

Antennas & Projects

20

ANTENNA BASICS

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.

The amount of available space should be high on the list of factors to consider when selecting an antenna. Those who live in urban areas often must accept a compromise antenna for the HF bands because a city lot won't accommodate full-size wire dipoles, end-fed systems or high supporting structures. Other limitations are imposed by the amount of money available for an antenna system (including supporting hardware), the number of amateur bands to be worked and local zoning ordinances.

Operation objectives also come into play. Do you want to dedicate yourself to serious contesting and DXing? Are you looking for general-purpose operation that will yield short- and long-haul QSOs during periods of good propagation? Your answers should result in selecting an antenna that will meet your needs. You might want to erect the biggest and best collection of antennas that space and finances will allow. If a modest system is the order of the day, then use whatever is practical and accept the performance that follows. Practically any radiator works well under some propagation conditions, assuming the radiator is able to accept power and radiate it at some useful angle. Any antenna is a good one if it meets your needs!

In general, the height of the antenna above ground is the most critical factor at the higher end of the HF spectrum, that is from roughly 14 through 30 MHz. This is because the antenna should be clear of conductive objects such as power lines, phone wires, gutters and the like, plus high enough to have a low radiation angle. Lower frequency antennas, operating between 2 and 10 MHz, should also be kept well away from conductive objects and as high above ground as possible if you want good performance.

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. *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 an antenna at a right angle to the earth (vertical) 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. 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. On multihop transmissions, in which the signal is refracted more than once from the ionosphere, and subsequently reflected from the Earth's surface during its travel, considerable polarization shift will occur. 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 good 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, 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 $\frac{1}{4} \lambda$. The 75- Ω feed-point impedance is most likely to be realized in a practical installation when the horizontal dipole is approximately $\frac{1}{2}$, $\frac{3}{4}$ or 1 wavelength above ground. Coax cable having a 50- Ω characteristic impedance is the most common transmission line used in amateur work.

Fig 20.1 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 0.2λ . 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 0.15λ , 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 $\frac{1}{4} \lambda$.

Conductor Size

The impedance of the antenna also depends on the diameter of the conductor in relation to the wavelength, as indicated in **Fig 20.2**. 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 into account those losses.

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,

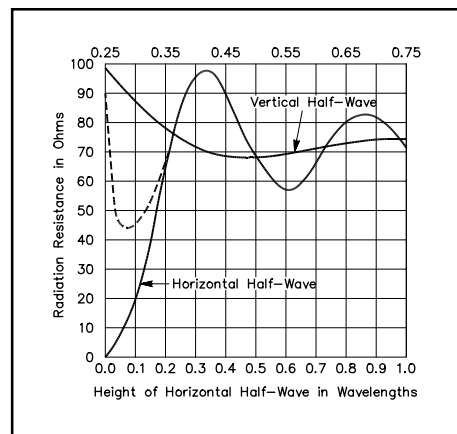


Fig 20.1—Curves showing the radiation resistance of vertical and horizontal half-wavelength dipoles at various heights above ground. The broken-line portion of the curve for a horizontal dipole shows the resistance over “average” real earth, the solid line for perfectly conducting ground.

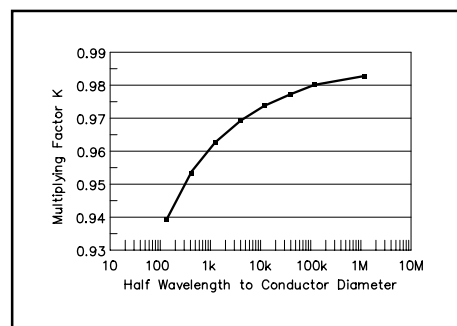


Fig 20.2—Effect of antenna diameter on length for half-wavelength resonance, shown as a multiplying factor, K, to be applied to the free-space, half-wavelength equation (Eq 1 in text).

if placed in the center of an imaginary sphere, evenly illuminate that sphere with radiation. The isotropic radiator is an unambiguous standard, and so is 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 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 20.1, 20.2** and **20.3** 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, 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 20.3** shows this effect at work in horizontal dipole antennas.

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 20.4**, where the eleva-

Table 20.1
Optimum Elevation Angles to Europe

<i>Band</i>	<i>Northeast</i>	<i>Southeast</i>	<i>Upper Midwest</i>	<i>Lower Midwest</i>	<i>West Coast</i>
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 20.2
Optimum Elevation Angles to Far East

<i>Band</i>	<i>Northeast</i>	<i>Southeast</i>	<i>Upper Midwest</i>	<i>Lower Midwest</i>	<i>West Coast</i>
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 20.3
Optimum Elevation Angles to South America

<i>Band</i>	<i>Northeast</i>	<i>Southeast</i>	<i>Upper Midwest</i>	<i>Lower Midwest</i>	<i>West Coast</i>
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°

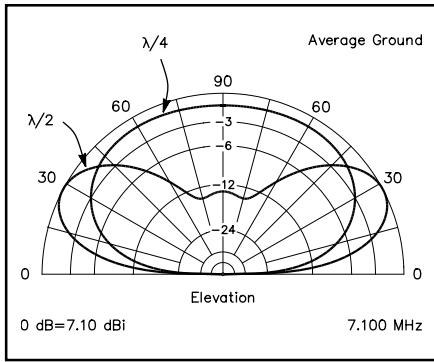


Fig 20.3—Elevation patterns for two 40-m dipoles over average ground (conductivity of 5 mS/m and dielectric constant of 13) at $\frac{1}{4} \lambda$ (33 ft) and $\frac{1}{2} \lambda$ (66 ft) heights. The higher dipole has a peak gain of 7.1 dBi at an elevation angle of about 26°, while the lower dipole has more response at high elevation angles.

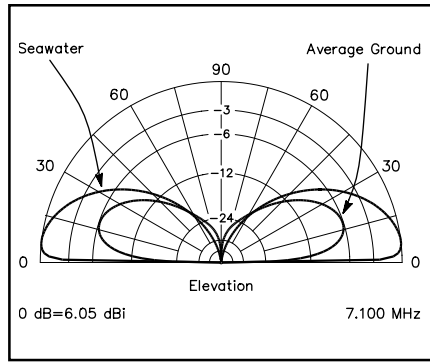


Fig 20.4—Elevation patterns for a vertical dipole over sea water compared to average ground. In each case the center of the dipole is just over $\frac{1}{4} \lambda$ high. The low-angle response is greatly degraded over average ground compared to sea water, which is virtually a perfect ground.

tion 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.

A vertical antenna may work well at HF 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

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

The actual length of a resonant $1/2\text{-}\lambda$ 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 20.2, 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 (end effect). The following formula is sufficiently accurate for wire antennas for frequencies up to 30 MHz.

$$\text{Length of half - wave antenna (ft)} = \frac{492 \times 0.95}{f(\text{MHz})} = \frac{468}{f(\text{MHz})} \quad (2)$$

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 20.2.

$$\text{Length of half - wave antenna (ft)} = \frac{492 \times K}{f(\text{MHz})} \quad (3)$$

$$\text{length (in.)} = \frac{5904 \times K}{f(\text{MHz})} \quad (4)$$

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

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

From equation 1 the ratio of half wavelength to conductor diameter (changing wavelength to inches) is

$$\frac{(9.82 \times 12)}{0.5 \text{ inch}} = 235.7$$

From Fig 20.2, K = 0.965 for this ratio. The length of the antenna, from equation 3 is

$$\frac{492 \times 0.965}{50.1} = 9.48 \text{ ft}$$

or 9 ft $5^{3/4}$ inches. The answer is obtained directly in inches by substitution in equation 4

$$\frac{5904 \times 0.965}{50.1} = 113.7 \text{ inches}$$

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](#) and [Station Setup](#) chapters.

Radiation Characteristics

The radiation pattern of a dipole antenna in free space is strongest at right angles to the wire (**Fig 20.5**). This figure-8 pattern appears in the real world if the dipole is $\frac{1}{2}\lambda$ 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 20.5. Minimum horizontal radiation occurs off the ends of the dipole if the antenna is parallel to the earth.

As an antenna is brought closer to ground, the elevation pattern peaks at a higher elevation angle as shown in [Fig 20.3](#). **Fig 20.6** illustrates what happens to the directional pattern as antenna height changes. Fig 20.6C shows that there is significant radiation off the ends of a low horizontal dipole. For the $\frac{1}{2}\lambda$ 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 $\frac{1}{4}$ -inch foam-dielectric cables only for low power (25 W or less) HF transmissions. Solid-dielectric $\frac{1}{4}$ -inch cables are okay for 300 W if the SWR is low. For high-power installations, use $\frac{1}{2}$ -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

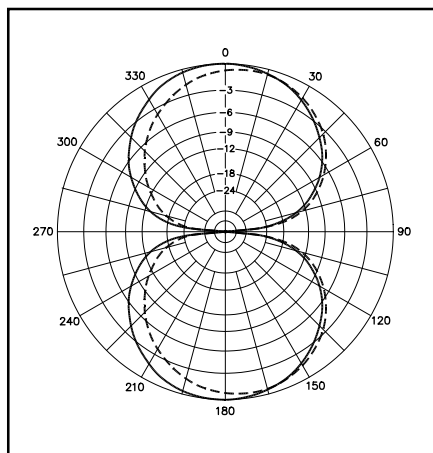


Fig 20.5—Response of a dipole antenna in free space, where the conductor is along 90° to 270° axis, solid line. If the currents in the halves of the dipole are not in phase, slight distortion of the pattern will occur, broken line. This illustrates case where balun is not used on a balanced antenna fed with unbalanced line.

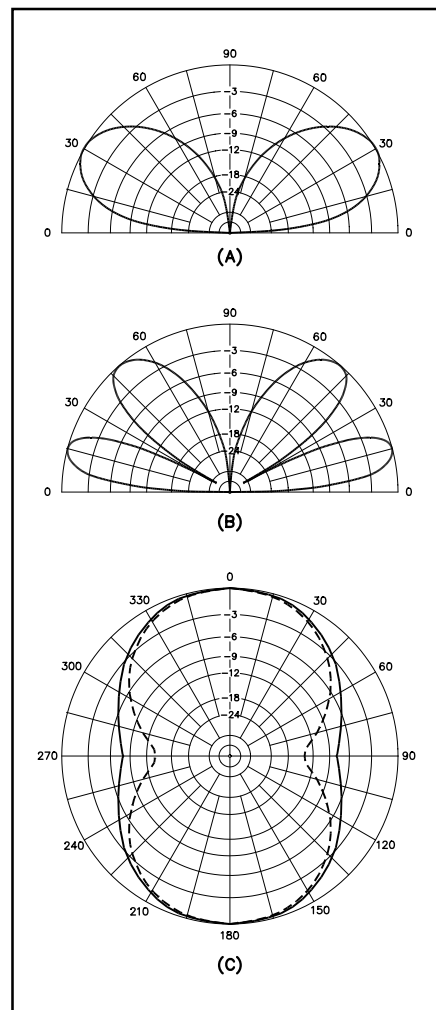


Fig 20.6—At A, elevation response pattern of a dipole antenna placed $\frac{1}{2}\lambda$ above a perfectly conducting ground. At B, the pattern for the same antenna when raised to one wavelength. For both A and B, the conductor is coming out of the paper at right angle. C shows the azimuth patterns of the dipole for the two heights at the most-favored elevation angle, the solid-line plot for the $\frac{1}{2}\lambda$ height at an elevation angle of 30°, and the broken-line plot for the 1λ height at an elevation angle of 15°. The conductor in C lies along 90° to 270° axis.

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 (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 feed-points), a balun should be used at the feed-point when a dipole is fed with coax. When coax feeds a dipole directly (as in **Fig 20.7**), 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.

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.

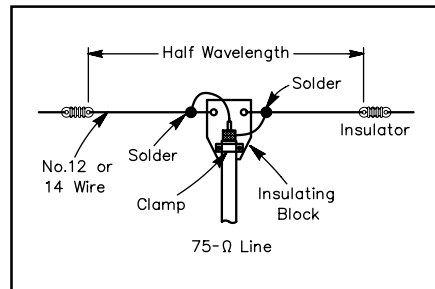


Fig 20.7—Method of affixing feed line to the center of a dipole antenna. A plastic block is used as a center insulator. The coax is held in place by a clamp. A balun is often used to feed dipoles or other balanced antennas to ensure that the radiation pattern is not distorted. See text for explanation.

Practical Dipole Antennas

A classic dipole antenna is $\frac{1}{2}\lambda$ 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 20.8A**) 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 $\frac{1}{8}\lambda$ 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 $\frac{1}{4}\lambda$ of open-wire feed line (see **Fig 20.8B**). 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 .

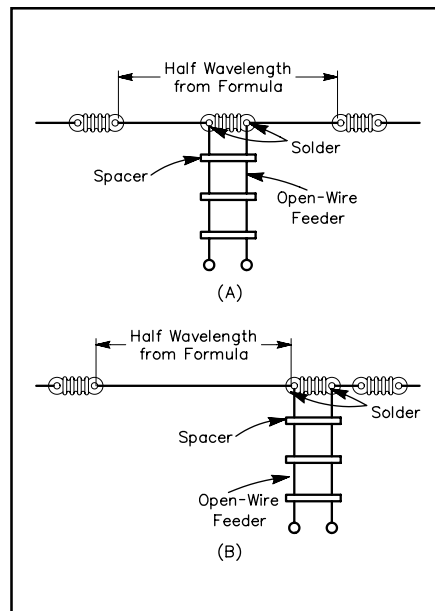


Fig 20.8—Center-fed multiband “Zepp” antenna (A) and an end-fed Zepp at (B).

Most dipoles require a little pruning to reach the desired resonant frequency. Here's a technique to speed the adjustment.

How much to prune: When assembling the antenna, cut the wire 2 to 3% longer than the calculated length and record the length. When the antenna is complete, raise it 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.

Loose ends: Here's another trick, if you use nonconductive end support lines. When assembling the antenna, mount the end insulators in about 5% from the ends. Raise the antenna and let the ends hang free. Figure how much to prune and cut it from the hanging ends. If the pruned ends are very long, wrap them around the insulated line for support.

Dipole Orientation

Dipole antennas need not be installed in a horizontal straight line. They are generally tolerant of bending, sloping or drooping as required by the antenna site. Remember, however, 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.

A *sloping dipole* is shown in Fig 20.9. 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 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.

An *Inverted V* antenna appears in Fig 20.10. While "V" accurately describes the shape of this antenna, this antenna should not be confused with long-wire V antennas, which are highly direc-

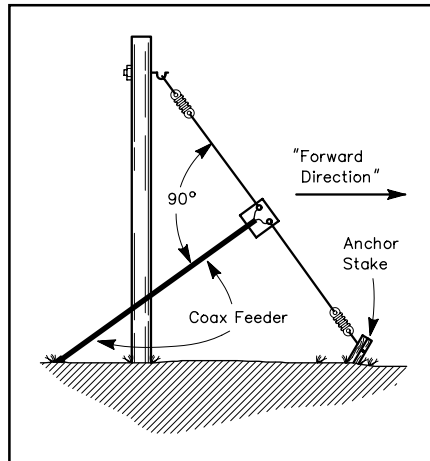


Fig 20.9—Example of a sloping $\frac{1}{2}\lambda$ dipole, or "full sloper." On the lower HF bands, maximum radiation over poor to average earth is off the sides and in the "forward direction" as indicated, if a nonconductive support is used. A metal support will alter this pattern by acting as a parasitic 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 guy wires.

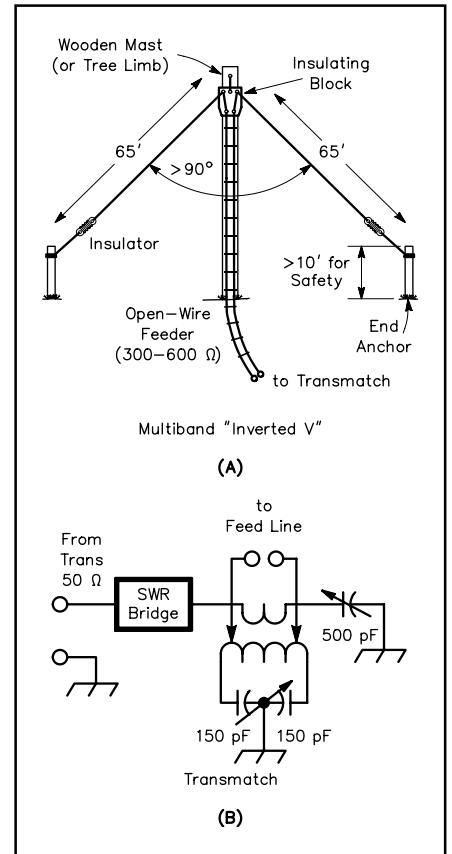


Fig 20.10—At A, details for an inverted V fed with open-wire line for multiband HF operation. A Transmatch is shown at B, suitable for matching the antenna to the transmitter over a wide frequency range. The included angle between the two legs should be greater than 90° for best performance.

tive. 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.

Bent dipoles may be used where antenna space is at a premium. **Fig 20.11** shows several possibilities; there are many more. Bending distorts the radiation pattern somewhat and may affect the impedance as well, but compromises are acceptable when the situation demands them. When an antenna bends back on itself (as in Fig 20.11B) some of the signal is canceled; avoid this if possible.

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. Be safe! Keep any bends, sags or hanging ends well clear of conductors (especially power lines) and combustibles, and beyond the reach of persons.

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.

Parallel dipoles are a simple and convenient answer. See **Fig 20.12**. 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-k Ω 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

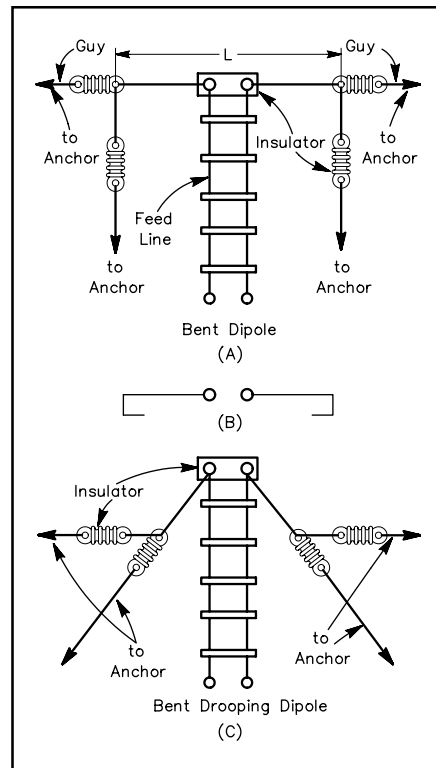


Fig 20.11—When limited space is available for a dipole antenna, the ends can be bent downward as shown at A, or back on the radiator as shown at B. The inverted V at C can be erected with the ends bent parallel with the ground when the available supporting structure is not high enough.

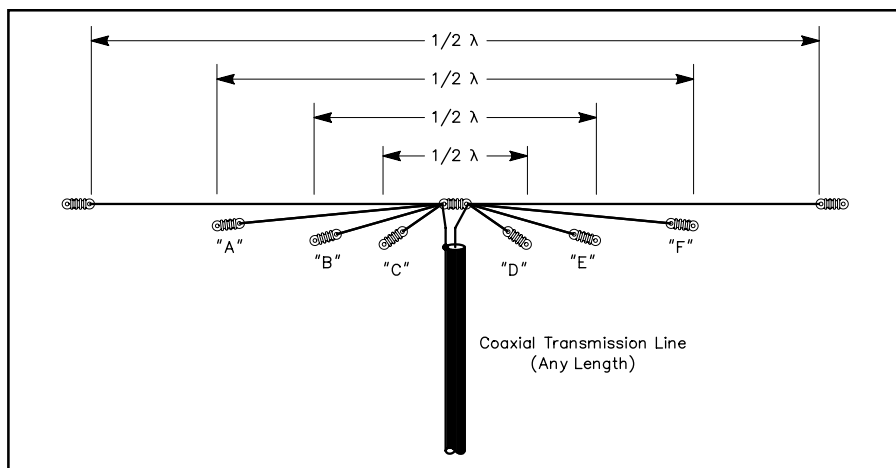


Fig 20.12—Multiband antenna using paralleled dipoles, all connected to a common 50 or 75- Ω coax line. The half-wave dimensions may be either for the centers of the various bands or selected for favorite frequencies in each band. The length of a half wave in feet is $468/\text{frequency in MHz}$, but because of interaction among the various elements, some pruning for resonance may be needed on each band. See text.

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 20.13** shows a two-band trap antenna. A trap is a parallel-resonant circuit that effectively disconnects wire beyond the trap at the resonant frequency. Traps may be constructed from coiled sections of coax or from discrete LC components.

Choose capacitors (C1 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 100Ω (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 $1/2 \lambda$ 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 $1/2\text{-}\lambda$ dipole.

Shortened Dipoles

Inductive loading increases the electrical length of a conductor without increasing its physical length. Therefore, we

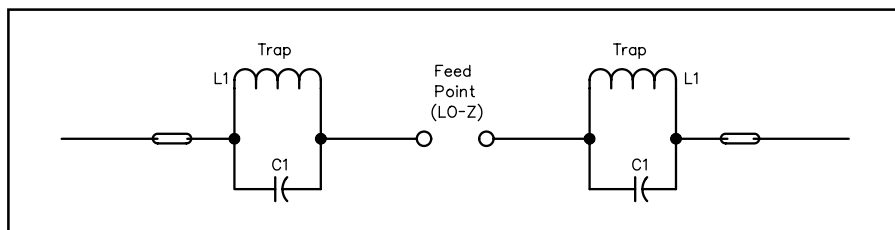


Fig 20.13—Example of a trap dipole antenna. L1 and C1 can be tuned to the desired frequency by means of a dip meter before they are installed in the antenna.

The Trusty Slingshot

Trees make excellent supports for wire antennas, but how do you get a rope over tall branches? Some hams use bows and arrows with good success, but many prefer a slingshot. Use a short section of leader (2 to 4 ft is adequate) between the weight and the line. The leader should be strong enough to withstand the shock of launching the weight, but must be rated at less tensile strength than the main line. Then, if the weight wraps around a limb or otherwise becomes stuck, pulling on the line will break the leader and free the main line. (Often, the weight breaks free and drops to the ground.) This arrangement works better than using one continuous piece of line and getting the whole mess hopelessly stuck in the tree.

Use a “Wrist Rocket” or equivalent, with 20 to 25-lb monofilament line (the main line) laid out neatly on the ground. Use an 8 to 12-lb monofilament line as the leader, with a 2 to 3-oz teardrop fishing weight. This combination is a low-cost method to shoot lines accurately over 100 to 125-ft fir trees. With a little patience, a 2 to 3-oz weight is sufficient to drop the line to ground level for attachment to support ropes, and so on.—K7FL

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%.

Building Dipole 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** 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 constant threat 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 *magnet-wire* is a good 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, because of 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. Radio Shack 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 20.14** 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 like a sponge. 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 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.

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 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 20.15** illustrates several different ways of attaching the feed line to the antenna. An idea for supporting ladder line is shown in **Fig 20.16**.

Putting It Together

Fig 20.17 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 20.5** 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

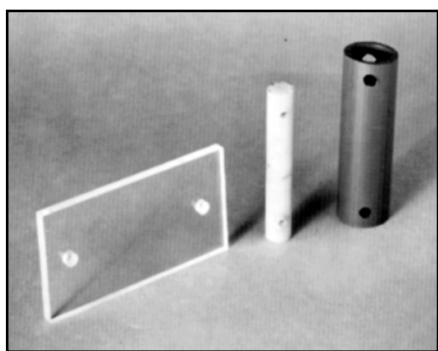


Fig 20.14—Some ideas for homemade antenna insulators.

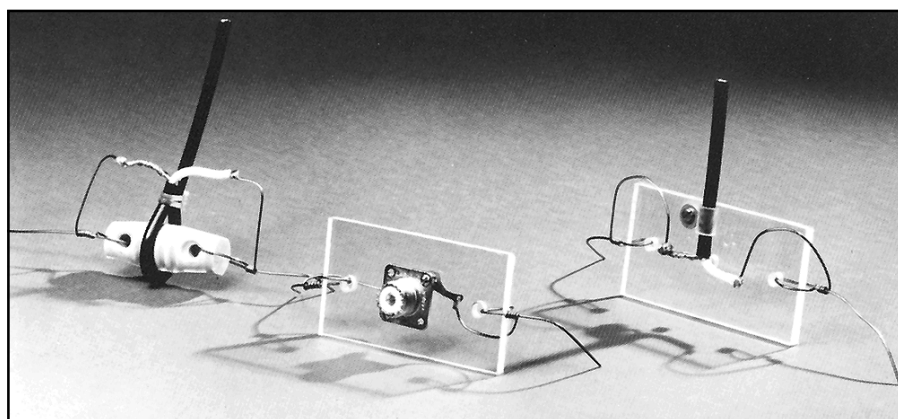


Fig 20.15—Some homemade dipole center insulators. The one in the center includes a built-in SO-239 connector. Others are designed for direct connection to the feed line. (See the [Transmission Lines](#) chapter for details on baluns.)

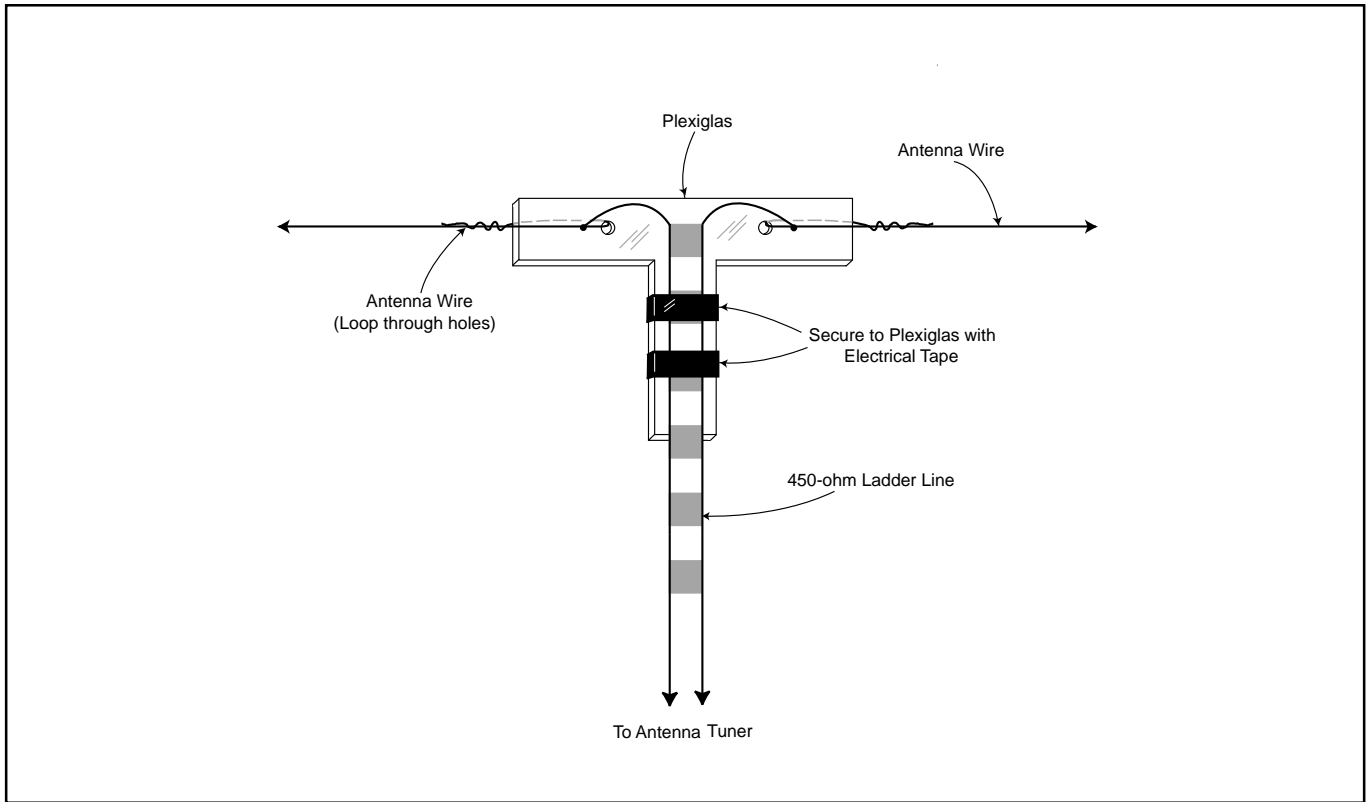


Fig 20.16—A piece of cut Plexiglas can be used as a center insulator and to support a ladder-line feeder. The Plexiglas acts to reduce the flexing of the wires where they connect to the antenna.

