Aerial Performers of the Radio Circuits

Basic Amateur Radio. Part 2: Why do some antennas get out better than others? Here are some practical answers plus all you need to know for building a simple coax-fed, half-wave dipole.†

By Margaret Koerner,* K0IQ (ex-WB0BEM)

A few miles west of this writer's amateur station, many of the mountain sides are dotted with gold mines, most of them long since abandoned. Out of those mines came ore — tons of ore from which a comparatively few ounces of coveted gold were laboriously obtained.

Producing a radio signal can be compared to a gold-mining operation, even though the coveted "gold" is not measured in ounces but in *watts* — units which indicate power. As in the mining of metallic gold, a great deal of labor is involved, a great deal of refining is necessary, and the amount of power which makes up the finished product may be small compared to the amount needed to produce it.

With a poor antenna installation, evidence of this last fact can be dramatic. To illustrate: Let's assume we have a transmitter which draws about 400 watts of alternating-current power from a wall outlet in order to generate 200 watts of radio-frequency power. This loss of 50 percent within the transmitter is basically beyond our control since it is dependent on equipment design. The 200 watts of rf power must then be sent through a feed line and antenna (which together make up the antenna system) before a signal can be radiated into space. The efficiency of the antenna system will determine whether the 200 watts will be utilized to the fullest advantage or be further reduced in strength. If our hypothetical antenna system is a "lossy" one, as much as three-fourths of that 200-watt output strength can be dissipated as heat, leaving as little as 50 watts of actual power to be radiated from the antenna. This means that of the 400 watts we started with, only 50 watts remain — a total power loss of 87.5 percent!

The left side of Fig. 6 shows the losses in the lossy feed line and antenna just described. In contrast, the right side shows the same transmitter, a low-loss feed line, and a well-constructed, 3-element beam antenna — a system which shows "gain" rather than loss. If you compare the illustrations, you can see where losses and gains occur. Now it's time to take a closer look at what we mean by decibels and gain.

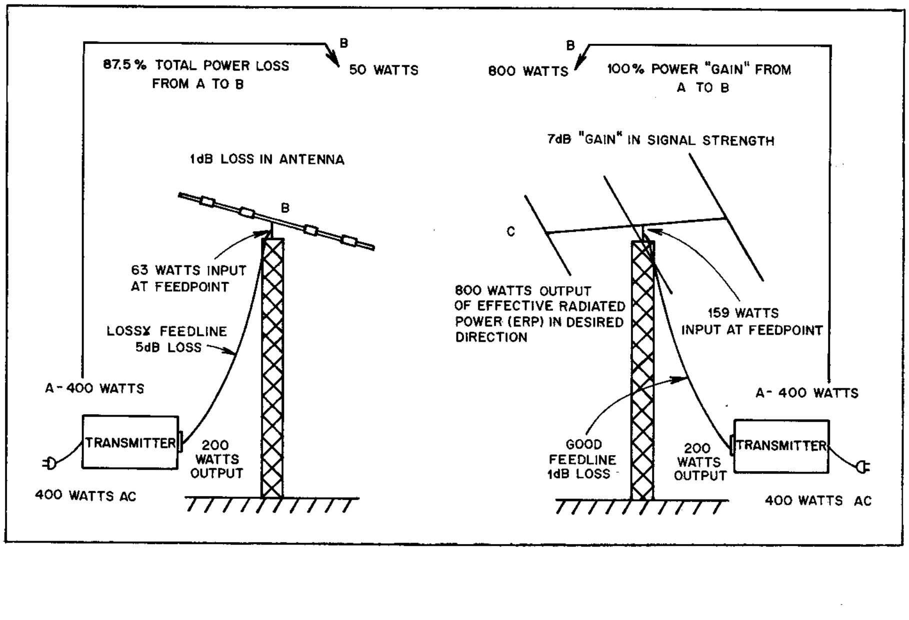
Decibels

The actual output power of a radio signal is measured in watts. In Amateur Radio discussions and in the exchange of signal reports on the air, however, we usually hear signals compared in terms of *decibels.*[1]

Decibels are units of comparison between two power levels. Used initially in audio engineering, a decibel (dB) is a just-detectable change in sound level under ideal conditions. Table 2 is a tabulation of some useful dB comparisons.

