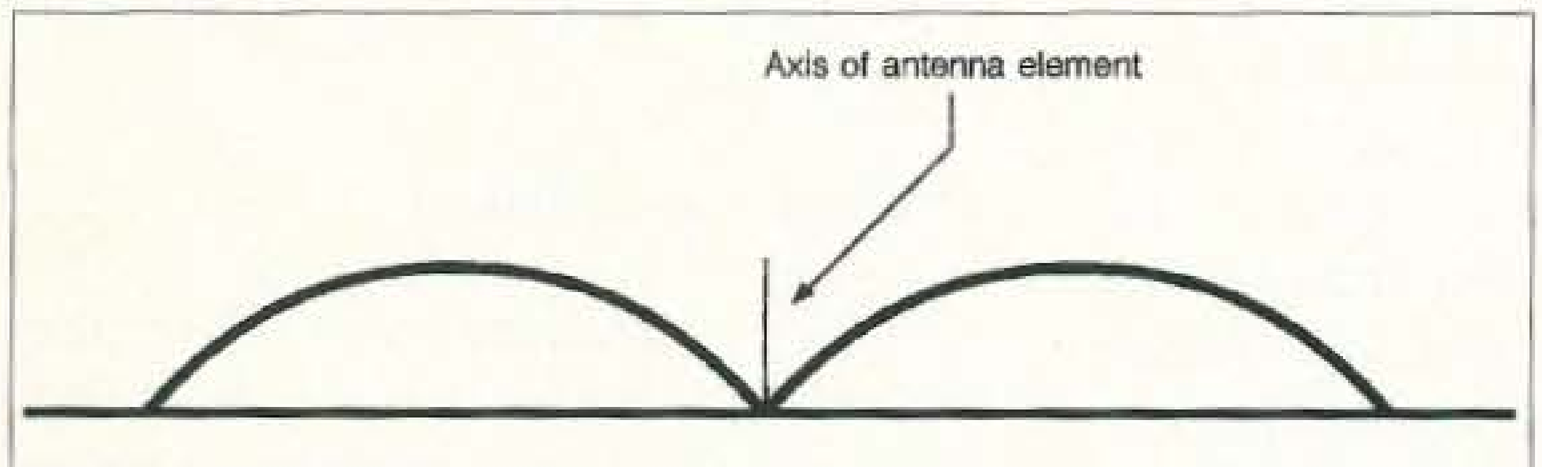


*Fig. 6. Idealized vertically compressed radiation pattern of a 1/4-wave gain-designed antenna.*

### Perfection is elusive

What happens if you can't get a horizontal antenna up nearly that high? Before you give up, I'll add—as in the case of radials—that this is the ideal. Lots of antenna schemes will work, even at the lower frequency HF bands, and on normal city lots—just don't be surprised at less-than-optimum or less-than-totally-predictable results. Many hams have antennas located much closer to the ground and to other conductive surfaces (houses, garages, outbuildings, etc., which often have aluminum siding or other conductive surfaces or structures), than the books suggest, and they still put out respectable signals. The benchmark figures shown above are simply what we should aim for to achieve optimum results. But this is real life, and often our aims and our eventual realizations are very much different, aren't they? Antennas much closer to the ground and to other surrounding objects will still work, but not perhaps quite as the textbook says that they should. One of the challenges of ham radio is making do with less than perfect layouts, both inside and outside the ham shack. It's usually pretty easy to design the ideal system if you have an unlimited budget and unlimited room to do it in; it's much more challenging—and often more rewarding—to accomplish similar feats using less orthodox setups. Hams have been known for this right from the start and it's become something of a hallmark of the hobby.

Again, it's not that a low-to-the-ground HF horizontal antenna won't work; it's just not going work optimally—but that's okay as long as we understand why and if we don't set our expectations higher than our antennas!

### Angle of radiation in vertical antennas

We've looked at how height above the Earth affects a horizontal HF antenna, but what about a ground-mounted vertical? You've probably heard that one of the attributes of a vertical at the HF frequencies is its low angle of radiation. That's because a vertical antenna's signal launch angle isn't as adversely affected by the ground beneath it nearly as much as in the case of a horizontal dipole installation. In fact, a vertical can be right at ground level and still provide a reasonably low signal launch angle. It's often cited as the reason why many hams choose that type of antenna when they have limited space, coupled perhaps with the inability to erect a tower or other tall structures needed for horizontal arrays. But as we noted before, the installation of a vertical isn't exactly free of problems, given the need for an effective ground-radial system. Even with that requirement, it may still be the best choice for an individual's particular circumstances; it's a matter that you'll have to decide for yourself based upon your own property restrictions and other physical considerations.

