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Chapter 9

Single-Band MF and HF Antennas

The antennas in this chapter are based on the principles of the dipole, the ground-plane, and the loop — the theory of which is covered in the first group of chapters in this book. These antennas can be combined into arrays for additional directivity as described in the **Multielement Arrays** and **Broadside and End-Fire Arrays** chapters.

This chapter presents practical designs most often used as single-band antennas on the amateur bands below 30 MHz. This is not to say that the antennas can *only* be used on a single band or below 30 MHz — many can be used on several bands as discussed in the **Multiband HF Antennas** chapter and the same principles can be used to create VHF and UHF antennas. Nevertheless, in these examples the discussion will be mainly concerned with issues antennas designed for use on the MF and HF bands. See the chapter **Antenna Materials and Construction** for information on the techniques used to build practical antennas.

The antennas in this chapter are generally installed to radiate either horizontally or vertically polarized signals. Several antennas, such as the dipole, can be installed in either orientation or some intermediate fashion. For most amateurs, the choice of what type of antenna to install and whether it is installed horizontally or vertically is one of necessity and is driven by constraints such as whether trees or a tower are available, restrictions on external antennas, and esthetic concerns. The goal of this chapter is to present a variety of options so that given the circumstances, the best choice or choices for the desired purpose can be made. This requires an understanding of the strengths and weaknesses of each type of polarization and so we begin with an overview.

As shown in the chapter **Effects of Ground**, radiation angles from horizontally polarized antennas are a very strong function of their height above ground in wavelengths. While low antennas will provide good regional coverage, to be effective for typical DX communications, heights of $\lambda/2$ to 1 λ are considered to be a minimum. As we go down in frequency these heights become harder to realize. For example, a 160 meter dipole at 70 feet is only 0.14 λ high, the equivalent of a 20 meter dipole only 9 feet off the ground! This antenna will be very effective for local and short distance QSOs but not very good for DXing. Despite this limitation, horizontal antennas are very popular on the lower bands because the low frequencies are often used for short range communications, local nets and rag chewing. Also horizontal antennas do not require extensive ground systems to be efficient.

On our MF band (160 meters) and the lower HF bands, quarter-wavelength vertical antennas become increasingly attractive — especially for making DX contacts — because they provide a means for lowering the radiation angle. This is especially true where practical heights for horizontally polarized antennas are too low. In addition, verticals can be very simple and unobtrusive structures. For example, it is very easy to disguise a vertical as a flagpole. In fact, an actual flagpole may be used as a vertical. Performance of a vertically polarized antenna is determined by several factors:

- Electrical height of the vertical portion of the radiator
- The ground or counterpoise system efficiency, if one is used
- Ground characteristics in the near- and far-field regions
- The efficiency of loading elements and matching networks

Determining which is appropriate depends on the intended use of the antenna. The chapter HF Antenna System Design will extend the discussion beyond individual antennas to the selection of antennas for a desired purpose, such as DX versus local or continental coverage.

Dipole or Doublet?

When does a dipole become a doublet and vice versa? There is no formal difference — these are just two different names for the same antenna. The term "doublet" is often applied to symmetrical center-fed antennas that are not resonant or that are used on multiple bands to distinguish them from the resonant center-fed dipole. This is a matter of convention only.

"Dipole" means "two poles" with the poles being the opposite polarity voltages on either side of the dipole. From the Wikipedia entry (**en.wikipedia.org/wiki/Dipole**) "An electric dipole is a separation of positive and negative charges. The simplest example of this is a pair of electric charges of equal magnitude but opposite sign, separated by some (usually small) distance."

The antenna feed line supplies voltages with opposite polarity on either side of the feed point, creating the pair of electric poles. The poles cause current to flow in the antenna, creating the radiation. As the length increases beyond a half-wavelength, the situation is much less clear because multiple poles eventually appear. For example, a 3/2-wavelength wire is really a tri-pole!

9.1 HORIZONTAL ANTENNAS

9.1.1 DIPOLE ANTENNAS

Half-wave dipoles and variations of these can be a very good choice for an HF antenna. Where only single-band operation is desired, the $\lambda/2$ antenna fed with 50- or 75-Ω coaxial cable is a popular and inexpensive antenna. It can also be used on the third harmonic with some adjustment as explained in the project at the end of this section. The basic and most common construction is shown in **Figure 9.1**.

The length of the $\lambda/2$ dipole in feet is often stated as ℓ = 468/f (MHz) although this rarely results in an antenna resonant at the desired frequency as discussed in the chapter **Dipoles and Monopoles**. It is more practical to begin with a length of 485/f or 490/f (**Table 9.1** gives lengths for each of the ham bands from 1.8 through 50 MHz) and then adjust the antenna according to the following procedure:

1) Assemble the antenna with length ℓ_1 for a desired frequency of f_1 but do not make the attachments to the end insulators permanent. Twisting the antenna wire at the insulators will suffice during adjustment.

2) Raise the antenna to its desired position and determine the frequency of lowest SWR, f_2.

3) Assuming that f_2 is too low (the antenna is too long), calculate the desired length $\ell_2 = \ell_1 \times f_2 / f_1$. Trim the antenna to the desired length by removing equal amounts of wire on each end to maintain electrical balance at the feed point.

Example: A dipole intended to be used at 14.250 MHz is initially built with a physical length of 490 / 14.250 = 34.4 feet (34 feet 5 in). Once in place, f_2 is determined to be 13.795 MHz. Using step 3, the desired length should be 34.4 × 13.795 / 14.250 = 33.3 feet and the antenna is 34.4 – 33.3 = 1.1 feet (1 foot 1 inch) too long. Remove 6.5 inches from each end of the antenna.

Table 9.1
Starting Lengths for Amateur Band Dipoles

Freq	*----------- Length in feet --------------*		
(MHz)	*468/f*	*485/f*	*490/f*
1.85	253.0	262.2	264.9
3.6	130.0	134.7	136.1
3.9	120.0	124.4	125.6
5.3	88.3	91.5	92.5
7.1	65.9	68.3	69.0
10.1	46.3	48.0	48.5
14.15	33.1	34.3	34.6
18.1	25.9	26.8	27.1
21.2	22.1	22.9	23.1
24.9	18.8	19.5	19.7
28.2	16.6	17.2	17.4
29	16.1	16.7	16.9
50.1	9.3	9.7	9.8

Coaxial lines present support problems as a concentrated weight at the center of the antenna, tending to pull the center of the antenna down, so care must be taken to make the feed point connections strong and provide support for the cable. If a center support or conveniently located tree is available, insulators with a rope attachment point can be used to support the weight.

The feed line should come away from the antenna at right angles for the longest practical distance so as to preserve electrical balance and minimize the effect of the feed line shield's outer surface on the antenna. Adding a choke or current balun at the feed point helps to electrically isolate the shield surface and prevent common-mode current from flowing on the feed line. (See the **Transmission Line System Techniques** chapter for a discussion of the use of baluns.)

Exact electrical balance is generally not critical for a dipole antenna to perform well. Common-mode current induced on the dipole's feed line shield will radiate a signal that generally serves to partially fill in some of the dipole's pattern nulls. Unless the common-mode current creates RF-related problems in the station, a balun is not required.

Shortening the Dipole

The simplest way to shorten a dipole is shown in **Figure 9.2**. If you do not have sufficient length between

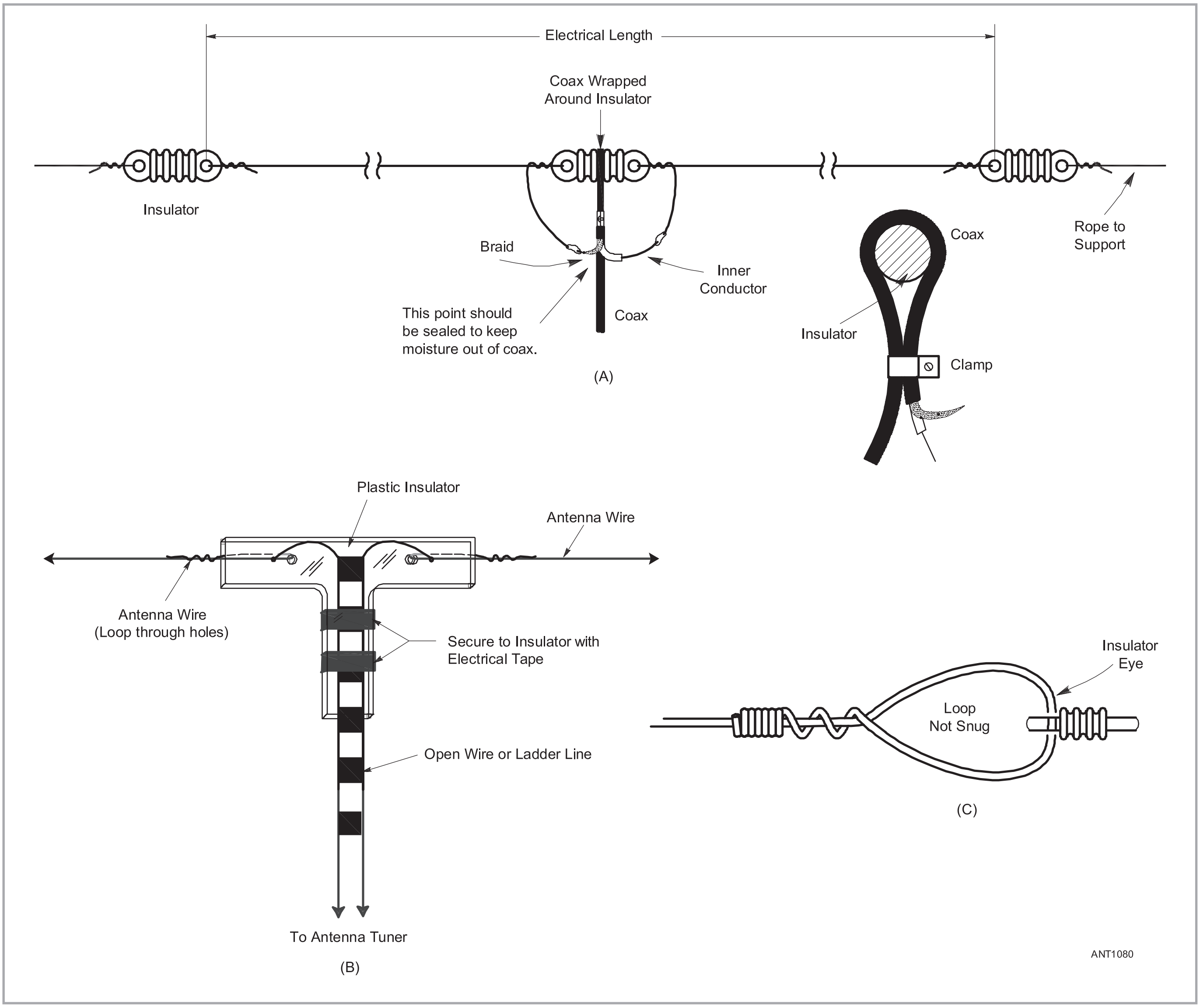


Figure 9.1 — Details of coax-fed dipole construction at A. The center-fed dipole is a balanced antenna and if coaxial cable feed line is used, a balun may be added at the feed point as described in the text. The dipole can also be fed with open-wire or ladder-line as shown at B. Detail of attaching an end insulator is shown at C. Note that the electrical length of the dipole extends to the tips of the loops of wire attached to the insulator.

the supports, simply hang as much of the center of the antenna as possible between the supports and let the ends hang down. The ends can be straight down or may be at an angle as indicated but in either case should be secured so that they do not move in the wind. As long as the center portion between the supports is at least $\lambda/4$, the radiation pattern will be very nearly the same as a full-length dipole.

The resonant length of the wire will be somewhat shorter than a full-length dipole and can best be determined by experimentally adjusting the length of ends, which may be conveniently near ground. Keep in mind that there can be very high voltages at the ends of the wires and for safety the ends should be kept out of reach.

Letting the ends hang down as shown is a form of capacitive end loading. Folding the ends back on the antenna is a type of *linear loading*. Both types of loading are discussed later in this chapter. While both techniques are efficient, it will also reduce the matching bandwidth — as does any form of loading.

A 40 – 15 Meter Dual-Band Dipole

As mentioned earlier, dipoles have harmonic resonances near odd multiples of their fundamental resonances. Because 21 MHz is the third harmonic of 7 MHz, 7-MHz dipoles are harmonically resonant in the popular ham band at 21 MHz. This is attractive because it allows you to install a 40 meter dipole, feed it with coax, and use it without an antenna tuner on both 40 and 15 meters.

But there's a catch: The third harmonic resonance is actually higher than three times the fundamental resonant

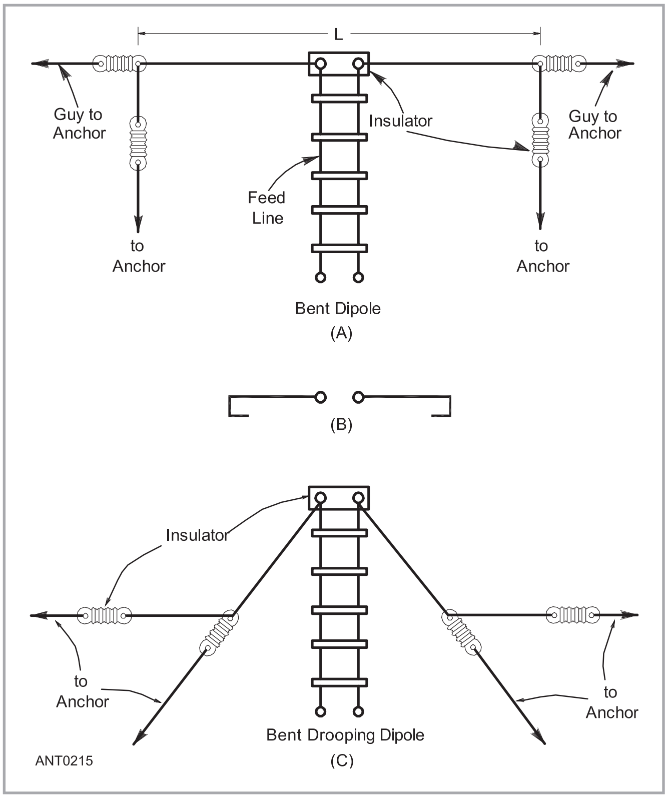


Figure 9.2 — When space is limited, the ends may be bent downward as shown at A, or back on the radiator as shown at B. The bent dipole ends may come straight down or be led off at an angle away from the center of the antenna. An inverted-V as shown in C can be erected with the ends bent parallel to the ground when the support structure is not high enough.

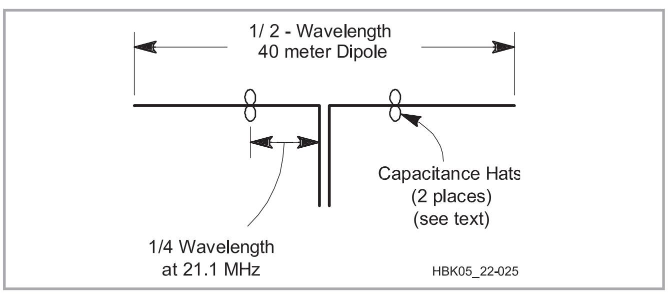


Figure 9.3 — Figure-8-shaped capacitance hats made and placed as described in the text, can make a 40 meter dipole resonate anywhere in the 15 meter band.

frequency. This is because there is no end effect in the center portion of the antenna where there are no insulators.

An easy fix for this, as shown in **Figure 9.3**, is to add capacitive loading to the antenna about ¼-λ wavelength (at 21.2 MHz) away from the feed point in both halves of the dipole. Known as *capacitance hats*, the simple loading wires lower the antenna's resonant frequency on 15 meters without substantially affecting resonance on 40 meters. This scheme can also be used to build a dipole that can be used on 80 and 30 meters and on 75 and 10 meters.

Measure, cut and adjust the dipole to resonance at the desired 40 meter frequency. Then, cut two 2-foot-long pieces of stiff wire (such as #12 or #14 AWG house wire) and solder the ends of each one together to form two loops. Twist the loops in the middle to form figure-8s, and strip and solder the wires where they cross. Install these capacitance hats on the dipole by stripping the antenna wire (if necessary) and soldering the hats to the dipole about a third of the way out from the feed point (placement isn't critical) on each wire. To resonate the antenna on 15 meters, adjust the loop shapes until the SWR is acceptable in the desired segment of the 15 meter band. Conversely, you can move the hats back and forth along the antenna until the desired SWR is achieved and then solder the hats to the antenna.

9.1.2 FOLDED DIPOLES

Figure 9.4 shows a *folded dipole* constructed from a ½-λ section of two wires spaced 4 to 6 inches apart and connected together at each end of the antenna. Plastic spacers are generally used to separate the conductors and 600-Ω open-wire line can also be used. The top conductor is continuous from end to end. The lower conductor, however, is cut in the middle and the feed line attached at that point. Parallel-wire transmission line is then used to connect the transmitter.

A folded dipole has exactly the same gain and radiation pattern as a single-wire dipole. However, because of the mutual coupling between the upper and lower conductors, the feed point impedance of a single-wire dipole is multiplied by the square of the number of conductors in the antenna. In this case, there are two conductors in the antenna, so the feed point impedance is $2^2 = 4$ times that of a single-wire dipole. Using three wires increases feed point impedance by $3^2 = 9$ and so forth. The squared ratio

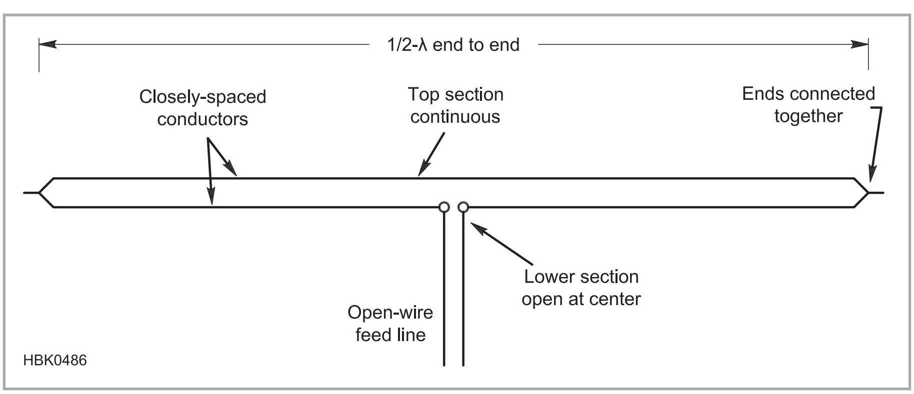


Figure 9.4 — The folded dipole is constructed from open-wire transmission line with the ends connected together. The close proximity of the two conductors and the resulting coupling act as an impedance transformer to raise the feed point impedance over that of a single-wire dipole by the square of the number of conductors used.

requires both wires to have the same diameter.

A common reason to use the folded dipole is to raise the feed point impedance of the antenna. This allows a low-loss parallel-wire line to be used with low SWR instead of coaxial cable when a very long feed line is required and using coax would result in too much loss. For example, a three-wire folded dipole would present a feed point impedance close to that of 450-Ω ladder line.

Another advantage of the two- and three-wire folded dipoles over the single-wire dipole is that they offer a better match over a wider band. This is particularly important if full coverage of the 3.5-MHz band is contemplated.

9.1.3 INVERTED-V DIPOLE

If only a single support is available, the halves of a dipole may be sloped to form an inverted-V dipole, as shown in **Figure 9.5**. This also reduces the horizontal space required for the antenna.

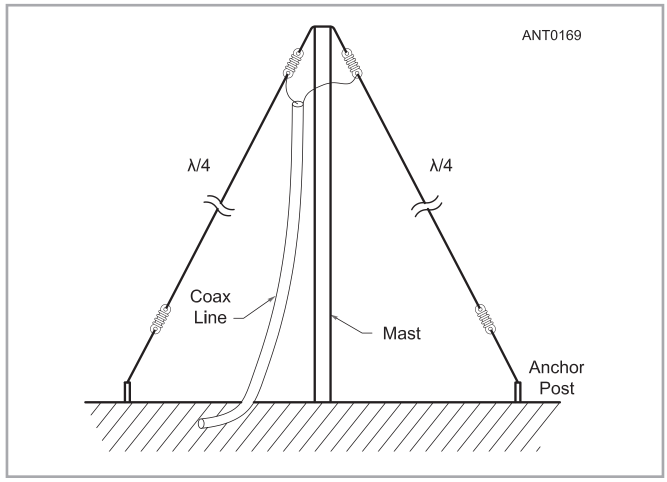


Figure 9.5 — The inverted-V dipole. The length and apex angle should be adjusted as described in the text.

There will be some difference in performance between a horizontal dipole and the inverted-V as shown by the radiation patterns in **Figure 9.6**. There is small loss in peak gain and the pattern is less directional.

Bringing a dipole's wires toward each other results in a decrease of the resonant frequency and a decrease in feed point impedance and bandwidth. (This is true whether the dipole is constructed as an inverted-V or not.) Thus, to maintain the same resonant frequency, the length of the dipole must be decreased somewhat over that of the horizontal configuration.

The amount of shortening required varies with the circumstances of the installation but a reasonable rule of thumb would be 5% for every 45 degrees that the legs of the dipole are lowered from horizontal. It might be wise to start with an initial length for a horizontal dipole and then trim it in the inverted-V configuration according to the procedure given for horizontal dipoles.

The angle at the apex is not critical, although angles smaller than 90° begin to compromise performance significantly. Because of the lower feed point impedance, a 50-Ω feed line should be used.

If a close match to the feed line impedance is desired, the usual procedure is to adjust the angle for lowest SWR while keeping the dipole resonant by adjustment of length. Bandwidth may be increased by using multiconductor elements, such as a cage or fan configuration as discussed below.

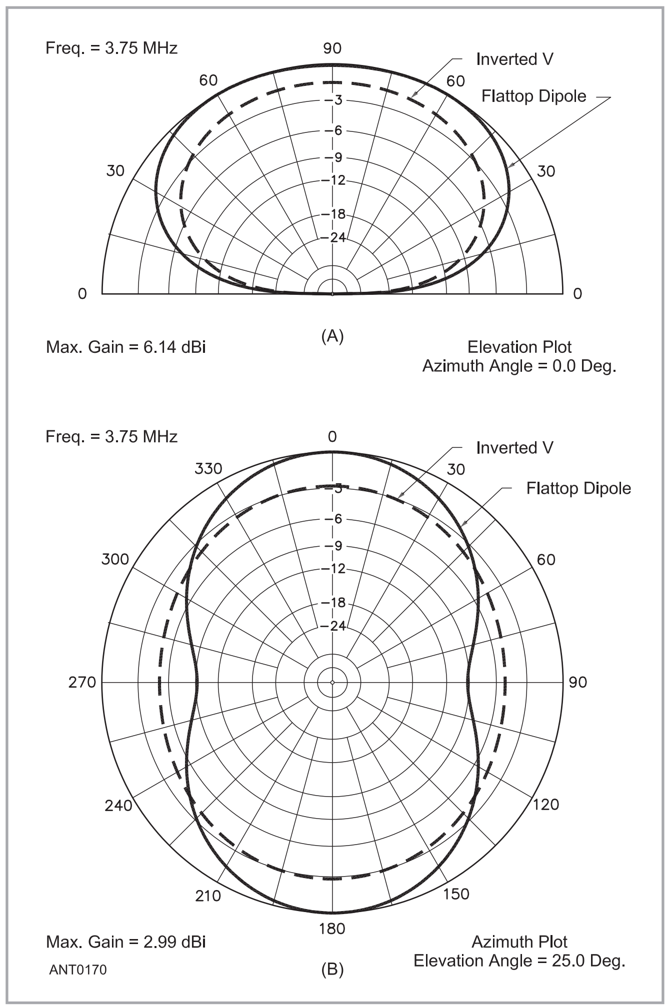


Figure 9.6 — At A, elevation and at B, azimuthal radiation patterns comparing a normal 80 meter dipole and an inverted-V dipole. The center of both dipoles is at 65 feet and the ends of the inverted-V are at 20 feet. The frequency is 3.750 MHz.

9.1.4 END-FED ZEPP

Other than to obtain a convenient feed point impedance and to be somewhat balanced, there is no reason why a dipole has to be fed exactly at the center. In the early days, the λ/2 dipole (then called a "Hertz" or "Hertzian" antenna) was often fed at one end where it was called an "End-fed Zepp" after the Zeppelin airships from which it was first deployed.

Figure 9.7 shows a typical end-fed Zepp with a parallel-wire feed line. Since the feed line is connected at a low-current/high-voltage point on the antenna, the feed point impedance is quite high and often in the neighborhood of 3000-5000 Ω. This is too high to present a match to even the widest-spaced

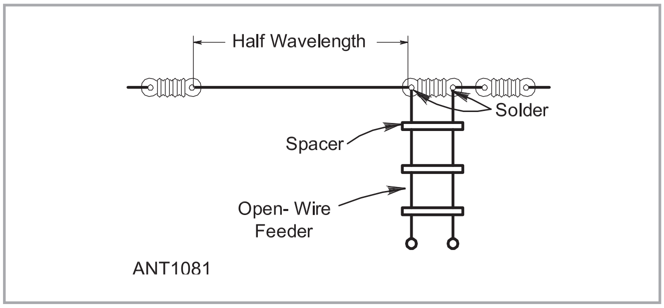


Figure 9.7 — An end-fed Zepp with a parallel-wire feed line connected at one end. Tuned feeders can be used to lower the high feed point impedance as described in the text.

parallel-wire lines and so *tuned feeders* are often employed in which the feed line is an odd number of quarter-wavelengths long. Such a feed line transforms a high impedance into a low impedance as described in the **Transmission Lines** chapter, allowing low-impedance feed lines such as coax to be connected with a more manageable SWR.

To lower the high end impedance, the feed point can be moved away from the end toward the middle of the antenna. At some point a close match to the 300 to 450-Ω impedance of parallel-wire feed lines can be obtained. This configuration is commonly known as the "off-center-fed dipole" described in the **Multiband HF Antennas** chapter.

Feed points that are not in the center of the antenna (ie – asymmetric) are intrinsically unbalanced and significant amounts of common-mode current will flow on the feed line, whether parallel-conductor or coaxial, unless blocked by choke baluns as described in the **Transmission Line System Techniques** chapter. End-fed antennas require the feed line's common-mode path as part of the antenna system. Off-center-fed antennas may or may not include the common-mode path depending on the antenna design.