The power of an Amateur Radio signal as it leaves the transmitter and travels through the feed line to the antenna can be measured at the transmitter output in units of *actual* power — watts. After the signal has been radiated from the

Fig. 6 — The antenna system at the left is lossy, resulting in an 87.5 percent loss of power from transmitter input to antenna erp (effective radiated power). Total loss is 6 dB due to power dissipation in the transmitter, poor connectors at the transmitter output and antenna feed point, lossy feed line, and poorly constructed and installed antenna. At the right, there is an overall power "gain," despite the same 3-dB power loss in the transmitter. A good-quality feed line has brought only 1 dB of loss, while a beam antenna has added 7 dB of "gain." Total erp from this antenna system is 800 watts.



---

[1] The bel was named in honor of Alexander Graham Bell. A decibel equals 1/10 of a bel.

*2133 9th St., Boulder, CO 80302

†Part 1 apeared in November 1978 *QST.*

antenna, its strength is usually expressed in decibels of *relative* power, as shown on a receiver's *S meter* (signal strength meter). S meters are marked in divisions which indicate decibels and groups of decibels. The groups are known as *S units;* the number of decibels in each S unit (usually 5 or 6) depends on receiver design. The meters themselves vary as far as design, readability and reliability are concerned, and unless they are calibrated against a signal of known accuracy, they do not, as a rule, indicate the actual strength of a signal. Instead, they show each signal's relative strength compared to (1) other signals, (2) the noise level, or (3) a change in strength of that same signal.

Comments concerning the strength of signals may indicate that one station is 6 dB louder than another, that a signal lost 2 S units when the transmitting station switched from one antenna to a different one, or that a signal increased 10 dB when an amplifier was turned on. You may be told that your signal is the strongest one on the band, that it is way down in the noise, or that it is anywhere in between. Many things affect the strength of a signal, but the antenna system, composed of feed line and antenna, always plays a major part.

In addition to *seeing* relative strength responses on a meter, we can often *hear* relative strengths of signals as they emerge from a speaker or headphones; our ears have the ability to respond to relative loudness, just as the meter responds to relative power. These responses are logarithmic (see Table 2), which means (1) it takes a really substantial increase in actual power to make any noticeable difference in signal strength, and (2) doubling the power increases a signal's relative strength by 3 dB. This holds true no matter what amount of power is being increased by a factor of two — 10 watts to 20 watts, 500 to 1000, or 1000 to 2000. Each of these increases raises the relative power by 3 dB.

If power is *decreased,* the same thing happens in the opposite direction: When power is cut from 1000 to 500 watts, the strength of a signal is reduced by 3 dB.

Gain Questions

The assigned work of any transmitting antenna system is to radiate as much of the energy sent to it from the transmitter as possible. An antenna cannot, and therefore does not, *generate* any energy. All it can do is *radiate.* Question 1, then, is this: Why do we refer to antenna "gain"? Gain over what? (Question 2) And why is it that some antennas put out much stronger signals than others receiving the same amount of power from a transmitter? (Question 3)

Questions 1 and 2 can be answered together. Whenever we discuss any type of gain, we are comparing one thing with something else. A train, for example, gains speed — its speed increases over what it was; there are gains in the stock market today, compared to yesterday's listings. Gain indicates a *comparison,* and a signal's gain in power is also a comparison — a comparison against a standard, or point of reference. The standard may be a certain type of *practical* antenna, usually a half-wave dipole, or the standard can be a *theoretical* antenna called an *isotropic radiator.* The isotropic antenna can (in theory) radiate equally in all directions. Practical antennas, on the other hand, always radiate more energy in some directions than in others. If you read an antenna advertisement that says a certain type of antenna has dBi gain, the i indicates that the comparison reference is an isotropic antenna. If it says dBd gain, the second d means that the gain is calculated by using a half-wave dipole as a standard. (Incidentally, a half-wave dipole shows a 2.1-dBi gain.) If the ad merely states that the antenna has "gain," it's anybody's guess what it refers to.