By understanding both the advantages and limitations of each choice, you should be armed with enough information that few surprises will await you once you've made a decision. The best surprise is no surprise!

**Near-field effects**

The presence of other nearby conducting obstacles is another matter altogether. A vertical's pattern—and perhaps tuning—can often be affected by other buildings and structures in the electrical near-field of the antenna, and most affected when they're within a half-wavelength of the antenna. Again, it may be impossible to avoid those near-field structures entirely, especially down on 40, 80 and 160 meters; again, we do the best that we can under the circumstances and work around any less-than-perfect results. It's also been said that any antenna, as long as it's able to be matched reasonably well to the transmitter and is well enough away from children and pets so that it's safe to operate, is much better than no antenna at all! It's very true. The operator must, however, be realistic with regard to how well any compromise antenna set-up will work, and exhibit some degree of patience when competing with others on the band whose antenna capabilities may be superior to his or her own. That, too, comes with knowledge of the theory and practical experience with a given installation.

**Gain antennas**

Changing gears a bit, I've not mentioned gain antennas to any degree so far. A horizontal beam antenna does provide gain, and can basically be thought of as a horizontal dipole with other near-field resonant elements placed to strategically alter the dipole's pattern in a desirable way; normally a beam concentrates most of the energy in one given direction, while restricting its radiation and pickup in all other directions. That's the theory, anyway! Beams aren't perfect, but they can do a very respectable job in accomplishing that objective. The major lobe of a well-designed, properly installed beam, is definitely concentrated in one direction only. There are minor side lobes, and some radiation from the rear of the beam, but most of the signal is radiated from the front as it's supposed to be. The very same conditions hold true for receiving, so beams can be used to reject interfering signals from other directions while providing varying degrees of gain for those in the favored direction—kind of a two-for-one bonus! The more elements a beam has, the greater its potential gain, but the narrower its beamwidth also becomes. Think of it in terms of a telephoto lens on a camera; it brings in objects from farther away, but also must be aimed more accurately.

What about gain in vertical antennas? As mentioned previously, gain in a VHF or UHF vertical is easily accomplished today with designs taller than one-half-wavelength, but in HF antennas, it becomes a matter of excessive overall height and the antenna would soon become too tall for most people to handle. It can be done, but it gets unwieldy. Gain and front-to-back rejection can be accomplished by installing two or more additional fixed vertical elements in beam-like fashion, but then you have to choose which direction to favor, because it isn't rotatable. Rotatable VHF/UHF vertical beams are quite practical though, and often used on those bands. In HF terms, however, adding ground-mounted vertical elements to achieve beam conditions becomes tricky; the additional vertical elements must be fed via phase-shifting networks that would not lend themselves to multiband operation very easily. I've mentioned it only because it is possible, and some AM broadcast stations employ this idea every day. Since broadcast stations are assigned just one particular frequency, they're often required to protect another station, some distance away but on the same frequency, by using several towers, fed out of phase, to provide a beam-like pattern along with minimal radiation in a certain direction—the direction of the other station being protected. But it's a juggling act, and not especially practical in ham radio terms. From a purely practical standpoint, think of HF vertical antennas as not having any gain—and probably a certain amount of loss—when compared to a full size horizontal dipole because most ground-mounted verticals are shortened trap-type designs to keep their size (height) down. Shortening an antenna reduces its radiation resistance—which is undesirable—and all traps introduce some loss. But then, the favorable angle of radiation from a vertical may at certain times more than make up for its lack of gain.

Radiation resistance, by the way, isn't a negative factor as the term resistance might suggest. All antennas need a certain amount of radiation resistance to function—it's part of how we explain what happens to the RF energy that's radiated into the air.

Additionally, there's the question of using horizontal-to-horizontal or vertical-to-vertical antennas. On the HF bands, it's many times a moot point. For line-of-sight communications it's important to maintain the same polarization, but once a signal begins to be reflected by the ionosphere, the polarization question is usually meaningless because polarity is shifted with each bounce encounter. And it doesn't always seem to be an exact 180-degree shift. In fact, most of the fading on HF skywave propagation can be attributed to polarization changes rather than actual signal strength variations. One only needs both a horizontal and a vertical antenna to switch between to prove that to themselves.