9.1.5 SLOPING DIPOLES

Another variation of the single-support configuration is the λ/2 *sloping dipole* shown in **Figure 9.8A**. This antenna

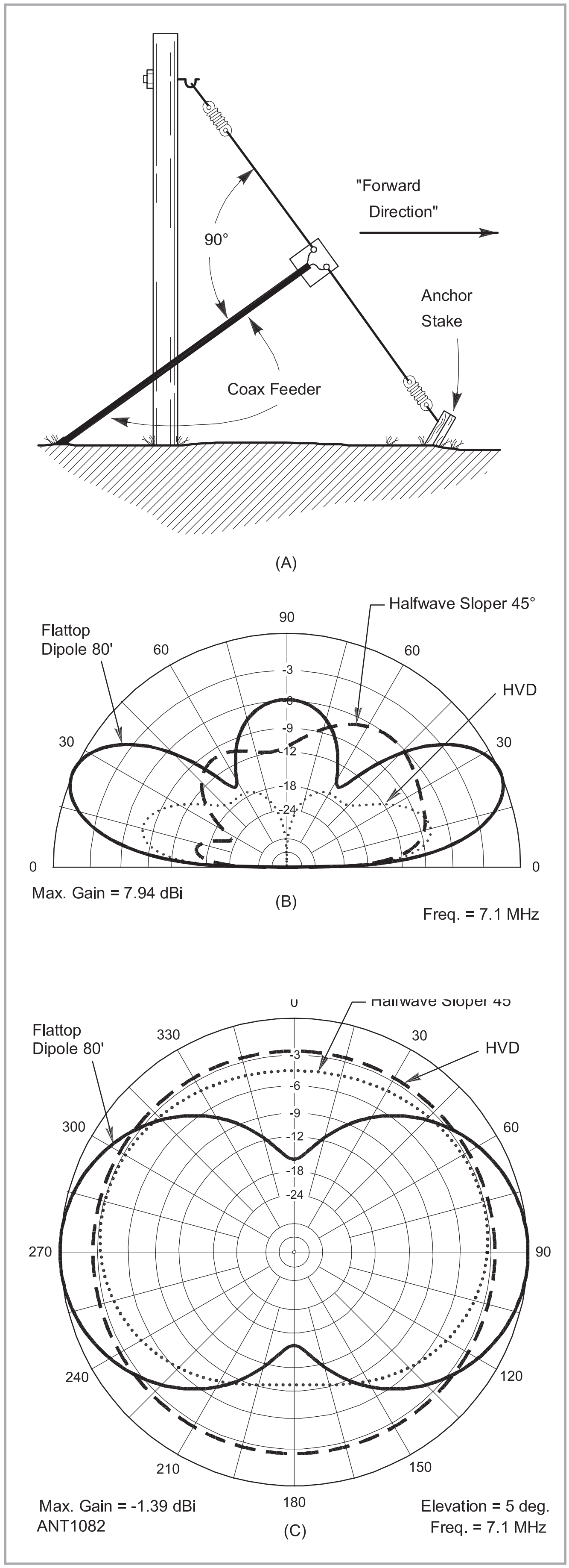


Figure 9.8 — Example of a sloping λ/2 dipole, or *full sloper*. On the lower HF bands, maximum radiation over poor to average ground is off the sides and in the *forward direction* indicated if a non-conductive support is used. A metal support will alter this pattern by acting as a parasitic element. How it alters the pattern is a complex issue depending on the electrical height of the support, what other antennas are located on it, and on the configuration of any guy wires. B compares the 40 meter azimuthal patterns at a DX takeoff angle of 5° for three configurations: a flattop dipole, a dipole tilted down 45° and an HVD (half wave vertical dipole). These are computed for ground with average conductivity and dielectric constant, and for a maximum height of 80 feet in each configuration. The sloping half wave dipole exhibits about 5 dB of front-to-back ratio, although even at its most favored direction it doesn't quite have the same maximum gain as the HVD or the flattop dipole. C shows the elevation patterns for the same antennas. Note that the sloping half wave dipole has more energy at higher elevation angles than either the flattop dipole or HVD.

is also known as a *sloper* or *half-wave sloper* to distinguish it from the *half sloper* described in the section on vertically-polarized antennas. The feed point impedance depends on the height of the antenna above ground, the characteristics of the ground, and the angle the antenna makes with the ground. In most cases, an acceptable SWR for coaxial cable can be achieved by altering the direction and height.

The amount of slope from horizontal can vary from 0°, where the dipole is in a flattop configuration, all the way to 90°, where the dipole becomes fully vertical. The latter configuration is sometimes called a *Halfwave Vertical Dipole* (*HVD*) and is discussed in the section on vertically polarized antennas.

This antenna slightly favors the *forward direction* as shown in Figure 9.8B. With a non-conducting support and average to poor ground, signals off the back are weaker than those off the front. With a non-conducting mast and good ground, the response is omnidirectional with no gain in any direction.

A conductive support such as a tower acts as a parasitic element. (So does the coax shield, unless it is routed at 90° from the antenna.) The parasitic effects vary with ground quality, support height and other conductors on the support (such as a beam at the top or other wire antennas). With such variables, performance is very difficult to predict but that is no reason not to put up the antenna and experiment with it. Many hams report good results with a sloper.

Losses increase as the antenna ends approach the support or the ground, so the same cautions about the height of the antenna ends apply as for the inverted-V antenna.

The question arises about how to treat the feed line to make sure it doesn't accidentally become part of the radiating system. The ideal situation would be to bring the feed line out perpendicular to the sloping wire for an infinite distance. To prevent feed line radiation, route the coax away from the feed point at 90° from the antenna as far as possible.

An intensive modeling study on feeding the closely-related HVD was done for the book *Simple and Fun Antennas for Hams* (see Bibliography). This study indicated that directing the feed line at an angle down to the ground of as little as 30° from the antenna can work with only minor interaction, provided that common-mode decoupling chokes were employed at the feed point and a quarter-wavelength down the line from the feed point. (See the **Transmission Line System Techniques** chapter.)

Two systems of multiple sloping dipoles are presented on this book's CD-ROM. A system designed for 7 MHz by K1WA and another for 1.8 MHz by K3LR give the builder some directivity while only requiring a single support. These systems can also be adapted to other bands.

9.1.6 BROADBAND DIPOLES

Producing a dipole with an SWR bandwidth covering an entire amateur band is difficult for the 160 meter and 80 meter bands due to their relative spans: approximately 10.5% for the 160 meter band and 13.4% for the 80 meter band from the lowest to the highest frequency of the allocation. Most single-wire dipoles have an SWR bandwidth of a few percent in comparison, making it difficult to cover these widest of our bands with just one antenna. The higher HF bands are much narrower in comparison and generally can be covered by a single-wire dipole.

The simplest way to increase the SWR bandwidth of a single-wire dipole is to increase the thickness of the wire (the length-to-diameter ratio) as discussed in the **Antenna Fundamentals** and **Dipoles and Ground-Planes** chapters. Since the range of available wire sizes is quite limited in the potential effect on bandwidth at MF and HF, the technique of employing multiple wires is used to create a larger-diameter conductor. (Additional methods of making broadband dipoles are discussed in the supplement "Broadband Antenna Matching" which is included on this book's CD-ROM in the folder associated with the **Transmission Line System Techniques** chapter.)

There are three common methods of using multiple wires in this way: the cage, the fan and the open-sleeve. The cage shown in **Figure 9.9** is a very old design, having been employed during the early days of "wireless" to increase bandwidth of antennas used for spark signals with their very wide bandwidths. The cage consists of several wires (three or

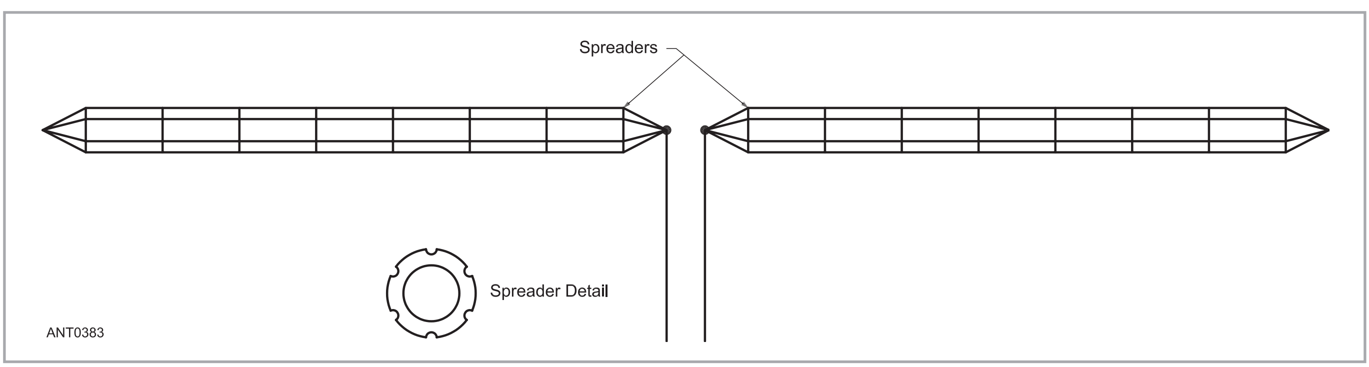


Figure 9.9 — Construction of a cage dipole. The spreaders need not be of conductive material and should be lightweight. Between adjacent conductors, the spacing should be 0.02 ℓ or less. The number of spreaders and their spacing along the dipole should be sufficient to maintain a relatively constant separation of the radiator wires. The spreaders can be round as shown in the detail or any suitable cross arrangement.

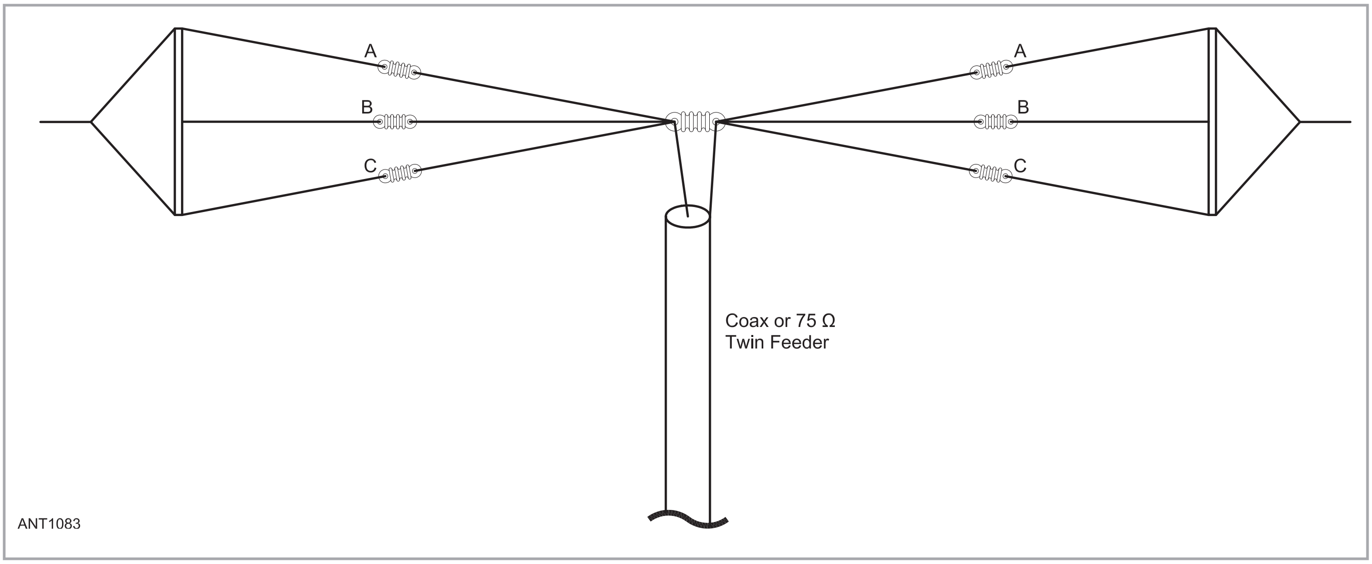


Figure 9.10 — A broad-banded "fan" dipole. The three dipoles a, b and c are cut to resonate at the band edges and center band frequency. This creates a single antenna that can be used over the entire 3.5 MHz band. On 80 meters, the dipole cut for 3.5 MHz will be approximately 7 feet longer than the one cut for 4 MHz. (Figure 9.10 from *Practical Wire Antennas*, courtesy RSGB — see Bibliography.)

more) held apart by spreaders (insulating or non-insulating) and connected together at the ends and at the feed point. A project describing the cage dipole in use at W1AW on 80 meters is included at the end of this section.

In fact, to increase bandwidth it is not necessary to increase the antenna's diameter over the entire length, just near the ends. Thus, a simplified variation on the cage is to create a "bow-tie" with just two wires in each leg of the dipole. The wires are tied together at the feed point and spread apart up to 10 feet at the ends of the dipole where they may be connected together or left separate. The bow-tie or "skeleton biconical dipole" was discussed by Hallas in May 2005 *QST*. (See the Bibliography.)

In both cases, extra tethers are usually required at the ends of the cage or fan to keep the antenna from twisting in the wind. This is less of a problem with the cage design which uses multiple spreaders to keep the wires apart. Such antennas provide excellent electrical performance at the cost

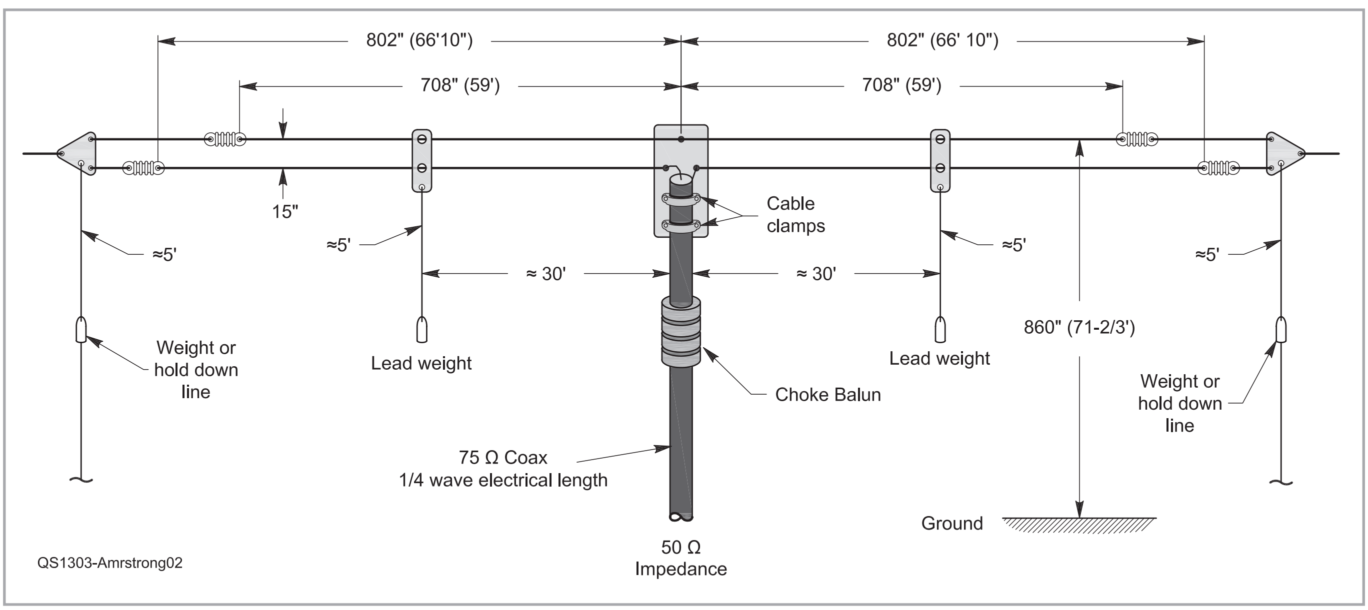


Figure 9.11 — Construction details and dimensions of the coupled resonator 75/80 meter antenna including a λ/4 impedance transformer of 75 Ω coax. Based on a coax velocity factor of 0.66 (66%) for solid polyethylene dielectric coax, the λ/4 transformer should be 43.3 feet long at 3.75 MHz. Measure and build the λ/4 transformer as described in the Transmission Line System Techniques chapter. The original article recommended type 43 ferrite beads but type 31 will provide more choking impedance at these frequencies.

of some mechanical complexity and extra weight. They may not be suitable in areas where heavy icing or high wind speed is common.

A second method of broad-banding a dipole is to create a fan of two or more dipoles with close but not identical resonant frequencies. This is illustrated in **Figure 9.10** in which three dipoles are cut for the bottom, middle and top frequencies in the 80 meter band (3.5, 3.75, and 4 MHz) and fed in parallel at the feed point. This is similar to the bow-tie mentioned in the previous paragraph but the ends of the dipoles are not connected together. A nonconducting spreader is used to hold the wires apart.

The dipole impedances interact to some degree depending on how different the frequencies are at which they are resonant. Modeling is recommended at the expected height above ground but may not give completely accurate results due to the very shallow angle at which the wires join at the feed point. Expect some adjustments as the three dipoles are adjusted to give the desired SWR curve across the band. Two dipoles can cover approximately two-thirds of the band.

The third method is to place a parasitic dipole extremely close to the driven dipole so that it couples to the driven dipole and essentially operates in parallel with it. This technique has been refined in several recent articles. **Figure 9.11** shows an implementation by Ted Armstrong, WA6RNC, from the March 2013 issue of *QST*. (This article is included on this book's CD-ROM along with a previous design from Rudy Severns, N6LF. Check the *Antenna Book's* website at **www.arrl.org/arrl-antenna-book-reference** for more information about broadband designs for antennas on 160 through 40 meters.)

An isolated wire is placed next to a dipole cut for the low end of the band. The shorter wire has a higher resonant frequency than that of outer, longer folded dipole and so acts as the radiator at the higher frequency. This antenna's SWR was less than 1.7:1 across the entire 75/80 meter band and lower at most frequencies. .

W1AW 80 Meter Cage Dipole

The 80 meter cage antenna used at W1AW is based loosely on a design that appeared in a December 1980 *QST* article by Allen Harbach, WA4DRU (SK). (See the Bibliography and the CD-ROM included with this book.) The antenna is used primarily for W1AW's scheduled transmissions. It is also used for regular visitor operations as well. The resonant frequency of the antenna is 3627 kHz but the overall SWR is less than 2:1 from 3580 to 3995 kHz.

The W1AW cage antenna differs from the original article in that it's meant to be in place for a long period of time. So, most parts of the antenna are designed more ruggedly than in the Harbach design.

Each leg of the dipole is a cage made of four 80 meter dipole antennas of #14 AWG stranded copper wire tied together both at the ends and at the feed point as shown in **Figure 9.12**. Although Copperweld or an equivalent heftier wire could have been used, this size wire was easy to work with. The four wires forming each leg of the dipole are separated using a crosspiece made of PVC pipe as shown in **Figure 9.13**. There is a crosspiece near the feed point and the ends. The spacing between the wires is three feet.

Each cage wire passes through one leg of each crosspiece. A keeper wire is soldered across around the end of the PVC tube to the antenna wire on either side. This keeps the crosspiece from moving up and down the antenna. Exterior silicone caulk is applied to the hole in the tubing to seal it from moisture. Inside the crosspieces are oak dowels and the ends of the crosspieces are also capped. This adds rigidity to the crosspiece.

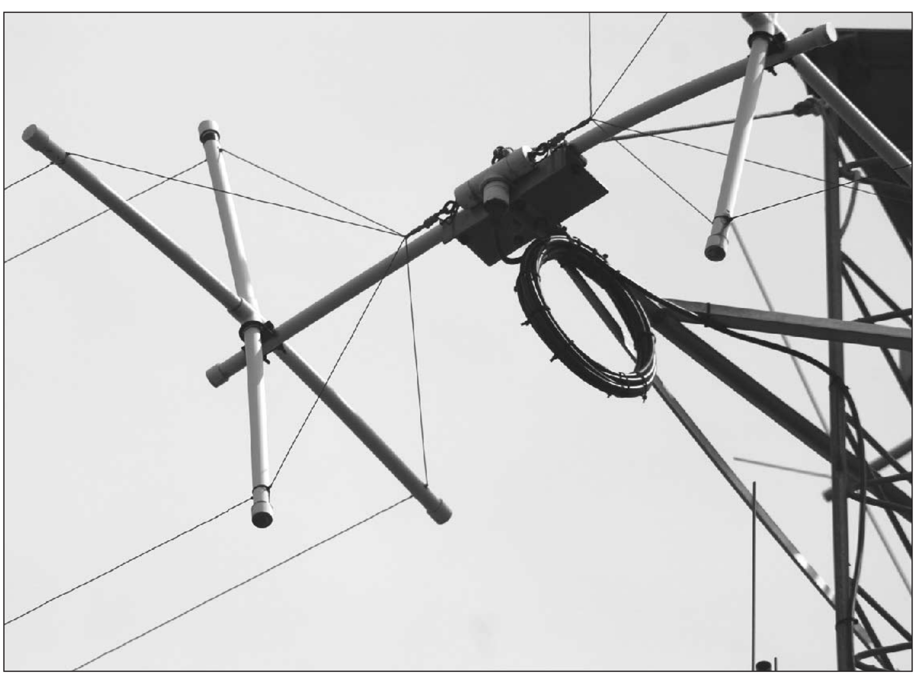


Figure 9.12 — The center insulator is constructed from a PVC pipe tee with end caps covering each end. Stainless steel eyebolts are used to hold the ends of the cage and solder lugs with jumpers connect to the cage wires. Inside the tee, jumpers connect the eyebolts to the SO-239 on the third pipe cap. A piece of PVC pipe is U-bolted to the inner crosspieces of both cage sections. The entire assembly is supported by a sidearm from one of the W1AW towers. The antenna was constructed by W1AW Chief Operator Joe Carcia, NJ1Q.

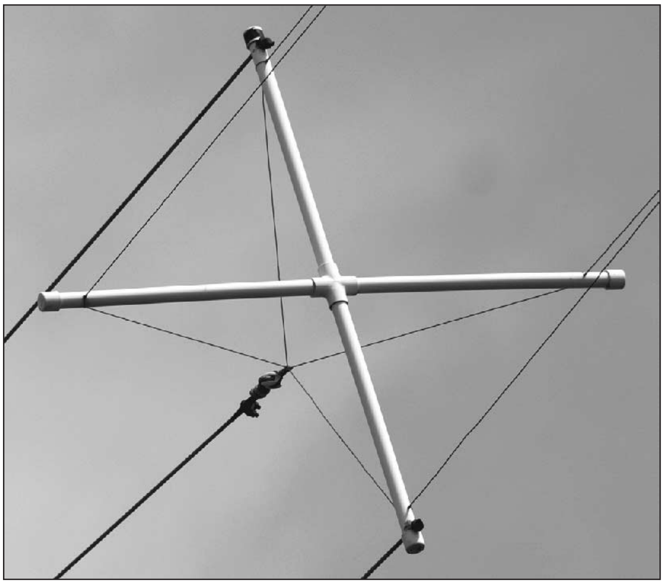


Figure 9.13 — The cage wires are kept separated by crosspieces of PVC pipe. The cage wires pass through a hole in the PVC pipe and a keeper wire is soldered to the cage wire on each side of the pipe to keep the crosspiece from moving along the wires.

The feed point assembly is a homebrew PVC center insulator consisting of a pair of 2-inch end caps attached to both ends of a 6-inch long, 2-inch PVC pipe tee. A stainless steel eyebolt with two solder lugs is mounted in the middle of each cap. One solder lug is on the outside of the cap for a connection to the antenna and the other is inside for connection to the SO-239 coax connector. The SO-239 is mounted on a third cap attached to the middle tee section.

An 8-turn coaxial choke is connected to the antenna at the center insulator. The choke is made from RG-213 coax using designs included in the **Transmission Line System Techniques** chapter.

The center insulator assembly is bolted to a 4-foot length piece of 1-inch PVC pipe. The inner crosspieces are also bolted to this section of pipe as shown in the figure. This provides added support to the antenna. The center insulator and length of PVC are secured to the tower using a side-arm.

At the feed point, the four wires of each leg are brought together and looped through the eye-bolt. They are then twisted and soldered together and a short jumper of wire connects the twisted wires to a solder lug on the eyebolt. Inside each end cap, a jumper wire connects a second solder lug on the eyebolt to the SO-239 on the remaining cap.

At the outside ends of the cage, all four wires are brought to a common point, twisted together, and then attached to a strain insulator. The strain insulator and two of the crosspiece arms are tied off to the supports. This keeps the antenna legs from twisting in the breeze.

Tuning the antenna can be a bit tricky since each leg (wire) must be trimmed the same amount. It is best to start off with wire lengths calculated using the lowest operating frequency (for example, 3500 kHz). After trimming, the overall length of the antenna will be slightly smaller than that of a single-wire 80 meter dipole. This is because the radiating element is three feet in diameter — much thicker than a single-wire dipole.

While construction of this antenna is a bit more involved than that of a regular dipole, the result is a broadbanded antenna that doesn't require a tuner. The design specifications can also be recalculated to fit other amateur bands.

9.2 VERTICAL ANTENNAS

9.2.1 THE HALF-WAVE VERTICAL DIPOLE (HVD)

The simplest form of vertical is that of a half-wave vertical dipole, an HVD. This is a horizontal dipole turned 90° so that it is perpendicular to the ground under it. Of course, the top end of such an antenna must be at least a half wave above the ground or else it would be touching the ground. This poses quite a construction challenge if the builder wants a free-standing low-frequency antenna. Hams fortunate enough to have tall trees on their property can suspend wire HVDs from these trees. Similarly, hams with two tall towers can run rope catenaries between them to hold up an HVD.

A vertical half-wave dipole has some operational advantages compared to a more-commonly used vertical configuration — the quarter-wave vertical used with some sort of above-ground counterpoise or an on-ground radial system. See **Figure 9.14**, which shows the two configurations discussed here. In each case, the lowest part of each antenna is 8 feet above ground, to prevent passersby from being able to touch any live wire. Each antenna is assumed to be made of #14 AWG wire resonant on 80 meters.

Feeding a Half-Wave Vertical Dipole

Figure 9.15 compares elevation patterns for the two antennas for "average ground." You can see that the half-wave vertical dipole has about 1.5 dB higher peak gain, since it compresses the vertical elevation pattern down somewhat closer to the horizon than does the quarter-wave ground plane. Another advantage to using a half-wave radiator besides higher gain is that less horizontal "real estate" is needed compared to a quarter-wave vertical with its horizontal radials.

The obvious disadvantage to an HVD is that it is taller than a quarter-wave ground plane. This requires a higher support (such as a taller tree) if you make it from wire, or a longer element if you make it from telescoping aluminum tubing.

Another problem is that theory says you must dress the feed line so that it is perpendicular to the half-wave radiator. This means you must support the coax feed line above

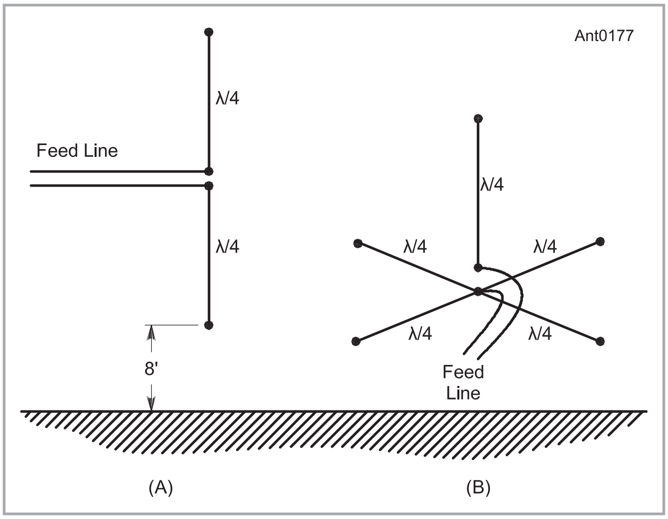


Figure 9.14 — At A, an 80 meter half-wave vertical dipole elevated 8 feet above the ground. The feed line is run perpendicularly away from the dipole. At B, a "ground plane" type of quarter-wave vertical, with four elevated resonant radials. Both antennas are mounted 8 feet above the ground to keep them away from passersby.