Table 2
Useful dB Comparisons

Gain in dB	*Increase in Relative Power**
0	1.0
1	1.3
2	1.6
3	2.0
4	2.5
5	3.2
6	4.0
7	5.0
8	6.3
9	8.0
10	10.0
20	100.0
30	1,000.0
40	10,000.0
50	100,000.0

*0 through 9 dB power increases are approximate; others are exact.

Now for Question 3, concerning how gain is achieved. In Part 1 of this antenna article (November *QST*) we discussed beam antennas — directive types such as Yagis and quads, which, if properly constructed, radiate stronger signals than less-directive types such as commonly used dipoles and verticals. They achieve this extra strength (the so-called gain) not by generating additional energy but by concentrating the energy they receive from the transmitter and radiating it in a chosen direction at the expense of other directions, much as a flashlight does. Certain antenna types, then, can produce what we call gain.

Some antenna systems show gain over others because they have a better location. An antenna system can also show gain by keeping losses to a minimum. By eliminating loss sources, thereby lowering the amount of total loss, an antenna system of any type can show signal gain over a more lossy antenna system. It can even show gain over its former self when improvements are made, such as replacing defective feed lines, tightening connections, increasing height above ground, and increasing the number of radials. The gain is usually expressed in decibels of relative power. Power *loss* (also expressed in decibels), which can occur in either feed line or antenna, is determined by the antenna system's efficiency — the ratio of its input power to its output or radiated power. In any type of antenna system, high efficiency is achieved by careful and proper construction and installation, including matching of feed line to antenna, particularly when coax is used.

Proper Construction and Installation

Those words represent our present-day responsibility in our radio mining operation. During the past hundred years or more, by ingenious labor, thousands of radio amateurs, as well as other engineers, scientists and experimenters, made our present amateur equipment and communication possible. Because of their efforts and experiments we can obtain alternating current (ac) at 60 hertz (cycles per second) from a simple wall outlet; can change that ac to direct current (dc) by rectification; can utilize the dc in transistors and tubes to again generate and amplify ac (this time at radio frequencies of millions of times per second), and can send that rf energy to an antenna system to be radiated into space. This last step is our responsibility; our job to see that the "gold" that has been produced in our transmitter gets shipped out efficiently and profitably to its various destinations. If we send our precious rf power to a lossy feed line, we have allowed our gold to be hijacked en route. If we send it to a poor antenna, we have for all practical purposes (though unintentionally) thrown most of it onto the mine dump.

Here, then, are three things to remember about antennas:

1) Antenna work involves *work.* Extra work on feed lines as well as on antennas can yield extra watts and extra decibels of precious rf power.

2) A well-constructed beam antenna, by concentrating most of its energy in one direction, can produce a signal 10 to 20 times (or in very large installations, even more than 20 times) greater than that of an equally well-constructed but nondirectional antenna. But (and this is good news for everyone) it is also true that an antenna *of any type* that performs well by keeping its losses to a minimum can also radiate a far stronger signal than that of an antenna system with low efficiency. And all this relative increase is without the use of a separate power amplifier.

3) A good small — even simple — antenna, such as a dipole or a vertical, can produce a better signal than a lossy big installation, no matter how impressive the latter may look.

So as you put up your first antenna (and later ones, too), set your sights and your antennas high, and the "gold in them thar hills" can then be yours.

So Which Will It Be?

One of the questions beginners always ask is this: *Which kind of antenna is best?* And it is no wonder they wonder. All about them, in commercial ads, on roofs and on towers, in conversations on and off the air, they see or hear about all sorts and species of antennas: the most common ones — dipoles, verticals, Yagis, quads and longwires; the less-common windoms, rhombics and Zepps (that last kind so-called because they were first used on the Zeppelin dirigible); and a few antennas with such strange and wonderful names as six-shooter, bobtailed curtain, Beverage and fishbone — the last two receiving antennas only. All of these are billed as skilled aerial performers in the radio circuits. Each, too, is a deciding factor (possibly *the* deciding factor) between a signal that really "gets out" and one that really doesn't.

