Chapter 22

Antennas

Every ham needs at least one antenna, and most hams have built one. This chapter, by Chuck Hutchinson, K8CH, covers theory and construction of antennas for most radio amateurs. Here you'll find simple verticals and dipoles, as well as quad and Yagi projects and other antennas that you can build and use.

ANTENNA POLARIZATION

Most HF-band antennas are either vertically or horizontally polarized. Although circular polarization is possible, just as it is at VHF and UHF, it is seldom used at HF. *Polarization* is determined by the position of the radiating element or wire with respect to the earth. Thus a radiator that is parallel to the earth radiates horizontally, while a vertical antenna radiates a vertical wave. If a wire antenna is slanted above earth, it radiates waves that have both a vertical and a horizontal component.

For best results in line-of-sight communications, antennas at both ends of the circuit should have the same polarization; cross polarization results in many decibels of signal reduction. However, it is not essential for both stations to use the same antenna polarity for ionospheric propagation (sky wave). This is because the radiated wave is bent and it tumbles considerably during its travel through the ionosphere. At the far end of the communications path the wave may be horizontal, vertical or somewhere in between at any given instant. For that reason, the main consideration for a good DX antenna is a low angle of radiation rather than the polarization.

ANTENNA BANDWIDTH

The *bandwidth* of an antenna refers generally to the range of frequencies over which the antenna can be used to obtain a specified level of performance. The bandwidth is often referenced to some SWR value, such as, "The 2:1 *SWR bandwidth* is 3.5 to 3.8 MHz." Popular amateur usage of the term bandwidth most often refers to the 2:1 SWR bandwidth. Other specific bandwidth terms are also used, such as the *gain bandwidth* and the *front-to-back ratio bandwidth*.

For the most part, the lower the operating frequency of a given antenna design, the narrower is the bandwidth. This follows the rule that the bandwidth of a resonant circuit doubles as the frequency of operation is doubled, assuming the Q is the same for each case. Therefore, it is often difficult to cover all of the 160 or 80-m band for a particular level of SWR with a dipole antenna. It is important to recognize that SWR bandwidth does not always relate directly to gain bandwidth. Depending on the amount of feed-line loss, an 80-m dipole with a relatively narrow 2:1 SWR bandwidth can still radiate a good signal at each end of the band, provided that an antenna tuner is used to allow the transmitter to load properly. Broadbanding techniques, such as fanning the far ends of a dipole to simulate a conical type of dipole, can help broaden the SWR response curve.

CURRENT AND VOLTAGE DISTRIBUTION

When power is fed to an antenna, the current and voltage vary along its length. The current is nearly zero (a current *node*) at the ends. The current does not actually reach zero at the current nodes, because of capacitance at the antenna ends. Insulators, loops at the antenna ends, and support wires all contribute to this capacitance, which is also called the *end effect*. In the case of a half-wave antenna there is a current maximum (a current *loop*) at the center.

The opposite is true of the RF voltage. That is, there is a voltage loop at the ends, and in the case of a half-wave antenna there is a voltage minimum (node) at the center. The voltage is not zero at its node because of the resistance of the antenna, which consists of both the RF resistance of the wire (ohmic loss resistance) and the *radiation resistance*. The radiation resistance is the equivalent resistance that would dissipate the power the antenna radiates, with a current flowing in it equal to the antenna current at a current loop (maximum). The loss resistance of a half-wave antenna is ordinarily small, compared with the radiation resistance, and can usually be neglected for practical purposes.

IMPEDANCE

The *impedance* at a given point in the antenna is determined by the ratio of the voltage to the current at that point. For example, if there were 100 V and 1.4 A of RF current at a specified point in an antenna and if they were in phase, the impedance would be approximately 71 Ω.

Antenna impedance may be either resistive or complex (that is, containing resistance and reactance). This will depend on whether or not the antenna is *resonant* at the operating frequency. You need to know the impedance in order to match the feeder to the feedpoint. Some operators mistakenly believe that a mismatch, however small, is a serious matter. This is not true. The importance of a matched line is described in detail in the **Transmission Lines** chapter of this book. The significance of a perfect match becomes more pronounced only at VHF and higher, where feed-line losses are a major factor.

Some antennas possess a theoretical input impedance at the feedpoint close to that of certain transmission lines. For example, a 0.5-λ (or half-wave) center-fed dipole,

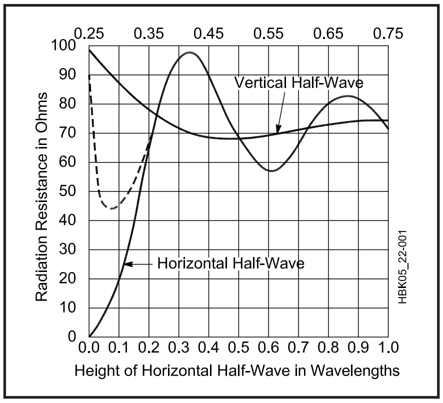


Fig 22.1 — Curves showing the radiation resistance of vertical and horizontal half-wavelength dipoles at various heights above ground. The broken-line portion of the curve for a horizontal dipole shows the resistance over *average* real earth, the solid line for perfectly conducting ground.

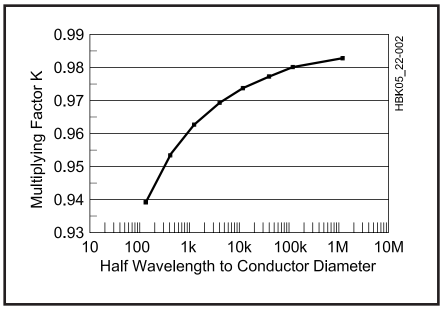


Fig 22.2 — Effect of antenna diameter on length for half-wavelength resonance, shown as a multiplying factor, K, to be applied to the free-space, half-wavelength equation.

Table 22.1
Optimum Elevation Angles to Europe

Band	*Northeast*	*Southeast*	*Upper Midwest*	*Lower Midwest*	*West Coast*
10 m	5°	3°	3°	7°	3°
12 m	5°	6°	4°	6°	5°
15 m	5°	7°	8°	5°	6°
17 m	4°	8°	7°	5°	5°
20 m	11°	9°	8°	5°	6°
30 m	11°	11°	11°	9°	8°
40 m	15°	15°	14°	14°	12°
75 m	20°	15°	15°	11°	11°

Table 22.2
Optimum Elevation Angles to Far East

Band	*Northeast*	*Southeast*	*Upper Midwest*	*Lower Midwest*	*West Coast*
10 m	4°	5°	5°	5°	6°
12 m	4°	8°	5°	12°	6°
15 m	7°	10°	10°	10°	8°
17 m	7°	10°	9°	10°	5°
20 m	4°	10°	9°	10°	9°
30 m	7°	13°	11°	12°	9°
40 m	11°	12°	12°	12°	13°
75 m	12°	14°	14°	12°	15°

Table 22.3
Optimum Elevation Angles to South America

Band	*Northeast*	*Southeast*	*Upper Midwest*	*Lower Midwest*	*West Coast*
10 m	5°	4°	4°	4°	7°
12 m	5°	5°	6°	3°	8°
15 m	5°	5°	7°	4°	8°
17 m	4°	5°	5°	3°	7°
20 m	8°	8°	8°	6°	8°
30 m	8°	11°	9°	9°	9°
40 m	10°	11°	9°	9°	10°
75 m	15°	15°	13°	14°	14°

placed at a correct height above ground, will have a feedpoint impedance of approximately 75 Ω. In such a case it is practical to use a 75-Ω coaxial or balanced line to feed the antenna. But few amateur half-wave dipoles actually exhibit a 75-Ω impedance. This is because at the lower end of the high-frequency spectrum the typical height above ground is rarely more than $^1/_4$ λ. The 75-Ω feed-point impedance is most likely to be realized in a practical installation when the horizontal dipole is approximately $^1/_2$, $^3/_4$ or 1 wavelength above ground. Coax cable having a 50-Ω characteristic impedance is the most common transmission line used in amateur work.

Fig 22.1 shows the difference between the effects of perfect ground and typical earth at low antenna heights. The effect of height on the radiation resistance of a horizontal half-wave antenna is not drastic so long as the height of the antenna is greater than 0.2 λ. Below this height, while decreasing rapidly to zero over perfectly conducting ground, the resistance decreases less rapidly with height over actual ground. At lower heights the resistance stops decreasing at around 0.15 λ, and thereafter increases as height decreases further. The reason for the increasing resistance is that more and more of the induction field of the antenna is absorbed by the earth as the height drops below $^1/_4$ λ.

CONDUCTOR SIZE

The impedance of the antenna also depends on the diameter of the conductor in relation to the wavelength, as indicated in **Fig 22.2**. If the diameter of the conductor is increased, the capacitance per unit length increases and the inductance per unit length decreases. Since the radiation resistance is affected relatively little, the decreased L/C ratio causes the Q of the antenna to decrease so that the resonance curve becomes less sharp with change in frequency. This effect is greater as the diameter is increased, and is a property of some importance at the very high frequencies where the wavelength is small.

DIRECTIVITY AND GAIN

All antennas, even the simplest types, exhibit directive effects in that the intensity of radiation is not the same in all directions from the antenna. This property of radiating more strongly in some directions than in others is called the *directivity* of the antenna.

The *gain* of an antenna is closely related to its directivity. Because directivity is based solely on the shape of the directive pattern, it does not take into account any power losses that may occur in an actual antenna system. Gain takes those losses into account.

Gain is usually expressed in decibels, and is based on a comparison with a *standard* antenna—usually a dipole or an *isotropic radiator*. An isotropic radiator is a theoretical antenna that would, if placed in the center of an imaginary sphere, evenly illuminate that sphere with radiation. The isotropic radiator is an unambiguous standard, and for that reason frequently used as the comparison for gain measurements. When the standard is the isotropic radiator in free space, gain is expressed in dBi. When the standard is a dipole, *also located in free space*, gain is expressed in dBd.

The more the directive pattern is compressed—or focused—the greater the power gain of the antenna. This is a result of power being concentrated in some directions at the expense of others. The directive pattern, and therefore the gain, of an antenna at a given frequency is determined by the size and shape of the antenna, and on its position and orientation relative to the Earth.

ELEVATION ANGLE

For long-distance HF communication, the (vertical) *elevation angle* of maximum radiation is of considerable importance. You will want to erect your antenna so that it radiates at desirable angles. **Tables 22.1**, **22.2** and **22.3** show optimum elevation angles from locations in the continental US. These figures are based on statistical averages over all portions of the solar sunspot cycle.

Since low angles usually are most effective for long distance communications, this generally means that horizontal antennas should be high—higher is usually better. Experience shows that satisfactory results can be attained on the bands above 14 MHz with antenna heights between 40 and 70 ft. **Fig 22.3** shows this effect at work in horizontal dipole antennas.

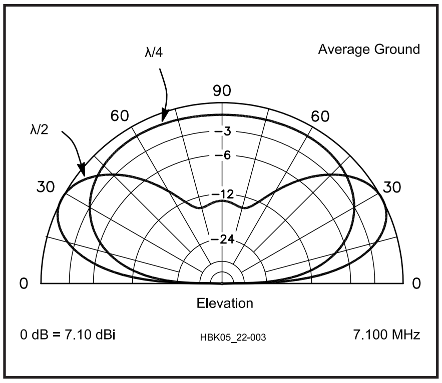


Fig 22.3 — Elevation patterns for two 40-m dipoles over average ground (conductivity of 5 mS/m and dielectric constant of 13) at $^1/_4$ λ (33 ft) and $^1/_2$ λ (66 ft) heights. The higher dipole has a peak gain of 7.1 dBi at an elevation angle of about 26°, while the lower dipole has more response at high elevation angles.

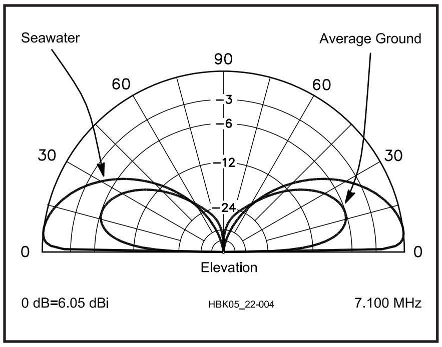


Fig 22.4 — Elevation patterns for a vertical dipole over sea water compared to average ground. In each case the center of the dipole is just over $^1/_4$ λ high. The low-angle response is greatly degraded over average ground compared to sea water, which is virtually a perfect ground.

The higher angles can be useful for medium to short-range communications. Dean Straw, N6BV, illustrates this in *The ARRL Antenna Book*. Straw shows that elevation angles between 20 and 65° are useful on the 40 and 80-m bands over the roughly 550-mile path between Cleveland and Boston. Even higher angles may be useful on shorter paths when using these lower HF frequencies. A 75-m dipole between 30 and 70 ft high works well for ranges out to several hundred miles. See the **Propagation of RF Signals** chapter.

IMPERFECT GROUND

Earth conducts, but is far from being a perfect conductor. This influences the radiation pattern of the antennas that we use. The effect is most pronounced at high vertical angles (the ones that we're least interested in for long-distance communications) for horizontal antennas. The consequences for vertical antennas are greatest at low angles, and are quite dramatic as can be clearly seen in **Fig 22.4**, where the elevation pattern for a 40-m vertical half-wave dipole located over average ground is compared to one located over saltwater. At 10° elevation, the saltwater antenna has about 7 dB more gain than its landlocked counterpart.

An HF vertical antenna may work very well for a ham living in the area between Dallas, Texas and Lincoln, Nebraska. This area is pastoral, has low hills, and rich soil. Ground of this type has very good conductivity. By contrast, a ham living in New Hampshire, where the soil is rocky and a poor conductor, may not be satisfied with the performance of a vertical HF antenna.

Dipoles and the Half-Wave Antenna

A fundamental form of antenna is a wire whose length is half the transmitting wavelength. It is the unit from which many more complex forms of antennas are constructed and is known as a *dipole antenna*. The length of a half-wave in free space is

$$\text{Length (ft)} = \frac{492}{\text{f (MHz)}} \qquad (1)$$

The actual length of a resonant $^1/_2$-λ antenna will not be exactly equal to the half wavelength in space, but depends on the thickness of the conductor in relation to the wavelength. The relationship is shown in Fig 22.2, where K is a factor that must be multiplied by the half wavelength in free space to obtain the resonant antenna length. An additional shortening effect occurs with wire antennas supported by insulators at the ends because of the capacitance added to the system by the insulators. This shortening is called end effect. The following formula is sufficiently accurate for wire antennas for frequencies up to 30 MHz.

Length of half-wave antenna (ft)

$$= \frac{492 \times 0.95}{\text{f (MHz)}} = \frac{468}{\text{f (MHz)}} \qquad (2)$$

Example: A half-wave antenna for 7150 kHz (7.15 MHz) is 468/7.15 = 65.45 ft, or 65 ft 5 inches.

Above 30 MHz use the following formulas, particularly for antennas constructed from rod or tubing. K is taken from Fig 22.2.

$$\text{Length (ft)} = \frac{492 \times \text{K}}{\text{f (MHz)}} \qquad (3)$$

$$\text{Length (in)} = \frac{5904 \times \text{K}}{\text{f (MHz)}} \qquad (4)$$

Example: Find the length of a half-wave antenna at 50.1 MHz, if the antenna is made of $^1/_2$-inch-diameter tubing. At 50.1 MHz, a half wavelength in space is

$$\frac{492}{50.1} = 9.82 \text{ ft}$$

The ratio of half wavelength to conductor diameter (changing wavelength to inches) is

$$\frac{(9.82 \text{ ft} \times 12 \,{}^{\text{in}}\!/_{\text{ft}})}{0.5 \text{ in}} = 235.7$$

From Fig 22.2, K = 0.945 for this ratio. The length of the antenna, from equation 3 is

$$\frac{492 \times 0.945}{50.1} = 9.28 \text{ ft}$$

or 9 ft $3^3/_8$ inches. The answer is obtained directly in inches by substitution in equation 4

$$\frac{5904 \times 0.945}{50.1} = 111.4 \text{ in}$$

The length of a half-wave antenna is also affected by the proximity of the dipole ends to nearby conductive and semiconductive objects. In practice, it is often necessary to do some experimental *pruning* of the wire after cutting the antenna to the computed length, lengthening or shortening it in increments to obtain a low SWR. When the lowest SWR is obtained for the desired part of an amateur band, the antenna is resonant at that frequency. The value of the SWR indicates the quality of the match between the antenna and the feed line. If the lowest SWR obtainable is too high for use with solid-state rigs, a Transmatch or line-input matching network may be used, as described in the **Transmission Lines** chapter.

RADIATION CHARACTERISTICS

The radiation pattern of a dipole antenna in free space is strongest at right angles to the wire (**Fig 22.5**). This figure-8 pattern appears in the real world if the dipole is $^1/_2$ λ or greater above earth and is not degraded by nearby conductive objects. This assumption is based also on a symmetrical feed system. In practice, a coaxial feed line may distort this pattern slightly, as shown in Fig 22.5. Minimum horizontal radiation occurs off the ends of the dipole if the antenna is parallel to the earth.

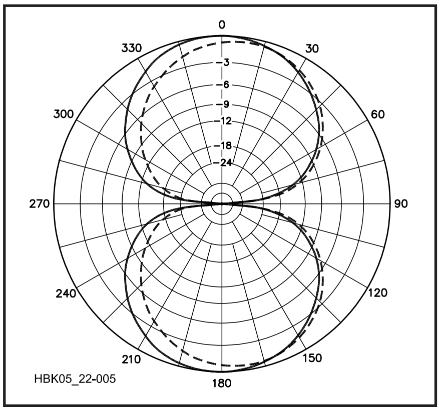


Fig 22.5 — Response of a dipole antenna in free space, where the conductor is along 90° to 270° axis, solid line. If the currents in the halves of the dipole are not in phase, slight distortion of the pattern will occur, broken line. This illustrates the case where a balun is not used on a balanced antenna fed with unbalanced line.

As a horizontal antenna is brought closer to ground, the elevation pattern peaks at a higher elevation angle as shown in Fig 22.3. **Fig 22.6** illustrates what happens to the directional pattern as antenna

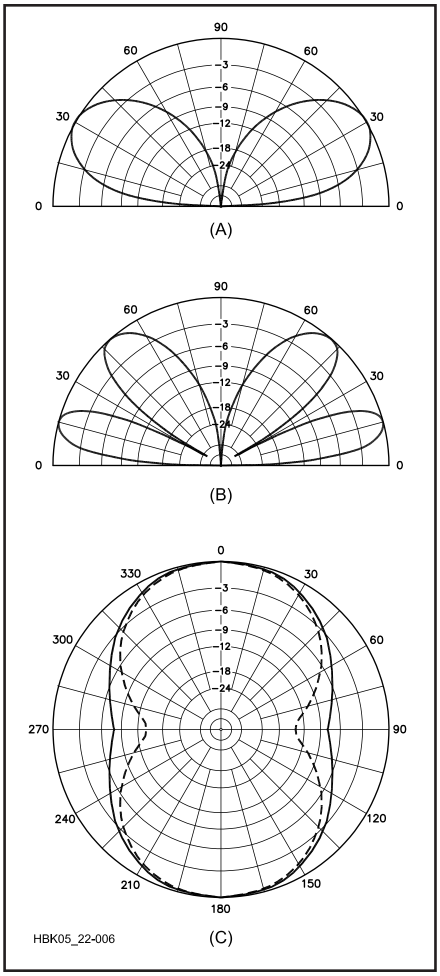


Fig 22.6 — At A, elevation response pattern of a dipole antenna placed $^1/_2$ λ above a perfectly conducting ground. At B, the pattern for the same antenna when raised to one wavelength. For both A and B, the conductor is coming out of the paper at right angle. C shows the azimuth patterns of the dipole for the two heights at the most-favored elevation angle, the solid-line plot for the $^1/_2$-λ height at an elevation angle of 30°, and the broken-line plot for the 1-λ height at an elevation angle of 15°. The conductor in C lies along 90° to 270° axis.

height changes. Fig 22.6C shows that there is significant radiation off the ends of a low horizontal dipole. For the $^1/_2$-λ height (solid line), the radiation off the ends is only 7.6 dB lower than that in the broadside direction.

FEED METHODS

Most amateurs use either *coax* or *open-wire* transmission line. Coax is the common choice because it is readily available, its characteristic impedance is close to that of the antenna and it may be easily routed through or along walls and among other cables. The disadvantages of coax are increased RF loss and low working voltage (compared to that of open-wire line). Both disadvantages make coax a poor choice for high-SWR systems.

Take care when choosing coax. Use $^1/_4$-inch foam-dielectric cables only for low power (25 W or less) HF transmissions. Solid-dielectric $^1/_4$-inch cables are okay for 300 W if the SWR is low. For high-power installations, use $^1/_4$-inch or larger cables.

The most common two-wire transmission lines are *ladder line* and *twin lead*. Since the conductors are not shielded, two-wire lines are affected by their environment. Use standoffs and insulators to keep the line several inches from structures or other conductors. Ladder line has very low loss (twin lead has a little more), and it can stand very high voltages (high SWR) as long as the insulators are clean.

Two-wire lines are usually used in balanced systems, so they should have a balun at the transition to an unbalanced transmitter or coax. A Transmatch will be needed to match the line input impedance to the transmitter.

BALUNS

A balun is a device for feeding a balanced load with an unbalanced line, or vice versa (see the Transmission Lines chapter of this book). Because dipoles are balanced (electrically symmetrical about their feedpoints), a balun is often used at the feedpoint when a dipole is fed with coax. When coax feeds a dipole directly (as in **Fig 22.7**), current flows on the outside of the cable shield. The shield can conduct RF onto the transmitter chassis and induce RF onto metal objects near the system. Shield currents can impair the function of instruments connected to the line (such as SWR meters and SWR-protection circuits in the transmitter). The shield current also produces some feed-line radiation, which changes the antenna radiation pattern, and allows objects near the cable to affect the antenna-system performance.

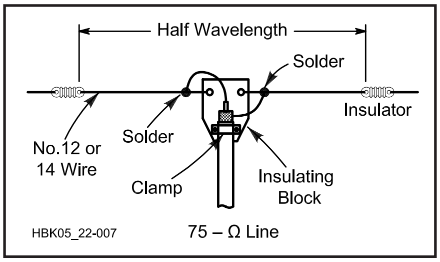


Fig 22.7 — Method of affixing feed line to the center of a dipole antenna. A plastic block is used as a center insulator. The coax is held in place by a clamp. A balun is often used to feed dipoles or other balanced antennas to ensure that the radiation pattern is not distorted. See text for explanation.

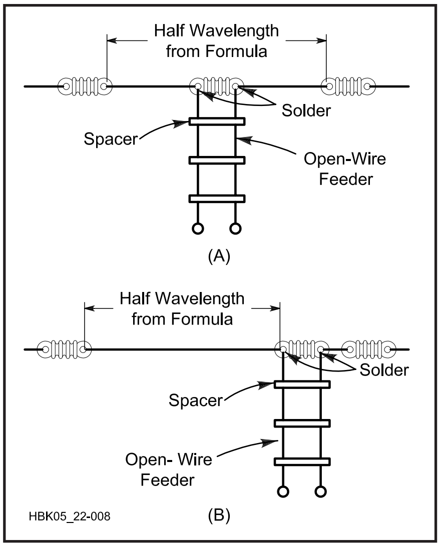


Fig 22.8 — Center-fed multiband *Zepp* antenna at A and an end-fed Zepp at B. See also Fig 22.11 for connection details.

The consequences may be negligible: A slight skewing of the antenna pattern usually goes unnoticed. Or, they may be significant: False SWR readings may cause the transmitter to shut down or destroy the output transistors; radiating coax near a TV feed line may cause strong local interference. Therefore, it is better to eliminate feed-line radiation whenever possible, and a balun should be used at any transition between balanced and unbalanced systems. (The **Transmission Lines** chapter thoroughly describes baluns and their construction.) Even so, balanced or unbalanced systems without a balun often operate with no apparent problems. For temporary or emergency stations, do not let the lack of a balun deter you from operating.

PRACTICAL DIPOLE ANTENNAS

A classic dipole antenna is $^1/_2$-λ long and fed at the center. The feed-point impedance is low at the resonant frequency, f_0, and odd harmonics thereof. (The impedance is high near even harmonics.) When fed with coax, a classic dipole provides a reasonably low SWR at f_0 and its odd harmonics.

When fed with ladder line (see **Fig 22.8A**) and a Transmatch, the classic dipole should be usable near f_0 and all harmonic frequencies. (With a wide-range Transmatch, it may work on all frequencies.) If there are problems (such as extremely high SWR or evidence of RF on objects at the operating position), change the feed-line length by adding or subtracting $^1/_8$ λ at the problem frequency. A few such adjustments should yield a workable solution. Such a system is sometimes called a *center-fed Zepp*. A true *Zepp* antenna is an end-fed dipole that is matched by $^1/_4$ λ of open-wire feed line (see Fig 22.8B). The antenna was originally used on zeppelins, with the dipole trailing from the feeder, which hung from the airship cabin. It is intended for use on a single band, but should be usable near odd harmonics of f_0.

Most dipoles require a little pruning to reach the desired resonant frequency. So, cut the wire 2 to 3% longer than the calculated length and record the length. Next, raise the dipole to the working height and check the SWR at several frequencies. Multiply the frequency of the SWR minimum by the antenna length and divide the result by the desired f_0. The result is the finished length; trim both ends equally to reach that length and you're done.

BUILDING DIPOLE AND OTHER WIRE ANTENNAS

The purpose of this section is to offer information on the actual physical construction of wire antennas. Because the dipole, in one of its configurations, is probably the most common amateur wire antenna, it is used in the following examples. The techniques described here, however, enhance the reliability and safety of all wire antennas.

Wire

Choosing the right type of wire for the project at hand is the key to a successful antenna—the kind that works well and stays up through a winter ice storm or a gusty spring wind storm. What gauge of wire to use is the first question to settle, and the answer depends on strength, ease of handling, cost, availability and visibility. Generally, antennas that are expected to support their own weight, plus the weight of the feed line should be made from #12 wire. Horizontal dipoles, Zepps, some long wires and the like fall into this category. Antennas supported in the center, such as inverted-V dipoles and delta loops, may be made from lighter material, such as #14 wire—the minimum size called for in the National Electrical Code.

The type of wire to be used is the next important decision. The wire specifications table in the **Component Data and References** chapter shows popular wire styles and sizes. The strongest wire suitable for antenna service is *copperclad steel*, also known as *copperweld*. The copper coating is necessary for RF service because steel is a relatively poor conductor. Practically all of the RF current is confined to the copper coating because of *skin effect*. Copper-clad steel is outstanding for permanent installations, but it can be difficult to work with. Kinking, which severely weakens the wire, is a potential problem when handling any solid conductor. Solid-copper wire, either hard drawn or soft drawn, is another popular material. Easier to handle than copper-clad steel, solid copper is available in a wide range of sizes. It is generally more expensive however, because it is all copper. Soft drawn tends to stretch under tension, so periodic pruning of the antenna may be necessary in some cases. Enamel-coated *magnetwire* is a suitable choice for experimental antennas because it is easy to manage, and the coating protects the wire from the weather. Although it stretches under tension, the wire may be prestretched before final installation and adjustment. A local electric motor rebuilder might be a good source for magnet wire.

Hook-up wire, speaker wire or even ac lamp cord are suitable for temporary installations. Almost any copper wire may be used, as long as it is strong enough for the demands of the installation. Steel wire is a poor conductor at RF; avoid it.

It matters not (in the HF region at least) whether the wire chosen is insulated or bare. If insulated wire is used, a 3 to 5% shortening beyond the standard 468/f length will be required to obtain resonance at the desired frequency. This is caused by the increased distributed capacitance resulting from the dielectric constant of the plastic insulating material. The actual length for resonance must be determined experimentally by pruning and measuring because the dielectric constant of the insulating material varies from wire to wire. Wires that might come into contact with humans or animals should be insulated to reduce the chance of shock or burns.

Insulators

Wire antennas must be insulated at the ends. Commercially available insulators are made from ceramic, glass or plastic. Insulators are available from many Amateur Radio dealers. RadioShack and local hardware stores are other possible sources.

Acceptable homemade insulators may be fashioned from a variety of material including (but not limited to) acrylic sheet or rod, PVC tubing, wood, fiberglass rod or even stiff plastic from a discarded container. **Fig 22.9** shows some homemade insulators. Ceramic or glass insulators will usually outlast the wire, so they are highly recommended for a safe, reliable, permanent installation. Other materials may tear under stress or break down in the presence of sunlight. Many types of plastic do not weather well.

Many wire antennas require an insulator at the feedpoint. Although there are many ways to connect the feed line, there are a few things to keep in mind. If you feed your antenna with coaxial cable, you have two choices. You can install an SO-239 connector on the center insulator and use a PL-259 on the end of your coax, or you can separate the center conductor from the braid and connect the feed line directly to the antenna wire. Although it costs less to connect direct, the use of connectors offers several advantages.

Coaxial cable braid soaks up water. If you do not adequately seal the antenna end of the feed line, water will find its way into the braid. Water in the feed line will lead to contamination, rendering the coax useless long before its normal lifetime is up. It is not uncommon for water to drip from the end of the coax inside the shack after a year or so of service if the antenna connection is not properly waterproofed. Use of a PL-259/SO-239 combination (or other connector of your choice) makes the task of waterproofing connections much easier. Another advantage to using the PL-259/SO-239 combination is that feed line replacement is much easier, should that become necessary or desireable.

Whether you use coaxial cable, ladder line, or twin lead to feed your antenna, an often-overlooked consideration is the mechanical strength of the connection. Wire antennas and feed lines tend to move

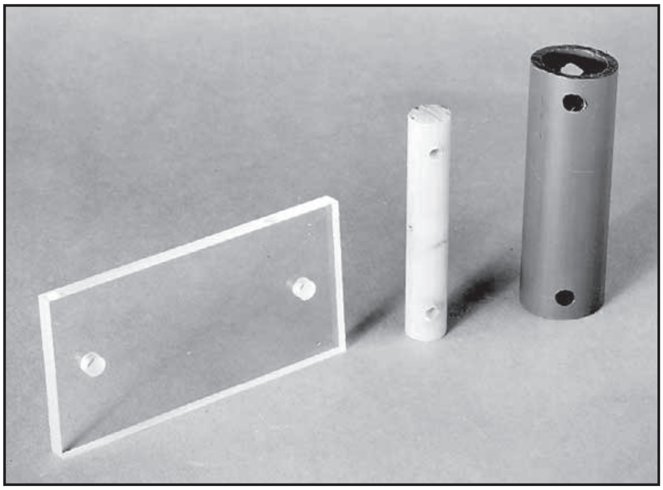


Fig 22.9 — Some ideas for homemade antenna insulators.

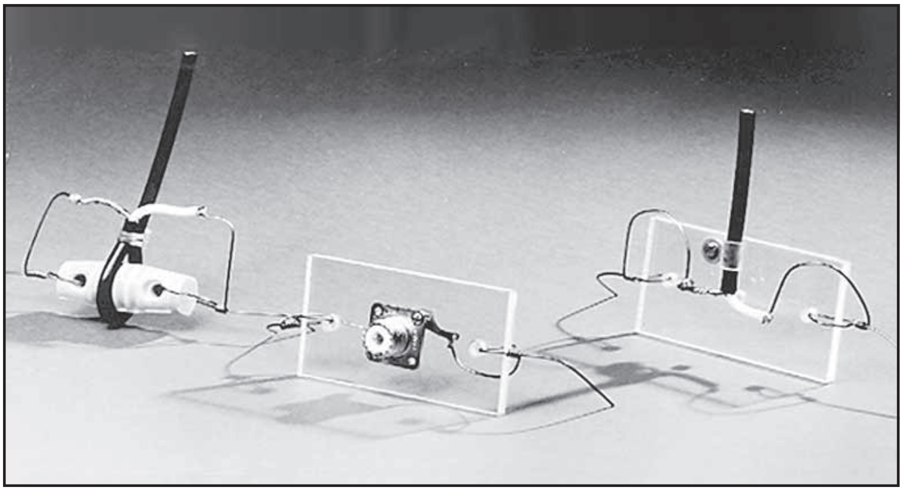


Fig 22.10 — Some homemade dipole center insulators. The one in the center includes a built-in SO-239 connector. Others are designed for direct connection to the feed line. (See the Transmission Lines chapter for details on baluns.)

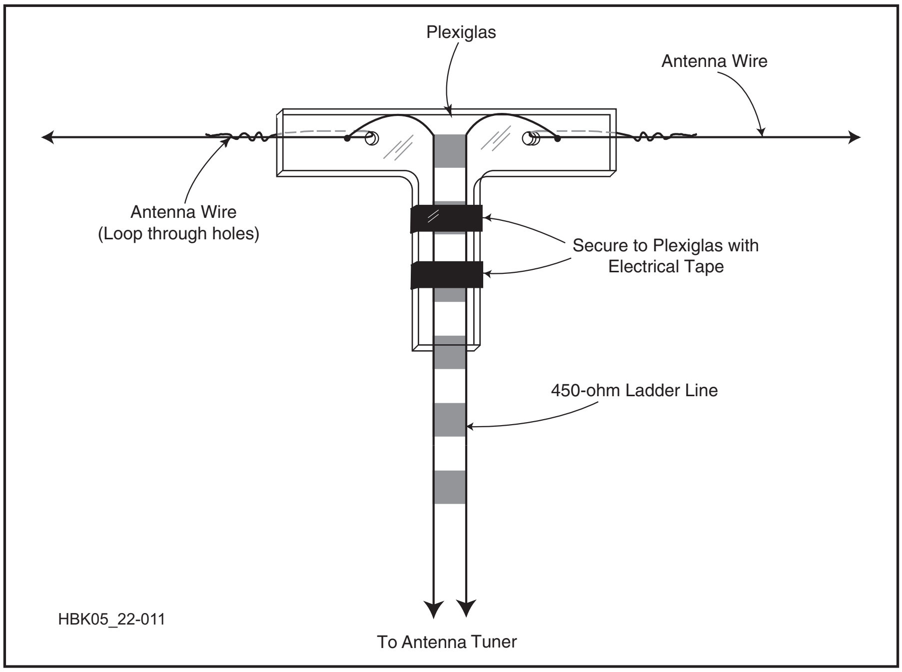


Fig 22.11 — A piece of cut Plexiglas can be used as a center insulator and to support a ladder-line feeder. The Plexiglas acts to reduce the flexing of the wires where they connect to the antenna.

Table 22.4
Dipole Dimensions for Amateur Bands

Freq MHz	*Overall Length*	*Leg Length*
28.4	16' 6"	8' 3"
24.9	18' 9½"	9' 4¾"
21.1	22' 2"	11' 1"
18.1	25' 10"	12' 11"
14.1	33' 2"	16' 7"
10.1	46' 4"	23' 2"
7.1	65' 10"	32' 11"
5.37	87' 2"	43' 7"
3.6	130' 0"	65' 0"

a lot in the breeze, and unless the feed line is attached securely, the connection will weaken with time. The resulting failure can range from a frustrating intermittent electrical connection to a complete separation of feed line and antenna. **Fig 22.10** illustrates several different ways of attaching the feed line to the antenna. An idea for supporting ladder line is shown in **Fig 22.11**.

Putting It Together

Fig 22.12 shows details of antenna construction. Although a dipole is used for the examples, the techniques illustrated here apply to any type of wire antenna. **Table 22.4** shows dipole lengths for the amateur HF bands.

How well you put the pieces together is second only to the ultimate strength of the materials used in determining how well your antenna will work over the long term. Even the smallest details, such as how you connect the wire to the insulators (Fig 22.12A), contribute significantly to antenna longevity. By using plenty of wire at the insulator and wrapping it tightly, you will decrease the possibility of the wire pulling loose in the wind. There is no need to solder the wire once it is wrapped. There is no electrical connection here, only mechanical. The high heat needed for soldering can anneal the

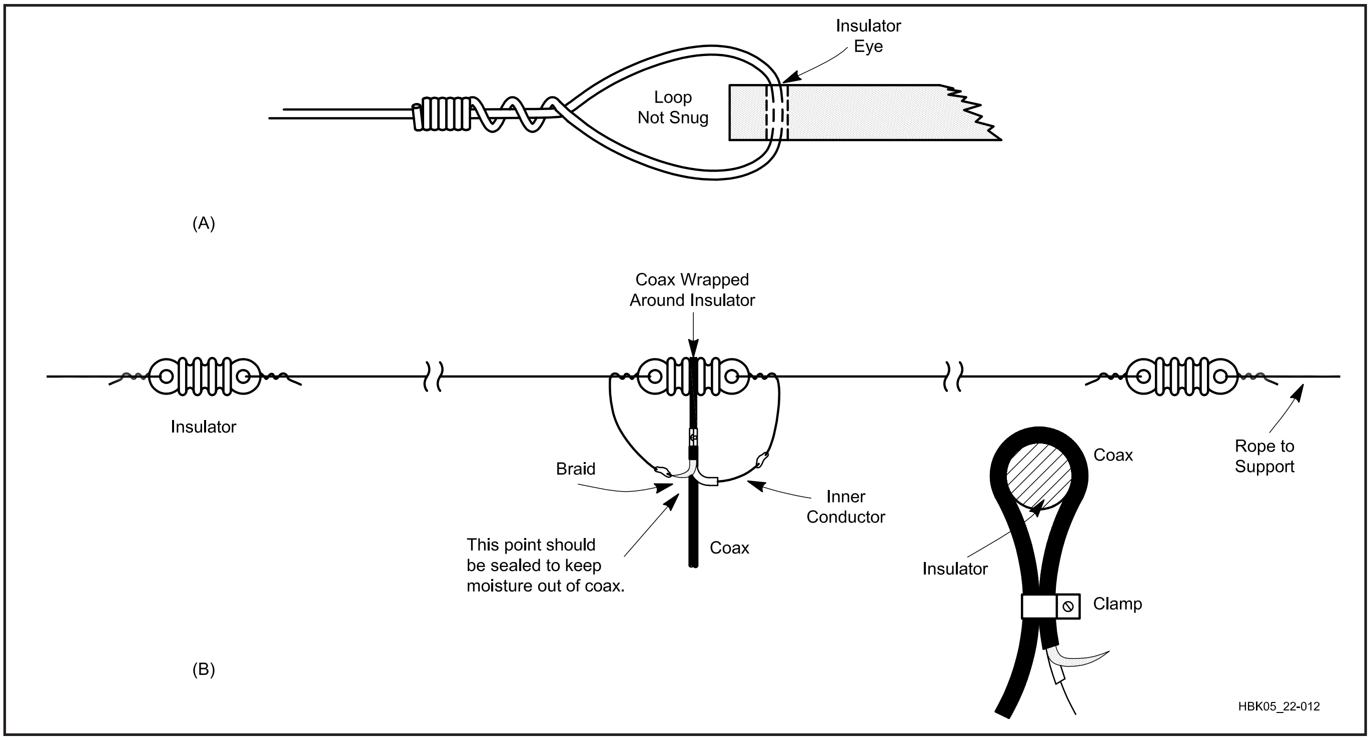


Fig 22.12 — Details of dipole antenna construction. The end insulator connection is shown at A, while B illustrates the completed antenna. This is a balanced antenna and is often fed with a balun.

wire, significantly weakening it at the solder point.

Similarly, the feed-line connection at the center insulator should be made to the antenna wires after they have been secured to the insulator (Fig 22.12B). This way, you will be assured of a good electrical connection between the antenna and feed line without compromising the mechanical strength. Do a good job of soldering the antenna and feed-line connections. Use a heavy iron or a torch, and be sure to clean the materials thoroughly before starting the job. Proper planning should allow you to solder indoors at a workbench, where the best possible joints may be made. Poorly soldered or unsoldered connections will become headaches as the wire oxidizes and the electrical integrity degrades with time. Besides degrading your antenna performance, poorly made joints can even be a cause of TVI because of rectification. Spray paint the connections with acrylic for waterproofing.

If made from the right materials, the dipole should give a builder years of maintenance-free service—unless of course a tree falls on it. As you build your antenna, keep in mind that if you get it right the first time, you won't have to do it again for a long time.

SHORTENED DIPOLES

Inductive loading increases the electrical length of a conductor without increasing its physical length. Therefore, we can build physically short dipole antennas by placing inductors in the antenna. These are called *loaded antennas*, and *The ARRL Antenna Book* shows how to design them. There are some trade-offs involved: Inductively loaded antennas are less efficient and have narrower bandwidths than full-size antennas. Generally they should not be shortened more than 50%.

DIPOLE ORIENTATION

Dipole antennas need not be installed horizontally and in a straight line. They are generally tolerant of bending, sloping or drooping. Bent dipoles may be used where antenna space is at a premium. **Fig 22.13** shows a couple of possibilities; there are many more. Bending distorts the radiation pattern somewhat and may affect the impedance as well, but compromises may be acceptable when the situation demands them. Remember that dipole antennas are RF conductors. For safety's sake, mount all antennas away from conductors (especially power lines), combustibles and well beyond the reach of passersby. When an antenna bends back on itself (as in Fig 22.13B) some of the signal is canceled; avoid this if possible.

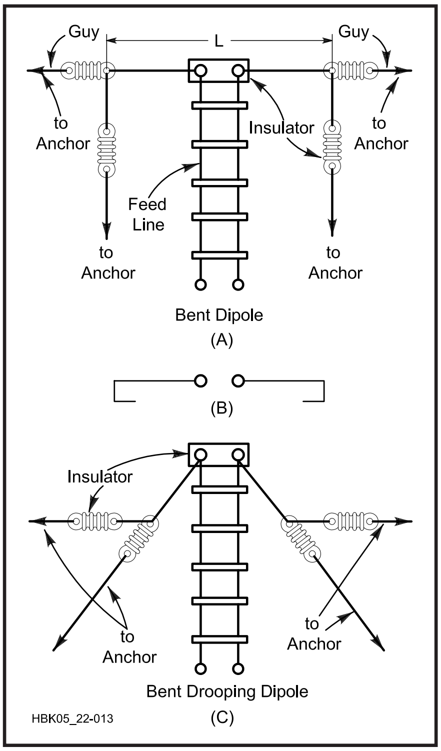


Fig 22.13 — When limited space is available for a dipole antenna, the ends can be bent downward as shown at A, or back on the radiator as shown at B. The inverted V at C can be erected with the ends bent parallel with the ground when the available supporting structure is not high enough.

DROOPING DIPOLE

A drooping dipole, also known as an *Inverted V dipole*, appears in **Fig 22.14**. While *V* describes the shape of this antenna, this antenna should not be confused with long-wire V antennas, which are highly directive. The radiation pattern and dipole impedance depend on the apex angle, and it is very important that the ends do not come too close to lossy ground. Remember that current produces the radiated signal, and current is maximum at the dipole center. Therefore, performance is best when the central area of the antenna is straight, high and clear of nearby objects.

SLOPING DIPOLE

A sloping dipole is shown in **Fig 22.15**. This antenna is often used to favor one direction (the *forward direction* in the figure). With a nonconducting support and poor earth, signals off the back are weaker than those off the front. With a nonconducting mast and good earth, the response is omnidirectional. There is no gain in any direction with a nonconducting mast.

A conductive support such as a tower acts as a parasitic element. (So does the coax shield, unless it is routed at 90° from

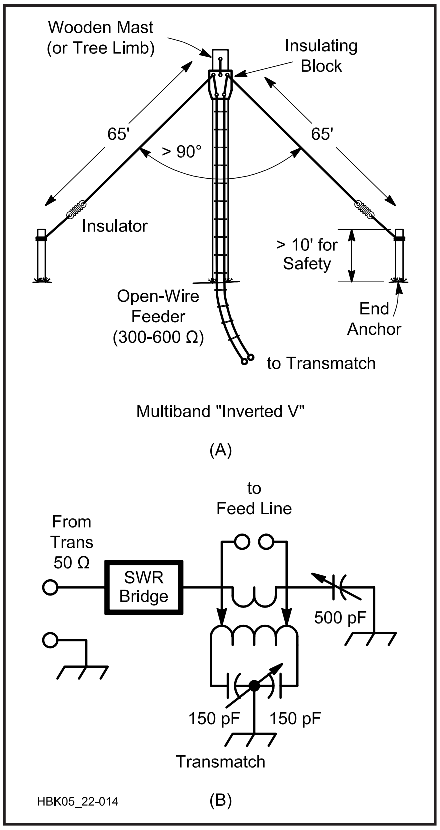


Fig 22.14 — At A, details for an inverted V fed with open-wire line for multiband HF operation. A Transmatch is shown at B, suitable for matching the antenna to the transmitter over a wide frequency range. The included angle between the two legs should be greater than 90° for best performance.

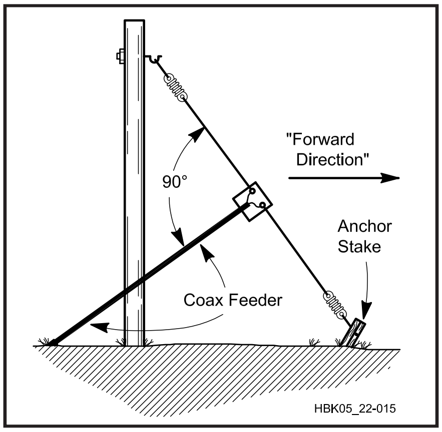


Fig 22.15 — Example of a sloping $\frac{1}{2}$-λ dipole, or *full sloper*. On the lower HF bands, maximum radiation over poor to average earth is off the sides and in the *forward direction* as indicated, if a nonconductive support is used. A metal support will alter this pattern by acting as a parasitic element. How it alters the pattern is a complex issue depending on the electrical height of the mast, what other antennas are located on the mast, and on the configuration of any guy wires.

the antenna.) The parasitic effects vary with earth quality, support height and other conductors on the support (such as a beam at the top). With such variables, performance is very difficult to predict.

Losses increase as the antenna ends approach the support or the ground. To prevent feed-line radiation, route the coax away from the feed-point at 90° from the antenna, and continue on that line as far as possible.

HALF-WAVE VERTICAL DIPOLE (HVD)

Unlike its horizontal counterpart, which has a figure-8 pattern, the azimuthal pattern of a vertical dipole is omnidirectional. In other words, it looks like a circle. Look again at Figs 22.3 and 22.4 and note the comparison between horizontal and vertical dipole elevation patterns. These two figures illustrate the fact that performance of a horizontal dipole depends to a great extent on its height above ground. By contrast, *half-wave vertical dipole* (HVD) performance is highly dependent on ground conductivity and dielectric constant.

After looking at these figures, you might easily conclude that there is no advantage to an HVD. Is that really the case? Experiments at K8CH run between 2001 and 2003 showed that the HVD mounted above average ground works well for long-distance (DX) contacts. Two antennas were used in the trials. The first was a 15-m HVD with its base 14 ft above ground (feedpoint at 25 ft). The second (reference) antenna was a 40-m dipole modified to operate with low SWR on 15 m. The reference dipole feedpoint was at 29 feet and the ends drooped slightly to provide a 160° included angle. Signals from outside North America were usually stronger on the HVD. Computer analysis revealed the reasons for this.

Fig 22.16 shows the elevation patterns for the vertical dipole and for the reference dipole at a pattern peak and at a null. The vertical dipole does not look impressive, does it? The large lobe in the HVD pattern at 48° is caused by the antenna being elevated 14 ft above ground. This lobe will shrink at lower heights.

Data compiled by Dean Straw, N6BV, shows that 90% of DX contacts from K8CH should use elevation angles of 10° or less. Further, nearly half of the contacts would use 3° or less. The azimuthal patterns for 10° are shown in **Fig 22.17** and for 3° in **Fig 22.18**. You can clearly see in the patterns the DX potential of an HVD.

Another advantage of the HVD is its radiation resistance at low heights. Look back in Fig 22.1 at the curve for the vertical half-wave antenna. With it's base just above ground, the HVD will have a radiation resistance of over 90 Ω. That can easily be turned to an advantage. Capacitive loading will lower the radiation resistance *and* shorten the antenna. It is possible to make a loaded vertical dipole that is half the height of an HVD and that has a good SWR when fed with 50-Ω coax.

MULTIBAND DIPOLES

There are several ways to construct coax-fed multiband dipole systems. These techniques apply to dipoles of all orientations. Each method requires a little more work than a single dipole, but the materials don't cost much.