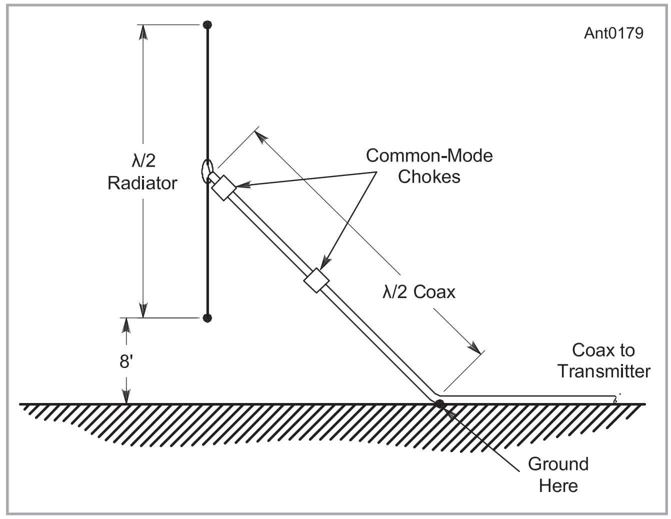


Figure 9.16 — A 20 meter HVD whose bottom is 8 feet above ground. This is fed with a λ/2 of RG-213 coax. This system uses a common-mode choke at the feed point and another λ/4 down the line. The resulting azimuthal radiation pattern is within 0.4 dB of being perfectly circular. The "wingspan" of this antenna system is 27 feet from the radiator to the point where the coax comes to ground level.

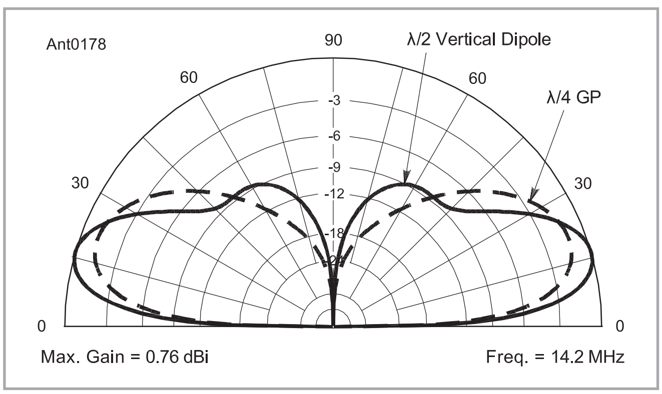


Figure 9.15 — A comparison of the elevation patterns for the two antennas in Figure 9.14. The peak gain of the HVD is about 1.5 dB higher than that for the quarter-wave ground-plane radiator with radials.

ground for some distance before bringing the coax down to ground level. A question immediately arises: How far must you go out horizontally with the feed line before going to ground level to eliminate common-mode currents that are radiated onto the coax shield? Such common-mode currents will affect the feed point impedance as well as the radiation pattern for the antenna system. Quite a bit of distortion in the azimuthal pattern can be created if common-mode currents aren't suppressed, usually by using a common-mode choke, also known as a current balun.

Constructing such a common-mode choke is very simple: ferrite beads of an approximate mix are slipped over the coax (before the connectors are soldered on or else they won't fit!) and taped in place. The only problem with this scheme is that an additional support (some sort of "skyhook") is required to support the coax horizontally. Let's try to simplify the installation, by slanting the feed line coax down to ground from the feed point at a fairly steep angle of about 30° from vertical. See **Figure 9.16**.

Note that the bottom end of the coax in Figure 9.16 is grounded to a ground rod. This serves as a mechanical connection to hold the coax in place and it provides some protection against lightning strikes. Now, as a purely practical matter, just how picky are we being here? What if we skip the second common-mode choke and just use one at the feed point? The computer model predicts that there will be some distortion in the azimuthal pattern — about 1.1 dB worth. Whether this is serious is up to you. However, you may find other problems with common-mode currents on the coax shield — problems such as RF in the shack or variable SWR readings depending on the way coax is routed in the shack. The addition of three extra ferrite beads to suppress the common-mode currents is cheap insurance.

Later in this chapter we'll discuss shortened vertical antennas, ones arranged both as vertical dipoles and as vertical monopoles with radial systems. A variation on the HVD that is shortened through the use of capacitive loading is the *Compact Vertical Dipole (CVD)*. An article describing the CVD is included on the CD-ROM accompanying this book.

9.2.2. THE C-POLE

The antenna, designed by Brian Cake, KF2YN, consists of a vertical half-wave dipole that has been folded virtually in half and the feed point offset as shown in **Figure 9.17**. By erecting this just above ground level the ground currents are reduced dramatically over those of a λ/4 ground-mounted monopole. There is some induced ground current but it is quite small. The elevation radiation pattern for this antenna

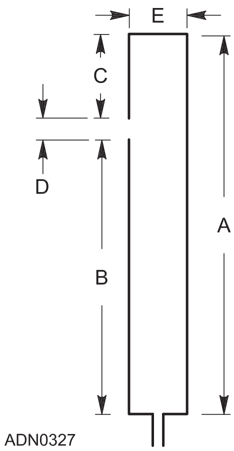


Figure 9.17 — Key to the dimensions in Table 9.2.

is virtually omni-directional. The design was originally published in the April 2004 issue of *QST*. The original article is included on this book's CD-ROM. The antenna's design is discussed in greater detail in *The Antenna Designer's Notebook* by the same author.

Construction is shown in **Figure 9.18** and dimensions for the HF amateur bands are given in **Table 9.2**. The author notes that using insulated wire or placing the antenna close to a structure will detune the antenna. Adjusting the length of the vertical wires is generally sufficient to restore proper operation.

Moving the feed point away from the voltage node at the antenna center increases the feed point impedance, and an exact match to 50 Ω at the center of the lower horizontal wire was obtained by shifting the position of the gap at the dipole ends. Unfortunately, doing this places the feed point at a position where there is a substantial common-mode potential. That is to say, the two antenna feed point terminals have the same potential on them relative to ground (in addition to the normal differential potential across the feed point), and this potential can be several hundred volts for an input power

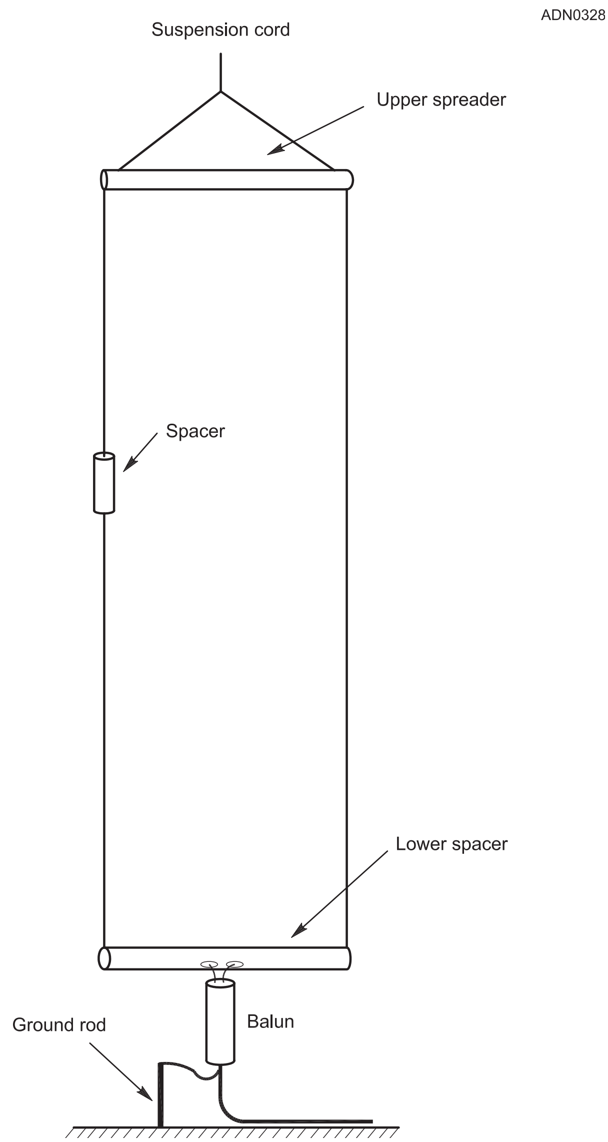


Figure 9.18 — C-pole construction details.

Table 9.2
Dimensions of C-pole Antennas
Wire diameter is 1⁄16-inch. Height of the lower horizontal wire is 12 inches to 24 inches and is non-critical.
See Figure 9.17 for the key to the dimensions.

Band (meters)	*A (inches)*	*B (inches)*	*C (inches)*	*D (inches)*	*E (inches)*	*2:1 SWR bandwidt (kHz)*
160	1666	924	994	60	80	58
80	840	460	360	30	40	120
60	591	322	249	20	26	250
40	450	240	190	20	20	260
30	320	167	139	14	14	360
20	177	85	84	8	40	400
15	124	60	60	4	20	600
10	87	46	37	4	20	800

level of 100 W. If the coax is connected directly to the feed point, the natural resonance of the antenna is destroyed and it becomes useless. The author specifies a balun to solve the problem as follows. The baluns are wound on FT-240-61 ferrite cores, and can use either twisted-pair feed line or coaxial cable wound through the core:

160 meters, 32 turns on two cores glued together to make a thick donut
80 meters, 32 turns on a single core
60 meters, 28 turns on a single core
40 meters, 23 turns on a single core
30 and 20 meters, 20 turns on a single core
17 meters and up, 15 turns on a single core, use FT-240-67 material

9.2.3 MONOPOLE VERTICALS WITH GROUND-PLANE RADIALS

For best performance the vertical portion of a ground-plane type of antenna should be λ/4 or more, but this is not an absolute requirement. With proper design, antennas as short as 0.1 λ or even less can be efficient and effective. Antennas shorter than λ/4 will be reactive and some form of loading and perhaps a matching network will be required.

If the radiator is made of wire supported by nonconducting material, the approximate length for λ/4 resonance can be found from:

$$\ell_{feet} = \frac{234}{f_{MHz}} \quad \text{(Eq 1)}$$

The same cautions about the effects of ground and wire or tubing diameter apply to this equation for verticals. For a tower, the resonant length will be shorter still. It is recommended that the builder start a few percent long and trim the antenna to length based on measurements taken with the antenna in place. (See the **Dipoles and Monopoles** chapter.)

The effect of ground characteristics on losses and elevation pattern is discussed in detail in the chapter **Effects of Ground**. The most important points made in that discussion are the effect of ground characteristics on the radiation pattern and the means for achieving low ground-loss resistance in a buried ground system. As ground conductivity increases, low-angle radiation improves. This makes a vertical very attractive to those who live in areas with good ground conductivity. If your QTH is on a saltwater beach, then a vertical would be very effective, even when compared to horizontal antennas at great height.

When a buried-radial ground system is used, the efficiency of the antenna will be limited by the loss resistance of the ground system. The ground can be a number of radial wires extending out from the base of the antenna for about λ/4. Driven ground rods, while satisfactory for electrical safety and for lightning protection, are of little value as an RF ground for a vertical antenna, except perhaps in marshy or beach areas. As pointed out, many long radials are desirable. In general, however, a large number of short radials are preferable to only a few long radials, although the best system would have 60 or more radials longer than λ/4. An

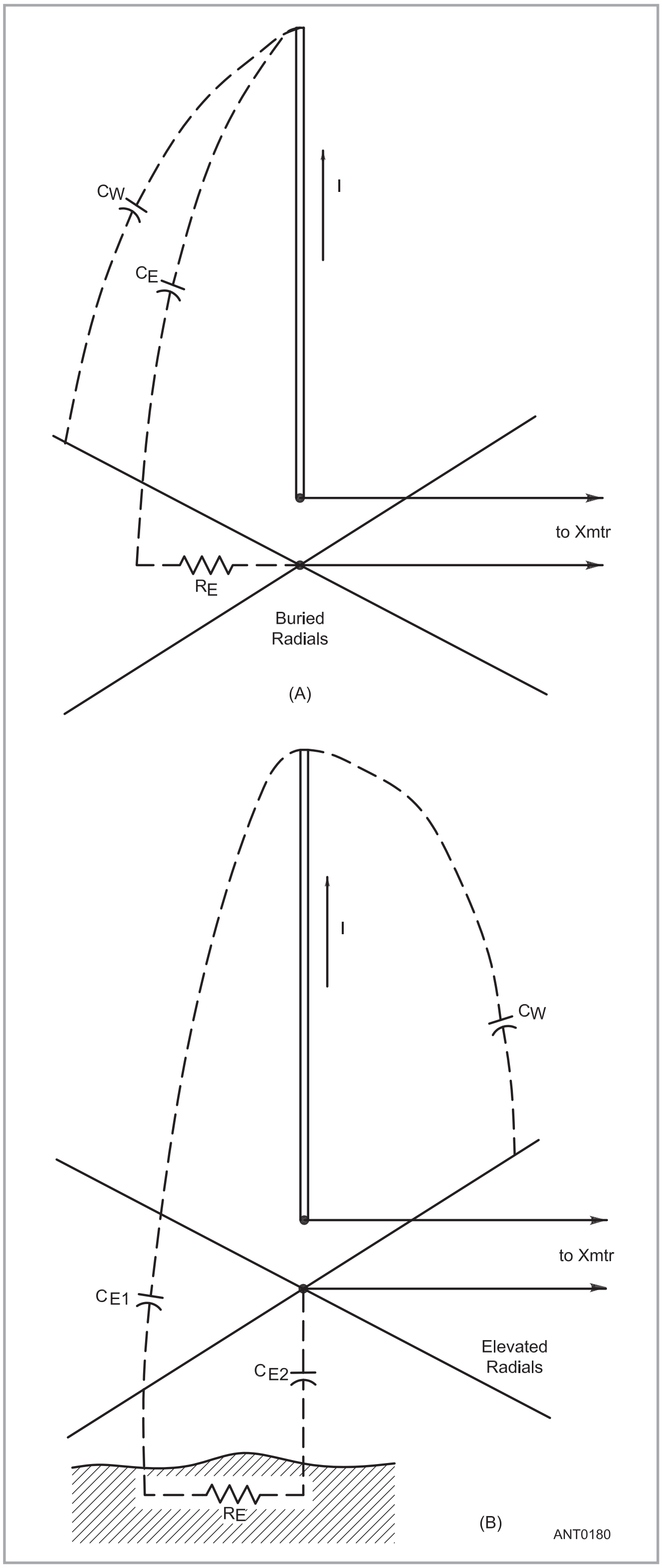


Figure 9.19 — How earth currents affect the losses in a short vertical antenna system. At A, the current through the combination of CE and RE may be appreciable if CE is much greater than CW, the capacitance of the vertical to the ground wires. This ratio can be improved (up to a point) by using more radials. By raising the entire antenna system off the ground, CE (which consists of the series combination of CE1 and CE2) is decreased while CW stays the same. The radial system shown at B is sometimes called a counterpoise.

Radial Spacing

Figuring out how to space radials equally around a circle is explained in this sidebar. The information was originally published on the Towertalk reflector by Rod Ehrhart, WN8R, of DX Engineering.

Begin by determining the radius of the circle in which the radials will be installed. If your area is irregular, choose the minimum radial length. An example is the best way of illustrating the process:

If your minimum radial length is 25 feet, establish a circle that has a radius (r) of 25 feet from the antenna mount. The circumference (C) of that circle is $2\pi r$ or $C = (2) \times (3.14) \times (25 \text{ feet})$, which equals 157 feet. If you have decided to install 60 radials ($N = 60$), the spacing (S) between each radial on the 25-foot radius circle is calculated as $S = C / N$ or $S = 157 \text{ feet} / 60 \text{ radials} = 2.6$ feet or about 2 feet, 7 inches between each radial on the circle. Use string to draw the circle and measure 2 feet, 7 inches spacing around the circle. If the radial is longer than 25 feet, stretch it straight out from the antenna mount so that it crosses the circle at the marked point.

If you want to install 90 radials, then it would be 157 feet / 90 radials = 1.74 feet/radial, or a little less than 1 foot 9 inches between each radial wire on the circle at 25 feet from the antenna mount.

Working this out in advance, you will not need to worry about how far apart the radials are where they end, or trying to eye-ball their spacing. When filling an irregular area with radials, each one will have a different spacing where they end. By using this measurement method, you will be able to make all of the radials evenly spaced, and as long as they can be, for maximum antenna system performance.

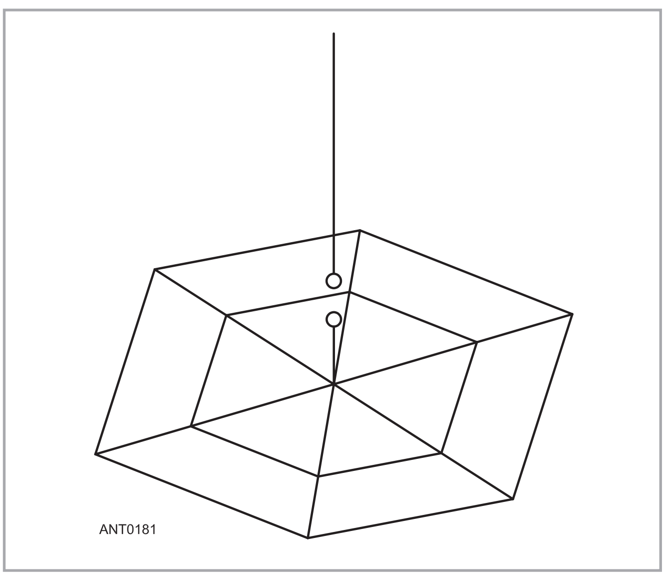


Figure 9.20 — Counterpoise, showing the radial wires connected together by cross wires. The length of the perimeter of the individual meshes should be < λ/4 to prevent undesired resonances. Sometimes the center portion of the counterpoise is made from wire mesh.

elevated system of radials or a ground screen (*counterpoise*) may be used instead of buried radials, and can result in an efficient antenna. **Figure 9.19** and **Figure 9.20** illustrate the difference between buried and elevated radial systems and counterpoises. The reader is directed to the chapter **Effects of Ground** for a discussion of ground plane radial systems and counterpoises for vertical monopole antennas.

9.2.4 GROUND-PLANE ANTENNAS

The ground-plane antenna is a λ/4 vertical with four radials, as shown in **Figure 9.21**. The entire antenna is elevated

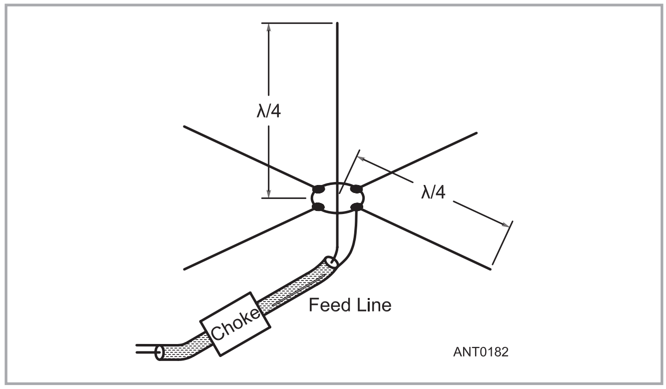


Figure 9.21 — The ground-plane antenna. Power is applied between the base of the vertical radiator and the center of the ground plane, as indicated in the drawing. Decoupling from the transmission line and any conductive support structure is highly desirable.

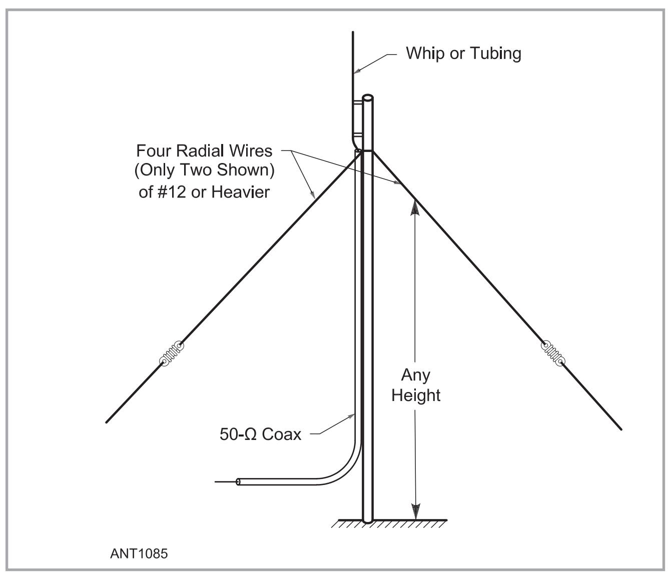


Figure 9.22 — A ground-plane antenna is effective for DX work on 7 MHz. Although its base can be any height above ground, losses in the ground underneath will be reduced by keeping the bottom of the antenna and the ground plane as high above ground as possible. Feeding the antenna directly with 50-Ω coaxial cable will result in a low SWR. The vertical radiator and the radials are all λ/4 long electrically. The radial's physical length will depend on their length-to-diameter ratios, the height over ground and the length of the vertical radiator, as discussed in text.

above ground. A practical example of a 7-MHz ground-plane antenna is given in **Figure 9.22**. As explained earlier, elevating the antenna reduces the ground loss and lowers the radiation angle somewhat. The radials are sloped downward to make the feed point impedance closer to 50 Ω.

The feed point impedance of the antenna varies with the height above ground, and to a lesser extent varies with the ground characteristics. **Figure 9.23** is a graph of feed point resistance (R_R) for a ground-plane antenna with the radials parallel to the ground. R_R is plotted as a function of height above ground. Notice that the difference between perfect ground and average ground (ε = 13 and σ = 0.005 S/m) is small, except when quite close to ground. Near ground R_R is between 36 and 40 Ω. This is a reasonable match for 50-Ω feed line but as the antenna is raised above ground R_R drops to approximately 22 Ω, which is not a very good match. The feed point resistance can be increased by sloping the radials downward, away from the vertical section.

The effect of sloping the radials is shown in **Figure 9.24**. The graph is for an antenna well above ground (> 0.3 λ). Notice that R_R = 50 Ω when the radials are sloped downward at an angle of 45°, a convenient value. The resonant length of the antenna will vary slightly with the angle. In addition, the resonant length will vary a small amount with height above the ground. It is for these reasons, as well as the effect of conductor diameter, that some adjustment of the radial lengths is usually required. When the ground-plane antenna is used on the higher HF bands and at VHF, the height above ground is usually such that a radial sloping angle of 45° will give a good match to 50-Ω feed line.

The effect of height on R_R with a radial angle of 45° is shown in **Figure 9.25**. At 7 MHz and lower frequencies, it is seldom possible to elevate the antenna a significant portion of a wavelength and the radial angle required to match to 50-Ω line is usually of the order of 10° to 20°. To make the vertical portion of the antenna as long as possible, it may be better to

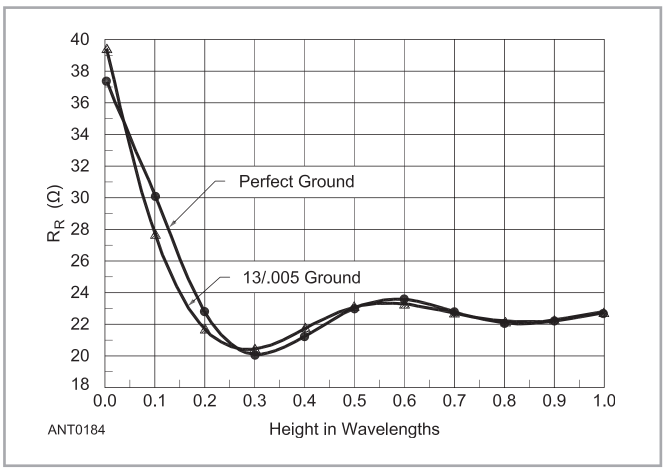


Figure 9.23 — Radiation resistance of a 4-radial ground-plane antenna as a function of height over ground. Perfect and average ground are shown. Frequency is 3.525 MHz. Radial angle (θ) is 0°.

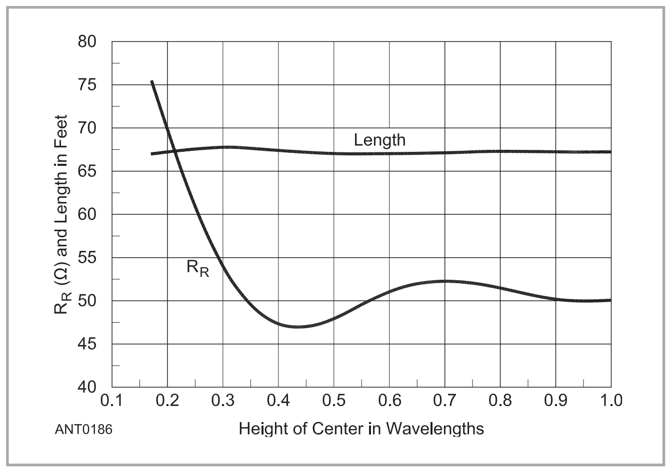


Figure 9.25 — Radiation resistance and resonant length for a 4-radial ground-plane antenna for various heights above average ground for radial droop angle θ = 45°.

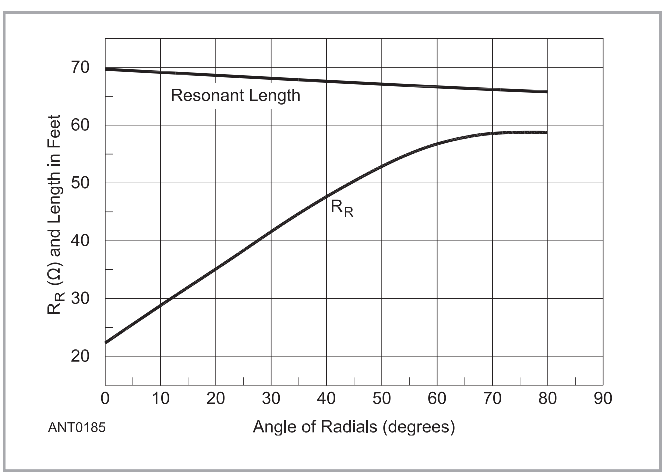


Figure 9.24 — Radiation resistance and resonant length for a 4-radial ground-plane antenna > 0.3 λ above ground as a function of radial droop angle (θ).

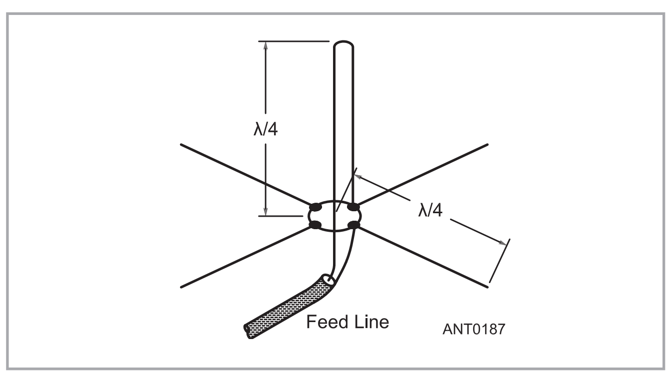


Figure 9.26 — The folded monopole antenna. Shown here is a ground plane of four λ/4 radials. The folded element may be operated over an extensive counterpoise system or mounted on the ground and worked against buried radials and the earth. As with the folded dipole antenna, the feed point impedance depends on the ratios of the radiator conductor sizes and their spacing.

accept a slightly poorer match and keep the radials parallel to ground.