The answer to the question of which one is best is simple: There is no such thing as one best antenna for everyone, but there *is* a best antenna for *you,* depending on your own special situation. Answering the following questions should help you evaluate your situation:

1) How much room do you have for your antenna installation? It's amazing how small a space can, if necessary, be enough.

2) How much money can you afford to spend for this part of your amateur station? You can get by on only a few dollars, or on what we will simply call "more."

3) Do you intend to build your first antenna or buy a commercial one? Materials for the construction of a simple wire dipole are easily available to almost everyone.

4) Are there neighborhood (or domestic) problems to be worked out?

Look at antennas and talk about them with others. Read about them in books and periodicals (five common types were described briefly in Part 1 of this article). Look again at your own situation. If, after that, you decide to put up a coax-fed, half-wave dipole that is inexpensive and relatively easy to build, the accompanying information should be of practical help. For that matter, even if your choice is different, you might read the section anyway and perhaps "mine" something of interest from it.

Constructing and Installing a Simple, Coax-fed, Half-wave Dipole

This section[2] will provide a step-by-step guide to building your own one- or two-band (see text), half-wave dipole antenna. It's the type most Novices (and some higher class licensees) use, and it just may be the right one for you.

Materials Needed

1) *Wire.* For a dipole antenna, both the wire size (gauge) and length are important. For a straight dipole supported at the ends, the wire must be strong enough to mechanically support both the dipole and the weight of its coax feed line. Wire sizes no. 12 to 18 are recommended, the smaller number indicating the larger size. The wire should preferably be of the copper-weld type, which has a steel center to give it strength and prevent it from stretching, and a copper outer layer bonded to the steel center to make it a good conductor. Electric fence wire, either copper-covered or galvanized, can also be used effectively.

If you are putting up a space-saving, drooping dipole (also known as an inverted V), you can use any of the above-mentioned kinds of wire or the softer all-copper wire, since this type of dipole has the coax and antenna weight supported at the middle by a mast.

The amount of wire needed for either type of dipole will depend on the band or bands for which the antenna is being constructed. The total length of wire will be approximately one-half wavelength long for the desired band; measuring from the center, each side of the dipole will be about one-quarter wavelength long plus a little extra for making connections. (See Table 3.)

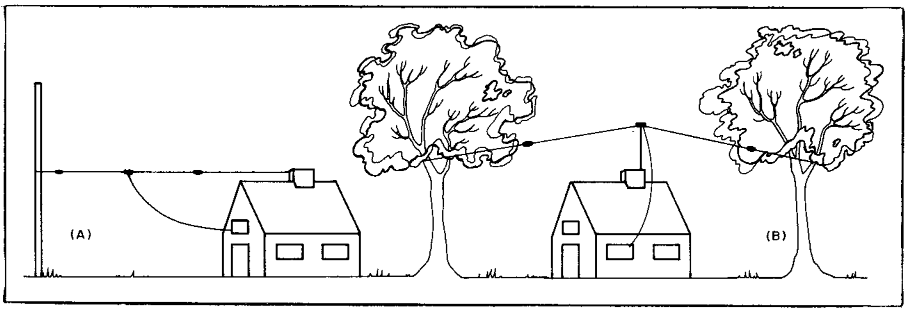
2) *Insulators.* Insulators are used at the center of the dipole and at the far ends of the two dipole wires. A center insulator is needed to keep the two halves of the dipole electrically separated and to provide an anchor for the two dipole wires and the feed line. This center insulator can be a commercial one or it can be made from a piece of acrylic or phenol-type plastic, such as the type shown in Fig. 8A, or it can even be made of wood. If it is made of wood, the wood should be saturated with hot paraffin or treated with varnish or some other coating to make it weatherproof.

Other insulators, usually made of porcelain, ceramic or glass, will be needed for the far ends of the dipole wires. The so-called egg insulator (Fig. 8B) or some other type of compression insulator, as well as "dog bone" type insulators (Fig. 8C) are in common use. Wood is not satisfactory for insulation at the ends of the dipole, as the rf voltage is much higher there than in the middle; if wood is used you may end up with high energy losses.