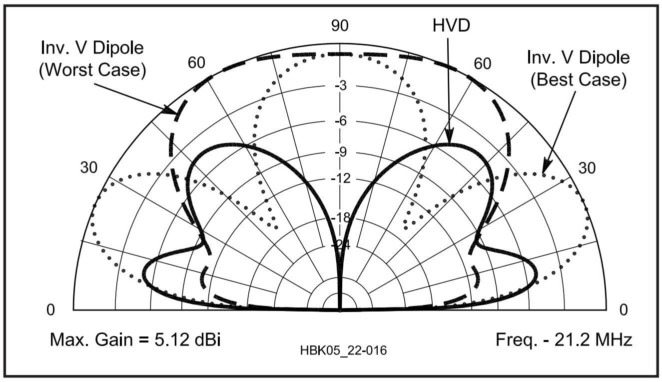


Fig 22.16 — Elevation patterns for the HVD (solid line) and the inverted V comparison antenna in its best case (dashed line) and worst case (dotted line).

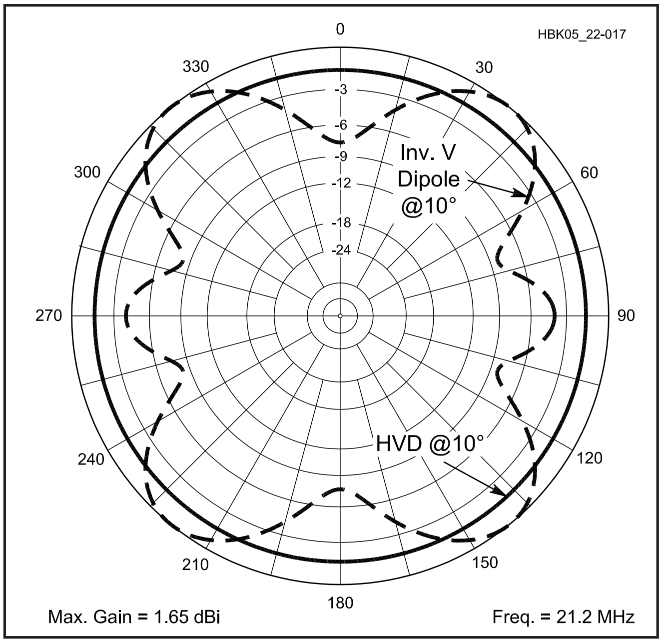


Fig 22.17 — Azimuth patterns at 10° elevation for the HVD (dashed line) and inverted V (solid line).

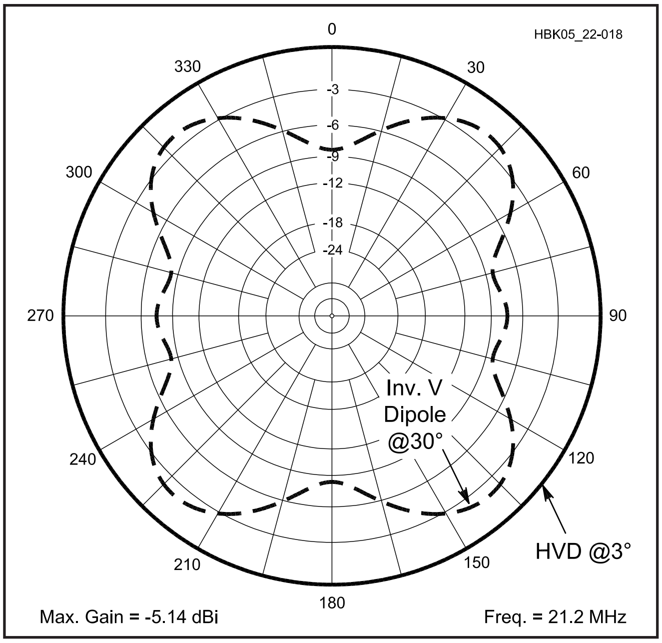


Fig 22.18 — Azimuth patterns at 3° elevation for the HVD (dashed line) and the inverted V (solid line).

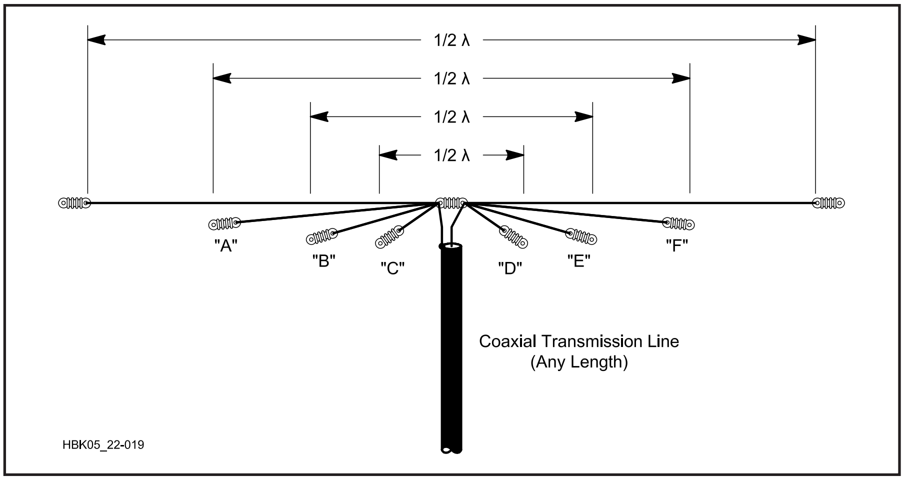


Fig 22.19 — Multiband antenna using paralleled dipoles, all connected to a common 50 or 75-Ω coax line. The half-wave dimensions may be either for the centers of the various bands or selected for favorite frequencies in each band. The length of a half wave in feet is 468/frequency in MHz, but because of interaction among the various elements, some pruning for resonance may be needed on each band. See text.

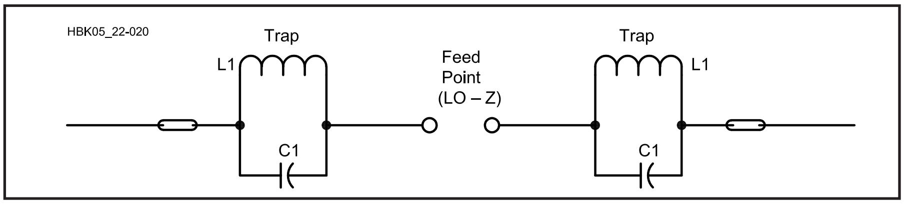


Fig 22.20 — Example of a trap dipole antenna. L1 and C1 can be tuned to the desired frequency by means of a dip meter *before* they are installed in the antenna.

Parallel dipoles are a simple and convenient answer. See **Fig 22.19**. Center-fed dipoles present low-impedances near f_0, or its odd harmonics, and high impedances elsewhere. This lets us construct simple multiband systems that automatically select the appropriate antenna. Consider a 50-Ω resistor connected in parallel with a 5-kΩ resistor. A generator connected across the two resistors will see 49.5 Ω, and 99% of the current will flow through the 50-Ω resistor. When resonant and nonresonant antennas are parallel connected, the nonresonant antenna takes little power and has little effect on the total feed-point impedance. Thus, we can connect several antennas together at the feed-point, and power naturally flows to the resonant antenna.

There are some limits, however. Wires in close proximity tend to couple and produce mutual inductance. In parallel dipoles, this means that the resonant length of the shorter dipoles lengthens a few percent. Shorter antennas don't affect longer ones much, so adjust for resonance in order from longest to shortest. Mutual inductance also reduces the bandwidth of shorter dipoles, so a Transmatch may be needed to achieve an acceptable SWR across all bands covered. These effects can be reduced by spreading the ends of the dipoles.

Also, the power-distribution mechanism requires that only one of the parallel dipoles is near resonance on any amateur band. Separate dipoles for 80 and 30 m should not be parallel connected because the higher band is near an odd harmonic of the lower band ($80/3 \approx 30$) and center-fed dipoles have low impedance near odd harmonics. (The 40 and 15-m bands have a similar relationship.) This means that you must either accept the lower performance of the low-band antenna operating on a harmonic or erect a separate antenna for those odd-harmonic bands. For example, four parallel-connected dipoles cut for 80, 40, 20 and 10 m (fed by a single Transmatch and coaxial cable) work reasonably on all HF bands from 80 through 10 m.

Trap dipoles provide multiband operation from a coax-fed single-wire dipole. **Fig 22.20** shows a two-band trap antenna. A trap comprises inductance and capacitance in parallel. At resonance that effectively disconnects wire beyond the trap at the resonant frequency. Above resonance, traps provide capacitive loading. Below resonance, they provide inductive loading. Traps may be constructed from coiled sections of coax or from discrete LC components.

Choose capacitors (Cl in the figure) that are rated for high current and voltage. Mica transmitting capacitors are good. Ceramic transmitting capacitors may work, but their values may change with temperature. Use large wire for the inductors to reduce loss. Any reactance (X_L and X_C) above 100 Ω (at f_0) will work, but bandwidth increases with reactance (up to several thousand ohms).

Check trap resonance before installation. This can be done with a dip meter and a receiver. To construct a trap antenna, cut a dipole for the highest frequency and connect the pretuned traps to its ends. It is fairly complicated to calculate the additional wire needed for each band, so just add enough wire to make the antenna 1/2 λ and prune it as necessary. Because the inductance in each trap reduces the physical length needed for resonance, the finished antenna will be shorter than a simple 1/2-λ dipole.

A 135-FT MULTIBAND CENTER-FED DIPOLE

An 80-m dipole fed with ladder line is a versatile antenna. If you add a wide-range matching network, you have a low-cost antenna system that works well across the entire HF spectrum. Countless hams have used one of these in single-antenna stations and for Field Day operations.

For best results place the antenna as high as you can, and keep the antenna and ladder line clear of metal and other conductive objects. Despite significant SWR on some bands, system losses are low. (See the **Transmission Lines** chapter.) You can make the dipole horizontal, or you can install it as an inverted V. ARRL staff analyzed a 135-ft dipole at 50 ft above typical ground and compared that to an inverted V with the center at 50 ft, and the ends at 10 ft. The results show that on the 80-m band, it won't make much difference which configuration you choose. (See **Fig 22.21**.) The inverted V exhibits additional losses because of its proximity to ground.

Fig 22.22 shows a comparison between a 20-m flat-top dipole and the 135-ft flat-top dipole when both are placed at 50 ft above ground. At a 10° elevation angle, the 135-ft dipole has a gain advantage. This advantage comes at the cost of two deep, but narrow, nulls that are broadside to the wire.

Fig 22.23 compares the 135-ft dipole to the inverted-V configuration of the same antenna on 14.1 MHz. Notice that the inverted-V pattern is essentially omnidirectional. That comes at the cost of gain, which is less than that for a horizontal flat-top dipole.

As expected, patterns become more

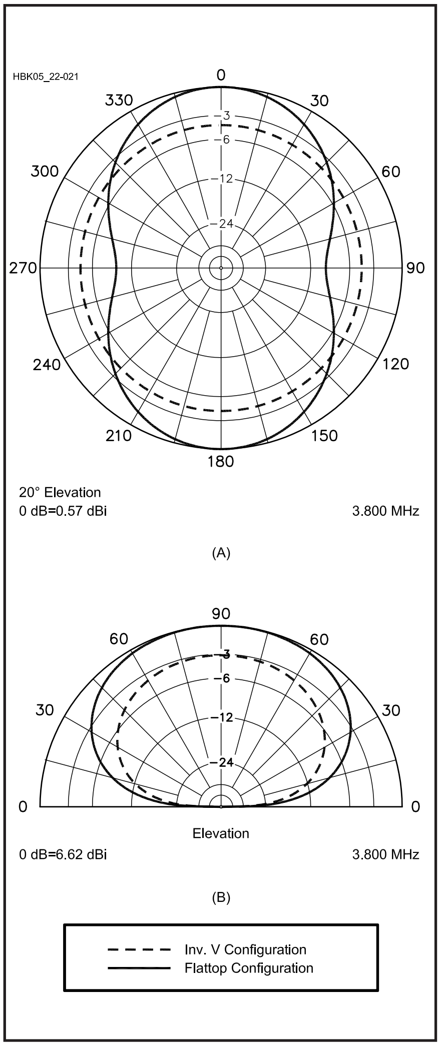


Fig 22.21 — Patterns on 80 m for 135-ft, center-fed dipole erected as a horizontal dipole at 50 ft, and as an inverted V with the center at 50 ft and the ends at 10 ft. The azimuth pattern is shown at A, where the conductor lies in the 90° to 270° plane. The elevation pattern is shown at B, where the conductor comes out of paper at a right angle. At the fundamental frequency the patterns are not markedly different.

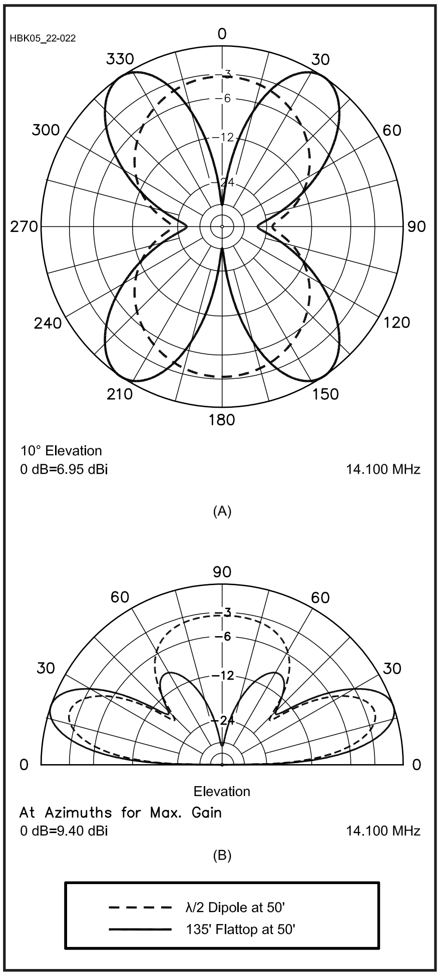


Fig 22.22 — Patterns on 20 m comparing a standard $^{1}/_{2}$-λ dipole and a multiband 135-ft dipole. Both are mounted horizontally at 50 ft. The azimuth pattern is shown at A, where conductors lie in the 90° to 270° plane. The elevation pattern is shown at B. The longer antenna has four azimuthal lobes, centered at 35°, 145°, 215°, and 325°. Each is about 2 dB stronger than the main lobes of the $^{1}/_{2}$-λ dipole. The elevation pattern of the 135-ft dipole is for one of the four maximum-gain azimuth lobes, while the elevation pattern for the $^{1}/_{2}$-λ dipole is for the 0° azimuthal point.

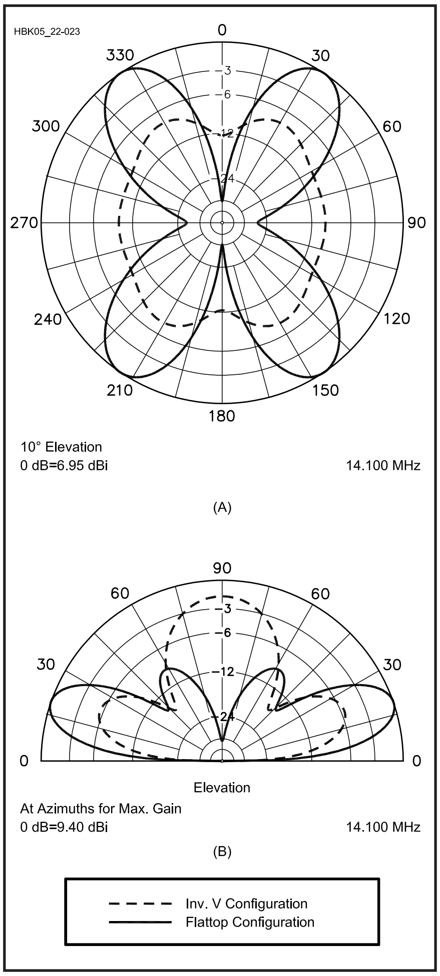


Fig 22.23 — Patterns on 20 m for two 135-ft dipoles. One is mounted horizontally as a flat-top and the other as an inverted V with 120° included angle between the two legs. The azimuth pattern is shown at A, and the elevation pattern is shown at B. The inverted V has about 6 dB less gain at the peak azimuths, but has a more uniform, almost omnidirectional, azimuthal pattern. In the elevation plane, the inverted V has a fat lobe overhead, making it a somewhat better antenna for local communication, but not quite so good for DX contacts at low elevation angles.

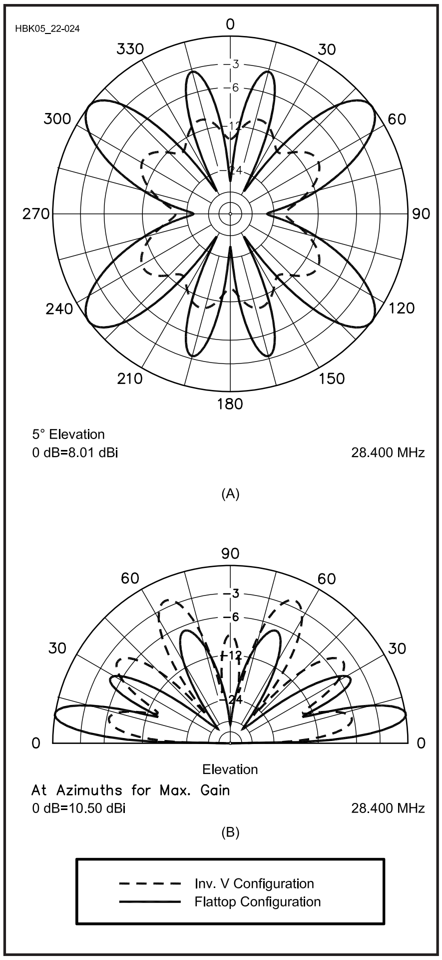


Fig 22.24 — Patterns on 10 m for 135-ft dipole mounted horizontally and as an inverted V, as in Fig 22.23. The azimuth pattern is shown at A, and the elevation pattern is shown at B. Once again, the inverted-V configuration yields a more omnidirectional pattern, but at the expense of almost 8 dB less gain than the flat-top configuration at its strongest lobes.

complicated at 28.4 MHz. As you can see in **Fig 22.24**, the inverted V has the advantage of a pattern with slight nulls, but with reduced gain compared to the flat-top configuration.

Installed horizontally, or as an inverted V, the 135-ft center-fed dipole is a simple antenna that works well from 3.5 to 30 MHz. Bandswitching is handled by a Transmatch that is located near your operating position.

Antenna Modeling by Computer

Modern computer programs have made it a *lot* easier for a ham to evaluate antenna performance. The elevation plots for the 135-ft long center-fed dipole were generated using a sophisticated computer program known as *NEC*, short for "Numerical Electromagnetics Code." *NEC* is a general-purpose antenna modeling program, capable of modeling almost any antenna type, from the simplest dipole to extremely complex antenna designs. Various mainframe versions of *NEC* have been under continuous development by US government researchers for several decades.

But because it is a general-purpose program, *NEC* can be very slow when modeling some antennas—such as long-boom, multi-element Yagis. There are other, specialized programs that work on Yagis much faster than *NEC*. Indeed, *NEC* has developed a reputation for being accurate (if properly applied!), but decidedly difficult to learn and use. A number of commercial software developers have risen to the challenge and created more *user-friendly* versions. Check the ads in *QST*.

NEC uses a *Method of Moments* algorithm. The mathematics behind this algorithm are pretty formidable to most hams, but the basic principle is simple. An antenna is broken down into a set of straight-line wire *segments*. The fields resulting from the current in each segment and from the mutual interaction between segments are vector-summed in the far field to create azimuth and elevation-plane patterns.

The most difficult part of using a *NEC*-type of modeling program is setting up the antenna's geometry—you must condition yourself to think in three-dimensional coordinates. Each end point of a wire is represented by three numbers: an x, y and z coordinate. An example should help sort things out. See **Fig A**, showing a *model* for a 135-foot center-fed dipole, made of #14 wire placed 50 ft above flat ground. This antenna is modeled as a single, straight wire.

For convenience, ground is located at the *origin* of the coordinate system, at (0, 0, 0) feet, directly under the center of the dipole. The dipole runs parallel to, and above, the y-axis. Above the origin, at a height of 50 feet, is the dipole's feedpoint. The *wingspread* of the dipole goes toward the left (that is, in the *negative y* direction) one-half the overall length, or –67.5 ft. Toward the right, it goes +67.5 ft. The *x* dimension of our dipole is zero. The dipole's ends are thus represented by two points, whose coordinates are: (0, –67.5, 50) and (0, 67.5, 50) ft. The thickness of the antenna is the diameter of the wire, #14 gauge.

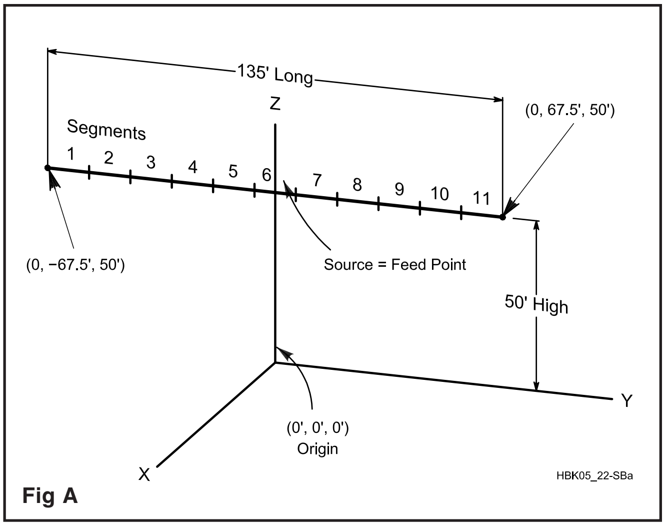


Fig A

To run the program you must specify the number of segments into which the dipole is divided for the method-of-moments analysis. The guideline for setting the number of segments is to use at least 10 segments per half-wavelength. In Fig A, our dipole has been divided into 11 segments for 80-m operation. The use of 11 segments, an odd rather than an even number such as 10, places the dipole's feedpoint (the *source* in *NEC*-parlance) right at the antenna's center and at the center of segment number six.

Since we intend to use our 135-foot long dipole on all HF amateur bands, the number of segments used actually should vary with frequency. The penalty for using more segments in a program like *NEC* is that the program slows down roughly as the square of the segments—double the number and the speed drops to a fourth. However, using too few segments will introduce inaccuracies, particularly in computing the feed-point impedance. The commercial versions of *NEC* handle such nitty-gritty details automatically.

Let's get a little more complicated and specify the 135-ft dipole, configured as an inverted-V. Here, as shown in **Fig B**, you must specify *two* wires. The two wires join at the top, (0, 0, 50) ft. Now the specification of the source becomes more complicated. The easiest way is to specify two sources, one on each end segment at the junction of the two wires. If you are using the *native* version of *NEC*, you may have to go back to your high-school trigonometry book to figure out how to specify the end points of our droopy dipole, with its 120° included angle. Fig B shows the details, along with the trig equations needed.

So, you see that antenna modeling isn't entirely a cut-and-dried procedure. The commercial programs do their best to hide some of the more unwieldy parts of *NEC*, but there's still some art mixed in with the science. And as always, there are trade-offs to be made—segments versus speed, for example.

However, once you do figure out exactly how to use them, computer models are wonderful tools. They can help you while away a dreary winter's day, designing antennas on-screen—without having to risk life and limb climbing an ice-covered tower. And in a relatively short time a computer model can run hundreds, or even thousands, of simulations as you seek to optimize an antenna for a particular parameter. Doesn't that sound better than trying to optimally tweak an antenna by means of a thousand cut-and-try measurements, all the while hanging precariously from your tower by a climbing belt?!—*R. Dean Straw, N6BV, Senior Assistant Technical Editor*

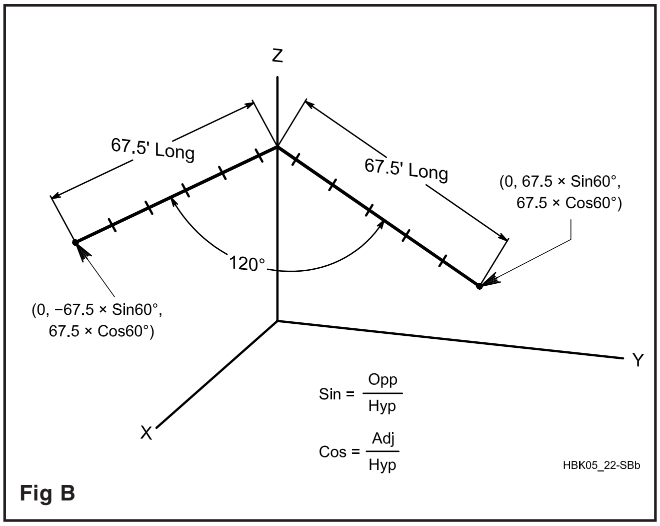


Fig B

A 40-M AND 15-M DUAL-BAND DIPOLE

As mentioned earlier, dipoles have harmonic resonances at 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-m dipole, feed it with coax, and use it without an antenna tuner on both 40 and 15 m.

But there's a catch: The third harmonic resonance is actually higher than three times the fundamental resonant frequency. This is because there is no end effect in the center portion of the antenna.

An easy fix for this, as shown in **Fig 22.25**, is to capacitively load the antenna about a quarter wavelength (at 21.2 MHz) away from the feedpoint in both wires. Known as *capacitance hats*, the simple loading wires shown lower the antenna's resonant frequency on 15 m without substantially affecting resonance on 40 m.

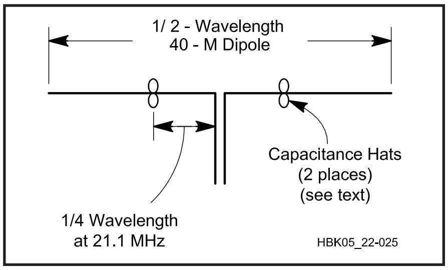


Fig 22.25 — Figure-8-shaped capacitance hats made and placed as described in the text, can make your 40-m dipole resonate anywhere you like in the 15-m band.

To put this scheme to use, first measure, cut and adjust the dipole to resonance at the desired 40-m frequency. Then, cut two 2-ft-long pieces of stiff wire (such as #12 or #14 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 feedpoint (placement isn't critical) on each wire. To resonate the antenna on 15 m, adjust the loop shapes (*not while you're transmitting!*) until the SWR is acceptable in the desired segment of the 15-m band.

THE K8SYL 75 AND 10-M DIPOLE

The same idea was adapted by Sylvia Hutchinson, K8SYL, to make a two-band dipole for 75 and 10 m. Her account was published in July 2002 *QST*.

She discovered that a dipole resonant in the General Class portion of the 75-m band is also resonant on 10 m. As in the case of the 40 and 15-m dipole, some additional loading may be required to move the 10-m resonance to the desired portion of the band.

There is another catch. The radiation resistance on 10 m is about 120 Ω. In another words, if you feed this antenna with 50-Ω coax your best SWR will be around 2.4:1. A quarter wavelength (at 10 m) of 75-Ω coax (such as RG-11) will transform that 120-Ω feedpoint impedance to just under 50 Ω. In this case, the SWR will be better than 1.1:1 at resonance.

The length of the matching section is a small fraction of a wavelength at 3.9 MHz. This will tend to narrow the SWR bandwidth, but only slightly. The antenna is shown in **Fig 22.26**.

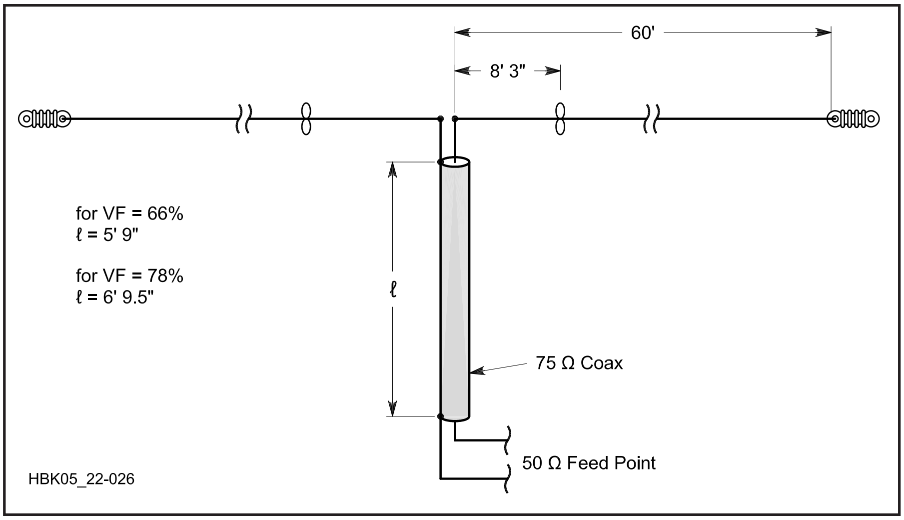


Fig 22.26 — The K8SYL dipole operates on the 75 and 10-m bands. A quarter-wave section of 75-Ω coax transforms the 10-m impedance. See text.

Make each capacitance hat from an 18 to 20-in length of #12 or #14 house wire. Solder the ends together to form a loop, leaving a couple of inches free for attaching to the dipole. Next, twist the loop to form a figure-8. The portion of the loop where the ends meet should be at the center of the figure-8. Strip the crossing wire at this point and the capacitance hat is ready to attach to the dipole.

Tune the antenna on 75 m first. Trim the dipole ends for resonance in your favorite portion of the band. For K8SYL, each leg was 59 ft, 4 inches long. Then check the SWR on 10 m. Adjust the loop shapes (*not while you're transmitting!*) until the SWR is acceptable in the desired segment of the 10-m band.

THE W4RNL INVERTED-U ANTENNA

This simple rotatable dipole was designed and built by L. B. Cebik, W4RNL, for use during the ARRL Field Day. For this and other portable operations we look for three antenna characteristics: simplicity, small size, and light weight. Complex assemblies increase the number of things that can go wrong. Large antennas are difficult to transport and sometimes do not fit the space available. Heavy antennas require heavy support structures, so the overall weight seems to increase exponentially with every added pound of antenna.

Today, a number of light-weight collapsible masts are available. Some will support—when properly guyed—antennas in the 5-10 pound range. Most are suitable for 10-m tubular dipoles and allow the user to hand-rotate the antenna. Extend the range of the antenna to cover 20-10 m, and you put these 20-30-foot masts to even better use. The inverted U meets this need.

THE BASIC IDEA OF THE INVERTED U

A dipole's highest current occurs within the first half of the distance from the feedpoint to the outer tips. Therefore, very little performance is lost if the outer end sections are bent. The W4RNL inverted U starts with a 10-m tubular dipole. You add extensions for 12, 15, 17, or 20 m to cover those bands.

You only need enough space to erect a 10-m rotatable dipole. The extensions hang down. **Fig 22.27** shows the relative proportions of the antenna on all bands from 10 to 20 m. The 20-m extensions are the length of half the 10-m dipole. Therefore, safety dictates an antenna height of at least 20 ft to keep the tips above 10 ft high. At any power level, the ends of a dipole have high RF voltages, and we must keep them out of contact with human body parts.

Not much signal strength is lost by drooping up to half the overall element length straight down. What is lost in bi-directional gain shows up in decreased side-nulls. **Fig 22.28** shows the free-space E-plane (azimuth) patterns of the inverted U with a 10-m horizontal section. There is an undetectable decrease in gain between the 10-m and 15-m versions. The 20-m version shows a little over a half-dB gain decrease and a signal increase off the antenna ends.

The real limitation of an inverted-U is a function of the height of the antenna above ground. With the feedpoint at 20 ft above ground, we obtain the elevation patterns shown in **Fig 22.29**. The 10-m pattern is typical for a dipole that is about 5/8 λ above ground. On 15, the antenna is only 0.45 λ high, with a resulting increase in the overall elevation angle of the signal and a reduction in gain. At 20 m, the angle grows still higher, and the signal strength diminishes as the antenna height drops to under 0.3 λ. Nevertheless, the signal is certainly usable. A full-size dipole at 20 m would show only a little more gain, and the elevation angle would be similar to that of the invert U, despite the difference in antenna shape. If we raise the inverted-U to 40 feet, the 20-m performance would be very similar to that shown by the 10-m elevation plot in Fig 22.29.

The feedpoint impedance of the inverted-U remains well within acceptable limits for virtually all equipment, even at 20 feet above ground. Also, the SWR curves are very broad, reducing the criticalness of finding exact dimensions, even for special field conditions.

BUILDING AN INVERTED-U

Approach the construction of an inverted-U in 3 steps: 1. the tubing arrangement, 2. the center hub and feedpoint assembly, and 3. the drooping extensions. A parts list appears in **Table 22.5**.

The Aluminum Tubing Dipole for 10 meters.

The aluminum tubing dipole consists of three longer sections of tubing and a short section mounted permanently to the feed point plate, as shown in **Fig 22.30**. Let's consider each half of the element separately. Counting from the center of the plate—the feedpoint—the element extends 5 inches using 3/4-inch aluminum tubing. Then we have two 33 inch exposed tubing sections, with an additional 3 inches of tubing overlap per section. These sections are 5/8- and 1/2-inch diameter, respectively. The outer section is 30 inches long exposed (with at least a 3 inches overlap) and consists of 3/8-inch diameter tubing.

Since the 5/8- and 1/2-inch sections are 36 inches long, you can make the outer 3/8-inch section the same overall length and use more overlap, or you can cut the tubing to 33 inches and use the 3 inch overlap. Three inches of overlap is sufficient to ensure a strong junction, and it minimizes excess weight. However, when not in use, the 3 outer tubing sections will nest inside each other for storage, and a 36-inch length for the outer section is a bit more convenient to un-nest for assembly. Keep the end hitch pin on the 3/8 inch tubing as an easy way of pulling it into final position. You may use the readily available 6063-T832 aluminum tubing that nests well and has a long history of antenna service.

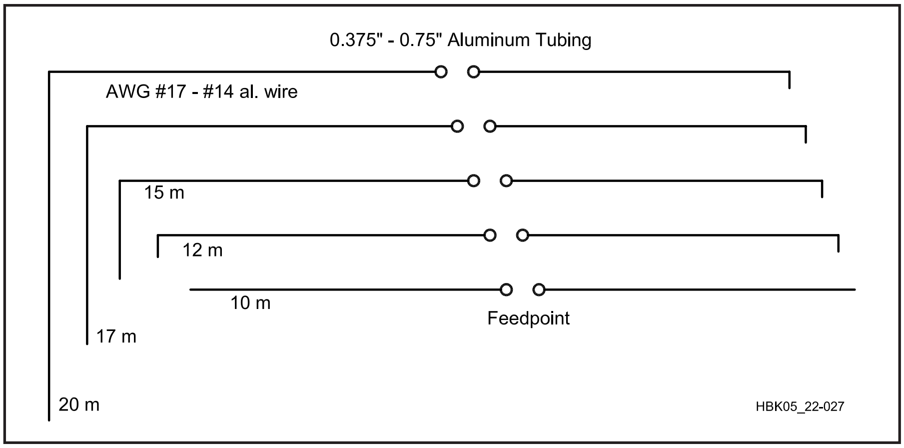


Fig 22.27 — The general outline of the inverted-U field dipole for 20 through 10 m. Note that the vertical end extension wires apply to both ends of the main 10-m dipole, which is constant for all bands.

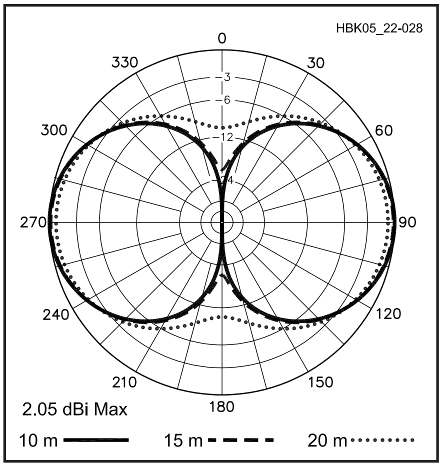


Fig 22.28 — Free-space E-plane (azimuth) patterns of the inverted-U for 10, 15, and 20 m, showing the pattern changes with increasingly longer vertical end sections.

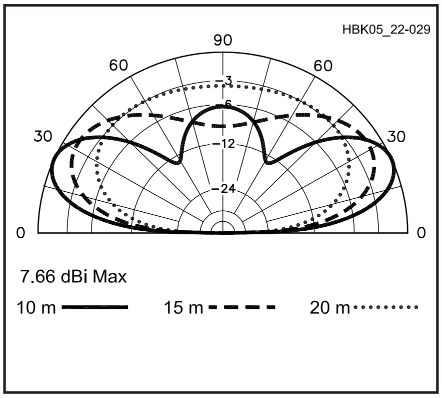


Fig 22.29 — Elevation patterns of the inverted-U for 10, 15, and 20 m, with the antenna feedpoint 20 ft above average ground. Much of the decreased gain and higher elevation angle of the pattern at the lowest frequencies is due to its ever-lower height as a fraction of a wavelength.

Table 22.5
Parts List for the Inverted-U

Amount	*Item*	*Comments*
6'	0.375" OD aluminum tubing	2 - 3' pieces
6'	0.5" OD aluminum tubing	2 - 3' pieces
6'	0.625" OD aluminum tubing	2 - 3' pieces
10"	0.75" OD aluminum tubing	2 - 5" pieces
4"	0.5" nominal (5/8" OD) CPVC	
50'	Aluminum wire AWG #17	
8	Hitch pin clips	Sized to fit tubing junctions.
1	4" by 4" by 1/4" Lexan plate	Other materials suitable.
2	SS U-bolts	Sized to fit support mast
2	Sets SS #8/10 1.5" bolt, nut, washers	SS = stainless steel
2	Sets SS #8 1" bolt, nut, washers	
2	Sets SS #8 .5" bolt, nut, washers	
1	Coax connector bracket, 1/16" aluminum	See text for dimensions and shape
1	Female coax connector	
2	Solder lugs, #8 holes	
2	Short pieces copper wire	From coax connector to solder lugs

Note: 6063-T832 aluminum tubing is preferred and can be obtained from such outlets as Texas Towers (**www.texastowers.com**). Lexan (polycarbonate) is available from such sources as McMasters-Carr (**www.mcmasters.com**), as are the hitch pin clips (if not locally available). Other items should be available from local home centers and radio parts stores.

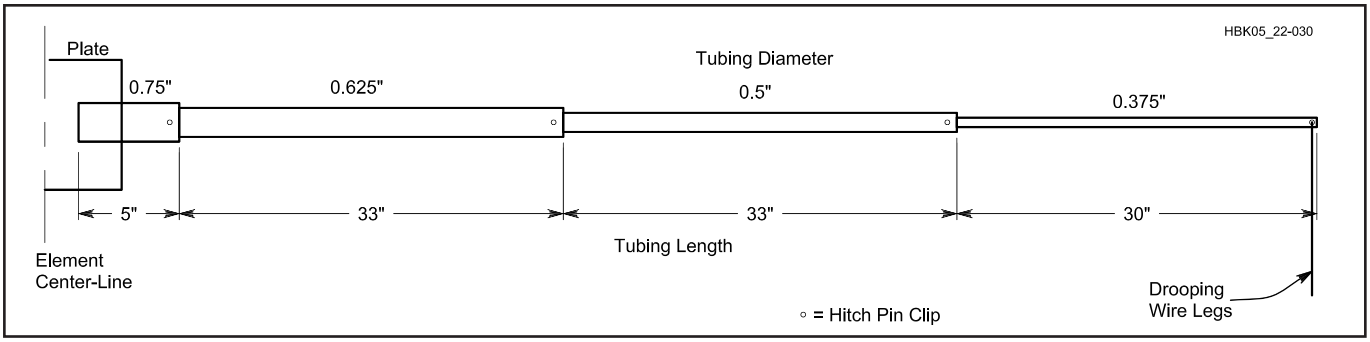


Fig 22.30 — The general tubing layout for the inverted-U for each half element. The opposite side of the dipole is a mirror image of the one shown.

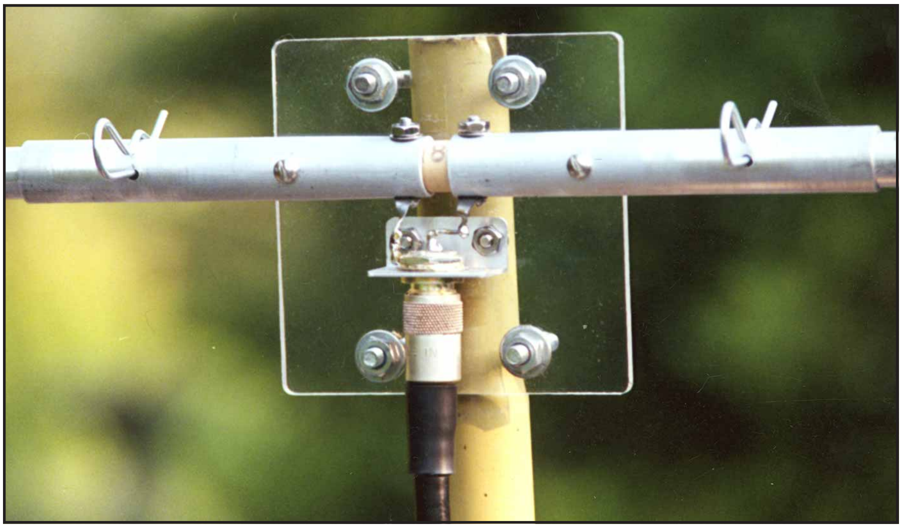


Fig 22.31 — A close-up of the element mounting plate assembly, including the hitch pin clips used to secure the next section of tubing.

The only construction operation that you need to perform on the tubing is to drill a hole at about the center of each junction to pass a hitch pin clip. Obtain hitch pin clips (also called hairpin cotter pin clips in some literature) that fit snugly over the tubing. One size will generally handle about 2 or 3 tubing sizes. In this antenna, I used $^{3}/_{32}$ (pin diameter) by 2$^{5}/_{8}$ inch long clips for the $^{3}/_{4}$- to $^{5}/_{8}$-inch and the $^{5}/_{8}$- to $^{1}/_{2}$-inch junctions, with $^{3}/_{32}$ by 1$^{5}/_{8}$-inch pins for the $^{1}/_{2}$- to $^{3}/_{8}$-inch junction and for the final hitch pin clip at the outer end of the antenna. Drill the $^{1}/_{8}$-inch diameter holes for the clips with the adjacent tubes in position relative to each other. Tape the junction temporarily for the drilling. Carefully deburr the holes so that the tubing slides easily when nested.

The hitch pin clip junctions, shown in **Fig 22.31**, hold the element sections in position. Actual electrical contact between sections is made by the overlapping portions of the tube. Due to the effects of weather, junctions of this type are not suitable for a permanent installation, but are completely satisfactory for short-term use. Good electrical contact requires clean, dry aluminum surfaces, so do not use any type of lubricant to assist the nesting and un-nesting of the tubes. Instead, clean both the inner and outer surfaces of the tubes before and after each use.

Hitch pin clips are fairly large and harder to lose in the grass of a field site than most nuts and bolts. However, you may wish to attach a short colorful ribbon to the loop end of each clip. Spotting the ribbon on the ground is simpler than probing for the clip alone.

Each half element is 101 inches long, for a total 10-m dipole element length of 202 inches (16 ft 10 inches). Length is not critical within about 1 inch, so you may preassemble the dipole using the listed dimensions. However, if you wish a more precisely tuned element, tape the outer section in position and test the dipole on your mast at the height that you will use. Adjust the length of the outer tubing segments equally at both ends for the best SWR curve on the lower 1 MHz of the 10-m band. Even though the impedance will be above 50 Ω throughout the band, you should easily obtain an SWR curve under 2:1 that covers the entire band segment.

The Center Hub: Mounting and Feedpoint Assembly.

Construct the plate for mounting the element and the mast from a 4 × 4 × $^{1}/_{4}$-inch-thick scrap of polycarbonate (trade name Lexan), as shown in **Fig 22.32**. You may use other materials so long as they will handle the element weight and stand up to field conditions.

At the top and bottom of the plate are holes for the U-bolts that fit around my mast. Since masts may vary in diameter at the top, size your U-bolts and their holes to suit the mast.

The element center, consisting of 2 5-inch lengths of $^{3}/_{4}$-inch aluminum tubing, is just above the centerline of the plate (to allow room for the coax fitting below). $^{1}/_{2}$-inch nominal CPVC has an outside diameter of about $^{5}/_{8}$ inch and makes a snug fit inside the $^{3}/_{4}$-inch tubing. The CPVC aligns the two aluminum tubes in a straight line and allows for a small (about $^{1}/_{2}$ inch) gap between them. When centered between the two tubes, the CPVC is the same width as the plate. A pair of 1.5-inch #8 or #10 stainless steel bolts—with washers and a nut—secures the element to the plate.

Note in the sketch that you may insert the $^{5}/_{8}$-inch tube as far into the $^{3}/_{4}$-inch tube as it will go and be assured of a 3-inch overlap. Drill all hitch pin clip holes perpendicular to the plate. Although this alignment is not critical to the junctions of the tubes, it is important to the outer ends of the tubes when you use the antenna below 10 m.

Mount a single-hole female UHF connector on a bracket made from a scrap of $^{1}/_{16}$-inch-thick L-stock that is 1 inch on a side. Drill the UHF mounting hole first, before cutting the L-stock to length and trimming part of the mounting side. Then drill two holes for $^{1}/_{2}$-inch long #8 stainless steel bolts about 1 inch apart, for a

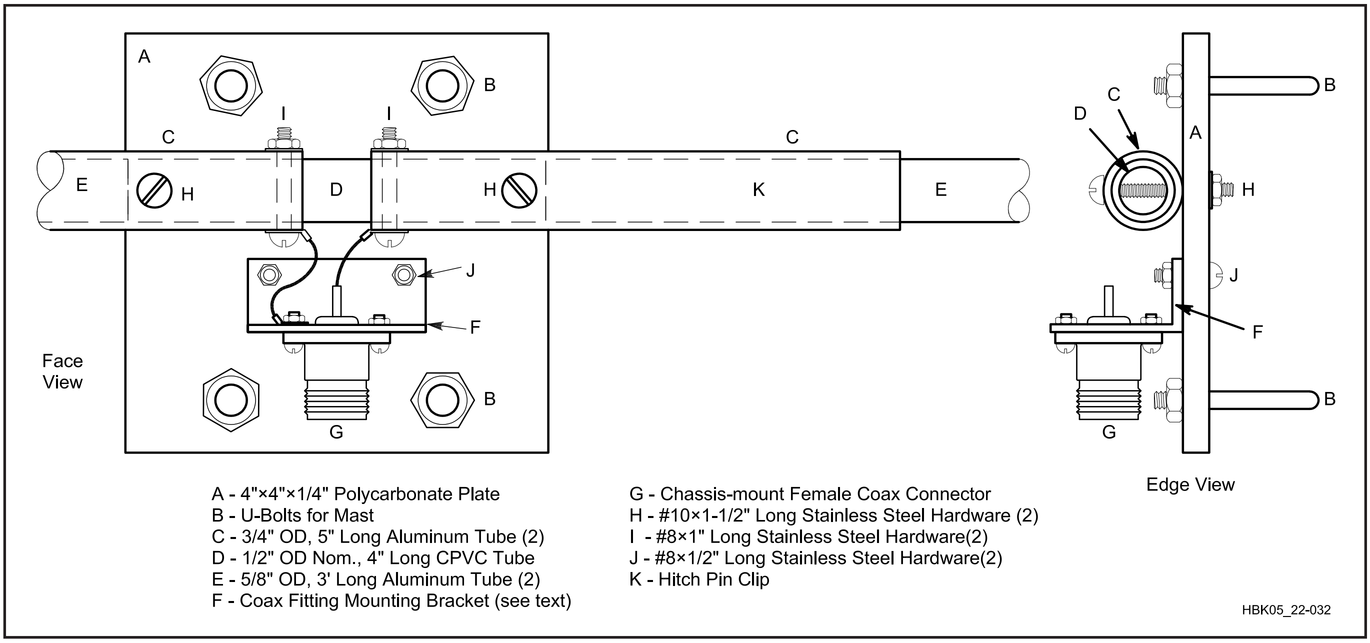


Fig 22.32 — The element and feedpoint mounting plate, with details of the construction used in the prototype.

total length of L-stock of about 1.5 inches. The reason for the wide strip is to place the bolt heads for the bracket outside the area where the mast will meet the plate on the back side. Note in Fig 22.32 that the bracket nuts are on the bracket-side of the main plate, while the heads face the mast. The bracket-to-plate mounting edge of the bracket needs to be only about 3/4 inch wide, so you may trim that side of the L-stock accordingly.