The principles of the folded dipole discussed earlier can also be applied to the ground-plane antenna, as shown in **Figure 9.26**. This is the *folded monopole* antenna. The feed point resistance can be controlled by the number of parallel vertical conductors and the ratios of their diameters.

As mentioned earlier, it is important in most installations to isolate the antenna from the feed line and any conductive supporting structure. This is done to minimize the return current conducted through the ground. A return current on the feed line itself or the support structure can drastically alter the radiation pattern, usually for the worse. For these reasons, a balun (see the chapter **Transmission Line System Techniques**) or other isolation scheme must be used. 1:1 baluns are effective for the higher bands but at 3.5 and 1.8 MHz commercial baluns often have too low a shunt inductance to provide adequate isolation. It is very easy to recognize when the isolation is inadequate. When the antenna is being adjusted while watching an isolated impedance or SWR meter, adjustments may be sensitive to your touching the instrument. After adjustment and after the feed line is attached, the SWR may be drastically different. When the feed line is inadequately isolated, the apparent resonant frequency or the length of the radials required for resonance may also be significantly different from what you expect.

In general, a choke balun inductance of 50 to 100 μH will be needed for 3.5 and 1.8-MHz ground-plane antennas. One of the easiest ways to make the required choke balun is to wind a length of coaxial cable into a coil as shown in **Figure 9.27**. For 1.8 MHz, 30 turns of RG-213 wound on a 14-inch length of 8-inch diameter PVC pipe will make a very good choke balun that can handle full legal power continuously. A smaller choke could be wound on 4-inch diameter plastic drain pipe using RG-8X or a Teflon insulated cable.

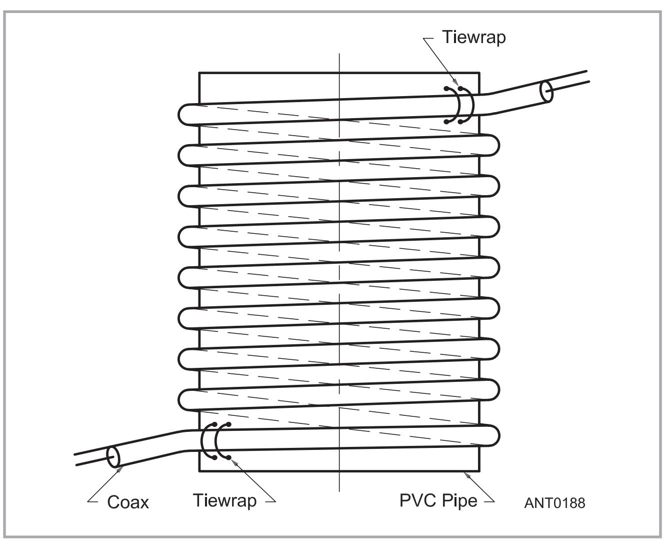


Figure 9.27 — A choke balun with sufficient impedance to isolate the antenna properly can be made by winding coaxial cable around a section of plastic pipe. Suitable dimensions are given in the text.

The important point here is to isolate or decouple the antenna from the feed line and support structure.

A full-size ground-plane antenna is often a little impractical for 3.5-MHz and quite impractical for 1.8 MHz, but it can be used at 7 MHz to good advantage, particularly for DX work. Smaller versions can be very useful on 3.5 and 1.8 MHz.

9.2.5 EXAMPLES OF VERTICALS

There are many possible ways to build a vertical antenna — the limits are set by your ingenuity. The primary problem is creating the vertical portion of the antenna with sufficient height. Some of the more common means are:

- A dedicated tower
- Using an existing tower with an HF Yagi on top
- A wire suspended from a tree limb or the side of a building
- A vertical wire supported by a line between two trees or other supports
- A tall pole supporting a conductor
- Flagpoles
- Light standards
- Irrigation pipe
- TV masts

If you have the space and the resources, the most straightforward means is to erect a dedicated tower for a vertical. While this is certainly an effective approach, many amateurs do not have the space or the funds to do this, especially if they already have a tower with an HF antenna on the top. The existing tower can be used as a top-loaded vertical, using shunt feed and a ground radial system. A system like this is shown in Figure 9.28B.

For those who live in an area with tall trees, it may be possible to install a support rope between two trees, or between a tree and an existing tower. (Under no circumstances should you use an active utility pole!) The vertical portion of the antenna can be a wire suspended from the support line to ground, as shown in Figure 9.28C. If top loading is needed, some or all of the support line can be made part of the antenna.

Your local utility company will periodically have older power poles that they no longer wish to keep in service. These are sometimes available at little or no expense. If you see a power line under reconstruction or repair in your area you might stop and speak with the crew foreman. Sometimes they will have removed older poles they will not use again and will have to haul them back to their shop for disposal. Your offer for local "disposal" may well be accepted. Such a pole can be used in conjunction with a tubing or whip extension such as that shown in Figure 9.28A. Power poles are not your only option. In some areas of the US, such as the southeast or northwest, tall poles made directly from small conifers are available.

Freestanding (unguyed) flagpoles and roadway illumination standards are available in heights exceeding 100 feet. These are made of fiberglass, aluminum or galvanized steel. All of these are candidates for verticals. Flagpole suppliers are listed under "Flags and Banners" in your Yellow Pages.

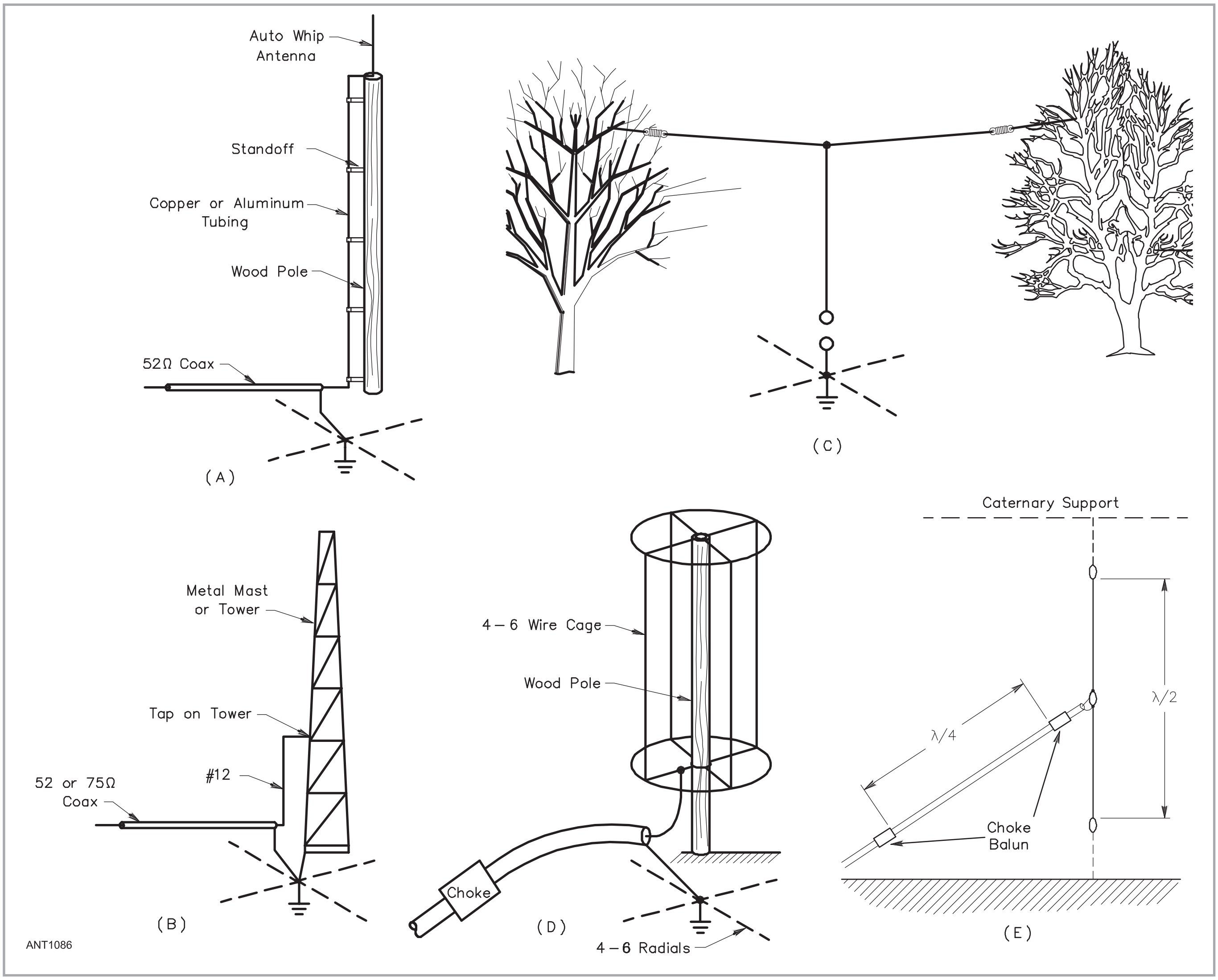


Figure 9.28 — Vertical antennas are effective for 3.5 or 7 MHz. The λ/4 antenna shown at A is fed directly with 50-Ω coaxial line, and the resulting SWR is usually less than 1.5 to 1, depending on the ground resistance. If a grounded antenna is used as at B, the antenna can be shunt fed with either 50- or 75-Ω coaxial line. The tap for best match and the value of C will have to be found by experiment. The line running up the side of the antenna should be spaced 6 to 12 inches from the antenna. If tall trees are available the antenna can be supported from a line suspended between the trees, as shown in C. If the vertical section is not long enough then the horizontal support section can be made of wire and act as top loading. A pole or even a grounded tower can be used with elevated radials if a cage of four to six wires is provided as shown in D. The cage surrounds the pole which may be wood or a grounded conductor.

For lighting standards (lamp posts), you can contact a local electrical hardware distributor. Like a wooden pole, a fiberglass flagpole does not require a base insulator, but metal poles do. Guy wires will be needed.

One option to avoid the use of guys and a base insulator is to mount the pole directly into the ground as originally intended and then use shunt feed. If you want to keep the pole grounded but would like to use elevated radials, you can attach a cage of wires (four to six) at the top as shown in Figure 9.28D. The cage surrounds the pole and allows the pole (or tower for that matter) to be grounded while allowing elevated radials to be used. The use of a cage of wires surrounding the pole or tower is a very good way to increase the effective diameter. This reduces the Q of the antenna, thereby increasing the bandwidth. It can also reduce the conductor loss, especially if the pole is galvanized steel, which is not a very good RF conductor.

Aluminum irrigation tubing, which comes in diameters of 3 and 4 inches and in lengths of 20 to 40 feet, is widely available in rural areas. One or two lengths of tubing connected together can make a very good vertical when guyed with non-conducting line. It is also very lightweight and relatively easy to erect. A variety of TV masts are available which can also be used for verticals.

1.8 to 3.5-MHz Vertical Using an Existing Tower

A tower can be used as a vertical antenna, provided that a good ground system is available. The shunt-fed tower is at its best on 1.8 MHz, where a full λ/4 vertical antenna is rarely possible. Almost any tower height can be used. If the beam structure provides some top loading, so much the better, but anything can be made to radiate — if it is fed properly. Earl Cunningham, K6SE (SK) used a self-supporting, aluminum, crank-up, tilt-over tower, with a TH6DXX tribander mounted at 70 feet. Measurements showed that the entire structure has about the same properties as a 125-foot vertical. It thus works quite well as an antenna on 1.8 and 3.5 MHz for DX work requiring low-angle radiation.

Preparing the Structure

Usually some work on the tower system must be done before shunt-feeding is tried. If present, metallic guys should be broken up with insulators. They can be made to simulate top loading, if needed, by judicious placement of the first insulators. Don't overdo it; there is no need to "tune the radiator to resonance" in this way since a shunt feed is employed. If the tower is fastened to a house at a point more than about one-fourth of the height of the tower, it may be desirable to insulate the tower from the building. Plexiglas sheet, ¼-inch or more thick, can be bent to any desired shape for this purpose if it is heated in an oven and bent while hot.

All cables should be taped tightly to the tower, on the inside, and run down to the ground level. It is not necessary to bond shielded cables to the tower electrically, but there should be no exceptions to the down-to-the-ground rule.

A good system of buried radials is very desirable. The ideal would be 120 radials, each 250 feet long, but fewer and shorter ones must often suffice. You can lay them around corners of houses, along fences or sidewalks, wherever they can be put a few inches under the surface, or even on the ground. Aluminum clothesline wire may be used extensively in areas where it will not be subject to corrosion. Neoprene-covered aluminum wire will be better in highly acid soils. Contact with the soil is not important. Deep-driven ground rods and connection to underground copper water pipes may be helpful, if available, especially to provide some protection from lightning.

Installing the Shunt Feed

Principal details of the shunt-fed tower for 1.8 and 3.5 MHz are shown in **Figure 9.29**. Rigid rod or tubing can be used for the feed portion, but heavy gauge aluminum or copper wire is easier to work with. Flexible stranded #8 AWG copper wire is used at K6SE for the 1.8-MHz feed, because when the tower is cranked down, the feed wire must come down with it. Connection is made at the top, 68 feet, through a 4-foot length of aluminum tubing clamped to the top of the tower, horizontally. The wire is clamped to the tubing at the outer end, and runs down vertically through standoff insulators. These are made by fitting 12-inch lengths of PVC plastic water pipe over 3-foot lengths of aluminum tubing. These are clamped to the tower at 15- to 20-foot intervals, with the bottom clamp about 3 feet above ground. These lengths allow for adjustment of the tower-to-wire spacing over a range of about 12 to 36 inches, for impedance matching.

The gamma-match capacitor for 1.8 MHz is a 250-pF variable with about ⅙-inch plate spacing. This is adequate

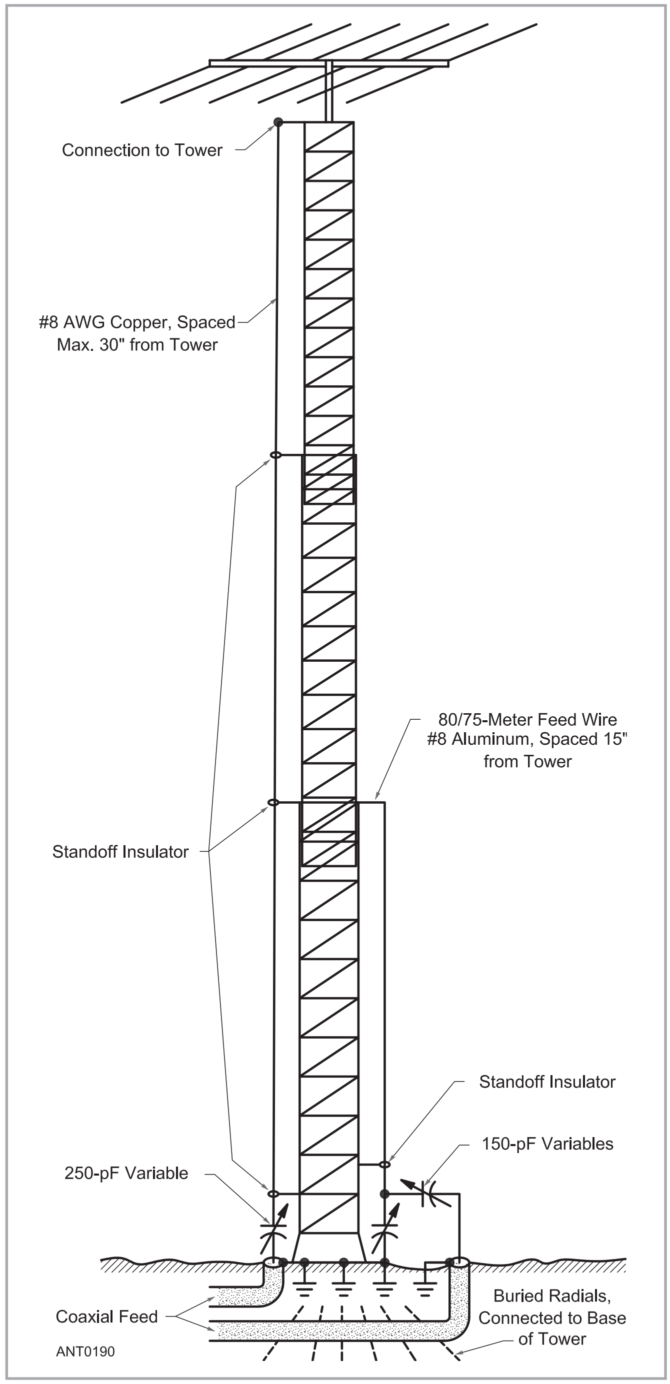


Figure 9.29 — Principal details of the shunt-fed tower at K6SE (SK). The 1.8-MHz feed, left side, connects to the top of the tower through a horizontal arm of 1-inch diameter aluminum tubing. The other arms have standoff insulators at their outer ends, made of 1-foot lengths of plastic water pipe. The connection for 3.5 to 4 MHz, right, is made similarly, at 28 feet, but two variable capacitors are used to permit adjustment of matching with large changes in frequency.

for power levels up to about 200 W. A large transmitting or a vacuum-variable capacitor should be used for high-power applications.

Tuning Procedure

The 1.8-MHz feed wire should be connected to the top of the structure if it is 75 feet tall or less. Mount the standoff insulators so as to have a spacing of about 24 inches between wire and tower. Pull the wire taut and clamp it in place at the bottom insulator. Leave a little slack below to permit adjustment of the wire spacing, if necessary.

Adjust the series capacitor in the 1.8-MHz line for minimum reflected power, as indicated on an SWR meter connected between the coax and the connector on the capacitor housing. Make this adjustment at a frequency near the middle of your expected operating range. If a high SWR is indicated, try moving the wire closer to the tower. Just the lower part of the wire need be moved for an indication as to whether reduced spacing is needed. If the SWR drops, move all insulators closer to the tower, and try again.

If the SWR goes up, increase the spacing. There will be a practical range of about 12 to 36 inches. If going down to 12 inches does not give a low SWR, try connecting the top a bit farther down the tower. If wide spacing does not make it, the omega match shown for 3.5 MHz should be tried. No adjustment of spacing is needed with the latter arrangement, which may be necessary with short towers or installations having little or no top loading.

The two-capacitor arrangement in the omega match is also useful for working in more than one 25-kHz segment of the 160 meter band. Tune up on the highest frequency, say 1990 kHz, using the single capacitor, making the settings of wire spacing and connection point permanent for this frequency. To move to the lower frequency, say 1810 kHz, connect the second capacitor into the circuit and adjust it for the new frequency. Switching the second capacitor in and out then allows changing from one segment to the other, with no more than a slight retuning of the first capacitor.

9.2.6 ELEVATED GROUND-PLANE ANTENNAS

This section describes a simple and effective means of using a grounded tower, with or without top-mounted antennas, as an elevated ground-plane antenna for 80 and 160 meters. It first appeared in a June 1994 *QST* article by Thomas Russell, N4KG.

From Sloper to Vertical

Recall the quarter-wavelength sloper, also known as the *half sloper*. (The half sloper is covered later in this chapter in more detail.) It consists of an isolated quarter wavelength of wire, sloping from an elevated feed point on a grounded tower. Best results are usually obtained when the feed point is somewhere below a top-mounted Yagi antenna. You feed a sloper by attaching the center conductor of a coaxial cable to the wire and the braid of the cable to the tower leg. Now, imagine four (or more) slopers, but instead of feeding each individually, connect them together to the center conductor of a single feed line. Voilà! Instant elevated ground plane.

Table 9.3
Effective Loading of Common Yagi Antennas

Antenna	*Boom Length (feet)*	*S (area, ft²)*	*Equivalent Loading (feet)*
3L 20	24	768	39
5L 15	26	624	35
4L 15	20	480	31
3L 15	16	384	28
5L 10	24	384	28
4L 10	18	288	24
3L 10	12	192	20
TH7	24	—	40 (estimated)
TH3	14	—	27 (estimated)

Now, all you need to do is determine how to tune the antenna to resonance. With no antennas on the top of the tower, the tower can be thought of as a fat conductor and should be approximately 4% shorter than a quarter wavelength in free space. Calculate this length and attach four insulated quarter-wavelength radials at this distance from the top of the tower. For 80 meters, a feed point 65 feet below the top of an unloaded tower is called for. The tower guys must be broken up with insulators for all such installations. For 160 meters, 130 feet of tower above the feed point is needed.

What can be done with a typical grounded-tower-and-Yagi installation? A top-mounted Yagi acts as a large capacitance hat, top loading the tower. Fortunately, top loading is the most efficient means of loading a vertical antenna.

The examples in **Table 9.3** should give us an idea of how much top loading might be expected from typical amateur antennas. The values listed in the *Equivalent Loading* column tell us the approximate vertical height replaced by the antennas listed in a top-loaded vertical antenna. To arrive at the remaining amount of tower needed for resonance, subtract these numbers from the non-loaded tower height needed for resonance. Note that for all but the 10 meter antennas, the equivalent loading equals or exceeds a quarter wavelength on 40 meters. For typical HF Yagis, this method is best used only on 80 and 160 meters.

Construction Examples

Consider this example: A TH7 triband Yagi mounted on a 40-foot tower. The TH7 has approximately the same overall dimensions as a full-sized 3-element 20 meter beam, but has more interlaced elements. Its equivalent loading is estimated to be 40 feet. At 3.6 MHz, 65 feet of tower is needed without loading. Subtracting 40 feet of equivalent loading, the feed point should be 25 feet below the TH7 antenna.

Ten $\lambda/4$ (65-foot) radials were run from a nylon rope tied between tower legs at the 15-foot level, to various supports 10 feet high. Nylon cord was tied to the insulated, stranded, #18 AWG wire, without using insulators. The radials are all

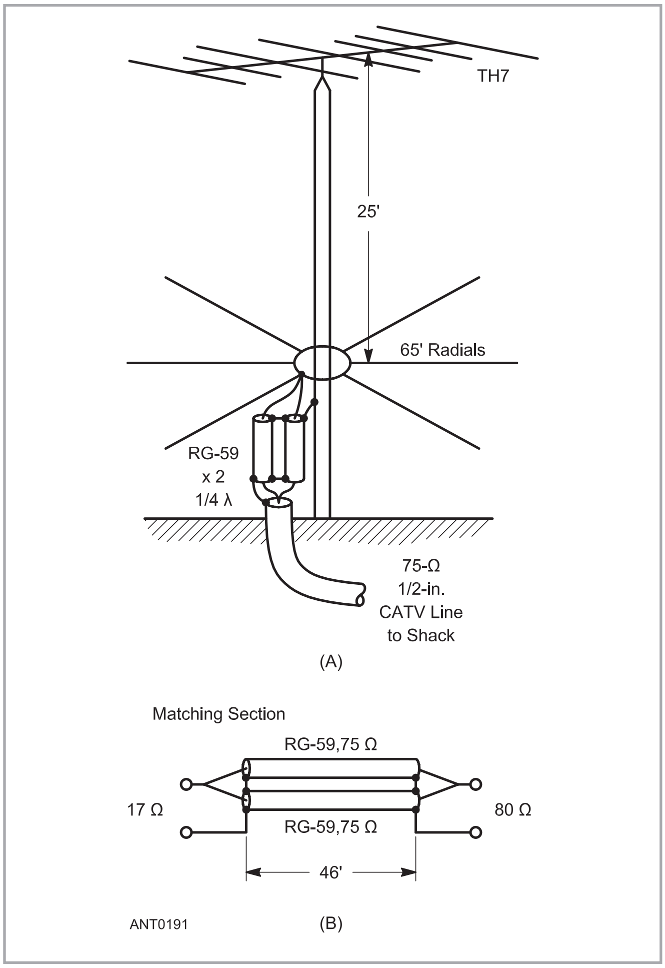


Figure 9.30 — At A, an 80 meter top-loaded, reverse-fed elevated ground plane, using a 40-foot tower carrying a TH7 triband Yagi antenna. At B, dimensions of the 3.6-MHz matching network, made from RG-59.

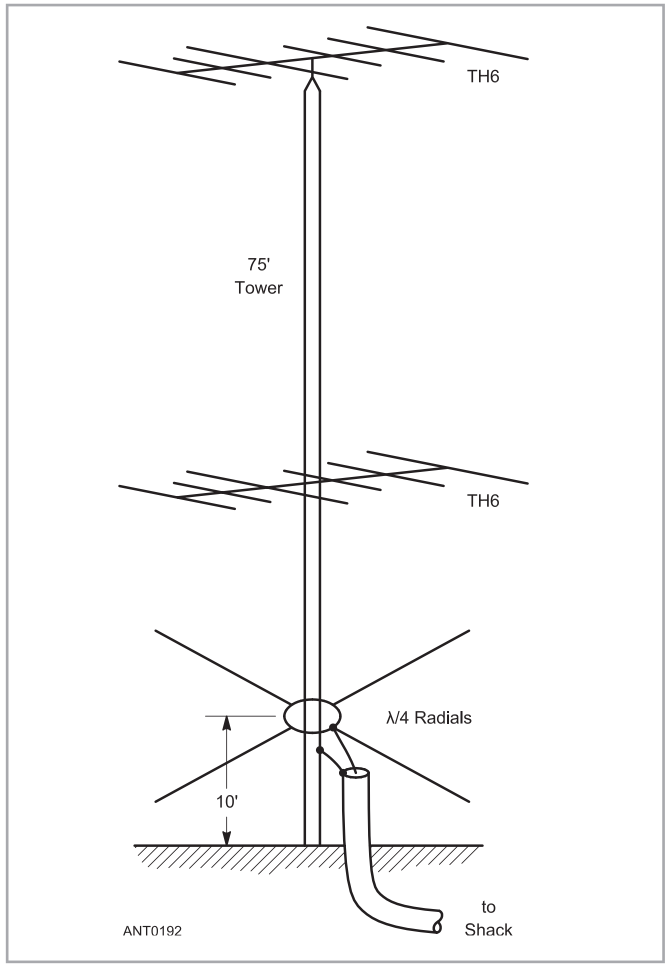


Figure 9.31 — A 160 meter antenna using a 75-foot tower carrying stacked triband Yagis.

connected together and to the center of an exact half wavelength (at 3.6 MHz) of RG-213 coax, which will repeat the antenna feed impedance at the other end. **Figure 9.30** is a drawing of the installation. The author used a Hewlett-Packard low-frequency impedance analyzer to measure the input impedance across the 80 meter band. An exact resonance (zero reactance) was seen at 3.6 MHz, just as predicted. The radiation resistance was found to be 17 Ω. The next question is, how to feed and match the antenna.

One good approach to 80 meter antennas is to tune them to the low end of the band, use a low-loss transmission line, and switch an antenna tuner in line for operation in the higher portions of the band. With a 50-Ω line, the 17-Ω radiation resistance represents a 3:1 SWR, meaning that an antenna tuner should be in-line for all frequencies. For short runs, it would be permissible to use RG-8 or RG-213 directly to the tuner. If you have a plentiful supply of low-loss 75-Ω CATV rigid coax, you can take another approach.