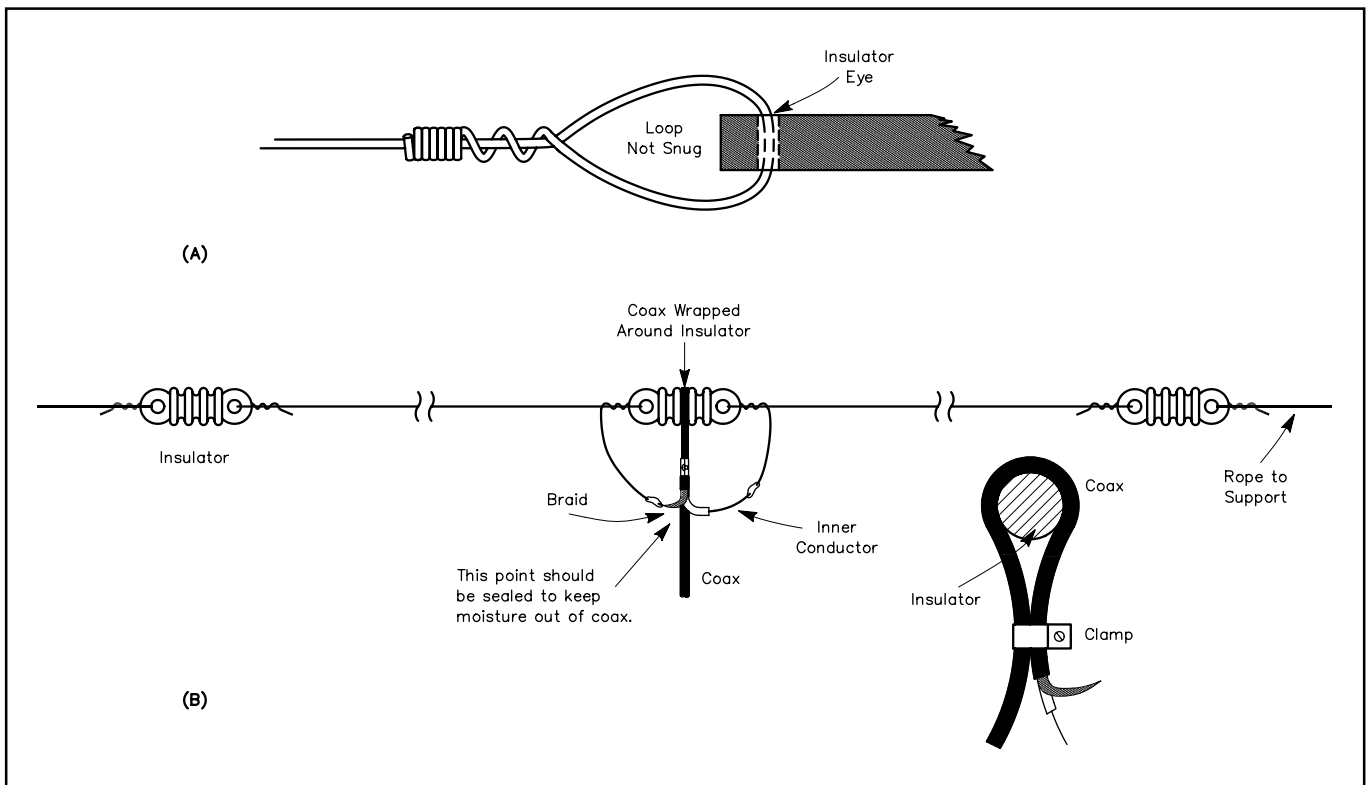


Fig 20.17—Details of dipole antenna construction. The end insulator connection is shown at A, while B illustrates the completed antenna. This is a balanced antenna and is often fed with a balun.

Table 20.5
Dipole Dimensions for
Amateur Bands

<i>Freq</i> <i>MHz</i>	<i>Overall</i> <i>Length</i>	<i>Leg</i> <i>Length</i>
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"
3.6	130' 0"	65' 0"

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 20.17A), 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 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 20.17B). 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 solder-

ing 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.

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 20.18](#).) The inverted V exhibits additional losses because of its proximity to ground.

[Fig 20.19](#) 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 20.20](#) 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 complicated at 28.4 MHz. As you can see in [Fig 20.21](#), the inverted V has the advantage of a

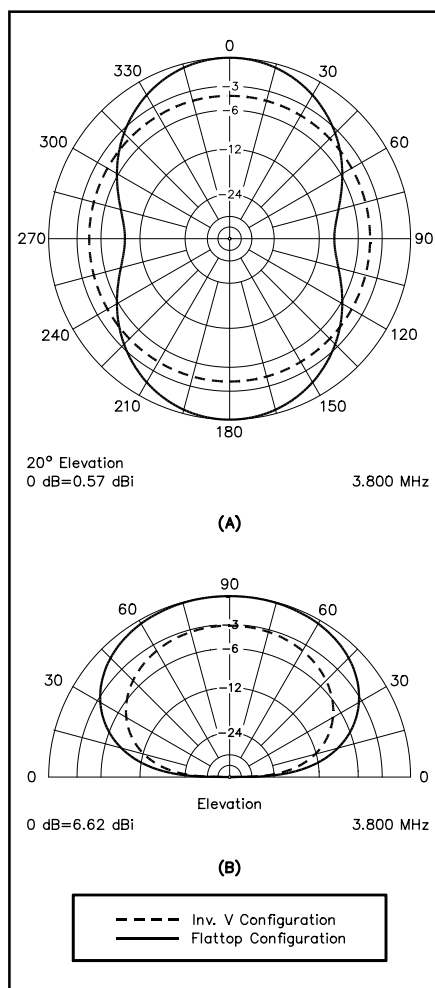


Fig 20.18—Patterns on 80 m for 135-ft, center-fed dipole erected as a horizontal dipole at 50 ft, and as an inverted V with the center at 50 ft and the ends at 10 ft. The azimuth pattern is shown at A, where conductor lies in the 90° to 270° plane. The elevation pattern is shown at B, where conductor comes out of paper at right angle. At the fundamental frequency the patterns are not markedly different.

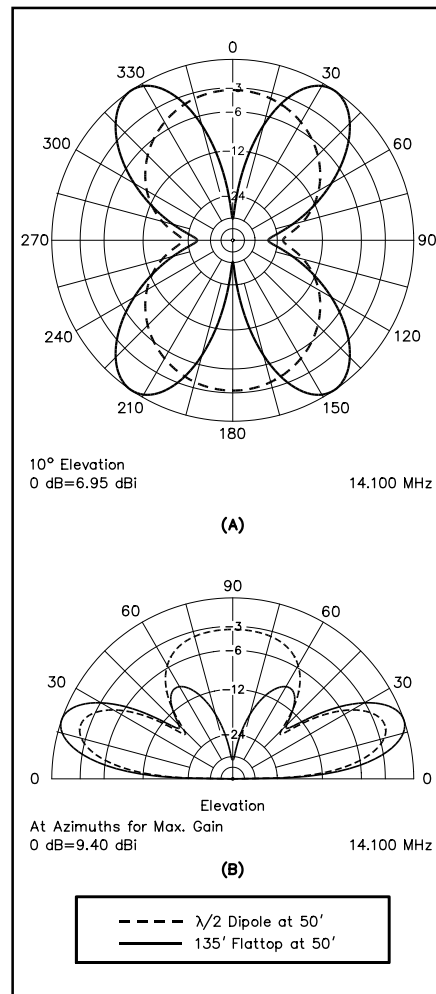


Fig 20.19—Patterns on 20 m comparing a standard $\frac{1}{2}\lambda$ dipole and a multiband 135-ft dipole. Both are mounted horizontally at 50 ft. The azimuth pattern is shown at A, where conductors lie in the 90° to 270° plane. The elevation pattern is shown at B. The longer antenna has four azimuthal lobes, centered at 35°, 145°, 215°, and 325°. Each is about 2 dB stronger than the main lobes of the $\frac{1}{2}\lambda$ 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 $\frac{1}{2}\lambda$ dipole is for the 0° azimuthal point.

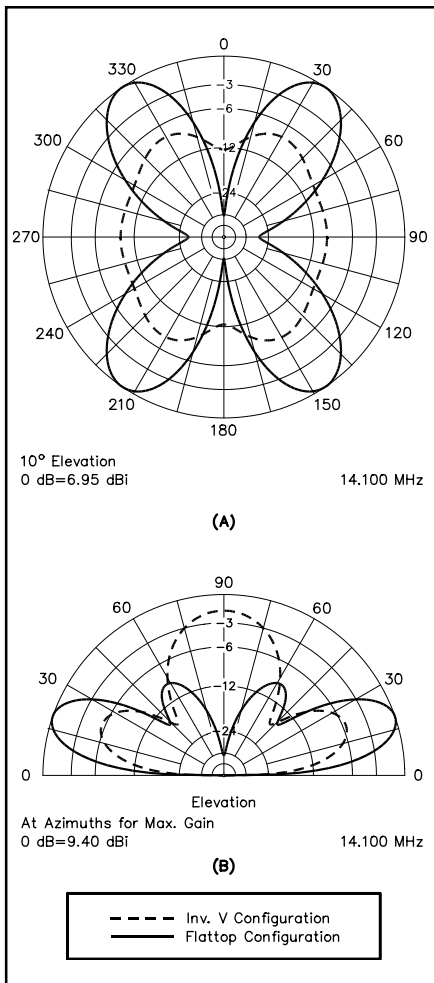


Fig 20.20—Patterns on 20 m for two 135-ft dipoles. One is mounted horizontally as a flat-top and the other as an inverted V with 120° included angle between the two legs. The azimuth pattern is shown at A, and the elevation pattern is shown at B. The inverted V has about 6 dB less gain at the peak azimuths, 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.

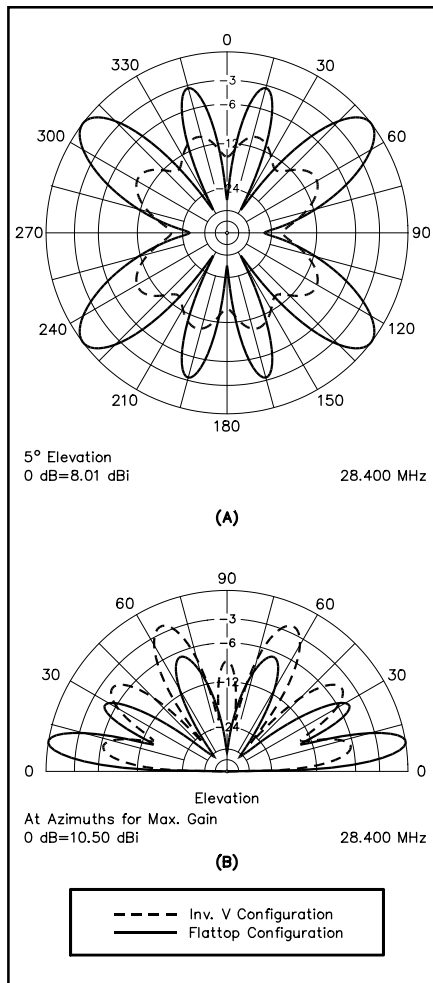


Fig 20.21—Patterns on 10 m for 135-ft dipole mounted horizontally and as an inverted V, as in Fig 20.20. The azimuth pattern is shown at A, and the elevation pattern is shown at B. Once again, the inverted-V configuration yields a more omnidirectional pattern, but at the expense of almost 8 dB less gain than the flat-top configuration at its strongest lobes.

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.

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

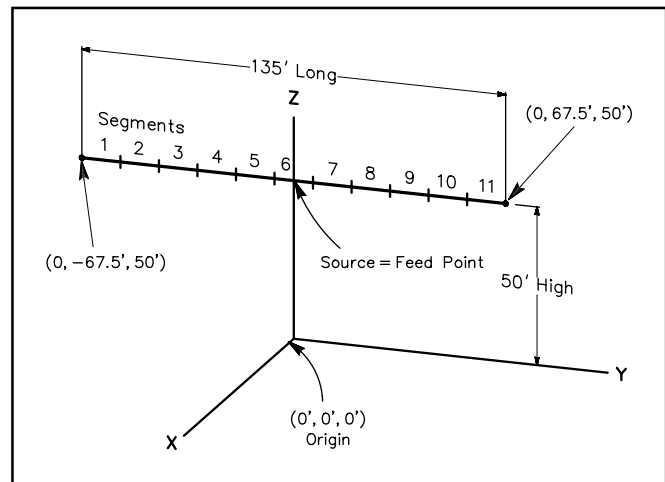


Fig A

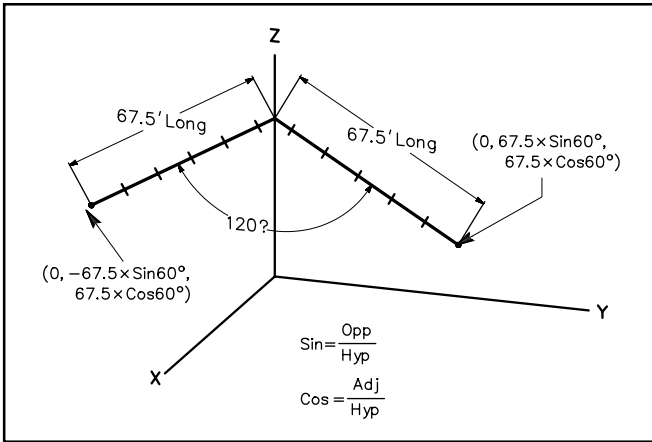


Fig B

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*

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

Computer-aided Design of Loaded Short-doublet Antennas

By Richard Ellers, K8JLK, 426 Central Pkwy, SE, Warren, OH 44483-6213

I've devised a BASIC program¹ you can use to design shortened doublet (dipole) antennas, using loading coils of known inductance. The program uses common BASIC commands and should run as-is on any IBM PC-compatible or Apple II personal computer. This program is an offshoot and adaptation of previously published charts, a formula and a BASIC program. The charts and formula, published in *QST*,² and the original BASIC program, published in *CQ*,³ were devised to calculate the inductances required to resonate a short doublet, given the overall antenna length, the coil spacing and the element diameter.

The development of my program began when I decided to build a 2-element phased array of short doublets, using four surplus mobile coils I'd bought at a hamfest. Checking through my ham magazines, I found Dick (K5QY) Sander's ingenious BASIC version of Jerry Hall's (then K1PLP, now K1TD) comprehensive work on the design of off-center-loaded antennas. However, I was in the opposite position: *I had the inductance values in hand* and needed instead to figure *where to place the coils* in an antenna of a certain size.

Not being very adept at higher math, I didn't even attempt to rewrite Jerry's formula or K5QY's program. Instead, I revised K5QY's program by adding a computer routine known as a *binary search*. Although more often used to seek data in large files, my program uses a binary search as a form of computerized empirical determination (more commonly known as cut-and-try). The search is accurate—and rapid. In just seconds, the routine finds the coil spacing that matches the desired antenna to the existing inductance.

I wrote the program to find the coil spacing for a single antenna (and for a series of 10 antennas) between two specified lengths. Incidentally, because the program actually calculates the center-to-coil distance (as did K5QY's version), it can be used to design short vertical antennas, but you must enter *twice the desired overall length*. As with K5QY's program, mine handles antenna elements of wire or tubing, the diameters being entered in decimal fractions of an inch where necessary. To keep the program short and simple, I omitted K5QY's optional wire table. (You can find such a wire table in Chapter 24, [Component Data](#), or use the following as a guide: 22-gauge wire has a diameter of 0.025 inch; 10-gauge wire's diameter is 0.101 inch.)

Program error traps catch (and explain) parameter combinations that don't match the given inductor. One trap catches dimensions that would normally put the program in an endless loop. I've tested my program for many configurations and frequencies using inductances first determined by K5QY's program: The results matched every time.

Notes

¹ The software contains ASCII QBASIC files for both IBM-compatible and Mac computers in file ELLERS.EXE. It is available at the ARRL Web site. See [page viii](#).

² J. Hall, "Off-Center-Loaded Antennas," *QST*, Sep 1974, pp 28-34 and 58.

³ D. Sander, "A Computer Designed Loaded Dipole Antenna," *CQ*, Dec 1981, p 44.

A TRAP DIPOLE FOR 40, 80 AND 160 M

This antenna was designed for amateurs with limited space who also wanted to operate the low bands. It was first described in July 1992 *QST* by A. C. Buxton, W8NX, and features innovative coaxial-cable traps.

Fig 20.25 shows the antenna layout; it is resonant at 1.865, 3.825, and 7.225 MHz. The antenna is made of #14 stranded wire and two pairs of coaxial traps. Construction is conventional in most respects, except for the high inductance-to-capacitance (L/C) ratio that results from the unique trap construction.

The traps use two series-connected coil layers, wound in the same direction using RG-58 coaxial cable's center conductor, together with the insulation over the center conductor. The black outer jacket from the cable is stripped and discarded. The shield braid is also removed from the cable (pushing is easier than pulling the shield off). No doubt you will want to save the braid for use in other projects. RG-58 with a stranded center conductor is best for this project. **Fig 20.26** shows the traps. The 3.8-MHz trap is shown with the weatherproofing cover of electrical tape removed to show construction details.

Precautions and Trap Specifications

With this trap-winding configuration, there are two thicknesses of coax dielectric material between

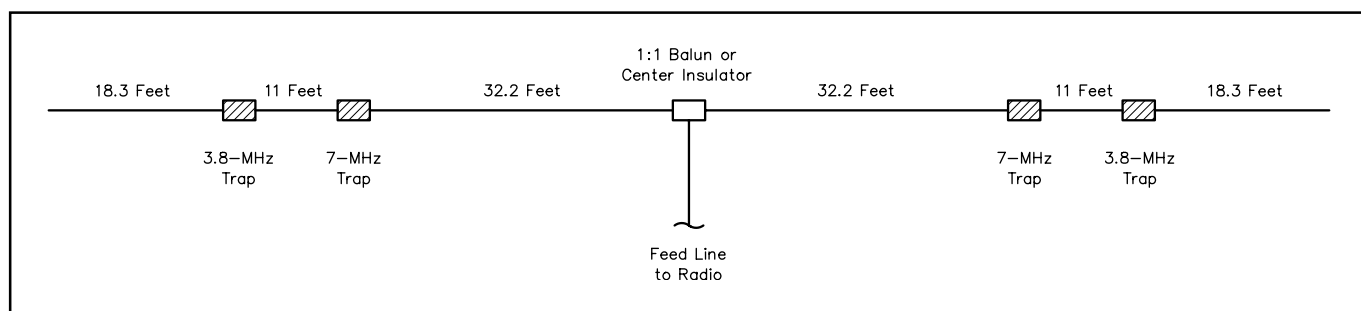
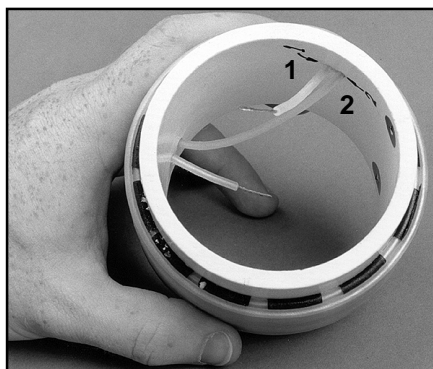
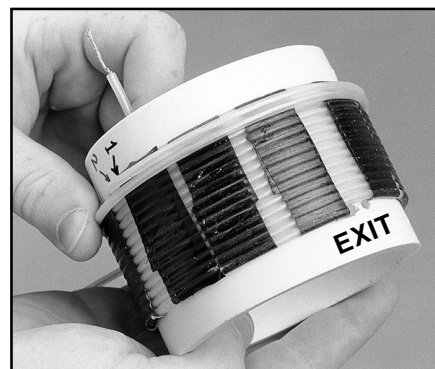


Fig 20.25—The W8NX trap dipole resonates in the SSB portions of the 40, 80 and 160-m bands. The antenna is 124 ft long.

Fig 20.26—The W8NX coaxial-cable traps use two layered windings in series to provide an unusually high inductance-to-capacitance ratio, higher Q, and twice the breakdown voltage of single-layer traps. At A is shown an inside view of a W8NX two-layer trap, showing how the windings enter and exit the form. Two holes at each end of the PVC form pass the windings in and out of the form. At B, an outside view of a partially assembled W8NX trap. The



(A)



(B)

bottom winding starts at hole "1" and reenters the form just below the "EXIT" hole. The wire then comes back through the inside of the form to hole "2," where it comes back out to make the second winding in the same direction, on top of the first. It reenters the form at the "EXIT" hole. The black electrical tape holds the bottom winding in place from spreading as you wind the top layer over it. Other holes drilled in the ends of the form provide convenient points for the antenna wires to connect mechanically to the traps.

adjacent turns, which doubles the breakdown voltage of the traps. The transformer action of the two windings gives a second doubling of the trap-voltage rating, bringing it to 5.6 kV.

The 7-MHz traps have 33 μH of inductance and 15 pF of capacitance, and the 3.8-MHz traps have 74 μH of inductance and 24 pF of capacitance. The trap Qs are over 170 at their design frequencies.

These traps are suitable for high-power operation. Do not use RG-8X or any other foam-dielectric cable for making the traps. Breakdown voltage is less for foam dielectric, and the center conductor tends to migrate through the foam when there is a short turn radius.

Loading caused by the traps causes a reduced bandwidth for any trap dipole compared to a half-wave dipole. This antenna covers 65 kHz of 160 m, 75 kHz of 80 m, and the entire 40-m band with less 2:1 SWR.

Construction

Although these traps are similar in many ways to other coaxial-cable traps, the shield winding of the common coax-cable trap has been replaced by a top winding that fits snugly into the grooves formed by the bottom layer. Capacitance is reduced to 7.1 pF per ft, compared to 28.5 pF per ft with conventional coax traps made from RG-58. Trap reactance can be up to four times greater than that provided by conventional coax-cable traps.

The coil forms are cut from PVC pipe. The 7-MHz trap form is made from 2-inch-ID pipe with an outer diameter of 2.375 inches. The 3.8-MHz trap form is made from 3-inch pipe with an outer diameter of 3.5 inches. The 7-MHz trap uses a 12.3-turn bottom winding and an 11.4-turn top winding. The 3.8-MHz trap uses a 14.3-turn bottom winding and a 13.4-turn top winding. All turns are close wound. The 40-m trap frequency is 7.17 MHz and the 80-m trap frequency is 3.85 MHz.

Use a #30 (0.128-inch) diameter drill for the feed-through holes in the PVC coil forms. The start and end holes of the 7-MHz traps are spaced 1.44 inches center to center, measured parallel to the trap center line. The holes in the 3.8-MHz traps are 1.66 inches apart. Wind the traps with a single length of coax center conductor. The lengths are 17.55 ft for the 7-MHz traps and 28.45 ft for the 3.8-MHz traps. These lengths include the trap pigtailed and a few inches for fine tuning.

Use electrical tape to keep the turns of the inner-layer winding closely spaced during the winding process. This counteracts the tendency of the tension in the outer-layer winding to spread the bottom-layer turns. Stick the tape strips directly to the coil form before winding and then tightly loop them over and around the bottom layer before winding the outer layer. Use six or more tape strips for each trap. Other smaller holes may be drilled in the ends of the traps to provide a place for the antenna wires to make secure mechanical connections to the traps.

80-M BROADBAND DIPOLE WITH COAXIAL RESONATOR MATCH

This material has been condensed from an article by Frank Witt, AI1H, that appeared in April 1989 *QST*. A full technical description appears in *The ARRL Antenna Compendium, Volume 2*.

Fig 20.27 shows the detailed dimensions of the 3.5-MHz coaxial resonator match broadband dipole. Notice that the coax is an electrical quarter wavelength, has a short at one end, an open at the other end, a strategically placed crossover, and is fed at a tee junction. (The crossover is made by connecting the shield of one coax segment to the center conductor of the adjacent segment and by connecting the remaining center conductor and shield in a similar way.) At AI1H, the antenna is constructed as an inverted-V dipole with a 110° included angle and an apex at 60-ft. The measured SWR vs frequency is shown in **Fig 20.28**. Also in Fig 20.28 is the SWR characteristic for an uncompensated inverted-V dipole made from the same materials and positioned exactly as was the broadband version.

The antenna is made from RG-8 coaxial cable and #14 AWG wire, and is fed with 50-W coax. The coax should be cut so that the stub lengths of Fig 20.27 are within $\frac{1}{2}$ inch of the specified values. PVC plastic pipe couplings and SO-239 UHF chassis connectors can be used to make the T and crossover connections, as shown in **Fig 20.29** at A and B. Alternatively, a standard UHF T connector and coupler can be used for the T, and the crossover may be a soldered connection (Fig 20.29C). Witt used RG-8 because of its ready availability, physical strength, power handling capability and moderate loss.

Cut the wire ends of the dipole about three ft longer than the lengths given in Fig 20.27. If there is a tilt in the SWR-frequency curve when the antenna is first built, it may be “flattened” to look like the shape given in Fig 20.28 by increasing or decreasing the wire length. Each end should be lengthened or shortened by the same amount.