With the element center sections and the bracket in place, drill two holes for 1 inch long #8 stainless steel bolts at right angles to the mounting bolts and as close as feasible to the edges of the tubing at the gap. These bolts have solder lugs attached for short leads to the coax fitting. Solder lugs do not come in stainless steel, so you should check these junctions before and after each use for any corrosion that may require replacement.

With all hardware in place, the hub unit is about 4 × 10 × 1 inch (plus U-bolts). It will remain a single unit from this point onward, so that your only field assembly requirements will be to extend tubing sections and install hitch pin clips. You are now ready to perform the initial 10-m resonance tests on your field mast.

The Drooping Extensions for 12 Through 20 Meters

The drooping end sections consist of aluminum wire. Copper is usable, but aluminum is lighter and quite satisfactory for this application. **Table 22.6** lists the approximate lengths of each extension *below* the element. Add 3 to 5 inches of wire—less for 12 m, more for 20 m—to each length listed.

Table 22.6
Inverted-U Drooping Wire Lengths

Band m	*Wire Length inches*
10	n/a
12	15.9
15	37.4
17	62.0
20	108.0

Note: The wire length for the drooping ends is measured from the end of the tubular dipole to the tip for AWG #17 wire. Little change in length occurs as a function of the change in wire size. However, a few inches of additional wire length is required for attachment to the element.

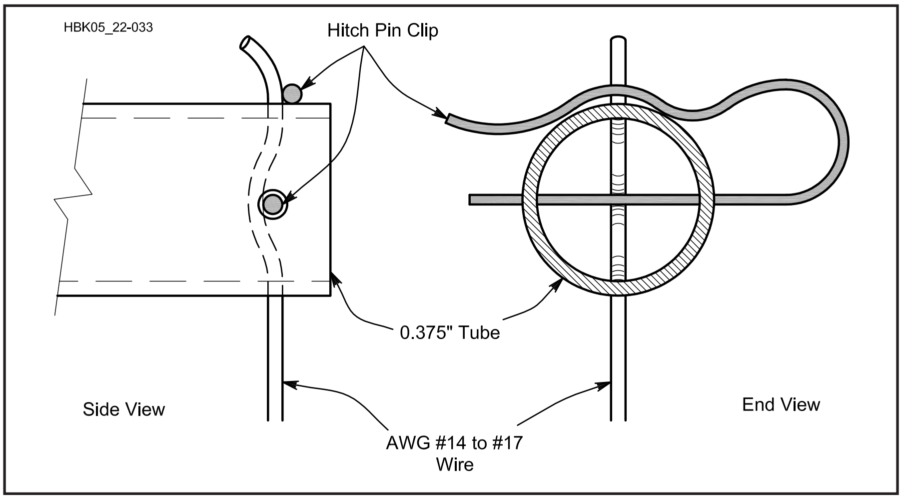


Fig 22.33 — A simple method of clamping the end wires to the 3/8-inch tube end using a hitch pin clip.

Common #17 aluminum electric fencing wire works well. Fence wire is stiffer than most wires of similar diameter, and it is cheap. Stiffness is the more important property, since you do not want the lower ends of the wire to wave excessively in the breeze, potentially changing the feedpoint properties of the antenna while it is in use.

When stored, the lengths of wire extensions for 12 and 15 m can be laid out without any bends. However, the longer extensions for 17 and 20 m will require some coiling or folding to fit the same space as the tubing when nested. Fold or coil the wire around any kind of small spindle that has at least a

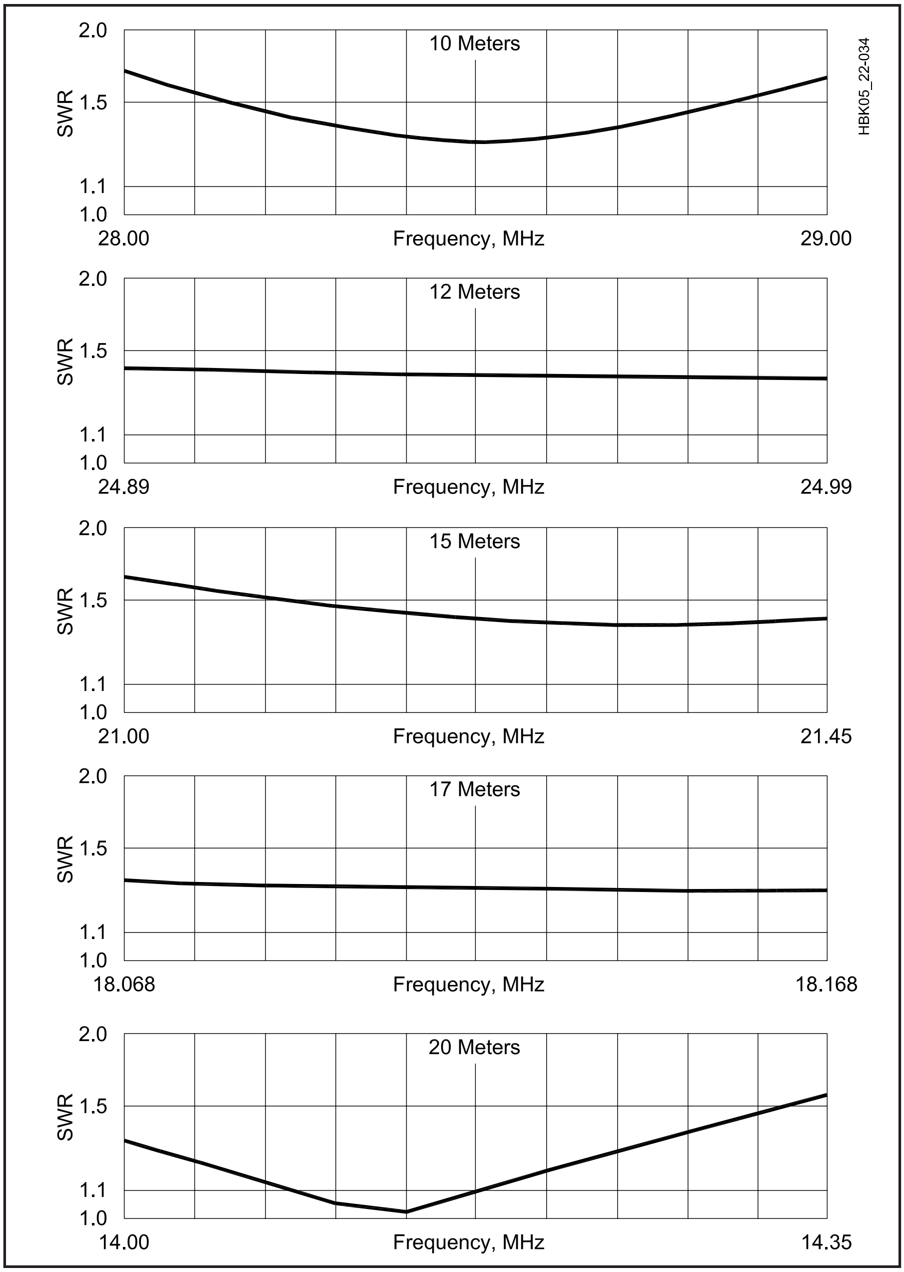


Fig 22.34 — Typical 50-Ω SWR curves for the inverted-U antenna at a feedpoint height of 20 ft.

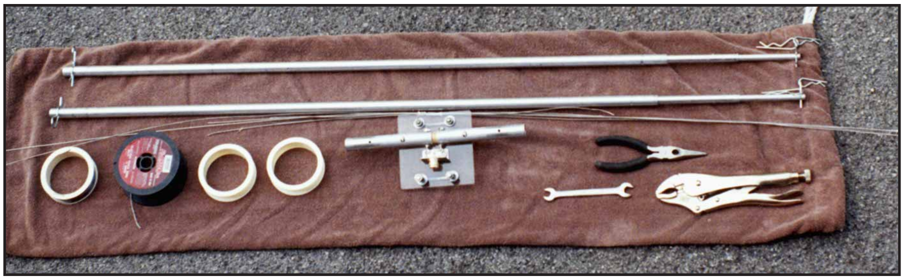


Fig 22.35 — The entire inverted-U antenna parts collection in semi-nested form, with its carrying bag. The tools stored with the antenna include a wrench to tighten the U-bolts for the mast-to-plate mount and a pair of pliers to help remove end wires from the tubing. The pliers have a wire-cutting feature to help replace a broken end wire. A pair of locking pliers makes a good removable handle for turning the mast. The combination of the locking and regular pliers helps to uncoil the wire extensions for any band; give them a couple of sharp tugs to straighten the wire.

2-inch diameter (larger is better). This measure prevents the wire from crimping and eventually breaking. Murphy dictates that a wire will break in the middle of an operating session. So carry some spare wire for replacement ends. All together, the ends require about 50 ft of wire.

Fig 22.33 shows the simple mounting scheme for the end wires. Push the straight wires through a pair of holes aligned vertically to the earth and bend the top portion slightly. To clamp the wire, insert a hitch pin clip though holes parallel to the ground, pushing the wire slightly to one side to reach the far hole in the tube. The double bend holds the wire securely (for a short-term field operation), but allows the wire to be pulled out when the session is over or to change bands.

Add a few inches to the lengths given in Table 22.6 as an initial guide for each band. Test the lengths and prune the wires until you obtain a smooth SWR curve below 2:1 at the ends of each band. Since an inverted-U antenna is full length, the SWR curves will be rather broad and suffer none of the narrow bandwidths associated with inductively loaded elements. **Fig 22.34** shows typical SWR curves for each band to guide your expectations.

You should not require much, if any, adjustment once you have found satisfactory lengths for each band. So you can mark the wire when you finish your initial test adjustments. However, leave enough excess so that you can adjust the lengths in the field.

Do not be too finicky about your SWR curves. An initial test and possibly one adjustment should be all that you need to arrive at an SWR value that is satisfactory for your equipment. Spending half of your operating time adjusting the elements for as near to a 1:1 SWR curve as possible will rob you of valuable contacts without changing your signal strength is any manner that is detectable.

Changing bands is a simple matter. Remove the ends for the band you are using and install the ends for the new band. An SWR check and possibly one more adjustment of the end lengths will put you back on the air.

FINAL NOTES

The inverted-U dipole with interchangeable end pieces provides a compact field antenna. All of the parts fit in a 3-ft long bag. A draw-string bag works very well. **Fig 22.35** shows the parts in their travel form. When assembled and mounted at least 20' up (higher is even better), the antenna will compete with just about any other dipole mounted at the same height. But the inverted-U is lighter than most dipoles at frequencies lower than 10 m. It also rotates easily by hand—assuming that you can rotate the mast by hand. Being able to broadside the dipole to your target station gives the inverted-U a strong advantage over a fixed wire dipole.

With a dipole having drooping ends, safety is very important. Do not use the antenna unless the wire ends for 20 m are higher than any person can touch when the antenna is in use. Even with QRP power levels, the RF voltage on the wire ends can be dangerous. With the antenna at 20 ft at its center, the ends should be at least 10 ft above ground.

Equally important is the maintenance that you give the antenna before and after each use. Be sure that the aluminum tubing is clean—both inside and out—when you nest and un-nest the sections. Grit can freeze the sections together, and dirty tubing can prevent good electrical continuity. Carry a few extra hitch pin clips in the package to be sure you have spares in case you lose one.

TWO W8NX MULTIBAND, COAX-TRAP DIPOLES

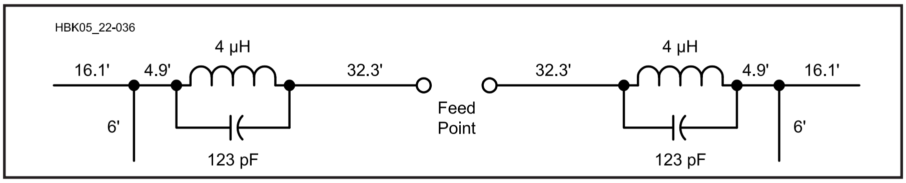


Fig 22.36 — A W8NX multiband dipole for 80, 40, 20, 15 and 10 m. The values shown (123 pF and 4 µH) for the coaxial-cable traps are for parallel resonance at 7.15 MHz. The low-impedance output of each trap is used for this antenna.

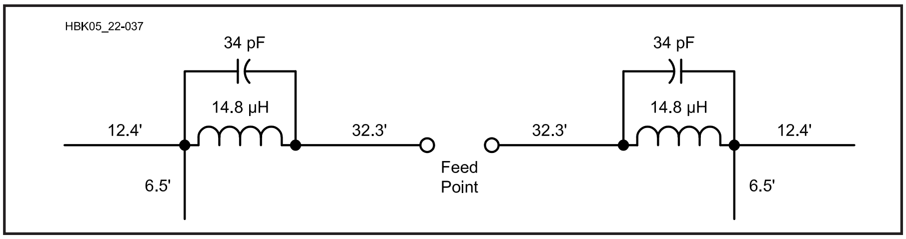


Fig 22.37 — A W8NX multiband dipole for 80, 40, 17 and 12 m. For this antenna, the high-impedance output is used on each trap. The resonant frequency of the traps is 7.15 MHz.

Over the last 60 or 70 years, amateurs have used many kinds of multiband antennas to cover the traditional HF bands. The availability of the 30, 17 and 12-m bands has expanded our need for multiband antenna coverage.

Two different antennas are described here. The first covers the traditional 80, 40, 20, 15 and 10-m bands, and the second covers 80, 40, 17 and 12 m. Each uses the same type of W8NX trap—connected for different modes of operation—and a pair of short capacitive stubs to enhance coverage. The W8NX coaxial-cable traps have two different modes: a high- and a low-impedance mode. The inner-conductor windings and shield windings of the traps are connected in series for both modes. However, either the low- or high-impedance point can be used as the trap's output terminal. For low-impedance trap operation, only the center conductor turns of the trap windings are used. For high-impedance operation, all turns are used, in the conventional manner for a trap. The short stubs on each antenna are strategically sized and located to permit more flexibility in adjusting the resonant frequencies of the antenna.

80, 40, 20, 15 AND 10-METER DIPOLE

Fig 22.36 shows the configuration of the 80, 40, 20, 15 and 10-m antenna. The radiating elements are made of #14 stranded copper wire. The element lengths are the wire span lengths in feet. These lengths do not include the lengths of the pigtails at the balun, traps and insulators. The 32.3-ft-long inner 40-m segments are measured from the eyelet of the input balun to the tension-relief hole in the trap coil form. The 4.9-ft segment length is measured from the tension-relief hole in the trap to the 6-ft stub. The 16.l-ft outer-segment span is measured from the stub to the eyelet of the end insulator.

The coaxial-cable traps are wound on PVC pipe coil forms and use the low-impedance output connection. The stubs are 6-ft lengths of $^1/_8$-inch stiffened aluminum or copper rod hanging perpendicular to the radiating elements. The first inch of their length is bent 90° to permit attachment to the radiating elements by large-diameter copper crimp connectors. Ordinary #14 wire may be used for the stubs, but it has a tendency to curl up and may tangle unless weighed down at the end. You should feed the antenna with 75-Ω coax cable using a good 1:1 balun.

This antenna may be thought of as a modified W3DZZ antenna due to the addition of the capacitive stubs. The length and location of the stub give the antenna designer two extra degrees of freedom to place the resonant frequencies within the amateur bands. This additional flexibility is particularly helpful to bring the 15 and 10-m resonant frequencies to more desirable locations in these bands. The actual 10-m resonant frequency of the original W3DZZ antenna is somewhat above 30 MHz, pretty remote from the more desirable low frequency end of 10 m.

80, 40, 17 AND 12-METER DIPOLE

Fig 22.37 shows the configuration of the 80, 40, 17 and 12-m antenna. Notice that the capacitive stubs are attached immediately outboard after the traps and are 6.5 ft long, $^1/_2$ ft longer than those used in the other antenna. The traps are the same as those of the other antenna, but are connected for the high-impedance parallel-resonant output mode. Since only four bands are covered by this antenna, it is easier to fine tune it to precisely the desired frequency on all bands. The 12.4-ft tips can he pruned to a particular 17-m frequency with little effect on the 12-m frequency. The stub lengths can be pruned to a particular 12-m frequency with little effect on the 17-m frequency. Both such pruning adjustments slightly alter the 80-m resonant frequency. However, the bandwidths of the antennas are so broad on 17 and 12 m that little need for such pruning exists. The 40-m frequency is nearly independent of adjustments to the capacitive stubs and outer radiating tip elements. Like the first antennas, this dipole is fed with a 75-Ω balun and feed line.

Fig 22.38 shows the schematic diagram of the traps. It illustrates the difference between the low and high-impedance modes of the traps. Notice that the high-impedance terminal is the output configuration used in most conventional trap applications. The low-impedance connection is made across only the inner conductor turns, corresponding to one-half of the total turns of the trap. This mode steps the trap's impedance down to approximately one-fourth of that of the high-impedance level. This is what allows a single trap design to be used for two different multiband antennas.

Fig 22.39 is a drawing of a cross-section of the coax trap shown through the long axis of the trap. Notice that the traps are conventional coaxial-cable traps, except for the added low-impedance output terminal. The traps are $8\frac{3}{4}$ close-spaced turns of RG-59 (Belden 8241) on a $2\frac{3}{8}$-inch-OD PVC pipe (schedule 40 pipe with a 2-inch ID) coil form. The forms are $4\frac{1}{8}$ inches long. Trap resonant frequency is very sensitive to the outer diameter of the coil form, so check it carefully. Unfortunately, not all PVC pipe is made with the same wall thickness. The trap frequencies should be checked with a dip meter and general-coverage receiver and adjusted to within 50 kHz of the 7150 kHz resonant frequency before installation. One inch is left over at each end of the coil forms to allow for the coax feed-through holes and holes for tension-relief attachment of the antenna radiating elements to the traps. Be sure to seal the ends of the trap coax cable with RTV sealant to prevent moisture from entering the coaxial cable.

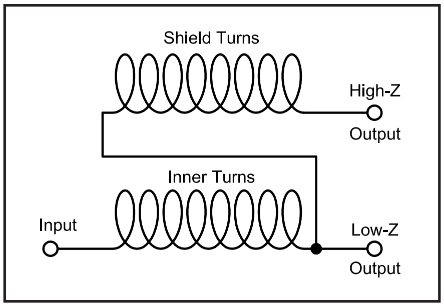


Fig 22.38 — Schematic for the W8NX coaxial-cable trap. RG-59 is wound on a $2\frac{3}{8}$-inch OD PVC pipe.

Also, be sure that you connect the 32.3-ft wire element at the start of the inner conductor winding of the trap. This avoids detuning the antenna by the stray capacitance of the coaxial-cable shield. The trap output terminal (which has the shield stray capacitance) should be at the outboard side of the trap. Reversing the input and output terminals of the trap will lower the 40-meter frequency by approximately 50 kHz, but there will be negligible effect on the other bands.

Fig 22.40 shows a coaxial-cable trap. Further details of the trap installation are shown in **Fig 22.41**. This drawing applies specifically to the 80, 40, 20, 15 and 10-m antenna, which uses the low-impedance trap connections. Notice the lengths of the trap pigtails: 3 to 4 inches at each terminal of the trap. If you use a different arrangement, you must modify the span lengths accordingly, All connections can be made using crimp connectors rather than by soldering. Access to the trap's interior is attained more easily with a crimping tool than with a soldering iron.

PERFORMANCE

The performance of both antennas has been very satisfactory. W8NX uses the 80, 40, 17 and 12-m version because it covers 17 and 12 m. (He has a triband Yagi for 20, 15 and 10 m.) The radiation pattern on 17 m is that of $^3/_2$-wave dipole. On 12 m, the pattern is that of a $^5/_2$-wave dipole. At his location in Akron, Ohio, the antenna runs essentially east and west. It is installed as an inverted V, 40 ft high at the center, with a 120° included angle between the legs. Since the stubs are very short, they radiate little power and make only minor contributions to the radiation patterns. In theory, the pattern has four major lobes on 17 m, with maxima to the northeast, southeast, southwest and northwest. These provide low-angle radiation into Europe, Africa, South Pacific, Japan and Alaska. A narrow pair of minor broadside

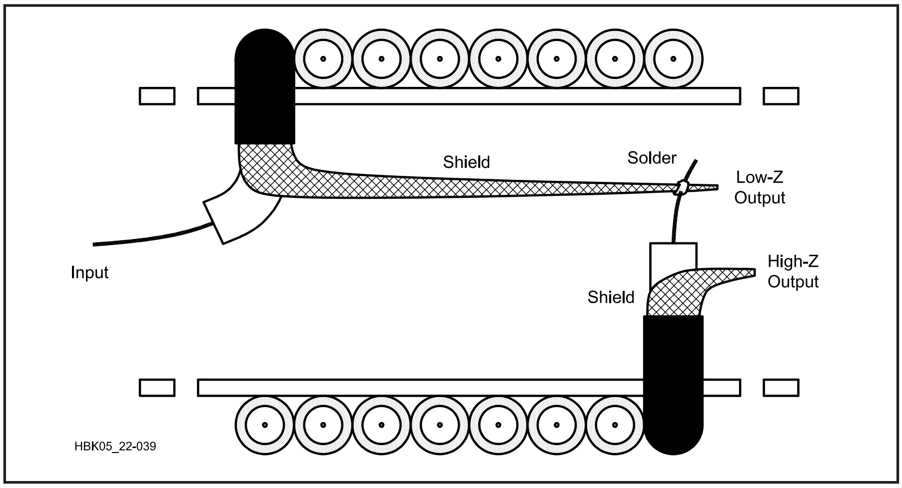


Fig 22.39 — Construction details of the W8NX coaxial-cable trap.

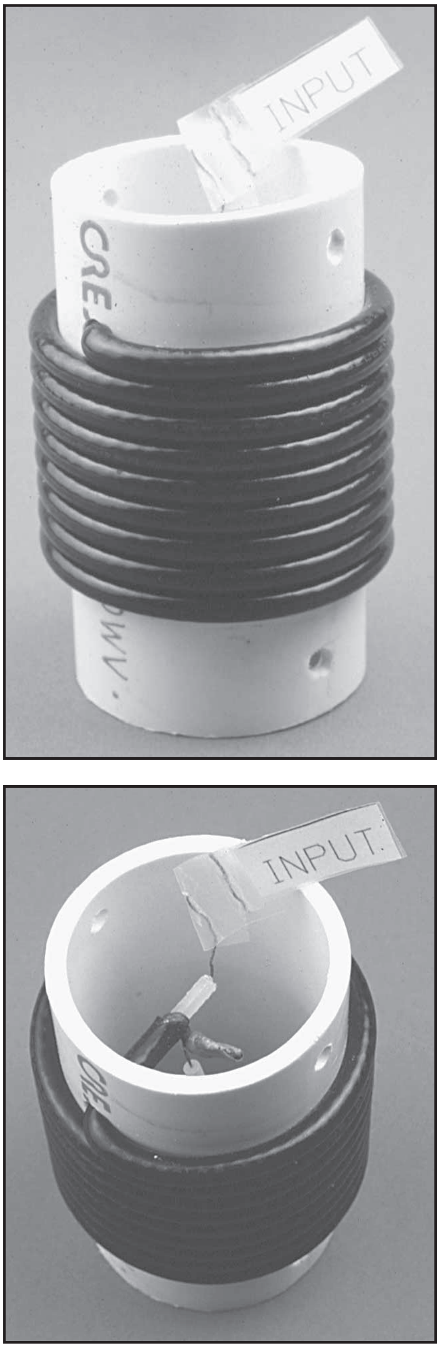


Fig 22.40 — Other views of a W8NX coax-cable trap.

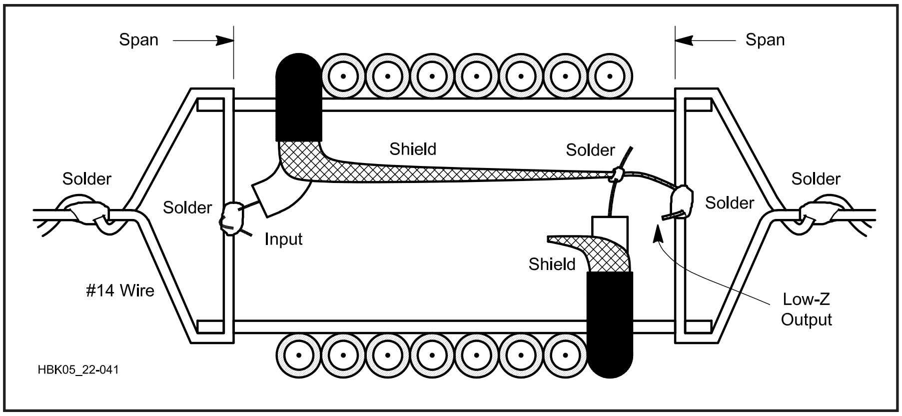


Fig 22.41 — Additional construction details for the W8NX coaxial-cable trap.

lobes provides north and south coverage into Central America, South America and the polar regions.

There are four major lobes on 12 m, giving nearly end-fire radiation and good low-angle east and west coverage. There are also three pairs of very narrow, nearly broadside, minor lobes on 12 m, down about 6 dB from the major end-fire lobes. On 80 and 40 m, the antenna has the usual figure-8 patterns of a half-wave-length dipole.

Both antennas function as electrical half-wave dipoles on 80 and 40 m with a low SWR. They both function as odd-harmonic current-fed dipoles on their other operating frequencies, with higher, but still acceptable, SWR. The presence of the stubs can either raise or lower the input impedance of the antenna from those of the usual third and fifth harmonic dipoles. Again W8NX recommends that 75-Ω, rather than 50-Ω, feed line be used because of the generally higher input impedances at the harmonic operating frequencies of the antennas.

The SWR curves of both antennas were carefully measured using a 75 to 50-Ω transformer from Palomar Engineers inserted at the junction of the 75-Ω coax feed line and a 50-Ω SWR bridge. The transformer is required for accurate SWR measurement if a 50-Ω SWR bridge is used with a 75-Ω line. Most 50-Ω rigs operate satisfactorily with a 75-Ω line, although this requires different tuning and load settings in the final output stage of the rig or antenna tuner. The author uses the 75 to 50-Ω transformer only when making SWR measurements and at low power levels. The transformer is rated for 100 W, and when he runs his 1-kW PEP linear amplifier the transformer is taken out of the line.

Fig 22.42 gives the SWR curves of the 80, 40, 20, 15 and 10-m antenna. Minimum SWR is nearly 1:1 on 80 m, 1.5:1 on 40 m, 1.6:1 on 20 m, and 1.5:1 on 10 m. The minimum SWR is slightly below 3:1 on 15 m. On 15 m, the stub capacitive reactance combines with the inductive reactance of the outer segment of the antenna to produce a resonant rise that raises the antenna input resistance to about 220 Ω, higher than that of the usual $^{3}/_{2}$-wavelength dipole. An antenna tuner may be required on this band to keep a solid-state final output stage happy under these load conditions.

Fig 22.43 shows the SWR curves of the 80, 40, 17 and 12-m antenna. Notice the excellent 80-m performance with a nearly unity minimum SWR in the middle of the band. The performance approaches that of a full-size 80-m wire dipole. The short stubs and the low-inductance traps shorten the antenna somewhat on 80 m. Also observe the good 17-m performance, with the SWR being only a little above 2:1 across the band.

But notice the 12-m SWR curve of this antenna, which shows 4:1 SWR across the band. The antenna input resistance approaches 300 Ω on this band because the capacitive reactance of the stubs combines with the inductive reactance of the outer antenna segments to give resonant rises in impedance. These are reflected back to the input terminals. These stub-induced resonant impedance rises are similar to those on the other antenna on 15 meters, but are even more pronounced.

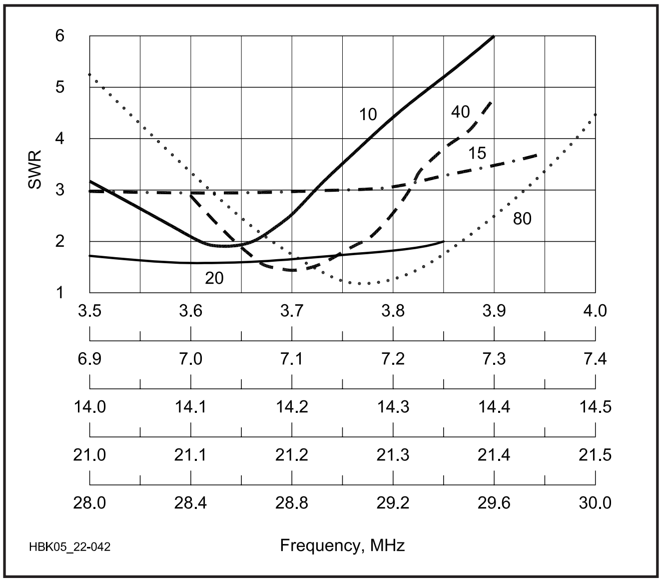


Fig 22.42 — Measured SWR curves for an 80, 40, 20, 15 and 10-meter antenna, installed as an inverted-V with 40-ft apex and 120° included angle between legs.

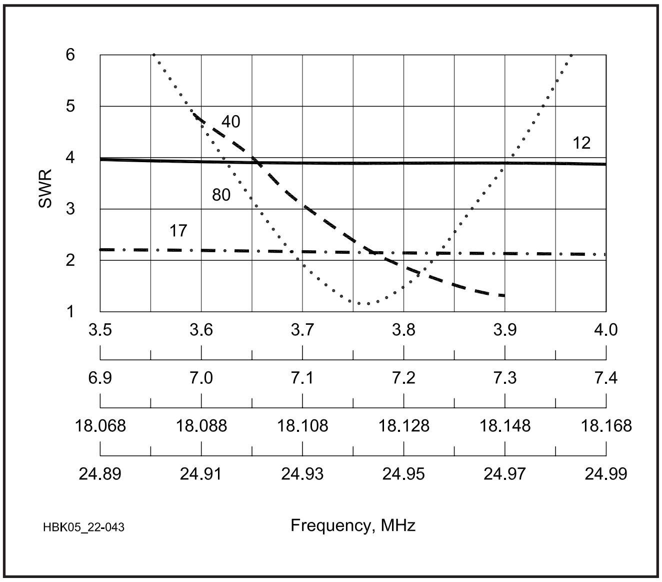


Fig 22.43 — Measured SWR curves for an 80, 40, 17 and 12-meter antenna, installed as an inverted-V with 40-ft apex and 120° included angle between legs.

Too much concern must not be given to SWR on the feed line. Even if the SWR is as high as 9:1 *no destructively high voltages will exist on the transmission line.* Recall that transmission-line voltages increase as the square root of the SWR in the line. Thus, 1 kW of RF power in 75-Ω line corresponds to 274 V line voltage for a 1:1 SWR. Raising the SWR to 9:1 merely triples the maximum voltage that the line must withstand to 822 V. This voltage is well below the 3700-V rating of RG-11, or the 1700-V rating of RG-59, the two most popular 75-Ω coax lines. Voltage breakdown in the traps is also very unlikely. As will be pointed out later, the operating power levels of these antennas are limited by RF power dissipation in the traps, not trap voltage breakdown or feed-line SWR.

TRAP LOSSES AND POWER RATING

Table 22.7 presents the results of trap Q measurements and extrapolation by a two-frequency method to higher frequencies above resonance. W8NX employed an old, but recently calibrated, Boonton Q meter for the measurements. Extrapolation to higher-frequency bands assumes that trap resistance losses rise with skin effect according to the square root of frequency, and that trap dielectric loses rise directly with frequency. Systematic measurement errors are not increased by frequency extrapolation. However, random measurement errors increase in magnitude with upward frequency extrapolation. Results are believed to be accurate within 4% on 80 and 40 m, but only within 10 to 15% at 10 m. Trap Q is shown at both the high- and low-impedance trap terminals. The Q at the low-impedance output terminals is 15 to 20% lower than the Q at the high-impedance output terminals.

W8NX computer-analyzed trap losses for both antennas in free space. Antenna-input resistances at resonance were first calculated, assuming lossless, infinite-Q traps. They were again calculated using the Q values in Table 22.7. The radiation efficiencies were also converted into equivalent trap losses in decibels. **Table 22.8** summarizes the trap-loss analysis for the 80, 40, 20, 15 and 10-m antenna and **Table 22.9** for the 80, 40,17 and 12-m antenna.

The loss analysis shows radiation efficiencies of 90% or more for both antennas on all bands except for the 80, 40, 20, 15 and 10-m antenna when used on 40 m. Here, the radiation efficiency falls to 70.8%. A 1-kW power level at 90% radiation efficiency corresponds to 50-W dissipation per trap. In W8NX's experience, this is the trap's survival limit for extended key-down operation. SSB power levels of 1 kW PEP would dissipate 25 W or less in each trap. This is well within the dissipation capability of the traps.

When the 80, 40, 20, 15 and 10-m antenna is operated on 40 m, the radiation efficiency of 70.8% corresponds to a dissipation of 146 W in each trap when 1 kW is delivered to the antenna. This is sure to burn out the traps—even if sustained for only a short time. Thus, the power should be limited to less than 300 W when this antenna is operated on 40 m under prolonged key-down conditions. A 50% CW duty cycle would correspond to a 600-W power limit for normal 40-m CW operation. Likewise, a 50% duty cycle for 40-m SSB corresponds to a 600-W PEP power limit for the antenna.

The author knows of no analysis where the burnout wattage rating of traps has been rigorously determined. Operating experience seems to be the best way to determine trap burn-out ratings. In his own experience with these antennas, he's had no traps burn out, even though he operated the 80, 40, 20, 15 and 10-m antenna on the critical 40-m band using his AL-80A linear amplifier at 600-W PEP output. He did not make a continuous, key-down, CW operating tests at full power purposely trying to destroy the traps!

Some hams may suggest using a different type of coaxial cable for the traps. The dc resistance of 40.7 Ω per 1000 feet of RG-59 coax seems rather high. However, W8NX has found no coax other than RG-59 that has the necessary inductance-to-capacitance ratio to create the trap characteristic reactance required for the 80, 40, 20, 15 and 10-m antenna. Conventional traps with wide-spaced, open-air inductors and appropriate fixed-value capacitors could be substituted for the coax traps, but the convenience, weatherproof configuration and ease of fabrication of coaxial-cable traps is hard to beat.

Table 22.7

Trap Q

Frequency (MHz)	3.8	7.15	14.18	18.1	21.3	24.9	28.6
High Z out (Ω)	101	124	139	165	73	179	186
Low Z out (Ω)	83	103	125	137	44	149	155

Table 22.8

Trap Loss Analysis: 80, 40, 20, 15, 10-Meter Antenna

Frequency (MHz)	3.8	7.15	14.18	21.3	28.6
Radiation Efficiency (%)	96.4	70.8	99.4	99.9	100.0
Trap Losses (dB)	0.16	1.5	0.02	0.01	0.003

Table 22.9

Trap Loss Analysis: 80, 40, 17, 12-Meter Antenna

Frequency (MHz)	3.8	7.15	18.1	24.9
Radiation Efficiency (%)	89.5	90.5	99.3	99.8
Trap Losses (dB)	0.5	0.4	0.03	0.006

Vertical Antennas

One of the more popular amateur antennas is the *vertical*. It usually refers to a single radiating element placed vertically over the ground. A typical vertical is an electrical $^1/_4$-λ long and is constructed of wire or tubing.

Single vertical antennas are omnidirectional radiators. This can be beneficial or detrimental, depending on the exact situation. On transmission there are no nulls in any direction, unlike most horizontal antennas. However, QRM on receive can't be nulled out from the directions that are not of interest, unless multiple verticals are used in an array.

When compared to horizontal antennas, verticals also suffer more acutely from two main types of losses—*ground return losses* for currents in the near field, and *far-field ground losses*. Ground losses in the near field can be minimized by using many ground radials. This is covered in the sidebar, **Optimum Ground Systems for Vertical Antennas**.

Far-field losses are highly dependent on the conductivity and dielectric constant of the earth around the antenna, extending out as far as 100 λ from the base of the antenna. There is very little that someone can do to change the character of the ground that far away—other than moving to a small island surrounded by saltwater! Far-field losses greatly affect low-angle radiation, causing the radiation patterns of practical vertical antennas to fall far short of theoretical patterns over *perfect ground*, often seen in classical texts. **Fig 22.44** shows the elevation pattern response for two different 40-m quarter-wave verticals. One is placed over a theoretical infinitely large, infinitely conducting ground. The second is placed over an extensive radial system over average soil, having a conductivity of 5 mS/m and a dielectric constant of 13. This sort of soil is typical of heavy clay found in pastoral regions of the US mid-Atlantic states. At a 10° elevation angle, the real antenna losses are almost 6 dB compared to the theoretical one; at 20° the difference is about 3 dB. See *The ARRL Antenna Book* chapter on the effects of the earth for further details.

While real verticals over real ground are not a magic method to achieve low-angle radiation, cost versus performance and ease of installation are incentives that inspire many antenna builders. For use on the lower frequency amateur bands—notably 160 and 80 m—it is not always

Optimum Ground Systems for Vertical Antennas

A frequent question brought up by old-timers and newcomers alike is: "So, how many ground radials do I *really* need for my vertical antenna?" Most hams have heard the old standby tales about radials, such as "if a few are good, more must be better" or "lots of short radials are better than a few long ones."

John Stanley, K4ERO, eloquently summarized a study he did of the professional literature on this subject in his article "Optimum Ground Systems for Vertical Antennas" in December 1976 *QST*. His approach was to present the data in a sort of "cost-benefit" style in Table A, reproduced here. John somewhat wryly created a new figure of merit—the total amount of wire needed for various radial configurations. This is expressed in terms of wavelengths of total radial wire.

Table A

Optimum Ground-System Configurations

Configuration Designation	*A*	*B*	*C*	*D*	*E*	*F*
Number of radials	*16*	*24*	*36*	*60*	*90*	*120*
Length of each radial in wavelengths	0.1	0.125	0.15	0.2	0.25	0.4
Spacing of radials in degrees	22.5	15	10	6	4	3
Total length of radial wire installed, in wavelengths	1.6	3	5.4	12	22.5	48
Power loss in dB at low angles with a quarter-wave radiating element	3	2	1.5	1	0.5	0*
Feed-point impedance in ohms with a quarter-wave radiating element	52	46	43	40	37	35

Note: Configuration designations are indicated only for text reference.

*Reference. The loss of this configuration is negligible compared to a perfectly conducting ground.

The results almost jumping out of this table are:

- If you can only install 16 radials (Case A), they needn't be very long—0.1 λ is sufficient. You'll use 1.6 λ of radial wire in total, which is about 450 feet at 3.5 MHz.
- If you have the luxury of laying down 120 radials (Case F), they should be 0.4 λ long, and you'll gain about 3 dB over the 16-radial case. You'll also use 48 λ of total wire—For 80 meters, that would be about 13,500 feet!
- If you can't put out 120 radials, but can install 36 radials that are 0.2 λ long (Case C), you'll lose only 1.5 dB compared to the optimal Case F. You'll also use 5.4 λ of total wire, or 1,500 feet at 3.5 MHz.
- A 50-Ω SWR of 1:1 isn't necessary a good thing—the worst-case ground system in Case A has the lowest SWR.

Table A represents the case for "Average" quality soil, and it is valid for radial wires either laid on the ground or buried several inches in the ground. Note that such ground-mounted radials are detuned because of their proximity to that ground and hence don't have to be a classical quarter-wave length that they need to be were they in "free space."

In his article John also made the point that ground-radial losses would only be significant on transmit, since the atmospheric noise on the amateur bands below 30 MHz is attenuated by ground losses, just like actual signals would be. This limits the ultimate signal-to-noise ratio in receiving.

So, there you have the tradeoffs—the loss in transmitted signal compared to the cost (and effort) needed to install more radial wires. You take your pick.

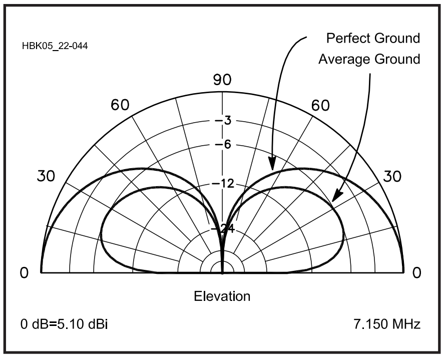


Fig 22.44 — Elevation patterns for two quarter-wave vertical antennas over different ground. One vertical is placed over *perfect* ground, and the other is placed over average ground. The far-field response at low elevation angles is greatly affected by the quality of the ground — as far as 100 λ away from the vertical antenna.

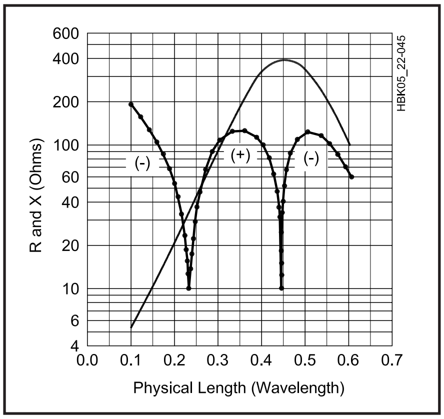


Fig 22.45 — Radiation resistance (solid curve) and reactance (dotted curve) of vertical antennas as a function of their physical height.

practical to erect a full-size vertical. At 1.8 MHz, a full-sized quarter-wave vertical is 130 ft high. In such instances it is often necessary to accept a shorter radiating element and use some form of *loading*.

Fig 22.45 provides curves for the physical height of verticals in wavelength versus radiation resistance and reactance. Although the plots are based on perfectly conducting ground, they show general trends for installations where many radials have been laid out to make a ground screen. As the radiator is made shorter, the radiation resistance decreases—with 6 Ω being typical for a 0.1-λ high antenna. The lower the radiation resistance, the more the antenna efficiency depends on ground conductivity and the effectiveness of the ground screen. Also, the bandwidth decreases markedly as the length is reduced toward the left of the scale in Fig 22.45. It can be difficult to develop suitable matching networks when radiation resistance is very low.

GROUND SYSTEMS

Generally a large number of shorter radials offers a better ground system than a few longer ones. For example, 8 radials of $^1/_4$ λ are preferred over 4 radials of $^1/_4$ λ. Optimum radial lengths are described in the sidebar.

The conductor size of the radials is not especially significant. Wire gauges from #4 to #20 have been used successfully by amateurs. Copper wire is preferred, but where soil is low in acid (or alkali), aluminum wire can be used. The wires may be bare or insulated, and they can be laid on the earth's surface or buried a few inches below ground. Insulated wires will have greater longevity by virtue of reduced corrosion and dissolution from soil chemicals.

When property dimensions do not allow a classic installation of equally spaced radial wires, they can be placed on the ground as space permits. They may run away from the antenna in only one or two compass directions. They may be bent to fit on your property.

A single ground rod, or group of them bonded together, is seldom as effective as a collection of random-length radial wires.

All radial wires should be connected together at the base of the vertical antenna. The electrical bond needs to be of low resistance. Best results will be obtained when the wires are soldered together at the junction point. When a grounded vertical is used, the ground wires should be affixed securely to the base of the driven element.

Ground return losses are lower when vertical antennas and their radials are elevated above ground, a point that is well-known by those using *ground plane* antennas on their roofs. Even on 160 or 80 m, effective vertical antenna systems can be made with as few as four quarter-wave long radials elevated 10 to 20 ft off the ground.

FULL-SIZE VERTICAL ANTENNAS

When it is practical to erect a full-size $^1/_4$-λ vertical antenna, the forms shown in **Fig 22.46** are worthy of consideration. The example at A is the well-known *vertical ground plane*. The ground system consists of four above-ground radial wires. The length of the driven element and $^1/_4$-λ radials is derived from the standard equation

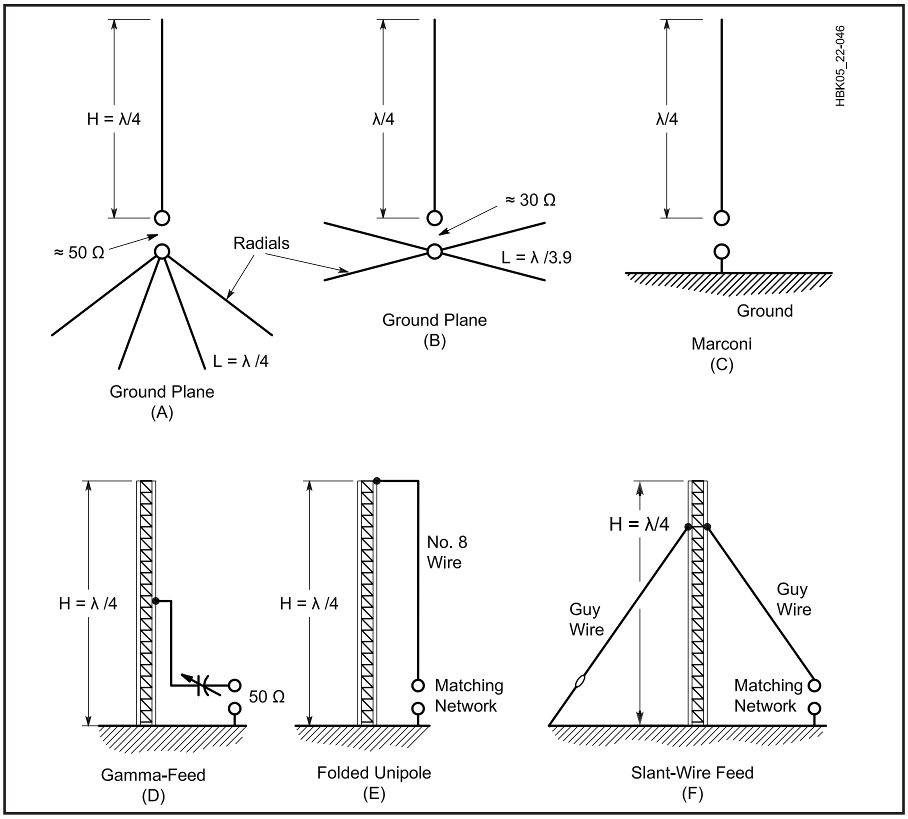


Fig 22.46 — Various types of vertical antennas.

$$L\,(\text{ft}) = \frac{234}{f\,(\text{MHz})} \qquad (6)$$

With four equidistant radial wires drooped at approximately 30° (Fig 22.46A), the feed-point impedance is roughly 50 Ω. When the radials are at right angles to the radiator (Fig 22.46B) the impedance approaches 36 Ω. Besides minimizing ground return losses, another major advantage in this type of vertical antenna over a ground-mounted type is that the system can be elevated well above nearby conductive objects (power lines, trees, buildings and so on). When drooping radials are used, they can also serve as guy wires for the mast that supports the antenna. The coax shield braid is connected to the radials, and the center conductor to the driven element.

The *Marconi* vertical antenna shown in Fig 22.46C is the classic form taken by a ground-mounted vertical. It can be grounded at the base and shunt fed, or it can be isolated from ground, as shown, and series fed. As always, this vertical antenna depends on an effective ground system for efficient performance. If a perfect ground were located below the antenna, the feed impedance would be near 36 Ω. In a practical case, owing to imperfect ground, the impedance is more apt to be in the vicinity of 50 Ω.

A gamma feed system for a grounded $^1/_4$-λ vertical is presented in Fig 22.46D. Some rules of thumb for arriving at workable gamma-arm and capacitor dimensions are to make the rod length 0.04 to 0.05 λ, its diameter $^1/_3$ to $^1/_2$ that of the driven element and the center-to-center spacing between the gamma arm and the driven element roughly 0.007 λ. The capacitance of C1 at a 50-Ω matched condition will be about 7 pF per meter of wavelength. The absolute value of C1 will depend on whether the vertical is resonant and on the precise value of the radiation resistance. For best results, make the radiator approximately 3% shorter than the resonant length.