Make a quarter-wave (70 feet × 0.66 velocity factor = 46 feet) 37-Ω matching line by paralleling two pieces of RG-59 and connecting them between the feed point and a run of the rigid coax to the transmitter. The magic of quarter-wave matching transformers is that the input impedance (R_i) and output impedance (R_o) are related by:

$$Z_0^2 = R_i \times R_o \qquad \text{(Eq 2)}$$

For R_i = 17 Ω and Z_0 = 37 Ω, R_o = 80 Ω, an almost perfect match for the matching section made from 75-Ω CATV coax. The resulting 1.6:1 SWR at the transmitter is good enough for CW operation without a tuner.

160 Meter Operation

On the 160 meter band, a resonant quarter-wavelength requires 130 feet of tower above the radials. That's a pretty tall order. Subtracting 40 feet of top loading for a 3-element 20 meter or TH7 antenna brings us to a more reasonable 90 feet above the radials. Additional top loading in the form of more antennas will reduce that even more.

Another installation, using stacked TH6s on a 75-foot tower, is shown in **Figure 9.31**. The radials are 10 feet off the ground.

9.3 LOADING TECHNIQUES FOR SHORT ANTENNAS

The following section was contributed by Rudy Severns, N6LF, who is well-known for his work with vertical antennas and the effects of ground. He has also been active as part of the WD2SXH ARRL experimental license team, evaluating amateur use of the proposed 630 meter allocation, including antenna system design and installation.

9.3.1 SHORT VERTICAL ANTENNAS

A λ/4 vertical can be a simple and efficient antenna but at lower operating frequencies it becomes increasingly difficult to accommodate the full λ/4 height and a set of full-length λ/4 radials. For example, at 3.7MHz λ/4 ≈ 66 feet, at 1.83 MHz λ/4 ≈ 134 feet, at 475 kHz λ/4 ≈ 518 feet and at 137 kHz λ/4 ≈ 1800 feet – more than 1/4 mile! Fortunately it's not necessary to make the antenna full-size (λ/4). With careful design the size of the antenna can be reduced by half or even much more while retaining reasonable efficiency and radiation pattern. Some form of loading, inductive and/or capacitive, will be needed both for matching and to maximize efficiency. When height falls below 0.1 λ, such as for typical suburban locations, design becomes more difficult but usable antennas are still possible.

The operating bandwidth of a shortened antenna will be reduced because shortened antennas have higher Q. This translates into a more rapid increase of reactance away from resonance. The effect can be mitigated to some extent by using larger-diameter conductors but bandwidth will still be a problem, particularly on the 3.5 to 4 MHz band which is very wide (13.3%) in proportion to the center frequency of 3.75 MHz.

This section discusses vertical antennas with heights (H) < λ/4 employing inductive and/or capacitive loading. The focus is on antennas for the current US amateur bands of 80 and 160 meters, along with anticipated allocations at 630 and 2200 meters. The loading techniques discussed here can also be used at higher frequencies and for horizontal antennas.

One word of advice: very short verticals rely on heavy capacitive top-loading to obtain reasonable efficiency. The details of the loading arrangements will vary at each location due to wide variations in available supports (poles, trees, and so on) or lack thereof. While it is possible to make approximate calculations for each structure to approximate the efficacy of a particular choice, it is much easier to model multiple possibilities using antenna modeling software and then choose the best design. Suitable software is available both free and at modest cost. (See the chapter on **Antenna Modeling**.) The use of modeling software can be of great help in optimizing a design for a particular installation and is strongly recommended.

9.3.2 EFFICIENCY OF SHORT VERTICALS

The essential problem of short antennas, generally, is that of efficiency. **Table 9.4** illustrates the dramatic effect of reducing an 80 meter vertical's physical height by adding base loading inductance. (Perfect ground and conductors are assumed in this design. The vertical section is 2 inches in diameter.) **Figure 9.32** graphs the feed point resistance (R_r), the magnitude of the capacitive reactance ($|X_C|$) and Q (Q_a) for an ideal vertical as a function of height (H in wavelengths), where $Q_a = |X_C|/R_r$. At resonance $R_r = 36\ \Omega$ and $X_C = 0$ but as H is reduced below resonance R_r falls quickly and $|X_C|$ increases very rapidly. For example when H = 0.125 λ, $R_r \approx 6.5\ \Omega$ and $|X_C| \approx 500\ \Omega$. As H is reduced further, R_r decreases proportional to H^2 and $|X_C|$ increases proportional to 1/H. As a result, Q_a increases proportional to $1/H^3$! Short antennas have low radiation resistances and high capacitive reactances at the feed point which becomes especially acute on 2200 meters where only very short (in terms of λ) verticals are practical. Short antennas also have very high Q resulting in narrow operating bandwidths.

From **Figure 9.32** we can see that a short vertical is essentially a capacitor in series with a resistance as shown by the electrical model in **Figure 9.33**.

In addition to R_r and X_C a real antenna will have several sources of loss:

- R_L — loading coil series resistance where $R_L = X_L/Q_L$, Q_L = inductor Q.
- R_g — equivalent ground loss resistance.
- R_c — conductor resistance.

Table 9.4
Effect of Shortening a Vertical Radiator Below λ/4 Using Inductive Base Loading.
Frequency is 3.525 MHz and for the Inductor Q_L = 200. Ground and conductor losses are omitted.

Length (feet)	*Length (λ)*	*R_r (Ω)*	*X_C (Ω)*	*R_L (Ω)*	*Efficiency (%)*	*Loss (dB)*
14	0.050	0.96	–761	3.8	20	–7.0
20.9	0.075	2.2	–533	2.7	45	–3.5
27.9	0.100	4.2	–395	2.0	68	–1.7
34.9	0.125	6.8	–298	1.5	82	–0.86
41.9	0.150	10.4	–220	1.1	90	–0.44
48.9	0.175	15.1	–153	0.77	95	–0.22
55.8	0.200	21.4	–92	0.46	98	–0.09
62.8	0.225	29.7	–34	0.17	99	–0.02

- R_l — losses due to leakage across the base insulator and insulators at wire ends.
- R_{cor} — corona loss at high voltage points. This can be a problem at higher altitudes.

R_n — Matching network losses

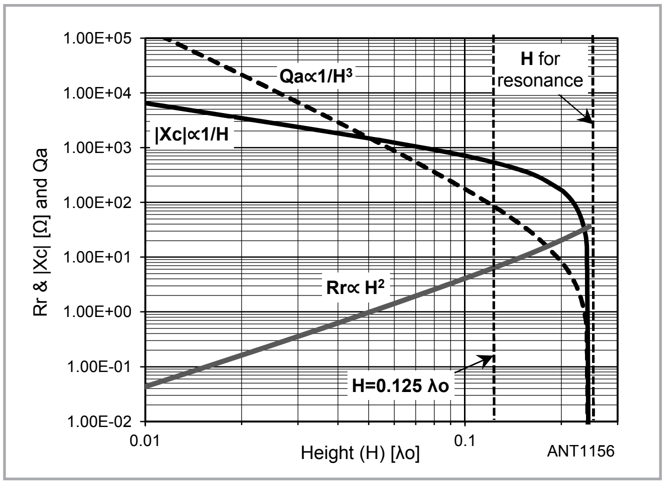


Figure 9.32 — Base impedances and Q of a lossless vertical over perfect ground.

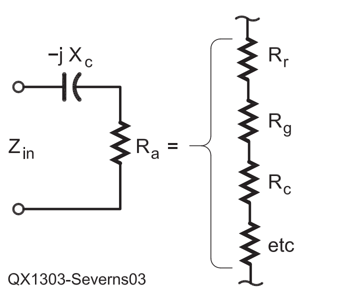


Figure 9.33 — Equivalent circuit for a short vertical including loss elements.

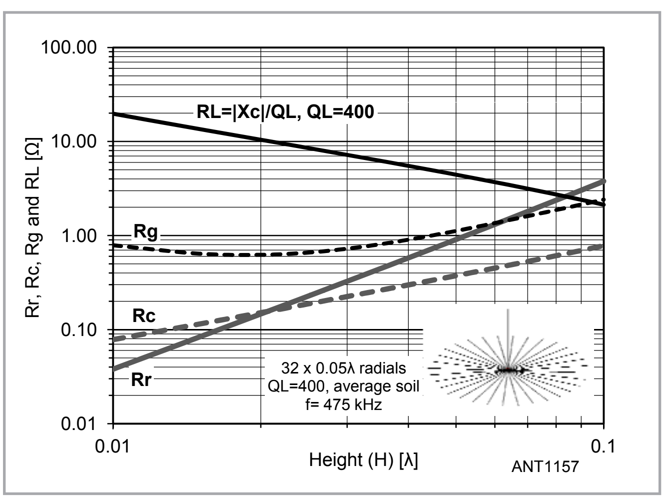


Figure 9.34 — Typical values for R_r, R_c, R_L and R_g as a function of H.

Figure 9.34 shows an example of typical values of R_r, R_c, R_g and R_L for a short vertical with a radial ground system over average soil. This example is for 630 meters but 160 and 80 meter verticals of the same electrical heights (in λ) will be similar.

Antenna efficiency (η) can be expressed as:

$$\eta = \frac{R_r}{R_r + \left(R_L + R_g + R_c + R_l + R_{cor} + R_n\right)} = \frac{R_r}{R_r + R_{loss}} \qquad \text{(Eq 3)}$$

The design goal is to increase efficiency by increasing R_r and decreasing R_{loss}.

9.3.3 BASE LOADING

A vertical with $H < l_o/4$ will require some form of loading and matching. The base of the antenna is a convenient point at which to add a loading inductor as shown in **Figure 9.35**.

Ignoring R_l, R_{cor} and R_n for the present, we can use Eq 1 and the loss resistance values in Figure 9.34 to graph the efficiency of that antenna as shown in **Figure 9.36**. H=0.01λ corresponds to a 72 foot vertical at 137 kHz. The efficiency is <0.2%!

The dashed line in Figure 9.36 shows the efficiency when only R_L is included compared to the sum of R_L and R_g (the solid line). This graph has a strong message: *Make the vertical as tall as possible (when H<λ/4) because even small increases in H can substantially improve efficiency.*

This graph also illustrates the low efficiency intrinsic to short base-loaded verticals. The efficiency of very short verticals is dominated by R_L because the resonating inductance value is large and therefore R_L is large ($R_L = X_C/Q_L$)**.** We can increase Q_L to reduce R_L but there are practical limits.

The base of the antenna is a convenient point at which to add a loading inductor, but it's usually not the lowest loss point at which an inductor could be placed. There is an extensive discussion of the optimum location for the loading coil in a short vertical as a function of ground loss and Q_L in the **Mobile and Maritime HF Antennas** chapter. This information should be reviewed before using inductive loading. Available for download from **www.arrl.org/arrl-antenna-book-reference** is the program *MOBILE.EXE*. This is an excellent tool for designing short, inductively loaded antennas. A loading inductor at the base has no effect on R_r but moving the loading coil from the base to near the middle can increase R_r significantly.

9.3.4 CAPACITIVE TOP-LOADING

As shown above, inductive loading is not a very efficient way to compensate for reduced antenna height. Capacitive top loading can be much more effective as shown in the example illustrated by **Table 9.5** for a top-loaded 3.525 MHz vertical made of 2-inch tubing. The vertical section is L_1 and the horizontal top-loading section is L_2, also a piece of 2-inch tubing adjusted to make the antenna resonant. As with the previous example, perfect ground and conductors are assumed.

A simple example using a wire suspended between two supports forming a "T" antenna is shown in **Figure 9.37**. We

Table 9.5
Effect of Shortening a Vertical Using Top Loading

L1 (feet)	*L2 (feet)*	*Length (λ)*	*R_r (Ω)*
14.0	48.8	0.050	4.0
20.9	38.6	0.075	8.5
27.9	30.1	0.100	14.0
34.9	22.8	0.125	19.9
41.9	17.3	0.150	25.5
48.9	11.9	0.175	30.4
55.8	7.0	0.200	33.9
62.8	2.4	0.225	35.7

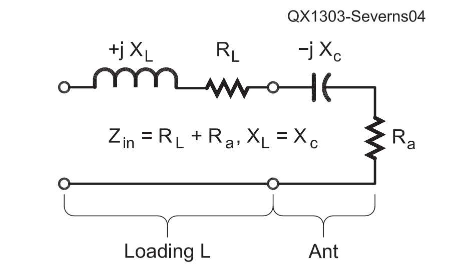


Figure 9.35 — Equivalent circuit for inductive base

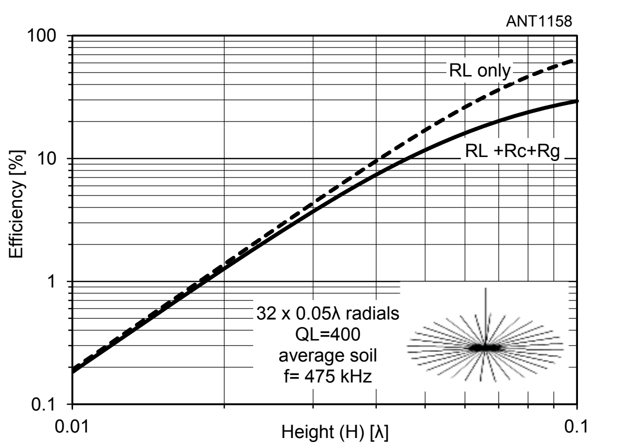


Figure 9.36 — Example of efficiency as a function of height.

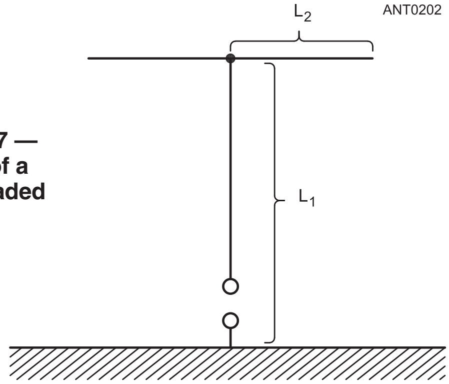


Figure 9.37 — Example of a "T" top-loaded vertical.

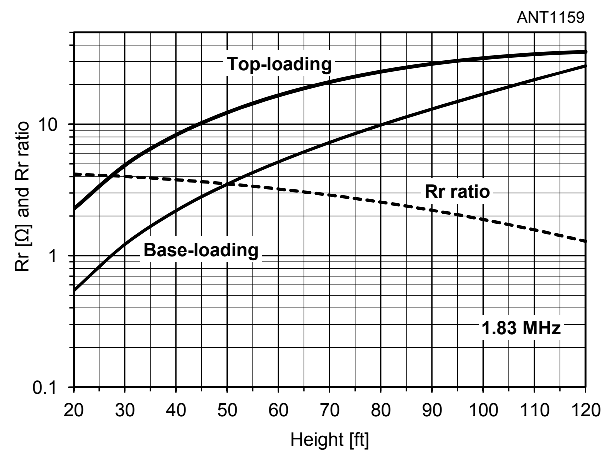


Figure 9.38 — R_r comparison between top and base loading.

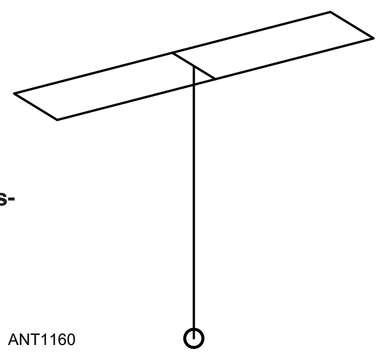


Figure 9.39 — Two wire top-loading using conductive spreaders.

can model this antenna varying H and adjusting L to resonate the antenna to illustrate the advantages of top-loading. A comparison of R_r between capacitive top-loading and inductive base loading is given in **Figure 9.38**. The dashed line shows the ratio of R_r-top to R_r-base. For a given vertical height, resonating the antenna with top-loading results in much higher radiation resistance R_r.

Compared to inductive base loading, top-loading significantly increases R_r while base loading does not. For Example, if H=20 feet (≈0.04λ @1.83 MHz) R_r with top-loading is over four times that for base loading. Besides increasing R_r, top-loading can reduce or eliminate R_L due to reduction in value of the base inductor. The net result can be a dramatic improvement in efficiency! As shown in **Figure 9.39** we can use multiple wires to obtain even more top-loading.

Figure 9.40 compares the span (= 2L, see Figure 9.37) of the top-loading wire(s) when using one or two wires. The use of two wires with conductive spreaders such as aluminum tubing significantly reduces the spacing (span) required between the supports for the top-loading wires. The span can be further reduced by using longer spreaders and additional well-spaced parallel wires. The design of this kind of top-loading will vary with every installation. Antenna modeling software will be of great assistance for optimizing the design.

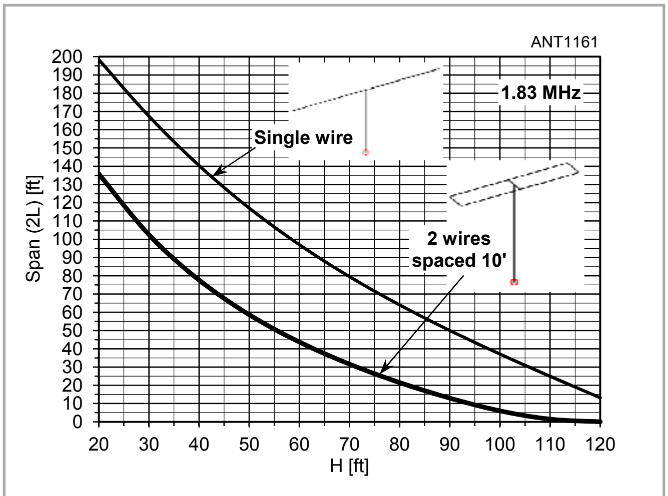


Figure 9.40 — Span (=2L) of the top hat for one or two wires.

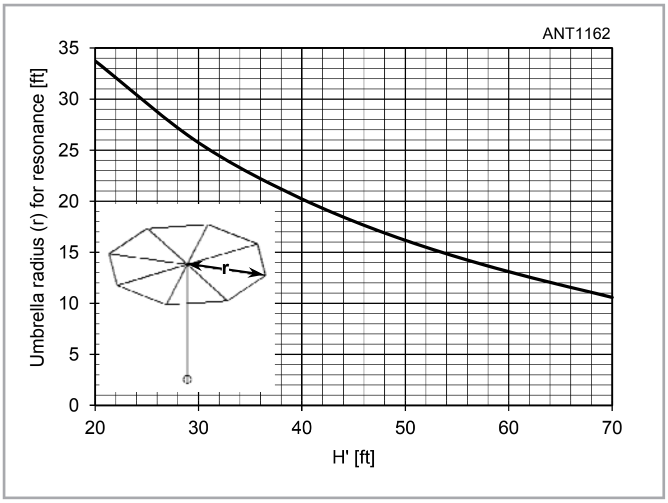


Figure 9.41 — Wagon wheel top-hat example.

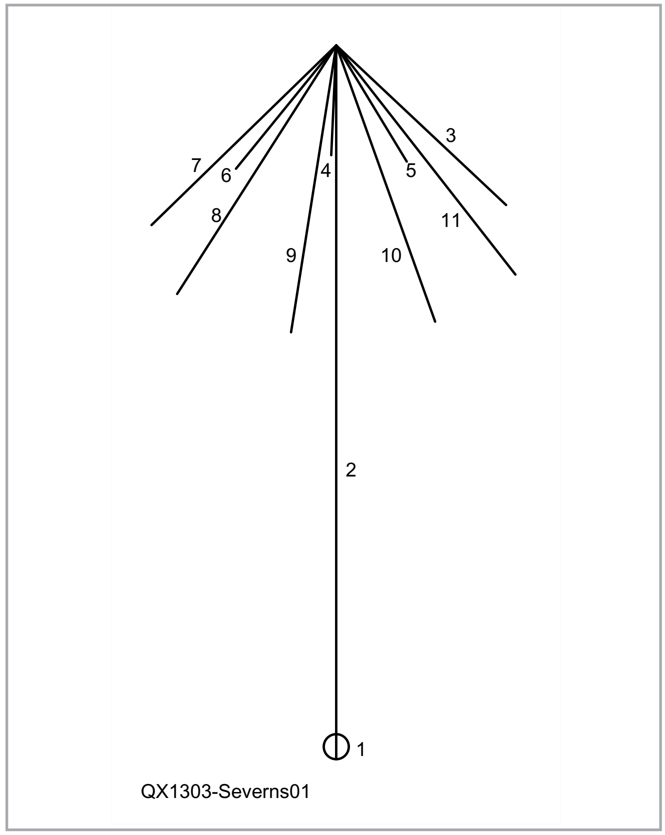


Figure 9.42 — Umbrella top-loading example.

(L.B. Cebik, W4RNL, also analyzed top-hat loading, comparing it to inductive loading. See the Bibliography.)

When no supports other than the vertical itself are available a top-hat using rigid spreaders can be used. **Figure 9.41** is a sketch of this kind of "wagon-wheel" top-hat along with the required radius for resonance at 1.83 MHz for a range of vertical heights. A simple way to make a capacitance hat would be to take four to six 8-foot CB mobile whips, arrange them like spokes in a wagon wheel and connect the ends with a peripheral wire. This arrangement will produce a 16-foot diameter hat that is economical and very durable. The whip lengths can be extended further with lengths of aluminum tubing. Another approach for a large hat would be to salvage the hub and spreaders from an old 20 meter quad and use them for the wagon-wheel.

Unfortunately, radii greater than ≈15 feet become increasingly impractical. The rigid supports can be replaced with wires sloping downward as shown in **Figure 9.42** to form what is called an "umbrella" vertical. To increase the loading effect of the umbrella more wires can be used as well as a skirt wire like that shown in Figure 9.41. The wires can also be made longer but there is a point where the reduction in R_L due to a smaller resonating inductor is offset by the decreasing value of R_r due to canceling currents flowing in the umbrella wires. This is situation where optimization is best done using modeling software.

Finding Capacitance Hat Size

Practically any sufficiently large metallic structure can be used for capacitive loading and the structure doesn't even have to be symmetric, but simple geometric forms such as the sphere, cylinder and disc are preferred because of the relative ease with which their capacitance can be calculated.

While antenna modeling software is very helpful for the design of top-loading structures the capacitance of common geometric forms can be estimated from the curves of **Figure 9.43** as a function of size. For the cylinder, the length is specified equal to the diameter. The sphere, disc and cylinder can be constructed from sheet metal, if such construction is feasible, but the capacitance will be almost the same if a "skeleton" type of construction with screen or wire networks or tubing is used.

The required value of the capacitance may be determined using the following procedure. The information in this section is based on a September 1978 *QST* article by Walter Schulz, K3OQF. (see Bibliography) The physical

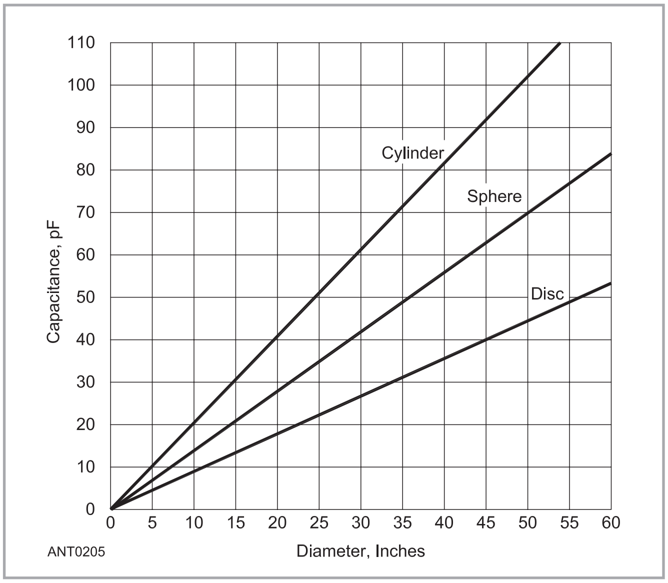


Figure 9.43 — Capacitance of sphere, disc and cylinder as a function of their diameters. The cylinder length is assumed equal to its diameter.

length of a shortened antenna can be found from:

$$h_{inches} = \frac{11808}{F_{MHz}} \qquad \text{(Eq 4)}$$

where h is length in inches and λ is the electrical length in wavelengths.

Thus, using an example of 7 MHz and a shortened length of 0.167 λ, h = 11808/7 × 0.167 = 282 inches, equivalent to 23.48 feet.

Consider the vertical radiator as an open-ended transmission line, so the impedance and top loading may be determined. The characteristic impedance of a vertical antenna can be found from

$$Z_0 = 60\left[\ln\left(\frac{4h}{d}\right) - 1\right] \qquad \text{(Eq 5)}$$

where
ln = natural logarithm
h = length (height) of vertical radiator in inches (as above)
d = diameter of radiator in inches

The vertical radiator for this example has a diameter of 1 inch. Thus, for this example,

$$Z_0 = 60\left[\ln\left(\frac{4 \times 281}{1}\right) - 1\right] = 361\,\Omega$$

The capacitive reactance required for the amount of top loading can be found from

$$X_C = \frac{Z_0}{\tan\theta} \qquad \text{(Eq 6)}$$

where
X_C = capacitive reactance, ohms
Z_0 = characteristic impedance of antenna (from Eq 4)
θ = amount of electrical loading, degrees.

This value for a 30° hat is 361/tan 30° = 625 Ω. This capacitive reactance may be converted to capacitance with the following equation,

$$C = \frac{10^6}{2\pi f X_C} \qquad \text{(Eq 7)}$$

where
C = capacitance in pF
f = frequency, MHz
X_C = capacitive reactance, ohms (from above).

For this example, the required C = $10^6/(2\pi \times 7 \times 625)$ = 36.4 pF, which may be rounded to 36 pF. A disc capacitor is used in this example. The appropriate diameter for 36 pF of hat capacitance can be found from **Figure 9.43**. The disc diameter that yields 36 pF of capacitance is 40 inches.

Combined Loading

As an antenna is shortened, the size of the top-loading device will become larger and at some point it will become impractical to resonate the antenna with top-loading only. In that situation inductive loading, usually placed either at the base or directly between the capacitance "hat" and the top of the antenna, can be added to resonate the antenna. An

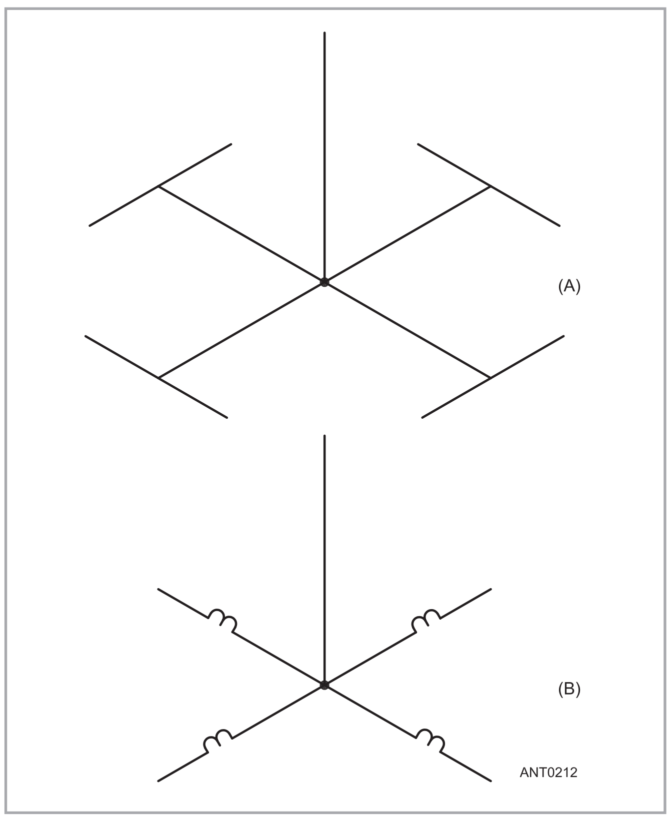


Figure 9.44 — Radials may be shortened by using either capacitive (A) or inductive (B) loading. In extreme cases both may be used but the operating bandwidth will be limited.

alternative would be to use linear loading in place of inductive loading.