**The half-wave vertical**

Finally, in the category of HF vertical antennas, there also exists a shortened, trap-type of half-wave vertical. They're commercially available and offer the advantage of being ground-independent, i.e., not requiring an extensive ground plane, because they are already half-wave designs. A half-wave vertical can be fed at its center with 52-ohm coaxial cable directly or via a balun, just like a horizontal half-wave dipole. Some designs permit end-feeding with regular coaxial cable via a special low impedance to high impedance matching network right at the antenna itself. Any antenna displays a high-voltage, low-current condition at the very end of the radiating element. This translates into a high impedance at the antenna's end. Since our transmitters and coaxial cables are low impedance, they can't be tied directly to the end of an antenna without special considerations. That's where the special matching network mentioned comes in. It allows us to end-feed an antenna without ill effects on either the coaxial cable or our transmitter. In addition to not requiring an extensive radial system, a half-wave HF vertical can also be mounted up higher in the air if you choose, getting the high-current, low-voltage center of the antenna—which does most of the radiating—up above some of the surrounding obstructions. This can have a positive influence on the overall effectiveness of the antenna and can often be a worthwhile factor to consider if your installation plans permit it. By far, however, the biggest advantage to a half-wave design is its freedom from the need of an extensive radial system, usually making its installation much less involved. Just be sure to keep any close-to-the-ground mounted half-wave antenna protected from coming in contact with children or animals. Non-conducting fencing works well. Remember that the end of a half-wave antenna can be a RF high voltage point. Safety is rarely overdone.

**Loop antennas**

There are many antenna designs that have been tried and written up over the years, by hams the world over. Most are just variations on those already mentioned and go under the names of slopers, inverted vees, bent dipoles, etc. One relatively new design is worth mentioning, since it's now available commercially as well—the compact HF loop antenna. Loops have been around in various forms for some time, but the low-resistance, remotely-tunable, wide-band coverage loop is relatively new. It uses a very low-loss metal loop, about three feet in diameter, and is integrally coupled to a remotely controlled tuning unit. The package is small for the frequencies that it's able to cover, but keep in mind that loops have always been very high-Q devices, meaning that they must be retuned whenever you change frequencies even a small amount. That's not a tremendous problem when the loop is remotely tunable, but it does present another condition that you *must* meet when skipping around the band. Present-day commercial loops also have definite maximum power restrictions—usually in the area of 150 watts—so the use of an amplifier with a loop is out of the question right now. Most currently available loops will not operate below 10 MHz either, so the 40, 80 and 160-meter bands are out of reach with these antennas. Loops can be mounted horizontally, giving omni-directional (all direction) patterns, or they can be vertically mounted and rotated for a bi-directional (two direction) pattern. They are said to provide comparable performance to a basic dipole design. As with all new designs, it's best to talk to someone who has one and learn of their experiences before making a final decision.

As long as the restrictions mentioned here are kept in mind, loops certainly seem capable of providing HF antenna possibilities in restricted-space locations where operation below 30 MHz might not otherwise be possible.

**Some final thoughts**

This pretty much covers the various types of HF antennas normally available to us as amateur radio operators. As you can see, there are several basic design alternatives to choose from, and a seemingly endless number of variations on these basics. Experimentation with different antenna types is possible without tremendous financial investment. At the same time, an effective antenna will probably do more for your signal per dollar than any other modification that you can make to your station.

A more effective antenna will enhance both your transmitted signal and all received signals with the same effort, and that's hard to beat from any point of view. As mentioned at the beginning of the article, this has been a general discussion, with the new ham in mind, and by no means is it a complete treatment of an extensive subject. I've simply tried to put some of the basic information in logical order so that it can be more easily digested by the newcomer to ham radio. It seems that over the years that I've been involved in the hobby, more articles have been written about specific antennas than any other single topic! I'd encourage you to do much more reading on the subject in the various books and magazines available, and be assured that I'll continue to do the same. I also think you'll find that antennas are an extremely interesting topic for discussion—over the air or in person—among most hams, each one having their own favorite variation on the basics. Few other subjects will generate as much conversation as antennas will among most hams; it's interesting to see how staunchly certain design variations will be defended by their devotees. As you experience more and more of the hobby, your knowledge base will expand along with it, and it's my hope that this piece will have helped to put some basic perspective into that process. 73

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