3) *Coax.* Get a good grade of 50-ohm coax for your dipole feed line. (See Fig. 1, November *QST,* page 43). If you can see through the braid to the insulation underneath, the braid's copper coverage (called "shield continuity") is probably inadequate. When you have installed the coax, be sure that none of the braid is left exposed, since exposed braid can soak up water like a wick. Use a silicone rubber compound (such as GE RTV) to weatherproof all connectors. You can also wrap connectors with electrical tape, cover them with a battery clamp "rubber boot," or use a combination of all three methods.

The antenna is fed directly from the transmitter, via the coax, at the center insulator, using a connector socket and plug (Fig. 8A). Use an SO-239 socket or its equivalent for the center connector and a PL-259 plug for the antenna end of the

Fig. 7 — At A, a typical half-wave dipole installation. Sturdy rope is used to connect the ends of the antenna to trees or other supports. At B is an inverted V, a half-wave dipole with the center part of the antenna raised. The ends should be as far apart as possible, for best results. Be sure to leave the ends of this type of antenna high enough above the ground so they can't be touched; someone could get an rf burn by touching the wire while the station is operating.



---

[2] Credit for the practical information in this construction section (as well as for many helpful suggestions and important items of information in previous sections) must go to Jim Snyder, W0UR/K0ZCM.