Shortening Radials

Very often the space required by full-length radials is not available. Like the vertical portion of the antenna, the radials can also be shortened and loaded in very much the same way. An example of end-loaded radials is given in **Figure 9.44A**. Radials half the usual length can be used with little reduction in efficiency but, as in the case of top loading, the antenna Q will be higher and the bandwidth reduced. As shown in **Figure 9.44B,** inductive loading can also be used. As long as they are not made too short (down to 0.1λ) loaded radials can be efficient — with careful design.

9.3.5 GENERAL RULES FOR LOADING VERTICAL ANTENNAS

Sound advice on the design of LF and MF antennas was given many years ago by Woodrow Smith: *"The main object in the design of low frequency transmitting antenna systems can be summarized briefly by saying that the general idea is to get as much wire as possible as high in the air as possible and to use excellent insulation and an extensive ground system*."

We can codify this advice in order of priority:

- Make the height as great as practical up to the point where H = λ/4.
- Provide as much top loading as possible.
- Make the diameter of the vertical section large. Tubing or a cage of smaller wires will work well.
- If the capacitive loading is insufficient, resonate the antenna with a high-Q inductor placed between the hat and the top of the antenna.
- For buried-ground systems, use as many radials (>0.2 λ) as possible, 32 or more is best.
- If an elevated ground plane is used, use 12 or more radials, 5 or more feet above ground.
- Use of high-quality insulators at the base and wire ends.
- If shortened radials must be used, capacitive loading is preferable to inductive loading.

9.3.6 LINEAR LOADING

Another alternative to inductive loading is *linear loading*. This little-understood method of shortening radiators can be applied to almost any antenna configuration — including parasitic arrays. Although commercial antenna manufacturers make use of linear loading in their HF antennas, relatively few hams have used it in their own designs. Linear loading can be used to advantage in many antennas because it introduces relatively little loss, does not degrade directivity patterns, and has low enough Q to allow reasonably good bandwidth. Some examples of linear-loaded antennas are shown in **Figure 9.45**.

Since the dimensions and spacing of linear-loading devices vary greatly from one antenna installation to another, the best way to employ this technique is to try a length of conductor 10% to 20% longer than the difference between the shortened antenna and the full-size dimension for the linear-loading device. Then use the "cut-and-try" method, varying both the spacing and length of the loading device to optimize the match. A hairpin match at the feed point can be useful in achieving a 1:1 SWR at resonance.

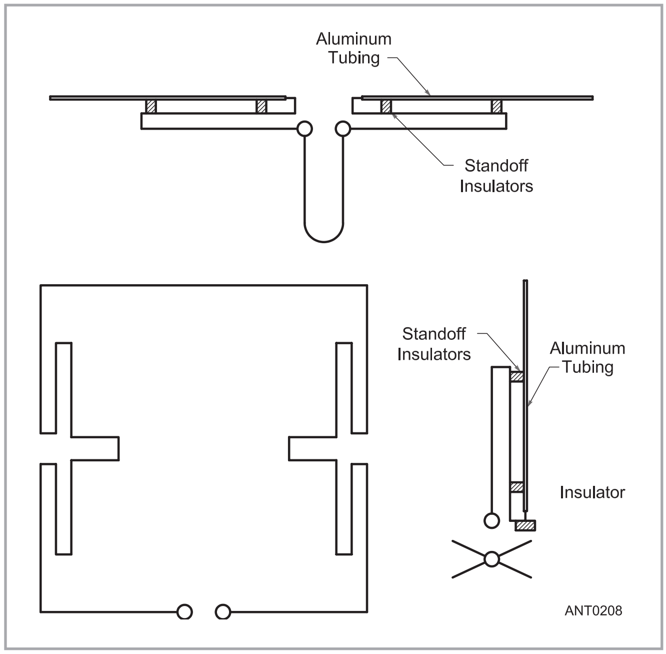


Figure 9.45 — Some examples of linear loading. The small circles indicate the feed points of the antennas.

Linear-Loaded Short Wire Antennas

More detail on linear loading is provided in this section, which was originally presented in *The ARRL Antenna Compendium Vol 5* by John Stanford, NNØF. Linear loading can significantly reduce the required length for resonant antennas. For example, it is easy to make a resonant antenna that is as much as 30 to 40% shorter than an ordinary dipole for a given band. The shorter overall lengths come from bending back some of the wire. The increased self-coupling lowers the resonant frequency. These ideas are applicable to short antennas for restricted space or portable use.

Experiments

The results of the measurements are shown in **Figure 9.46** and are also consistent with values given by Rashed and Tai from an earlier paper. This shows several simple wire antenna configurations, with resonant frequencies and impedance (radiation resistance). The reference dipole has a resonant frequency f_0 and resistance R = 72 Ω. The f/f_0 values give the effective reduced frequency obtained with the linear loading in each case. For example, the two-wire linear-loaded dipole has its resonant frequency lowered to about 0.67 to 0.70 that of the simple reference dipole of the same length.

The three-wire linear-loaded dipole has its frequency reduced to 0.55 to 0.60 of the simple dipole of the same length. As you will see later, these values will vary with conductor diameter and spacing.

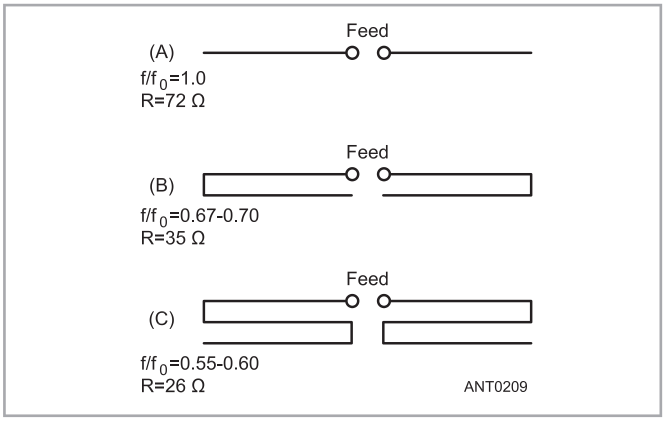


Figure 9.46 — Wire dipole antennas. The ratio f/f_0 is the measured resonant frequency divided by frequency f_0 of a standard dipole of same length. R is radiation resistance in ohms. At A, standard single-wire dipole. At B, two-wire linear-loaded dipole, similar to folded dipole except that side opposite feed line is open. At C, three-wire linear-loaded dipole.

The two-wire linear-loaded dipole (Figure 9.46B) looks almost like a folded dipole but, unlike a folded dipole, it is open in the middle of the side opposite where the feed line is attached. Measurements show that this antenna structure has a resonant frequency lowered to about two-thirds that of the reference dipole, and R equal to about 35 Ω. A three-wire linear-loaded dipole (Figure 9.46C) has even lower resonant frequency and R about 25 to 30 Ω.

Linear-loaded monopoles (one half of the dipoles in Figure 9.46) working against a radial ground plane have similar resonant frequencies, but with only half the radiation resistance shown for the dipoles.

A Ladder-Line Linear-Loaded Dipole

Based on these results, NNØF next constructed a linear loaded dipole as in Figure 9.46B, using 24 feet of 1-inch 450-Ω window line for the dipole length. He hung the system from a tree using nylon fishing line, about 4 feet from the tree at the top, and about 8 feet from the ground on the bottom end. It was slanted at about a 60° angle to the ground. This antenna resonated at 12.8 MHz and had a measured resistance of about 35 Ω. After the resonance measurements, he fed it with 1-inch ladder open-wire line (a total of about 100 feet to the shack).

For brevity, this is called a vertical LLSD (linear-loaded short dipole). A tuner resonated the system nicely on 20 and 30 meters. On these bands the performance of the vertical LLSD seemed comparable to his 120-foot long, horizontal center-fed Zepp, 30 feet above ground. In some directions where the horizontal, all-band Zepp has nulls, such as toward Siberia, the vertical LLSD was definitely superior. This system also resonates on 17 and 40 meters. However, from listening to various signals, NNØF had the impression that this length LLSD is not as good on 17 and 40 meters as the horizontal 120-foot antenna.

Using Capacitance End Hats

He also experimented with an even shorter resonant length by trying an LLSD with capacitance end-hats. The hats, as expected, increased the radiation resistance and lowered the resonant frequency. Six-foot long, single-wire hats were used on each end of the previous 24-foot LLSD, as shown in **Figure 9.47**. The antenna was supported in the same way as the previous vertical dipole, but the bottom-end hat wire was only inches from the grass. This system resonated at 10.6 MHz with a measured resistance of 50 Ω.

If the dipole section were lengthened slightly, by a foot or so, to about 25 feet, it should hit the 10.1-MHz band and be a good match for 50-Ω coax. It would be suitable for a restricted space, shortened 30 meter antenna. Note that this antenna is only about half the length of a conventional 30 meter dipole, needs no tuner, and has no losses due to traps. It does have the loss of the extra wire, but this is essentially negligible.

Any of the linear-loaded dipole antennas can be mounted either horizontally or vertically. The vertical version can be used for longer skip contacts — beyond 600 miles or so — unless you have rather tall supports for horizontal antennas to

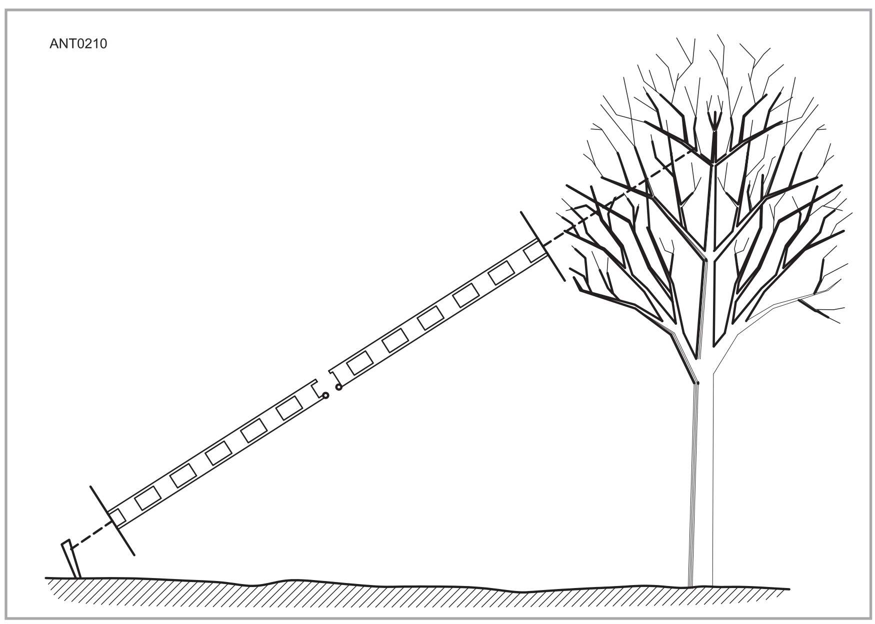


Figure 9.47 — Two-wire linear-loaded dipole with capacitance end hats. Main dipole length was constructed from 24 feet of "windowed" ladder line. The end-hat elements were stiff wires 6 feet long. The antenna was strung at about a 60° angle from a tree limb using monofilament fishing line. Measured resonant frequency and radiation resistance were 10.6 MHz and 50 Ω.

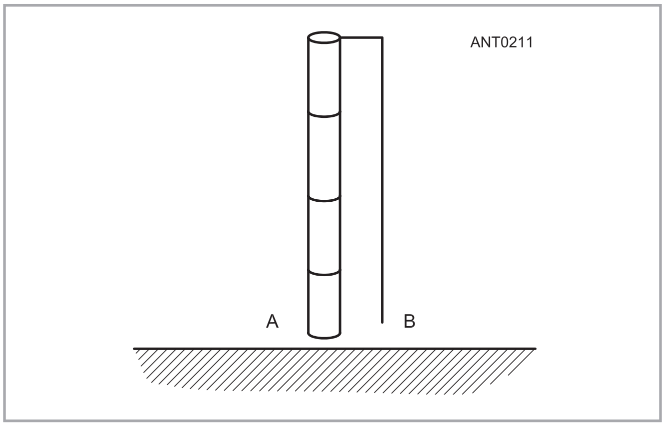


Figure 9.48 — Vertical ground-plane antenna with a 10-foot pipe and #12 AWG wire as the linear-loaded element. Resonant frequency and radiation resistance depend on which end (A or B) is fed. The other end (B or A) is *not* grounded. See text for details.

give a low elevation angle. Using different diameter conductors in linear-loaded antenna configurations yields different results, depending on whether the larger or small diameter conductor is fed. NNØF experimented with a vertical ground-plane antenna using a 10-foot piece of electrical conduit pipe (⅝ inch OD) and #12 AWG copper house wire.

Figure 9.48 shows the configuration. The radial ground system was buried a couple of inches under the soil and is not shown. Note that this is not a folded monopole, which would have either A or B grounded.

The two conductors were separated by 2 inches, using plastic spreaders held onto the pipe by stainless-steel hose clamps obtained from the local hardware store. Hose clamps intertwined at right angles were also used to clamp the pipe on electric fence stand-off insulators on a short 2 × 4 post set vertically in the ground.

The two different diameter conductors make the antenna characteristics change, depending on how they are configured. With the antenna bridge connected to the larger diameter conductor (point A in Figure 9.48), and point B unconnected, the system resonated at 16.8 MHz and had R = 35 Ω. With the bridge at B (the smaller conductor), and point A left unconnected, the resonance lowered to 12.4 MHz and R was found to be about 24 Ω.

The resonant frequency of the system in Figure 9.48 can be adjusted by changing the overall height, or for increasing the frequency, by reducing the length of the wire. Note that a 3.8-MHz resonant ground plane can be made with height only about half that of the usual 67 feet required, if the smaller conductor is fed (point B in Figure 9.48). In this case, the pipe would be left unconnected electrically. The lengths given above can be scaled to determine a first-try attempt for your favorite band. Resonant lengths will, however, depend on the conductor diameters and spacing.

The same ideas hold for a dipole, except that the lengths should be doubled from those of the ground plane in Figure 9.48. The resistance will be twice that of the ground plane.

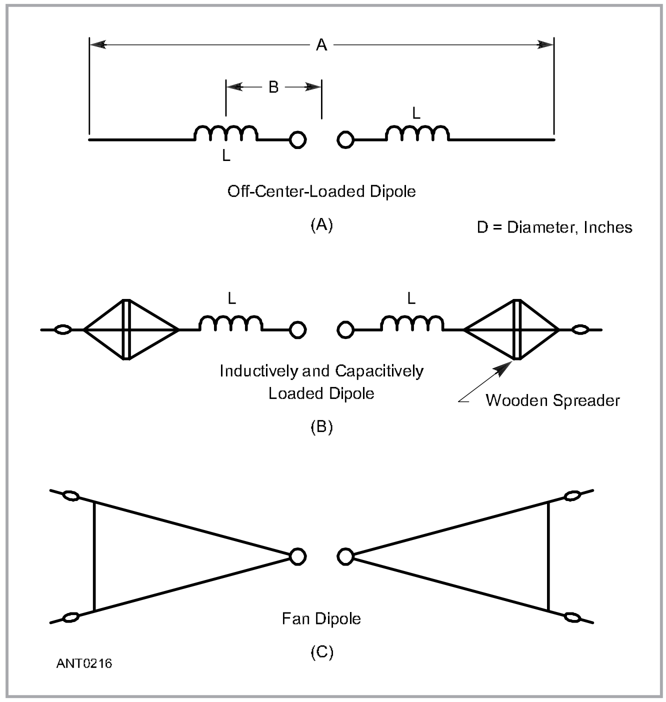


Figure 9.49 — At A is a dipole antenna lengthened electrically with off-center loading coils. For a fixed dimension A, greater efficiency will be realized with greater distance B, but as B is increase, L must be larger in value to maintain resonance. At B, capacitive loading of the ends will reduce the required inductance of the coils.

Say, how about a shortened 40 meter horizontal beam to enhance your signal?

9.3.7 INDUCTIVELY LOADED DIPOLES

Similar to inductive loading of vertical antennas, dipoles can also be shortened by inserting loading coils in the antenna. Two identical coils are used, one on each side of the feed point, placed equal distances from the feed point. To accomplish a specific amount of shortening, the farther from the feed point the coils are placed, the more reactance they must have.

The most serious drawback associated with inductive loading is loss in the coils themselves. It is important that you use "high-Q" inductors made from reasonably large wire or tubing to minimize this problem. Close winding of turns should also be avoided if possible. A good compromise is to use some off-center inductive loading in combination with capacitive end loading, keeping the inductor losses small and the efficiency as high as possible.

Some examples of off-center coil loading and capacitive-end loading are shown in **Figure 9.49.** This technique was described by Jerry Hall, K1TD in Sep 1974 *QST* and by Luiz Duarte Lopes, CT1EOJ in Oct 2003 *QST*. (These articles are included with this book's CD-ROM and are listed in the Bibliography.) Approximate inductive reactances for single-band resonance (for the antenna in Figure 9.49A only) may be determined with the aid of **Figure 9.50**. The final values

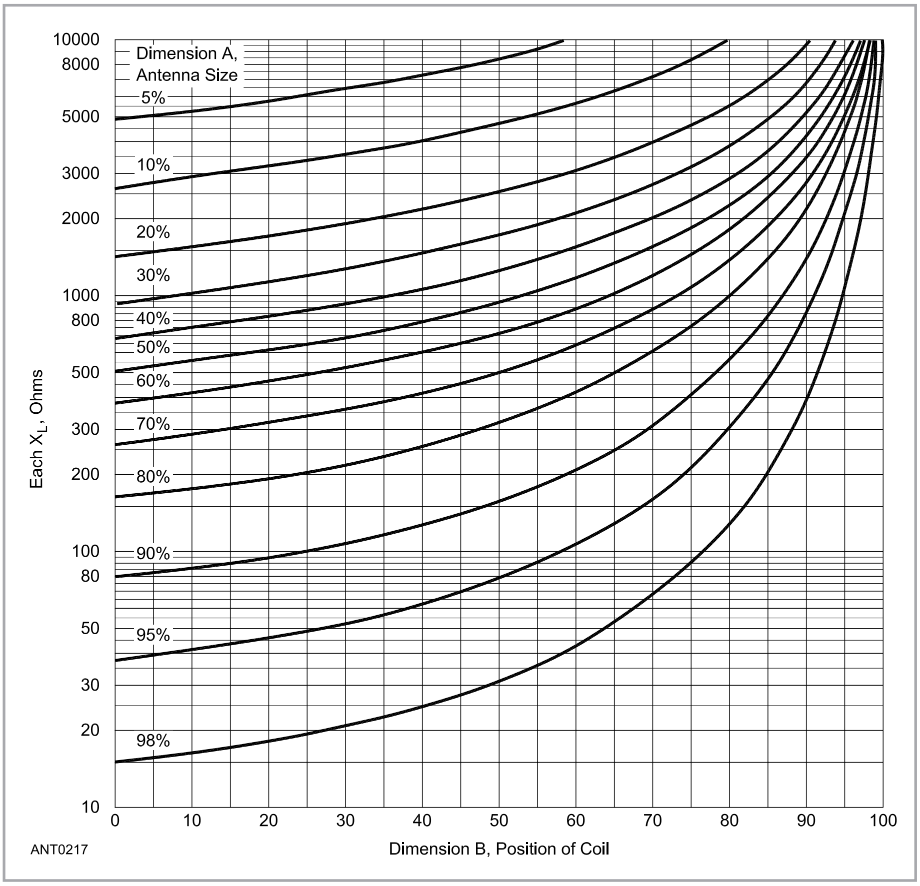


Figure 9.50 — Chart for determining approximate inductance values for off-center-loaded dipoles shown in Figure 9.49A. At the intersection of the appropriate curve from the body of the chart for dimension A and proper value for the coil position from the horizontal scale at the bottom of the chart, read the required inductive reactance for resonance from the scale at the left. Dimension A is expressed as percent length of the shortened antenna with respect to the length of a half-wave dipole of the same conductor material (that is, how much shorter than a full-size λ/2 dipole). Dimension B is expressed as the percentage of coil distance from the feed point to the end of the antenna. For example, a shortened antenna, which is 50% or half the size of a half-wave dipole (λ/4 overall) with loading coils positioned midway between the feed point and each end (50% out), would require coils having an inductive reactance of approximately 950 Ω at the operating frequency for antenna resonance.

will depend on the proximity of surrounding objects in individual installations and must be determined experimentally.

The use of high-Q low-loss coils is important for maximum efficiency. This is particularly important if high power is to be used. Several calculators and online articles are available to guide the antenna builder. Serge Stroobandt, ON4AA, has made available a sophisticated inductor design calculator web page at **hamwaves.com/antennas/inductance.html** which takes into account a number of important effects that affected the accuracy of earlier calculators. Tom Rauch, W8JI, has published a great deal of information about loading coils at **www.w8ji.com/loading_inductors.htm**. And as an example of building high-performance loaded antennas, Steve Babcock, VE6WZ, shows construction methods for some rugged 80 meter Yagi loading coils at **www.qsl.net/ve6wz/coil.htm**. One caveat for the coil winder — if you use copper tubing instead of wire, it is specified by its inside diameter, not the outside diameter, as is done for wire.

An antenna analyzer is recommended for use during adjustment of the system. Note that the minimum inductance required is for a center-loaded dipole where the coil is at the feed point (B=0). If the inductive reactance is read from Figure 9.50 for a dimension B of zero, one coil having approximately twice this reactance can be used near the center of the dipole. The 7 MHz “Shorty Forty” by Jack Sobel, WØSVM, shown in **Figure 9.51** illustrates this idea.

9.4 INVERTED-L ANTENNAS

The antenna shown in **Figure 9.51** is called an inverted-L antenna. It is simple and easy to construct and is a good antenna for the beginner or the experienced 1.8-MHz DXer. This antenna is a form of top-loaded vertical, where the top loading is asymmetrical. This results in both vertical and horizontal polarization because the currents in the top wire do not cancel like they would in a symmetrical-T vertical. This is not necessarily a bad thing because it eliminates the zenith null present in a true vertical. This allows for good communication at short ranges as well as for DX. The azimuthal radiation pattern is slightly asymmetrical with »1 to 2 dB increase in the direction opposite to the horizontal wire. This antenna requires a good buried ground system or elevated radials and will have a 2:1 SWR bandwidth of about 50 kHz on 160 meters.

Because the overall electrical length is made somewhat greater than λ/4, the feed point resistance is on the order of 50 Ω, with an inductive reactance. A resonant λ/4 vertical

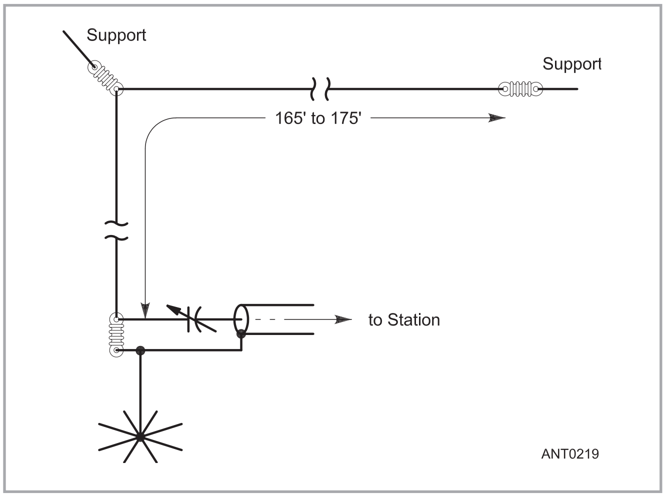


Figure 9.51 — The 1.8-MHz inverted-L. Overall wire length is 165 to 175 feet. The variable capacitor has a capacitance range from 100 to 800 pF, at 3 kV or more. Adjust antenna length and variable capacitor for lowest SWR.

monopole has a feed point impedance of approximately 36 Ω. To raise that impedance for a better match to 50 Ω, the antenna is lengthened.

At an electrical length of 102° a vertical wire antenna will have a feed point impedance of approximately $50 + j100\ \Omega$ over good ground. As an exercise, the inverted-L is designed at 1.82 MHz as a 45.6-meter (149.6-foot) vertical if constructed from #12 AWG wire.) That reactance is canceled by a series capacitor as indicated in the figure.

Bending part of the vertical so that it is parallel to the ground or sloping will change the feed point impedance and lower the resistive component. For example, with a 20-meter (65.6-foot) vertical section and the horizontal wire parallel to the ground, the resonant antenna (now 41.25 meters long overall) has a feed point impedance of only 20 Ω. As with the vertical antenna, the length is increased to raise the feed point impedance. With the horizontal section extended to 39.7 meters (130.25 feet) the feed point impedance becomes $50 + j517\ \Omega$. This requires a series capacitor of 169 pF to cancel the inductive reactance and reduce SWR to 1:1. Various other combinations of vertical and horizontal lengths behave similarly as shown in **Table 9.6**. (The dimensions can be scaled to 80 meters with approximately half the series capacitance required.) The inverted-L is an excellent antenna on which to practice modeling and matching skills.

As for other wire antennas, the bandwidth of the antenna can be improved by increasing its effective diameter. For example, making the vertical radiator out of window or ladder line with both conductors tied together at the top and bottom will show some increase in operating bandwidth, the horizontal section remaining a single wire. Jim Brown, K9YC, reports using a pair of #10 AWG wires spaced 10 inches apart increased the 1.5:1 SWR bandwidth of his L to 100 kHz. A tower can also be used as the vertical section as described below.

Table 9.6
Inverted L Dimensions for 50-Ω Feed Point Resistance at 1.82 MHz

Vertical Height (m)	*Horizontal Length (m)*	*Inductive Reactance (Ω)*	*Capacitance Required (pF)*
10	59.9	1238	71
20	39.7	517	169
30	21	235	372

Results modeled by *EZNEC 5.0* over real ground
Capacitance specified as series value to cancel inductive reactance

A yardarm attached to a tower or a tree limb can be used to support the vertical section. As with any vertical, for best results the vertical section should be as long as possible. A good ground system is necessary for good results — the better the ground, the better the results.

If you don't have the space for the inverted-L shown in Figure 9.51 (with its 115-foot horizontal section) and if you don't have a second tall supporting structure to make the top wire horizontal, consider sloping the top wire down toward ground. **Figure 9.52** illustrates such a setup, with a 60-foot high vertical section and a 79-foot sloping wire. As always, you will have to adjust the length of the sloping wire to fine-tune the resonant frequency. For a good ground radial system, the feed point impedance is about 12 Ω, which may be transformed to 50 Ω with a 25-Ω quarter-wave transformer consisting of two paralleled 50-Ω quarter-wave coaxes. The peak gain will decrease about 1 dB compared to the inverted-L shown in Figure 9.51. **Figure 9.53** overlays the elevation responses for average ground conditions. The 2:1 SWR bandwidth will be about 30 kHz, narrower than the larger system in Figure 9.51.