A word of caution: If the coaxial cable chosen is not RG-8 or equivalent, the dimensions will need to be modified. The following cable types have about the same characteristic impedance, loss and velocity

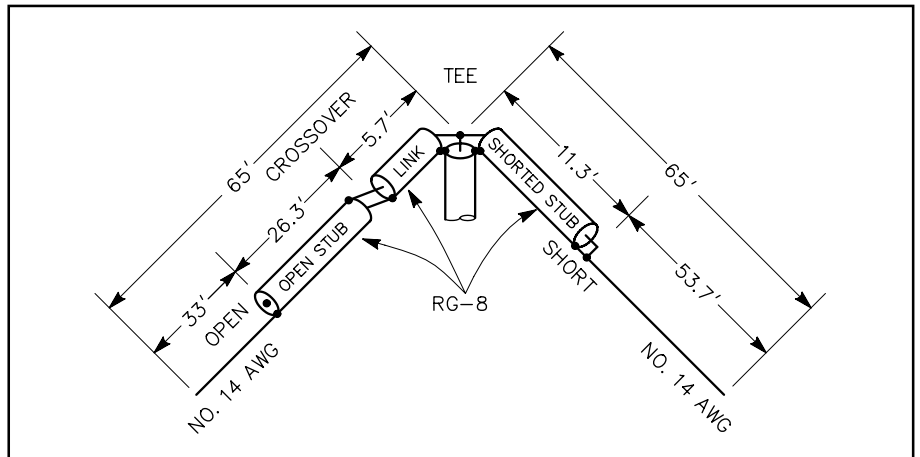


Fig 20.27—Coaxial-resonator-match broadband dipole for 3.5 MHz. The coax segment lengths total $\frac{1}{4} \lambda$. The overall length is the same as that of a conventional inverted-V dipole.

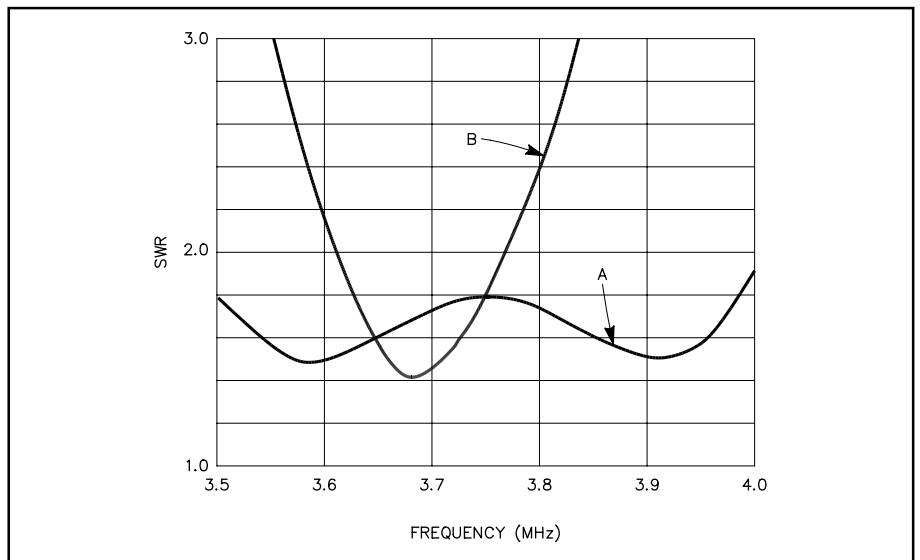


Fig 20.28—The measured SWR performance of the antenna of Fig 20.27, curve A. Also shown for comparison is the SWR of the same dipole without compensation, curve B.

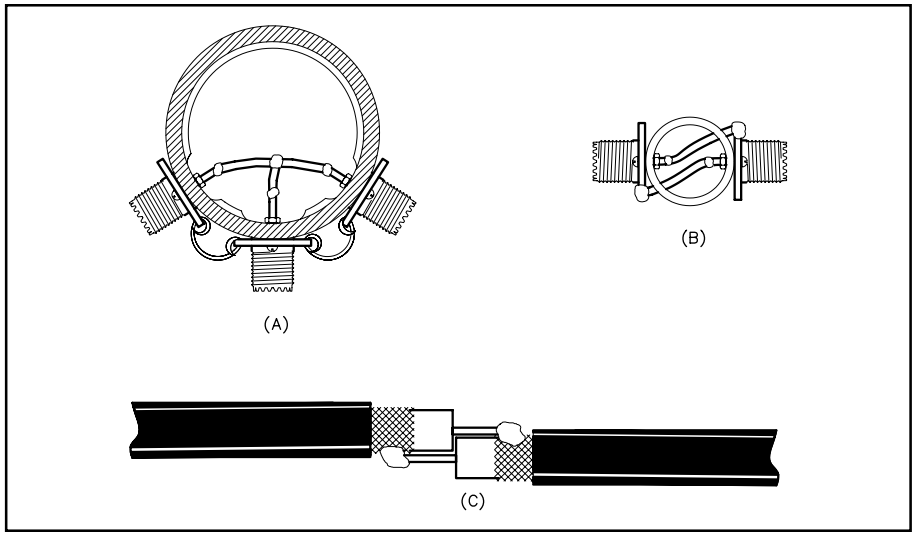


Fig 20.29—T and crossover construction. At A, a 2-inch PVC pipe coupling can be used for the T, and at B, a 1-inch coupling for the crossover. These sizes are the nominal inside diameters of the PVC pipe which is normally used with the couplings. The T could be made from standard UHF hardware (an M-358 T and a PL-258 coupler). An alternative construction for the crossover is shown at C, where a direct solder connection is made.

factor as RG-8 and could be substituted: RG-8A, RG-10, RG-10A, RG-213 and RG-215. If the Q of the dipole is particularly high or the radiation resistance is unusually low because of different ground characteristics, antenna height, surrounding objects and so on, then different segment lengths will be required. In fact, if the dipole Q is too high, broadbanding is possible, but an SWR under 2:1 over the whole band cannot be achieved.

What is the performance of this broadband antenna relative to that of a conventional inverted-V dipole? Apart from the slight loss (about 1 dB at band edges, less elsewhere) because of the nonideal matching network, the broadband version will behave essentially the same as a dipole cut for the frequency of interest. That is, the radiation patterns for the two cases will be virtually the same. In reality, the dipole itself is not “broadband,” but the coaxial resonator match provides a broadband match between the transmission line and the dipole antenna. This match is a remarkably simple way to broaden the SWR response of a dipole.

The Coaxial Resonator Match

The coaxial resonator match performs the same function as the T match and the gamma match; that is, matching a

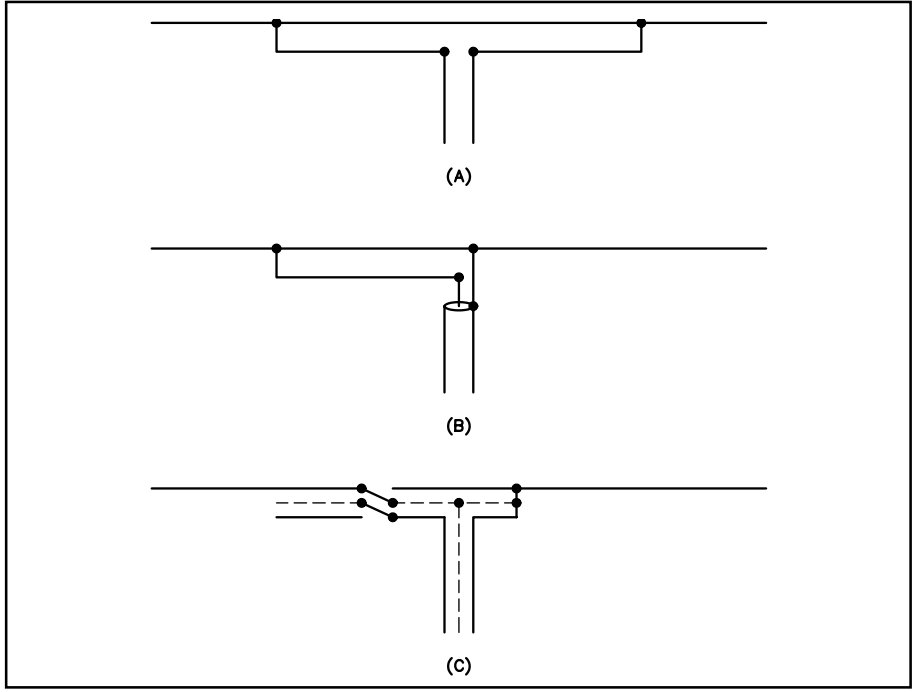


Fig 20.30—Dipole matching methods. At A, the T match; at B, the gamma match; at C, the coaxial resonator match.

transmission line to a resonant dipole. These familiar matching devices as well as the coaxial resonator match are shown in Fig 20.30. The coaxial resonator match has some similarity to the gamma match in that it allows connection of the shield of the coaxial feed line to the center of the dipole, and it feeds the dipole off center. The coaxial resonator match has a further advantage: It can be used to broadband the antenna system while it is providing an impedance match.

The coaxial resonator match is a resonant transformer made from a quarter-wave long piece of coaxial cable. It is based on a technique used at VHF and UHF to realize a low-loss impedance transformation.

The Coaxial Resonator Match Broadband Dipole

Fig 20.31 shows the evolution of the broadband dipole. Now it becomes clear why coaxial cable is used for the quarter-wave resonator/transformer; interaction between the dipole and the matching network is minimized. The effective dipole feedpoint is located at the crossover. In effect, the match is physically located “inside” the dipole. Currents flowing on the inside of the shield of the coax are associated with the resonator; currents flowing on the outside of the shield of the coax are the usual dipole currents. Skin effect provides a degree of isolation and allows the coax to perform its dual function. The wire extensions at each end make up the remainder of the dipole, making the overall length equal to one half-wave.

A useful feature of an antenna using the coaxial resonator match is that the entire antenna is at the same dc potential as the feed line, thereby avoiding charge buildup on the antenna. Hence, noise and the potential of lightning damage are reduced.

A Model for DXers

The design of Fig 20.27 may be modified to yield a “3.5-MHz DX Special.” In this case the band extends from 3.5 MHz to 3.85 MHz. Over that band the SWR is better than 1.6:1 and the matching network loss is less than 0.75 dB. See [Fig 20.32](#) for measured performance of a 3.5-MHz DX Special built and used by Ed Parsons, K1TR. Design dimensions for the DX Special are given in [Fig 20.33](#).

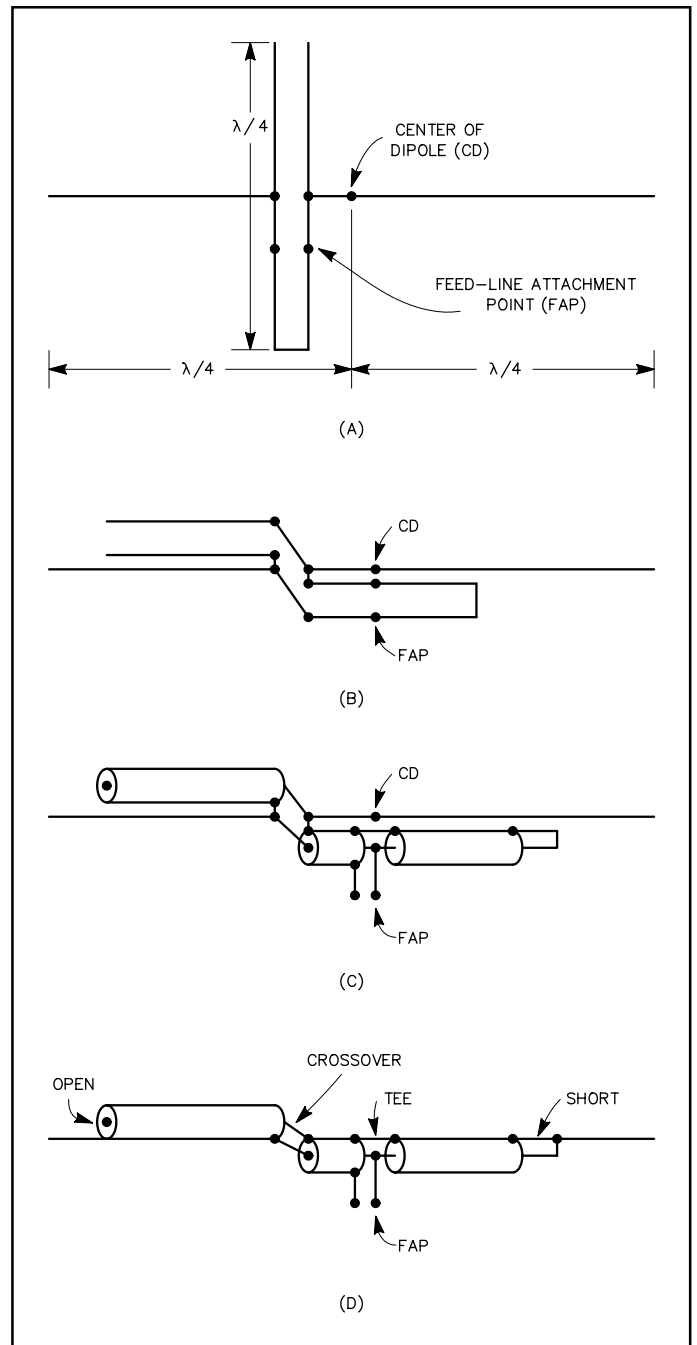


Fig 20.31—Evolution of the coaxial-resonator-match broadband dipole. At A, the resonant transformer is used to match the feed line to the off-center-fed dipole. The match and dipole are made collinear at B. At C, the balanced transmission-line resonator/transformer of A and B is replaced by a coaxial version. Because the shield of the coax can serve as a part of the dipole radiator, the wire adjacent to the coax match may be eliminated, D.

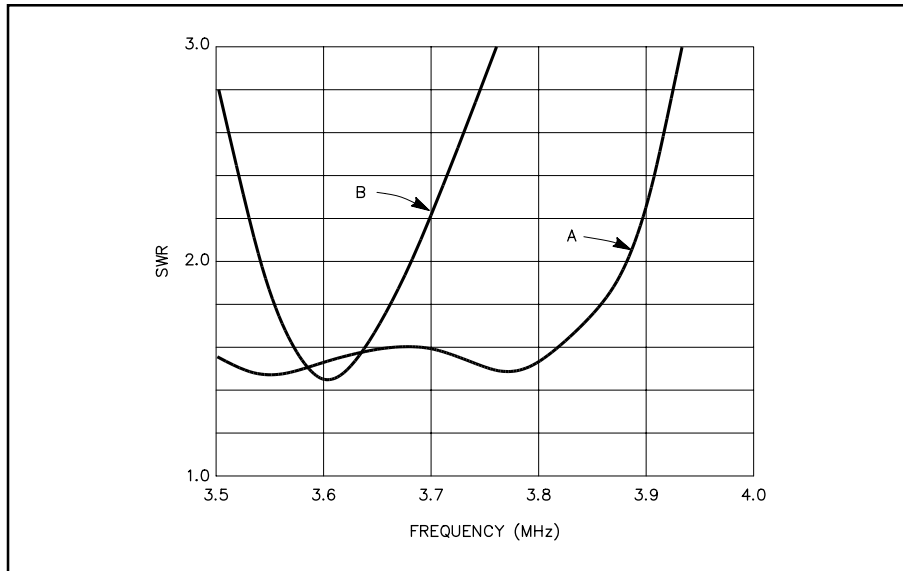


Fig 20.32—Measured SWR performance of the 3.5-MHz DX Special, curve A. Note the substantial broadbanding relative to a conventional uncompensated dipole, curve B.

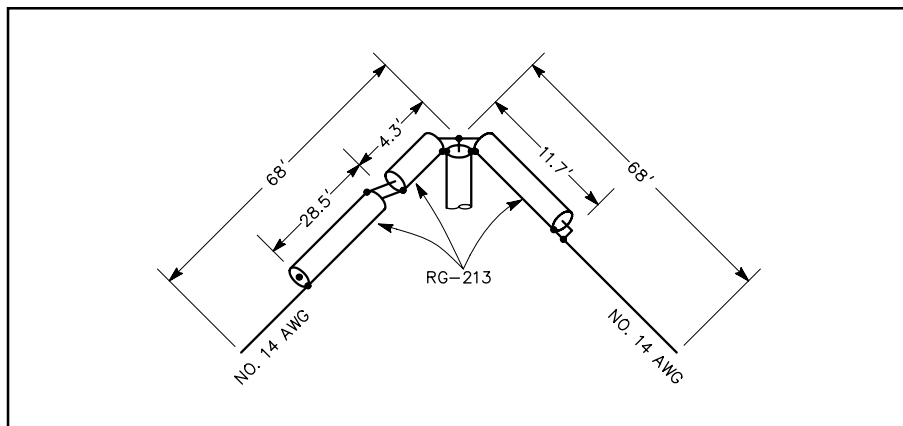


Fig 20.33—Dimensions for the 3.5-MHz DX Special, an antenna optimized for the phone and CW DX portions of the 3.5-MHz band.

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

Two popular ham bands, especially for Novice and Technician class operators, are those at 7 and 21 MHz. 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 of the Novice 40-m allocation (7100-7150 kHz) begins at 21,300 kHz; yet the Novice segment of 15 m is 21,100-21,200 kHz. As a result of this and other effects, a 40-m dipole does not provide a low SWR in the 40 *and* 15-m Novice segments without a tuner.

An easy fix for this, as shown in **Fig 20.34**, is to capacitively load the antenna about a quarter wavelength (at 21.1 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.

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.

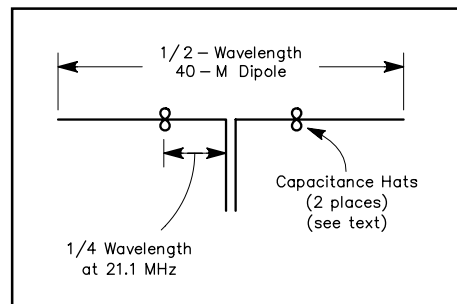


Fig 20.34—Figure-8-shaped capacitance hats made and placed as described in the text, can make your 40-m dipole resonate anywhere you like in the 15-m band.

A RESONANT FEED-LINE DIPOLE

This antenna, first described by James Taylor, W2OZH in August 1991 *QST*, uses a section of the feed line as part of the antenna. Taylor's design takes advantage of the fact that separate currents can flow on the inside and outside of the shield of a coaxial cable. Current flows from the feed-point back along the outside of the coax's shield. At $\frac{1}{4} \lambda$ from the feedpoint, an RF choke effectively stops current flow, and thus the dipole is formed.

The antenna, also known as an RFD, is shown in **Fig 20.35**. Dipole dimensions can be taken from Table 20.5. Length of coax and number of turns for the choke are given in **Table 20.7**.

The RFD has the advantage of being end fed. That means no feed line supported by the antenna. This makes it easy to erect, and makes the RFD particularly handy for portable operation. Like any dipole, the RFD should be installed as high, and in the clear, as possible.

Table 20.7
Choke Dimensions for RFD Antenna

Freq	RG-213, RG-8	RG-58
3.5	22 ft, 8 turns	20 ft, 6-8 turns
7	22 ft, 10 turns	15 ft, 6 turns
10	12 ft, 10 turns	10 ft, 7 turns
14	10 ft, 4 turns	8 ft, 8 turns
21	8 ft, 6-8 turns	6 ft, 8 turns
28	6 ft, 6-8 turns	4 ft, 6-8 turns

Wind the indicated length of coaxial feed line into a coil (like a coil of rope) and secure with electrical tape. Lengths are not highly critical.

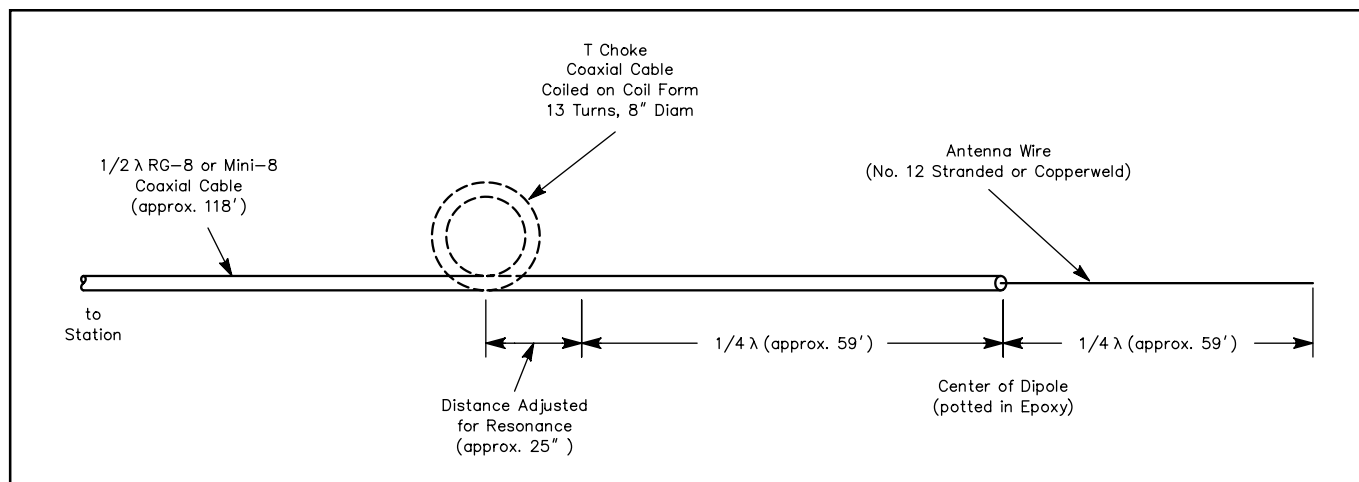


Fig 20.35—The RFD (resonant feed-line dipole) antenna for 80 m. Be sure to weatherproof the feedpoint.

A Simple Quad for 40 Meters

Many amateurs yearn for a 40-meter antenna with more gain than a simple dipole. While two-element rotary 40-meter 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-meter band.

This quad uses a 2-inch outside diameter, 18-foot boom, which should be mounted no less than 60 feet 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-meter 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-meter quad at a boom height of 70 feet is shown in **Fig 20.36**. The wires for each element are pulled out sideways from the boom with black $\frac{1}{8}$ -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

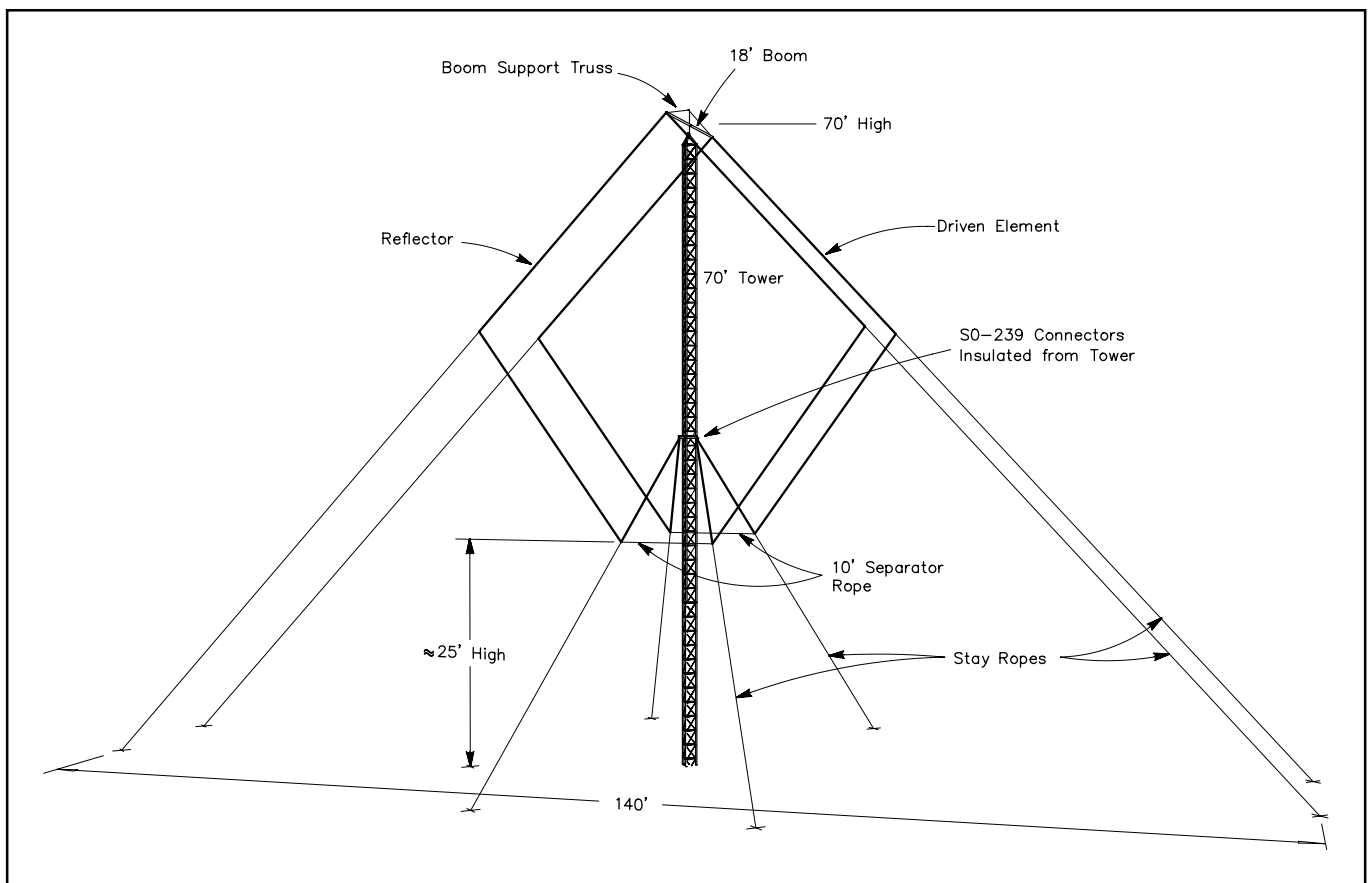


Fig 20.36—Layout of 40-meter quad with a boom height of 70 feet. The four stay ropes on each loop pull out each loop into the desired shape. Note the 10-foot separator rope at the bottom of each loop, which helps it hold its shape. The feed line is attached to the driven element through a choke balun, 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 19](#). 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.

broke during a windstorm! At a boom height of 70 feet, the quad requires a “wingspread” of 140 feet 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 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 20.36.

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 20.37. 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.

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 feet 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-foot high tower, the loop wires are brought back to the tower at the 37.5-foot level and tied there using insulators and rope. The lowest points of the loops are located about 25 feet above ground for a 70-foot tower. Fig 20.38 gives dimensions for the driven element and reflector for both the CW and the Phone portions of the 40-meter 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 certain guys (probably at the top of the

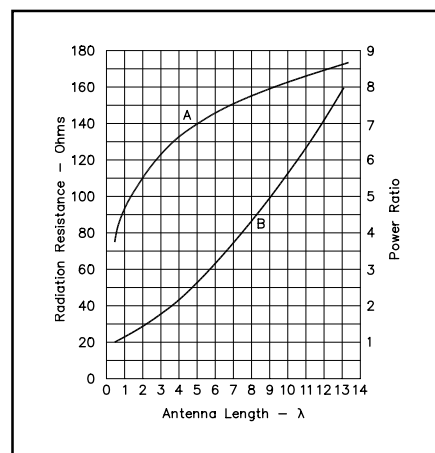


Fig 20.37—Plot of SWR versus frequency for a quad tuned for CW operation.