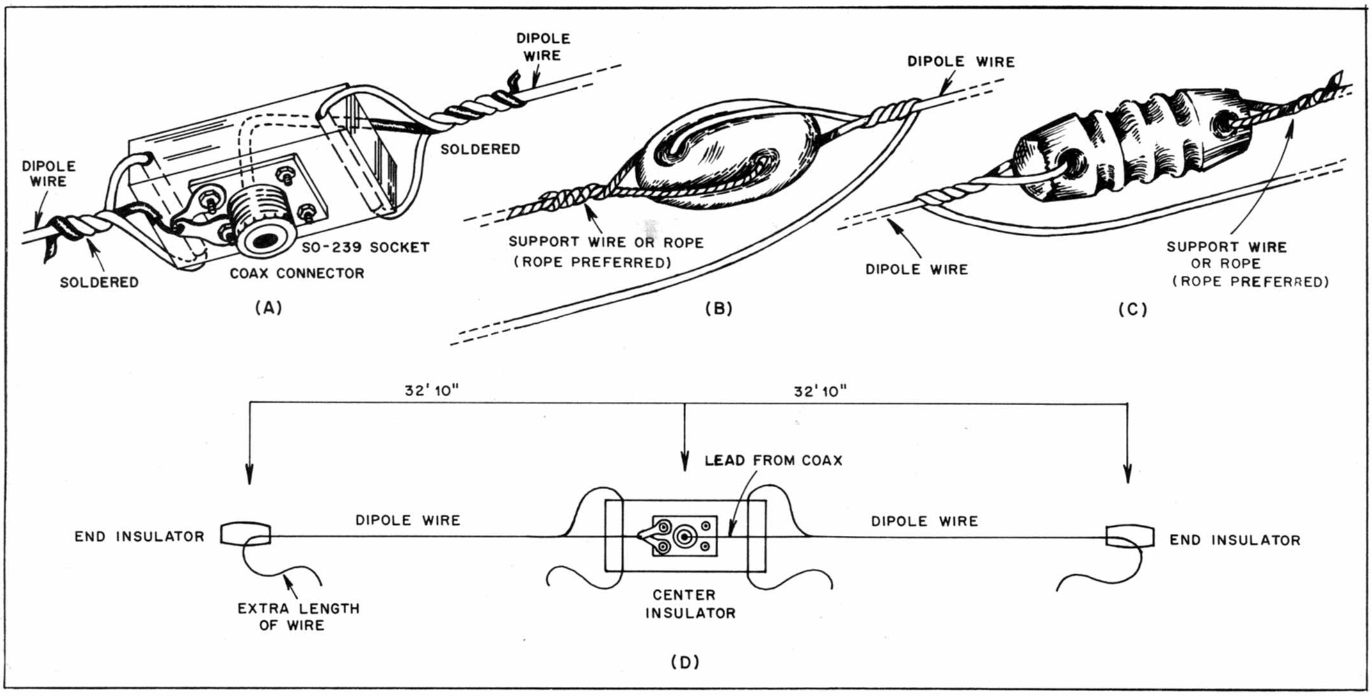


Fig. 8 — At A is a homebrew center insulator. This type is also available commercially. The "egg" type compression insulator (B) and the "dog bone" type (C) are common end insulators. A diagram of a 40-meter half-wave dipole is at D. All wire connections should be soldered. Trim the extra length of wire in (B) and (C) for minimum SWR. *(drawings based on originals by G. Ladwig)*

coax. The other end of the coax must have a connector that fits your rig. Using a properly installed connector at the feed point of the antenna, rather than splitting the coax (as is sometimes done), prevents water from getting into the coax.

4) *Supports.* For an inverted V, you will probably need a center support to get the high (middle) portion of the antenna up in the clear. This center support, called a mast, may be a metal pipe, a TV push-up mast, a 2 × 4 or some other type of center support strong enough to stand up against wind, ice and the antenna's weight.

For either the inverted-V or straight dipole, you will need to fasten the far ends of the dipole wires to sturdy objects. Plan ahead to determine what these objects will be — a roof, tree, pole or anything else convenient for the purpose. Have the antenna ends as far apart as possible.

Assuming that you or someone else in your family has a tool box with screwdrivers, pliers, wire-cutters and other essentials, the only expenses for your first antenna will be coax, wire and perhaps a few insulators and connectors. You may know an amateur who will bring some of his own equipment and perhaps contribute needed materials to the cause. Most amateurs have overflowing junk boxes and, since they are probably traders and scroungers themselves, will be happy to help other scroungers, particularly beginning ones, any way they can.

Preliminary Construction (things to do on the ground)

1) Measure the wire according to the following table, but *before cutting* it be sure you have included an additional length needed to go through the insulators and secure them, and another bit extra if you are putting up a drooping dipole instead of a straight one.

2) If you are using bare copper wire that has become tarnished, clean off the ends for several inches with steel wool so that it will be possible to make good solder connections. If insulated wire is used, remove the insulation at both ends with wire strippers or a knife.

3) Always use *rosin-core solder* on all connections. Acid-core solder will cause the wires to corrode.

4) Put the coax connector on the center insulator block and attach the dipole wires to the coax leads from the connector, as shown in Fig. 4.

5) Measure the two dipole wires again (now that they are attached to the center insulator), and mark the points which indicate the length needed for each side, using the band measurements listed in Table 2. Attach the end insulators, as shown in Fig. 8. Be sure to note the wiring illustration for the egg insulator. Wired as shown in the illustration, the dipole will not come apart, even if the insulator breaks.

Table 3

Wire Lengths* for a Straight Half-Wave Dipole

Novice Band	*Length Each Side (1/4 λ)****	*Full Length (1/2 λ)*
80 meter	62' 10"	125' 8"
40 meter**	32' 10"	65' 8"
15 meter	11' 1-1/2"	22' 3"
10 meter	8' 3-1/2"	16' 7"

*Before cutting the wires for either a straight or drooping dipole, be sure to add extra lengths of wire to go through the insulators and secure them. See Fig. 8. For a drooping dipole, also add about 2 percent extra to the lengths shown in the table, provided the antenna is up high enough so that the ends of the dipole wires are not close to the ground or to other objects.

**A 40-meter dipole can generally be used effectively on 15 meters, without change.

***Feet × 0.3048 = m; inches × 25.4 = mm.

6) Cut the length of 50-ohm coax you will need, allowing for some slack, and put on the two connectors. Put the connector sleeves on the coax before soldering the main part of each connector. *The Radio Amateur's Handbook*[3] contains complete information on installing coaxial connectors.