If the ground system suggested for Figures 9.42 and 9.43 is not practical, you can use a single elevated radial as shown in **Figure 9.54**. For the dimensions shown in the figure, $Z_i = 50 + j\ 498\ \Omega$, requiring a 175-pF series resonating capacitor. The azimuthal radiation pattern is shown

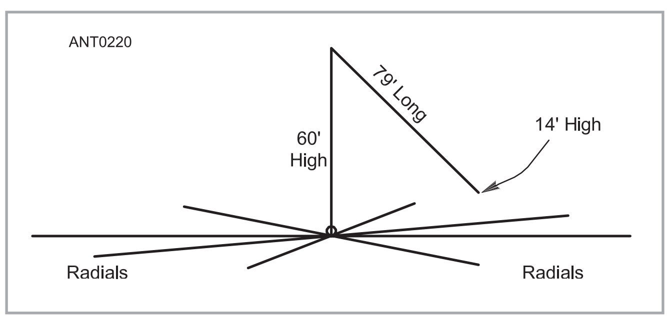


Figure 9.52— Sketch showing a modified 160 meter inverted-L, with a single supporting 60-foot high tower and a 79-foot long slanted top-loading wire. The feed point impedance is about 12 Ω in this system, requiring a quarter-wave matching transformer made of paralleled 50-Ω coaxes.

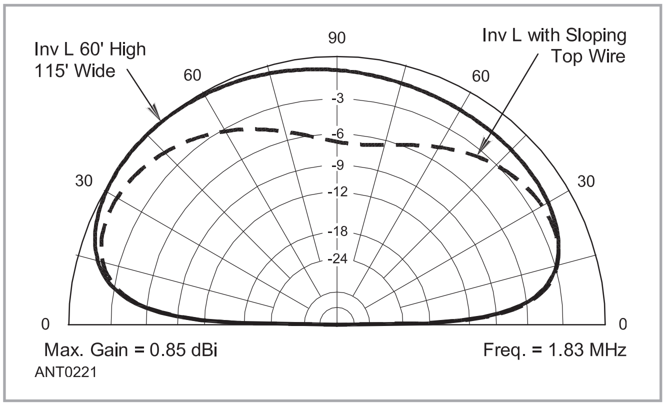


Figure 9.53 — Overlay of the elevation responses for the inverted-L antennas in Figure 9.51 (solid line) and Figure 9.52 (dashed line). The gains are very close for these two setups, provided that the ground radial system for the antenna in Figure 9.52 is extensive enough to keep ground losses low.

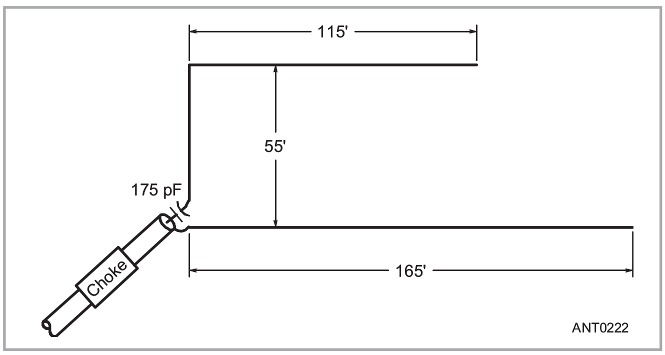


Figure 9.54 — A single elevated radial can be used for the inverted-L. This changes the directivity slightly. The series tuning capacitor is approximately 175 pF for this system.

in **Figure 9.55** compared to the inverted-L in Figure 9.42. Note that the 1 to 2 dB asymmetry is now in the direction of the horizontal wires, just the opposite of that for a symmetrical ground system. The 2:1 SWR bandwidth is about 40 kHz, assuming that the series capacitor is adjusted at 1.83 MHz for minimum SWR.

Figure 9.56 shows the azimuthal response at a 5° elevation angle for an 80 meter version of the inverted-L in Figure 9.42. The peak response occurs at an azimuth directly behind the direction in which the horizontal portion of the inverted-L points. For comparison, the response for a 100-foot high flattop dipole is also shown. The top wire of this antenna is only 40 feet high and the 2:1 SWR bandwidth is about 150 kHz wide with a good, low-loss ground-radial system.

Figure 9.56 illustrates that the azimuth response of an inverted-L is nearly omnidirectional. This gives such an antenna an advantage in certain directions compared to a flattop dipole, which is constrained by its supporting mounts (such as trees or towers) to favor fixed directions. For example, the flattop dipole in Figure 9.56 is at its weakest at azimuths of 90° and 270°, where it is down about 12 dB compared to the inverted-L. Hams who are fortunate enough to have high rotary dipoles or rotatable low-band Yagis have found them to be very effective antennas indeed.

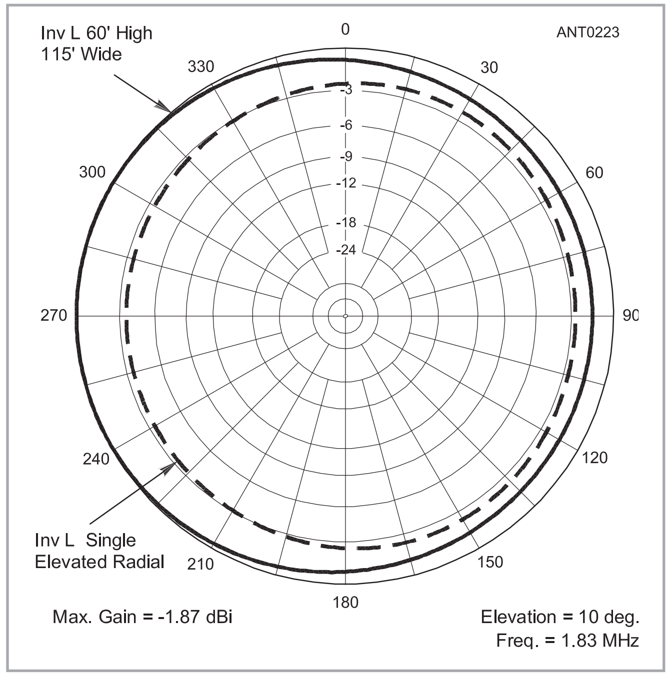


Figure 9.55 — Azimuthal pattern comparison for inverted-L antennas shown in Figure 9.51 (solid line) and the compromise, single-radial system in Figure 9.54 (dashed line). This is for a takeoff angle of 10°.

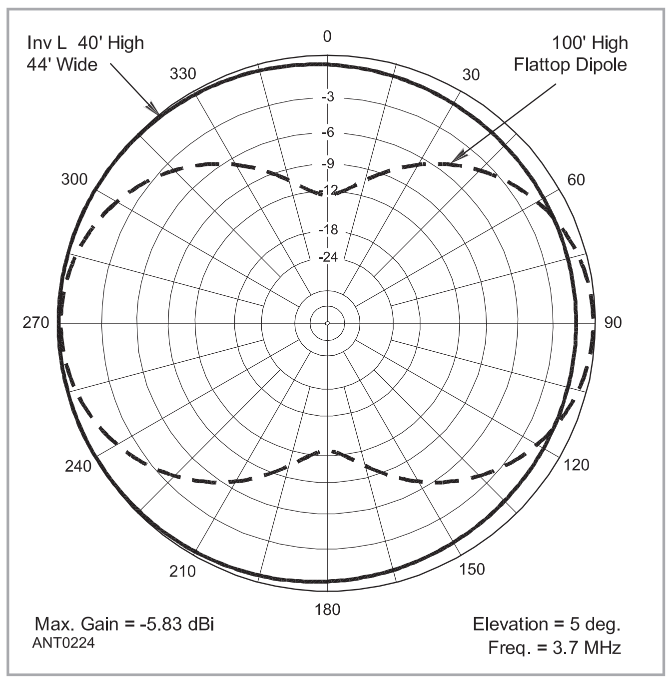
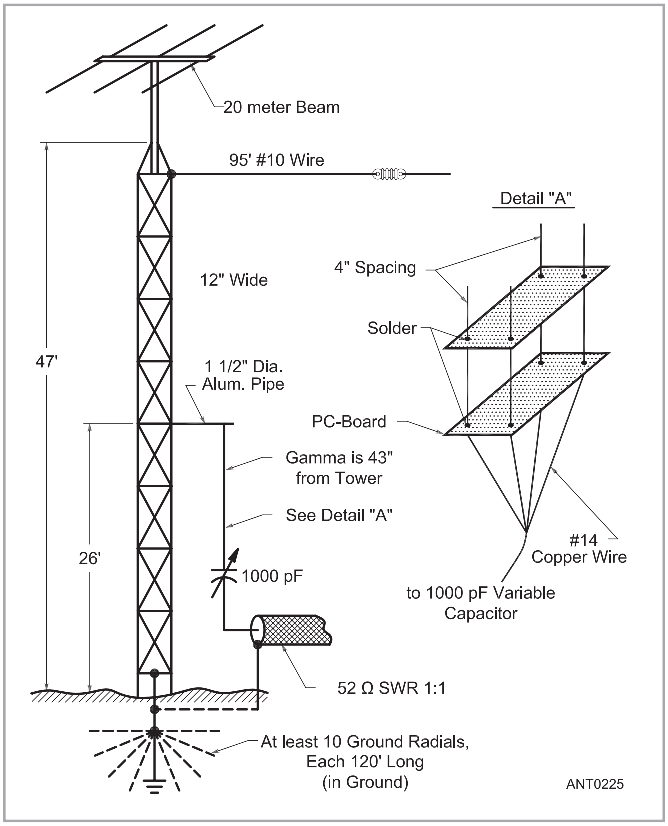


Figure 9.56 — Azimuthal pattern at a takeoff angle of 5° for an 80 meter version of the inverted-L (solid line) in Figure 9.51, compared to the response for a 100-foot high flattop dipole (dashed line).



9.4.1 TOWER-BASED INVERTED-L

Figure 9.57 shows the method used by Doug DeMaw, W1FB (SK), to gamma match his self-supporting 50-foot tower operating as an inverted-L. A wire cage simulates a gamma rod of the proper diameter. The tuning capacitor is fashioned from telescoping sections of 1¼ and 1½-inch aluminum tubing with polyethylene tubing serving as the dielectric. This capacitor is more than adequate for power levels of 100 W. The horizontal wire connected to the top of the tower provides the additional top loading.

Figure 9.57 — Details and dimensions for gamma-match feeding a 50-foot tower as a 1.8-MHz vertical antenna. The rotator cable and coaxial feed line for the 14-MHz beam is taped to the tower legs and run into the shack from ground level. No decoupling networks are necessary.

9.5 HALF-SLOPER ANTENNAS

Sloping dipoles and λ/2 dipoles can be very useful antennas on the low bands. These antennas can have one end attached to a tower, tree or other structure and the other end near ground level, elevated high enough so that passersby can't contact them, of course. The following section gives a number of examples of these types of antennas.

Perhaps one of the easiest antennas to install is the λ/4 sloper shown in **Figure 9.58**. As pointed out above, a sloping λ/2 dipole is known among radio amateurs as a *sloper* or sometimes as a *full sloper*. If only one half of it is used, it becomes a *half sloper*. The performance of the two types of sloping antennas is similar — they exhibit some directivity in the direction of the slope and radiate vertically polarized energy at low angles respective to the horizon. The amount of directivity will range from 3 to 6 dB, depending upon the individual installation, and will be observed in the slope direction.

The main advantage of the half sloper over the full half wave-long sloping dipole is that its supporting tower needn't be as high. Both the half sloper and the full sloper place the feed point (the point of maximum current) high above lossy ground. But the half-sloper only needs half as much wire to build the antenna for a given amateur band. The disadvantage of the half sloper is that it is sometimes difficult or even impossible to obtain a low SWR when using coaxial-cable feed, especially without a good isolating choke balun. (See

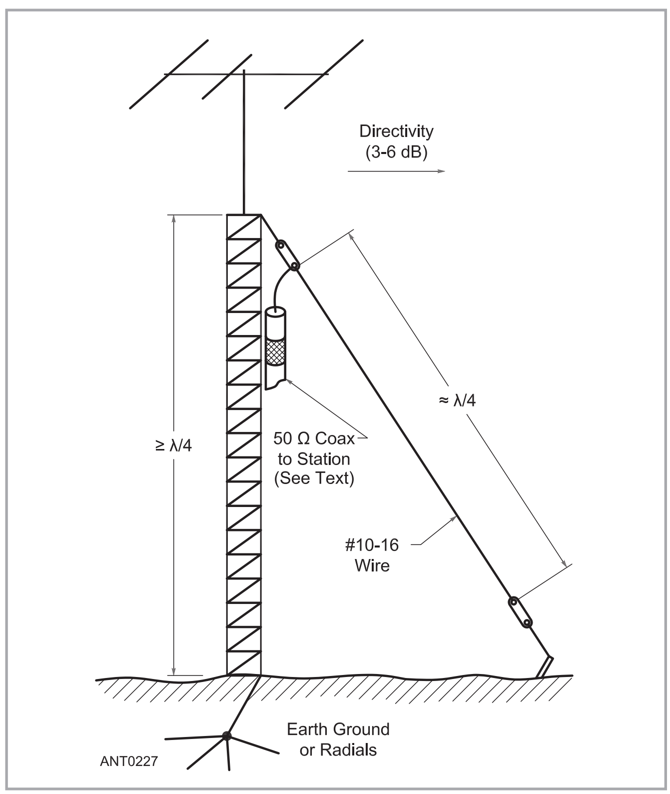


Figure 9.58 — The λ/4 "half sloper" antenna.

the section above on isolating ground-plane antennas.)

Other factors that affect the feed-impedance are tower height, height of the attachment point, enclosed angle between the sloper and the tower, and what is mounted atop the tower (HF or VHF beams). Further, the quality of the ground under the tower (ground conductivity, radials, etc) has a marked effect on the antenna performance. The final SWR can vary (after optimization) from 1:1 to as high as 6:1. Generally speaking, the closer the low end of the slope wire is to ground, the more difficult it will be to obtain a good match.

The half sloper can be an excellent DX type of antenna. Hams usually install theirs on a metal supporting structure such as a mast or tower. The support needs to be grounded at the lower end, preferably to a buried or on-ground radial system. If a nonconductive support is used, the outside of the coax braid becomes the return circuit and should be grounded at the base of the support. As a starting point you can attach the sloper so the feed point is approximately λ/4 above ground. If the tower is not high enough to permit this, the antenna should be fastened as high on the supporting structure as possible. Start with an enclosed angle of approximately 45°, as indicated in Figure 9.58. Cut the wire to the length determined from

$$\ell = \frac{260}{f_{MHz}}$$

This will allow sufficient extra length for pruning the wire for the lowest SWR. A metal tower or mast becomes an operating part of the half sloper system. In effect, it and the slope wire function somewhat like an inverted-V dipole antenna. In other words, the tower operates as the missing half of the dipole. Hence its height and the top loading (beams) play a significant role.

Detailed modeling indicates that a sufficiently large mass of metal (that is, a large, "Plumber's Delight" Yagi) connected to the top of the tower acts like enough of a "top counterpoise" that the tower may be removed from the model with little change in the essential characteristics of the half-sloper system. Consider an installation using a freestanding 50-foot tower with a large 5-element 20 meter Yagi on top. This Yagi is assumed to have a 40-foot boom oriented 90° to the direction of the slanted 80 meter half-sloper wire. The best SWR that could be reached by changing the length and slant angle for this sloper is 1.67:1, representing a feed point impedance of 30.1 – j 2.7 Ω. The peak gain at 3.8 MHz is 0.97 dBi at an elevation angle of 70°. **Figure 9.59** shows the azimuth-plane pattern for this half sloper, compared to a 100-foot high flattop dipole for reference, at an elevation angle of 5°.

Removing the tower from the model resulted in a feed point impedance of 30.1 – j 1.5 Ω and a peak gain of 1.17 dBi. The tower is obviously not contributing much in this setup, since the mass of the large 20 meter Yagi is acting like an elevated counterpoise all by itself. It's interesting to rotate the boom of the model Yagi and observe the change in SWR that occurs on the half-sloper antenna. With the boom turned 90°, the SWR falls to 1.38:1. This level of SWR change could be

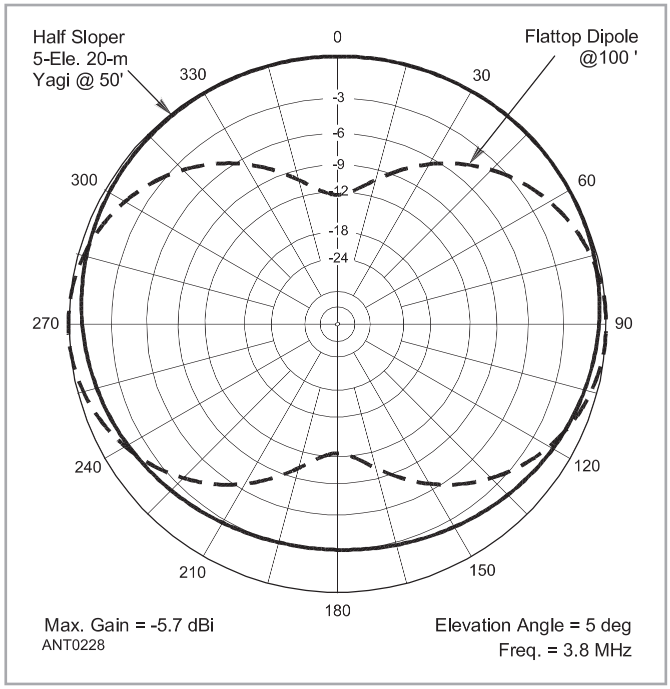


Figure 9.59 — Radiation pattern for a typical half sloper (solid line) mounted on a 50-foot high tower with a large 5-element 20 meter beam on the top compared to that for a flattop dipole (dashed line) at 100 feet. At a 5° takeoff angle typical for DX work on 80 meters, the two antennas are pretty comparable in the directions favored by the high dipole. In other directions, the half sloper has an advantage of more than 10 dB.

measured with amateur-type instrumentation.

On the other hand, substituting a smaller 3-element 20 meter Yagi with an 18-foot boom in the model does result in significant change in feed point impedance and gain when the tower is removed from the model, indicating that the "counterpoise effect" of the smaller beam is insufficient by itself. Interestingly enough, the best SWR for the half sloper/tower and the 3-element Yagi (with its boom in line with the half sloper is 1.33:1), changing to 1.27:1 with the boom turned 90°. Such a small change in SWR would be difficult to measure using typical amateur instrumentation.

In any case, the 50-Ω transmission line feeding a half sloper should be taped to the tower leg at frequent intervals to make it secure. The best method is to bring it to earth level, then route it to the operating position along the surface of the ground if it can't be buried. This will ensure adequate RF decoupling, which will help prevent RF energy from affecting the equipment in the station. Rotator cable and other feed lines on the tower or mast should be treated in a similar manner.

Adjustment of the half sloper is done with an SWR indicator in the 50-Ω transmission line. A compromise can usually be found between the enclosed angle and wire length, providing the lowest SWR attainable in the center of the chosen part of an amateur band. If the SWR "bottoms out" at 2:1 or lower, the system will work fine without using an antenna

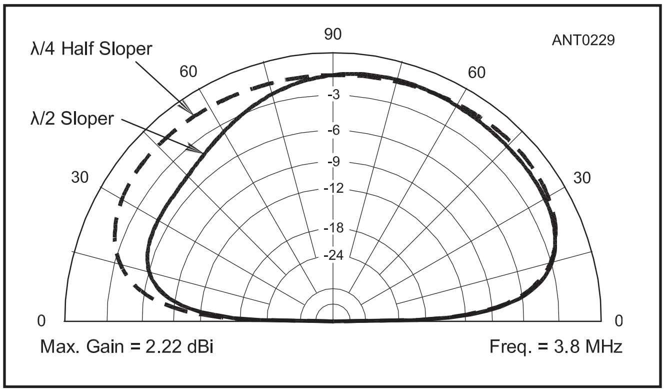


Figure 9.60 — Comparison of elevation patterns for a full-sized half wave sloper (solid line) on a 100-foot tower and a half sloper (dashed line) on a 50-foot tower with a 5-element 20 meter Yagi acting as a top counterpoise. The performance is quite comparable for these two systems.

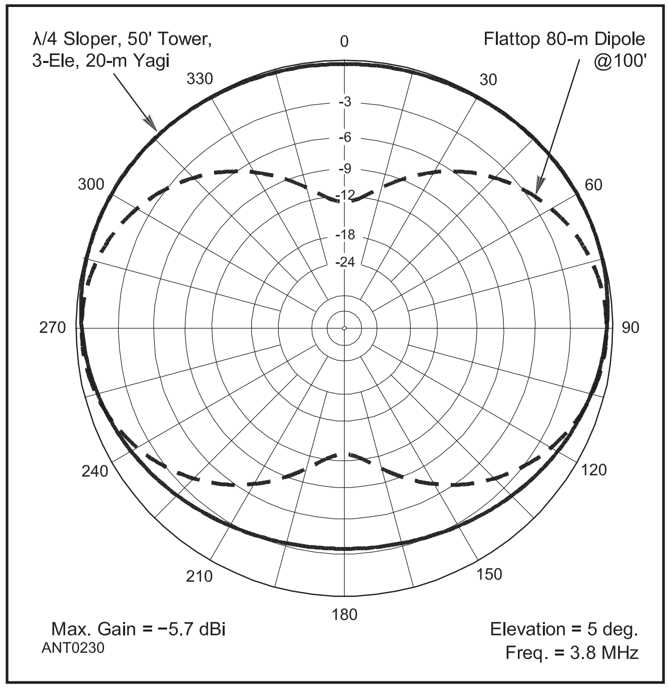


Figure 9.61 — Comparing the azimuthal response of a half sloper (solid line) on a 50-foot tower with a 3-element 20 meter Yagi on top to that of a flattop dipole (dashed line) at 100 feet. The two are again quite comparable at a 5° takeoff angle.

tuner, provided the transmitter can work into the load. Typical optimum values of SWR for 3.5 or 7-MHz half slopers are between 1.3:1 and 2:1. A 100-kHz bandwidth is normal on 3.5 MHz, with 200 kHz being typical at 7 MHz.

If the lowest SWR possible is greater than 2:1, the attachment point can be raised or lowered to improve the match. Readjustment of the wire length and enclosed angle may be necessary when the feed point height is changed. If the tower is guyed, the guy wires will need to be insulated from the tower and broken up with additional insulators to prevent resonance.

At this point you may be curious about which antenna is better — a full sloper or a half sloper. The peak gain for each antenna is very nearly identical. **Figure 9.60** overlays the elevation-plane pattern for the full-sized half wave sloper on a 100-foot tower and for the half sloper shown in Figure 9.60 on a 50-foot tower with a 5-element 20 meter Yagi on top. The full-sized half wave sloper has more front-to-back ratio, but it is only a few dB more than the half sloper. **Figure 9.61** compares the azimuthal patterns at a 5° takeoff angle for a 100-foot high flattop dipole and a half-sloper system on a 50-foot tower with a 3-element 20 meter Yagi on top.

Despite the frustration some have experienced trying to achieve a low SWR with some half-sloper installations, many operators have found the half sloper to be an effective and low-cost antenna for DX work.

9.5.1 1.8-MHZ ANTENNA SYSTEMS USING TOWERS

The half sloper discussed above for 80 or 40 meter operation will also perform well on 1.8 MHz where vertically polarized radiators can achieve the low takeoff angles needed on Top Band. Prominent 1.8-MHz operators who have had success with the half sloper antenna suggest a minimum tower height of 50 feet. Dana Atchley, W1CF (SK), used the configuration sketched in **Figure 9.62**. He reported that the uninsulated guy wires act as an effective counterpoise for the sloping wire. In **Figure 9.63** is the feed system used by Doug DeMaw, W1FB (SK), on a 50-foot self-supporting tower. The ground for the W1FB system is provided by buried radials connected to the tower base. Jack Belrose, VE2CV and DeMaw also described an interesting method of using a sloping wire to create a "half delta" usable on the lower HF bands. The system is described in the Sep 1982 *QST* article, "The Half-Delta Loop: A Critical Analysis and Practical Deployment" which is also available on this book's CD-ROM.

As described previously, a tower can also be used as a true vertical antenna, provided a good ground system is used. The shunt-fed tower is at its best on 1.8 MHz, where a full λ/4 vertical antenna is rarely possible. Almost any tower height can be used. An HF beam at the top provides some top loading.

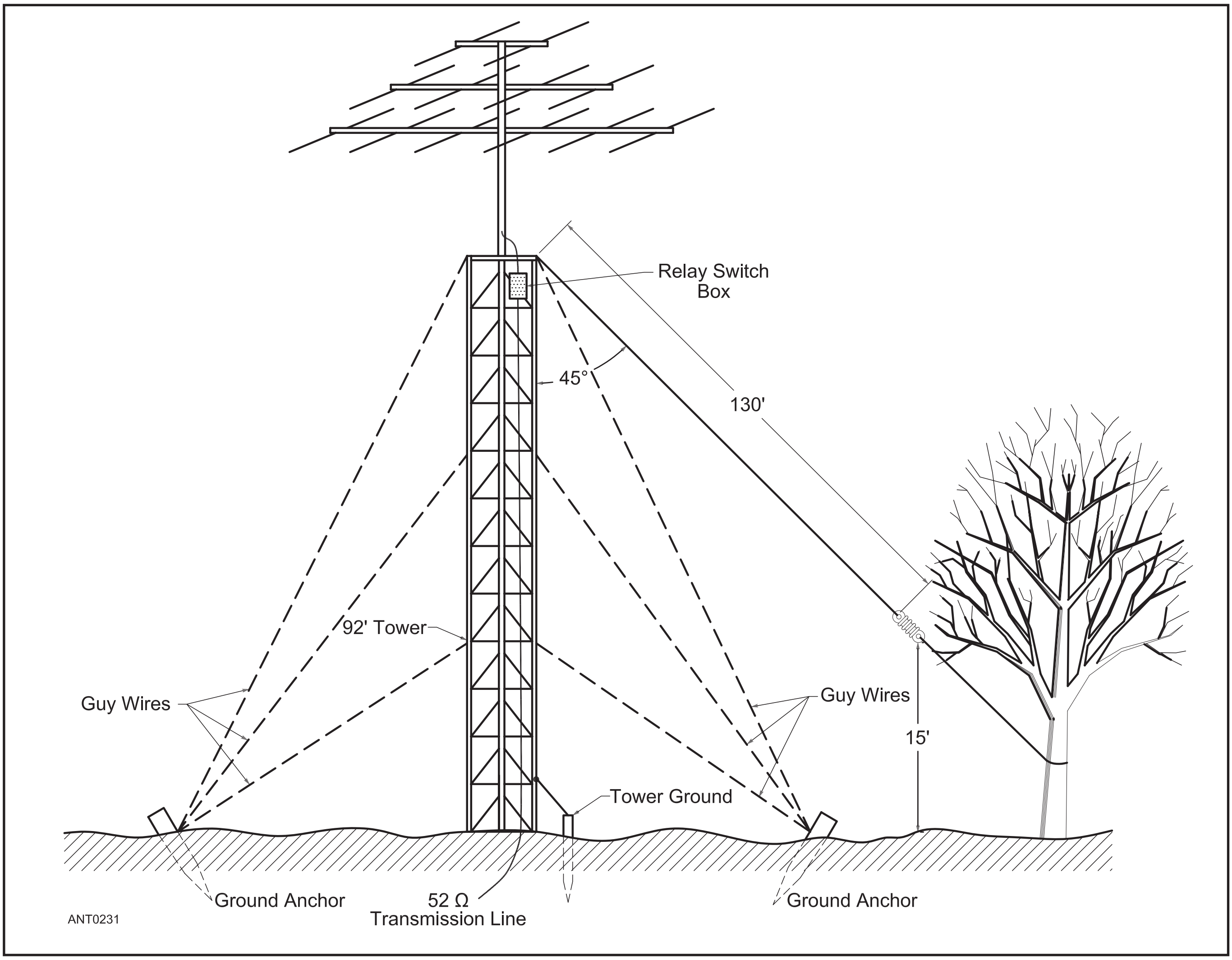


Figure 9.62 — The W1CF half sloper for 160 meters is arranged in this manner. Three monoband antennas atop the tower provide capacitive loading.