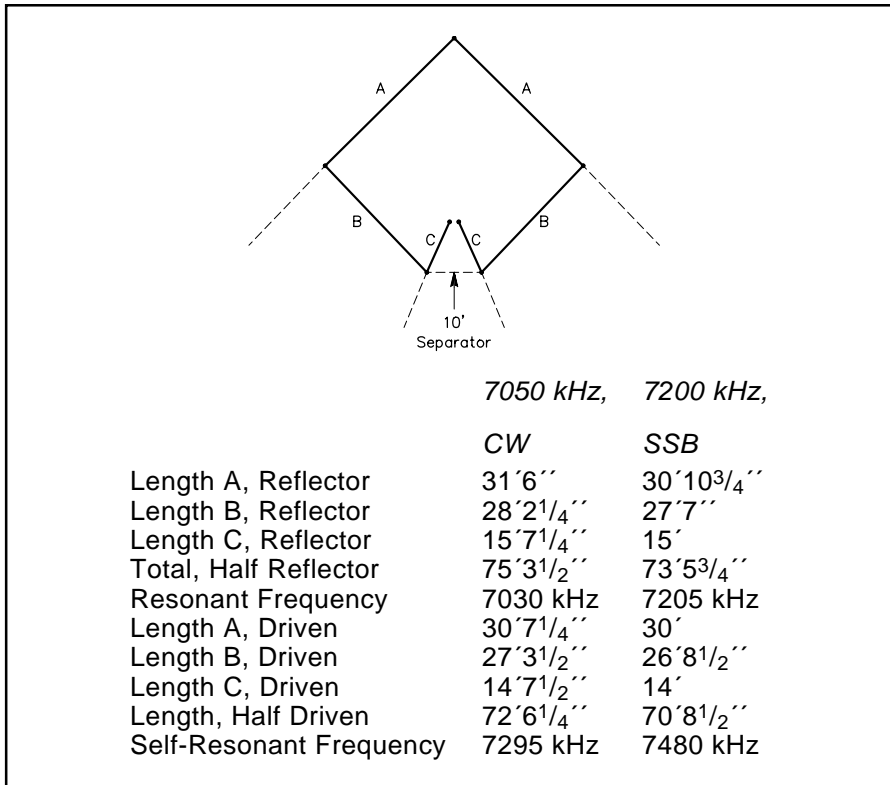


Fig 20.38—Dimensions of each loop, for CW or Phone operation.

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 20.38 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 feet high. However, it will work

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. Sample *EZNEC* modeling files for this quad antenna are available on the ARRL Web site. (See [page viiii](#).) *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.

considerably better for DX work if you can put the boom up even higher. **Fig 20.39** shows the elevation patterns for four antennas: a reference inverted-V dipole at 70 feet (with a 90° included angle between the two legs), and three quads, with boom height of 70, 90 and 100 feet respectively. At an elevation angle of 20°, typical for DX work on 40 meters, the quad at 100 feet has about a 5 dB advantage over an inverted-V dipole at 70 feet, and about a 3 dB advantage over a quad with a boom height of 70 feet.

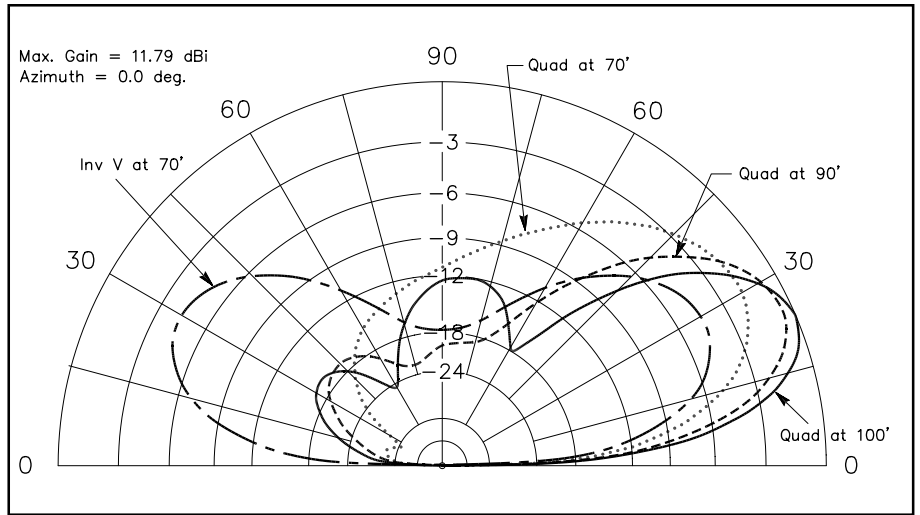


Fig 20.39—Comparisons of the elevation patterns for quads at boom heights of 70, 90 and 100 feet, referenced to an inverted-V dipole at 70 feet.

Vertical Antennas

One of the more popular amateur antennas is the *vertical*. Although amateurs often use the term “vertical” somewhat loosely, it usually refers to a single radiating element placed vertically over the ground. A vertical is usually $\frac{1}{4}\lambda$ long electrically and constructed out of wire or tubing. Many amateurs live on city lots with zoning restrictions preventing them from putting up tall towers with large Yagi arrays. Amateurs are also creative and ingenious—a vertical disguised to look like a flagpole can be both patriotic and a good radiator of RF!

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 detail in the [following section](#).

Far-field losses are highly dependent on the conductivity and dielectric constant of the earth around the antenna, extending out as far as 100λ 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 20.41** 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 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 20.42 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

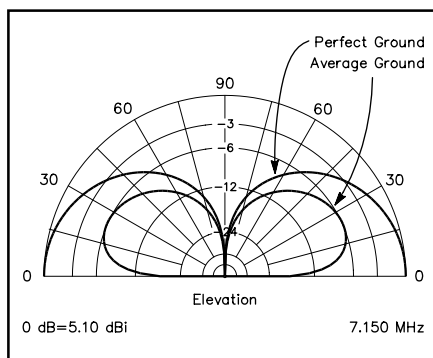


Fig 20.41—Elevation patterns for two quarter-wave vertical antennas over different ground. One vertical is placed over “perfect” ground, and the other is placed over average ground. The far-field response at low elevation angles is greatly affected by the quality of the ground—as far as 100λ away from the vertical antenna.

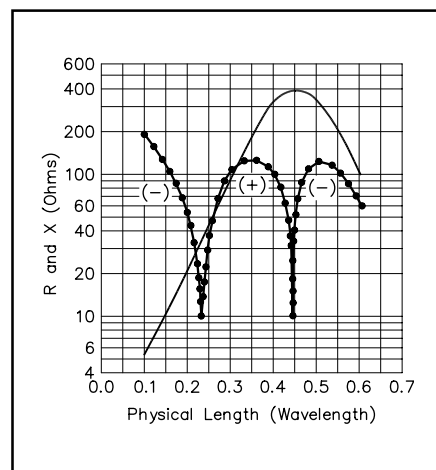


Fig 20.42—Radiation resistance (solid curve) and reactance (dotted curve) of vertical antennas as a function of physical height.

where many radials have been laid out to make a ground screen. As the radiator is made shorter, the radiation resistance decreases—with 6Ω being typical for a $0.1\text{-}\lambda$ 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 20.42](#). It can be difficult to develop suitable matching networks when radiation resistance is very low.

Ground Systems

The importance of an effective ground system for vertical antennas cannot be emphasized too strongly. However, it is not always possible to install a radial network that approaches the ideal. The AM broadcast industry uses 120 buried radials as a standard radial ground system for their antennas. This is rarely practical for most amateurs, and a compromise ground is certainly better than no ground at all. The amateur should experiment with whatever is physically possible when working with vertical antennas. Even modest radial systems can produce contacts, even if they don't consistently crack big pileups!

Although the matter of less-than-optimum ground systems could be debated almost endlessly, some practical rules of thumb are in order for those wishing to erect vertical antennas. Generally a large number of shorter radials offers a better ground system than a few longer ones. For example, 8 radials of $\frac{1}{8} \lambda$ are preferred over 4 radials of $\frac{1}{4} \lambda$. If the physical height of the vertical is an $\frac{1}{8} \lambda$, the radial wires should be of the same length and dispersed uniformly from the base.

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 (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. The amateur should bury as much ground wire as time and budget permit. Some operators have literally miles of wire buried radially beneath their vertical antennas.

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. In some instances a group of short radial wires can be used in combination with ground rods driven into the soil near the base of the antenna. Bear in mind, though, that RF currents at MF and HF seldom penetrate the earth more than several inches. If a metal fence skirts the property it can be used as part of the ground system. Rolls of galvanized "chicken wire" fencing fanned out from the base of the vertical make good ground systems, especially when used in conjunction with longer wire radials. Six 30-ft long by 3-ft wide rolls of chicken wire make a good ground screen for a 160-m vertical, backed up with 6 or more 130-ft long radials. A good rule is to use anything that will serve as a ground when developing a radial ground system.

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 (and chicken-wire screen, if used) 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. A lawn edging tool is excellent for cutting slits in grass sod or in soil when laying radial wires.

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 $\frac{1}{4} \lambda$ vertical antenna, the forms shown in [Fig 20.43](#) are worthy

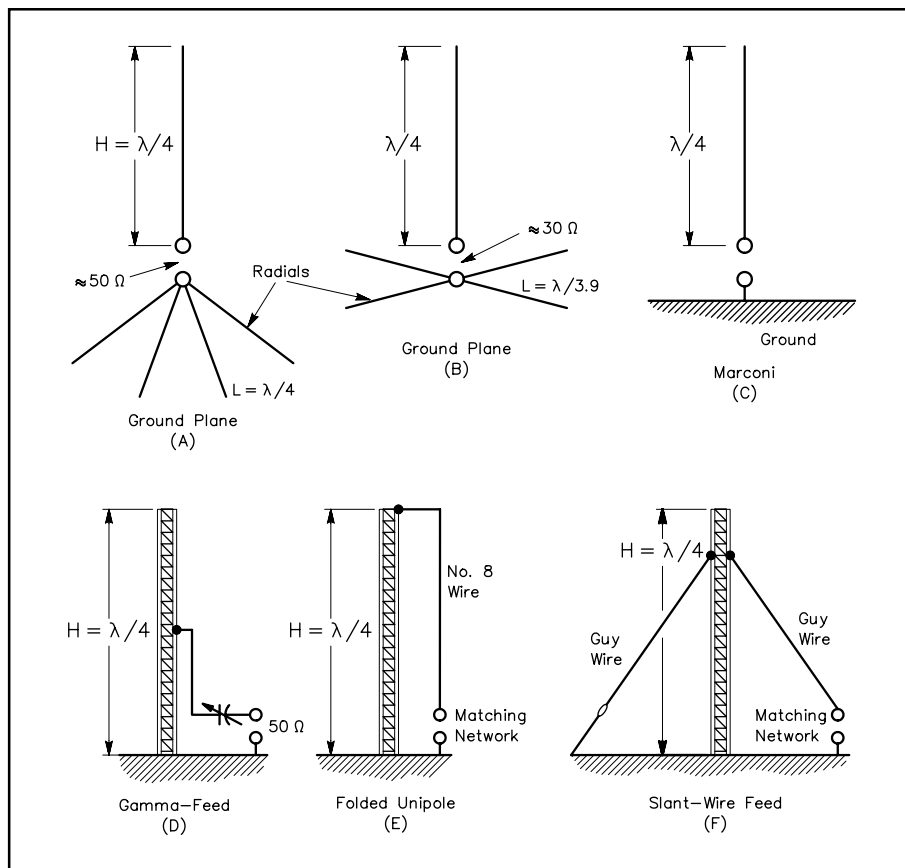


Fig 20.43—Various types of vertical antennas.

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 20.43C 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 to 75 Ω.

A gamma feed system for a grounded $\frac{1}{4}\lambda$ vertical is presented in Fig 20.43D. 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 $\frac{1}{3}$ to $\frac{1}{2}$ 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 (making it common to the tower top) to form a folded unipole (Fig 20.43E). 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

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 radials and the driven element is derived from the standard equation

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

With four equidistant radial wires drooped at approximately 45° (Fig 20.43A), the feed-point impedance is roughly 50 Ω. When the radials are at right angles to the radiator (Fig 20.43B) 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

cases where the tower and beam antennas are not able to provide $1/4\text{-}\lambda$ 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 20.43. 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 20.43F 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 $50\ \Omega$.

Physically Short Verticals

A group of short vertical radiators is presented in Fig 20.44. 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 20.44. 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 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 $16\ \Omega$.

A method for using guy wires to top load a short vertical is illustrated in Fig 20.44D. This system works well with gamma feed. The loading wires

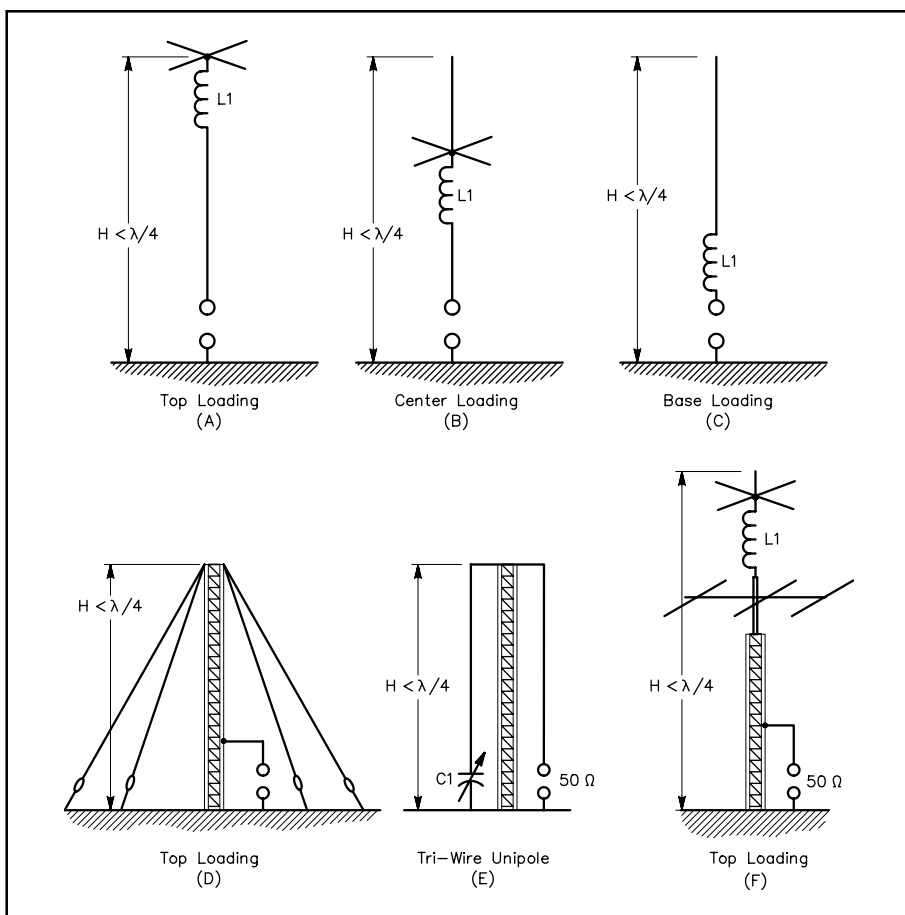


Fig 20.44—Vertical antennas that are less than one-quarter wavelength in height.

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-band 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 nicely to operation on 160 m.

A method for constructing the top-loading shown in Fig 20.44F is illustrated in **Fig 20.45**. 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 $3/8 \times 24$ 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 20.45B) 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 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 20.43 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

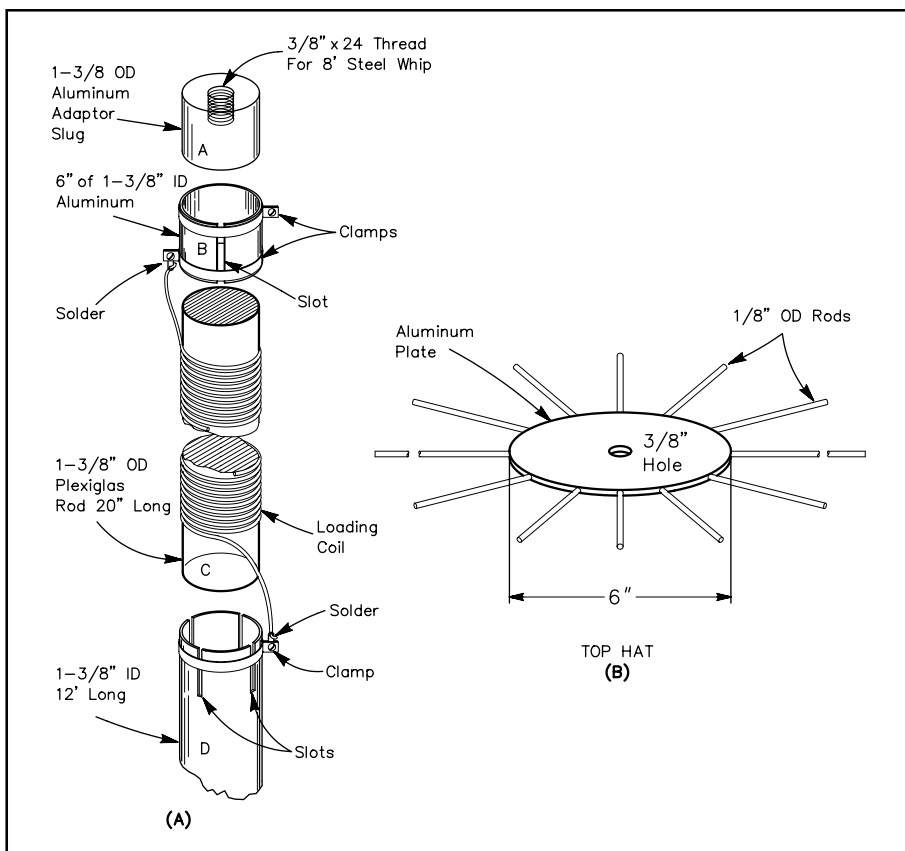


Fig 20.45—At A are the details for the tubing section of the loading assembly. Illustration B shows the top hat and its spokes. The longer the spokes, the better.

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 20.46** operates in much the same manner as a trap dipole or trap Yagi. The notable 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 $1/4\text{-}\lambda$ radiators. The portion of the antenna below the trap is adjusted as a $1/4\text{-}\lambda$ 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 next to 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.

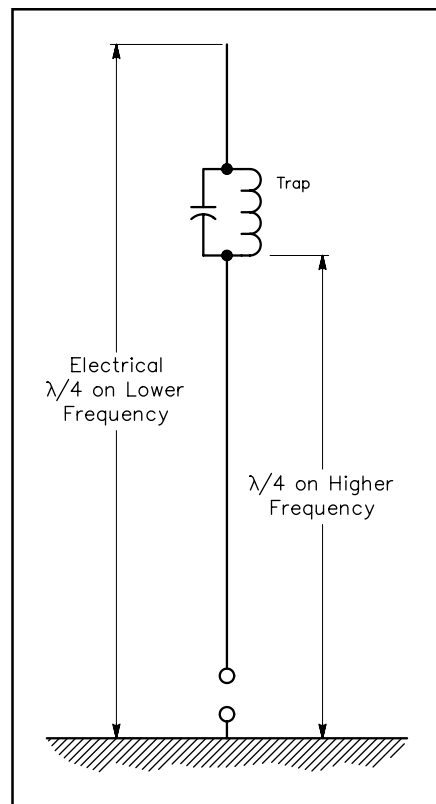


Fig 20.46—A two-band trap vertical antenna. The trap should be resonated by itself as a parallel resonant circuit at the center of the operating range for the higher frequency band. The reactance of either the inductor or the capacitor range from 100 to 300 Ω . At the lower frequency the trap will act as a loading inductor, adding electrical length to the total antenna.

Tips On Installing And Connecting To Ground Rods

Driving a ground rod 8 feet into the ground with a sledgehammer batters the rod end into an ugly flare. Some types of ground clamps can't open far enough to slip over the enlarged rod. Of course, you can file, grind or saw off the flared end, but doing all of these things at ground level can be difficult.

Alternatively, you could slip the clamp over the rod before driving it into the ground; or use a clamp that opens far enough to pass over the flare. In the case of 1/2-inch ground rods, however, clamps wide enough to pass the flare may not tighten adequately.

After considering these problems, I attached my shack ground wire to a 1/2-inch ground rod as follows. I drilled a tap-size hole, about 3/4 inch deep, into the rod top. I tapped this hole for a 1/4-inch, standard thread. Driving in a hex-head bolt permitted firm attachment of the wire to the rod end.

Although I did this by drilling only one hole, drilling a pilot hole—say, about 1/8 inch in diameter—*before* driving in the rod would assist. Doing so would allow you to put the rod in a vise for stability and accurate drilling. Your sledgehammer may obliterate this hole, but you should be able to relocate it by probing with a center punch.

In any such drilling and thread cutting, use a sharp drill and lubricate it and your tap often while cutting. One more tip: If you have a welder friend, consider having him or her weld a 1/4-inch bolt to the ground-rod top—after you've driven it in—to provide a stud for connections.—*A. W. Edwards, K5CN, Corpus Christi, Texas*

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 $\frac{1}{4}\lambda$ vertical into a 0.625λ vertical for the 12-m band, and a 40-m $\frac{1}{4}\lambda$ vertical into a 0.625λ 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 $\frac{1}{4}\lambda$ (in this case 0.625λ) 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 $-155\ \Omega$ (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 20.47**) 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 $2\frac{1}{2}$ inches, and has 6 turns per inch (B&W stock no. 3029). Resonance on 12 m was established with $3\frac{1}{4}$ 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.

The Ground System

Maximum RF current density—and therefore maximum ground losses—for $\frac{1}{4}\lambda$ verticals occurs in the immediate area of the base of the antenna. Maximum return current ground loss for a 0.625λ vertical occurs about $\frac{1}{2}\lambda$ 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 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 20.8 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.

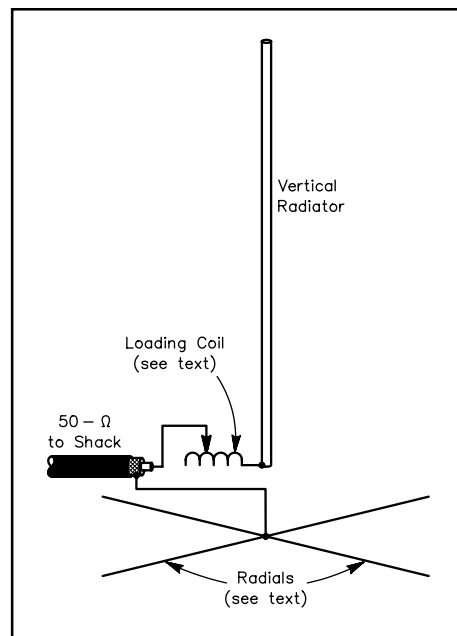


Fig 20.47—Dual-band vertical. Use a switch or relay to remove the loading coil from the circuit for lower frequency operation. Adjust the coil tap for best SWR on the higher-frequency band. The radial system should be as extensive as possible. See *The ARRL Antenna Book* for more information on ground systems for vertical antennas.

Table 20.8**Specifications for Dual-Band Verticals**

<i>Bands</i>	<i>Height</i>	<i>Required Matching Inductance (μH)</i>
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 $3\frac{1}{8}$ turns of #12 wire wound at 6 turns per inch, providing an inductance of about 2.8 mH. 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.

Ferrite Shield-Current Chokes Cure Stray RF On Vertical-Antenna Transmission Lines

A vertical antenna can induce current on the shield of its coax feeder. The antenna induces current on the shield in the same manner that it induces current in the ground-system radials.

Since the shield is connected to station ground, RF current flowing on the feeder shield also flows on the outer surfaces of the equipment when the transmitter operates. This current can induce undesirable voltages in interconnecting cables, causing erratic operation of computer keyboards and power supplies. RF feedback also can occur through the transmitter microphone circuit.

These problems occurred when I operated my kilowatt power amplifier and Kenwood TS-940S transceiver. (RF feedback in the TS-940 microphone preamplifier has been recognized by others and can be solved with bypass capacitors and RF chokes.) A better solution—one that will address all station problems caused by coax-shield RF currents—is to prevent the RF from getting into the station from the coax shield. Gary Peterson, K0CX, suggested that I do this by putting a ferrite-bead shield-current choke in my antenna feed line where it enters my station.

A good source of the required components is The Wireman, Inc (see Address List in [References](#)). The required components are a package of 50 type FB73-2401 ferrite beads (Wireman part #912B), 15 inches of RG-303 coax, and two coax connectors (UHF connectors [PL-259s; the Wireman's #702] with inserts [UG-175s; the Wireman's #704] for installation on RG-58 coax, or N connectors intended for installation on RG-58 [UG-536B/Us, available as the Wireman's #737]). Although the Wireman sells these parts bundled as part of a W2DU Balun kit [#833], the coax in the kit is too short to accommodate the connectors, so I recommend ordering the parts individually instead of buying them as The Wireman's W2DU Balun kit.

To assemble the choke, install one connector on the cable. Because the UG-536B/U connector is made for RG-58 (which has a larger diameter than RG-303), you must heat-shrink a piece of 1-inch-long, $\frac{3}{16}$ -inch-diameter plastic tubing on the end of the coax before you install the connector. This will make the connector fit the cable tightly.

Next, put a $\frac{1}{2}$ -inch-long piece of heat-shrink tubing on the cable about 1 inch from the connector to hold the beads in place. Then place the 50 beads on the cable. Put on another $\frac{1}{2}$ -inch piece of tubing to anchor the other end of the beads, and then shrink a piece of $\frac{3}{8}$ -inch-diameter tubing over the beads. Install the other connector on the cable. Install the choke on the transmission line where it leaves your station.

This should largely do away with problems related to stray RF traveling into your station on your feed line's coax shield. An idea for clubs: Build one or more chokes that members can borrow to test this fix's effectiveness before building their own chokes.

If your station is not in the immediate vicinity of your antenna and you have problems with stray RF with a dipole or inverted V, the problem may be due to lack of a balun or use of an ineffective balun. If this is the case, install the choke at the antenna feedpoint as discussed in W2DU's book *Reflections* rather than using the choke at the station end of your feed line.—Bruce R. Palmer, K0WM, Edmond, Oklahoma

A TREE-MOUNTED HF GROUNDPLANE ANTENNA

A tree-mounted, vertically polarized antenna may sound silly. But is it, really? Perhaps engineering references do not recommend it, but such an antenna does not cost much, is inconspicuous, and it works. This idea was described by Chuck Hutchinson, K8CH, in *QST* for September 1984.