Amateur antenna towers lend themselves to use as shunt-fed verticals, even though an HF-band beam antenna is usually mounted on the tower. The overall system should be close to resonance at the desired operating frequency if a gamma feed is used. The HF-band beam will contribute somewhat to *top loading* of the tower. The natural resonance of such a system can be checked by dropping a #12 or #14 wire from the top of the tower (connecting it to the tower top) to form a folded unipole (Fig 22.46E). A four- or five-turn link can be inserted between the lower end of the drop wire and the ground system. A dip meter is then inserted in the link to determine the resonant frequency. If the tower is equipped with guy wires, they should be broken up with strain insulators to prevent unwanted loading of the vertical. In such cases where the tower and beam antennas are not able to provide $^1/_4$-λ resonance, portions of the top guy wires can be used as top-loading capacitance. Experiment with the guy-wire lengths (using the dip-meter technique) while determining the proper dimensions.

A folded-unipole is depicted at E of Fig 22.46. This system has the advantage of increased feed-point impedance. Furthermore, a Transmatch can be connected between the bottom of the drop wire and the ground system to permit operation on more than one band. For example, if the tower is resonant on 80 m, it can be used as shown on 160 and 40 m with reasonable results, even though it is not electrically long enough on 160. The drop wire need not be a specific distance from the tower, but you might try spacings between 12 and 30 inches.

The method of feed shown at Fig 22.46F is commonly referred to as *slant-wire feed*. The guy wires and the tower combine to provide quarter-wave resonance. A matching network is placed between the lower end of one guy wire and ground and adjusted for an SWR of 1:1. It does not matter at which level on the tower the guy wires are connected, assuming that the Transmatch is capable of effecting a match to 50 Ω.

PHYSICALLY SHORT VERTICALS

A group of short vertical radiators is presented in **Fig 22.47**. Illustrations A and B are for top and center loading. A capacitance hat is shown in each example. The hat should be as large as practical to increase the radiation resistance of the antenna and improve the bandwidth. The wire in the loading coil is chosen for the largest gauge consistent with ease of winding and coil-form size. The larger wire diameters will reduce the resistive (I^2R) losses in the system. The coil-form material should have a medium or high dielectric constant. Phenolic or fiberglass tubing is entirely adequate.

A base-loaded vertical is shown at C of Fig 22.47. The primary limitation is that the high current portion of the vertical exists in the coil rather than the driven element. With center loading, the portion of the antenna below the coil carries high

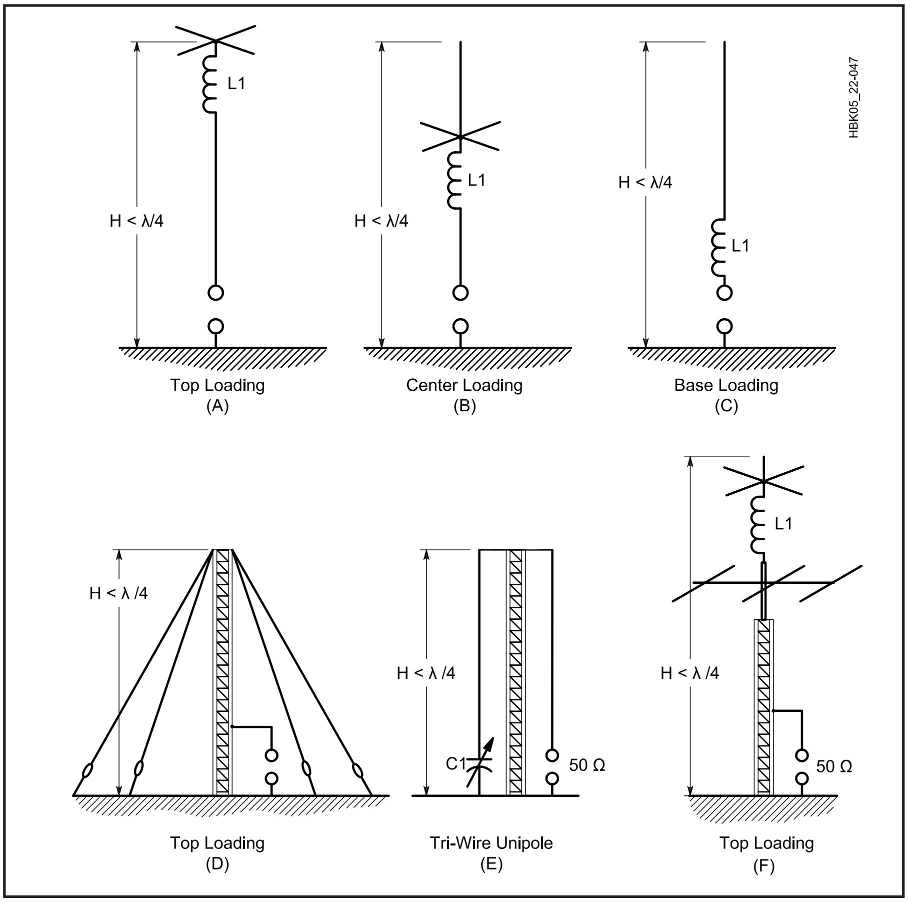


Fig 22.47 — Vertical antennas that are less than one-quarter wavelength in height.

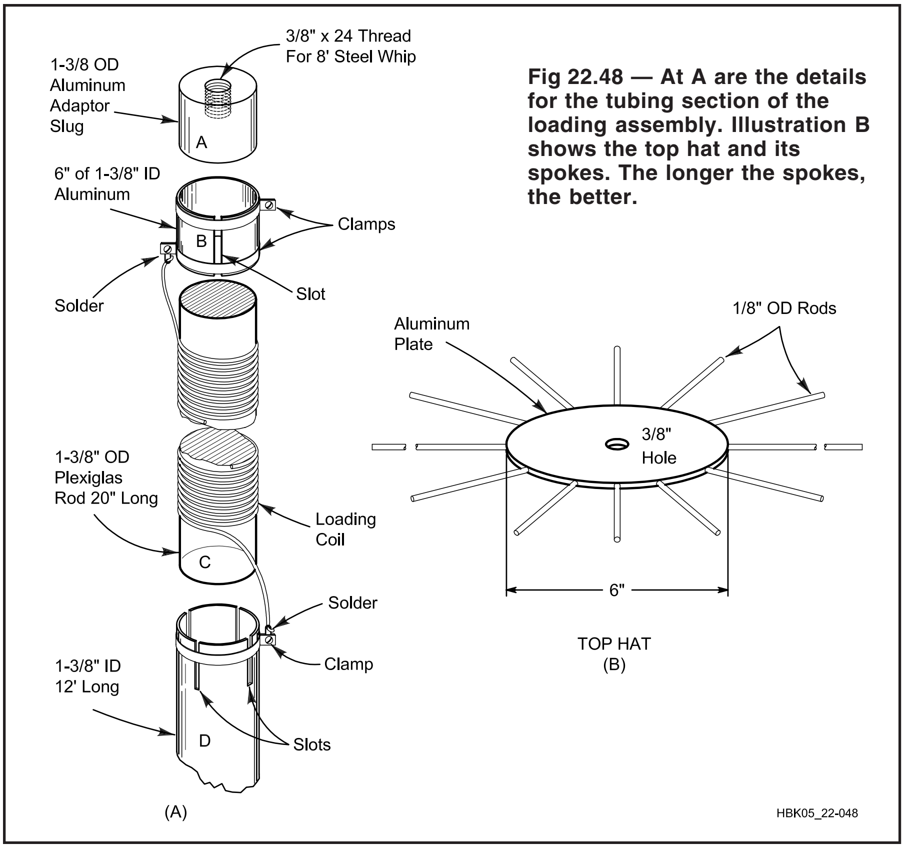


Fig 22.48 — At A are the details for the tubing section of the loading assembly. Illustration B shows the top hat and its spokes. The longer the spokes, the better.

current, and in the top-loaded version the entire vertical element carries high current. Since the high-current part of the antenna is responsible for most of the radiating, base loading is the least effective of the three methods. The radiation resistance of the coil-loaded antennas shown is usually less than 16 Ω.

A method for using guy wires to top load a short vertical is illustrated in Fig 22.47D. This system works well with gamma feed. The loading wires are trimmed to provide an electrical quarter wavelength for the overall system. This method of loading will result in a higher radiation resistance and greater bandwidth than the systems shown at A through C. If an HF or VHF array is at the top the tower, it will simply contribute to the top loading.

A three-wire unipole is shown at E. Two #8 drop wires are connected to the top of the tower and brought to ground level. The wires can be spaced any convenient distance from the tower—normally 12 to 30 inches from one side. C1 is adjusted for best SWR. This type of vertical has a fairly narrow bandwidth, but because C1 can be motor driven and controlled from the operating position, frequency changes can be accomplished easily. This technique will not be suitable for matching to 50-Ω line unless the tower is less than an electrical quarter wavelength high.

A different method for top loading is shown at F. Barry Boothe, W9UCW, described this method in December 1974 *QST*. An extension is used at the top of the tower to effect an electrical quarter-wavelength vertical. L1 is a loading coil with sufficient inductance to provide antenna resonance. This type of antenna lends itself to operation on 160 m.

A method for constructing the top-loading shown in Fig 22.47F is illustrated in **Fig 22.48**. Pipe section D is mated with the mast above the HF-band beam antenna. A loading coil is wound on solid Plexiglas rod or phenolic rod (item C), then clamped inside the collet (B). An aluminum slug (part A) is clamped inside item B. The top part of A is bored and tapped for a 3/8 × 24 stud. This permits a standard 8-ft stainless-steel mobile whip to be threaded into item A above the loading coil. The capacitance hat (Fig 22.48B) can be made from a 1/4-inch-thick brass or aluminum plate. It may be round or square. Lengths of 1/8-inch brazing rod can be threaded and screwed into the edge of the aluminum plate. The plate contains a row of holes along its perimeter, each having been tapped for a 6-32 thread. The capacitance hat is affixed to item A by means of the 8-ft whip antenna. The whip will increase the effective height of the vertical antenna.

CABLES AND CONTROL WIRES ON TOWERS

Most vertical antennas of the type shown in Fig 22.46 consist of towers, usually with HF or VHF beam antennas at the top. The rotator control wires and the coaxial feeders to the top of the tower will not affect antenna performance adversely. In fact, they become a part of the composite antenna. To prevent unwanted RF currents from following the wires into the shack, simply dress them close to the tower legs and bring them to ground level. This decouples the wires at RF. The wires should then be routed along the earth surface (or buried underground) to the operating position. It is not necessary to use bypass capacitors or RF chokes in the rotator control leads if this is done, even when maximum legal power is employed.

TRAP VERTICALS

The 2-band trap vertical antenna of **Fig 22.49** operates in much the same manner as a trap dipole or trap Yagi. The notable

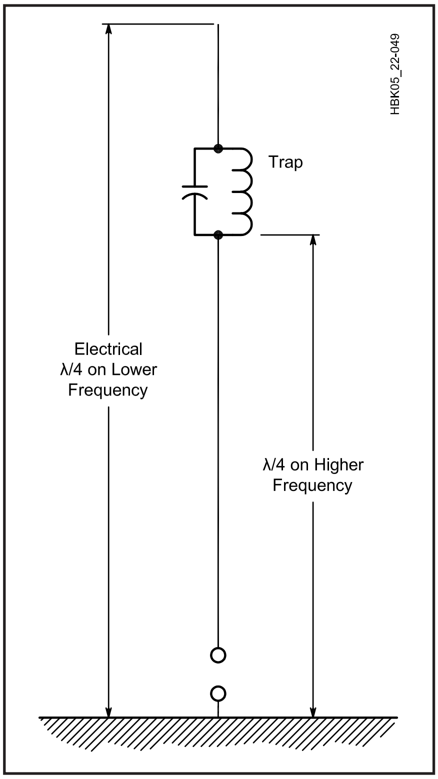


Fig 22.49 — A two-band trap vertical antenna. The trap should be resonated by itself as a parallel resonant circuit at the center of the operating range for the higher frequency band. The reactance of either the inductor or the capacitor range from 100 to 300 Ω. At the lower frequency the trap will act as a loading inductor, adding electrical length to the total antenna.

difference is that the vertical is one half of a dipole. The radial system (in-ground or above-ground) functions as a ground plane for the antenna, and represents the missing half of the dipole. Once again, the more effective the ground system, the better will be the antenna performance.

Trap verticals usually are adjusted as $^1/_4$-λ radiators. The portion of the antenna below the trap is adjusted as a $^1/_4$-λ radiator at the higher proposed operating frequency. That is, a 20/15-m trap vertical would be a resonant quarter wavelength at 15 m from the feedpoint to the bottom of the trap. The trap and that portion of the antenna above the trap (plus the 15-m section below the trap) constitute the complete antenna during 20-m operation. But because the trap is in the circuit, the overall physical length of the vertical antenna will be slightly less than that of a single-band, full-size 20-m vertical.

TRAPS

The trap functions as the name implies: It traps the 15-m energy and confines it to the part of the antenna below the trap. During 20-m operation it allows the RF energy to reach all of the antenna. The trap in this example is tuned as a parallel resonant circuit to 21 MHz. At this frequency it divorces the top section of the vertical from the lower section because it presents a high impedance (barrier) at 21 MHz. Generally, the trap inductor and capacitor have a reactance of 100 to 300 Ω. Within that range it is not critical.

The trap is built and adjusted separately from the antenna. It should be resonated at the center of the portion of the band to be operated. Thus, if one's favorite part of the 15-m band is between 21.0 and 21.1 MHz, the trap should be tuned to 21.05 MHz.

Resonance is checked by using a dip meter and detecting the dipper signal in a calibrated receiver. Once the trap is adjusted it can be installed in the antenna, and no further adjustment will be required. It is easy, however, to be misled after the system is assembled: Attempts to check the trap with a dip meter will suggest that the trap has moved much lower in frequency (approximately 5 MHz lower in a 20/15-m vertical). This is because the trap is part of the overall antenna, and the resultant resonance is that of the total antenna. Measure the trap separate from the rest of the antenna.

Multiband operation is quite practical by using the appropriate number of traps and tubing sections. The construction and adjustment procedure is the same, regardless of the number of bands covered. The highest frequency trap is always closest to the feed end of the antenna, and the lowest frequency trap is always the farthest from the feedpoint. As the operating frequency is progressively lowered, more traps and more tubing sections become a functional part of the antenna.

Traps should be weatherproofed to prevent moisture from detuning them. Several coatings of high dielectric compound, such as Polystyrene Q Dope, are effective. Alternatively, a protective sleeve of heat-shrink tubing can be applied to the coil after completion. The coil form for the trap should be of high dielectric quality and be rugged enough to sustain stress during periods of wind.

DUAL-BAND VERTICALS FOR 17/40 OR 12/30 M

Thanks to the harmonic relationships between the HF ham bands, many antennas can be made to do double duty. The simple verticals described here cover two bands at once. Here's how to turn a 30-m $^1/_4$-λ vertical into a 0.625-λ vertical for the 12-m band, and a 40-m $^1/_4$-λ vertical into a 0.625-λ vertical for the 17-m band. These verticals were designed and constructed by John J. Reh, K7KGP. The write-up first appeared in April 1989 *QST*.

CONSTRUCTION DETAILS

For the 30 and 12-m vertical, an old aluminum multiband vertical was cut to a length of 25 ft, 3 inches. This corresponds to a design frequency of 24.95 MHz. The length-to-diameter ratio is approximately 460. The input impedance of a vertical that is substantially longer than a $^1/_4$-λ (in this case 0.625 λ) is particularly sensitive to the λ/D ratio of the radiating element. If this antenna is duplicated with materials having a significantly different λ/D ratio, the results may be different.

After installing a good ground system, the input impedance was measured and found to have a resistance of about 50 Ω, and a capacitance of about –155 Ω (at 24.95 MHz). At 10.125 MHz, the input impedance was just under 50 Ω, and purely resistive. To tune out the reactance at 24.95 MHz, a series inductor is installed (see **Fig 22.50**) and tapped to resonance at the design frequency. The easiest way to find resonance is by measuring the antenna SWR. Use a good-quality coil for the series inductor. The recommended coil has a diameter of $2^1/_2$ inches, and has 6 turns per inch (B&W stock no. 3029). Resonance on 12 m was established with $3^1/_4$ turns. The SWR on 12 m is 1.1:1, and on 30 m, 1:1. To change bands from 12 to 30 m, move the coil tap to the end of the coil closest to the vertical element. Alternatively, a single-pole switch or remotely operated relay can be installed at the base of the vertical for bandswitching. Later, you'll see how to build the antenna with automatic bandswitching.

THE GROUND SYSTEM

Maximum RF current density—and therefore maximum ground losses—for $^1/_4$-λ verticals occurs in the immediate area of the base of the antenna. Maximum return current ground loss for a 0.625-λ vertical occurs about $^1/_2$ λ away from the base of the antenna. It's important to have the lowest possible losses in the immediate area for both types of verticals. In addition to a ground radial system, 6×6-ft

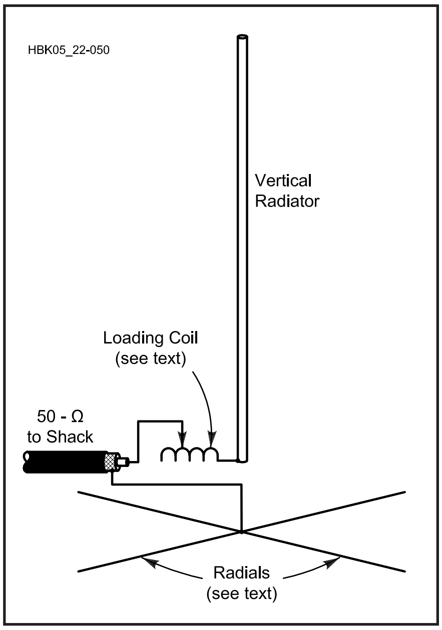


Fig 22.50 — Dual-band vertical. Use a switch or relay to remove the loading coil from the circuit for lower frequency operation. Adjust the coil tap for best SWR on the higher-frequency band. The radial system should be as extensive as possible. See *The ARRL Antenna Book* for more information on ground systems for vertical antennas.

aluminum ground screen is used at the base of the antenna. The screen makes a good tie point for the radials and conducts ground currents efficiently. Seventeen wire radials, each about 33 ft long, are spaced evenly around the antenna. More radials would probably work better. Each radial is bolted to the screen using corrosion-resistant #10-24 hardware. (Do not attempt to connect copper directly to aluminum. The electrical connection between the two metals will quickly deteriorate.) The radials can be made of bare or insulated wire. Make sure the ground screen is bolted to the ground side of the antenna with heavy-gauge wire. Current flow is fairly heavy at this point.

Table 22.10 gives specifications for the dual-band vertical. If your existing 40-m vertical is a few inches longer than 32 ft, 3 inches, try using it anyway—a few inches isn't too critical to performance on 17 m.

Table 22.10
Specifications for Dual-Band Verticals

Bands	*Height*	*Required Matching Inductance (μH)*
12 m & 30 m	23' 5"	0.99
17 m & 40 m	32' 3"	1.36

AUTOMATIC BANDSWITCHING

In October 1989 *QST*, James Johnson, W8EUI, presented this scheme for automatic bandswitching of the 40/17-m vertical. Johnson shortened his 40-m vertical approximately 12 inches and found an inductance that gave him 40 and 17-m band operation with an SWR of less than 1.4:1 across each band. He used an inductor made from B&W air-wound coil stock (no. 3033). This coil is 3 inches in diameter, and has $3^{1}/_{8}$ turns of #12 wire wound at 6 turns per inch, providing an inductance of about 2.8 μH. Johnson experimentally determined the correct tap position.

For the 30/12-m version, start with the vertical radiator 9 inches shorter than the value given in the table. In both cases, radiator height and inductance should be adjusted for optimum match on the two bands covered.

Inverted L and Sloper Antennas

This section covers variations on the vertical antenna. **Fig 22.51A** shows a flat-top T vertical. Dimension H should be as tall as possible for best results. The horizontal section, L, is adjusted to a length that provides resonance. Maximum radiation is polarized vertically despite the horizontal top-loading wire. A variation of the T antenna is depicted at B of Fig 22.51. This antenna is commonly referred to as an *inverted L*. Vertical member H should be as long as possible. L is added to provide an electrical quarter wavelength overall.

THE HALF-SLOPER ANTENNA

Many hams have had excellent results with *half-sloper* antennas, while others have not had such luck. Investigations by ARRL Technical Advisor John S. Belrose, VE2CV, have brought some insight to the situation through computer modeling with *ELNEC* and antenna-range tests. The following is taken from VE2CV's Technical Correspondence in Feb 1991 *QST*, pp 39 and 40. Essentially, the half sloper is a top-fed vertical antenna worked against a ground plane (such as a grounded Yagi antenna) at the top of the tower. The tower acts as a reflector.

For half slopers, the input impedance, the resonant length of the sloping wire and the antenna pattern all depend on the tower height, the angle (between the sloper and tower) the type of Yagi and the Yagi orientation. Here are several configurations extracted from VE2CV's work:

At 160 m—use a 40-m beam on top of a 95-ft tower with a 55° sloper apex angle. The radiation pattern varies little with Yagi type. The pattern is slightly cardioid with about 8 dB front-to-back ratio at a 25° takeoff angle (see Fig 22.51D and E). Input impedance is about 50 Ω.

At 80 m—use a 20-m beam on top of a 50-ft tower with a 55° sloper apex angle. The radiation pattern and input impedance are similar to those of the 160-m half sloper.

At 40 m—use a 20-m beam on top of a 50-ft tower with a 55° sloper apex angle. The radiation pattern and impedance depend strongly on the azimuth orientation of the Yagi. Impedance varies from 76 to 127 Ω depending on Yagi direction.

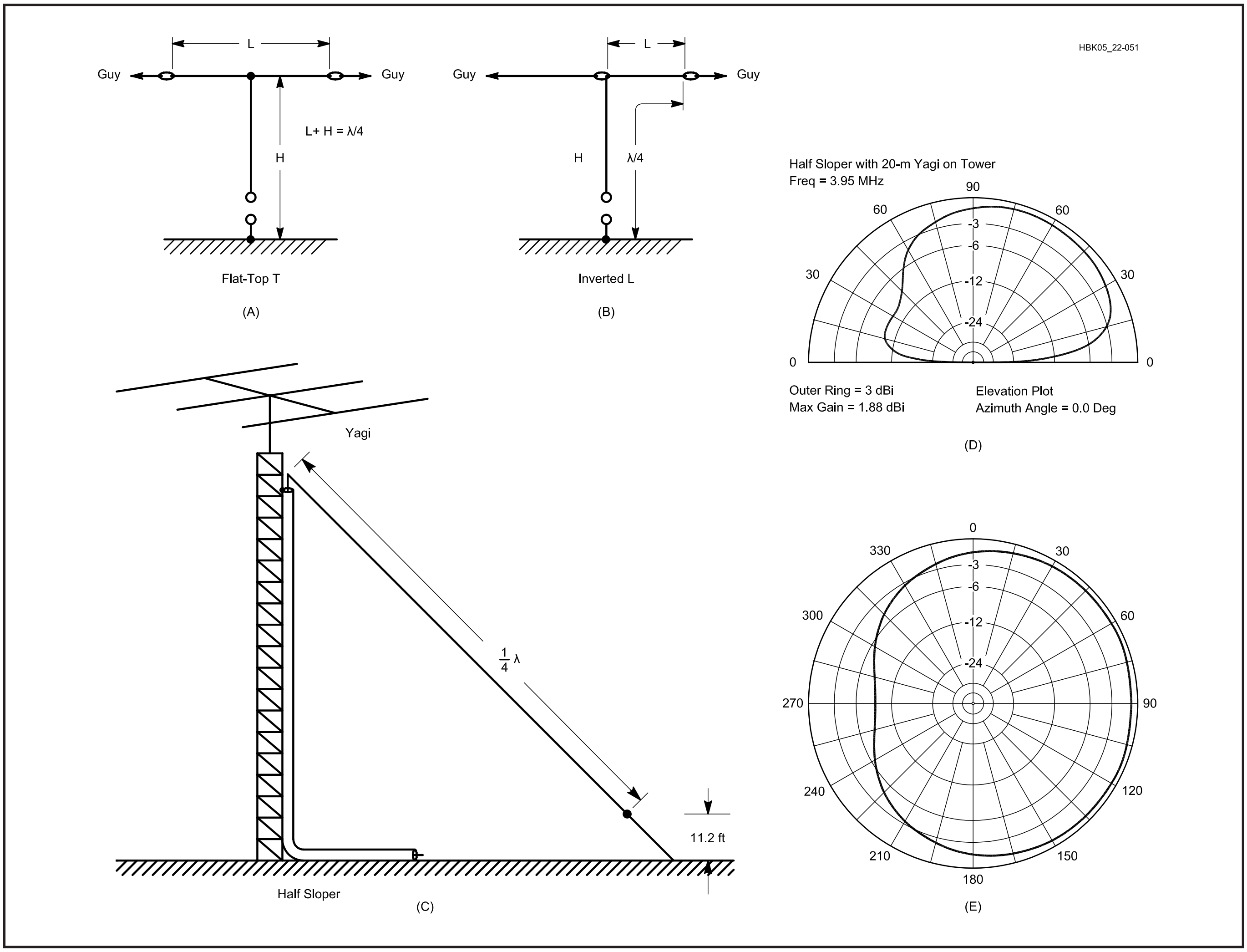


Fig 22.51 — Some variations in vertical antennas. D is the vertical radiation pattern in the plane of a half sloper, with the sloper to the right. E is the azimuthal pattern of the half sloper (90° azimuth is the direction of the sloping wire). Both patterns apply to 160- and 80-m antennas described in the text.

1.8-MHz INVERTED L

The antenna shown in **Fig 22.52** is simple and easy to construct. It is a good antenna for the beginner or the experienced 1.8 MHz DXer. Because the overall electrical length is greater than $^{1}/_{4}$ λ, the feed-point resistance is on the order of 50 Ω, with an inductive reactance. That reactance is canceled by a series capacitor, which for power levels up to the legal limit can be an air-variable capacitor with a voltage rating of 1500 V. Adjust antenna length and vari-

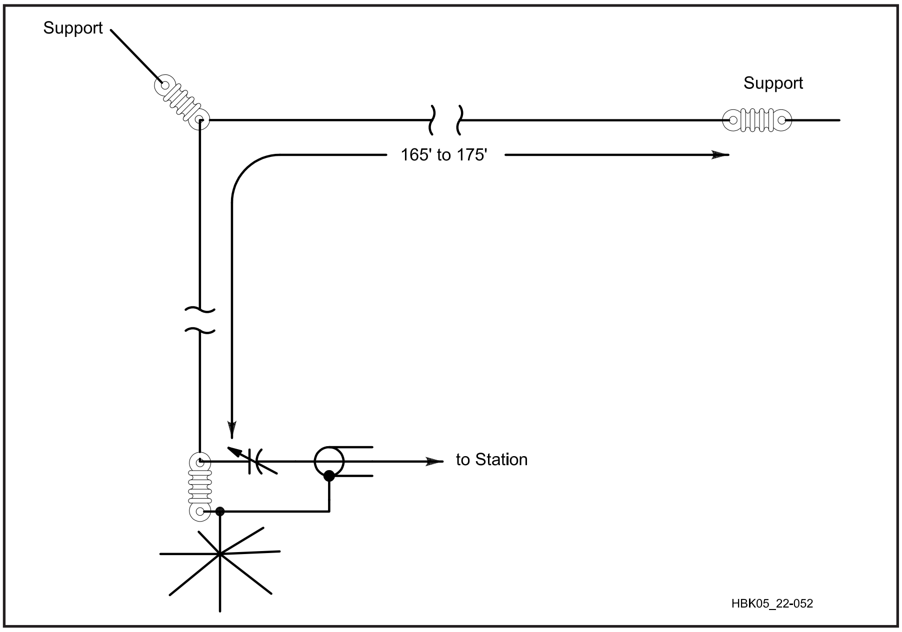


Fig 22.52 — The 1.8-MHz inverted L. Overall wire length is 165 to 175 ft. The variable capacitor has a maximum capacitance of 500 to 800 pF.

able capacitor for lowest SWR.

A yardarm or a length of line attached to a tower can be used to support the vertical section of the antenna. (Keep the inverted L as far from the tower as is practical. Certain combinations of tower height and Yagi top loading can interact severely with the Inverted-L antenna—a 70-ft tower and a 5-element Yagi, for example.) For best results the vertical section should be as long as possible. A good ground system is necessary for good results.

THE HALF-WAVE VERTICAL DIPOLE (HVD)

Chuck Hutchinson, K8CH, describes a 15-m vertical dipole (HVD) that he built in the ARRL book, *Simple and Fun Antennas for Hams*. The performance of this antenna, with its base at 14 ft, compares favorably with a horizontal dipole at 30 ft when making intercontinental QSOs.

CONSTRUCTION OF A 15-M HVD

The 15-meter HVD consists of four 6-ft lengths of 0.875-inch aluminum tube with 0.058 wall thickness. In addition there are two 1-ft lengths of 0.75-inch tubing for splices, and two one-foot lengths of 0.75-inch fiberglass rod for insulators. See **Table 22.11** for dimensions.

Start by cutting off 1 foot from a 6-ft length of 0.875-inch tubing. Next, insert six inches of one of the 1-foot-long 0.75-inch tubes into the machine-cut end of your tubing and fasten the tubes together. Now, slide an end of a 6-ft length of 0.875 tube over the protruding end of the 0.75 tube and fasten them together. Repeat this procedure with the remaining 0.875-inch tubing.

Table 22.11

HVD Dimensions

Length using 0.875-inch aluminum tubing

MHz	*Feet*	*Inches*
18.11	33	11
21.2	22	0
24.94	18	9
28.4	16	5

These lengths should divided by two to determine the length of the dipole legs.

You should now have two 11-ft-long elements. As you can see in **Fig 22.53**, K8CH was temporarily out of aluminum pop rivets, so he used sheet metal screws. Either will work fine, but pop rivets can easily be drilled out and the antenna disassembled if you ever want to make changes.

Fig 22.53 — Element splice uses a 1-ft length of 0.75-inch tubing inserted into the 0.875-inch sections to join them together. Self-tapping sheet-metal screws are used in this photo, but aluminum pop rivets or machine screws with washers and nuts can be used.

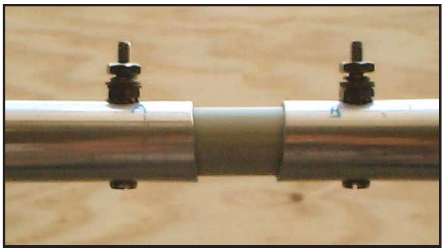


Fig 22.54 — The center insulator of the 15-m HVD is a 1-ft length of 0.75-inch fiberglass rod. Insulator and elements have been drilled to accept #8 hardware.

Because hand-made cuts are not perfectly square, put those element ends at the center of the antenna. Slip these cut ends over the ends of a 1-ft length of 0.75-inch fiberglass rod. This rod serves as the center insulator. Leave about a 1-inch gap at the center. Drill aluminum and fiberglass for #8 hardware as shown in **Fig 22.54**.

Now, slip half of the remaining 1-ft length of 0.75-inch fiberglass rod into one end the dipole. (This end will be the bottom end or base.) Drill and secure with #8 hardware. See **Fig 22.55**.

The final step is to secure the guy wires to your vertical. You can see how K8CH did that in **Fig 22.56**. Start by drilling a pilot hole and then drive a sheet metal screw into the antenna about a foot above the center. The purpose of that screw is to prevent the clamp and guys from sliding down the antenna.

The guys are clean lengths of $^{3}/_{16}$-inch Dacron line. (The Dacron serves a dual purpose: it supports the antenna vertically, and it acts as an insulator.) Tie secure knots into the guy ends and secure these knotted ends to the antenna with a stainless-steel worm-screw-type hose clamp. Take care to not over tighten the clamps. You don't want the clamp to slip (the knots and the sheet-metal screw will help), but you especially don't want to cut your guy lines. Your

Fig 22.55 — The HVD base insulator is a 1-ft length of 0.75-inch fiberglass rod.

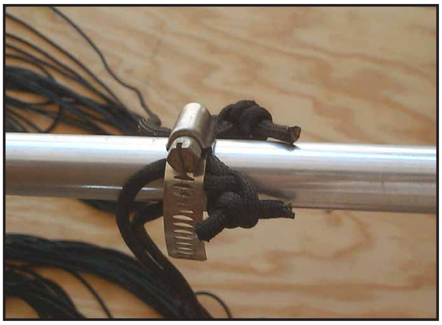


Fig 22.56 — Guys are made of Dacron line that is attached to the HVD by a stainless-steel worm-screw-type hose clamp. A self-tapping sheet-metal screw (not visible in the photo) prevents the clamp from sliding down the antenna.

Fig 22.57 — At K8CH, the HVD base insulator sits in this saddle-shaped wooden fixture. This was photo was taken before the fixture was painted—a necessary step to protect against the weather.

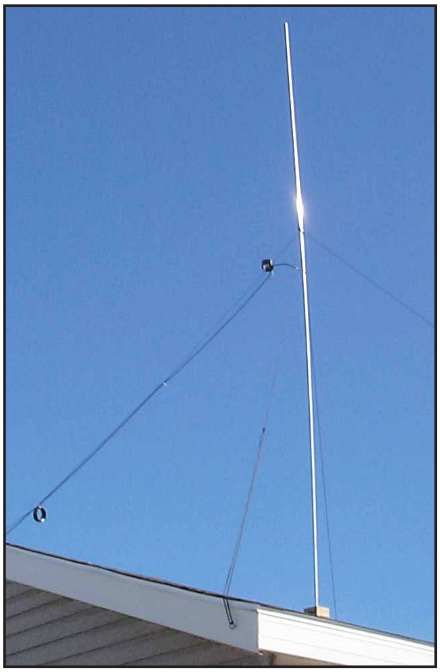


Fig 22.58 — The HVD installed at K8CH. An eye screw that is used for securing one of the guy lines is visible in the foreground. You can also see the two choke baluns that are used in the feed system (see text).

antenna is ready for installation.

INSTALLATION

Installation requires two things. First, a place to sit or mount the base insulator. Second, you need anchors for the support guys.

K8CH used a piece of 2 × 6 lumber to make a socket to hold the HVD base securely in place. He drilled a 3/4-inch-deep hole with a 3/4-inch spade bit. A couple of pieces of 2 × 2 lumber at the ends of the base form a saddle which nicely straddles the ridge at the peak of his garage roof. You can see how I did this in **Fig 22.57**. The dimensions are not critical, but you should paint your base to protect it from the weather.

BALUN

This antenna needs a common-mode choke to ensure that stray RF doesn't flow on the shield of the coax. This device is also known as a choke balun. Unlike a horizontal dipole, don't consider it an option to omit the common-mode choke when building and installing an HVD.

You can use 8 ft of the RG-213 feed line wound into 7 turns for a balun. Secure the turns together with electrical tape so that each turn lies parallel with the next turn, forming a solenoid coil. Secure the feed line and balun to one of the guy lines with UV-resistant cable ties.

Because the feed line slants away from the antenna, you'll want to do *all* that you can to eliminate common-mode currents from the feed line. For that reason, make another balun about 11.5 ft from the first one. This balun also consists of 8 ft of the RG-213 feed line wound into 7 turns. See **Fig 22.58**.

THE COMPACT VERTICAL DIPOLE (CVD)

An HVD for 20 m will be about 33 ft tall, and for 30 m, it will be around 46 ft tall. Even the 20-m version can prove to be a mechanical challenge. The compact vertical dipole (CVD), designed by Chuck Hutchinson, K8CH, uses capacitance loading to shorten the antenna. Starting with the 15-m HVD described in the previous project, Chuck added capacitance loading wires to lower the resonance to 30 m. Later, he shortened the wires to move resonance to the 20-m band. This project describes those two CVDs.

PERFORMANCE ISSUES

Shortened antennas frequently suffer reduced performance caused by the shortening. A dipole that is less than a half wave in length is a compromise antenna. The question becomes how much is lost in the compromise. In this case there are two areas of primary interest, radiation efficiency and SWR bandwidth.

Radiation Efficiency

Capacitance loading at the dipole ends is the most efficient method of shortening the antenna. Current distribution in the high-current center of the antenna remains virtually unchanged. Since radiation is related directly to current, this is the most desireable form of loading. Computer modeling shows that radiation from a 30-m CVD is only 0.66 dB less than that from a full-size 30-m HVD when both have their bases 8 ft above ground. The angle of maximum radiation shifts up a bit for the CVD. Not a bad compromise when you consider that the CVD is 22-ft long compared to the approximately 46-ft length of the HVD.

SWR and SWR Bandwidth

Shortened antennas usually have lower radiation resistance and less SWR bandwidth than the full-size versions. The amount of change in the radiation resistance is related to the amount and type of loading (shortening), being lower with shorter the antennas. This can be a benefit in the case of a shortened vertical dipole. In Fig 22.1 you can see that vertical dipoles have a fairly high radiation resistance. With the dipole's lower end $1/8\ \lambda$ above ground, the radiation resistance is roughly 80 Ω. In this case, a shorter antenna can have a better SWR when fed with 50-Ω coax.

SWR bandwidth tends to be wide for vertical dipoles in general. A properly designed CVD for 7-MHz or higher should give you good SWR (1.5:1 or better) across the entire band!

As you can see, in theory the CVD provides excellent performance in a compact package. Experience confirms the theory.

CONSTRUCTION

To convert the K8CH 15-m HVD to 20 or 30 m, you'll need to add four loading wires at the top and four more at the bottom of the HVD. The lengths are shown in **Table 22.12**. The upper wires droop at a 45° angle and the lower wires run horizontally. The antenna is supported by 4 guy lines. See **Fig 22.59**. You can connect the wires to the vertical portion with #8 hardware. Crimp and solder terminals on the wire ends to make connections easier. The technique is illustrated in **Fig 22.60**.

The upper loading wires can be extended with insulated line and used for additional guying. The lower wires are extended with insulated line and fasten to the guy lines so that the lower wires run horizontally.

Prune the lower wires for best SWR across the band of interest. The K8CH CVD has its base at 14 ft. This antenna has an SWR of less than 1.2:1 on 30 m and less than 1.3:1 across the entire 20-m band.

EXPERIENCE

The 30-m CVD was compared to a ground-mounted quarter-wave vertical and a horizontal dipole at 30 ft. In tests, the CVD was always the superior antenna.

Table 22.12
CVD Loading Wires

Length using #14 insulated copper wire

Band	Feet	Inches	
30 m	6	0	Top & Bottom
20 m	4	2¼	Top
20 m	3	½	Bottom

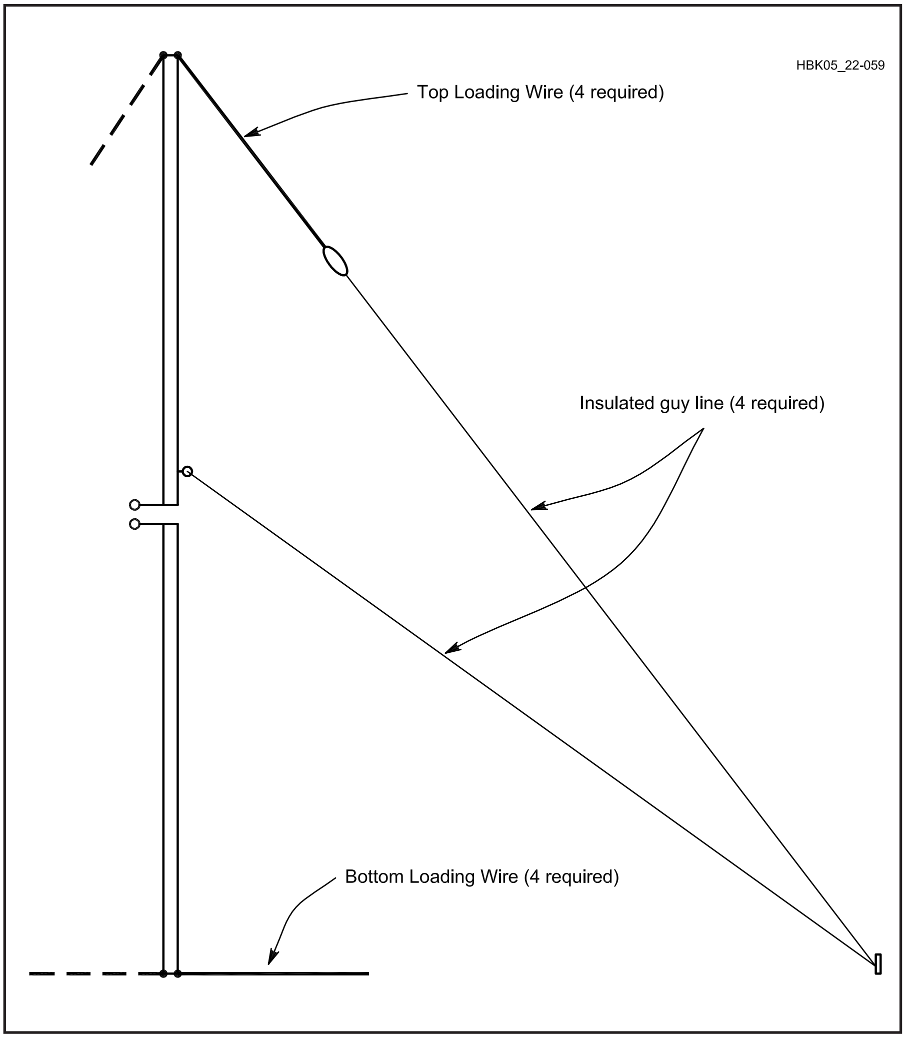


Fig 22.59 — The CVD consists of a vertical dipole and loading wires. Only one set of the four loading wires and only one guy line is shown in this drawing. See text for details.

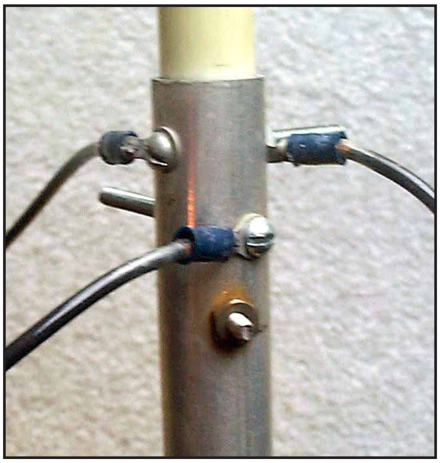


Fig 22.60 — CVD loading wires can be attached using #8 hardware. Crimp and solder terminals on the wire ends to make connections easier.

Every DX station that was called by K8CH responded with one or two calls. What more could you ask for?

Later, the CVD loading wires were shortened for operation on 20 m. Once again the results were very encouraging. Many contest QSOs were entered in the log using this antenna.

Finally, a late winter ice storm deposited about $^{3}/_{4}$ inch of radial ice on the antenna, loading wires and guys. The antenna would probably have survived had it not been for the sustained 45 mph winds that followed. The upper loading wires and their guy lines were not heavy enough to support the load and the antenna bent and broke. This combination of ice and wind is very unusual.

ALL WIRE 30-M CVD

If you have a tree or other support that will support the upper end of a CVD at 32 ft above the ground, you might want to consider an all-wire version of the 30-m CVD. The vertical is 24 ft long and it will have an SWR of less than 1.1:1 across the band. The four loading wires at top and bottom are each 5 ft, 2 inches long.

The configuration is shown in **Fig 22.61**. As with any vertical dipole, you'll need to use a blaun between the feedline and the antenna.

Alternatively you can use two loading wires at the top and two at the bottom. In this case each of the loading wires is 8 ft 7 $^{1}/_{2}$ inches long.

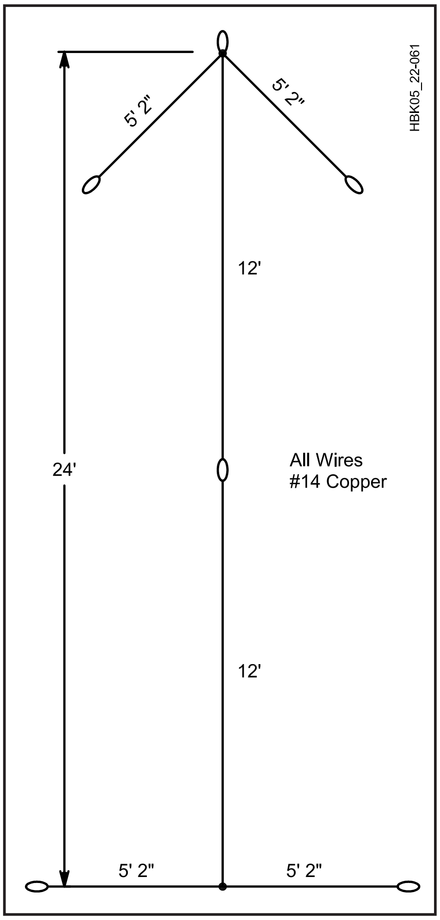


Fig 22.61 — The all-wire 30-m CVD consists of a vertical dipole and loading wires. It can be made entirely with #14 wire. Support lines have been omitted for simplicity. See text for details.

Yagi and Quad Directive Antennas

Most antennas described earlier in this chapter have unity gain compared to a dipole, or just slightly more. For the purpose of obtaining gain and directivity it is convenient to use a Yagi-Uda or cubical quad beam antenna. The former is commonly called a *Yagi*, and the latter is usually referred to as a *quad*.

Most operators prefer to erect these antennas for horizontal polarization, but they can be used as vertically polarized arrays merely by rotating the elements by 90°. In effect, the beam antenna is turned on its side for vertical polarity. The number of elements used will depend on the gain desired and the limits of the supporting structure. Many amateurs obtain satisfactory results with only two elements in a beam antenna, while others have four or five elements operating on a single amateur band.

Regardless of the number of elements used, the height-above-ground considerations discussed earlier for dipole antennas remain valid with respect to the angle of radiation. This is demonstrated in **Fig 22.62** at A and B where a comparison of radiation characteristics is given for a 3-element Yagi at one-half and one wavelength above average ground. It can be seen that the higher antenna (Fig 22.62B) has a main lobe that is more favorable for DX work (roughly 15°) than the lobe of the lower antenna in Fig 22.62A (approximately 30°). The pattern at B shows that some useful high-angle radiation exists also, and the higher lobe is suitable for short-skip contacts when propagation conditions dictate the need.

The azimuth pattern for the same antenna is provided in **Fig 22.63**. Most of the power is concentrated in the *main lobe* at 0° azimuth. The lobe directly behind the main lobe at 180° is often called the *backlobe*. Note that there are small *sidelobes* at approximately 110° and 260° in azimuth. The peak power difference, in decibels, between the *nose* of the main lobe at 0° and the strongest rearward lobe is called the *front-to-rear ratio (F/R)*. In this case the worst-case rearward lobe is at 180°, and the F/R is 12 dB. It is infrequent that two 3-element Yagis with different element spacings and tuning will yield the same lobe patterns. The pattern of Fig 22.63 is shown only for illustrative purposes.

PARASITIC EXCITATION

In most of these arrangements the additional elements receive power by induction or radiation from the driven element and reradiate it in the proper phase relationship to give the desired effect. These elements are called *parasitic elements*, as contrasted to *driven elements*, which receive power directly from the transmitter through the transmission line.

The parasitic element is called a *director* when it reinforces radiation on a line pointing to it from the driven element, and a *reflector* when the reverse is the case. Whether the parasitic element is a director or reflector depends on the parasitic element tuning, which is usually adjusted by changing its length.

GAIN, FRONT-TO-REAR RATIO AND SWR

The gain of an antenna with parasitic elements varies with the spacing and tuning of the elements. Element tuning is a function of length, diameter and taper schedule if the element is constructed with telescoping tubing. For any given spacing, there is a tuning condition that will give maximum gain at this spacing. However, the maximum front-to-rear ratio seldom, if ever, occurs at the same condition that gives maximum forward gain. The impedance of the driven element in a parasitic array, and thus the SWR, also varies with the tuning and spacing.