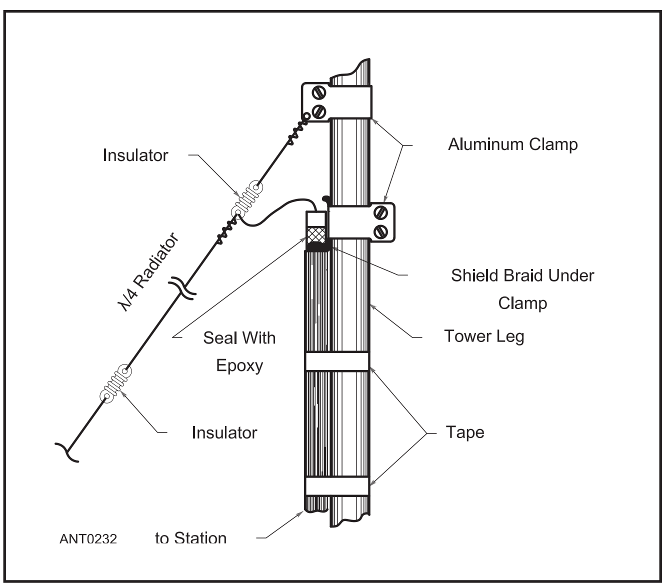


Figure 9.63 — Feed system used by W1FB for 1.8 MHz half sloper on a 50-foot self-supporting tower.

9.6 ONE-WAVELENGTH LOOPS

A loop antenna one wavelength in circumference is a very effective antenna that is also very tolerant of changes in shape and orientation to fit available space and supports. A detailed discussion of how the loop antenna works is presented in the **Loop Antennas** chapter along with several design variations for full-sized quad and delta loops. *Low-Band DXing* by Devoldere (see Bibliography) has an extensive section on loop antennas, as well.

This section presents several examples of loop antennas optimized for use on one band although they can be used on multiple bands with the use of an antenna tuner. In general, these designs can be scaled to work on other bands by multiplying all dimensions by the ratio of the design frequency to the new frequency = f_{design} / f_{new}.

9.6.1 A FULL-SIZE LOOP FOR 7 MHZ

This design is an effective but simple 7 MHz antenna that has a theoretical gain of approximately 1 dB over a dipole. Such a loop need not be square, as illustrated in **Figure 9.64A**. It can be trapezoidal, rectangular, circular, or some distorted configuration in between those shapes. For best results, however, you should attempt to make the loop as square as possible. The more rectangular the shape, the greater the cancellation of energy in the system, and the less effective it will be. In the limiting case, the antenna loses its identity as a loop and becomes a folded dipole.

You can feed the loop in the center of one of the vertical sides if you want vertical polarization. For horizontal polarization, you feed either of the horizontal sides at the center. Since optimum directivity occurs at right angles to the plane of the loop (or in more simple terms, broadside to the loop), you should hang the loop to radiate the maximum amount in some favored direction.

Figure 9.65A shows the azimuthal response at a takeoff

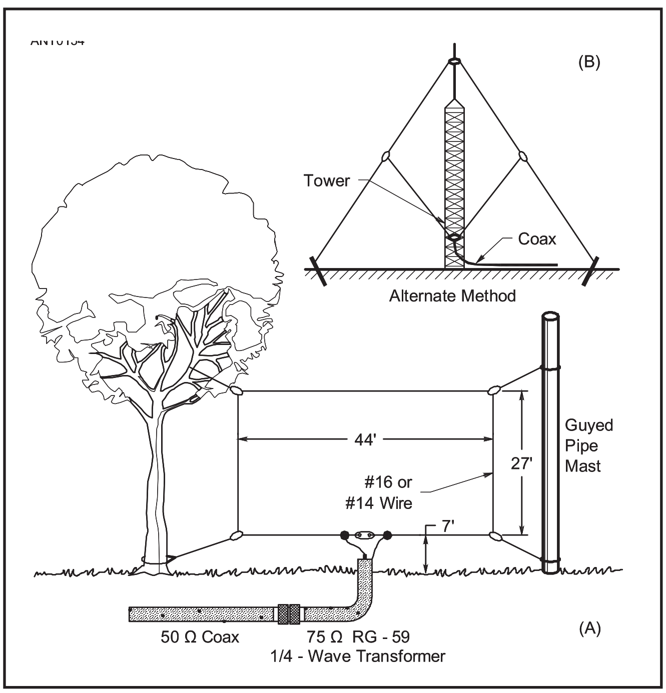


Figure 9.64 — At A, details of the rectangular full-wave loop. The dimensions given are for operation at 7.05 MHz. The height above ground was 7 feet in this instance, although improved performance should result if the builder can install the loop higher above ground without sacrificing length on the vertical sides. At B, illustration how a single supporting structure can be used to hold the loop in a diamond-shaped configuration. Feeding the diamond at the lower tip provides radiation in the horizontal plane. Feeding the system at either side will result in vertical polarization of the radiated signal.

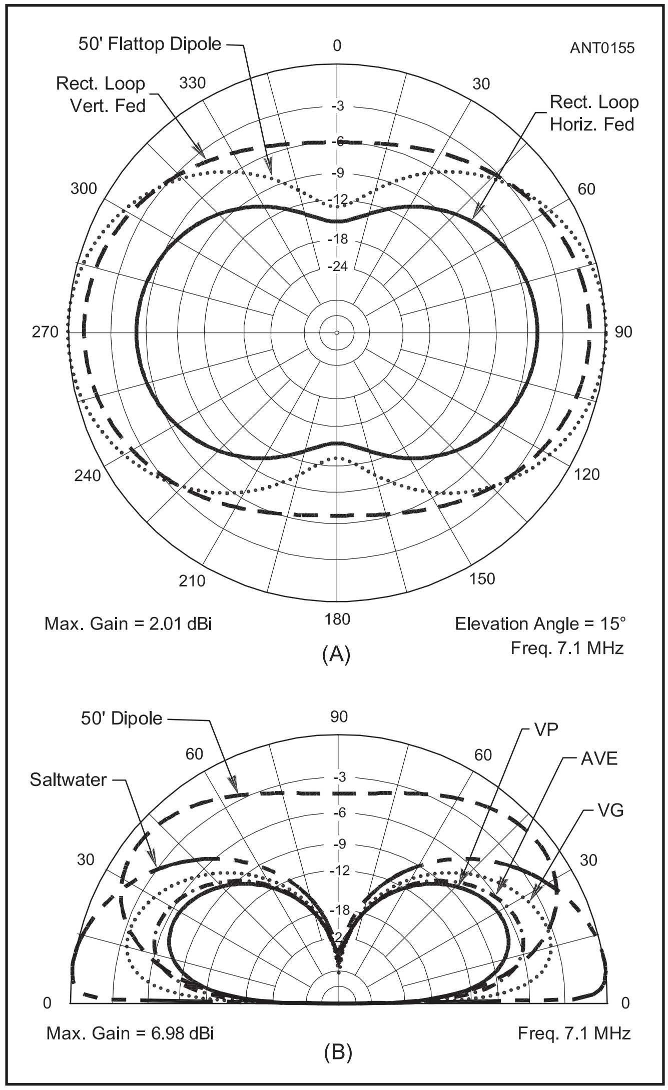


Figure 9.65 — At A, azimuthal plane responses for the vertically and horizontally polarized 7-MHz loop, compared to a flattop 50-foot high dipole, all at a takeoff angle of 15° for DX work. The solid line is for feeding the loop horizontally at the bottom; the dashed line is for feeding the loop vertically at a side, and the dotted line is for a simple flattop horizontal dipole at 50 feet in height. For DX work, the vertically polarized loop is an excellent performer.

angle of 15°, a typical angle for 40 meter DX, for vertical and horizontal feed systems over ground with "average" conductivity and dielectric constant. Figure 9.65A includes, for reference, the response of a flattop dipole 50 feet high. For DX work on 40 meters, the vertically polarized loop can perform as well as or substantially better than either a horizontally polarized loop or a flattop dipole, particularly in the azimuthal nulls of the dipole.

For the low elevation angles that favor DX work, the optimal feed point is at the center of one of the vertical wires. Feeding the loop at one of the corners at the bottom gives a compromise result for both local and DX work. The actual impedance is roughly the same at each point: bottom horizontal center, corner or vertical side center.

Figure 9.65B demonstrates how the gain for vertical polarization changes over different type of grounds: saltwater, very poor ground (conductivity = 1 mS/m, dielectric constant = 5) very good (conductivity = 30 mS/m, dielectric constant = 20) and average ground (conductivity = 5 mS/m, dielectric constant = 13). Again, for reference a 50-foot high flattop dipole's elevation response is included. As has been mentioned previously in other chapters, a seaside location is a wonderful environment for verticals!

Just how you erect such a loop will depend on what is available in your backyard. Trees are always handy for supporting loop antennas. A disadvantage to the rectangular loop shown in Figure 9.64A is that two 34-foot high supports are needed, although in many instances your house may be high enough to serve as one of these supports. If you have a tower higher than about 50 feet, Figure 9.64B demonstrates how you can use it to support a diamond-shaped loop for 40 meters. The elevation and azimuthal responses are almost the same for either loop configuration, rectangular- or diamond-shaped.

The overall length of the wire used in a loop is determined in feet from the formula 1005/f (MHz). Hence, for operation at 7.125 MHz the overall wire length will be 141 feet. The matching transformer, an electrical ¼ λ of 75-Ω coax cable, can be computed by dividing 246 by the operating frequency in MHz, then multiplying that number by the velocity factor of the cable being used. Thus, for operation at 7.125 MHz, 246/7.125 MHz = 34.53 feet. If coax with solid polyethylene insulation is used, a velocity factor of 0.66 must be employed. Foam-polyethylene coax has a velocity factor of 0.80. Assuming RG-59 is used, the length of the matching transformer becomes 34.53 (feet) × 0.66 = 22.79 feet, or 22 feet, 9½ inches.

This same loop antenna in Figure 9.64A fed vertically may be used on the 14 and 21 MHz bands, although its pattern will not be as good as that on its fundamental frequency and you will have to use an open-wire transmission line to feed the loop for multiband use. **Figure 9.66** shows the response at the peak lobe of the loop, at a 45° angle to the plane of the loop, compared to the peak response for a simple half-wave 20 meter dipole, 30 feet high. The gain from a simple flattop dipole, mounted at 30 feet, will be superior to the loop operated on a harmonic frequency.

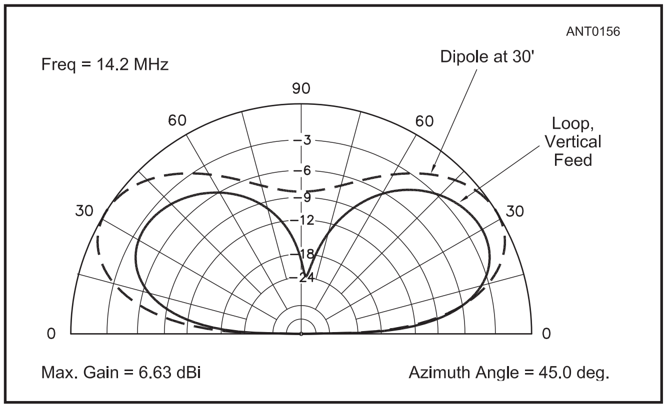


Figure 9.66 — Elevation-plane response of 7-MHz loop used on 14.2 MHz. This is for a feed point at the center of one of the two vertical wires. The dashed line is the response of a flattop 20-meter dipole at 30 feet in height for comparison.

9.6.2 A HORIZONTALLY POLARIZED RECTANGULAR LOOP

This antenna design provides some gain over a dipole or inverted-V and can easily be constructed for use on the upper HF bands as shown in **Table 9.7**. The original design was created by Brian Beazley, K6STI, and described in the July 1994 *QST* article "A Gain Antenna for 28 MHz." To use the antenna on other bands, multiply each dimension by 28.4/f (MHz), where f is the desired operating frequency in MHz.

The loop develops 2.1 dB gain over a dipole at low radiation angles with the top mounted one wavelength or more above ground. The antenna is simple to feed — no matching network is necessary. When fed with 50-Ω coax, the SWR is close to 1:1 at the design frequency. The original antenna, designed for resonance at 28.4 MHz, presented less than 2:1 SWR from 28.0-28.8 MHz. At lower frequencies, the effects of ground will affect the antenna's resonant frequency and feed point impedance, but not drastically — be prepared to adjust the dimensions.

The antenna is made from #12 AWG wire (see **Figure 9.67**) and is fed at the center of the bottom wire. Coil the coax into a few turns about one foot in diameter near the feed point to provide a simple choke balun at 14 MHz and higher. (See the **Transmission Line System Techniques** chapter for more

Table 9.7
Loop Dimensions for 7 through 28 MHz Bands

Freq (MHz)	*Side A (inches)*	*Side B (inches)*	*Side A (feet)*	*Side B (feet)*
28.4	73.0	146.0	6.1	12.2
24.9	83.3	166.5	6.9	13.9
21.2	97.8	195.6	8.1	16.3
18.1	114.5	229.1	9.5	19.1
14.15	146.5	293.0	12.2	24.4
10.1	205.3	410.5	17.1	34.2
7.15	290.0	579.9	24.2	48.3

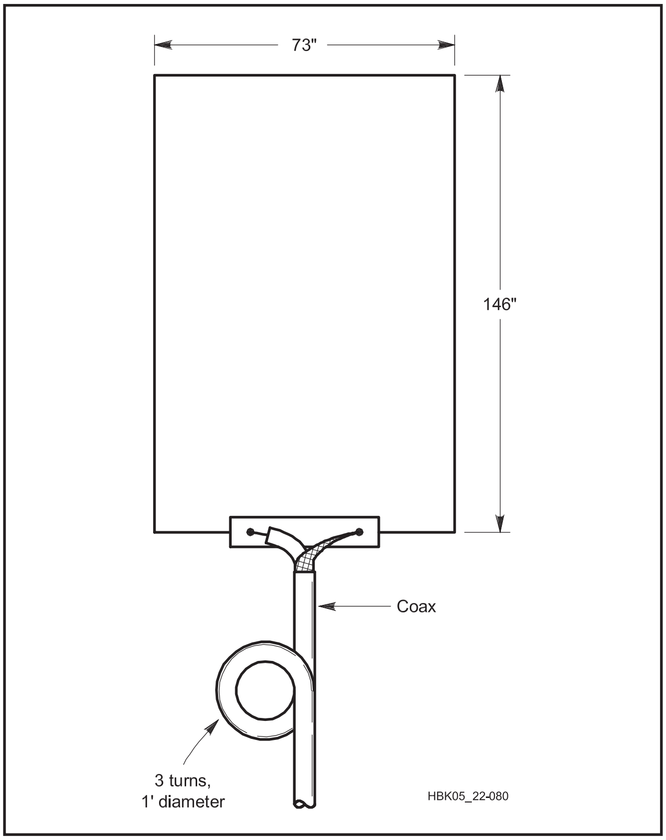


Figure 9.67 — Construction details of the 10 meter rectangular loop. See Table 9.7 for dimensions for other bands.

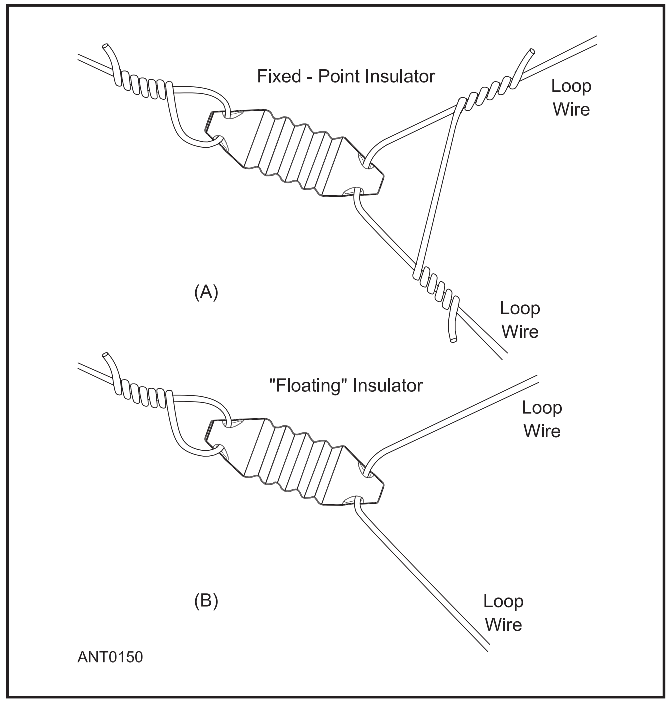
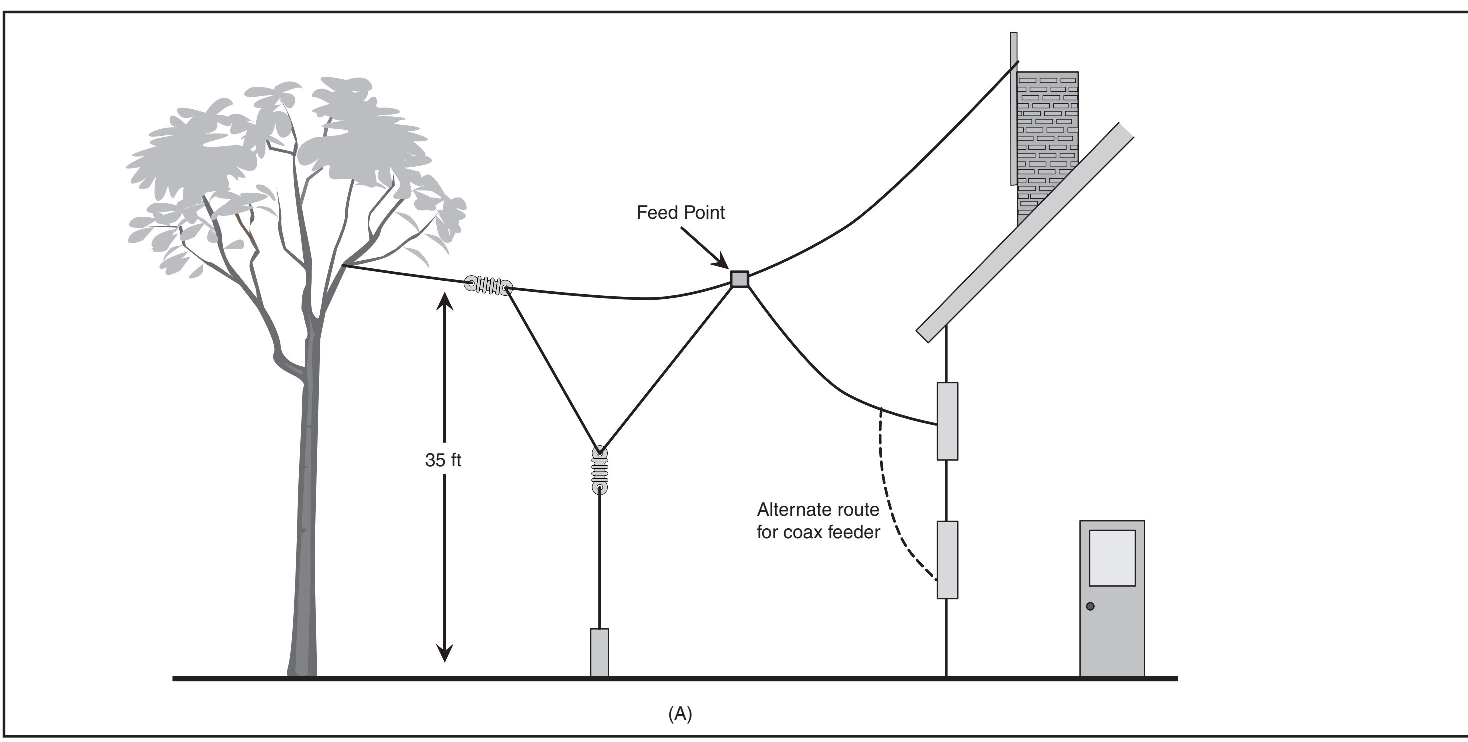


Figure 9.68 — Two methods of installing insulators at loop corners. The eyes of a floating insulator (B) should be smooth and have a large radius so that the loop wire does not make a sharp bend.



information on choke baluns.) The antenna can be suspended from trees or supported on a mast with spreaders made of bamboo, fiberglass, wood, PVC or other non-conducting material. You can also use aluminum tubing both for support and conductors, but you may have to readjust the antenna dimensions for resonance.

Figure 9.68 shows two methods of supporting the loop wires with insulators. If Figure 9.68 is used, be sure the inside of the insulator eye is smooth and has a large radius or the loop wire will eventually break from repeated bending as it slides through the insulator.

The rectangular loop achieves gain by compressing its radiation pattern in the elevation plane. This happens because the top and bottom of the loop (where the current maxima are located) are farther apart than for a square loop. The antenna's beamwidth is slightly higher than that of a dipole (it's about the same as that of an inverted-V). A broad pattern is an advantage for a general-purpose, fixed antenna. The rectangular loop provides a bidirectional gain over a wide range of directions.

Mount the loop as high as possible. To provide 1.7 dB gain at low angles over an inverted-V, the top wire must be at least one wavelength high. The loop will work at lower heights, but its gain advantage disappears. For example, at ⅔ λ the loop provides the same gain at low angles as an inverted-V.

9.6.3 A VERTICALLY POLARIZED DELTA LOOP FOR 14 MHZ

Two common methods of building a delta loop for the 14 MHz band are shown in **Figure 9.69**. (The design is from *Practical Wire Antennas* published by the RSGB.) Both radiate vertically-polarized signals and so ground quality will have an effect on the antenna's efficiency. The total length of wire in the loop should be approximately 1005/f (MHz) = 71 feet for a resonant frequency of 14.15 MHz. For the optimum pattern, the loop should be equilateral with all three sides about the same length.

The antenna in Figure 9.69A has an effective height of about λ/2. The placement of the feed point at one of the upper corners configures the antenna to provide low-angle radiation for DX operation. The feed line should be suspended so that it runs directly away from the corner of the loop.

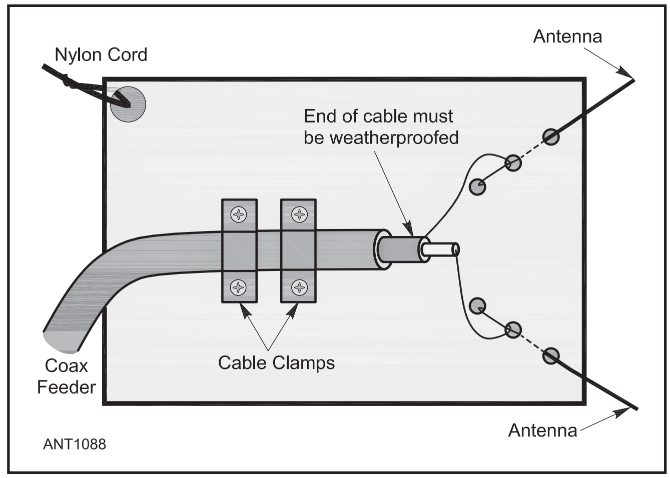


Figure 9.70 — One possible method of constructing a feed point for the delta loop antenna from polycarbonate or other insulating material. A commercial dipole center insulator can also be used.

Figure 9.69 — A "flat top" delta loop for 14 MHz is shown at A. Suspended from two supports, its elevation angle of maximum radiation is approximately 20 degrees. The version at B uses only a single support but its effective height is lower than for A, raising the angle of peak signal.

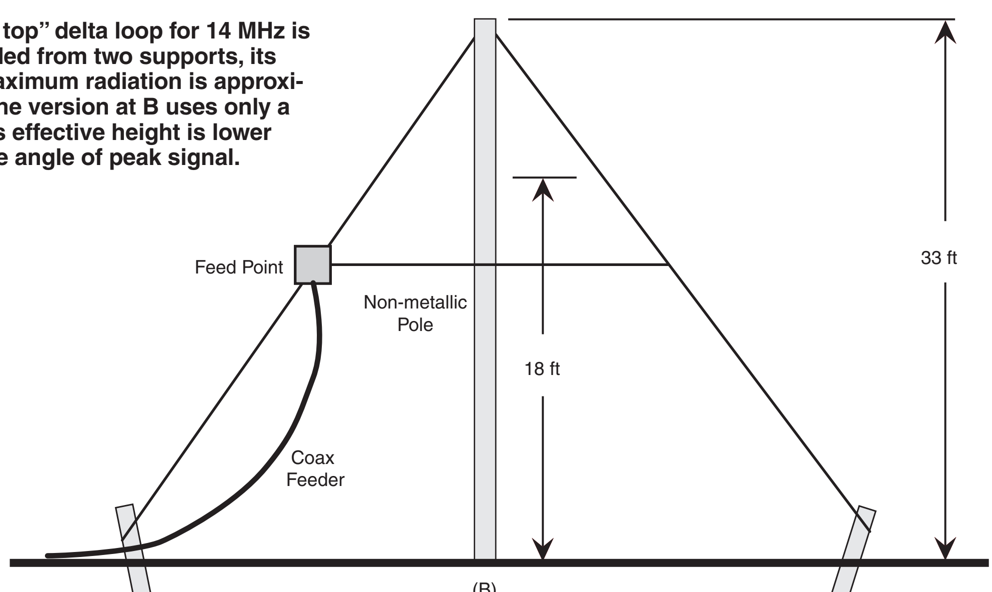


Figure 9.69B inverts the delta to use a single supporting mast or the antenna can be suspended from a tree. The effective height of this antenna is much lower than the "flat-top" version in Figure 9.69A and so the elevation angle of maximum radiation will be higher. Nevertheless, the convenience of this configuration makes it a good choice for Field Day and portable operation. The orientation of the feed line is much less important in this configuration — it can simply drop vertically to the ground.

Figure 9.70 shows an example of how a feed point can be constructed. A commercial dipole center insulator with the built-in support point will also work well in this application. The antenna can be supported with lightweight fishing line or nylon cord. It is recommended that the lower corner or corners be secured as well to prevent the antenna from moving too much in the wind. Insulators can be installed as in Figure 9.70.

The feed point impedance of both configurations will be 100-150 Ω and a quarter-wave matching section of feed line can be used to match the loop to 50 or 75-Ω feed line. A choke balun should be used at the feed point. (See the **Transmission Line System Techniques** chapter for more information on quarter-wave matching sections and choke baluns.)

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