The antenna itself is simple, as shown in **Fig 20.48**. A piece of RG-58 cable runs to the feedpoint of the antenna, and is attached to a porcelain insulator. Two radial wires are soldered to the coax-line braid at this point. Another piece of wire forms the radiator. The top of the radiator section is suspended from a tree limb or other convenient support, and in turn supports the rest of the antenna.

The dimensions for the antenna are given in **Fig 20.49**. (You can use the values given for leg lengths in [Table 20.5](#).) All three wires of the antenna are $\frac{1}{4}\lambda$ long. This generally limits the usefulness of the antenna for portable operation to 7 MHz and higher bands, as temporary supports higher than 35 or 40 ft are difficult to come by. Satisfactory operation can be accomplished on 3.5 MHz with an inverted-L configuration of the radiator, if you can overcome the accompanying difficulty of erecting the antenna at the operating site. The tree-mounted vertical idea can also be used for fixed station installations to make an “invisible” antenna. Shallow trenches can be slit for burying the coax feeder and the radial wires. The radiator itself is difficult to see unless you are standing right next to the tree.



Fig 20.48—The feedpoint of the tree-mounted groundplane antenna. The opposite ends of the two radial wires may be connected to stakes or other convenient anchor points. Make sure that the radials are high enough so that people cannot come in contact with them.

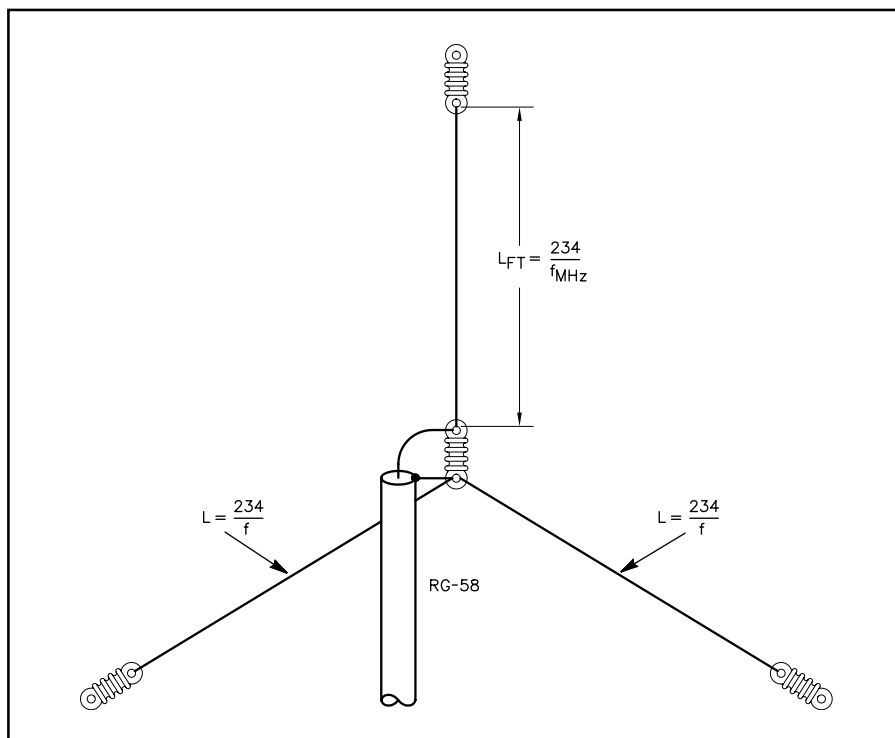


Fig 20.49—Dimensions and construction of the tree-mounted groundplane antenna.

Inverted L and Sloper Antennas

This section covers variations on the vertical antenna. **Fig 20.50A** 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 20.50. 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.

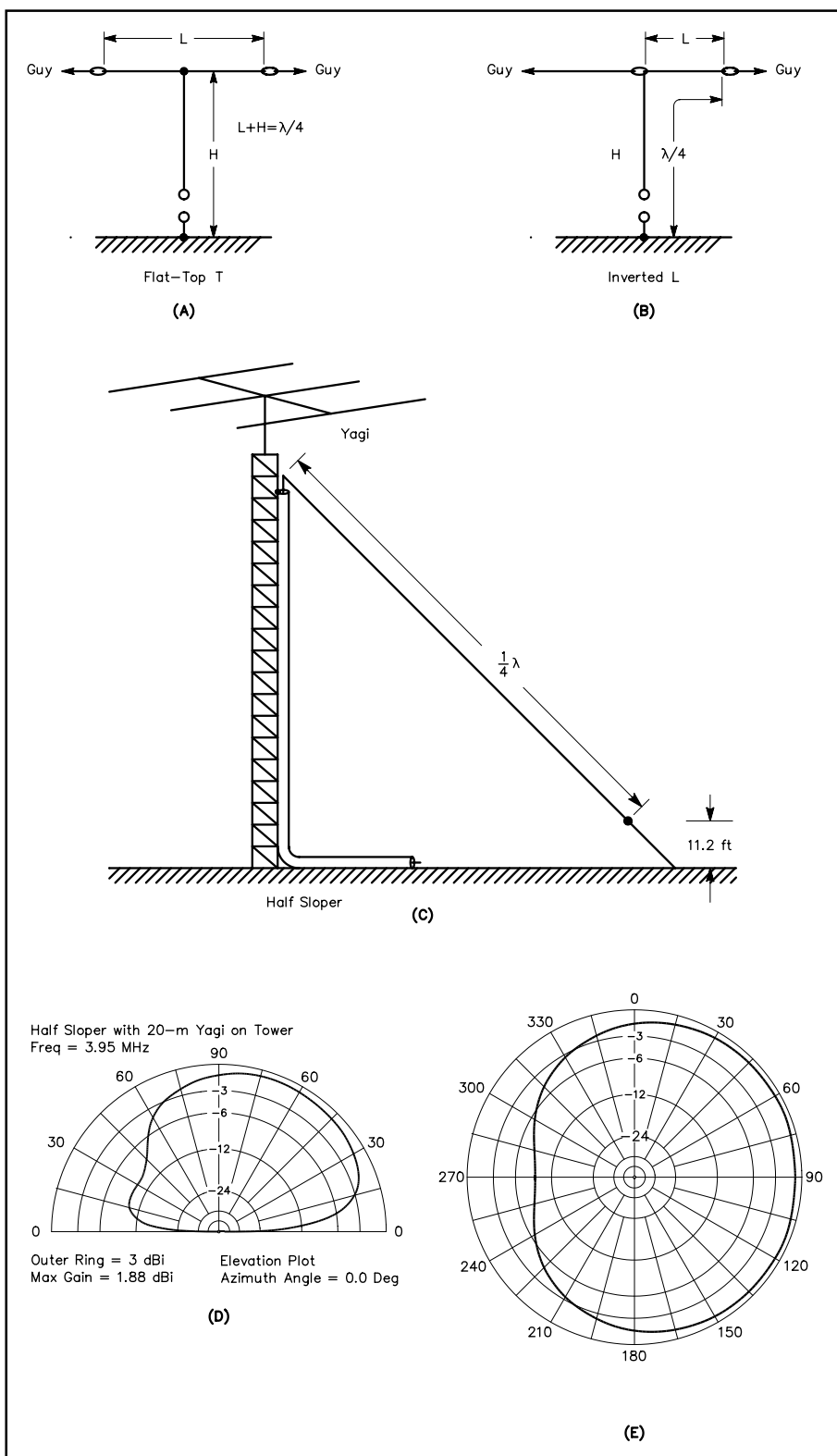


Fig 20.50—Some variations in vertical antennas. D is the vertical radiation pattern in the plane of a half sloper, with the sloper to the right. E is the azimuthal pattern of the half sloper (90° azimuth is the direction of the sloping wire). Both patterns apply to 160- and 80-m antennas described in the text.

THE HALF-SLOPER ANTENNA

Many hams have had excellent results with *half-sloper* antennas, while others have not had such luck. Work by ARRL Technical Advisor John S. Belrose, VE2CV, has 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 20.50D 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.

1.8-MHz INVERTED L

The antenna shown in **Fig 20.51** 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 $\frac{1}{4} \lambda$, the feed-point resistance is on the order of 50Ω , with an inductive reactance. That reactance is canceled by a series capacitor, which for power levels up to the legal limit can be a air-variable capacitor with a voltage rating of 1500 V. Adjust antenna length and variable 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.

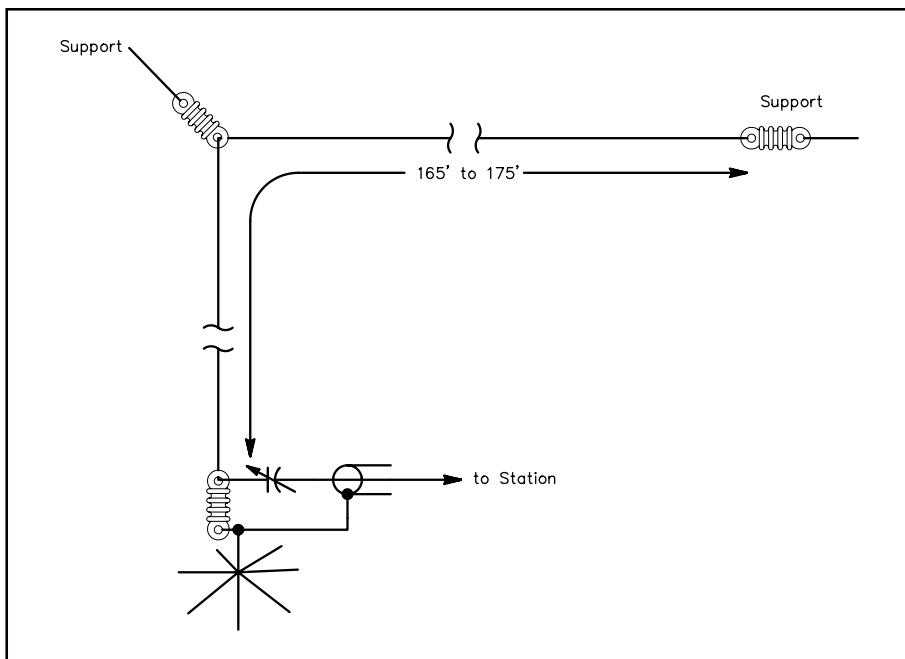


Fig 20.51—The 1.8-MHz inverted L. Overall wire length is 165 to 175 ft. The variable capacitor has a maximum capacitance of 500 to 800 pF.

THE AE6C DUAL-BAND INVERTED-L ANTENNA

In July 1991 *QST*, Dennis Monticelli, AE6C, described a dual-band inverted L. A drawing of his installation is shown in **Fig 20.52**. Dimensions and values are given in **Table 20.9**. For ease of explanation, only the 80/40-m version is described here. On 80 m the antenna is 0.375λ long, which raises the antenna's radiation resistance and feed-point impedance, and thus decreases the effect of ground losses. (The feed-point exhibits inductive reactance—which is canceled with series capacitance.) For 40 m the antenna is 0.75λ long, and is therefore resonant on that band. The pattern on 40 m, depending on how you install the antenna, resembles a combination of a vertical and a low dipole.

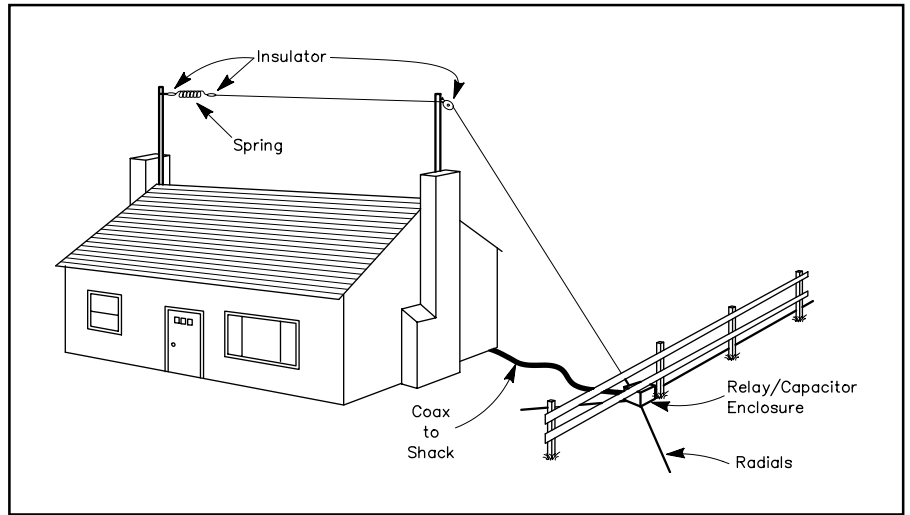


Fig 20.52—Drawing of the Dual-Band Inverted-L antenna installed at AE6C.

If you use a modest radial system with this antenna, the feed-point impedance is roughly 100Ω on both bands. **Fig 20.53** and **Fig 20.54** show details of the matching system and the 1:2 (50 to 100Ω) broadband transformer. The matching capaci-

Table 20.9

Recommended Wire Lengths and Capacitor Values*

Bands	Vertical Length (ft)	Horizontal Length (ft)	Total Length (ft)	Series Capacitor
80/40	32	64	96	$\approx 100 \text{ pF}$
160/80	64	128	192	$\approx 200 \text{ pF}$

* The total length is important, but the portions allocated to the vertical and horizontal members aren't critical.

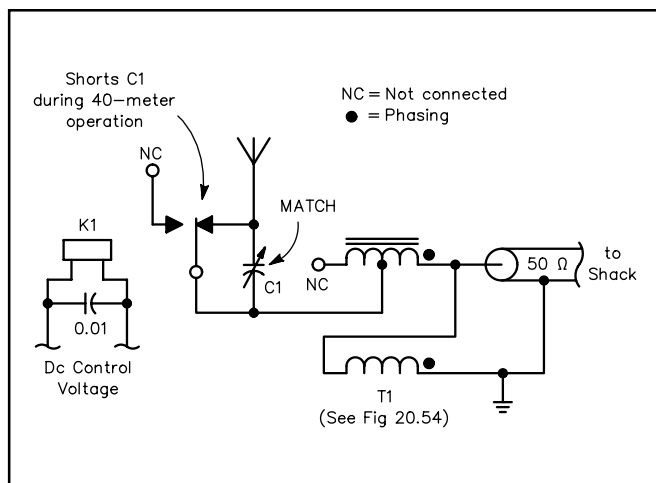


Fig 20.53—The resonating, impedance-matching, and band-switching circuitry required at the base of the inverted L. **Fig 20.54** shows details of T1.

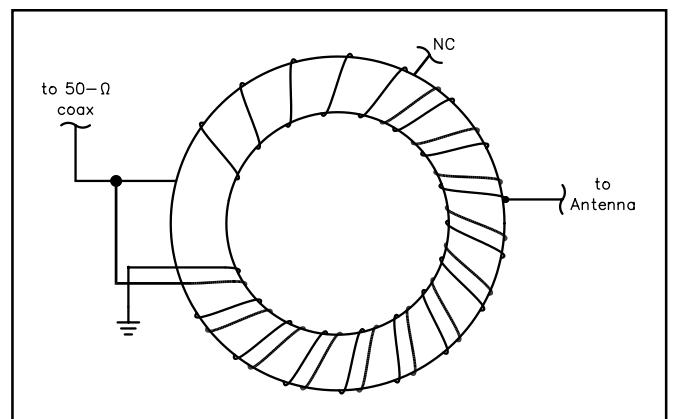


Fig 20.54—Winding details for constructing broadband bifilar transformer T1, which is wound on T-200-2 core. The primary is 16 turns of #14 enameled wire, and the secondary is 10 turns of #14 enameled wire tapped at about the eighth turn from the feed-line end.

tor, C1, is not used on the higher frequency band, and so it is shorted out to operate there.

To tune the antenna, start with the dimensions given in Table 20.9. With the series capacitor shorted, trim the wire length for best SWR at your 40-m frequency of interest. Unshort the capacitor and adjust it for best SWR at your frequency of interest on 80 m. You can further adjust SWR by changing transformer taps. (This will affect both bands.) As shown in **Fig 20.55**, a single capacitance value yields a 2:1 SWR bandwidth of approximately 225 kHz on 80 m. Different capacitance values can be used to cover other parts of the 80-m band.

You can make your own fixed-value, high-voltage, high-current capacitor from a piece of coax. For example, RG-8 (solid dielectric) exhibits 29.5 pF per ft and can withstand 4 kV at several amperes. Connect it by attaching one end of the inner conductor to the antenna and the braid (at the same end) to the feed system; leave the other end open. Start with about 4 ft of RG-8 and trim the coax for minimum SWR. (Make your cuts when you're not transmitting!) Other solid-dielectric cables are also suitable for this application. The **Transmission Lines** chapter gives capacitance per unit length in its table of coaxial-cable characteristics. The ends of the coaxial capacitors must be sealed to prevent water ingress.

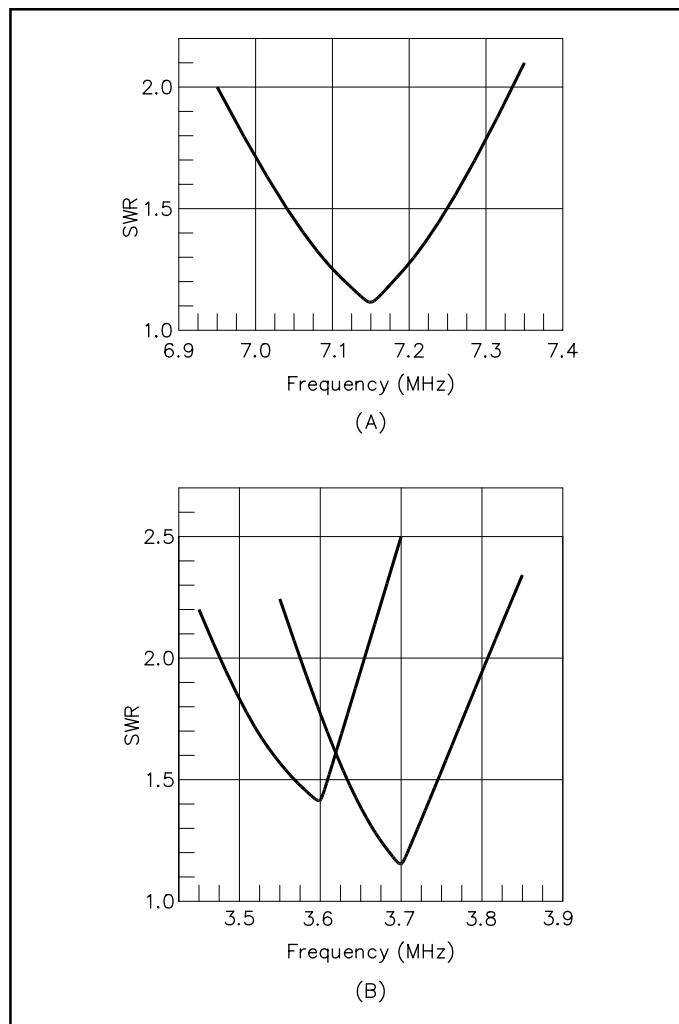


Fig 20.55—At A, 40-m SWR curve. At B, measured SWR curves for 80 m. Curves representing two different series capacitor values are shown.

Cork Your SO-239 Connectors!

Those little red plastic caps (CAPPLUGS) that are used to protect unused coax (SO-239) connectors from moisture, dirt and damage are expensive if you are lucky enough to find them. An alternative is to use plastic caps from inexpensive champagne bottles (**Fig A**). These caps fit perfectly.—Roy Berkowitz, K3NFU, Monroeton, Pennsylvania



Fig A—Champagne corks may be recycled into protective caps for SO-239 connectors.

SIMPLE, EFFECTIVE, ELEVATED GROUND-PLANE ANTENNAS

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

FROM SLOPER TO VERTICAL

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

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

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

The examples in **Fig 20.56** should give us an idea of how much top loading might be expected from typical amateur antennas. The values along the horizontal axis tell us the approximate vertical height replaced by the antennas listed in a top-loaded vertical antenna. To arrive at the remaining amount of tower needed for resonance, subtract these numbers from the nonloaded tower height needed for resonance. Note that for all but the 10-m antennas, the equivalent loading equals or exceeds a quarter wavelength on 40 m. For typical HF Yagis, this method is best used only on 80 and 160 m.

CONSTRUCTION EXAMPLES

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

Ten quarter-wavelength (65-ft) radials were run from a nylon rope tied between tower legs at the 15-ft level, to various supports 10 ft high. Nylon cord was tied to the insulated, stranded, #18 wire, without using insulators. The radials are all connected together and to the center of an exact half wavelength (at 3.6 MHz) of RG-213 coax, which will repeat the antenna feed impedance at the other end. **Fig 20.57** is a drawing of the installation. The author used a Hewlett-Packard low-frequency impedance analyzer to measure the input impedance across the 80-m band.

An exact resonance (zero reactance) was seen

Antenna	Boom Length (feet)	Equivalent Loading (feet)
3L 20	24	39
5L 15	26	35
4L 15	20	31
3L 15	16	28
5L 10	24	28
4L 10	18	24
3L 10	12	20
TH7	24	40 (estimated)
TH3	14	27 (estimated)

Fig 20.56— Effective loading of common Yagi antennas.

at 3.6 MHz, just as predicted. The radiation resistance was found to be 17 Ω. The next question is, how to feed and match the antenna.

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

Make a quarter-wave (70 feet × 0.66 velocity factor = 46 ft) 37-Ω matching line by paralleling two pieces of RG-59 and connecting them between the feedpoint and a run of the rigid coax to the transmitter.

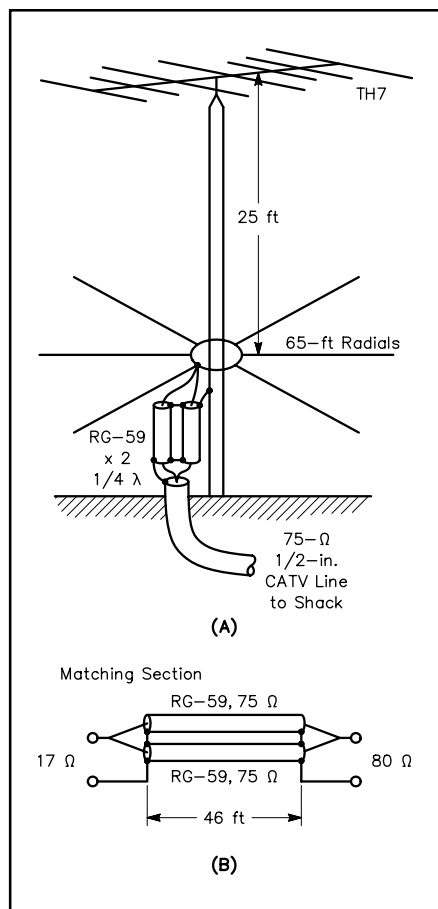


Fig 20.57—At A, an 80-m top-loaded, reverse-fed elevated ground plane, using a 40-ft tower carrying a TH7 triband Yagi antenna. At B, dimensions of the 3.6-MHz matching network, made from RG-59.

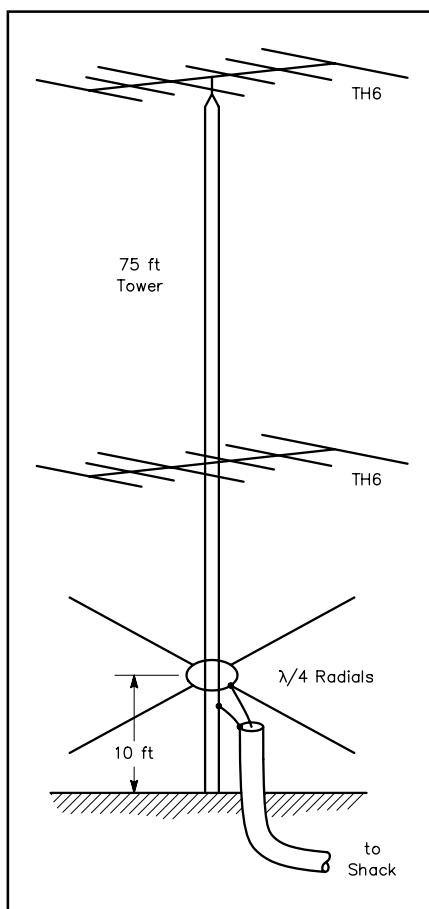


Fig 20.58—A 160-m antenna using a 75-ft tower carrying stacked triband Yagis.

of quarter-wave matching transformers is that the input impedance (R_i) and output impedance (R_o) are related by:

$$Z_o^2 = R_i \times R_o \quad (\text{Eq 1})$$

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

160-M OPERATION

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

Another installation, using stacked TH6s on a 75-ft tower, is shown in **Fig 20.58**. The radials are 10 ft off the ground.

North Shadow

By Irvin L. McNally, K6WX, 26119 Fairlane Dr, Sun City, CA 92586

Determining which way is north is essential for setting up a satellite dish or beam antenna. Articles I've read have shown different ways of making this determination. One method covers the use of a magnetic compass and a knowledge of the local magnetic variation (the difference between true north and magnetic north). However, an accurate value of the local magnetic variation is not always available. And with small hand-held compasses, it's difficult to read the exact bearing because the scale isn't graduated in degrees.

Another method is to observe the north star, Polaris, and sight from the observer to a vertical plumb-bob line to the star. The latter step isn't easy to do in the dark. Furthermore, unless a *Nautical Almanac* is available to determine the exact time of Polaris' meridian transit, there will be a maximum error of about 1°.

Homeowners can try another source of information: the surveyor's plot plan may have noted the magnetic or true bearing relative to the property line.

Mariners use the noon sight to determine their position at sea. With a sextant and chronometer, the altitude and time of the sun's meridian crossing is determined. Combining this data with the declination of the sun, equation of time,² sextant correction, refraction and dip, the position can readily be calculated.

I figured that this method could be used in a reverse calculation to find north. Knowing your exact longitude and the equation of time, the local time of the sun's meridian crossing can be determined. This is the time when the shadow of a vertical pole or tower points true north.

Because the equation of time varies from day to day, its value must be taken from the *Nautical Almanac* or an appropriate table. This difference is shown in the *Nautical Almanac* for each day of the year. World globes used to have an analema printed on a barren area of the Pacific Ocean. The analema is a figure-eight pattern that represents the year-long cycle of the sun's declination and the equation of time. Most globe users fail to grasp its significance.

I've written an IBM BASIC computer program¹ that determines the local time of the north shadow for any day of the year. The required information is: local longitude, month number, day number and local time zone number. A *Nautical Almanac* isn't needed because the equation of time, taken from Mixer's *Primer of Navigation*,² is in the program. The maximum error using this table is about 20 seconds, with a possible error of 2 seconds or less, four times a year.

Notes

¹ The program *NSHADOW.EXE* is available at the ARRL Web site. See [page viii](#).

² G. Mixer, *Primer of Navigation* (New York: Van Nostrand Reinhold Co., 5th ed.), 1967, Chapter 21, Table 10, p 539. ISBN: 0-442-05443-2.