7) If you have access to an ohmmeter, test the coax for continuity and shorts after putting on the connectors. Place one probe on the *center conductor* at one end of the coax and the other probe on the *center conductor* of the other end. The ohmmeter should indicate less than 1 ohm of resistance — a virtual dead short. Again using the ohmmeter, touch the probes to the *braid* at both ends. Again, the result should be a virtual dead short. Finally, touch one probe to a center conductor and one probe to the braid (either at the same end of the coax or at the two ends) and you should get an infinity reading — infinite resistance. Failure to show these readings indicates a break in the coax or bad solder connections for the first two tests, and a short in the coax or connectors for the last one.

8) For your safety and for best operation of the antenna system, a ground

---

[3] *The Radio Amateur's Handbook,* ARRL, 56th Ed., 1979, pp. 17-5, 17-6.

connection is necessary. Run a metal rod (4-8 feet/1.2-2.4-m long) into the ground outside the shack. Attach a piece of heavy bare or insulated copper wire (12 gauge or larger) or a strap of copper or galvanized metal to this rod and attach the other end to the chassis of the rig.

9) A Blitzbug or some other kind of lightning arrestor should also be properly installed in the coax line.

Installing the Dipole

Only general directions can be given for this process since each situation is different and your resourcefulness will be needed to determine where and how. Certain suggestions may nevertheless prove helpful.

1) Get your antenna as high as the given situation will permit.

2) Keep your antenna wires away from power lines; *never* go over or under them. If you fail to follow these precautions you may not even live to regret it.

3) Treat your coax with great care. Don't walk on it and don't put mechanical stress or strain on it.

4) As you pull the antenna into position, watch that the wires do not kink. Our apologies for not telling you *how* to pull it into position or how to fasten it to the mast; you'll have to figure out how to do this for your own situation.

5) For either the drooping or straight dipole, bring the coax down vertically as far as possible.

6) If your antenna end support is a living tree, put a piece of rubber hose around the tree (for the tree's protection) and run the support wire or rope through the hose. There should be an additional length of cord or wire, after the end insulator, to secure it in place via the rubber tubing.

7) Be sure to solder and, where necessary, weatherproof all connections carefully. The antenna and upper part of your coax will not be readily accessible like other parts of your station. Eventually any weak spot is sure to be damaged by the wind and other elements, and will have to be repaired. Ultraviolet light from the sun can weaken guy ropes, so use strong cord such as plastic clothesline with a polyethylene center for your supports. *Never* use rope with a wire center as a support for any type of antenna.

8) Even though there is a legitimate use for a piece of equipment called a *balun* (rhymes with gallon and is derived from the combination of balanced and unbalanced), it is usually not needed as an electrical balancing device for this type of simple, coax-fed antenna. Feeding the coax directly to the antenna and using the connectors as described cuts down the cost and makes the entire installation simpler.

9) You may hear someone talking about an antenna matching or tuning unit, such as a match box or Transmatch. These are useful or even required in some situations, but since most modern rigs are made to operate into a nominal 50-ohm load, a matching unit for this coax-fed dipole should not be necessary. You can learn more about matching (and baluns) in *The Radio Amateur's Handbook*.

10) You will also hear people talking about SWR meters or the SWR (standing wave ratio) of their antenna systems. They may report SWRs of 1:1 (known as 1 to 1), 1.7:1 or 3:1. SWR could take up an entire article, but we will limit our discussion of it to one brief statement. Antennas are supposed to be tuned to a desired resonant frequency (usually a frequency at about the middle of a desired band). The use of an *SWR meter* or *SWR bridge* is one way of finding out whether the tuning of a coax-fed antenna has been properly achieved. A *change in length* is usually the means by which simple antennas are adjusted to take care of the tuning. If it is determined from an SWR meter reading that the resonant frequency of your antenna is lower than you desire, you can *raise* the resonant frequency by *shortening* both sides of the dipole, equally. If the resonant frequency is *higher* than desired, you can *lower* the resonant frequency by *lengthening* both sides of the dipole equally. See Fig. 8.

But don't worry too much about the SWR of your simple, coax-fed half-wave dipole. If you use good 50-ohm coax, cut your dipole wires the proper length, make sure all connections are tight, and put your antenna up as high and in the clear as possible, you should be able to "mine" your share of the radio spectrum for years to come. QST