It is important to remember that all these parameters change as the operating frequency is varied. For example, if you operate both the CW and phone portions

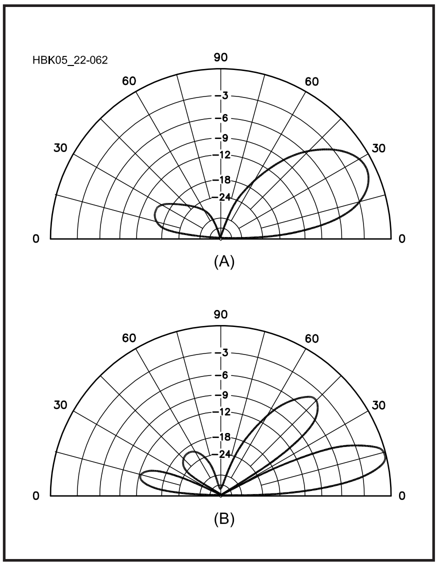


Fig 22.62 — Elevation-plane response of a 3-element Yagi placed $\frac{1}{2}$ λ above perfect ground at A and the same antenna spaced 1 λ above ground at B.

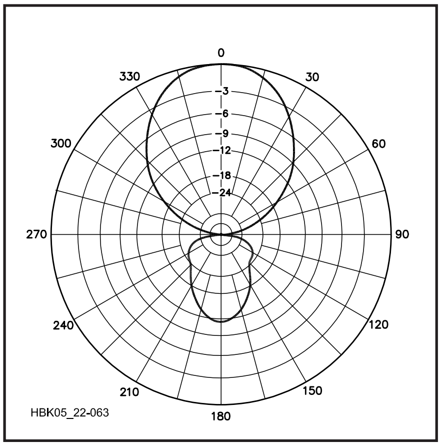


Fig 22.63 — Azimuth-plane pattern of a typical three-element Yagi in free space. The Yagi's boom is along the 0° to 180° axis.

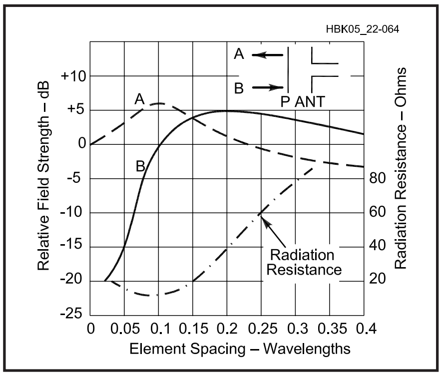


Fig 22.64 — Gain vs element spacing for a 2-element Yagi, having one driven and one parasitic element. The reference point, 0 dB, is the field strength from a half-wave antenna alone. The greatest gain is in the direction A at spacings of less than 0.14 λ, and in direction B at greater spacings. The front-to-rear ratio is the difference in decibels between curves A and B. Variation in radiation resistance of the driven element is also shown. These curves are for the special case of a self-resonant parasitic element, but are representative of how a 2-element Yagi works. At most spacings the gain as a reflector can be increased by slight lengthening of the parasitic element; the gain as a director can be increased by shortening. This also improves the front-to-rear ratio.

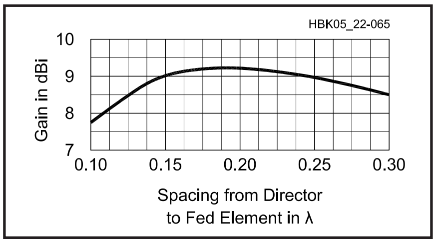


Fig 22.65 — General relationship of gain of 3-element Yagi vs director spacing, the reflector being fixed at 0.2 λ. This antenna is tuned for maximum forward gain.

Table 22.13

10-m Optimized Yagi Designs

	Spacing Between Elements (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Seg 3 Length (in.)*	*Midband Gain F/R*
310-08					
Refl	0	24	18	66.750	7.2 dBi
DE	36	24	18	57.625	22.9 dB
Dir 1	54	24	18	53.125	
410-14					
Refl	0	24	18	64.875	8.4 dBi
DE	36	24	18	58.625	30.9 dB
Dir 1	36	24	18	57.000	
Dir 2	90	24	18	47.750	
510-24					
Refl	0	24	18	65.625	10.3 dBi
DE	36	24	18	58.000	25.9 dB
Dir 1	36	24	18	57.125	
Dir 2	99	24	18	55.000	
Dir 3	111	24	18	50.750	

Note: For all antennas, the tube diameters are: Seg 1=0.750 inch, Seg 2=0.625 inch, Seg 3=0.500 inch.

Table 22.14

12-m Optimized Yagi Designs

	Spacing Between Elements (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Seg 3 Length (in.)*	*Midband Gain F/R*
312-10					
Refl	0	36	18	69.000	7.5 dBi
DE	40	36	18	59.125	24.8 dB
Dir 1	74	36	18	54.000	
412-15					
Refl	0	36	18	66.875	8.5 dBi
DE	46	36	18	60.625	27.8 dB
Dir 1	46	36	18	58.625	
Dir 2	82	36	18	50.875	
512-20					
Refl	0	36	18	69.750	9.5 dBi
DE	46	36	18	61.750	24.9 dB
Dir 1	46	36	18	60.500	
Dir 2	48	36	18	55.500	
Dir 3	94	36	18	54.625	

Note: For all antennas, the tube diameters are: Seg 1 = 0.750 inch, Seg 2 = 0.625 inch, Seg 3 = 0.500 inch.

of the 20-m band with a Yagi or quad antenna, you probably will want an antenna that *spreads out* the performance over most of the band. Such designs typically must sacrifice a little gain in order to achieve good F/R and SWR performance across the band. The longer the boom of a Yagi or a quad, and the more elements that are placed on that boom, the better will be the overall performance over a given amateur band. For the lower HF bands, the size of the antenna quickly becomes impractical for truly *optimal* designs, and compromise is necessary.

TWO-ELEMENT BEAMS

A 2-element beam is useful—especially where space or other considerations prevent the use of a three element, or larger, beam. The general practice is to tune the parasitic element as a reflector and space it about 0.15 λ from the driven element, although some successful antennas have been built with 0. l-λ spacing and director tuning. Gain vs element spacing for a 2-element antenna is given in **Fig 22.64** for the special case where the parasitic element is resonant. It is indicative of the performance to be expected under maximum-gain tuning conditions. Changing the tuning of the driven element in a Yagi or quad will not materially affect the gain or F/R. Thus, only the spacing and the tuning of the single parasitic element have any effect on the performance of a 2-element Yagi or quad. Most 2-element Yagi designs achieve a compromise F/R of about 10 dB, together with acceptable SWR and gain across a frequency band with a percentage bandwidth less than about 4%. A 2-element quad can achieve better F/R, gain and SWR across a band, at the expense of greater mechanical complexity compared to a Yagi.

THREE-ELEMENT BEAMS

A theoretical investigation of the 3-element case (director, driven element and reflector) has indicated a maximum gain of about 9.7 dBi. A number of experimental investigations have shown that the spacing between the driven element and reflector for maximum gain is in the region of 0.15 to .25 λ. With 0.2-λ reflector spacing, **Fig 22.65** shows that the gain variation with director spacing is not especially critical. Also, the overall length of the array (boom length in the case of a rotatable antenna) can be anywhere between 0.35 and 0.45 λ with no appreciable difference in the maximum gain obtainable.

If maximum gain is desired, wide spacing

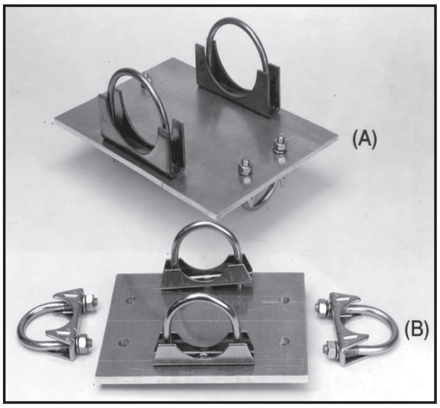


Fig 22.67 — The boom-to-element plate at A uses muffler-clamp-type U-bolts and saddles to secure the round tubing to the flat plate. The boom-to-mast plate at B is similar to the boom-to-element plate. The main difference is the size of materials used.

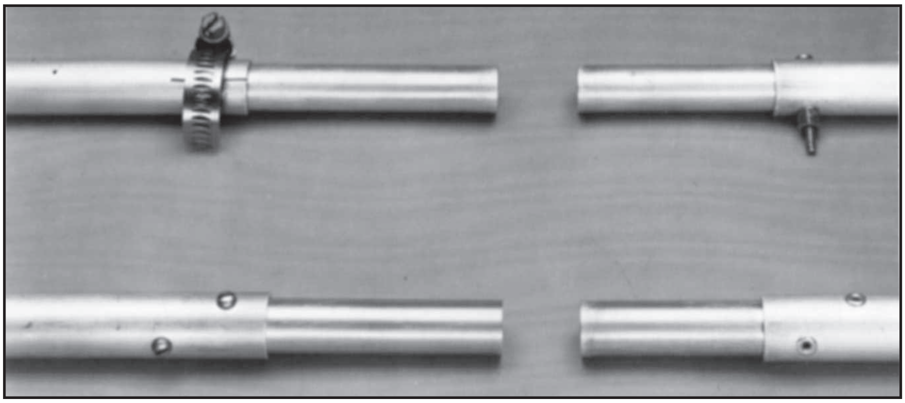


Fig 22.66 — Some methods of connecting telescoping tubing sections to build beam elements. See text for a discussion of each method.

of both elements is beneficial because adjustment of tuning or element length is less critical and the input resistance of the driven element is generally higher than with close spacing. A higher input resistance improves the efficiency of the antenna and makes a greater bandwidth possible. However, a total antenna length, director to reflector, of more than 0.3 λ at frequencies of the order of 14 MHz introduces difficulty from a construction standpoint. Lengths of 0.25 to 0.3 λ are therefore used frequently for this band, even though they are less than opti-

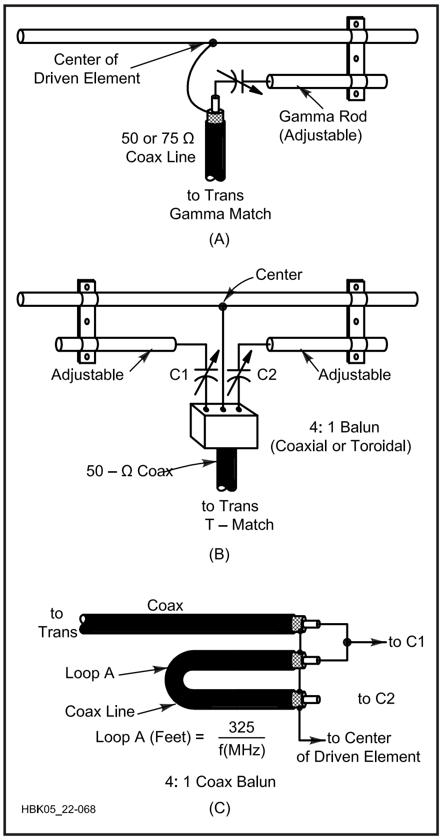


Fig 22.68 — Illustrations of gamma and T matching systems. At A, the gamma rod is adjusted along with C until the lowest SWR is obtained. A T match is shown at B. It is the same as two gamma-match rods. The rods and C1 and C2 are adjusted alternately for a best SWR. A coaxial 4:1 balun transformer is shown at C. A toroidal balun can be used in place of the coax model shown. The toroidal version has a broader frequency range than the coaxial one. The T match is adjusted for 200 Ω and the balun steps this balanced value down to 50 Ω, unbalanced. Or the T match can be set for 300 Ω, and the balun used to step this down to 75 Ω unbalanced. Dimensions for the gamma and T match rods will depend on the tubing size used, and the spacing of the parasitic elements of the beam. Capacitors C, C1 and C2 can be 140 pF for 14-MHz beams. Somewhat less capacitance will be needed at 21 and 28 MHz.

Table 22.15

15-m Optimized Yagi Designs

	Spacing Between Elements (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Seg 3 Length (in.)*	*Seg 4 Length (in.)*	*Midband Gain F/R*
315-12						
Refl	0	30	36	18	61.375	7.6 dBi
DE	48	30	36	18	49.625	25.5 dB
Dir 1	92	30	36	18	43.500	
415-18						
Refl	0	30	36	18	59.750	8.3 dBi
DE	56	30	36	18	50.875	31.2 dB
Dir 1	56	30	36	18	48.000	
Dir 2	98	30	36	18	36.625	
515-24						
Refl	0	30	36	18	62.000	9.4 dBi
DE	48	30	36	18	52.375	25.8 dB
Dir 1	48	30	36	18	47.875	
Dir 2	52	30	36	18	47.000	
Dir 3	134	30	36	18	41.000	

Note: For all antennas, the tube diameters (in inches) are:
Seg 1 = 0.875, Seg 2 = 0.750, Seg 3 = 0.625, Seg 4 = 0.500.

Table 22.16

17-m Optimized Yagi Designs

	Spacing Between Elements (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Seg 3 Length (in.)*	*Seg 4 Length (in.)*	*Seg 5 Length (in.)*	*Midband Gain F/R*
317-14							
Refl	0	24	24	36	24	60.125	8.1 dBi
DE	65	24	24	36	24	52.625	24.3 dB
Dir 1	97	24	24	36	24	48.500	
417-20							
Refl	0	24	24	36	24	61.500	8.5 dBi
DE	48	24	24	36	24	54.250	27.7 dB
Dir 1	48	24	24	36	24	52.625	
Dir 2	138	24	24	36	24	40.500	

Note: For all antennas, tube diameters (inches) are: Seg 1=1.000, Seg 2=0.875, Seg 3=0.750, Seg 4=0.625, Seg 5=0.500.

Table 22.17

20-m Optimized Yagi Designs

	Spacing Between Elements (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Seg 3 Length (in.)*	*Seg 4 Length (in.)*	*Seg 5 Length (in.)*	*Seg 6 Length (in.)*	*Midband Gain F/R*
320-16								
Refl	0	48	24	20	42	20	69.625	7.3 dBi
DE	80	48	24	20	42	20	51.250	23.4 dB
Dir 1	106	48	24	20	42	20	42.625	
420-26								
Refl	0	48	24	20	42	20	65.625	8.6 dBi
DE	72	48	24	20	42	20	53.375	23.4 dB
Dir 1	60	48	24	20	42	20	51.750	
Dir 2	174	48	24	20	42	20	38.625	

Note: For all antennas, tube diameters (inches) are: Seg 1=1.000, Seg 2=0.875, Seg 3=0.750, Seg 4=0.625, Seg 5=0.500.

mum from the viewpoint of maximum gain.

In general, Yagi antenna gain drops off less rapidly when the reflector length is increased beyond the optimum value than it does for a corresponding decrease below the optimum value. The opposite is true of a director. It is therefore advisable to err, if necessary, on the long side for a reflector and on the short side for a director. This also tends to make the antenna performance less dependent on the exact frequency at which it is operated: An increase above the design frequency has the same effect as increasing the length of both parasitic elements, while a decrease in frequency has the same effect as shortening both elements. By making the director slightly short and the reflector slightly long, there will be a greater spread between the upper and lower frequencies at which the gain starts to show a rapid decrease.

We recommend *plumbers delight* construction, where all elements are mounted directly on, and grounded to, the boom. This puts the entire array at dc ground potential, affording better lightning protection. A gamma- or T-match section can be used for matching the feed line to the array.

COMPUTER-OPTIMIZED YAGIS

Yagi designers are now able to take advantage of powerful personal computers and software to optimize their designs for the parameters of gain, F/R and SWR across frequency bands. ARRL Senior Assistant Technical Editor Dean Straw, N6BV, has designed a family of Yagis for HF bands. These can be found in **Tables 22.13**, **22.14**, **22.15**, **22.16** and **22.17**, for the 10, 12, 15, 17 and 20-m amateur bands.

For 12 through 20 m, each design has been optimized for better than 20 dB F/R, and an SWR of less than 2:1 across the entire amateur frequency band. For the 10-m band, the designs were optimized for the lower 800 kHz of the band, from 28.0 to 28.8 MHz. Each Yagi element is made of telescoping 6061-T6 aluminum tubing, with 0.058 inch thick walls. This type of element can be telescoped easily, using techniques shown in **Fig 22.66**. Measuring each element to an accuracy of $^1/_8$ inch results in performance remarkably consistent with the computations, without any need for *tweaking* or fine-tuning when the Yagi is on the tower.

Each element is mounted above the boom with a heavy rectangular aluminum plate, by means of galvanized U-bolts with saddles, as shown in **Fig 22.67**. This method of element mounting is rugged and stable, and because the element is mounted away from the boom, the amount of element detuning due to the presence of the boom is minimal. The element dimensions given in each table already take into account any element detuning due to the boom-to-element mounting plate. The element-to-boom mounting plate for all the 10-m Yagis is a 0.250-inch thick flat aluminum plate, 4 inches wide by 4 inches long. For the 12 and 15-m Yagis, a 0.375-inch thick flat aluminum plate, 5 inches wide by 6 inches long is used, and for the 17 and 20-m Yagis, a 0.375-inch thick flat aluminum plate, 6 inches wide by 8 inches long is used. Where the plate is rectangular, the long dimension is in line with the element.

Each design table shows the dimensions for *one-half* of each element, mounted on one side of the boom. The other half of each element is the same, mounted on the other side of the boom. Use a tubing sleeve inside the center portion of the element so that the element is not crushed by the mounting U-bolts. Each telescoping section is inserted 3 inches into the next size of tubing. For example, in the 310-08.YAG design (3 elements on an 8-ft boom), the reflector tip, made out of $^1/_2$-inch OD tubing, sticks out 66.75 inches from the $^5/_8$-inch OD tubing. For each 10-m element, the overall length of each $^5/_8$-inch OD piece of tubing is 21 inches, before insertion into the $^3/_4$-inch piece. Since the $^3/_4$-inch OD tubing is 24 inches long on each side of the boom, the center portion of each element is actually 48 inches of uncut $^3/_4$-inch OD tubing.

The boom for all these antennas should be constructed with at least 2-inch-OD tubing, with 0.065-inch wall thickness. Because each boom has 3 inches extra space at each end, the reflector is actually placed 3 inches from one end of the boom. For the 310-08.YAG, the driven element is placed 36 inches ahead of the reflector, and the director is placed 54 inches ahead of the driven element.

Each antenna is designed with a driven element length appropriate for a gamma or T matching network, as shown in **Fig 22.68**. The variable gamma or T capacitors can be housed in small plastic enclosures for weatherproofing; receiving-type variable capacitors with close plate spacing can be used at powers up to a few hundred watts. Maximum capacitance required is usually 140 pF at 14 MHz and proportionally less at the higher frequencies.

The driven-element's length may require slight readjustment for best match, particularly if a different matching network is used. *Do not change either the lengths or the telescoping tubing schedule of the parasitic elements*—they have been optimized for best performance and will not be affected by tuning of the driven element.

TUNING ADJUSTMENTS

Preliminary matching adjustments can be done on the ground. The beam should be set up so the reflector element rests on the earth, with the beam pointing upward. The matching system is then adjusted for best SWR. When the antenna is raised to its operating height, only slight touch-up of the matching network may be required.

CONSTRUCTION OF YAGIS

Most beams and verticals are made from sections of aluminum tubing. Compromise beams have been fashioned from less-expensive materials such as electrical conduit (steel) or bamboo poles wrapped with conductive tape or aluminum foil. The steel conduit is heavy, is a poor conductor and is subject to rust. Similarly, bamboo with conducting material attached to it may deteriorate rapidly in the weather. The dimensions shown for the Yagis in the preceding section are designed for specific telescoping aluminum elements, but the elements may be scaled to different sizes by using the information about tapering and scaling in Chapter 2 of *The ARRL Antenna Book*, although with a likelihood of deterioration in performance over the whole frequency band.

For reference, **Table 22.18** details the standard sizes of aluminum tubing, available in many metropolitan areas. Dealers may be found in the Yellow Pages under *Aluminum*. Tubing usually comes in 12-ft lengths, although 20-ft lengths are available in some sizes. Your aluminum dealer will probably also sell aluminum plate in various thicknesses needed for boom-to-mast and boom-to-element connections.

Aluminum is rated according to its hardness. The most common material used in antenna construction is grade 6061-T6. This material is relatively strong and has good workability. In addition, it will bend without taking a *set*, an advantage in antenna applications where the pieces are constantly flexing in the wind. The softer grades (5051, 3003 and so on) will bend much more easily, while harder grades (7075 and so on) are more brittle.

Wall thickness is of primary concern when selecting tubing. It is of utmost importance that the tubing fits snugly where the element sections join. Sloppy joints will make a mechanically unstable antenna. The magic wall thickness is 0.058 inch. For example (from Table 22.18), 1-inch outside diameter (OD) tubing with a 0.058-inch wall has an inside diameter (ID) of 0.884 inch. The next smaller size of tubing, $^7/_8$ inch, has an OD of 0.875 inch. The 0.009-inch difference provides just the right amount of clearance for a snug fit.

Table 22.18
Standard Sizes of Aluminum Tubing

6061-T6 (61S-T6) Round Aluminum Tube in 12-ft Lengths

OD (in.)	***Wall Thickness*** *(in.)*	*stubs ga*	*ID (in.)*	***Approx Weight (lb)*** *per ft*	*per length*
3/16	0.035	no. 20	0.117	0.019	0.228
	0.049	no. 18	0.089	0.025	0.330
1/4	0.035	no. 20	0.180	0.027	0.324
	0.049	no. 18	0.152	0.036	0.432
	0.058	no. 17	0.134	0.041	0.492
5/16	0.035	no. 20	0.242	0.036	0.432
	0.049	no. 18	0.214	0.047	0.564
	0.058	no. 17	0.196	0.055	0.660
3/8	0.035	no. 20	0.305	0.043	0.516
	0.049	no. 18	0.277	0.060	0.720
	0.058	no. 17	0.259	0.068	0.816
	0.065	no. 16	0.245	0.074	0.888
7/16	0.035	no. 20	0.367	0.051	0.612
	0.049	no. 18	0.339	0.070	0.840
	0.065	no. 16	0.307	0.089	1.068
1/2	0.028	no. 22	0.444	0.049	0.588
	0.035	no. 20	0.430	0.059	0.708
	0.049	no. 18	0.402	0.082	0.948
	0.058	no. 17	0.384	0.095	1.040
	0.065	no. 16	0.370	0.107	1.284
5/8	0.028	no. 22	0.569	0.061	0.732
	0.035	no. 20	0.555	0.075	0.900
	0.049	no. 18	0.527	0.106	1.272
	0.058	no. 17	0.509	0.121	1.452
	0.065	no. 16	0.495	0.137	1.644
3/4	0.035	no. 20	0.680	0.091	1.092
	0.049	no. 18	0.652	0.125	1.500
	0.058	no. 17	0.634	0.148	1.776
	0.065	no. 16	0.620	0.160	1.920
	0.083	no. 14	0.584	0.204	2.448
7/8	0.035	no. 20	0.805	0.108	1.308
	0.049	no. 18	0.777	0.151	1.810
	0.058	no. 17	0.759	0.175	2.100
	0.065	no. 16	0.745	0.199	2.399
1	0.035	no. 20	0.930	0.123	1.467
	0.049	no. 18	0.902	0.170	2.040
	0.058	no. 17	0.884	0.202	2.424
	0.065	no. 16	0.870	0.220	2.640
	0.083	no. 14	0.834	0.281	3.372
1 1/8	0.035	no. 20	1.055	0.139	1.668
	0.058	no. 17	1.009	0.228	2.736
1 1/4	0.035	no. 20	1.180	0.155	1.860
	0.049	no. 18	1.152	0.210	2.520
	0.058	no. 17	1.134	0.256	3.072
	0.065	no. 16	1.120	0.284	3.408
	0.083	no. 14	1.084	0.357	4.284
1 3/8	0.035	no. 20	1.305	0.173	2.076
	0.058	no. 17	1.259	0.282	3.384
1 1/2	0.035	no. 20	1.430	0.180	2.160
	0.049	no. 18	1.402	0.260	3.120
	0.058	no. 17	1.384	0.309	3.708
	0.065	no. 16	1.370	0.344	4.128
	0.083	no. 14	1.334	0.434	5.208
	*0.125	1/8"	1.250	0.630	7.416
	*0.250	1/4"	1.000	1.150	14.823
1 5/8	0.035	no. 20	1.555	0.206	2.472
	0.058	no. 17	1.509	0.336	4.032
1 3/4	0.058	no. 17	1.634	0.363	4.356
	0.083	no. 14	1.584	0.510	6.120
1 7/8	0.508	no. 17	1.759	0.389	4.668
2	0.049	no. 18	1.902	0.350	4.200
	0.065	no. 16	1.870	0.450	5.400
	0.083	no. 14	1.834	0.590	7.080
	*0.125	1/8"	1.750	0.870	9.960
	*0.250	1/4"	1.500	1.620	19.920
2 1/4	0.049	no. 18	2.152	0.398	4.776
	0.065	no. 16	2.120	0.520	6.240
	0.083	no. 14	2.084	0.660	7.920
2 1/2	0.065	no. 16	2.370	0.587	7.044
	0.083	no. 14	2.334	0.740	8.880
	*0.125	1/8"	2.250	1.100	12.720
	*0.250	1/4"	2.000	2.080	25.440
3	0.065	no. 16	2.870	0.710	8.520
	*0.125	1/8"	2.700	1.330	15.600
	*0.250	1/4"	2.500	2.540	31.200

*These sizes are extruded; all other sizes are drawn tubes.
Shown here are standard sizes of aluminum tubing that are stocked by most aluminum suppliers or distributors in the United States and Canada.

Fig 22.66 shows several methods of fastening antenna element sections together. The slot and hose clamp method shown in Fig 22.66A is probably the best for joints where adjustments are needed. Generally, one adjustable joint per element half is sufficient to tune the antenna—usually the tips at each end of an element are made adjustable. Stainless steel hose clamps (beware—some "stainless steel" models do not have a stainless screw and will rust) are recommended for longest antenna life.

Fig 22.66B, C and D show possible fastening methods for joints that are not adjustable. At B, machine screws and nuts hold the elements in place. At C, sheet metal screws are used. At D, rivets secure the tubing. If the antenna is to be assembled permanently, rivets are the best choice. Once in place, they are permanent. They will never work free, regardless of vibration or wind. If aluminum rivets with aluminum mandrels are employed, they will never rust. Also, being aluminum, there is no danger of corrosion from interaction between dissimilar metals. If the antenna is to be disassembled and moved periodically, either B or C will work. If machine screws are used, however, take precautions to keep the nuts from vibrating free. Use of lock washers, lock nuts and flexible adhesive such as silicone bathtub sealant will keep the hardware in place.

Use of a conductive grease at the element joints is essential for long life. Left untreated, the aluminum surfaces will oxidize in the weather, resulting in a poor connection. Some trade names for this conductive grease are Penetrox, Noalox and Dow Corning Molykote 41. Many electrical supply houses carry these products.

BOOM MATERIAL

The boom size for a rotatable Yagi or quad should be selected to provide stability to the entire system. The best diameter for the boom depends on several factors, but mostly the element weight, number of elements and overall length. Two-inch-diameter booms should not be made any longer than 24 ft unless additional support is given to reduce both vertical and horizontal bending forces. Suitable reinforcement for a long 2-inch boom can consist of a truss or a truss and lateral support, as shown in **Fig 22.69**.

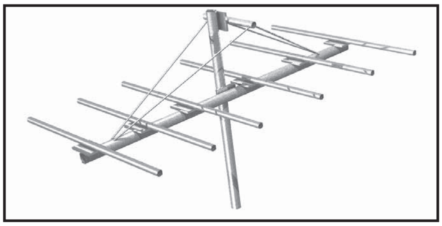


Fig 22.69 — A long boom needs both vertical and horizontal support. The crossbar mounted above the boom can support a double truss, which will help keep the antenna in position.

A boom length of 24 ft is about the point where a 3-inch diameter begins to be very worthwhile. This dimension provides a considerable amount of improvement in overall mechanical stability as well as increased clamping surface area for element hardware. The latter is extremely important to prevent rotation of elements around the boom if heavy icing is commonplace. Pinning an element to the boom with a large bolt helps in this regard. On smaller diameter booms, however, the elements sometimes work loose and tend to elongate the pinning holes in both the element and the boom. After some time the elements shift their positions slightly (sometimes from day to day) and give a ragged appearance to the system, even though this may not harm the electrical performance.

A 3-inch-diameter boom with a wall thickness of 0.065 inch is very satisfactory for antennas up to about a 5-element, 20-m array that is spaced on a 40-ft boom. A truss is recommended for any boom longer than 24 ft. One possible source for large boom material is irrigation tubing sold at farm supply houses.

PUTTING IT TOGETHER

Once you assemble the boom and elements, the next step is to fasten the elements to the boom securely and then fasten the boom to the mast or supporting structure. Be sure to leave plenty of material on either side of the U-bolt holes on the element-to-boom mounting plates. The U-bolts selected should be a snug fit for the tubing. If possible, buy muffler-clamp U-bolts that come with saddles.

The boom-to-mast plate shown in Fig 22.67B is similar to the boom-to-element plate. The size of the plate and number of U-bolts used will depend on the size of the antenna. Generally, antennas for the bands up through 20 m require only two U-bolts each for the mast and boom. Longer antennas for 15 and 20 m (35-ft booms and up) and most 40-m beams should have four U-bolts each for the boom and mast because of the torque that the long booms and elements exert as the antennas move in the wind. When tightening the U-bolts, be careful not to crush the tubing. Once the wall begins to collapse, the connection begins to weaken. Many aluminum suppliers sell 1/4-inch or 3/8-inch plates just right for this application. Often they will shear pieces to the correct size on request. As with tubing, the relatively hard 6061-T6 grade is a good choice for mounting plates.

The antenna should be put together with good-quality hardware. Stainless steel is best for long life. Rust will attack plated steel hardware after a short while, making nuts difficult, if not impossible, to remove. If stainless muffler clamps are not available, the next best thing is to have them plated. If you can't get them plated, then at least paint them with a good zinc-chromate primer and a finish coat or two. Good-quality hardware is more expensive initially, but if you do it right the first time, you won't have to take the antenna down after a few years and replace the hardware. Also, when repairing or modifying an installation, nothing is more frustrating than fighting rusty hardware at the top of a tower.

Quad Antennas

One of the more effective DX arrays is called a *quad* antenna. It consists of two or more loops of wire, each supported by a bamboo or fiberglass cross-arm assembly. The loops are a quarter wavelength per side (full wavelength overall). One loop is driven and the other serves as a parasitic element—usually a reflector. A variation of the quad is called the *delta loop*. The electrical properties of both antennas are the same. Both antennas are shown in **Fig 22.70**. They differ mainly in their physical properties, one being of plumber's delight construction, while the other uses insulating support members. One or more directors can be added to either antenna if additional gain and directivity are desired, though most operators use the 2-element arrangement.

It is possible to interlace quads or deltas for two or more bands, but if this is done the formulas given in Fig 22.70 may have to be changed slightly to compensate for the proximity effect of the second antenna. For quads the length of the full-wave loop can be computed from

$$\text{Full-wave loop} = \frac{1005}{\text{f (MHz)}}\ \text{ft} \qquad (7)$$

If multiple arrays are used, each antenna should be tuned separately for maximum forward gain, or best front-to-rear ratio, as observed on a field-strength meter. The reflector stub on the quad should be adjusted for this condition. The gamma match should be adjusted for best SWR. The resonance of the antenna can be found by checking the frequency at which the lowest SWR occurs. By lengthening or shortening it, the driven element length can be adjusted for resonance in the most-used portion of the band.

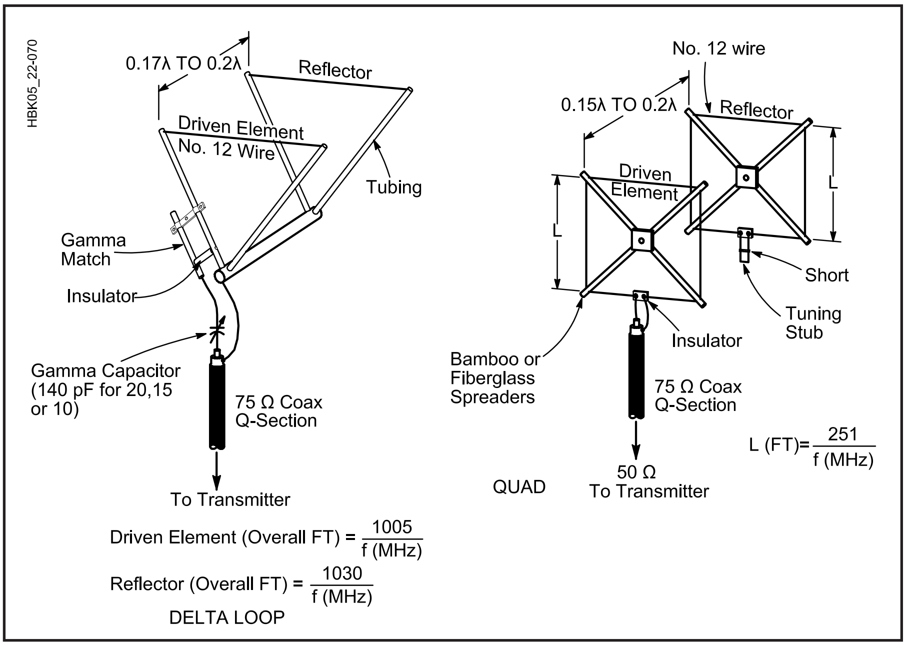


Fig 22.70 — Information on building a quad or a delta-loop antenna. The antennas are electrically similar, but the delta-loop uses plumber's delight construction. The $\lambda/4$ length of 75-Ω coax acts as a Q-section transformer from approximate 100-Ω feedpoint impedance of quad to 50-Ω feed line coax.

A FIVE-BAND, TWO-ELEMENT HF QUAD

Two quad designs are described in this article, both nearly identical. One was constructed by KC6T from scratch, and the other was built by Al Doig, W6NBH, using modified commercial triband quad hardware. The principles of construction and adjustment are the same for both models, and the performance results are also essentially identical. One of the main advantages of this design is the ease of (relatively) independent performance adjustments for each of the five bands. These quads were described by William A. Stein, KC6T, in *QST* for April 1992. Both models use 8-ft-long, 2-inch diameter booms, and conventional X-shaped spreaders (with two sides of each quad loop parallel to the ground).

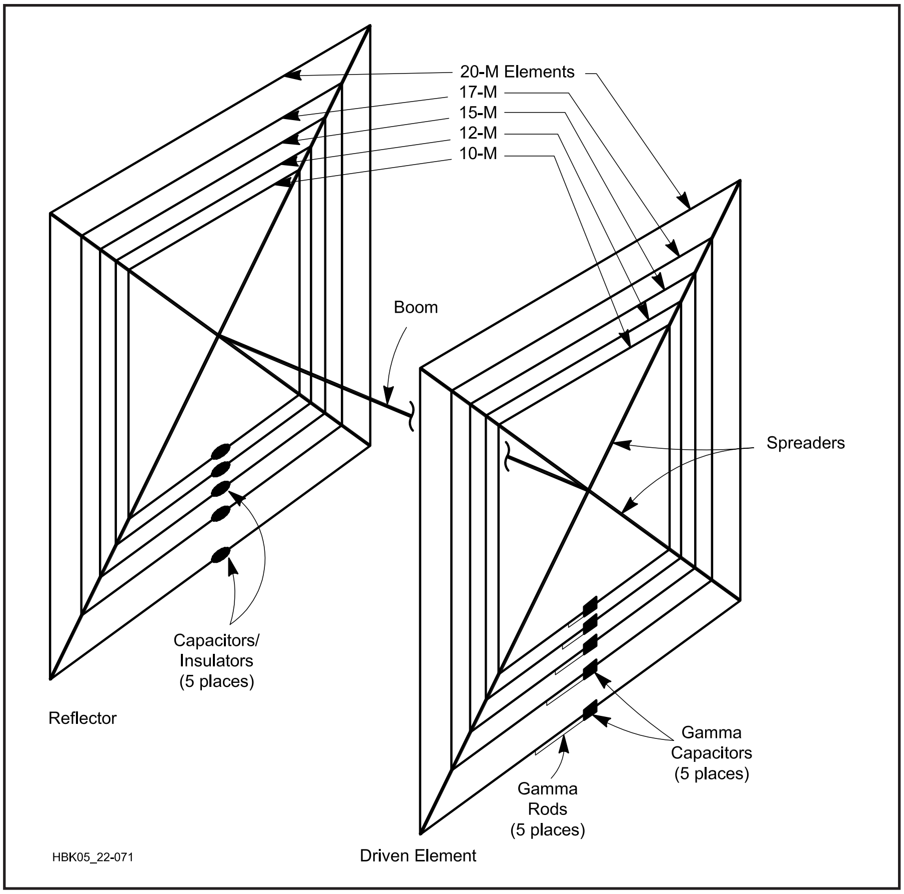


Fig 22.71 — Mechanical layout of the five-band quad. The boom is 8 ft long; see Table 22.19 for all other dimensions.

THE FIVE-BAND QUAD AS A SYSTEM

Unless you are extraordinarily lucky, you should remember one general rule: Any quad must be adjusted for maximum performance after assembly. Simple quad designs can be tuned by pruning and restringing the elements to control front-to-rear ratio and SWR at the desired operating frequency. Since each element of this quad contains five concentric loops, this adjustment method could lead to a nervous breakdown!

Fig 22.71 shows that the reflectors and driven elements are each independently adjustable. After assembly, adjustment is simple, and although gamma-match components on the driven element and capacitors on the reflectors add to the antenna's parts count, physical construction is not difficult. The reflector elements are purposely cut slightly long (except for the 10-m reflector), and electrically shortened by a tuning capacitor. The driven-element gamma matches set the lowest SWR at the desired operating frequency.

As with most multiband directive antennas, the designer can optimize any two of the following three attributes at the expense of the third: forward gain, front-to-rear ratio and bandwidth (where the SWR is less than 2:1). These three characteristics are related, and changing one changes the other two. The basic idea behind this quad design is to permit (without resorting to trimming loop lengths, spacing or other gross mechanical adjustments):

- The forward gain, bandwidth and front-to-rear ratio may be set by a simple adjustment after assembly. The adjustments can be made on a band-by-band basis, with little or no effect on previously made adjustments on the other bands.
- Setting the minimum SWR in any portion of each band, with no interaction with previously made front-to-back or SWR adjustments.

The first of the two antennas described, the KC6T model, uses aluminum spreaders with PVC insulators at the element attachment points. (The author elected not to use fiberglass spreaders because of their high cost.) The second antenna, the W6NBH model, provides dimensions and adjustment values for the same antenna, but using standard triband-quad fiberglass spreaders and hardware. If you have a triband quad, you can easily adapt it to this design. When W6NBH built his antenna, he had to shorten the 20-m reflector because the KC6T model uses a larger 20-m reflector than W6NBH's fiberglass spreaders would allow. Performance is essentially identical for both models.

MECHANICAL CONSIDERATIONS

Even the best electrical design has no value if its mechanical construction is lacking. Here are some of the things that contribute to mechanical strength: The gamma-match capacitor KC6T used was a small, air-variable, chassis-mount capacitor mounted in a plastic box (see **Fig 22.72**). A male UHF connector was mounted to the box, along with a screw terminal for connection to the gamma rod.

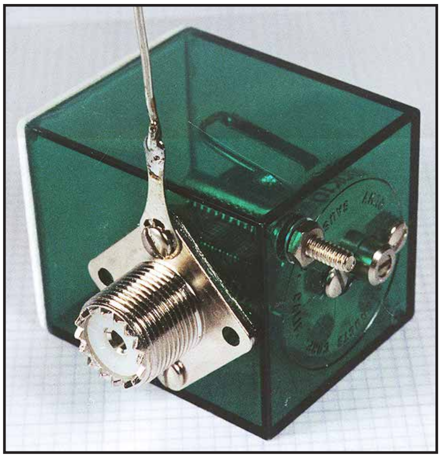


Fig 22.72 — Photo of one of the feed-point gamma-match capacitors.

The terminal lug and wire are for later connection to the driven element. The box came from a local hobby shop, and the box lid was replaced with a piece of 1/32-inch ABS plastic, glued in place after the capacitor, connector and wiring had been installed. The capacitor can be adjusted with a screwdriver through an access hole. Small vent (drain) holes were drilled near corresponding corners of each end.

Enclose the gamma-match capacitor in such a manner that you can tape unwanted openings closed so that moisture can't be directly blown in during wind and rainstorms. Also, smaller boxes and sturdy mounts to the driven element ensure that you won't pick up gamma capacitor assemblies along with the leaves after a wind storm.

Plastic gamma-rod insulators/standoffs were made from 1/32-inch ABS, cut 1/2-inch wide with a hole at each end. Use a knife to cut from the hole to the side of each insulator so that one end can be slipped over the driven element and the other over the gamma rod. Use about four such insulators for each gamma rod, and mount the first insulator as close to the capacitor box as possible. Apply five-minute epoxy to the element and gamma rod at the insulator hole to keep the insulators from sliding. If you intend to experiment with gamma-rod length, perform this gluing operation after you have made the final gamma-rod adjustments.

ELEMENT INSULATORS

As shown in Fig 22.71, the quad uses insulators in the reflectors for each band to break the loop electrically, and to allow reflector adjustments. Similar insulators were used to break up each driven element so that element impedance measurements could be made with a noise bridge. After the impedance measurements, the driven-element loops are closed again. The insulators are made from 1/4 × 2 × 3/4-inch phenolic stock. The holes are 1/2-inch apart. Two terminal lugs (shorted together at the center hole) are used in each driven element. They offer a convenient way to open the loops by removing one screw. **Fig 22.73** shows these insulators and the gamma-match construction schematically. **Table 22.19** lists the component values, element lengths and gamma-match dimensions.

ELEMENT-TO-SPREADER ATTACHMENT

Probably the most common problem with quad antennas is wire breakage at the element-to-spreader attachment points. There are a number of functional attachment methods; **Fig 22.74** shows one of them. The attachment method with both KC6T and W6NBH spreaders is the same, even though the spreader constructions differ. The KC6T model uses #14 AWG, 7-strand copper wire; W6NBH used #18, 7-strand wire. At the point of element attachment (see **Fig 22.75**), drill a hole through both walls of the spreader using a #44 (0.086-inch) drill. Feed a 24-inch-long piece of antenna wire through the hole and center it for use as an attachment wire.

After fabricating the spider/spreader assembly, lay the completed assembly on a flat surface and cut the element to be installed to the correct length, starting with the 10-m element. Attach the element ends to the insulators to form a closed loop before attaching the elements to the spreaders. Center the insulator between the spreaders on what will become the bottom side of the quad loop, then carefully measure and mark the element-mounting-points with fingernail polish (or a similar substance). Do *not* depend on the at-rest position of the spreaders to guarantee that the mounting points will all be correct.

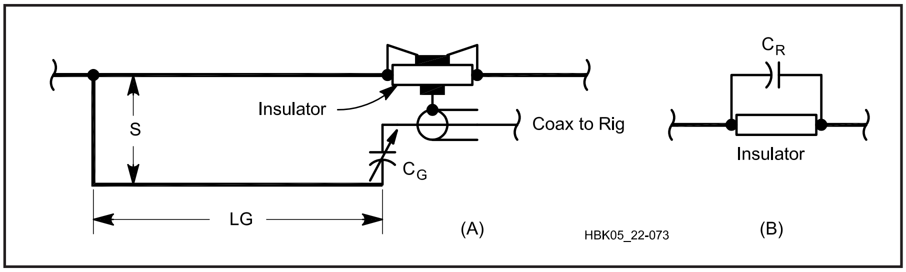


Fig 22.73 — Gamma-match construction details at A and reflector-tuning capacitor (C_R) attachment schematic at B. The gamma matches consist of matching wires (one per band) with series capacitors (C_g). See Table 22.19 for lengths and component specifications.

Table 22.19

Element Lengths and Gamma-Match Specifications of the KC6T and W6NBH Five-Band Quads

KC6T Model

Band (MHz)	Driven Element	Length (in.)	Gamma Match Spacing	Gamma Match C_g(pF)	Reflector Length (in.)	C_R (pF)
14	851.2	33	2	125	902.4	68
18	665.6	24	2	110	705.6	47
21	568	24	1.5	90	604.8	43
24.9	483.2	29.75	1	56	514.4	33
28	421.6	26.5	1	52	448.8	(jumper)

W6NBH Model

Band (MHz)	Driven Element	Length (in.)	Gamma Match Spacing	Gamma Match C_g(pF)	Reflector Length (in.)	C_R (pF)
14	851.2	31	2	117	890.4	120
18	665.6	21	2	114	705.6	56
21	568	26	1.5	69	604.8	58
24.9	483.2	15	1	75.5	514.4	54
28	421.6	18	1	41	448.8	(jumper)

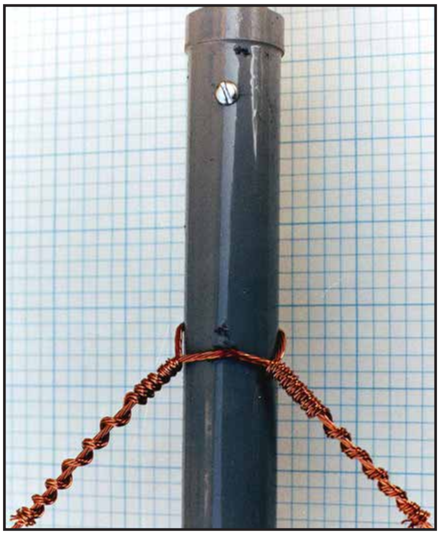
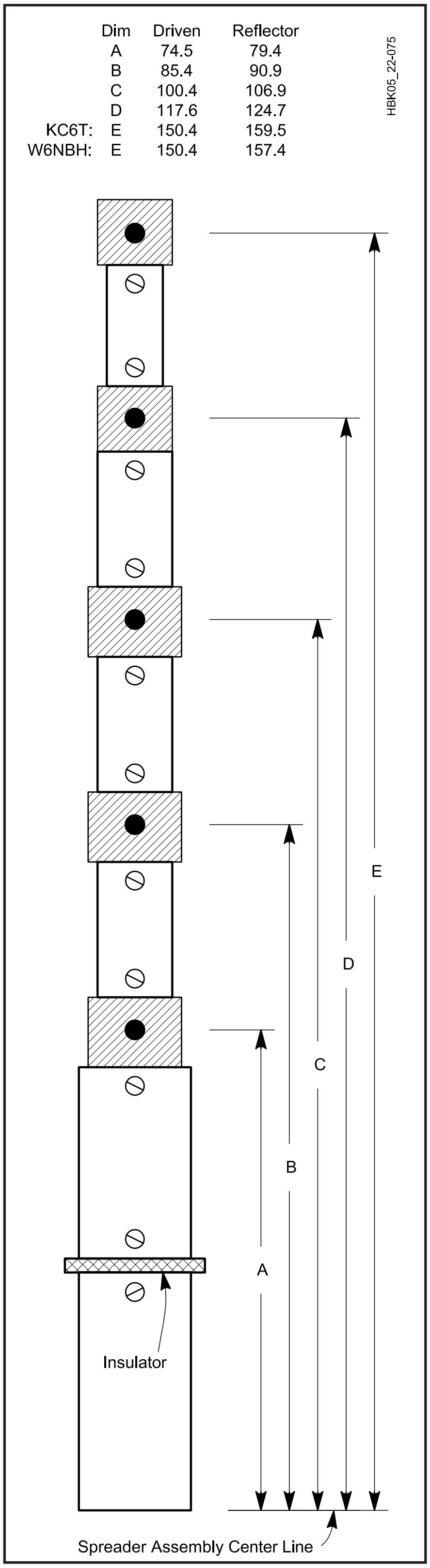


Fig 22.74 — Attaching quad wires to the spreaders must minimize stress on the wires for best reliability. This method (described in the text) cuts the chances of wind-induced wire breakage by distributing stress.



Dim	Driven	Reflector
A	74.5	79.4
B	85.4	90.9
C	100.4	106.9
D	117.6	124.7
KC6T: E	150.4	159.5
W6NBH: E	150.4	157.4

Fig 22.75 — Spreader-drilling diagram and dimensions (in.) for the five-band quad. These dimensions apply to both spreader designs described in the text, except that most commercial spreaders are only a bit over 13 ft (156 inches) long. This requires compensation for the W6NBH model's shorter 20-m reflector as described in the text.

Holding the mark at the centerline of the spreader, tightly loop the attachment wire around the element and then gradually space out the attachment-wire turns as shown. The attachment wire need not be soldered to the element. The graduated turn spacing minimizes the likelihood that the element wire will flex in the same place with each gust of wind, thus reducing fatigue-induced wire breakage.