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 quad beam antenna. The former is commonly called a *Yagi*, and the latter is 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 20.60** 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 20.60B) has a main lobe that is more favorable for DX work (roughly 15°) than the lobe of the lower antenna in Fig 20.60A (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 20.61**. 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 20.61 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

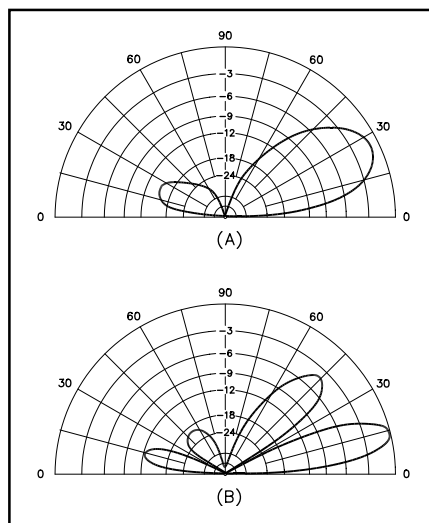


Fig 20.60—Elevation-plane response of a 3-element Yagi placed $\frac{1}{2} \lambda$ above perfect ground at (A) and the same antenna spaced 1λ above ground at (B).

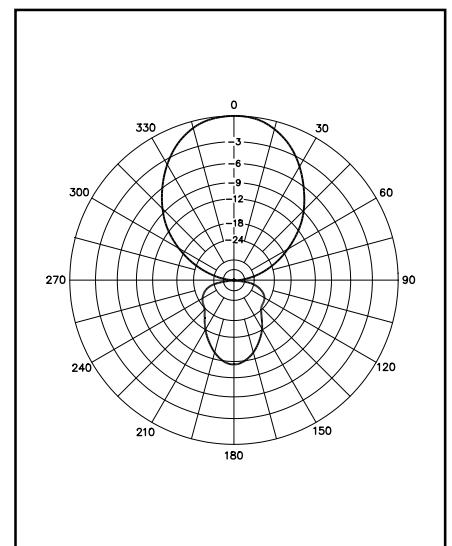


Fig 20.61—Azimuth-plane pattern of a typical three-element Yagi in free space. The Yagi's boom is along the 0° to 180° axis.

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 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 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 0.15λ from the driven element, although some successful antennas have been built with 0.1λ spacing and director tuning. Gain vs element spacing for a 2-element antenna is given in **Fig 20.62** 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 $.25 \lambda$. With 0.2λ reflector spacing, **Fig 20.63** shows that the gain variation with director spacing is not especially critical. Also, the overall length of the array (boom length

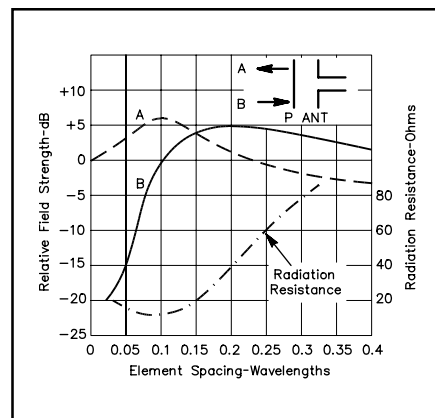


Fig 20.62—Gain vs element spacing for a 2-element Yagi, having one driven and one parasitic element. The reference point, 0 dB, is the field strength from a half-wave antenna alone. The greatest gain is in the direction A at spacings of less than 0.14λ , and in direction B at greater spacings. The front-to-rear 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.

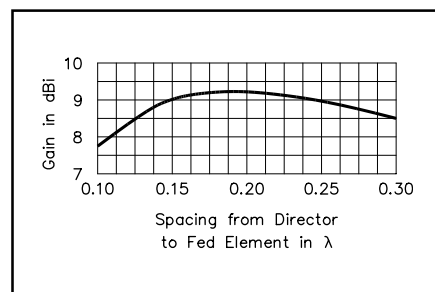


Fig 20.63—General relationship of gain of 3-element Yagi vs director spacing, the reflector being fixed at 0.2λ . This antenna is tuned for maximum forward gain.

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 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 optimum 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 20.10, 20.11, 20.12, 20.13** and **20.14**, 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

Table 20.10
10-m Optimized Yagi Designs

	<i>Spacing Between Elements (in.)</i>	<i>Seg 1 Length (in.)</i>	<i>Seg 2 Length (in.)</i>	<i>Seg 3 Length (in.)</i>	<i>Midband Gain F/R</i>
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 20.11**12-m Optimized Yagi Designs**

	<i>Spacing Between Elements (in.)</i>	<i>Seg 1 Length (in.)</i>	<i>Seg 2 Length (in.)</i>	<i>Seg 3 Length (in.)</i>	<i>Midband Gain F/R</i>
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.

Table 20.12**15-m Optimized Yagi Designs**

	<i>Spacing Between Elements (in.)</i>	<i>Seg 1 Length (in.)</i>	<i>Seg 2 Length (in.)</i>	<i>Seg 3 Length (in.)</i>	<i>Seg 4 Length (in.)</i>	<i>Midband Gain F/R</i>
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 20.13**17-m Optimized Yagi Designs**

	<i>Spacing Between Elements (in.)</i>	<i>Seg 1 Length (in.)</i>	<i>Seg 2 Length (in.)</i>	<i>Seg 3 Length (in.)</i>	<i>Seg 4 Length (in.)</i>	<i>Seg 5 Length (in.)</i>	<i>Midband Gain F/R</i>
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 20.14**20-m Optimized Yagi Designs**

	<i>Spacing Between Elements (in.)</i>	<i>Seg 1 Length (in.)</i>	<i>Seg 2 Length (in.)</i>	<i>Seg 3 Length (in.)</i>	<i>Seg 4 Length (in.)</i>	<i>Seg 5 Length (in.)</i>	<i>Seg 6 Length (in.)</i>	<i>Midband Gain F/R</i>
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.

telescoped easily, using techniques shown in **Fig 20.64**. Measuring each element to an accuracy of $\frac{1}{8}$ 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 20.65**. 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 $\frac{1}{2}$ -inch OD tubing, sticks out 66.75 inches from the $\frac{5}{8}$ -inch OD tubing. For each 10-m element, the overall length of each $\frac{5}{8}$ -inch OD piece of tubing is 21 inches, before insertion into the $\frac{3}{4}$ -inch

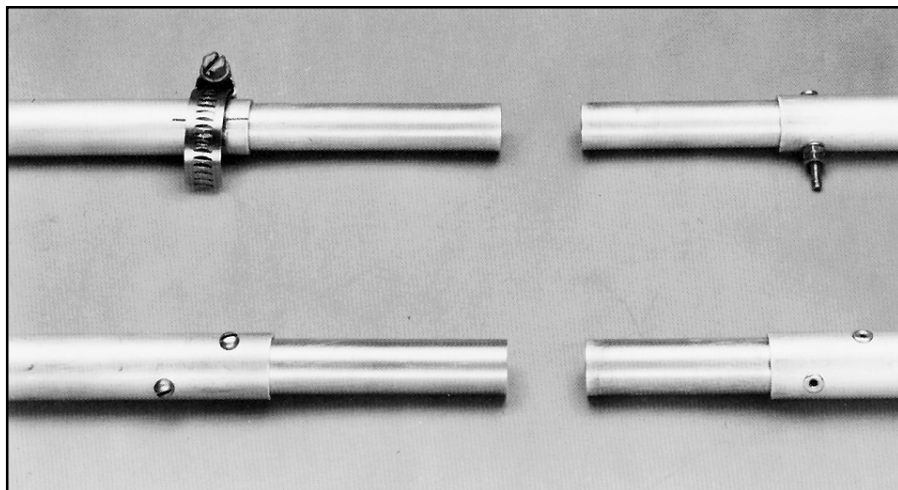


Fig 20.64—Some methods of connecting telescoping tubing sections to build beam elements. See text for a discussion of each method.

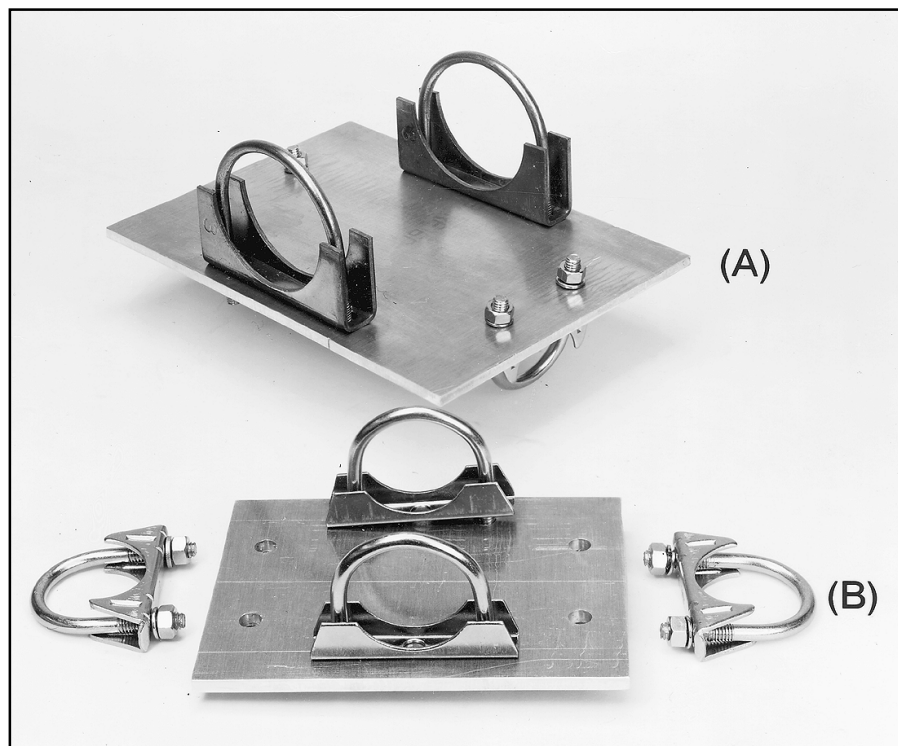


Fig 20.65—The boom-to-element plate at A uses muffer-clamp-type U-bolts and saddles to secure the round tubing to the flat plate. The boom-to-mast plate at B is similar to the boom-to-element plate. The main difference is the size of materials used.

piece. Since the $\frac{3}{4}$ -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 $\frac{3}{4}$ -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 20.66. The variable gamma or T capacitors can be housed in small plastic cups 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 will 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

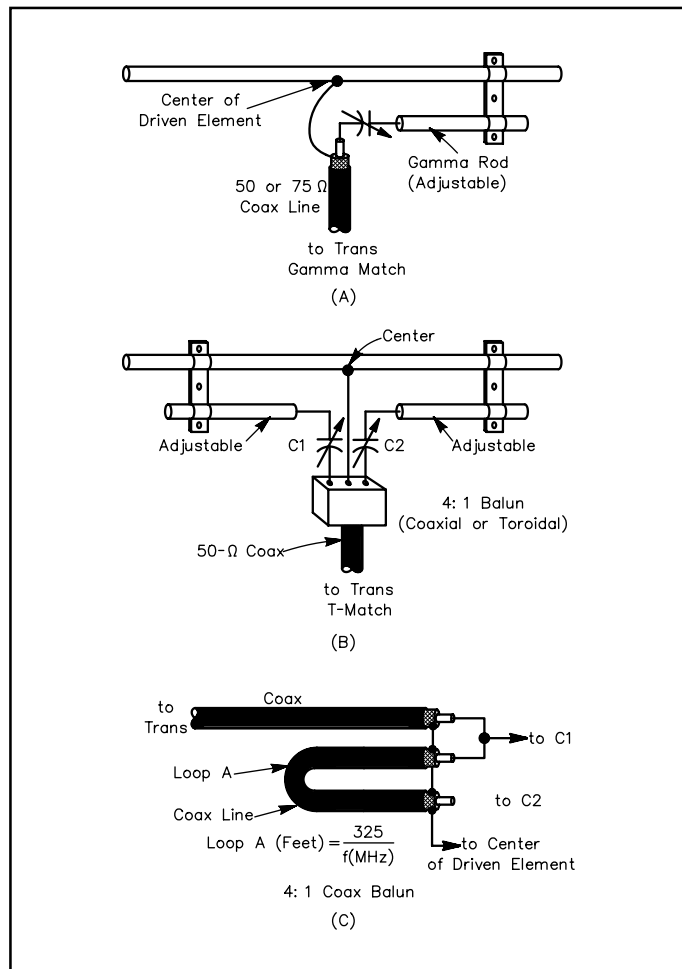


Fig 20.66—Illustrations of gamma and T matching systems. At A, the gamma rod is adjusted along with C until the lowest SWR is obtained. A T match is shown at B. It is the same as two gamma-match rods. The rods and C1 and C2 are adjusted alternately for a best SWR. A coaxial 4:1 balun transformer is shown 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.

with a likelihood of deterioration in performance over the whole frequency band.

For reference, **Table 20.15** 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 20.15), 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, $\frac{7}{8}$ inch, has an OD of 0.875 inch. The 0.009-inch difference provides just the right amount of clearance for a snug fit.

Fig 20.64 shows several methods of fastening antenna element sections together. The slot and hose clamp method shown in Fig 20.64A 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

Table 20.15
Standard Sizes of Aluminum Tubing

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

OD (in.)	Wall Thickness		ID (in.)	Approx Weight (lb)	
	(in.)	stubs ga		per ft	per length
$\frac{3}{16}$	0.035	no. 20	0.117	0.019	0.228
	0.049	no. 18	0.089	0.025	0.330
$\frac{1}{4}$	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
$\frac{5}{16}$	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
$\frac{3}{8}$	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
$\frac{7}{16}$	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
$\frac{1}{2}$	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
$\frac{5}{8}$	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

Continued on [next page](#).

Table 20.15**Standard Sizes of Aluminum Tubing**Continued from [previous page](#).

OD (in.)	Wall Thickness		ID (in.)	Approx Weight (lb)	
	(in.)	stubs ga		per ft	per length
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
1 5/8	*0.250	1/4"	1.000	1.150	14.823
	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
	0.049	no. 18	2.152	0.398	4.776
2 1/4	0.065	no. 16	2.120	0.520	6.240
	0.083	no. 14	2.084	0.660	7.920
	0.065	no. 16	2.370	0.587	7.044
2 1/2	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
	0.065	no. 16	2.870	0.710	8.520
3	*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.

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 20.64B, 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 20.67.

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 20.65B 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

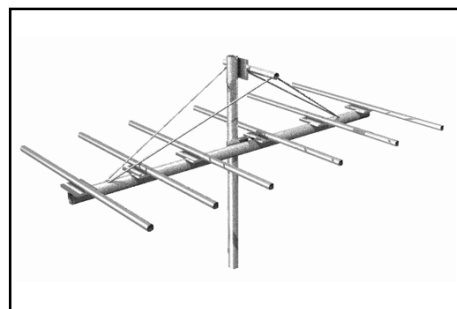


Fig 20.67—A long boom needs both vertical and horizontal support. The crossbar mounted above the boom can support a double truss, which will help keep the antenna in position.

(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 20.68**. 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 20.68 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

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

If multiple arrays are used, each antenna should be tuned separately for maximum forward gain, or best front-to-rear ratio, as noted 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. The element length (driven element) can be adjusted for resonance in the most-used portion of the band by lengthening or shortening it.

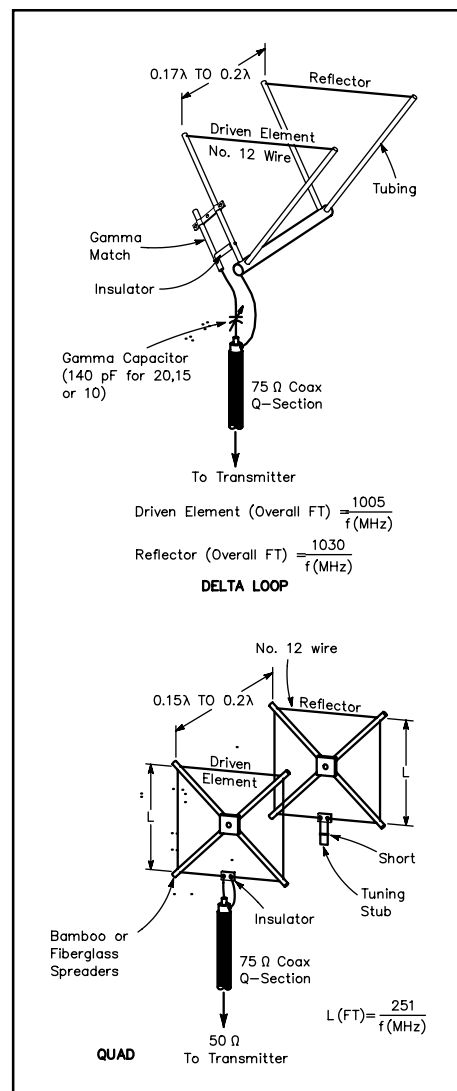


Fig 20.68—Information on building a quad or a delta-loop antenna. The antennas are electrically similar, but the delta-loop uses plumber's delight construction. The $\lambda/4$ length of 75-Ω coax acts as a Q-section transformer from approximate 100-Ω feedpoint impedance of quad to 50-Ω feed line coax.

Feeding A Quad With Open-Wire Line

After purchasing a GEM quad antenna, I determined that the best place for the antenna on my property was 375 feet from my operating position. Even low-loss coax could easily result in a 3-dB loss at 28 MHz.

At the encouragement of Jay Kolinsky, NE2Q, I looked at using open-wire transmission line. Using readily available 450- Ω line, the losses would be low and the line cost went down to only 10 cents per foot. As we learned later, there were even bigger benefits.

Feeding the Antenna

I've talked to a lot of people using quads, and I couldn't find anyone who had fed their quad with open-wire line. A call to the antenna manufacturer produced some suggestions, but not firm guidance on how to do the job.

The antenna was set up for four bands: 20, 17, 15 and 10 m. Jay and I decided to take the easy way out and tie all of its driven elements together, spacing their terminals with a 1 $\frac{1}{2}$ -inch porcelain insulator, and feed all four driven elements with the open-wire line as shown in Figure 2. We ignored the driven elements' sum feed-point impedance, since using open-wire line meant using an antenna tuner between the transmitter and the line, anyway. We did not attempt to tune the antenna's driven elements, deciding instead to carefully adjust the quad's front-to-back ratio on each band and let the tuner take care of the rest.

Unexpected Results

Careful front-to-back ratio adjustments yielded results better than those claimed by the antenna manufacturer. NT5E went on the air with a new antenna, and the performance proved well worth the work. Using the tuner, I was able to operate anywhere in the bands with a 1:1 SWR. The only drawback was that I still needed antennas for 7, 10 and 24 MHz—or did I?

A quick check proved that the system would load up at 10 and 24 MHz. More careful adjustments were required for tuning up at 7 MHz. We roughly measured its radiation pattern as similar to that of a half-wave loop. My antenna had grown—at least in terms of frequency coverage! Further rough measurements at 7 MHz showed that there was a slight front-to-back ratio, possibly because of the reflectors present for 14, 18, 21 and 28 MHz.—*Curtis Robb, NT5E, Boerne, Texas*

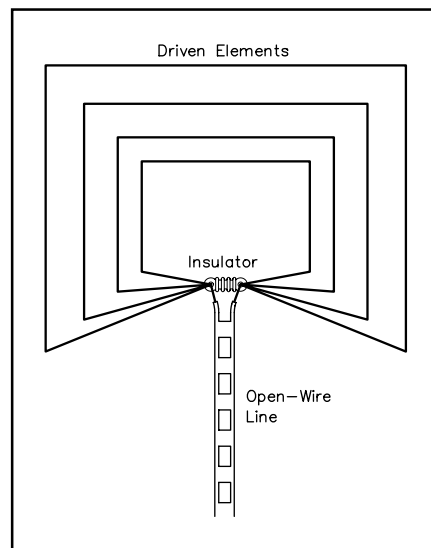


Figure 2—Curtis, NT5E, simplified his quad feed by connecting its elements' feed points together and feeding all three simultaneously with open-wire line.

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).

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 20.69 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 means of 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):

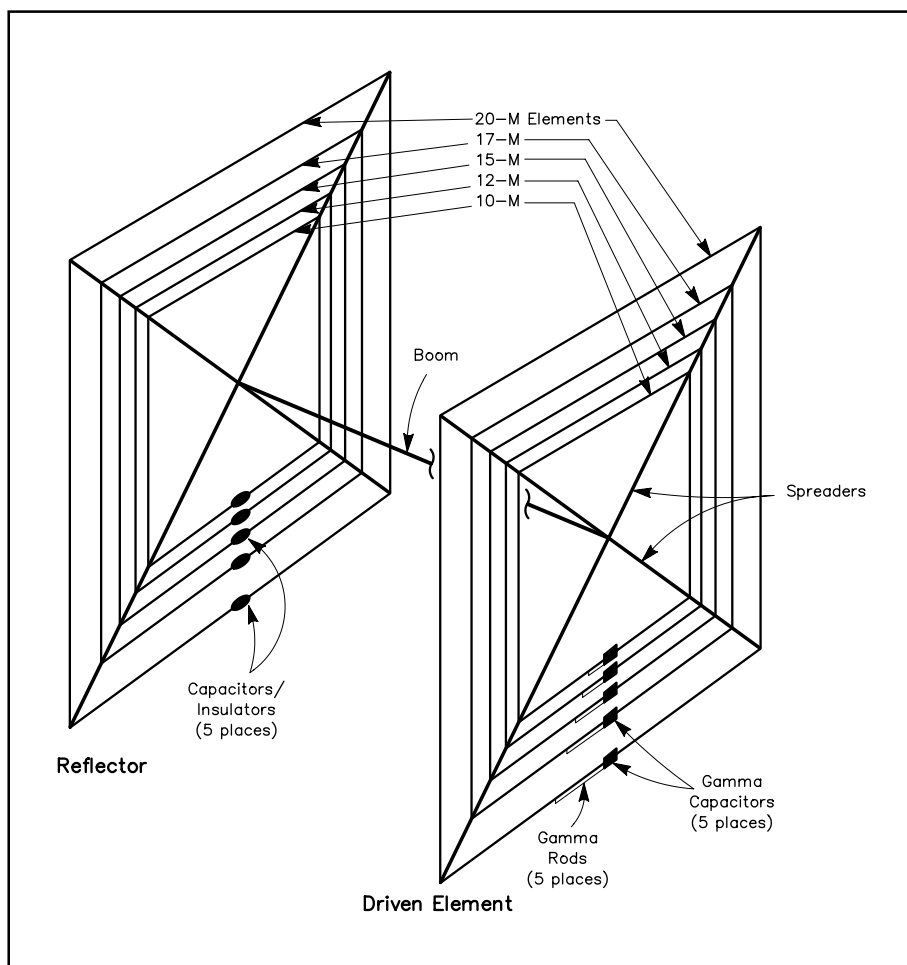


Fig 20.69—Mechanical layout of the five-band quad. The boom is 8 ft long; see [Table 20.16](#) for all other dimensions.

- 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 20.70**). A male UHF connector was mounted to the box, along with a screw terminal for connection to the gamma rod. 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 20.69**, 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 $1/4 \times 2 \times 3/4$ -inch phenolic stock. The holes are $1/2$ -inch apart. Two terminal lugs (shorted together at

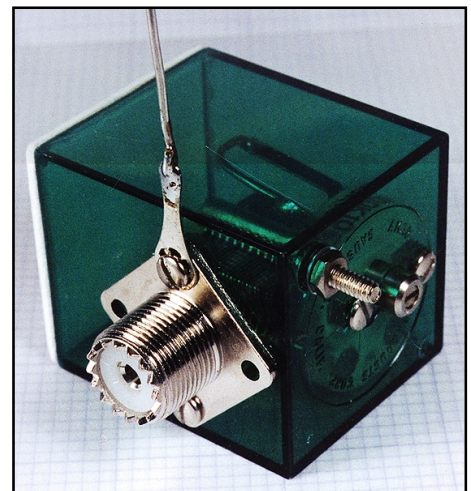


Fig 20.70—Photo of one of the feed-point gamma-match capacitors.

the center hole) are used in each driven element. They offer a convenient way to open the loops by removing one screw. **Fig 20.71** shows these insulators and the gamma-match construction schematically. **Table 20.16** 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 20.72** 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 20.73**), 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.

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

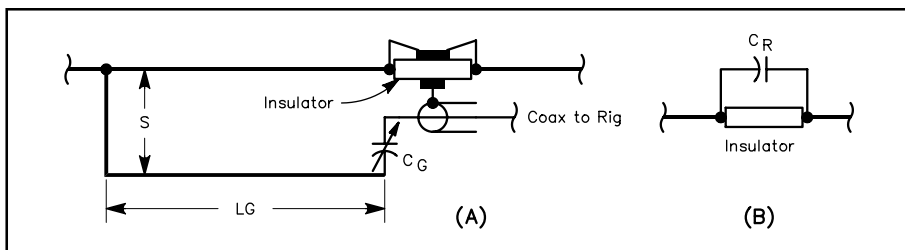


Fig 20.71—Gamma-match construction details (A) and reflector-tuning capacitor (C_R) attachment schematic (B). The gamma matches consist of matching wires (one per band) with series capacitors (C_g). See Table 20.16 for lengths and component specifications.

Table 20.16
Element Lengths and Gamma-Match Specifications of the KC6T and W6NBH Five-Band Quads

KC6T Model

Band (MHz)	Driven Element	Length (in.)	Gamma Match		Reflector Length (in.)	C_R (pF)
			Spacing	C_g (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		Reflector Length (in.)	C_R (pF)
			Spacing	C_g (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)

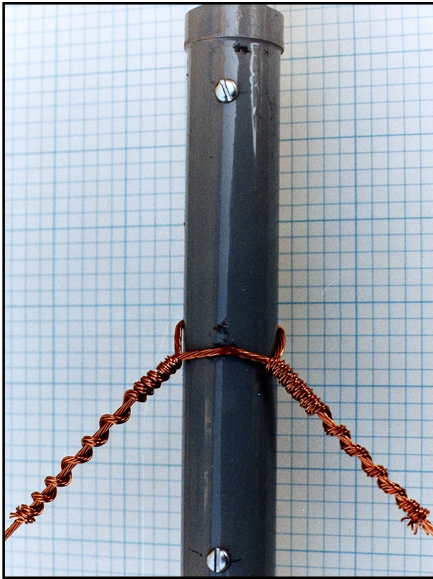


Fig 20.72—Attaching quad wires to the spreaders must minimize stress on the wires for best reliability. This method (described in the [text](#)) cuts the chances of wind-induced wire breakage by distributing stress.

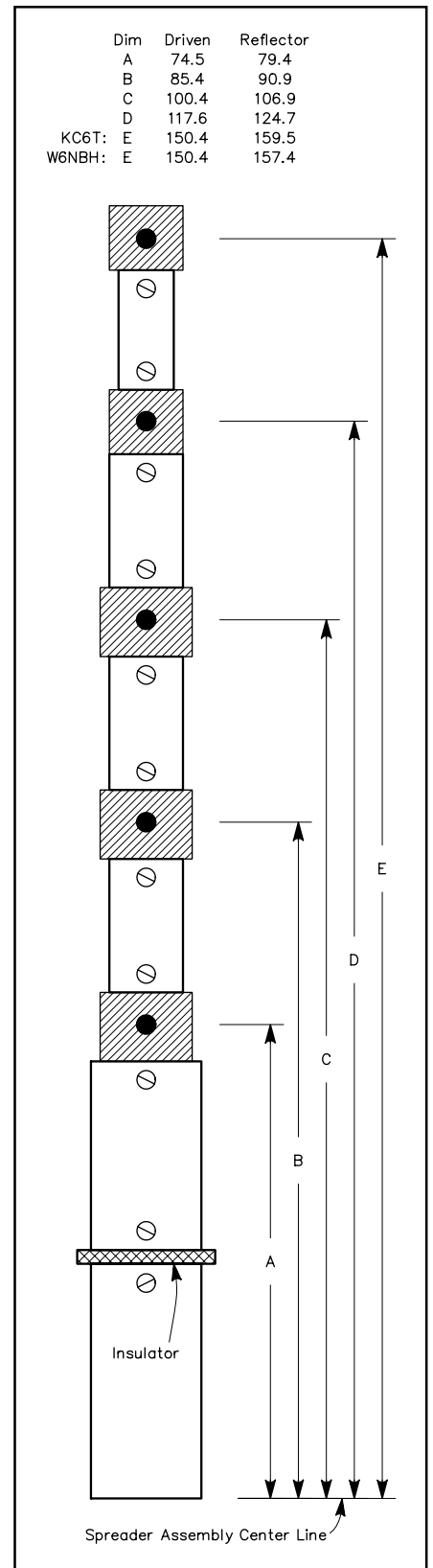


Fig 20.73—Spreader-drilling diagram and dimensions (in.) for the five-band quad. These dimensions apply to both spreader designs described in the text, except that most commercial spreaders are only a bit over 13 ft (156 inches) long. This requires compensation for the W6NBH model's shorter 20-m reflector as described in the [text](#).

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 20.73) is 1¹/₈-inch diameter × 0.058-inch wall. The next three sections are 3/4-inch diameter × 0.035-inch wall, and the outer length is made from 1/2 inch diameter × 0.035-inch wall. The dimensions shown in Fig 20.73 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 20.73, 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 20.16. 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 20.16, 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 20.17**.

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, but 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 20.16](#)). 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.

Table 20.17
Measured Front-to-Rear Ratios

<i>Band</i>	<i>KC6T Model</i>	<i>W6NBH Model</i>
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

Loops

The quad is not the only loop antenna used by radio amateurs. Horizontal full-wave loops, much like the quad driven element, are performers that are worth considering. Multiband operation is a natural, and you only need one feed line.

Physically small loops can also be used for transmitting. They're compact, but the price is a narrow bandwidth and somewhat reduced efficiency.

THE LOOP SKYWIRE

Here's a multiband HF antenna that's easy to build, costs nearly nothing and works great—yet relatively few amateurs use it. The antenna is the full-size horizontal loop—or, as this one's called—the *Loop Skywire*. The Loop Skywire eliminates the need for multiple antennas to cover the HF bands, is made only of wire and coaxial cable (or open-wire line) and often needs no Transmatch. It's efficient and omnidirectional over real earth, can be used on all harmonics of the fundamental frequency, and fits on almost every amateur's lot. The Loop Skywire has been called “the best easy-to-build, multiband antenna around,” and to those who now use it, it's “the best kept secret in the amateur circle.”

It is curious that many references to this antenna are brief pronouncements that it operates best as a high-angle radiator and is good for only short-distance contacts. This is not the case. Those who use the Loop Skywire know that DX is easy to work. This antenna was originally featured in November 1985 *QST* and was presented by Dave Fischer, W0MHS.

The Design

The Loop Skywire is shown in **Fig 20.74**. It is simply a full-wavelength loop antenna erected horizontal to the earth. Maximize enclosed area within the wire loop, and mount the antenna up as high as possible above ground. The antenna has one wavelength of wire in its perimeter at the design, or fundamental, frequency. If you choose to calculate L_{total} in ft, use the following equation:

$$L_{\text{total}} = 1005/f \quad (8)$$

where f equals the frequency in MHz. (This is the standard formula for determining the length of full-wavelength loops.)

Given any length of wire, a circle encloses the maximum possible area. Since it takes an infinite number of supports to support a circular loop, a square loop (with four supports) is more practical. Further reducing the area enclosed by the wire loop (fewer supports) brings the antenna closer to the properties of the folded dipole; both harmonic-impedance and feed-line voltage problems can result. Loop ge-

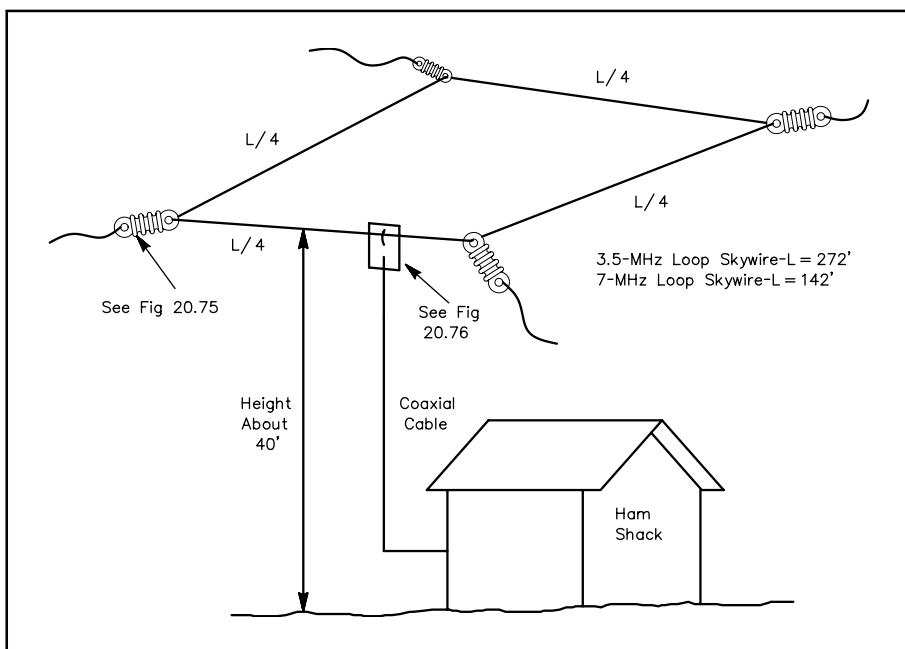


Fig 20.74—A complete view of the Loop Skywire. The square loop is erected horizontal to the earth.

ometries other than a square are thus possible, but remember the two fundamental requirements for the Loop Skywire—its horizontal position and maximum enclosed area.

Construction

The antenna's construction is simple. Although the loop can be made for any band or frequency of operation, the following two Loop Skywires are star performers. Both antennas work on the 10-MHz band also.

3.5-MHz Loop Skywire: (3.5-28 MHz), total loop perimeter: 272 ft. Square side length: 68 ft.

7-MHz Loop Skywire: (7-28 MHz), total loop perimeter: 142 ft. Square side length: 35.5 ft.

The actual total length can vary by a few ft, as the length is not at all critical. Do not worry about tuning and pruning the loop to resonance. No signal difference will be detected on the air.

Insulated, stranded copper wire—#12 to #18—is usually used for the loop. **Fig 20.75** shows the placement of the insulators at the loop corners. Either lock or tie the insulator in place with a loop wire tie, as shown in Fig 20.75A, or leave the insulator free to “float” or slide along the wire, Fig 20.75B. Most loop users float at least two insulators. This allows pulling the slack out of the loop once it is in the air, and eliminates the need to have all the supports exactly placed for proper tension in each leg. It's best to float two opposite corners.

The feedpoint can be positioned anywhere along the loop. Most users feed the Skywire at a corner, however. **Fig 20.76** shows a method of doing this. It is advantageous to keep the feed-point mechanically away from a corner support. Feeding a foot or so from one corner allows the feed line to exit more freely.

Generally, a minimum of four supports is required. If trees are used for supports, then at least two of the ropes or guys used to support the insulators should be counterweighted and allowed to move freely. The feed-line corner is almost always tied down, however. Several loops have been constructed with bungee cords tied to three of the four insulators. This eliminates the need for counter weighting.

Recommended height for the antenna is 40 ft or more. Higher is better. However, suc-

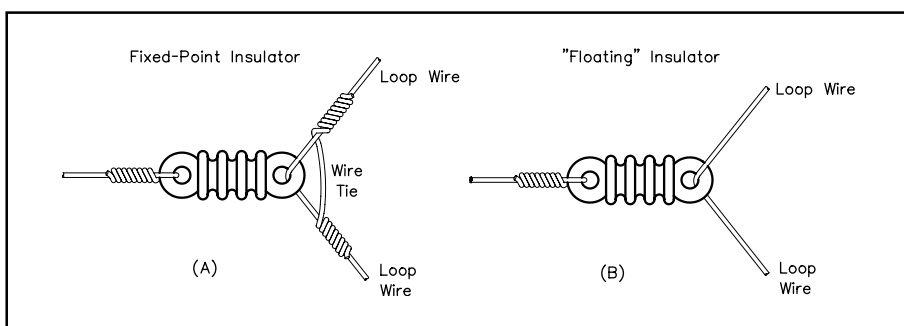


Fig 20.75—Two methods of installing the insulators at the corners of the loop.

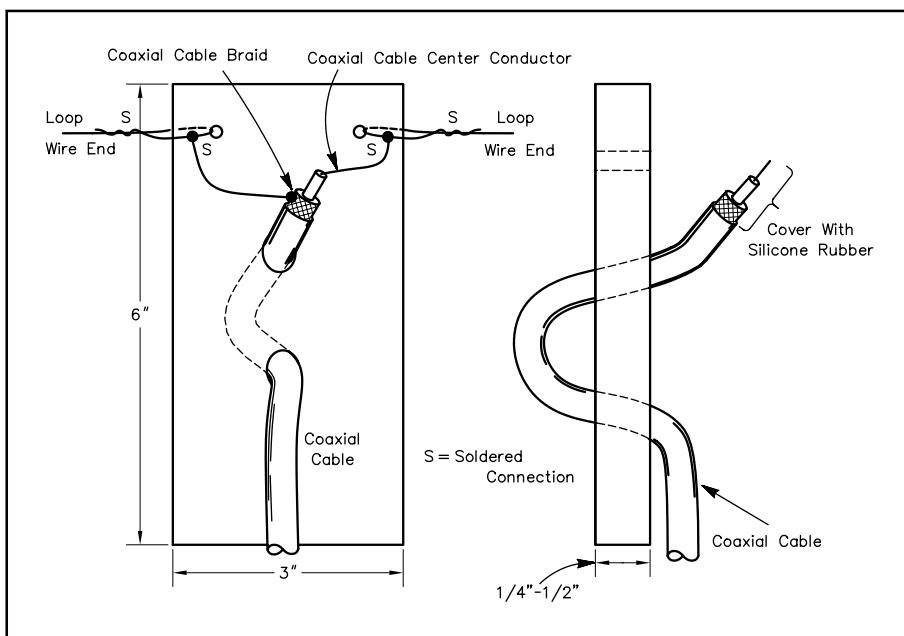


Fig 20.76—Most users feed the Loop Skywire at the corner. Dimensions shown are approximate.

cessful local and DX operation has been reported in several cases with the loop as low as 25 ft.

The SWR will depend on operating frequency and the type of feed line used. Coaxial cable is sufficient. Open-wire line works well, too. Many users feed the loop with RG-58. The SWR from either of these loops is rarely over 3:1. If you are concerned about the SWR, use a Transmatch.

When constructing the loop, connect (solder) the coaxial feed line ends directly to the loop wire ends. Baluns or choke coils at the feedpoint are unnecessary. The highest SWR usually occurs at the second harmonic of the design frequency. The Loop Skywire is somewhat more broadband than corresponding dipoles, and is also more efficient. Do not expect SWR curves that are “dummy load” flat.

Using the Loop Skywire as a Vertical

Another interesting feature of this loop is its ability to be used as an all-band vertical antenna with top-hat loading. This is accomplished by keeping the feed-line run from the shack as vertical as possible and clear of metallic objects. Both feed-line conductors are then tied together (by means of a shorted SO-239 jack, for example), and the antenna is fed against a good ground system. This method allows excellent performance of the 40-m loop on 80 m, and the 80-m loop on 160 m.

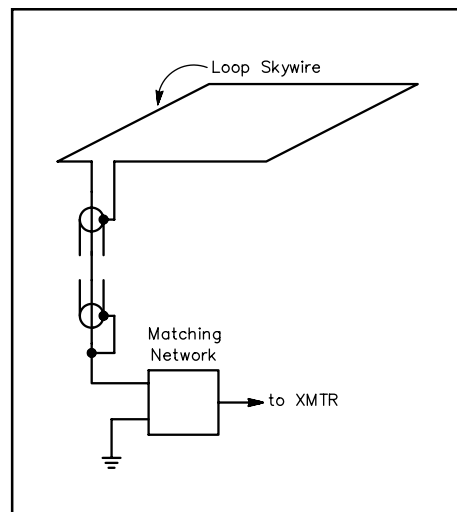


Fig 20.77—The feed arrangement for operating the loop as a vertical antenna.

A Simple Gain 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 A**) 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'll 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.

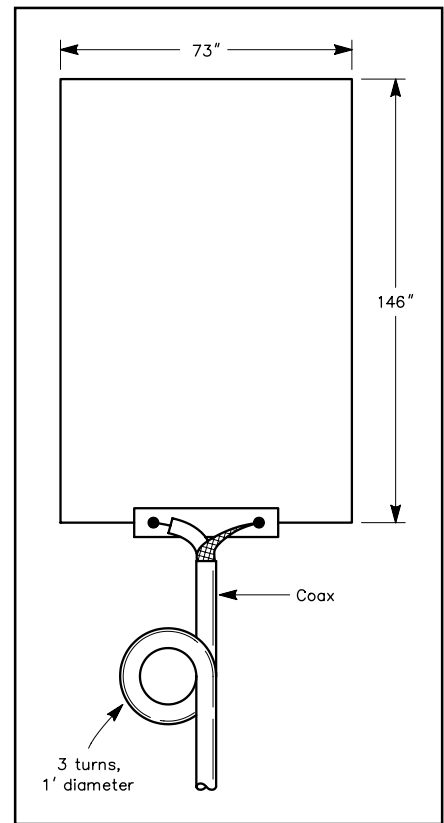


Fig A—Construction details of the 10-m rectangular loop antenna.

A SMALL LOOP FOR 160 M

For amateurs with limited space, a small loop antenna is ideal for 160 m. Because small loops have high Q, they exhibit very narrow bandwidth, suppress harmonics and give a significant receiving noise reduction compared to dipoles. This project by Charles J. Mozzochi, W1LYQ, appeared in the June 1993 issue of *QST*. More information on theory and design considerations can be found in *The ARRL Antenna Book*.

Mozzochi found that for distances of 700 to 1000 miles, his loop performed the same as a full-size inverted-V antenna (62 ft high at the midpoint and fed with open-wire transmission line). Contacts with Europe report signals from the loop essentially the same as that from the inverted V. However, some report signals from the loop slightly stronger than from the inverted V. Both antennas are oriented to favor Europe. Also, the inverted V is more than 90% efficient, whereas the loop's efficiency is close to 50% (≈ 3 dB)

Radiation Pattern

Fig 20.78 compares the vertical radiation patterns of the loop with those of a vertical and a dipole. The inner-pattern axis is perpendicular to that of the outer patterns. Note that the loop performs better at low angles, making it a good DX antenna. **Fig 20.79** compares horizontal patterns at four elevation angles.

Physical Description

Fig 20.80 shows the antenna schematically and **Fig 20.81** shows the base section of the antenna. The outer loop is made in the form of a hexagon with eight 10-ft sections of 1-inch copper pipe joined with 45° couplers. The inner loop is a circle, 15 ft, 6 inches in circumference, made from $5/8$ -inch copper pipe. Choose values and ratings for C1, C2 and C3 as discussed later.

The antenna is mounted vertically, approximately a foot off the ground, although it would be wise to mount it higher or install a protective wooden fence around the antenna to keep away people or pets. Very high voltages occur on small transmitting loops! Mozzochi installed 12 radials, $1/4\lambda$ long, under the loop. These radials are joined under the loop, but are not electrically connected to it. The radials act as a reflective screen to help

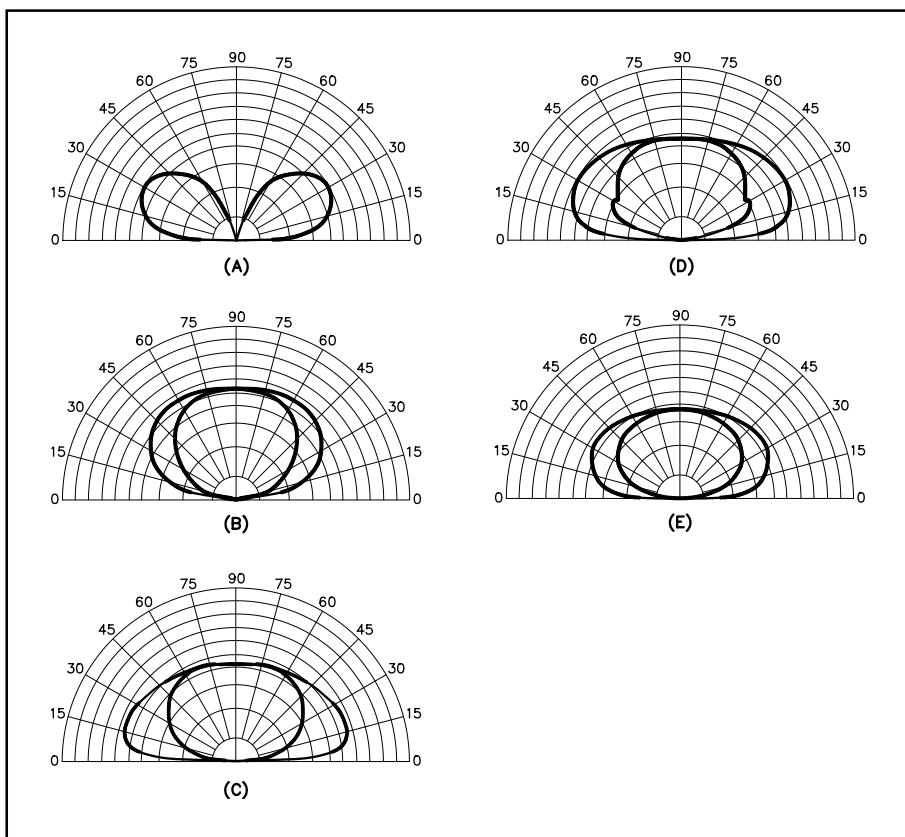


Fig 20.78—Relative comparisons of small loop elevation-plane radiation patterns to those of dipoles and verticals. At A, a vertical; B, a dipole; C, loop over radials; D, loop over short radials; E, loop over ground (no radials). In B, the inner pattern is that in the plane parallel to the antenna axis. In C through E, the inner patterns are those in the plane perpendicular to the antenna axis.

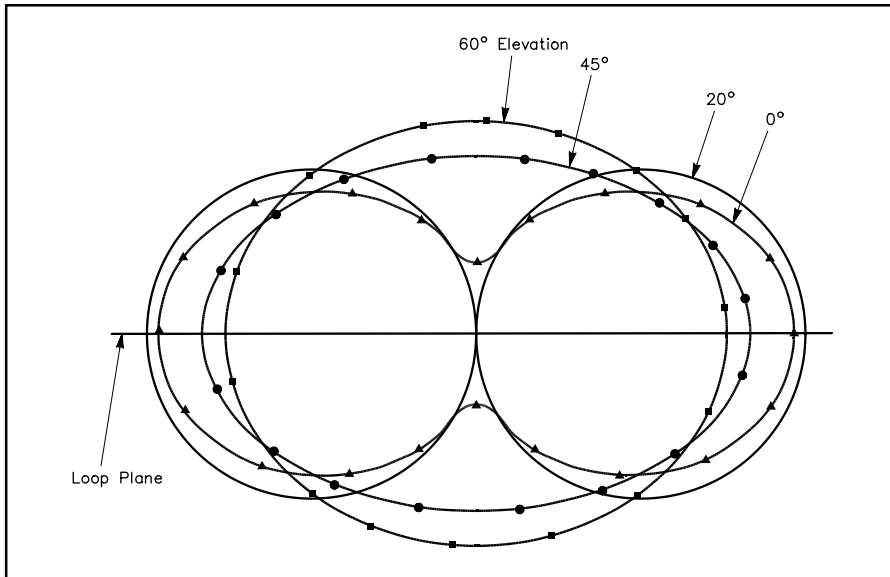


Fig 20.79—Electrically small loop antenna azimuth-plane radiation patterns at several wave angles.

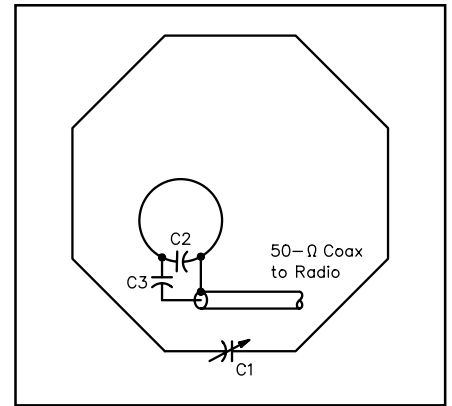


Fig 20.80—Schematic of the loop antenna.

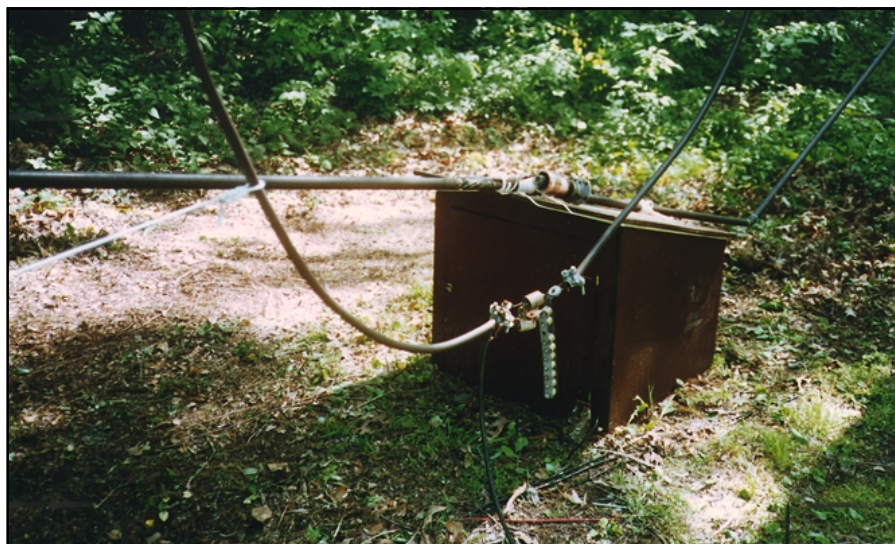


Fig 20.81—Feed-point detail of the W1LYQ loop. C1, a vacuum variable, is secured to the top of a wooden box. C2 is made of ten “doorknob” capacitors in parallel, and C3 is one large doorknob. The loops are tied off to nearby objects for support.

reduce ground loss. The use of radials is not absolutely necessary, but they can help reduce losses.

Construction

Because the outer loop’s radiation resistance is on the order of 0.1Ω , every effort must be made to minimize losses. Antenna efficiency increases with the diameter of the pipe used in both loops. One-inch copper pipe is used as a compromise in the outer loop; larger pipe would provide better efficiency, but would weigh considerably more. Mozzochi supports the outer loop with nylon rope strung between two trees. Smaller nylon ropes guy the

lower section between trees and a fence. The inner loop is hung from the top of the outer loop with nylon rope, and nylon rope is used to guy and position the inner loop.

Solder all of the loop joints with rosin-core tin/lead or tin/lead/silver solder. Do not use acid-core solder.

Capacitors

C1 is a 200-pF vacuum-variable unit. A split-stator capacitor would work in place of a vacuum variable; however, under no circumstances should a conventional variable capacitor be used at C1 because the loss in the wiper contacts is significant compared to the outer loop’s radiation resistance.

C2 is composed of ten 100-pF “doorknob” capacitors connected in parallel via copper straps, and C3 is a single 740-pF doorknob.

The outer loop radiates and the inner loop functions as a low loss matching and coupling device. This antenna puts very high voltages across C1 and C2 and passes unusually high currents through them. The formulas in **Table 20.18** give approximate currents and voltages for C1, C2 and C3, where P is the applied power, in watts.

The formulas in Table 20.18 are based on a steady-state analysis, under the assumption that the radiation resistance and the loss resistance in the outer loop are each 0.1 Ω. These resistances can differ significantly from this value depending on how the loop is constructed and located. Furthermore, substantial transient currents and voltages can occur under certain situations. It is wise to incorporate a safety factor of two to three after calculating the capacitor voltages and currents from these equations.

Tuning and Matching

To adjust the antenna to resonance at 1.85 MHz, follow this procedure:

- 1) Place the inner loop in either lower corner area of the outer loop, but *not touching it*, in a plane parallel to the outer loop and approximately 20 inches from the outer loop.
- 2) Set the transmitter to 1.85 MHz.
- 3) Adjust C1 for minimum SWR.

By making minor adjustments in the loop position and C1’s setting, you should easily get the SWR down to 1:1. Once a 1:1 SWR is achieved at 1.85 MHz, you need only adjust C1 for other frequencies between 1.8 and 2 MHz. The achievable SWR will be 1:1 from 1.8 to 1.85 MHz, and beginning at 1.85 MHz the SWR will climb slowly but steadily to 2:1 at 2 MHz. Changing frequency by more than 2 to 3 kHz requires readjusting C1 for minimum SWR. Keep in mind that a change of 1 pF in C1 makes a change of 3 to 5 kHz in the antenna’s resonant frequency. Be sure that you use a motor drive with sufficient gear reduction.

For optimum performance, C1 should be mounted at the top of the loop. Also, it is possible to eliminate C2 and C3 by a suitable choice of the size and position of the inner loop. Consider this if you’re planning to use high power with the loop.

Warning

Operating a loop antenna indoors or close to dwellings can raise the risk of interference to consumer devices and ham gear. Also, it’s prudent to minimize RF exposure to people who may be near the antenna by using the minimum necessary transmitter power to carry on the desired communications. Whenever possible, mount your antennas as far as possible from people and dwellings.