FEEDING THE DRIVEN ELEMENTS

Each driven element is fed separately, but feeding five separate feed lines down the tower and into the shack would be costly and mechanically difficult. The ends of each of these coax lines also require support other than the tension (or lack of thereof) provided by the driven element at the feed-point. It is best to use a remote coax switch on the boom approximately 1 ft from the driven-element spider-assembly attachment point.

At installation, the cables connecting the gamma-match capacitors and the coax switch help support the driven elements and gamma capacitors. The support can be improved by taping the cables together in several places. A single coaxial feed line (and a control cable from the remote coax switch, if yours requires one) is the only required cabling from the antenna to the shack.

THE KC6T MODEL'S COMPOSITE SPREADERS

If you live in an area with little or no wind, spreaders made from wood or PVC are practical but, if you live where winds can reach 60 to 80 mi/h, strong, lightweight spreaders are a must. Spreaders constructed with electrical conductors (in this case, aluminum tubing) can cause a myriad of problems with unwanted resonances, and the problem gets worse as the number of bands increases.

To avoid these problems, this version uses composite spreaders made from machined PVC insulators at the element-attachment points. Aluminum tubing is inserted into (or over) the insulators 2 inches on each end. This spreader is designed to withstand 80 mi/h winds. The overall insulator length is designed to provide a 3-inch center insulator clear of the aluminum tubing. The aluminum tubing used for the 10-m section (inside dimension "A" in Fig 22.75) is $1\frac{1}{8}$-inch diameter × 0.058-inch wall. The next three sections are $\frac{3}{4}$-inch diameter × 0.035-inch wall, and the outer length is made from $\frac{1}{2}$-inch diameter × 0.035-inch wall. The dimensions shown in Fig 22.75 are *attachment point* dimensions only.

Attach the insulators to the aluminum using #6 sheet metal screws. Mechanical strength is provided by Devcon no. S 220 Plastic Welder Glue (or equivalent) applied liberally as the aluminum and plastic parts are joined. Paint the PVC insulators before mounting the elements to them. Paint protects the PVC from the harmful effects of solar radiation. As you can see from Fig 22.75, an additional spreader insulator located about halfway up the 10-m section (inside dimension "A") removes one of the structure's electrical resonances not eliminated by the attachment-point insulators. Because it mounts at a relatively high-stress point in the spreader, this insulator is fabricated from a length of heavy-wall fiberglass tubing.

Composite spreaders work as well as fiberglass spreaders, but require access to a well-equipped shop, including a lathe. The main objective of presenting the composite spreader is to show that fiberglass spreaders aren't a basic requirement—there are many other ways to construct usable spreaders. If you can lay your hands on a used multiband quad, even one that's damaged, you can probably obtain enough spreaders to reduce construction costs considerably.

GAMMA ROD

The gamma rod is made from a length of #12 solid copper wire (W6NBH used #18, 7-strand wire). Dimensions and spacings are shown in Table 22.19. If you intend to experiment with gamma-rod lengths and capacitor settings, cut the gamma-rod lengths about 12 inches longer than the length listed in the table. Fabricate a sliding short by soldering two small alligator clips back-to-back such that they can be clipped to the rod and the antenna element and easily moved along the driven element. Note that gamma-rod spacing varies from one band to another. When you find a suitable shorting-clip position, mark the gamma rod, remove the clip, bend the gamma rod at the mark and solder the end to the element.

THE W6NBH MODEL

As previously mentioned, this model uses standard 13-ft fiberglass spreaders, which aren't quite long enough to support the larger 20-m reflector specified for the KC6T model. The 20-m W6NBH reflector loop is cut to the dimensions shown in Table 22.19, 12 inches shorter than that for the KC6T model. To tune the shorter reflector, a 6-inch-long stub of antenna wire (spaced 2 inches) hangs from the reflector insulator, and the reflector tuning capacitor mounts on another insulator at the end of this stub.

GAMMA-MATCH AND REFLECTOR-TUNING CAPACITOR

Use an air-variable capacitor of your choice for each gamma match. Approximately 300 V can appear across this capacitor (at 1500 W), so choose plate spacing appropriately. If you want to adjust the capacitor for best match and then replace it with a fixed capacitance, remember that several amperes of RF will flow through the capacitance. If you choose disc-ceramic capacitors, use a parallel combination of at least four 1-kV units of equal value. Any temperature coefficient is acceptable. NP0 units are not required. Use similar components to tune the reflector elements.

ADJUSTMENTS

Well, here you are with about 605 ft of wire. Your antenna will weigh about 45 pounds (the W6NBH version is slightly lighter) and have about 9 square ft of wind area. If you chose to, you can use the dimensions and capacitance values given, and performance should be excellent. If you adjust the antenna for minimum SWR at the band centers, it should cover all of the lower four bands and 28 to 29 MHz with SWRs under 2:1; front-to-rear ratios are given in **Table 22.20**.

Table 22.20
Measured Front-to-Rear Ratios

Band	*KC6T Model*	*W6NBH Model*
14	25 dB	16 dB
18	15 dB	10 dB
21	25 dB	>20 dB
24.9	20 dB	>20 dB
28	20 dB	>20 dB

Instead of building the quad to the dimensions listed and hoping for the best, you can adjust your antenna to account for most of the electrical environment variables of your installation. The adjustments are conceptually simple: First adjust the reflector's electrical length for maximum front-to-rear ratio (if you desire good gain, and are willing to settle for a narrower than maximum SWR bandwidth), or accept some compromise in front-to-rear ratio that results in the widest SWR bandwidth. You can make this adjustment by placing an air-variable capacitor (about 100-pF maximum) across the open reflector loop ends, one band at a time, and adjusting the capacitor for the desired front-to-rear ratio. The means of doing this will be discussed later.

During these reflector adjustments, the driven-element gamma-match capacitors may be set to any value and the gamma rods may be any convenient length (but the sliding-short alligator clips should be installed somewhere near the lengths specified in Table 22.19). After completing the front-to-rear adjustments, the gamma capacitors and rods are adjusted for minimum SWR at the desired frequency.

ADJUSTMENT SPECIFICS

Adjust each band by feeding it separately. You can make a calibrated variable capacitor (with a hand-drawn scale and wire pointer). Calibrate the capacitor using your receiver, a known-value inductor and a dip meter (plus a little calculation).

To adjust front-to-rear ratio, simply clip the (calibrated) air-variable capacitor across the open ends of the desired reflector loop. Connect the antenna to a portable receiver with an S meter. Point the back of the quad at a signal source, and slowly adjust the capacitor for a dip in the S-meter reading.

After completing the front-to-rear adjustments, replace the variable capacitor with an appropriate fixed capacitor sealed against the weather. Then move to the driven-element adjustments. Connect the coax through the SWR bridge to the 10-m gamma-match capacitor box. Use an SWR bridge that requires only a watt or two (not more than 10 W) for full-scale deflection in the calibrate position on 10 m. Using the minimum necessary power, measure the SWR. Go back to receive and adjust the capacitor until (after a number of transmit/receive cycles) you find the minimum SWR. If it is too high, lengthen or shorten the gamma rod by means of the sliding alligator-clip short and make the measurements again.

Stand away from the antenna when making transmitter-on measurements. The adjustments have minimal effect on the previously made front-to-rear settings, and may be made in any band order. After making all the adjustments and sealing the gamma capacitors, reconnect the coax harness to the remote coax switch.

A SIMPLE QUAD FOR 40 METERS

Many amateurs yearn for a 40-m antenna with more gain than a simple dipole. While two-element rotary 40-m beams are available commercially, they are costly and require fairly hefty rotators to turn them. This low-cost, single-direction quad is simple enough for a quick Field Day installation, but will also make a home station very competitive on the 40-m band.

This quad uses a 2-inch outside diameter, 18-ft boom, which should be mounted no less than 60 ft high, preferably higher. (Performance tradeoffs with height above ground will be discussed later.) The basic design is derived from the N6BV 75/80-meter quad described in *The ARRL Antenna Compendium, Vol 5*. However, since this simplified 40-m version is unidirectional and since it covers only one portion of the band (CW or Phone, but not both), all the relay-switched components used in the larger design have been eliminated.

The layout of the simple 40-m quad at a boom height of 70 ft is shown in **Fig 22.76**. The wires for each element are pulled out sideways from the boom with black $^{1}/_{8}$-inch Dacron rope designed specifically to withstand both abrasion and UV radiation. The use of the proper type of rope is very important—using a cheap substitute is not a good idea. You will not enjoy trying to retrieve wires that have become, like Charlie Brown's kite, hopelessly entangled in nearby trees, all because a cheap rope broke during a windstorm! At a boom height of 70 ft, the quad requires a *wingspread* of 140 ft for the side ropes. This is the same wingspread needed by an inverted-V dipole at the same apex height with a 90° included angle between the two legs.

The shape of each loop is rather unusual, since the bottom ends of each element are brought back close to the supporting tower. (These element ends are insulated from the tower and from each other). Having the elements near the tower makes fine-tuning adjustments much easier—after all, the ends of the loop wires are not 9 feet out, on the ends of the boom! The feed-point resistance with this loop configuration is close to 50 Ω, meaning that no matching network is necessary. By contrast, a more conventional diamond or square quad-loop configuration exhibits about a 100-Ω resistance.

Another bonus to this loop configuration is that the average height above ground is higher, leading to a slightly lower angle of radiation for the array and less loss because the bottom of each element is raised higher above lossy ground. The drawback to this unusual layout is that

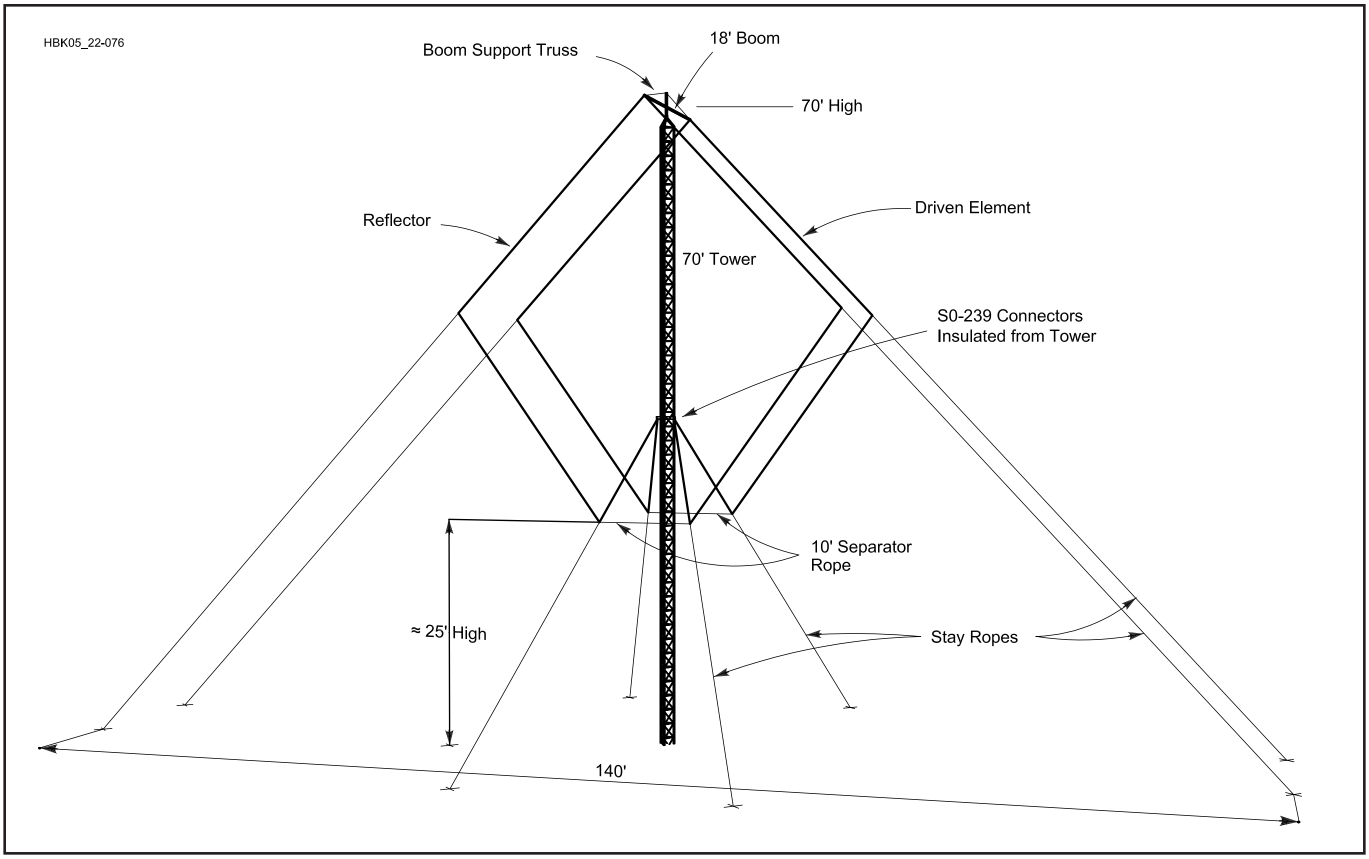


Fig 22.76 — Layout of 40-meter quad with a boom height of 70 feet. The four stay ropes on each loop pull out each loop into the desired shape. Note the 10-foot separator rope at the bottom of each loop, which helps it hold its shape. The feed line is attached to the driven element through a choke balun, consisting of 10 turns of coax in a 1-foot diameter loop. You could also use large ferrite beads over the feed-line coax, as explained in Chapter 21. Both the driven element and reflector loops are terminated in SO-239 connectors tied back to (but insulated from) the tower. The reflector SO-239 has a shorted PL-259 normally installed in it. This is removed during fine-tuning of the quad, as explained in the text.

four more *tag-line* stay ropes are necessary to pull the elements out sideways at the bottom, pulling against the 10-foot separator ropes shown in Fig 22.76.

CONSTRUCTION

You must decide before construction whether you want coverage on CW (centered on 7050 kHz) or on Phone (centered on 7225 kHz), with roughly 120 kHz of coverage between the 2:1 SWR points. If the quad is cut for the CW portion of the band, it will have less than about a 3.5:1 SWR at 7300 kHz, as shown in **Fig 22.77**. The pattern will deteriorate to about a 7 dB F/B at 7300 kHz, with a reduction in gain of almost 3 dB from its peak in the CW band. It is possible to use a quad tuned for CW in the phone band if you use an antenna tuner to reduce the SWR and if you can take the reduction in performance. To put things in perspective, a quad tuned for CW but operated in the phone band will still work about as well as a dipole.

Next, you must decide where you want to point the quad. A DXer or contester in the USA might want to point this single-direction design to cover Europe and North Africa. For Field Day, a group operating on the East Coast would simply point it west, while their counterparts on the West Coast would point theirs east.

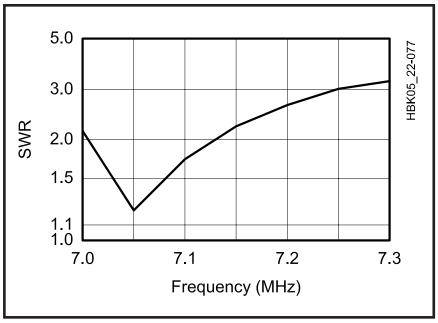
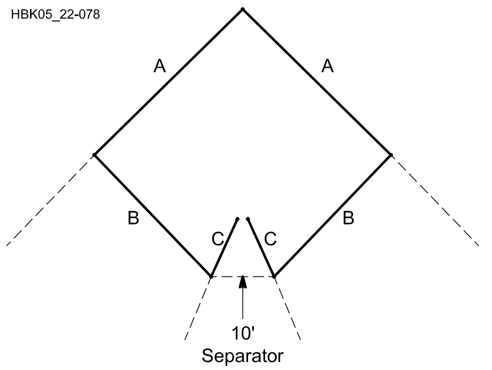


Fig 22.77 — Plot of SWR versus frequency for a quad tuned for CW operation.

The mechanical requirements for the boom are not severe, especially since a top truss support is used to relieve stress on the boom due to the wires pulling on it from below. The boom is 18 ft long, made of 2-inch diameter aluminum tubing. You can probably find a suitable boom from a scrapped triband or monoband Yagi. You will need a suitable set of U-bolts and a mounting plate to secure the boom to the face of a tower. Or perhaps you might use lag screws to mount the boom temporarily to a suitable tree on Field Day! On a 70-ft high tower, the loop wires are brought back to the tower at the 37.5-ft level and tied there using insulators and rope. The lowest points of the loops are located about 25 ft above ground for a 70-ft tower. **Fig 22.78** gives dimensions for the driven element and reflector for both the CW and the Phone portions of the 40-m band.

GUY WIRES

Anyone who has worked with quads knows they are definitely three-dimensional objects! You should plan your installation carefully, particularly if the supporting tower has guy wires, as most do. Depending on where the guys are located on the tower and the layout of the quad with reference to those guys, you will probably have to string the quad loops over



	7050 kHz, CW	*7200 kHz, SSB*
Length A, Reflector	31’6”	30’10$^{3}/_{4}$”
Length B, Reflector	28’2$^{1}/_{4}$”	27’7”
Length C, Reflector	15’7$^{1}/_{4}$”	15’
Total, Half Reflector	75’3$^{1}/_{2}$”	73’5$^{3}/_{4}$”
Resonant Frequency	7030 kHz	7205 kHz
Length A, Driven	30’7$^{1}/_{4}$”	30’
Length B, Driven	27’3$^{1}/_{2}$”	26’8$^{1}/_{2}$”
Length C, Driven	14’7$^{1}/_{2}$”	14’
Length, Half Driven	72’6$^{1}/_{4}$”	70’8$^{1}/_{2}$”
Self-Resonant Frequency	7295 kHz	7480 kHz

Fig 22.78 — Dimensions of each loop, for CW or Phone operation.

certain guys (probably at the top of the tower) and under other guys lower down.

It is very useful to view the placement of guy wires using the VIEW ANTENNA function in the *EZNEC* modeling program. This allows you to visualize the 3-D layout of an antenna. You can ROTATE yourself around the tower to view various aspects of the layout. *EZNEC* will complain about grounding wires directly but will still allow you to use the View Antenna function. Note also that it is best to insulate guy wires to prevent interaction between them and the antennas on a tower, but this may not be necessary for all installations.

FINE TUNING, IF NEEDED

We specify stranded #14 hard-drawn copper wire for the elements. During the course of installation, however, the loop wires could possibly be stretched a small amount as you pull and yank on them, trying to clear various obstacles. This may shift the frequency response and the performance slightly, so it is useful to have a tuning procedure for the quad when it is finally up in the air.

The easiest way to fine-tune the quad while on the tower is to use a portable, battery-operated SWR indicator (such as the Autek RF-1 or the MFJ-259) to adjust the reflector and the driven element lengths for specific resonant frequencies. You can eliminate the influence of mutual coupling to the other element by open-circuiting the other element.

For convenience, each quad loop should be connected to an SO-239 UHF female connector that is insulated from but tied close to the tower. You measure the driven element’s resonant frequency by first removing the shorted PL-259 normally inserted into the reflector connector. Similarly, the reflector’s resonant frequency can be determined by removing the feed line normally connected to the driven element’s feed point.

Obviously, it’s easiest if you start out with extra wire for each loop, perhaps 6 inches extra on each side of the SO-239. You can then cut off wire in $^{1}/_{2}$-inch segments equally on each side of the connector. This procedure is easier than trying to splice extra wire while up on the tower. Alligator clips are useful during this procedure, but just don’t lose your hold on the wires! You should tie safety strings from each wire back to the tower. Prune the wire lengths to yield the resonant frequencies (±5 kHz) shown in Fig 22.78 and then solder things securely. Don’t forget to reinsert the shorted PL-259 into the reflector SO-239 connector to turn it back into a reflector.

HIGHER IS BETTER

This quad was designed to operate with the boom at least 60 ft high. However, it will work considerably better for DX work if you can put the boom up even higher. **Fig 22.79** shows the elevation patterns for four antennas: a reference inverted-V dipole at 70 ft (with a 90° included angle between the two legs), and three quads, with boom height of 70, 90 and 100 ft respectively. At an elevation angle of 20°, typical for DX work on 40 m, the quad at 100 ft has about a 5 dB advantage over an inverted-V dipole at 70 ft, and about a 3 dB advantage over a quad with a boom height of 70 ft.

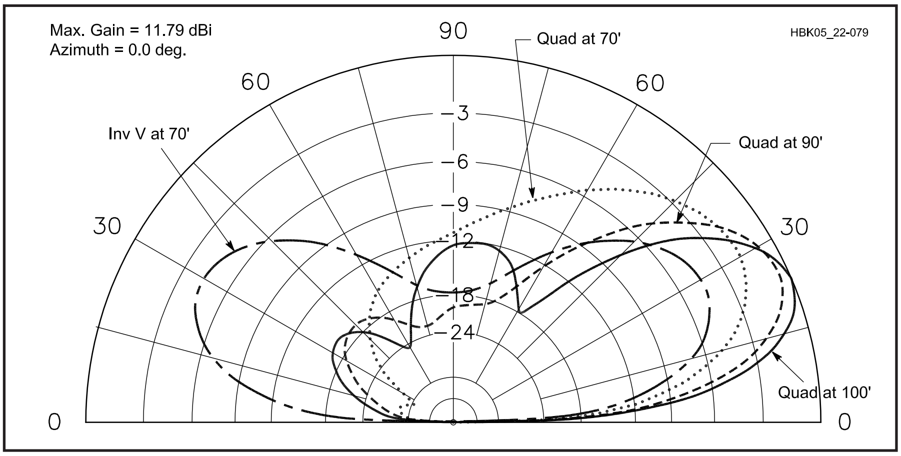


Fig 22.79 — Comparisons of the elevation patterns for quads at boom heights of 70, 90 and 100 ft, referenced to an inverted-V dipole at 70 ft.

A SIMPLE LOOP ANTENNA FOR 28 MHZ

With the large number of operators and wide availability of inexpensive, single-band radios, the 10-m band could well become the hangout for local ragchewers that it was before the advent of 2-m FM, even at a low point in the solar cycle.

This simple antenna provides gain over a dipole or inverted V. It is a resonant loop with a particular shape. It provides 2.1 dB gain over a dipole at low radiation angles when mounted well 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, and is less than 2:1 from 28.0-28.8 MHz for an antenna resonant at 28.4 MHz.

The antenna is made from #12 AWG wire (see **Fig 22.80**) and is fed at the center of the bottom wire. Coil the coax into a few turns near the feedpoint to provide a simple balun. A coil diameter of about a foot will work fine. You can support the antenna on a mast with spreaders made of bamboo, fiberglass, wood, PVC or other nonconducting material. You can also use aluminum tubing both for support and conductors, but you may have to readjust the antenna dimensions for resonance.

This rectangular loop has two advantages over a resonant square loop. First, a square loop has just 1.1 dB gain over a dipole. This is a power increase of only 29%. Second, the input impedance of a square loop is about 125 Ω. You must use a matching network to feed a square loop with 50-Ω coax. The rectangular loop achieves gain by compressing its radiation pattern in the elevation plane. The azimuth plane pattern is slightly wider 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 broad azimuth region.

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 30 ft high. The loop will work at lower heights, but its gain advantage disappears. For example, at 20 ft the loop provides the same gain at low angles as an inverted V.

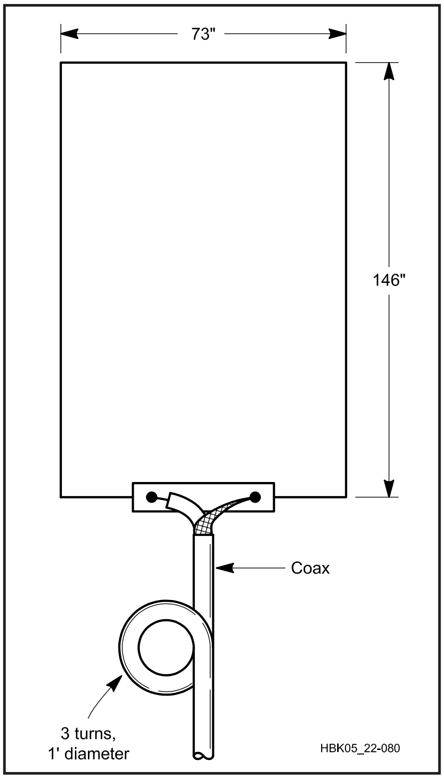


Fig 22.80 — Construction details of the 10-m rectangular loop antenna.

HF Mobile Antennas

This section is by Jack Kuecken, KE2QJ. Jack is an antenna engineer who has written a number of articles for ARRL publications.

An ideal HF mobile antenna is:

1. Sturdy. Stays upright at highway speeds.
2. Mechanically stable. Sudden stops or sharp turns do not cause it to whip about, endangering other vehicles.
3. Flexibly mounted. Permits springing around branches and obstacles at slow speeds.
4. Weatherproof. Handles the impact of wind, rain, snow and ice at high speed.
5. Tunable to all of the HF bands without stopping the vehicle.
6. Mountable without altering the vehicle in ways which lower the resale value.
7. Efficient as possible.
8. Easily removed for sending the car through a car wash, etc.

For HF mobile operation, the ham must use an electrically small antenna. The possibility that the antenna might strike a fixed object places a limitation on its height. On Interstate highways, an antenna tip at 11.5 feet above the pavement is usually no problem. However, on other roads you may encounter clearances of 9.5 or 10 feet. You should be able to easily *tie down* the antenna for a maximum height of about 7 feet to permit passage through low-clearance areas. The antenna should be usable while in the tied-down position.

If the base of an antenna is 1 ft above the pavement and the tip is at 11.5 ft, the length is 10.5 ft which is 0.1 λ at 9.37 MHz, and 0.25 λ at 23.4 MHz. That means that the antenna will require a matching network for all of the HF bands except 10 and 12 m.

The power radiated by the antenna is equal to the radiation resistance times the square of the antenna current. The radiation resistance of an electrically small antenna is given by:

$$Rr = 395 \times (h/\lambda)^2$$

where

h = radiator height in meters

λ = wavelength in meters = 300/Freq in MHz

The capacitance in pF of an electrically small antenna is given approximately by:

$$C = \frac{55.78 \times h}{((\text{den1}) \times (\text{den2}))}$$

where

(den1) = (ln(h/r)–1)

(den2) = (1 – (f × h/75)^2)

Table 22.21

Characteristics of a 10.5-foot whip antenna

F (MHz)	*C (pF)*	*Rr*	*Impedance*	*Efficiency*	*L (μH)*
1.8	30.1	0.146	13.72 –*j*2716	0.01064	240
3.5	30.6	0.55	7.43 –*j*1375	0.074	62.5
7	32.8	2.2	7.04 –*j*644	0.312	14.6
10	36.5	4.5	6.5 –*j*408	0.692	6.49
14	46.5	8.8	10 –*j*232	0.88	2.64

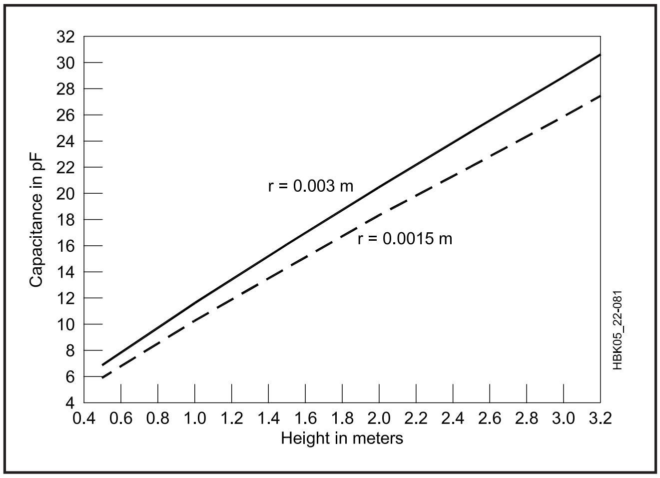


Fig 22.81 — Relationship at 3.5 MHz between vertical radiator length and capacitance. The two curves show that the capacitance is not very sensitive to radiator diameter.

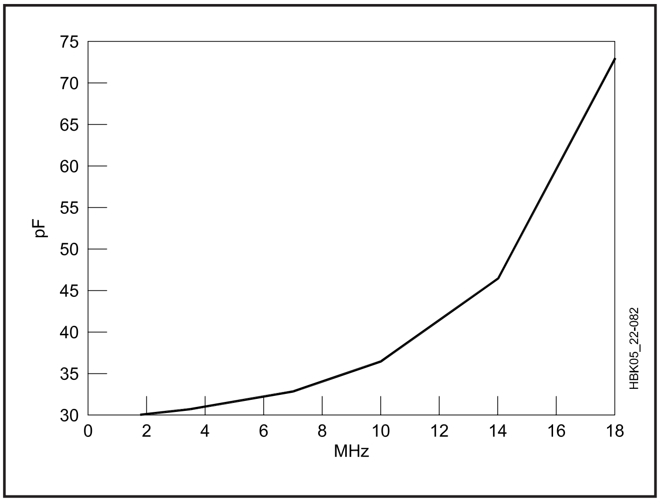


Fig 22.82 — Relationship between frequency and capacitance for a 3.2-meter vertical whip.

ln = natural logarithm
r = conductor radius in meters
f = frequency in MHz

Characteristics of a 10.5-ft (3.2 m) whip with a 0.003 m radius and, assuming a base loading coil with a Q of 200 and coil stray capacitance of 2 pF, are given in **Table 22.21**.

Radiation resistance rises in a nonlinear fashion and the capacitance drops just as dramatically with increase in the ratio h/λ. **Fig 22.81** shows the relationship of capacitance to height. This can be used for estimating antenna capacitance for other heights.

Fig 22.82 shows that capacitance is not very sensitive to frequency for h/λ less than 0.075, 8 MHz in this case. However, the sensitivity increases rapidly thereafter.

Table 22.21 shows that at 3.5 MHz an inductance of 62.5 µH will cancel the capacitive reactance. This results in an impedance of 7.43 Ω which means that additional matching is required. In this case the radiation efficiency of the system is only 0.074 or 7.4%. In other words, nearly 93% of energy at the terminals is wasted in heating the matching coil.

System Q is controlled by the Q of the coil. The bandwidth between 2:1 SWR points of the system = 0.36 × f/Q. In this case, bandwidth = 0.36 × 3.5/200 = 6.3 kHz

If we could double the Q of the coil, the efficiency would double and the bandwidth would be halved. The converse is also true. In the interest of efficiency, the highest possible Q should be used!

Another significant factor arises from the high Q. Let's assume that we deliver 100 watts to the 7.43 Ω at the antenna terminals. The current is 3.67 A and flows through the 1375-Ω reactance of the coil giving rise to 1375 × 3.67= 5046 VRMS (7137 Vpeak) across the coil.

With only 30.6 pF of antenna capacitance, the presence of significant stray capacitance at the antenna base shunts currents away from the antenna. RG-58 has about 21 pF/foot. A 1.5-foot length would halve the radiation efficiency of our example antenna. For cases like the whip at 3.5 MHz, the matching network has to be right at the antenna!

BASE, CENTER OR DISTRIBUTED LOADING

There is no clear-cut advantage in terms of radiation performance for either base or center-loaded antennas for HF mobile. Antennas with distributed (or continuous) loading have appeared in recent use. How do they compare?

Base Loading

In the design procedure, one estimates the capacitance, capacitive reactance and radiation resistance as shown previously. One then calculates the expected loss resistance of the loading coil required to resonate the antenna. There is generally additional resistance amounting to about half of the coil loss which must be added in. As a practical matter, it is usually not possible to achieve a coil Q in excess of 200 for such applications.

Using the radiation resistance plus 1.5 times the coil loss and the power rating desired for the antenna, one may select the wire size. For high efficiency coils, a current density of 1000 A/inch^2 is a good compromise. For the 3.67 A of the example we need a wire 0.068-inch diameter, which roughly corresponds to #14 AWG. Higher current densities can lead to a melted coil.

Design the coil with a pitch equal to twice the wire diameter and the coil diameter approximately equal to the coil length. These proportions lead to the highest Q in air core coils.

The circuit of **Fig 22.83** will match essentially all practical HF antennas on a car or truck. The circuit actually matches the antenna to 12.5 Ω and the transformer boosts it up to 50 Ω. Actual losses alter the required values of both the shunt inductor and the series capacitor. At a frequency of 3.5 MHz with an antenna impedance of 0.55 –*j*1375 Ω and a base capacitance of 2 pF results in the values shown in **Table 22.22.** Inductor and capacitor values are highly sensitive to coil Q. Furthermore, the inductor values are considerably below the 62.5 µH required to resonate the antenna.

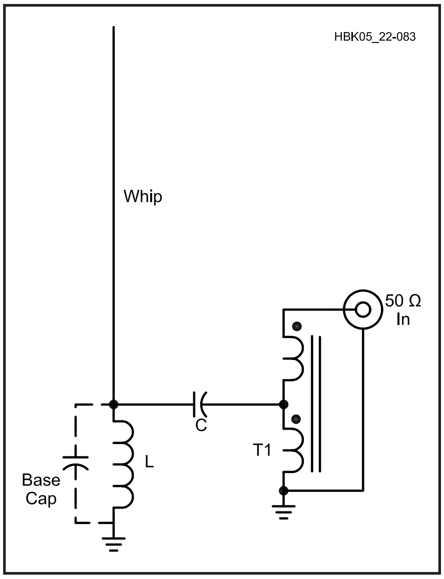


Fig 22.83 — The base-matched mobile whip antenna.

Table 22.22

Values of L and C for the Circuit of Fig 22.83 on 3.5 MHz

Coil Q	*L (μH)*	*C (pF)*	*System Efficiency*
300	44	11.9	0.083
200	29.14	35	0.0372
100	22.2	58.1	0.014

This circuit has the advantage that the tuning elements are all at the base of the antenna. The whip radiator itself has minimal mass and wind resistance. In addition, the rig is protected by the fact that there is a dc ground on the radiator so any accidental discharge or electrical contact is kept out of the cable and rig. Variable tuning elements allow the antenna to be tuned to other frequencies.

Connect the antenna, L and C. Start with less inductor than required to resonate the antenna. Tune the capacitor to minimum SWR. Increase the inductance and tune for minimum SWR. When the values of L and C are right, the SWR will be 1:1.

For remote or automatic tuning the drive motors for the coil and capacitor and the limit switches can be operated at RF ground potential. Mechanical connections to the RF components should be through insulated couplings.

Center Loading

Center loading increases the current in the lower half of the whip as shown in **Fig 22.84**. One can start by calculating the capacitance for the section above the coil just as done for the base loaded antenna. This permits the calculation of the loading inductance. The center loaded antenna is often operated without any base matching in which case the resistive component can be assumed to be 50 Ω for purposes of calculating the current rating and selecting wire size for the inductor.

The reduced size top section results in reduced capacitance which requires a much larger loading inductor. Center loading requires twice as much inductive reactance as base loading. For equal coil Qs, loss resistance is twice as great for center loading. If the coil is above the center, the inductance must be even larger, and the loss resistance increases accordingly. These factors tend to negate the advantage of the improved current distribution.

Because of the high value of inductance required, optimum Q coils are very large. One manufacturer of this type coil does not recommend their use in rain or inclement weather. The large wind resistance necessitates a very sturdy mount for operation at highway speed. Owing to the Q of these large coils the use of a base matching element in the form of either a tapped inductor or a shunt capacitor is usually needed to match to 50 Ω.

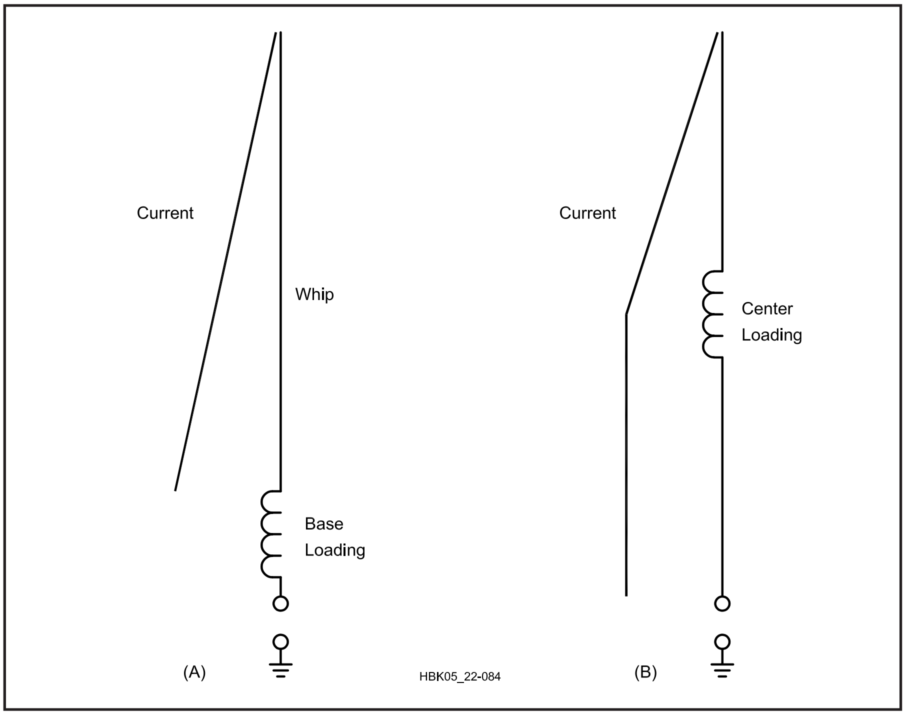


Fig 22.84 — Relative current distribution on a base-loaded antenna is shown at A and for a center-loaded antenna at B.

Another manufacturer places the coil above the center and uses a small extendable *wand* for tuning. To minimize wind resistance, the coil lengths are several times their diameters. These antenna coils are usually close wound with enameled wire. The coils are covered with a heat-shrink sleeve. If used in heavy rain or snow for extended periods water may get under the sleeving and seriously detune and lower the Q of the coils. These antennas usually do not require a base matching element. The resistance seems to come out close enough to 50 Ω.

It is possible to make a center-loaded antenna that is remotely tunable across the HF bands; however, this requires a certain amount of mechanical sophistication. The drive motor, limit switches and position sensor can be located in a box at the antenna base and drive the coil tuning mechanism through an electrically isolated shaft. Alternatively, the equipment could be placed adjacent to the loading coil requiring all of the electrical leads to be choked off to permit RF feeding of the base. The latter choice is probably the most difficult to realize.

Continuously Loaded Antennas

Antennas consisting of a fiberglass sleeve with the radiator wound in a continuous spiral to shorten a CB antenna from 8.65 feet to 5 or 6 feet have been on the market for many years. This modest shortening has little impact on the efficiency but does narrow the bandwidth.

One line of mobile antennas uses periodic loading on a relatively small diameter tube. A series of taps along the length are used to select among the HF bands. An adjustable tip allows one to move about a single band. Because the length to diameter ratio is so large the loading coil Q is relatively low. The antenna is most effective above 20 meters.

THE SCREWDRIVER ANTENNA

The screwdriver antenna consists of a top whip attached to a long slender coil about 1.5 inches in diameter. The coil screws itself out of a base tube which has a set of contact fingers at the top. For lower frequencies more of the coil is screwed out of the base tube and at maximum frequency the coil is entirely *swallowed* by the base tube.

The antenna is tunable over a wide range of frequencies by remote control. It has the advantage that the drive mechanism is operated at ground potential with RF isolation in the mechanical drive shaft. On the other hand, the antenna is not easily extended to 10.5 foot length for maximum efficiency on 80 and 40 meters. Because of its shape, coil Q will not be very high.

DIGITAL VERSUS ANALOG COUPLERS

Digital HF antenna couplers were first used by the military about 1960 for radios with Automatic Link Establishment. In this mode, the military radio has a list of frequencies ranging 2 to 30 MHz. It will try these in some sequence and will *lock* on the frequency giving the best reception. During the search, frequencies change much too fast to permit the use of conventional roller coils and motor driven vacuum capacitors. By comparison the digital coupler can jump from one memory setting to another in milliseconds.

For matching a mobile whip, the circuit shown in **Fig 22.85** will suffice. The inductor and capacitor can each be made up of about 8 binary sequenced steps. For example, at 3.5 MHz, the 10.5-foot antenna has an impedance of about $0.55 - j1684\ \Omega$. From Table 22.22 we see that we could use a series inductance sequence of 20, 10, 5, 2.5, 1.25, 0.625, 0.32 and 0.16 µH. We can use a relay to short unwanted elements. In this way we could theoretically produce any value of inductance between 0 and 39.84 µH in steps of 0.16 µH. In reality you will never reach a zero inductance. With all of the relays shorted, the wiring inductance and contact inductance of 8 relays appear in series. Also, each of the coils will have the open circuit capacitance of a relay contact across it in addition to the normal stray capacitance.

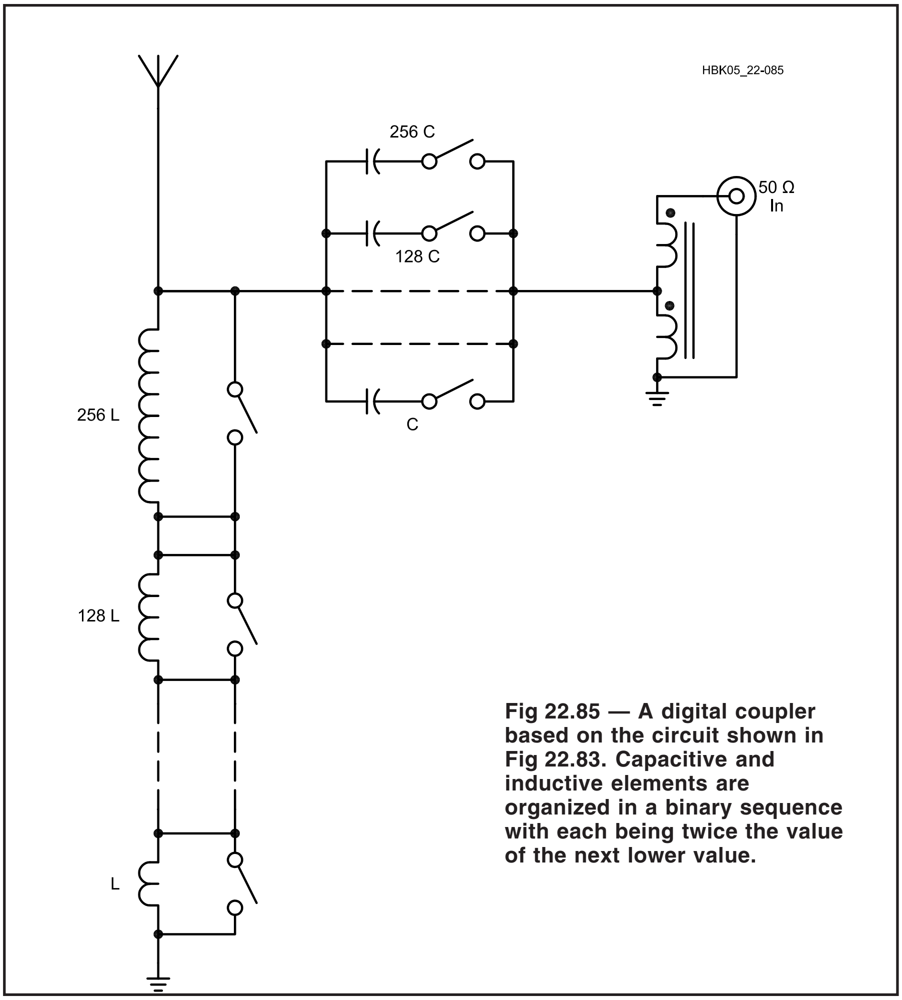


Fig 22.85 — A digital coupler based on the circuit shown in Fig 22.83. Capacitive and inductive elements are organized in a binary sequence with each being twice the value of the next lower value.

With most relays it does not make sense to switch less than 2 pF. For that reason, the capacitance chain would consist of 2, 4, 8, 16, 32, 64, 128 and possibly 256 pF. This would give a maximum of 510 pF and a step size of 2 pF. Each relay has an open circuit capacitance of about 1 pF, and that gives a minimum capacitance of 8 to 9 pF. As a practical matter, there is also the stray capacitance between the relay contacts and the coil windings.

In a high Q matching circuit that handles 100 W, the individual relays must handle 4 or 5 kV with the contacts open and several amperes of RF with the contacts closed. If we can unkey the transmitter so that the coupler will not have to switch under power, we'll still need some sizeable relays. If the inductors have lower Q, the voltages and currents will be correspondingly lower. Some military couplers use Jennings vacuum latching relays. This is expensive, as each of the 16 or 17 relays costs more than $100.

If coil and antenna Qs are kept or forced low, the voltages and currents become more reasonable. However, if the antenna size is restricted this reduction comes only at the cost of decreased efficiency. A commercially available ham/marine digital coupler employs RF reed relays rated for 5 kV and 1 A, and restricts the power at low frequencies if the antenna is small. Another ham/marine unit uses small relays in series where voltage requirements are great and in parallel where current requirements are great—not good engineering practice. A third offering is not too specific about the power rating with very high Q loads.

There are no successful examples of 100 W plus couplers that use PIN diode switching. Their use is highly problematic given the high-Q loads they would handle.

A REMOTELY TUNED ANALOG ANTENNA COUPLER

KE2QJ built an antenna coupler designed for 100-W continuous-duty operation that will tune an antenna 10 feet or longer to any frequency from 3.5 to 30 MHz. With longer antennas, the power rating is higher and the lowest frequency is lower. The design requires only hand tools to build; however, access to a drill press and a lathe could save labor.

The roller coils and air variable capacitors to be used are not widely manufactured these days. Tube-type linear amplifiers still use air variable capacitors but these are generally built on order for the manufacturer and are not readily available to consumers in small quantity.

Until the 1970s, E. F. Johnson manufactured roller coils and air variable capacitors that were suitable for kilowatt amplifier finals and high power antenna couplers. On occasion one or more of these may be found in the original box, but they tend to be expensive. Ten Tec and MFJ both manufacture antenna couplers and offer some components in small quantities.

The following data refer to generic motors, capacitors and inductors. The descriptions are intended to aid the builder in selecting items from surplus, hamfest flea market offerings or salvage of old equipment.

THE MOTORS

Two motors are required, one to drive the inductor and one to drive the capacitor. The design employs permanent magnet dc gearhead motors with a nominal 12-V rating. A permanent magnet (PM) motor can be reversed by simply reversing the polarity of the drive voltage, and its speed can be controlled over a wide range by pulsing the power on and off with a variable duty cycle. The motor should have an output shaft speed on the order of 60 to 180 r/min (1 to 3 r/s) although this is not critical. New, such motors, can cost as much as $65 to $150 in small quantities. However, they can be found surplus and in repair shops for a few dollars.

The motor you are looking for is 1 to 1.5 inches in diameter and perhaps 2.5 inches long. It might be rated 12 or 24 V and have a $^1/_4$-inch diameter output shaft. At 12 V it should have enough torque to make it hard to stop the shaft with your fingers. Tape recorders, fax machines, film projectors, windshield wipers and copiers often use this type of motor.

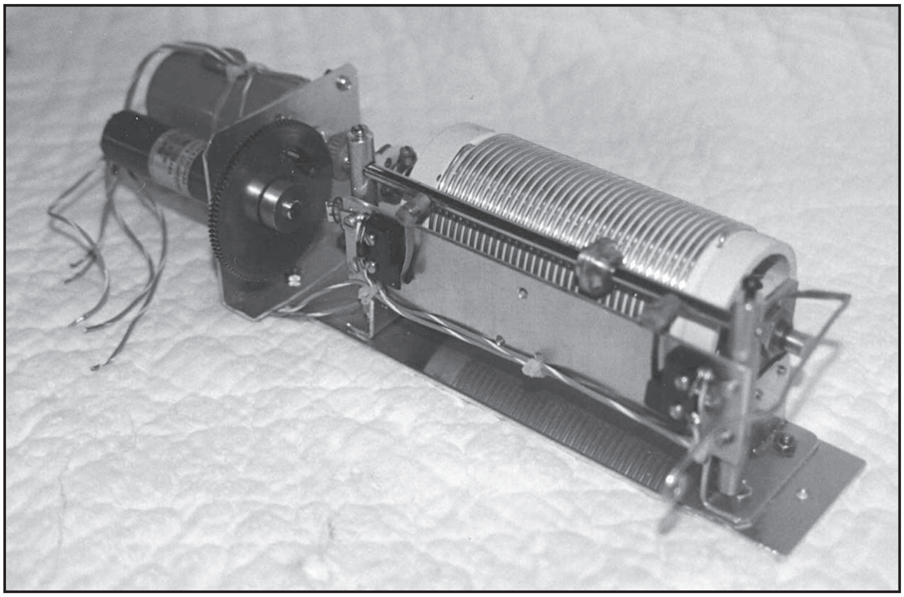


Fig 22.86 — At A, motor control circuit used by KE2QJ. This circuit uses pulse modulation for speed control with good starting torque. Direction of rotation is controlled by the relay. At B, how to add limit switches to the circuit. See text.

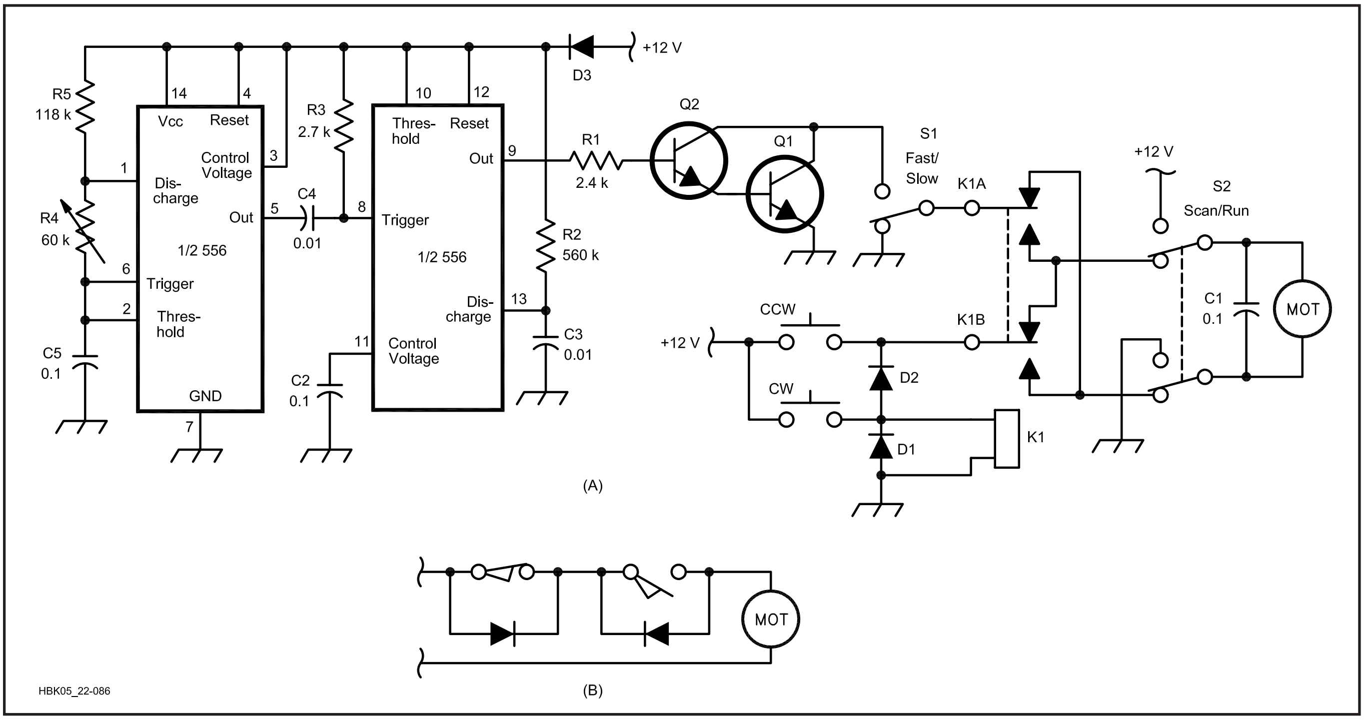


Fig 22.87 — Photo of the inductor drive assembly from KE2QJ's antenna coupler.

LIMIT SWITCHES

On a remotely operated unit it is usually necessary to have limit switches to prevent the device from *crashing* into the ends. On an external roller coil these can be microswitches with paddles mounted on each end of the coil. As the coil is wound to one end, the roller operates the paddle and opens the limit switch which stops the motor.

Fig 22.86A illustrates a simple motor control circuit. Relay K1 is arranged as a DPDT polarity reversing switch. If switch CCW is pressed, the motor rotates CCW and the steering diode D2 prevents the relay from operating. If CW is pressed, relay K1 operates reversing the polarity at the motor. The motor is energized through the steering diode.

Fig 22.86B shows how to add limit switches. The diodes across the switches are called anti-jam diodes. When a switch opens, the diode permits current to flow in the reverse direction and the motor to move the roller away from the open switch.

The photograph of **Fig 22.87** shows the mounting of the switches on the coil. The diode should be a power rectifier type rated for several times the motor current and at least 60 V.

POSITION READER

While not necessary, it is worthwhile to have a way to determine inductor position. An easy way to do this is to couple a 10-turn potentiometer to the coil shaft or drive gears. Make sure that the potentiometer turns less than 10 turns between limits. Don't try to make it come out exact.

Because the potentiometer is a light mechanical load, a belt drive reduction works well and won't slip if properly tensioned. Fig 22.87 shows the potentiometer and the gear drive.

You may be able to find suitable gears. However, a belt drive requires less precise shaft positioning than fine tooth gears. With a lathe, pulleys can be made in almost any ratio. Vacuum cleaner belts and O rings make handy belts.

COUPLINGS

In this coupler circuit, both ends of the capacitor are *hot* with RF although the end adjacent to the transformer is at relatively low voltage. Nevertheless, the capacitor shaft must be insulated from the motor shaft. The coil can be driven from the grounded end. Insulation is not necessary, but use a coupler between the motor shaft and the coil to compensate for any misalignment. Universal joints and insulating couplings are available from most electronics supply houses. You can make a coupling from a length of flexible plastic tubing which fits snugly over the shafts. Clamp the tubing to the shafts to avoid slippage.

THE CAPACITOR

The easiest capacitor to use is an air variable. It should have a range of approximately 10 to 250 pF. The plate spacing should be 2 mm (1/16 inch) or more, and the plate edges should be smooth and rounded. The capacitor should be capable of continuous 360° rotation, and it would be nice if it had ball bearings. The straight-line capacitance design is best for this application. Several capacitors of this type are available in military surplus ARC-5 series transmitters. These are approximately 2 × 2 × 3 inches.

The capacitor must be mounted on stand-off insulators although high voltage will not be present on the frame. A cam that briefly operates a microswitch when the capacitor goes through minimum can be used to flash an LED on the remote control panel. This provides an indication that the capacitor is turning.

THE INDUCTOR

As calculated earlier, and assuming an inductor Q a bit under 300 is attainable, the roller inductor for this coupler should have a maximum inductance on the order of 40 µH. The wire should be at least #14 AWG wound about 8 t/inch.

Table 22.23
Data for 40 µH Coils

Diameter	*Length*	*Turns*
2.3 inch (58 mm)	5.625 inch (143 mm)	45
2.8 inch (71 mm)	4.25 inch (108 mm)	34
3.3 inch (84 mm)	3.375 inch (86 mm)	27

You can use **Table 22.23** as a guide to buy a roller coil at a hamfest. The seller may not know the inductance of the coil. The antenna loading coil from an ARC-5 transmitter will work, but the wire is a bit small.

You could make the loading coil by threading 2, 2.5 or 3-inch diameter white, thick-wall PVC pipe with 8 t/inch. If the pipe is threaded in a lathe, the wire can be wound into the threads under considerable tension. This helps to prevent the wires from coming loose with wear or temperature.

THE TRANSFORMER

The transformer consists of a bifilar winding on an Amidon FT-114-61 core. Start with two 2-foot lengths of #18 insulated wire; Teflon insulation is preferable. Twist the wire with a hand drill until there are about 5 t/inch (not critical). Wind 12 turns onto the core. This should about fill it up. Attach the starting end of one wire to the finish end of the other. This is the 12.5-Ω tap. One of the free ends is grounded and the other is the 50-Ω tap. Mount the coil on a plastic or wooden post through the center of the coil. A metal screw can be used as long as it does not make a complete turn around the core.

CONSTRUCTION

For ease of service, mount the inductor, its drive motor, position sensing poten-

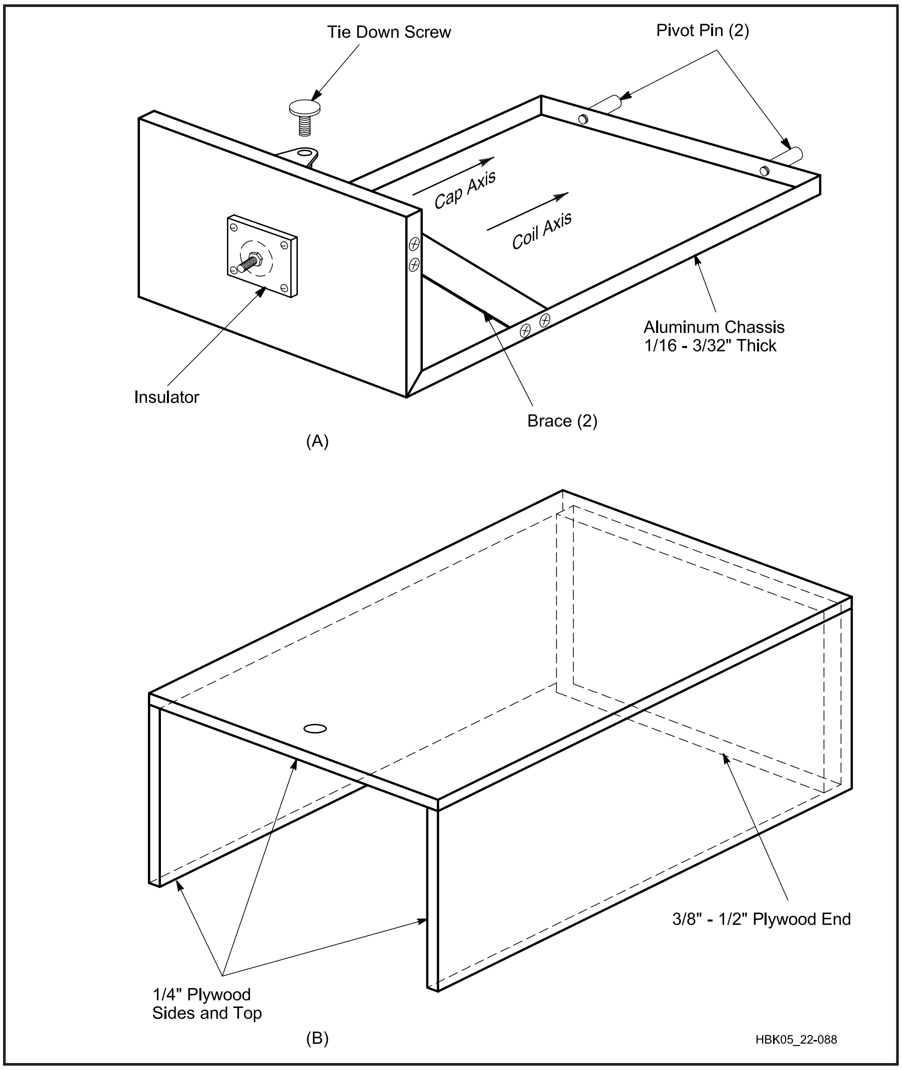


Fig 22.88 — At A, the chassis for the coupler mounting box. At B, the box cover.

tiometer and limit switch assembly on a single aluminum plate. A plug and socket assembly permits rapid disconnection and removal. Make a similar assembly for the capacitor, its drive motor, transformer and the interrupter. Both assemblies should be made on $^1/_{16}$ to $^1/_4$-inch thick aluminum. These individual assemblies make it easier to fix problems.

The chassis shown in **Fig 22.88A** is made of a single piece $^1/_{16}$ to $^3/_{32}$-inch aluminum bent in an L shape. Two chassis-stiffening braces are riveted in place. Alternatively, the chassis can be made of flat sheets with aluminum angles riveted around the edge.

Mount the coil and capacitor assemblies parallel to the long leg of the L. Punch a 1-inch hole in the center of the short end of the L. Cover the hole with an insulator made of PVC, Teflon or other suitable material.

The rest of the case is a 4-sided wooden assembly as shown in Fig 22.88B. The back wall of the box is drilled to accept the two pivot pins. The box is slid over the chassis and the pivot pins engaged. The tie-down screw secures the box. For service, remove the tie-down screw and slide off the cover. The works of the coupler are very easy to get at!

The box is made of $^1/_4$-inch exterior grade plywood except for the back plate, which is $^3/_8$ or $^1/_2$-inch plywood. The sides, top and back should overlap the flanges on the chassis by $^1/_2$ inch. The inside corner seams of the box should be reinforced with $^1/_2$ or $^3/_4$-inch square strips. Assembly can be with any water resistant glue.

Finish the box, inside and out, with several coats of clear urethane varnish, sanding lightly between coats. This leaves a smooth plastic finish. This can be sprayed with an exterior paint that matches your car's color.

If the sides of the box fit closely over the flanges, no fastening beside the tie-down screw is required. A nearly perfect seal will leak out hot air when the sun shines on it and will draw in cold damp air in the evening, trapping moisture inside. A moderate fit will keep rain and snow out and permit the box to *breathe* freely, thereby keeping the inside dry.

MOUNTING THE WHIP AND THE BOX

Plastics in bumpers and bodies makes the mounting of a mobile whip antenna problematic. Modern bumpers are covered with plastic and the bumper is attached to the car unibody through a *5-MPH* shock absorber. The latter item is an unreliable ground.

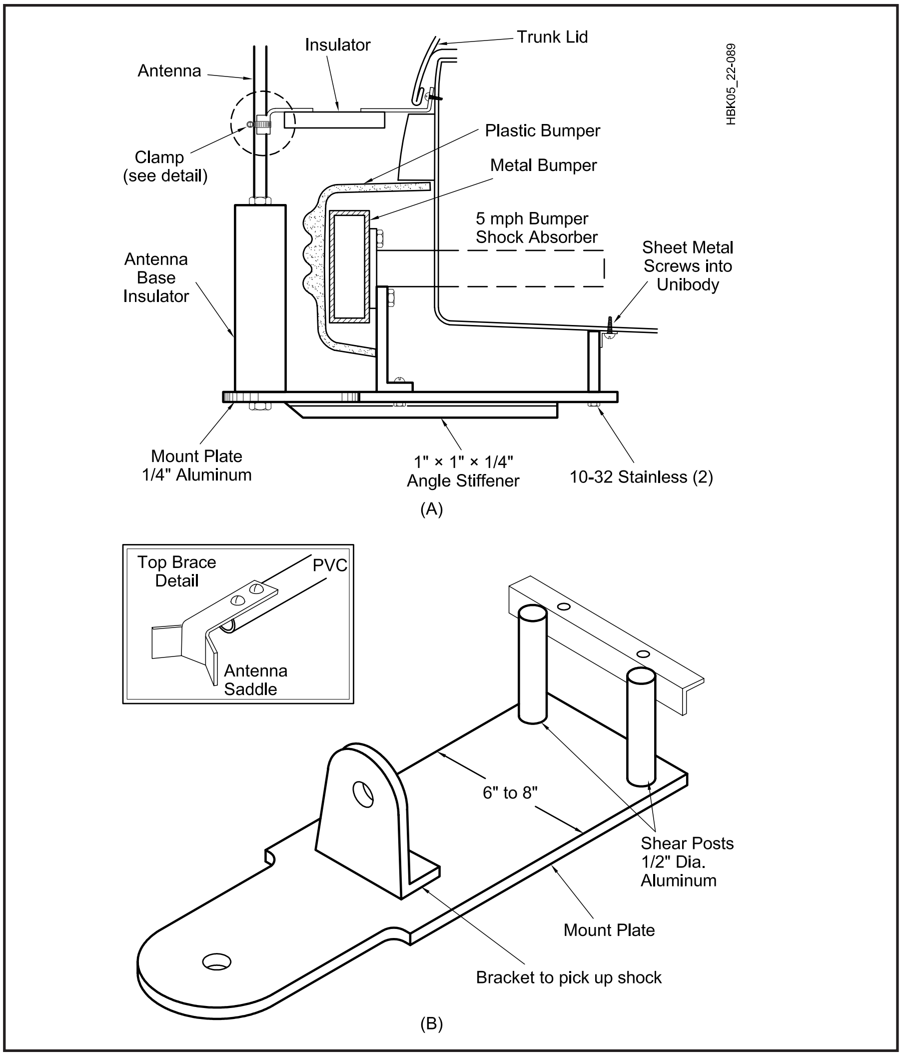


Fig 22.89 — Antenna mounting detail. At A, the overall plan. At B, detail of the mount plate.

The arrangement of **Fig 22.89** solves many of these problems. It uses a $^1/_4$-inch aluminum plate 6 to 8 inches wide and long enough to fit between a reasonably strong place on the unibody and the place behind the bumper where the antenna wants to be. This plate is fitted with an angle bracket for the lower bolt on the shock/bumper mounting. This plate is stiffened with a length of 1 × 1 × $^1/_4$ inch aluminum angle bolted in several places.

Near the forward edge of the plate, two $^1/_2$-inch diameter aluminum shear posts are fitted. The bottom of each is tapped 10-32 and bolted through the mount plate with a stainless 10-32 screw. At the top of these shear posts another piece of 1 × 1 × $^1/_2$-inch angle is attached which is screwed to the unibody with three or four #10 stainless sheet metal screws. A bracket attaches the mount plate to the bumper's shock absorber. The angle bracket may either be welded to the plate or bolted with angle stock. In the event that the car is hit from behind or backs into an obstacle, the two 10-32 screws will shear off, thereby preventing the mount from defeating the 5 MPH crushable shock absorber. The part protruding behind the bumper may be cut down in width to 3 inches and rounded for appearance and safety.

Any type of base insulator may be used, but try to bring the base of the antenna to the height of the coupler output terminal. You can make a good base insulator from thick-wall white PVC 1$^1/_2$-inch pipe. Reinforce each end. Start with a 1$^1/_2$-inch length of pipe. Remove a $^5/_8$-inch wide strip so the remaining portion can be rolled and pressed into the open end of the insulator. Apply PVC pipe glue just before pressing in the piece; this gives the insulator a double wall thickness at each end. Aluminum plugs can be turned for a snug fit and tapped for $^3/_8$-24 hardware. The plugs can be held in place with 8-32 stainless screws.

The upper antenna brace has an aluminum plate at one end that goes under the trunk lid (see Fig 22.89). A length of 1/2-inch diameter heavy-wall white PVC pipe, which serves as an insulator, is screwed to this. At the other end of the insulator, another aluminum piece is bent to form a saddle for the antenna which is clamped to the saddle. This clamp should be as high as convenient above the mount plate, preferably not less than a foot. The mount plate should be sturdy enough for you to stand on and with the brace will easily hold a whip upright at 70 MPH or more.

The coupler box mounting is shown in **Fig 22.90**. Brackets can be made of 1/8 × 2-inch aluminum with a brace going perhaps 2 inches from the corner. The brackets bolt or rivet to the chassis. The bracket reaches through the gap between the trunk lid and the plastic top of the bumper. For reinforcement, a pair of reinforcement plates 1.5 × 2 × 1/4-inch thick are bolted to the plastic on the under side of the bumper. Ground the reinforcement plates to the unibody with some 3/4 or 1 inch ground braid.

Two 10-32 stainless screws hold each reinforcement plate to the plastic bumper and a central 1/4-20 tapped hole holds down the box bracket. One need only remove two screws to get the box off the car for car wash, etc. You have to open the trunk to remove the antenna coupler, and this provides a measure of security.

THE SPRING AND WHIP

A section of 1-inch diameter aluminum tubing extends from the top of the insulator to the base of the spring. It's usually best to have the spring about 4 ft above the pavement. The type used for CB whips works well. A 7-ft whip brings the top to about 11.5 ft above the pavement. The 7-ft whip can be a cut down CB unit. Don't use the type with helical winding. When the antenna is tied down, the bow of the whip should be about 7 ft above the pavement.

TUNING

It is best to initially tune the antenna using low power. A power attenuator just after the transceiver will limit SWR, but your SWR indicator must be on the antenna side of the attenuator.

For a first tune-up, set the capacitor control to SCAN and slowly advance the inductor from minimum inductance toward maximum. As the inductor approaches the correct value the SWR will start to kick down. At this point take the capacitor off of SCAN and JOG it to a best tune. Next, JOG the inductor and repeat; the SWR should go down. Continue until a 1:1 SWR is obtained. Record the potentiometer setting. The next time you want to use this frequency run the coil directly to the logged setting.

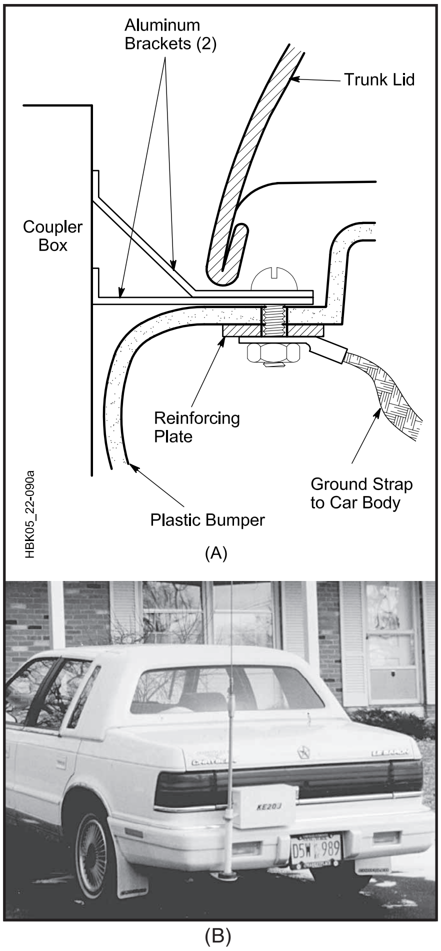


Fig 22.90 — Box mounting detail. At A, mounting-bracket design. At B, photo of KE2QJ's installation.

In the SCAN position the capacitor motor runs at full voltage. When you JOG the capacitor for low SWR you will find the speed far too fast for sharp tuning. The slow speed tuning is provided by using duty-factor modulation of the motor current. The circuit of Fig 22.86A supplies fixed width pulses with variable timing. At the slowest speed, the unit will supply about one pulse per second and the motor shaft will rotate one degree or so per pulse. The full voltage pulse provides good starting torque.

If the SWR cannot be brought to 1:1, examine the coil and capacitor to see whether either is at maximum or minimum. At high frequencies above 24 MHz it may be necessary to place a capacitor between the coupler and the antenna base.

RADIATION PATTERNS

At the lower frequencies the pattern tends to be essentially round in azimuth. At 20 meters the pattern tends to become more and more directive. The patterns in **Fig 22.91** were calculated using *EZNEC*. The frequency is 18.13 MHz and the antenna is mounted at the left rear corner of a mid-size sedan. It may be seen that the pattern has more than 10 dB maximum-to-minimum ratio with the broad maximum along the diagonal of the vehicle occupied by the antenna. If the antenna were mounted in the center of the vehicle, the omnidirectional characteristics would be improved. However, the antenna would have to be much shorter to stay under 11.5 feet. The shorter antenna would likely be weaker in its best direction than the taller antenna is in its worst.

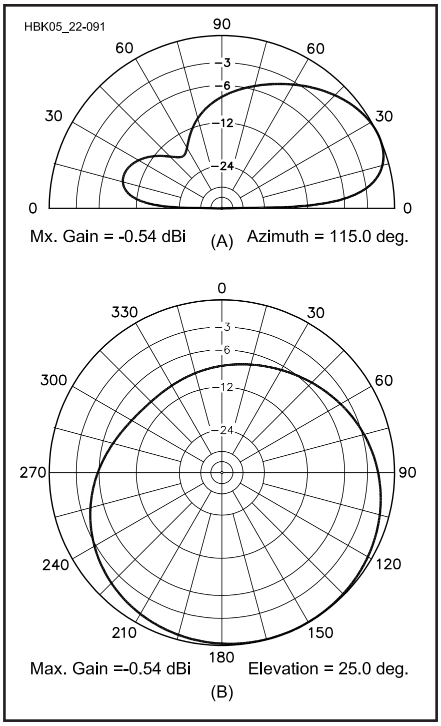


Fig 22.91 — At A, elevation pattern of the KE2QJ mobile antenna. The pattern is in the plane that runs diagonal through the car. At B, azimuth pattern at 25° elevation for the same antenna. The operating frequency is 18.130 MHz.

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VHF/UHF Antennas

Improving an antenna system is one of the most productive moves open to the VHF enthusiast. It can increase transmitting range, improve reception, reduce interference problems and bring other practical benefits. The work itself is by no means the least attractive part of the job. Even with high-gain antennas, experimentation is greatly simplified at VHF and UHF because an array is a workable size, and much can be learned about the nature and adjustment of antennas. No large investment in test equipment is necessary.

Whether we buy or build our antennas, we soon find that there is no one *best* design for all purposes. Selecting the antenna best suited to our needs involves much more than scanning gain figures and prices in a manufacturer's catalog. The first step should be to establish priorities.

GAIN

As has been discussed previously, shaping the pattern of an antenna to concentrate radiated energy, or received signal pickup, in some directions at the expense of others is the only possible way to develop gain. Radiation patterns can be controlled in various ways. One is to use two or more driven elements, fed in phase. Such arrays provide gain without markedly sharpening the frequency response, compared to that of a single element. More gain per element, but with some sacrifice in frequency coverage, is obtained by placing parasitic elements into a Yagi array.

RADIATION PATTERN

Antenna radiation can be made omnidirectional, bidirectional, practically unidirectional, or anything between these conditions. A VHF net operator may find an omnidirectional system almost a necessity but it may be a poor choice otherwise. Noise pickup and other interference problems tend to be greater with omnidirectional antennas. Maximum gain and low radiation angle are usually prime interests of the weak-signal DX aspirant. A clean pattern, with lowest possible pickup and radiation off the sides and back, may be important in high-activity areas, where the noise level is high, or when challenging modes like EME (Earth-Moon-Earth) are employed.

HEIGHT GAIN

In general, the higher a VHF antenna is installed, the better will be the results. If raising the antenna clears its view over nearby obstructions, it may make dramatic improvements in coverage. Within reason, greater height is almost always worth its cost, but height gain must be balanced against increased transmission-line loss. Line losses can be considerable at VHF, and they increase with frequency. The best available line may be none too good, if the run is long in terms of wavelength. Consider line losses in any antenna planning.

PHYSICAL SIZE

A given antenna design for 432 MHz, say a 5-element Yagi on a 1-λ boom, will have the same gain as one for 144 MHz, but being only one-third the size it will intercept only one-ninth as much energy in receiving. Thus, to be equal in communication effectiveness, the 432-MHz array should be at least equal in physical size to the 144-MHz one, requiring roughly three times the number of elements. With all the extra difficulties involved in going higher in frequency, it is well to be on the big side in building an antenna for the UHF bands.

DESIGN FACTORS

Having sorted out objectives in a general way, we face decisions on specifics, such as polarization, type of transmission line, matching methods and mechanical design.

POLARIZATION

Whether to position the antenna elements vertically or horizontally has been a question since early VHF pioneering. Tests show little evidence on which to set up a uniform polarization policy. On long paths there is no consistent advantage, either way. Shorter paths tend to yield higher signal levels with horizontal in some kinds of terrain. Man-made noise, especially ignition interference, tends to be lower with horizontal. Verticals, however, are markedly simpler to use in omnidirectional systems and in mobile work.

Early VHF communication was largely vertical, but horizontal gained favor when directional arrays became widely used. The major trend to FM and repeaters, particularly in the 144-MHz band, has tipped the balance in favor of verticals in mobile work and for repeaters. Horizontal predominates in other communication on 50 MHz and higher frequencies. It is well to check in advance in any new area in which you expect to operate, however, as some localities may use vertical polarization. A circuit loss of 20 dB or more can be expected with cross-polarization.

TRANSMISSION LINES

There are two main categories of transmission lines used at HF through UHF: balanced and unbalanced. Balanced lines include *open-wire lines* separated by insulating spreaders, and *twin-lead*, in which the wires are embedded in solid or foamed insulation. Unbalanced lines are represented by the family of coaxial cables, commonly called *coax*. Line losses in either types of line result from ohmic resistance, radiation from the line and deficiencies in the insulation.

Large conductors, closely spaced in terms of wavelength, and using a minimum of insulation, make the best balanced lines. Characteristic impedances are between 300 to 500 Ω. Balanced lines work best in straight runs, but if bends are unavoidable, the angles should be as gentle as possible. Care should also be taken to prevent one wire from coming closer to metal objects than the other.

Properly built open-wire line can operate with very low loss in VHF and even UHF installations. A total line loss under 2 dB per hundred ft at 432 MHz is readily obtained. A line made of #12 wire, spaced $^3/_4$ inch or less with Teflon spreaders, and running essentially straight from antenna to station, can be better than anything but the most expensive *Hardline* coax, at a fraction of the cost. This assumes the use of high-quality baluns to match into and out of the balanced line, with a short length of low-loss coax for the rotating section from the top of the tower to the antenna. A similar 144-MHz setup could have a line loss under 1 dB.

Small coax such as RG-58 or RG-59 should never be used in VHF work if the run is more than a few feet. Half-inch lines (RG-8 or RG-11) work fairly well at 50 MHz, and are acceptable for 144-MHz runs of 50 ft or less. If these lines have foam rather than solid insulation they are about 30% better. Aluminum-jacket *Hardline* coaxial cables with large inner conductors and foam insulation are well worth their cost. Hardline can sometimes even be obtained for free from local Cable TV operators as *end runs*—pieces at the end of a roll. The most common CATV variety is $^1/_2$-inch OD 75-Ω Hardline. Waterproof commercial connectors for Hardline are fairly expensive, but enterprising amateurs have *home-brewed* low-cost connectors. If they are properly waterproofed, connectors and Hardline can last almost indefinitely. Of course, a disadvantage implied by their name is that Hardline must not be bent too sharply, because it will kink. See *The ARRL Antenna Book* for details on Hardline connectors.

Effects of weather on transmission lines should not be ignored. A well-constructed open-wire line works well in nearly any weather, and it stands up well. TV type twin-lead is almost useless in heavy rain, wet snow or icing. The best grades of coax are impervious to weather. They can be run underground, fastened to metal towers without insulation, or bent into almost any convenient position, with no adverse effects on performance. However, beware of *bargain* coax. Lost transmitter power can be made up to some extent by increasing power, but once lost, a weak signal can never be recovered in the receiver.

IMPEDANCE MATCHING

Theory and practice in impedance matching are given in detail in the **Transmission Lines** chapter, and in theory, at least, is the same for frequencies above 50 MHz. Practice may be similar, but physical size can be a major modifying factor in choice of methods.

Delta Match

Probably the first impedance match was made when the ends of an open line were fanned out and tapped onto a half-wave antenna at the point of most efficient power transfer, as in **Fig 22.92A**. Both the side length and the points of connection either side of the center of the element must be adjusted for minimum reflected power in the line, but the impedances need not be known. The delta makes no provision for tuning out reactance, so the length of the dipole is pruned for best SWR.

Once thought to be inferior for VHF applications because of its tendency to radiate if adjusted improperly, the delta has come back to favor now that we have good methods for measuring the effects of matching. It is very handy for phasing multiple-bay arrays with low-loss open lines, and its dimensions in this use are not particularly critical.

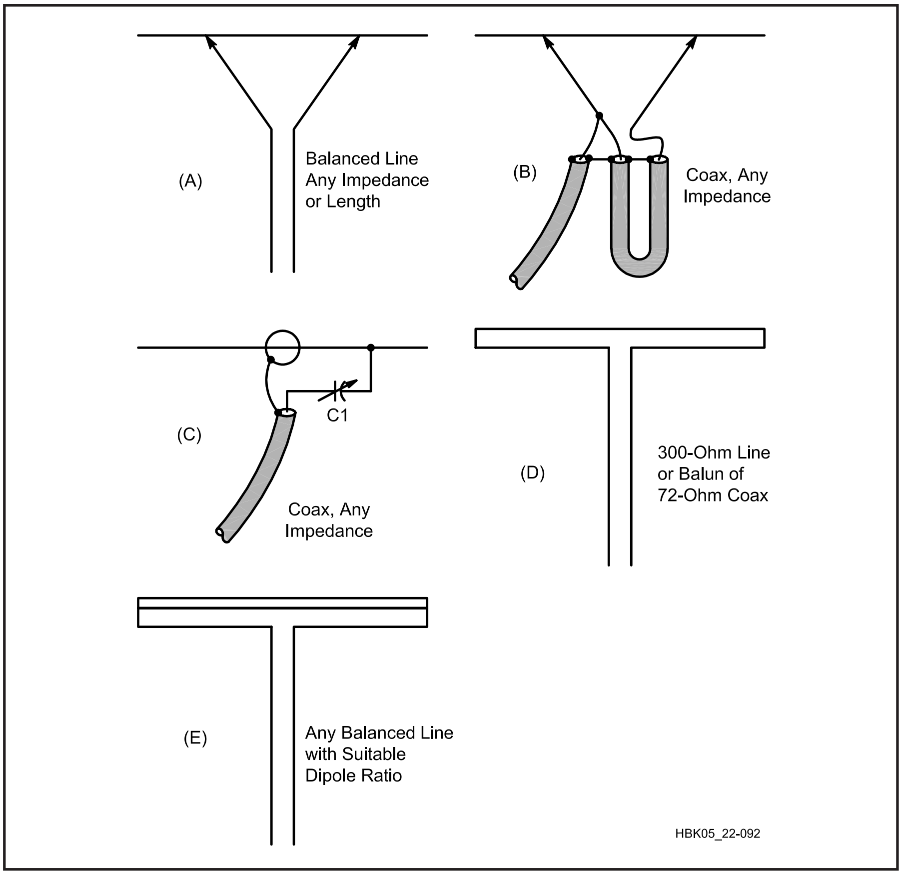


Fig 22.92 — Matching methods commonly used in VHF antennas. In the delta match, A and B, the line is fanned out to tap on the dipole at the point of best impedance match. The gamma match, C, is for direct connection of coax. C1 tunes out inductance in the arm. Folded dipole of uniform conductor size, D, steps up antenna impedance by a factor of four. Using a larger conductor in the unbroken portion of the folded dipole, E, gives higher orders of impedance transformation.

Gamma and T Matches

The gamma match is shown in Fig 22.92C, and the T match is shown in Fig 22.92D. These matches are covered in more detail in the **Transmission Lines** chapter. There being no RF voltage at the center of a half-wave dipole, the outer conductor of the coax is connected to the element at this point, which may also be the junction with a metallic or wooden boom. The inner conductor, carrying the RF current, is tapped out on the element at the matching point. Inductance of the arm is canceled by means of C1. Both the point of contact with the element and the setting of the capacitor are adjusted for zero reflected power, with a bridge connected in the coaxial line.

The capacitor can be made variable temporarily, then replaced with a suitable fixed unit when the required capacitance value is found, or C1 can be mounted in a waterproof box. Maximum capacitance should be about 100 pF for 50 MHz and 35 to 50 pF for 144 MHz. The capacitor and arm can be combined with the arm connecting to the driven element by means of a sliding clamp, and the inner end of the arm sliding inside a sleeve connected to the inner conductor of the coax. It can be constructed from concentric pieces of tubing, insulated by plastic sleeving or shrink tubing. RF voltage across the capacitor is low, once the match is adjusted properly, so with a good dielectric, insulation presents no great problem, if the initial adjustment is made with low power. A clean, permanent, high-conductivity bond between arm and element is important, as the RF current is high at this point.

Because it is inherently somewhat unbalanced, the gamma match can sometimes introduce pattern distortion, particularly on long-boom, highly directive Yagi arrays. The T-match, essentially two gamma matches in series creating a balanced feed system, has become popular for this reason. A coaxial balun like that shown in Fig 22.92B is used from the balanced T-match to the unbalanced coaxial line going to the transmitter.

Folded Dipole

The impedance of a half-wave antenna broken at its center is 72 Ω. If a single conductor of uniform size is folded to make a half-wave dipole, as shown in Fig 22.92D, the impedance is stepped up four times. Such a folded dipole can thus be fed directly with 300-Ω line with no appreciable mismatch. Coaxial line of 70 to 75 Ω impedance may also be used if a 4:1 balun is added. Higher impedance step-up can be obtained if the unbroken portion is made larger in cross-section than the fed portion, as in Fig 22.92E.

BALUNS

Conversion from balanced loads to unbalanced lines, or vice versa, can be per-

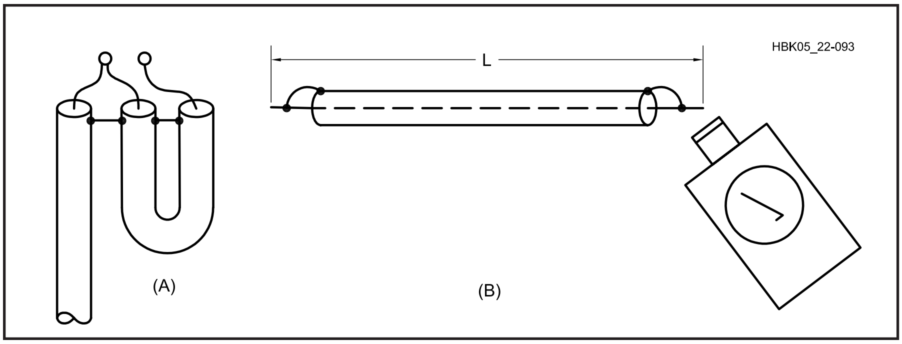


Fig 22.93 — Conversion from unbalanced coax to a balanced load can be done with a half-wave coaxial balun, A. Electrical length of the looped section should be checked with a dip meter, with ends shorted, B. The half-wave balun gives a 4:1 impedance step up.

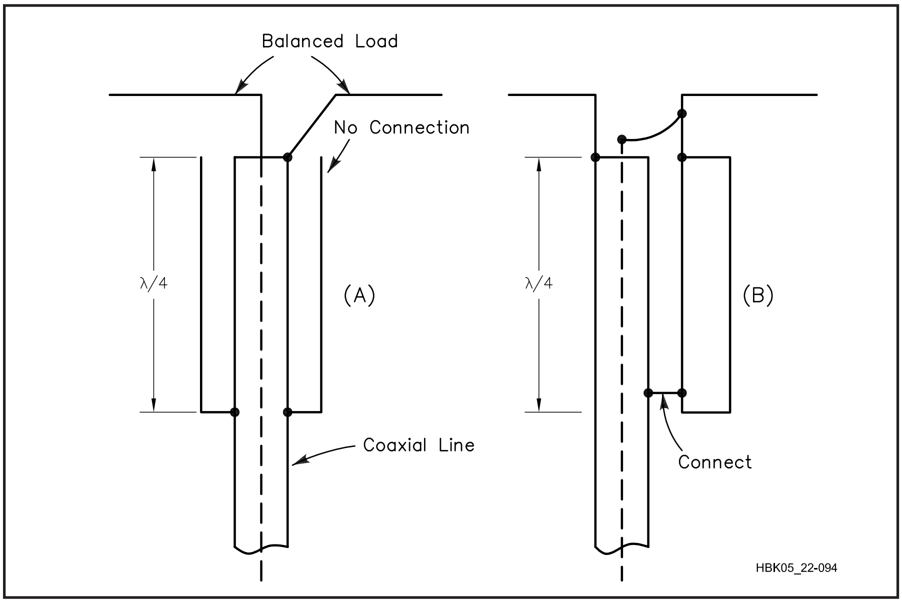


Fig 22.94 — The balun conversion function, with no impedance change, is accomplished with quarter-wave lines, open at the top and connected to the coax outer conductor at the bottom. The coaxial sleeve shown at A is preferred.

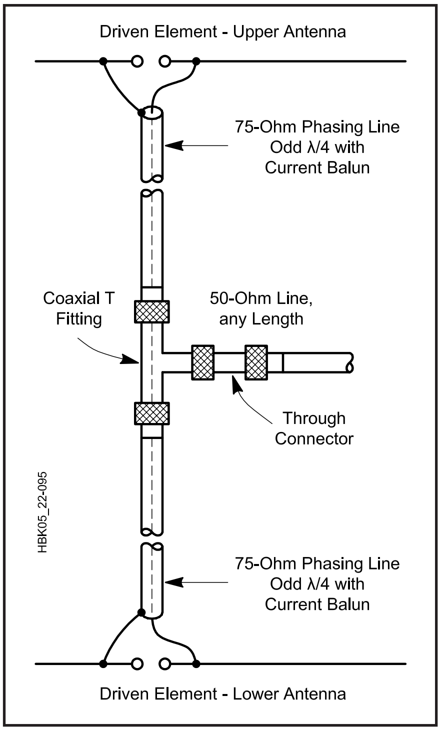


Fig 22.95 — A method for feeding a stacked Yagi array. Note that baluns at each antenna are not specifically shown. Modern-day practice is to use current (choke) baluns made up of ferrite beads slipped over the outside of the coax and taped to prevent movement. See the Transmission Lines chapter for details.

formed with electrical circuits, or their equivalents made of coaxial line. A balun made from flexible coax is shown in **Fig 22.93A**. The looped portion is an electrical half-wave. The physical length depends on the propagation factor of the line used, so it is well to check its resonant frequency, as shown at B. The two ends are shorted, and the loop at one end is coupled to a dip-meter coil. This type of balun gives an impedance step-up of 4:1, 50 to 200 Ω, or 75 to 300 Ω typically.

Coaxial baluns giving a 1:1 impedance transfer are shown in **Fig 22.94**. The coaxial sleeve, open at the top and connected to the outer conductor of the line at the lower end (A) is the preferred type. A conductor of approximately the same size as the line is used with the outer conductor to form a quarter-wave stub, in B. Another piece of coax, using only the outer conductor, will serve this purpose. Both baluns are intended to present an infinite impedance to any RF current that might otherwise tend to flow on the outer conductor of the coax.

STACKING YAGIS

Where suitable provision can be made for supporting them, two Yagis mounted one above the other and fed in phase may be preferable to one long Yagi having the same theoretical or measured gain. The pair will require a much smaller turning space for the same gain, and their lower radiation angle can provide interesting results. On long ionospheric paths a stacked pair occasionally may show an apparent gain much greater than the 2 to 3 dB that can be measured locally as the gain from stacking.

Optimum spacing for Yagis with booms longer than 1 λ is one wavelength, but this may be too much for many builders of 50-MHz antennas to handle. Worthwhile results are possible with as little as $^1/_2$ λ (10 ft), but $^5/_8$ λ (12 ft) is markedly better. The difference between 12 and 20 ft may not be worth the added structural problems involved in the wider spacing, at 50 MHz at least.

The closer spacings give lowered measured gain, but the antenna patterns are cleaner (less power in the high-angle elevation lobes) than with one-wavelength spacing. Extra gain with wider spacings is usually the objective on 144 MHz and higher bands, where the structural problems are not quite as severe as on 50 MHz.

One method for feeding two 50-Ω antennas, as might be used in a stacked Yagi array, is shown in **Fig 22.95**. The transmission lines from each antenna, with a balun feeding each antenna (not shown in the drawing for simplicity), to the common feedpoint must be equal in length and an odd multiple of a quarter wavelength. This line acts as an quarter-wave (Q-section) impedance transformer and raises the feed impedance of each antenna to 100 Ω. When the coaxes are connected in parallel at the coaxial T fitting, the resulting impedance is close to 50 Ω.

CIRCULAR POLARIZATION

Polarization is described as *horizontal* or *vertical*, but these terms have no meaning once the reference of the Earth's surface is lost. Many propagation factors can cause polarization change—reflection or refraction and passage through magnetic fields (Faraday rotation), for example. Polarization of VHF waves is often random, so an antenna capable of accepting any polarization is useful. Circular polarization, generated with helical antennas or with crossed elements fed 90° out of phase, will respond to any linear polarization.

The circularly polarized wave in effect threads its way through space, and it can be left- or right-hand polarized. These polarization senses are mutually exclusive, but either will respond to any plane (horizontal or vertical) polarization. A wave generated with right-hand polarization, when reflected from the moon, comes back with left-hand plarization, a fact to be borne in mind in setting up EME circuits. Stations communicating on direct paths should have the same polarization sense.

Both senses can be generated with crossed dipoles, with the aid of a switchable phasing harness. With helical arrays, both senses are provided with two antennas wound in opposite directions.

SIMPLE, PORTABLE GROUNDPLANE ANTENNA

This utility antenna is built on a coaxial connector. UHF connectors work well, but you may prefer to use type N or BNC connectors. With only two radials, it is essentially two dimensional, which makes it easier to store when not in use.

If the antenna is sheltered from weather, copper wire is sufficiently rigid for the radiating element and radials. Antennas exposed to the wind and weather can be made from brazing rod, which is available at welding supply stores. Alternatively, #12 or #14 copper-clad steel wire could be used to construct this antenna.

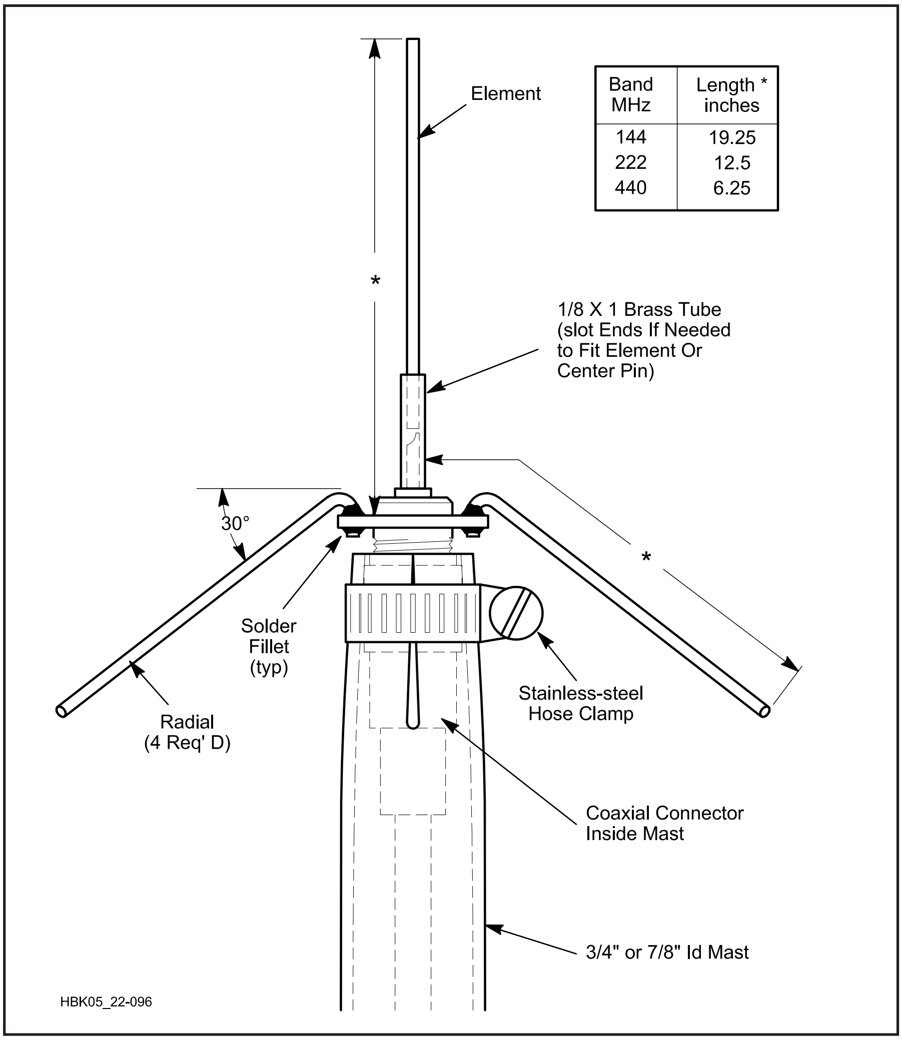
The ground-plane antenna is shown in **Fig 22.96** and uses a female chassis-mount connector to support the element and two radials. To eliminate sharp ends, it's a good idea to bend the element and radial ends into a circle or to terminate them with a solder lug. See **Fig 22.97**. The solder lug approach is easier with stiff wire. Crimp and then solder the lug to the wire. Make the overall length of the element and radials the same as shown in Fig 22.96, measuring to the outer tip of the loop or lug.

Radials may be attached directly to the mounting holes of the coaxial connector. Bend a hook at one end of each radial for insertion through the connector. Solder the radials to the connector using a large soldering iron or propane torch.

Solder the element to the center pin of the connector. If the element does not fit inside the solder cup, use a short section of brass tubing as a coupler (a slotted 1/8-inch-ID tube will fit over an SO-239 or N-receptacle center pin).

Tune the antenna by adjusting the radial droop angle for best SWR. If necessary, you can also prune the element length.

One mounting method for fixed-station antennas appears in Fig 22.96. The feed line and connector are inside the mast, and a hose clamp squeezes the slotted mast end to tightly grip the plug body. Once the antenna is mounted and tested, thoroughly seal the open side of the coaxial connector with RTV sealant, and weatherproof the connections with rust-preventative paint.



Band MHz	Length * inches
144	19.25
222	12.5
440	6.25

Fig 22.96 — A simple groundplane antenna for the 144, 222 or 440-MHz bands. The feed line and connector are inside the mast, and a hose clamp squeezes the slotted mast end to tightly grip the plug body. Element and radial dimensions given in the drawing are good for the entire band.

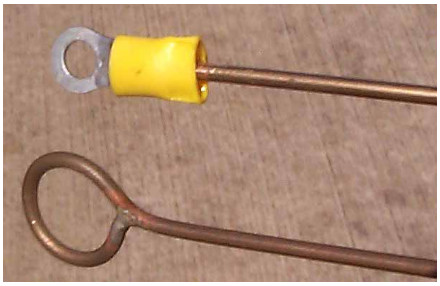


Fig 22.97 — Alternate methods for terminating element and radial tips on the simple groundplane antenna. See text. [Photo by K8CH]

DUAL-BAND ANTENNA FOR 146/446 MHZ

This nifty project by Wayde Bartholomew, K3MF (ex-WA3WMG), first appeared in *The ARRL Antenna Compendium, Volume 5*. This mobile whip antenna won't take long to build, works well and only requires one feed line for the two-band coverage.

Wayde used a commercial NMO-style base and magnetic mount. For the radiator and decoupling stub, He used brazing rod, which he coated with a rust inhibitor after all the tuning was done. You can start with a 2-m radiator that's 20.5 inches long. This is an inch longer than normal so that it may be pruned for best SWR.

Next tack on the 70-cm decoupling stub, which is 6.5 inches long. Trim the length of the 2-m radiator for best SWR at 146 MHz and then tune the 70-cm stub on 446 MHz, moving it up and down for best SWR. There should be no significant interaction between the adjustments for either frequency.

Final dimensions are shown in **Fig 22.98**. The SWR in the repeater portions of both bands is less than 2:1.

ADAPTING WA3WMG'S MOBILE ANTENNA FOR FIXED-STATION USE

You can use the WA3WMG dual-band mobile whip as the radiating element for the groundplane antenna in Fig 22.96. Don't change the 2-m radials. Instead, add two 70-cm radials at right angles to the 2-m set. See **Fig 22.99**. The antenna is no longer two dimensional, but you do have two bands with one feed line *and* automatic band switching.

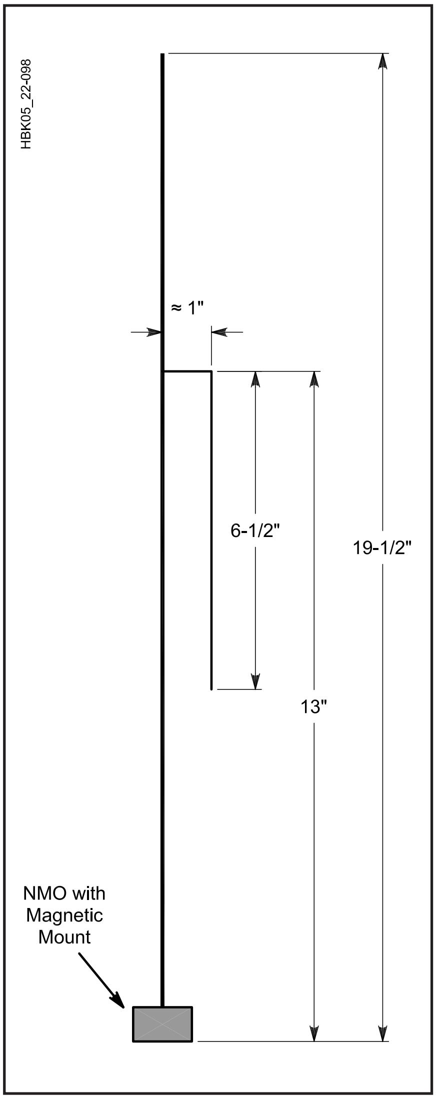


Fig 22.98 — Diagram of WA3WMG's dual-band 146/446-MHz mobile whip. Brazing rod is used for the 2-m radiator and for the 70-cm decoupling stub.

Fig 22.99 — WA3WMG's whip can be used to make a dual-band groundplane antenna. Separate radials for 2-m and 70-cm simplifies tuning. [Photo by K8CH]

A QUICK ANTENNA FOR 223 MHZ

William Bruce Cameron, WA4UZM, built the antenna for 223 MHz shown in **Fig 22.100**. It took less than an hour to build. To make one, you'll need 9 feet of #10 copper wire, 6 inches of small-diameter copper tubing, and a 10-foot length of PVC pipe or some other physical support.

Bend the antenna from one piece of wire. Slide the copper tubing over the top end of the antenna, and adjust how far it extends beyond the wire to get the lowest SWR. (Don't handle the antenna while transmitting—make adjustments only while receiving.) For more precision, you can move the coaxial feed line taps on the antenna's matching stub (the 12-inch section at the bottom) about an eighth of an inch at a time. The antenna shows an SWR of 1.2 at 223 MHz.

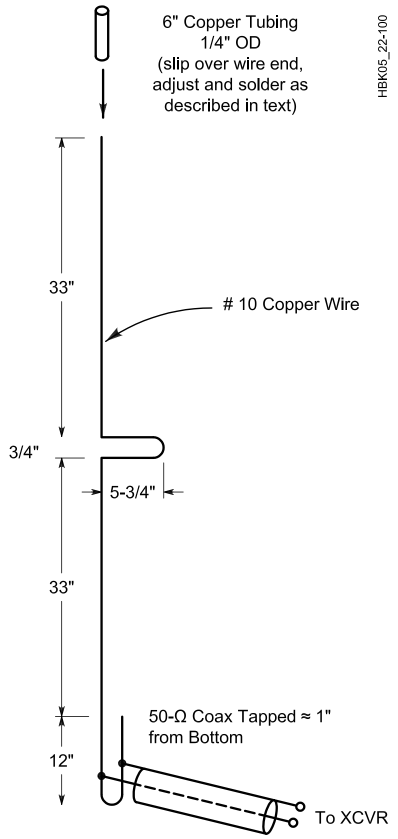


Fig 22.100 — WA4UZM's quick 223-MHz antenna gets you going on $1^1/_4$ meters in a hurry. The text explains how to adjust it for minimum SWR. To support the antenna, lash it to a piece of PVC pipe with UV-resistant nylon cable ties.

AN ALL-COPPER 2-M J-POLE

Rigid copper tubing, fittings and assorted hardware can be used to make a really rugged J-pole antenna for 2 m. When copper tubing is used, the entire assembly can be soldered together, ensuring electrical integrity, and making the whole antenna weatherproof. This material came from an article by Michael Hood, KD8JB, in *The ARRL Antenna Compendium, Vol. 4*.

No special hardware or machined parts are used in this antenna, nor are insulating materials needed, since the antenna is always at dc ground. Best of all, even if the parts aren't on sale, the antenna can be built for less than $15. If you only build one antenna, you'll have enough tubing left over to make most of a second antenna.

CONSTRUCTION

Copper and brass is used exclusively in this antenna. These metals get along together, so dissimilar metal corrosion is eliminated. Both metals solder well, too. See **Fig 22.101**. Cut the copper tubing to the lengths indicated. Item 9 is a $1^1/_4$-inch nipple cut from the 20-inch length of $^1/_2$-inch tubing. This leaves $18^3/_4$ inches for the $\lambda/4$-matching stub. Item 10 is a $3^1/_4$-inch long nipple cut from the 60-inch length of $^3/_4$-inch tubing. The $^3/_4$-wave element should measure $56^3/_4$ inches long. Remove burrs from the ends of the tubing after cutting, and clean the mating surfaces with sandpaper, steel wool, or emery cloth.

After cleaning, apply a very thin coat of flux to the mating elements and assemble the tubing, elbow, tee, endcaps and stubs. Solder the assembled parts with a propane torch and rosin-core solder. Wipe off excess solder with a damp cloth, being careful not to burn yourself. The copper tubing will hold heat for a long time after you've finished soldering. After soldering, set the assembly aside to cool.

Flatten one each of the $^1/_2$-inch and $^3/_4$-inch pipe clamps. Drill a hole in the flattened clamp as shown in Fig 22.101B. Assemble the clamps and cut off the excess metal from the flattened clamp using the unmodified clamp as a template. Disassemble the clamps.

Assemble the $^1/_2$-inch clamp around the $^1/_4$-wave element and secure with two of the screws, washers, and nuts as shown in Fig 22.101B. Do the same with the $^3/_4$-inch clamp around the $^3/_4$-wave element. Set the clamps initially to a spot about 4 inches above the bottom of the *J* on their respective elements. Tighten the clamps only finger tight, since you'll need to move them when tuning.

TUNING

The J-Pole can be fed directly from 50 Ω coax through a choke balun (3 turns of the feed coax rolled into a coil about 8 inches in diameter and held together with electrical tape). Before tuning, mount the antenna vertically, about 5 to 10 ft above the ground. A short TV mast on a tripod works well for this purpose. When tuning VHF antennas, keep in mind that they are sensitive to nearby objects—such as your body. Attach the feed line to the clamps on the antenna, and make sure all the nuts and screws are at least finger tight. It really doesn't matter to which element ($^3/_4$-wave element or stub) you attach the coaxial center lead. Tune the antenna by moving the two feed-point clamps equal distances a small amount each time until the SWR is minimum at the desired frequency. The SWR will be close to 1:1.

FINAL ASSEMBLY

The final assembly of the antenna will determine its long-term survivability. Perform the following steps with care. After adjusting the clamps for minimum SWR, mark the clamp positions with a pencil and then remove the feed line and clamps. Apply a very thin coating of flux to the inside of the clamp and the corresponding surface of the antenna element where the clamp attaches. Install the clamps and tighten the clamp screws.

Solder the feed line clamps where they are attached to the antenna elements. Now, apply a small amount of solder around the screw heads and nuts where they contact the clamps. Don't get solder on the screw

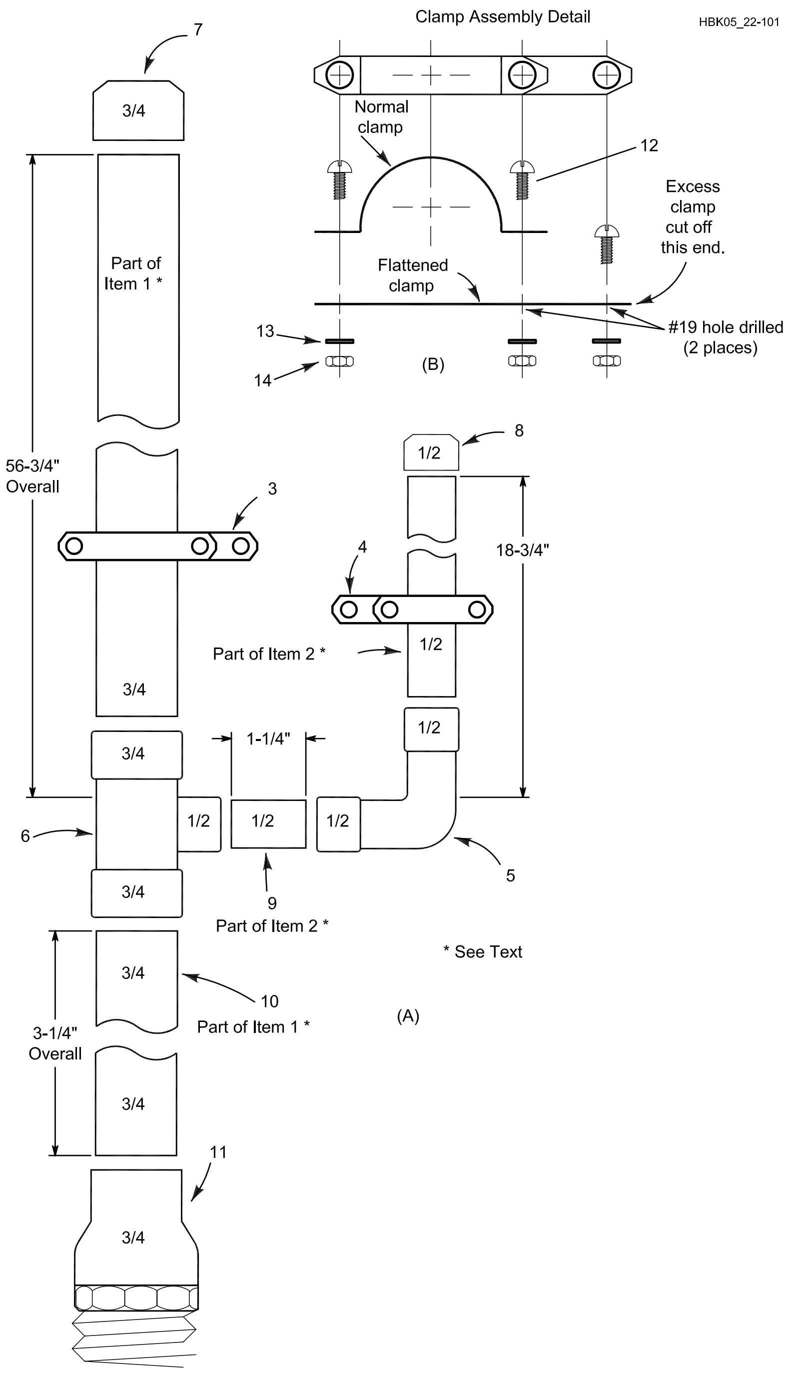


Fig 22.101 — At A, exploded assembly diagram of all-copper J-Pole antenna. At B, detail of clamp assemblies. Both clamp assemblies are the same.

Item	*Qty*	*Part or Material Name*
1	1	$^3/_4$ inch × 10 ft length of rigid copper tubing (enough for 2 antennas, 60 inches per antenna)
2	1	$^1/_2$ inch × 10 ft length of rigid copper tubing (enough for 6 antennas, 20 inches per antenna)
3	2	$^3/_4$ inch copper pipe clamps
4	2	$^1/_2$ inch copper pipe clamps
5	1	$^1/_2$ inch copper elbow
6	1	$^3/_4$ × $^1/_2$ inch copper tee
7	1	$^3/_4$ inch copper end cap
8	1	$^1/_2$ inch copper end cap
9	1	$^1/_2$ × 1$^1/_4$ inch copper nipple (Make from item 2. See text)
10	1	$^3/_4$ × 3$^1/_4$ inch copper nipple (Make from item 1. See text)
11	1	Your choice of coupling to mast fitting ($^3/_4$ × 1 inch NPT used at KD8JB)
12	6	# 8-32 × $^1/_2$ inch brass machine screws (round, pan, or binder head)
13	6	# 8 brass flat washers
14	6	# 8-32 brass hex nuts

threads! Clean away excess flux with a non-corrosive solvent.

After final assembly and erecting/mounting the antenna in the desired location, attach the feed line and secure with the remaining washer and nut. Weatherseal this joint with RTV. Otherwise, you may find yourself repairing the feed line after a couple years.

ON-AIR PERFORMANCE

The author had no problem working various repeaters around town with a $^{1}/_{4}$-wave antenna, but simplex operation left a lot to be desired. The J-Pole performs just as well as a Ringo Ranger, and significantly better than the $^{1}/_{4}$-wave ground-plane vertical.

VHF/UHF Yagis

Without doubt, the Yagi is king of home-station antennas these days. Today's best designs are computer optimized. For years amateurs as well as professionals designed Yagi arrays experimentally. Now we have powerful (and inexpensive) personal computers and sophisticated software for antenna modeling. These have brought us antennas with improved performance, with little or no element pruning required.

A more complete discussion of Yagi design can be found earlier in this chapter. For more coverage on this topic and on stacking Yagis, see the most recent edition of *The ARRL Antenna Book*.

3 AND 5-ELEMENT YAGIS FOR 6 M

Boom length often proves to be the deciding factor when one selects a Yagi design. ARRL Senior Assistant Technical Editor Dean Straw, N6BV, created the designs shown in **Table 22.24**. Straw generated the designs in the table for convenient boom lengths (6 and 12 ft). The 3-element design has about 8 dBi gain, and the 5-element version has about 10 dBi gain. Both antennas exhibit better than 22 dB front-to-rear ratio, and both cover 50 to 51 MHz with better than 1.6:1 SWR.

Element lengths and spacings are given in the table. Elements can be mounted to the boom as shown in **Fig 22.102**. Two muffler clamps hold each aluminum plate to the boom, and two U bolts fasten each element to the plate, which is 0.25 inches thick and 4·4 inches square. Stainless steel is the best choice for hardware, however, galvanized hardware can be substituted. Automotive muffler clamps do not work well in this application, because they are not galvanized and quickly rust once exposed to the weather.

The driven element is mounted to the boom on a Bakelite plate of similar dimension to the other mounting plates. A 12-inch piece of Plexiglas rod is inserted into the driven element halves. The Plexiglas allows the use of a single clamp on each side of the element and also seals the center of the elements against moisture. Self-tapping screws are used for electrical connection to the driven element.

Refer to **Fig 22.103** for driven element and Hairpin match details. A bracket made from a piece of aluminum is used to mount the three SO-239 connectors to the driven element plate. A 4:1 transmission-line balun connects the two element halves, transforming the 200-Ω resistance at the Hairpin match to 50 Ω at the center connector. Note that the electrical length of the balun is λ/2, but the physical length

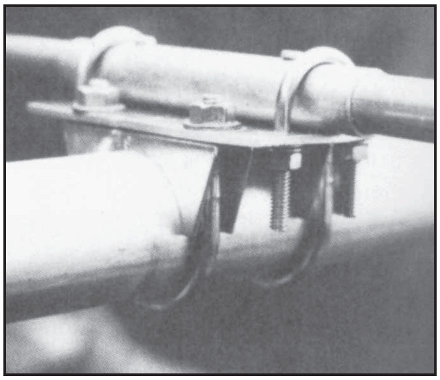


Fig 22.102 — The element-to-boom clamp. Galvanized U bolts are used to hold the element to the plate, and 2-inch galvanized muffler clamps hold the plates to the boom.

Table 22.24

Optimized 6-m Yagi Designs

	Spacing From Reflector (in.)	*Seg 1 Length (in.)*	*Seg 2 Length (in.)*	*Midband Gain F/R*
306-06				
Refl	0	36	22.500	8.1 dBi
DE	24	36	16.000	28.3 dB
Dir 1	66	36	15.500	
506-12				
OD		0.750	0.625	
Refl	0	36	23.625	10.0 dBi
DE	24	36	17.125	26.8 dB
Dir 1	36	36	19.375	
Dir 2	80	36	18.250	
Dir 3	138	36	15.375	

Note: For all antennas, telescoping tube diameters (in inches) are: Seg1=0.750, Seg2=0.625. See figure 22.66 for element details.

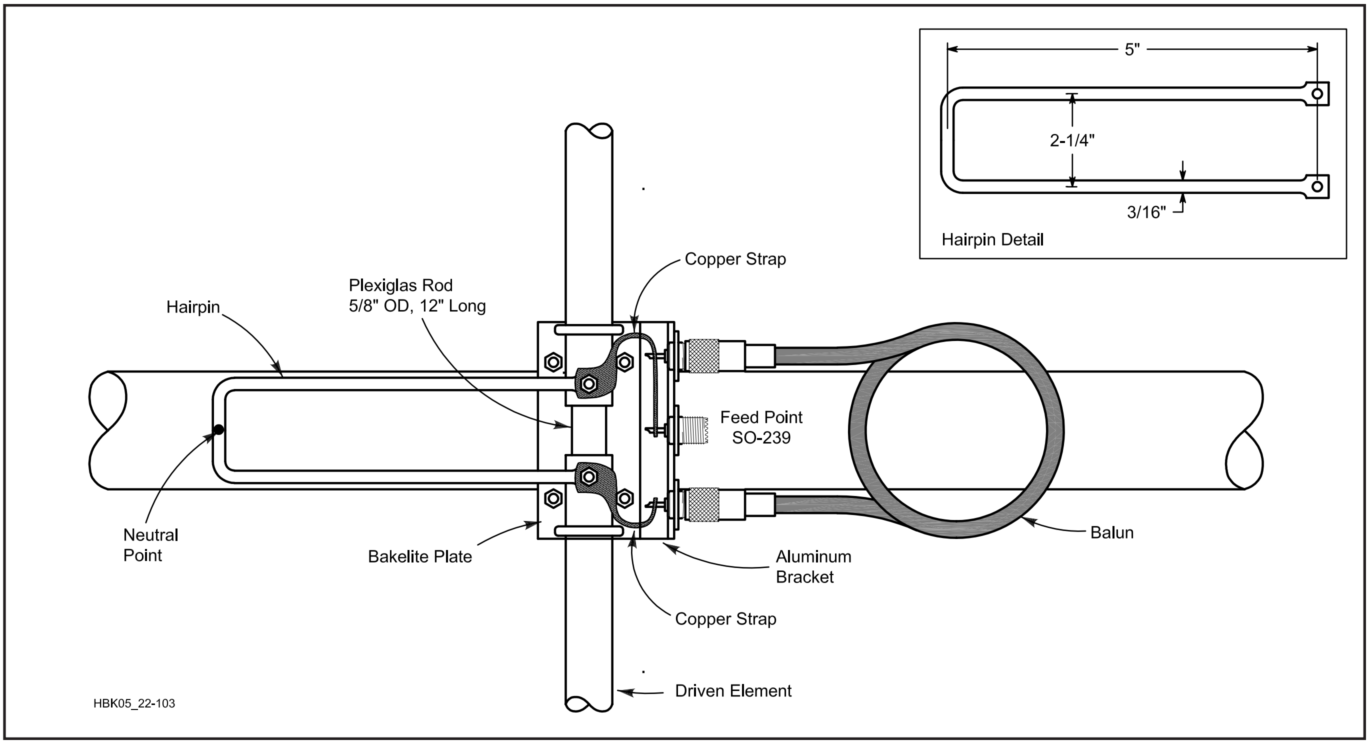


Fig 22.103 — Detailed drawing of the feed system used with the 50-MHz Yagi. Balun lengths: For cable with 0.80 velocity factor — 7 ft, $10^3/_8$ in. For cable with 0.66 velocity factor — 6 ft, $5^3/_4$ in.

will be shorter due to the velocity factor of the particular coaxial cable used. The Hairpin is connected directly across the element halves. The exact center of the hairpin is electrically neutral and should be fastened to the boom. This has the advantage of placing the driven element at dc ground potential.

The Hairpin match requires no adjustment as such. However, you may have to change the length of the driven element slightly to obtain the best match in your preferred portion of the band. Changing the driven-element length will not adversely affect antenna performance. *Do not adjust the lengths or spacings of the other elements—they are optimized already*. If you decide to use a gamma match, add 3 inches to each side of the driven element lengths given in the table for both antennas.

A MEDIUM GAIN 2-M YAGI

This project was designed and built by L. B. Cebik, W4RNL. Practical Yagis for 2 meters abound. What makes this one a bit different is the selection of materials. The elements, of course, are high-grade aluminum. However, the boom is PVC and there are only two #6 nut-bolt sets and two #8 sheet metal screws in the entire antenna. The remaining fasteners are all hitch-pin clips. The result is a very durable 6-element Yagi that you can disassemble with fair ease for transport.

THE BASIC ANTENNA DESIGN

The 6-element Yagi presented here is a derivative of the *optimized wide-band antenna* (OWA) designs developed for HF use by NW3Z and WA4FET. **Fig 22.104** shows the general outline. The reflector and first director largely set the impedance. The next 2 directors contribute to setting the operating bandwidth. The final director (Dir. 4) sets the gain. This account is over-simplified, since every element plays a role in every facet of Yagi performance. However, the notes give some idea of which elements are most sensitive in adjusting the performance figures.

Designed on *NEC-4*, the antenna uses 6 elements on a 56 inch boom. **Table 22.25** gives the specific dimensions for the version described in these notes. The parasitic elements are all $^3/_{16}$-inch aluminum rods. For ease of construction, the driver is $^1/_2$-inch aluminum tubing. Do not alter the element diameters without referring to a source, such as RSGB's *The VHF/UHF DX Book*, edited by Ian White, G3SEK, (Chapter 7), for information on how to recalculate element lengths.

The driver is the simplest element to readjust. Table 22.25 shows an alternative driver using $^3/_{16}$-inch diameter material. Of all the elements, the driver is perhaps the only one for which you may extrapolate reasonable lengths for other diameters from the two lengths and diameters shown. However, the parasitic elements may require more work than merely substituting one diameter and length for another. The lower portion of the table shows the design adjusted for $^1/_8$-inch elements throughout. Not all element lengths change by the same amount using any single formula.

The OWA design provides about 10.2 dBi of free-space gain with better than 20 dB front-to-back (or front-to-rear) ratio across the entire 2-m band. Azimuth (or E-plane) patterns show solid performance across the entire band. This applies not only to forward gain but rejection from the rear.

One significant feature of the OWA design is its direct 50-Ω feedpoint impedance that requires no matching network. Of course, a choke balun to suppress any currents on the feedline is desirable, and a simple bead-choke of W2DU design works well in this application. The SWR, shown in **Fig 22.105**, is very flat across the band and never reaches 1.3:1. The SWR and the pattern consistency together create a very useful utility antenna for 2 m, whether installed vertically or horizontally. The only remaining question is how to effectively build the beam in the average home shop.

THE BEAM MATERIALS

The boom is Schedule 40, 1/2-inch nominal PVC. Insulated booms are good for test antennas, since they do not require recalculating the element lengths due to the effects of a metal boom.

White PVC stands up for a decade of exposure in Tennessee, but apparently does not do as well in every part of the US. You may wish to use the gray electrical conduit version. If you use any other material for your boom, be sure that it is UV-protected. You'll find a parts list in **Table 22.26**. Sources for the parts are given in the table. However, you are encouraged to develop your own sources for antenna materials.

Fig 22.106 shows the element layout

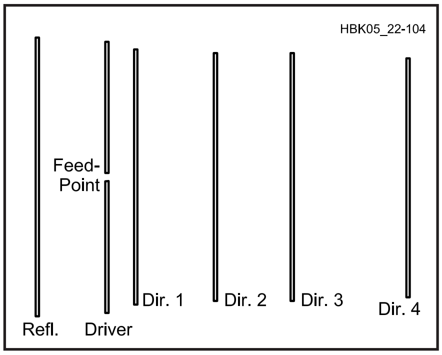


Fig 22.104 — The general outline of the 2-m 6-element OWA Yagi. Dimensions are given in Table 22.25.

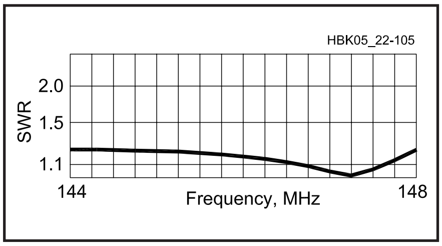


Fig 22.105 — SWR curve as modeled on *NEC-4* for the 2-m 6-element OWA Yagi.

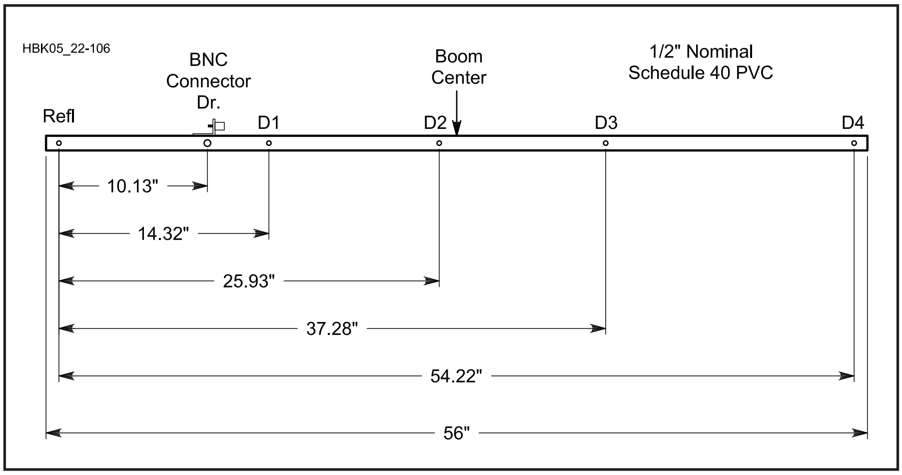


Fig 22.106 — Layout of elements along the PVC boom for the 2-m 6-element OWA Yagi, showing placement of the BNC connector and the boom center.

Table 22.25

2-m OWA Yagi Dimensions

Element	*Element Length in Inches*	*Spacing from Reflector in Inches*	*Element Diameter in Inches*
Version described here:			
Refl.	40.52	——	0.1875
Driver	39.70	10.13	0.5
(Alt. Driver	*39.96*	*10.13*	*0.1875)*
Dir. 1	37.36	14.32	0.1875
Dir. 2	36.32	25.93	0.1875
Dir. 3	36.32	37.28	0.1875
Dir. 4	34.96	54.22	0.1875
Version using 1/8-inch diameter elements throughout:			
Refl.	40.80	——	0.125
Driver	40.10	10.20	0.125
Dir. 1	37.63	14.27	0.125
Dir. 2	36.56	25.95	0.125
Dir. 3	36.56	37.39	0.125
Dir. 4	35.20	54.44	0.125

Table 22.26

Parts List for the 2-Meter OWA Yagi

Qty	*Item*
17'	0.1875" (3/16") 6061-T6 aluminum rod (Source: Texas Towers)
3.5'	0.5" (1/2") 6063-T832 aluminum tubing (Source: Texas Towers)
7'	Schedule 40, 1/2" PVC pipe (Source: local hardware depot)
3	Schedule 40, 1/2" PVC Tee connectors (Source: local hardware depot)
2	Schedule 40, 1/2" PVC L connectors (Source: local hardware depot) depot)
—	Miscellaneous male/female threaded pipe diameter transition fittings (Source: local hardware depot)
1	Support mast
10	Stainless steel hitch-pin clips (hairpin cotter pins), 3/16" to 1/4" shaft range, 0.04" "wire" diameter (McMasters-Carr part number 9239A024)
2	Stainless steel #6 nut/bolt/lock-washer sets, bolt length 1" (Source: local hardware depot)
2	Stainless steel #8 sheet metal screws (Source: local hardware depot)
1	BNC connector (Source: local electronics outlet)
2"	1/16" thick aluminum L-stock, 1" per side (Source: local hardware depot)
1	VHF bead-balun choke (Source: Wireman, Inc.)

along the 56-inch boom. Centering the first element hole 1 inch from the rear end of the boom results in a succession of holes for the 3/16-inch pass-through parasitic elements. Only the driver requires special treatment. We shall use a 3/8-inch hole to carry a short length of fiberglass rod that will support the two sides of the driver element. Note that I used a BNC connector, mounted on a small plate that we shall meet along the way.

The boom is actually a more complex structure than initially meets the eye. You need a support for the elements, and a means of connecting the boom to the mast. If you break the boom in the middle to install a Tee connector for the mast junction, you come very close to the 2nd director. **Fig 22.107** shows how to avoid the predicament.

Before drilling the boom, assemble it from common Schedule 40 1/2-inch fittings and insert the lengths of PVC pipe. Fig 22.107 shows the dimensions for the center section of the boom assembly. However, PVC dimensions are always *nominal*, that is, meeting certain minimum size standards. So you may have to adjust the lengths of the linking pieces slightly to come up with a straight and true boom assembly.

Use scrap lumber to help keep everything aligned while cementing the pieces together. A 1×4 and a 1×6 nailed together along the edges produces a very good platform with a right-angle. Start with the two upper Tees and the Ls below each one. Dry-fit scrap PVC into the openings except for the short link that joins the fitting. Cement these in place and align them using the dry-fit pieces as guides to keep everything parallel. Next, cement the two short (2 3/4-inch) links into the third Tee. Then, cement one link into its L, using the dry-fit tube in the upper Tee as an alignment guide.

Before proceeding further, carefully measure the required length of PVC for the boom section between Tees. How well you measure here will determine whether the boom will be straight or whether it will bow up or down. Now, cement both the L and the Tee at the same time, pressing the cemented sections into the 2-board jig to assure alignment.

The final step in the process is to add the 23-inch boom end pieces to the open ends of the upper Tees. For the brief period in which the PVC cement is wet, it is possible to misalign the tubing. Dry-fit end caps on the boom ends and do the cement work using the 2-board jig. By pressing the assembly into the right angle of the boards, you can assure that you have a very true boom. When you've put the PVC cement back onto its shelf, your boom should be ready to drill.

Consider the boom-to-mast connection. The lower Tee in Fig 22.107 receives a short length of 1/2-inch nominal Schedule 40 PVC. This material has an outside diameter of about 7/8-inch, not a useful size for joining to a mast. However, PVC fittings have a handy series of threaded couplers that allow you to screw-fit a series of ever-larger sizes until you reach a more useful size. As **Fig 22.108B** shows, enough of these fittings will finish off with a 1 1/4-inch threaded female side and a 1 1/4-inch cement-coupling side. To this fitting, cement a length of 1 1/4-inch tubing that slides over a length of common TV mast. For a tight fit, wrap the TV mast with several layers of electrical tape in two places—one near the upper end of the PVC pipe section and the other close to where the PVC pipe ends. You may then use stainless steel through-bolts or set-screws to prevent the PVC assembly from turning.

BOOM AND ELEMENTS

Before installing the elements, you need to drill the holes in the boom. The two-board jig comes in handy once more. The key goals in the drilling process are to: A) precisely position the holes; B) create holes that are a fairly tight fit for the rod elements; and C) keep the elements aligned in a flat plane. For this purpose, a drill press is almost a necessity for all but those with the truest eyes.

Use the jig and a couple of clamps to

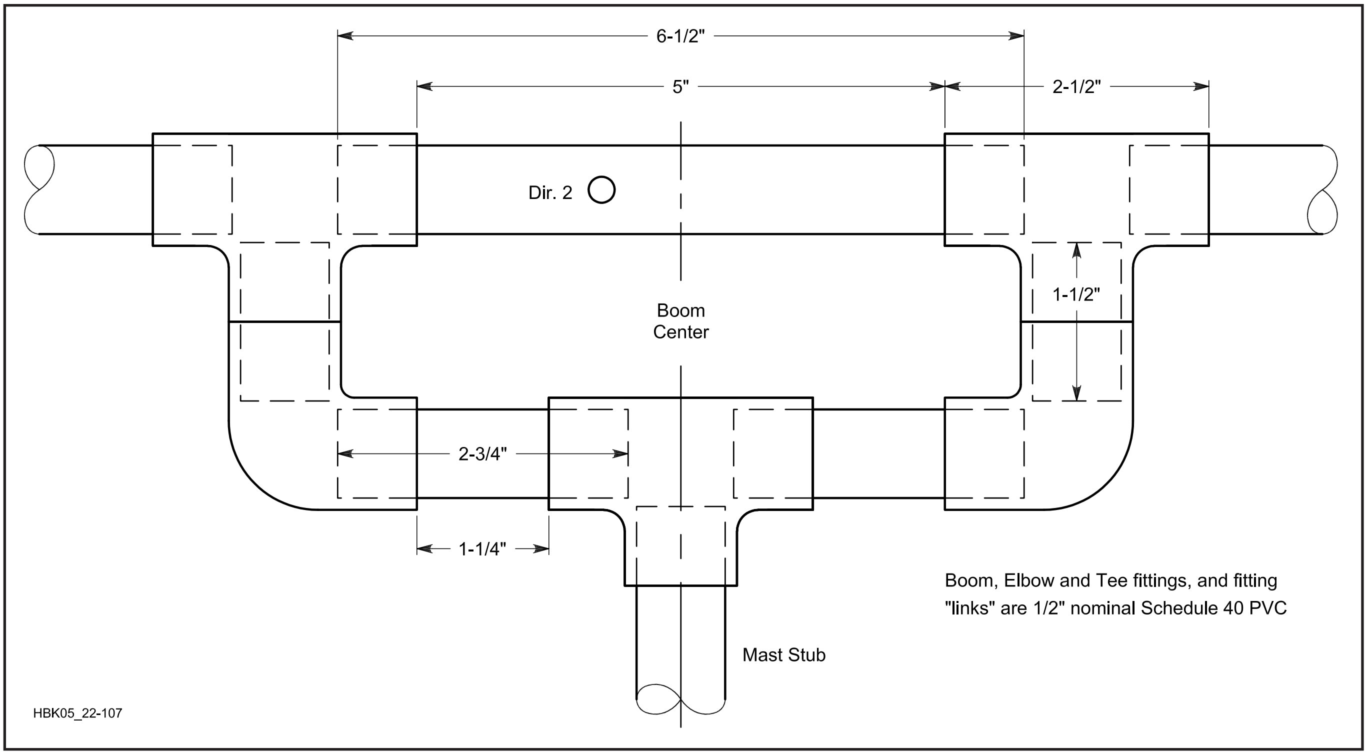
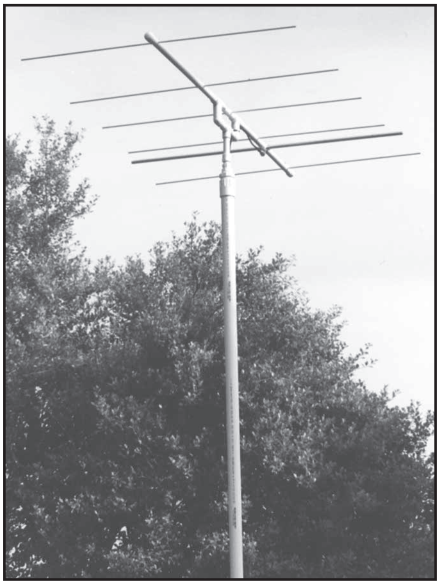


Fig 22.107 — Details of a parallel PVC pipe structure for the Yagi boom and mount.

hold the boom assembly in place. Because the assembly has two parallel sections, laying it flat will present the drill press with the correct angle for drilling through the PVC in one stroke. Drill the holes at premarked positions, remembering that the driver hole is 3/8 inch while all the others are 3/16 inch. Clean the holes, but do not enlarge them in the process.


(A)


(B)

Fig 22.108 — The completed Yagi is shown at A. A close-up view of the parallel PVC boom and mount, the sequence of threaded fittings, and the hitch-pin clips used to secure parasitic elements is shown at B.

By now you should have the rod and tube stock in hand. For antenna elements, don't rely on questionable materials that are designed for other applications. Rather, obtain 6063-T832 tubing and 6061-T6 rods from mail order sources, such as Texas Towers, McMasters-Carr, and others. These materials are often not available at local hardware depots.

Cut the parasitic elements to length and smooth their ends with a fine file or sandpaper. Find the center of each element and carefully mark a position about 1/16" outside where the element will emerge from each side of the boom. You'll drill small holes in these locations. You may wish to very lightly file a flatted area where the hole is to go to prevent the drill bit from slipping as you start the hole.

Drill 1/16-inch holes at each marked location all the way through the rod. De-burr the exit ends so that the rod will pass through the boom hole. These holes are the locations for hitch-pin clips. **Fig 22.109** shows the outline of a typical hitch-pin clip, which is also called a hairpin cotter pin in some catalogs and stores. Obtain stainless steel pins whose bodies just fit tightly over the rod when installed. Initially, install 1 pin per parasitic element. Slide the element through the correct boom hole and install the second pin. Although the upper part of the drawing shows a bit of room between the boom and pin, this space is for clarity. Install the pins as close to each side of the boom as you can.

Pins designed for a 3/16-inch rod are small enough that they add nothing significant to the element, and antenna tests showed that they did not move the performance curve of the antenna. Yet, they have held securely through a series of shock tests given to the prototype. These pins—in various sizes—offer the home builder a handy fastener that is applicable to many types of portable or field antennas. Although you may wish to use better fasteners when making permanent metal-to-metal connections, for joining sections of Field Day and similar antennas, the hitch-pin clips perform the mechanical function, while clean tubing sections themselves provide adequate electrical contact for a limited period of use.

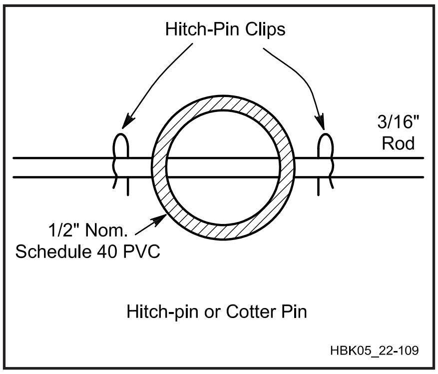


Fig 22.109 — The parasitic element mounting system, showing the placement of the hitch-pin clips and the shape of the clips.

THE DRIVER AND FEEDLINE CONNECTOR

The final construction step is perhaps the one requiring the most attention to detail, as shown in **Fig 22.110**. The driver and feedpoint assembly consists of a 4- to 6-inch length of 3/8-inch fiberglass or other non-conductive rod, two sections of the driver element made from 1/2-inch aluminum tubing, a BNC connector, a homemade mounting plate, two sets of stainless steel #6 nuts, bolts, and lock-washers, and two stainless steel #8 sheet metal screws. Consult both the upper and lower portions of the figure, since some detail has been omitted from each one to show other detail more clearly.

First, trial fit the driver tubing and the fiberglass rod, marking where the rod exits the boom. Now pre-drill 9/64-inch holes through the tubing and the fiberglass rod. Do not use larger hardware, since the resulting hole will weaken the rod, possibly to the breaking point. If you use an alternative plastic material, observe the same caution and be certain that the rod remains strong after drilling. Do not use wooden dowels for this application, since they do not have sufficient strength. Position the holes about 1/4 to 3/8 inch from the tubing end where it presses against the boom. One hole will receive a solder lug and the other will connect to an extension of the BNC mounting plate.

Second, install the fiberglass rod through the boom. You can leave it loose, since the elements will press against boom and hold it in place. Alternatively, you may glue it in place with a 2-part epoxy. Slide the driver element tubes over the rod and test the holes for alignment by placing the #6 bolts in them.

Next, cut and shape the BNC mounting plate from 1/16-inch thick aluminum. I made my fitting from a scrap of L-stock 1 inch on a side. Before cutting the stock, I drilled the 3/8-inch hole needed for the BNC connector. Then I cut the vertical portion. The horizontal portion requires a curved tab that reaches the bolt on one side of the boom. I used bench vise to bend the tab in a curve and then flatten it for the bolt-hole. It takes several tries to get the shape and tab exact, so be patient. When the squared-edge piece found its perfect

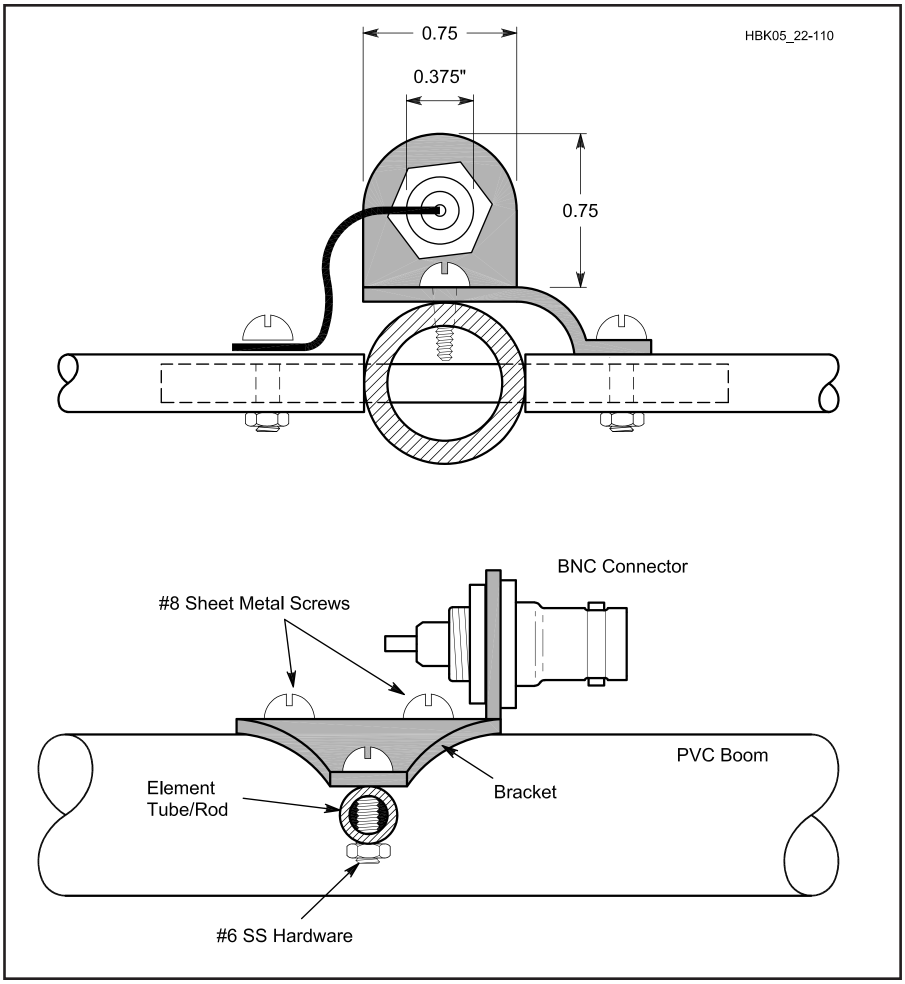


Fig 22.110 — Details of the feedpoint of the Yagi, showing the BNC connector, mounting plate, and connections to the 1/2-inch driver element halves placed over a central 3/8-inch fiberglass rod.

shape, I took it to a disk sander and rounded the vertical piece to follow the connector shape. I also tapered the tap edges to minimize excess material. The last step is to drill the mounting holes that receive the #8 sheet metal screws.

Mounting the assembly involves loosely attaching both the #6 and #8 hardware and alternatively tightening up all pieces. Be certain that the side of the BNC connector that receives the coax points toward the mast. Next, mount the BNC connector. The shield side is already connected to one side of the driver. Mount the other side of the driver, placing a solder lug under the bolt head. Connect a short wire as directly as possible from the solder lug to the center pin of the BNC connector. After initial testing, you may coat all exposed connections with Plasti-Dip for weather protection.

TUNE-UP

Testing and tuning the antenna is a simple process if you build carefully. The only significant test that you can perform is to ensure that the SWR curve comes close to the one shown in Fig 22.105. If the SWR is high at 148 MHz but very low at 144 MHz, then you will need to shorten the driver ends by a small amount—no more than 1/8 inch per end at a time. I found that shaving the ends with a disk sander was most effective.

Using the antenna with vertical polarization will require good spacing from any support structure with metal vertical portions. One of the easiest ways to devise such a mounting is to create a PVC structure that turns the entire boom by 90 degrees. If you feel the need for added support, you can create an angular brace by placing 45-degree connectors in both the vertical and horizontal supports and running a length of PVC between them.

As an alternative, you can let the rear part of the boom be slightly long. To this end you can cement PVC fixtures—including the screw-thread series to enlarge the support pipe size. Create a smooth junction that you attach with a through-bolt instead of cement. By drilling one side of the connection with two sets of holes, 90-degrees apart, you can change the antenna from horizontal polarization to vertical and back in short order.

The 6-element OWA Yagi for 2 meters performs well. It serves as a good utility antenna with more gain and directivity than the usual 3-element general-use Yagi. When vertically polarized, the added gain confirms the wisdom of using a longer boom and more elements. With a length under 5 feet, the antenna is still compact. The ability to disassemble the parts simplifies moving the antenna to various portable sites.

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