Table 20.18
Calculating Capacitor Ratings

$$\begin{aligned}V_{C1} &= 1800 \sqrt{P} \\V_{C2} &= 18 \sqrt{P} \\V_{C3} &= 17 \sqrt{P} \\I_{C1} &= 2.2 \sqrt{P} \\I_{C2} &= 0.21 \sqrt{P} \\I_{C3} &= 0.15 \sqrt{P}\end{aligned}$$

Example: if P = 100 watts, then
 $V_{C1} = 18,000$; $V_{C2} = 180$; $V_{C3} = 170$;
 $I_{C1} = 22$ A; $I_{C2} = 2.1$ A; and
 $I_{C3} = 1.5$ A.

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

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:

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

where

h = radiator height in meters

λ = wavelength in meters = $300/\text{Freq}$ in MHz

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

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

where

(den1) = $(\ln(h/r) - 1)$

(den2) = $(1 - (F \times h/75)^2)$

\ln = natural logarithm

r = conductor radius in meters

F = frequency in MHz

Characteristics of a 10.5-foot (3.2 meter) 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 20.19**.

Table 20.19

Characteristics of a 10.5-foot whip antenna

F (MHz)	C (pF)	R_r	Impedance	Efficiency	L (μH)
1.8	30.1	0.146	$13.72 - j2716$	0.01064	240
3.5	30.6	0.55	$7.43 - j1375$	0.074	62.5
7	32.8	2.2	$7.04 - j644$	0.312	14.6
10	36.5	4.5	$6.5 - j408$	0.692	6.49
14	46.5	8.8	$10 - j232$	0.88	2.64

Radiation resistance rises in a nonlinear fashion and the capacitance drops just as dramatically with increase in the ratio h/λ . **Fig 20.82** shows the relationship of capacitance to height. This can be used for estimating antenna capacitance for other heights.

Fig 20.83 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 20.19 shows that at 3.5 MHz an inductance of $62.5 \mu\text{H}$ will cancel the capacitive reactance. This results in an impedance of 7.43Ω 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 $= 0.36 \times F/Q$. In this case, bandwidth $= 0.36 \times 3.5/200 = 6.3 \text{ kHz}$

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 7.43Ω at the antenna terminals. The current is 3.67 A and flows through the $1375\text{-}\Omega$ reactance of the coil giving rise to $1375 \times 3.67 = 5046 \text{ VRMS}$ (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!

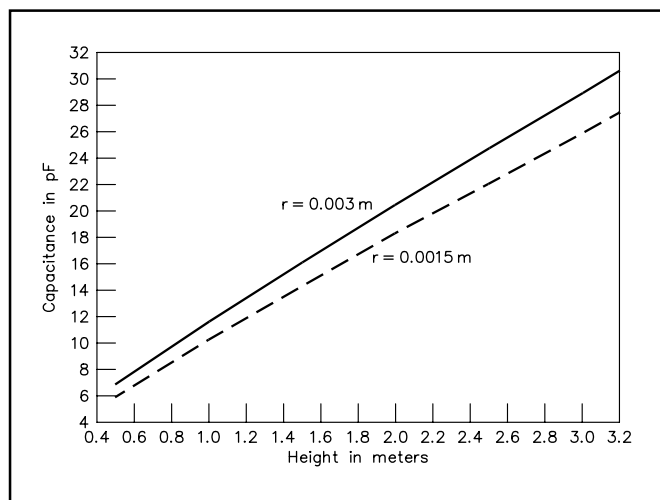


Fig 20.82—Relationship at 3.5 MHz between vertical radiator length and capacitance. The two curves show that the capacitance is not very sensitive to radiator diameter.

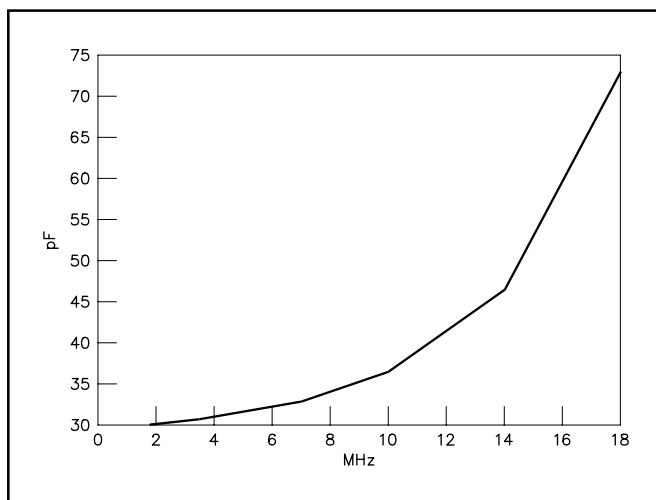


Fig 20.83—Relationship between frequency and capacitance for a 3.2-meter vertical whip.

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/inch² 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 20.84** 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 $0.55 - j1375 \Omega$ and a base capacitance of 2 pF results in the values shown in **Table 20.20**. 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.

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.

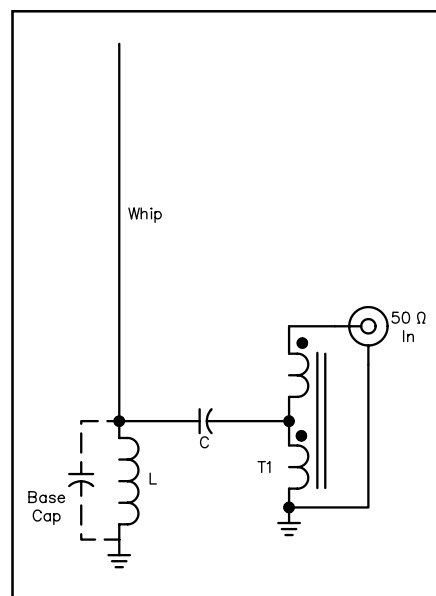


Fig 20.84—The base-matched mobile whip antenna.

CENTER LOADING

Center loading increases the current in the lower half of the whip as shown in **Fig 20.85**. 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

Table 20.20

Values of L and C for the Circuit of Fig 20.84 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

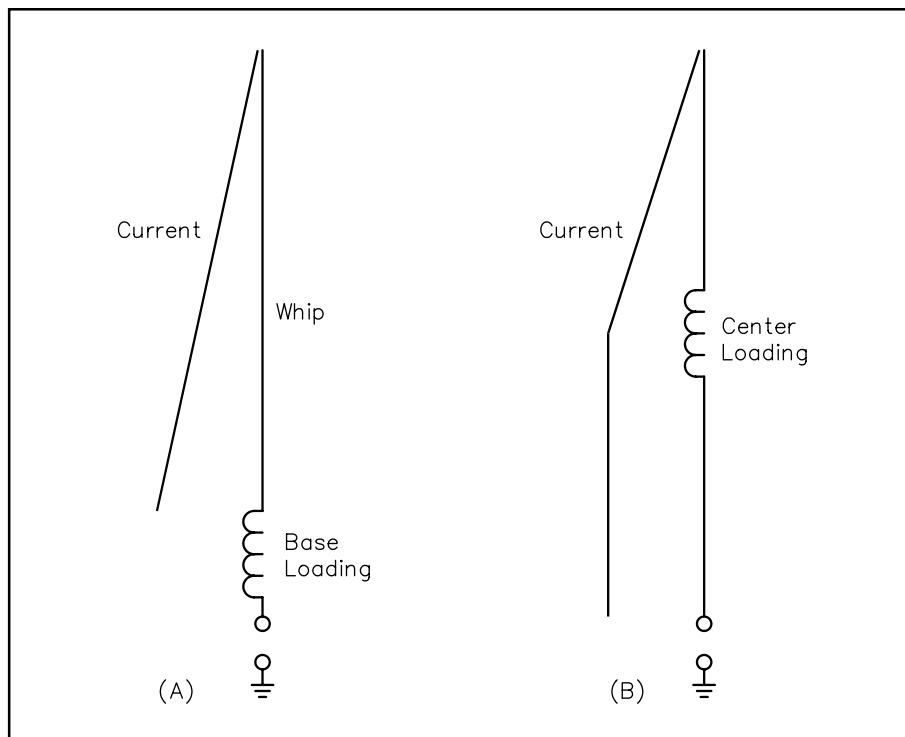


Fig 20.85—Relative current distribution on a base-loaded antenna is shown at A and for a center-loaded antenna at B.

antenna is often operated without any base matching in which case the resistive component can be assumed to be $50\ \Omega$ 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 $50\ \Omega$.

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 $50\ \Omega$.

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.

On 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 20.86** 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 20.20** we see that we could use a series inductance sequence of 20, 10, 5, 2.5, 1.25, 0.625, 0.32 and $0.16 \mu\text{H}$. We can use a relay to short unwanted elements. In this way we could theoretically produce any value of inductance between 0 and $39.84 \mu\text{H}$ in steps of $0.16 \mu\text{H}$. 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.

With most relays it does not make sense to switch less than 2 pF. For that reason, the capacitance chain would consist

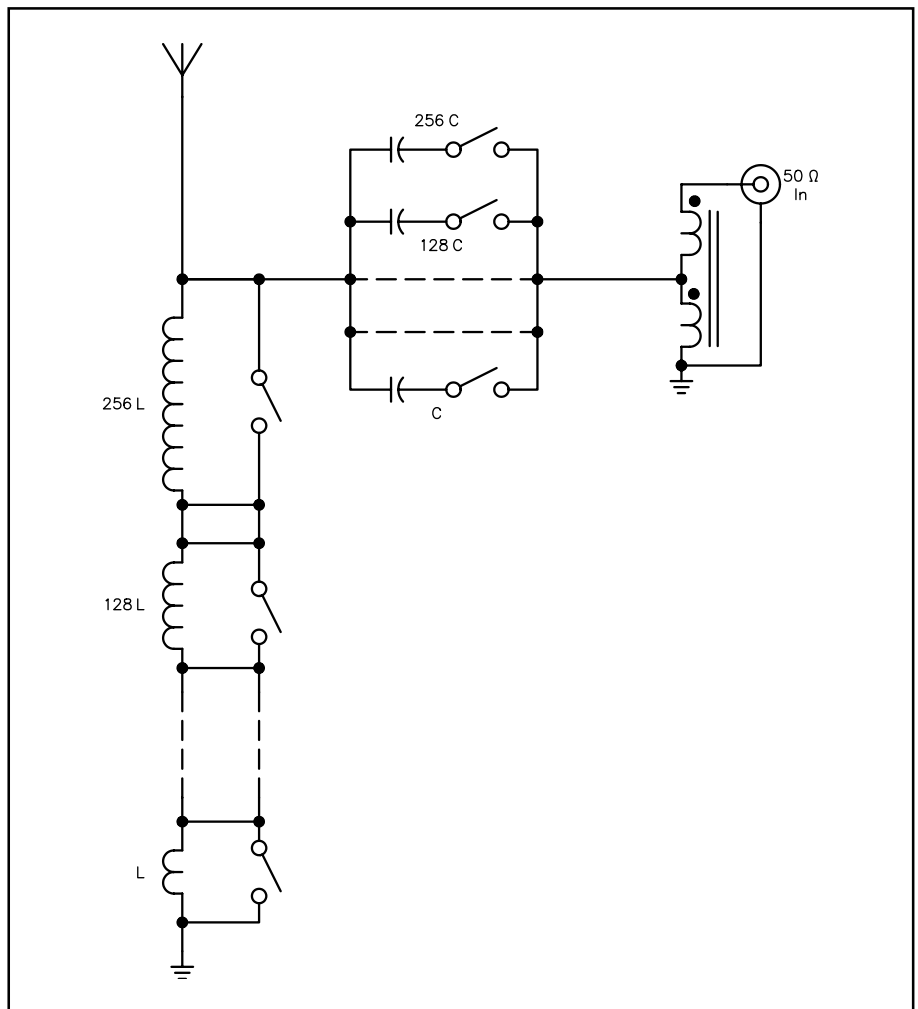


Fig 20.86—A digital coupler based on the circuit shown in **Fig 20.84**. Capacitive and inductive elements are organized in a binary sequence with each being twice the value of the next lower value.

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.

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 20.87A 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 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 20.87B 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 20.88** 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.

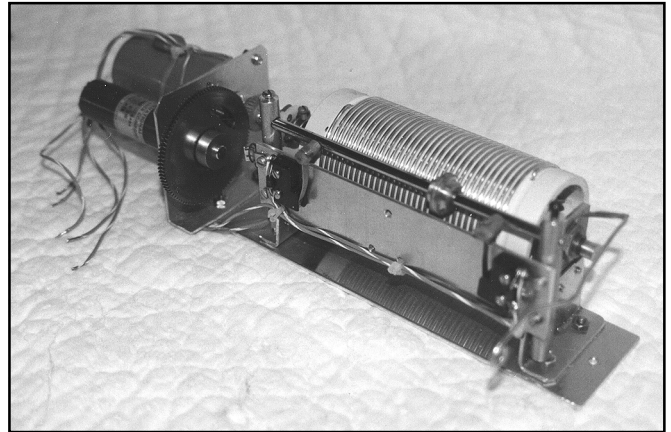


Fig 20.88—Photo of the inductor drive assembly from KE2QJ's antenna coupler.

POSITION READER

While not necessary, it is worthwhile to have a way to determine inductor position. An easy way

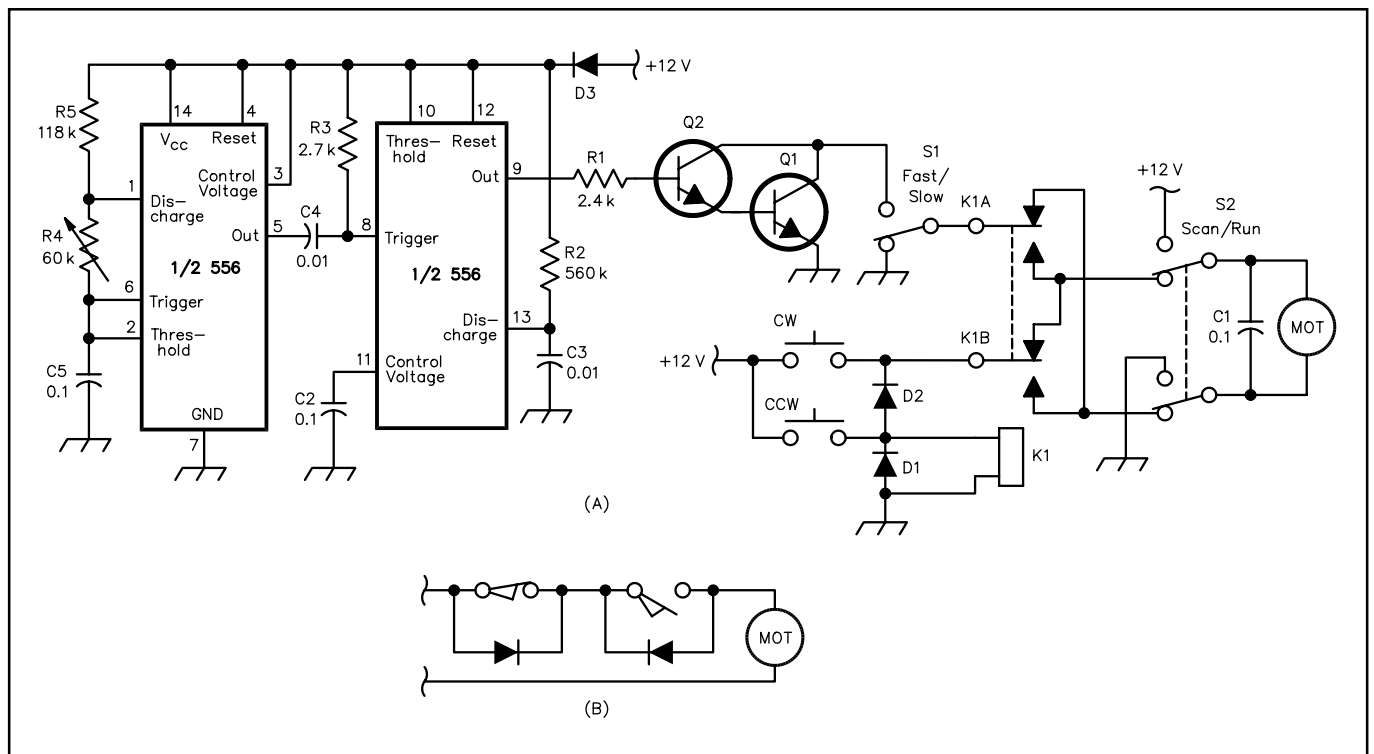


Fig 20.87—At A, motor control circuit used by KE2QJ. This circuit uses pulse modulation for speed control with good starting torque. Direction of rotation is controlled by the relay. At B, how to add limit switches to the circuit. See text.

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 20.87A 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.

You can use Table 20.21 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.

Table 20.21
Data for 40 μH Coils

<i>Diameter</i>	<i>Length</i>	<i>Turns</i>
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

CONSTRUCTION

For ease of service, mount the inductor, its drive motor, position sensing potentiometer 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 $1/8$ -inch thick aluminum. These individual assemblies make it easier to fix problems.

The chassis shown in **Fig 20.89A** 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 20.89B. 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.

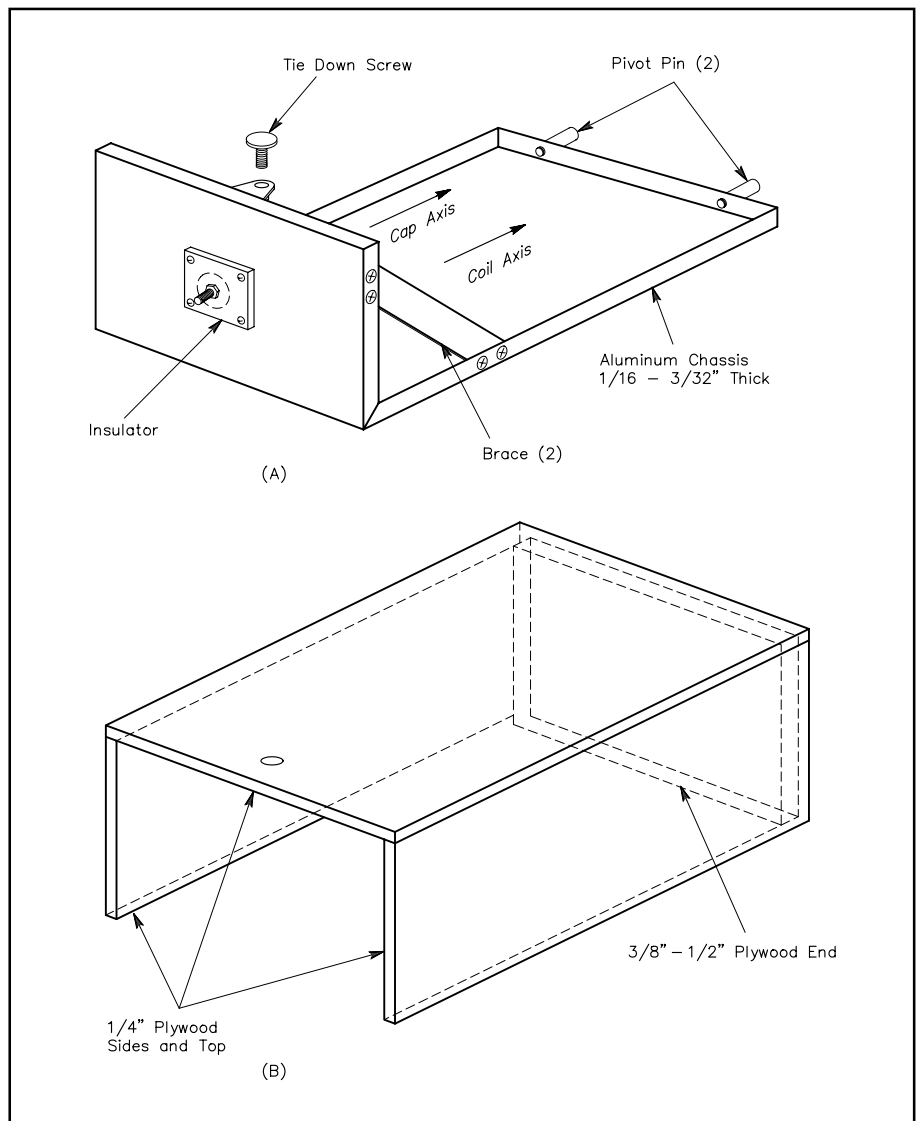


Fig 20.89—At A, the chassis for the coupler mounting box. At B, the box cover.

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.

The arrangement of **Fig 20.90** solves many of these problems. It uses a $\frac{1}{4}$ -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 $1 \times 1 \times \frac{1}{4}$ -inch aluminum angle bolted in several places.

Near the forward edge of the plate, two $\frac{1}{2}$ -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 $1 \times 1 \times \frac{1}{2}$ -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 $1\frac{1}{2}$ inch pipe. Reinforce each end. Start with a $1\frac{1}{2}$ inch length of pipe. Remove a $\frac{5}{8}$ -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 $\frac{3}{8}$ -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 20.90). A length of $\frac{1}{2}$ -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.

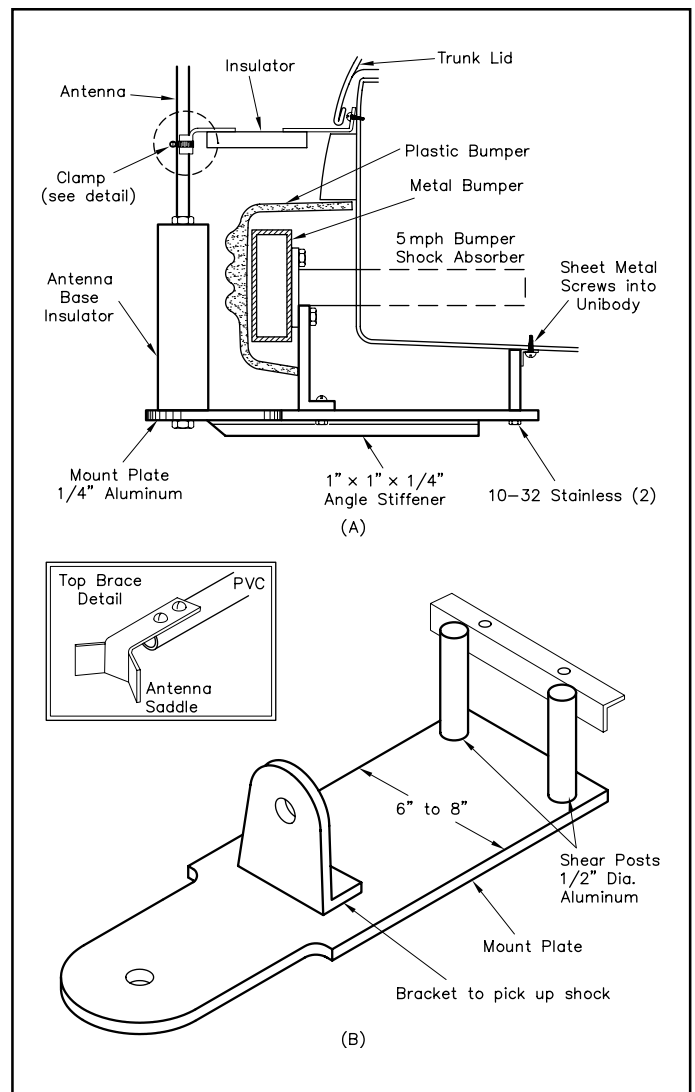


Fig 20.90—Antenna mounting detail. At A, the overall plan. At B, detail of the mount plate.

The coupler box mounting is shown in **Fig 20.91**. Brackets can be made of $1/8 \times 2$ -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 $1.5 \times 2 \times 1/4$ -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 feet above the pavement. The type used for CB whips works well. A 7-foot whip brings the top to about 11.5 feet above the pavement. The 7-foot 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 feet 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.

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 20.87A](#) 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 20.92](#) 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

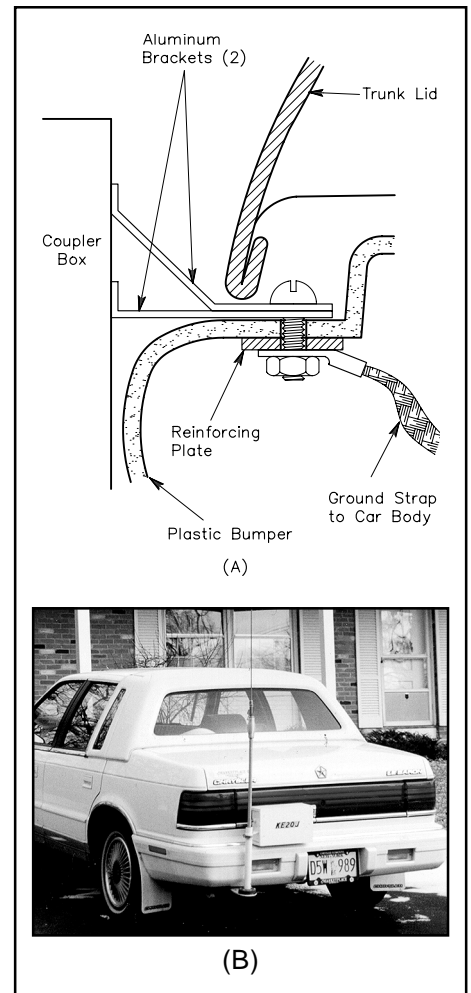


Fig 20.91—Box mounting detail. At A, mounting-bracket design. At B, photo of KE2QJ's installation.

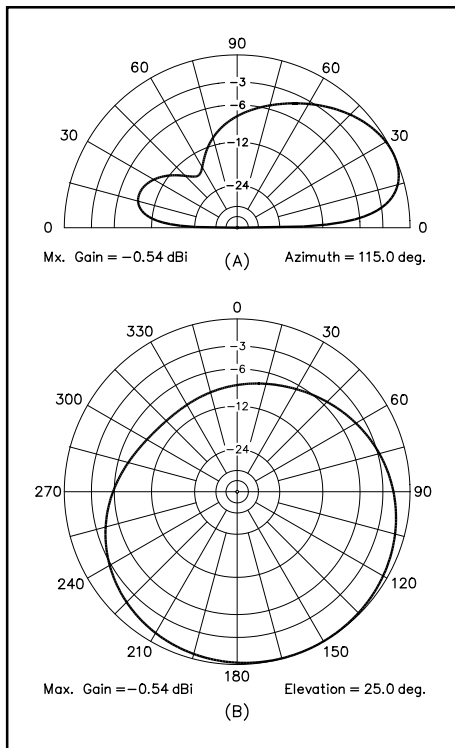


Fig 20.92—At A, elevation pattern of the KE2QJ mobile antenna. The pattern is in the plane that runs diagonal through the car. At B, azimuth pattern at 25° elevation for the same antenna. The operating frequency is 18.130 MHz.

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.

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VHF/UHF Antennas

INTRODUCTION

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 $1-\lambda$ 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 $\frac{3}{4}$ 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 $\frac{1}{2}$ -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 20.93A**. 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.

Gamma and T Matches

The gamma match is shown in Fig 20.93C, and the T match is shown in Fig 20.93D. These matches are covered in more detail in the chapter on [Transmission Lines](#). 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 pre-

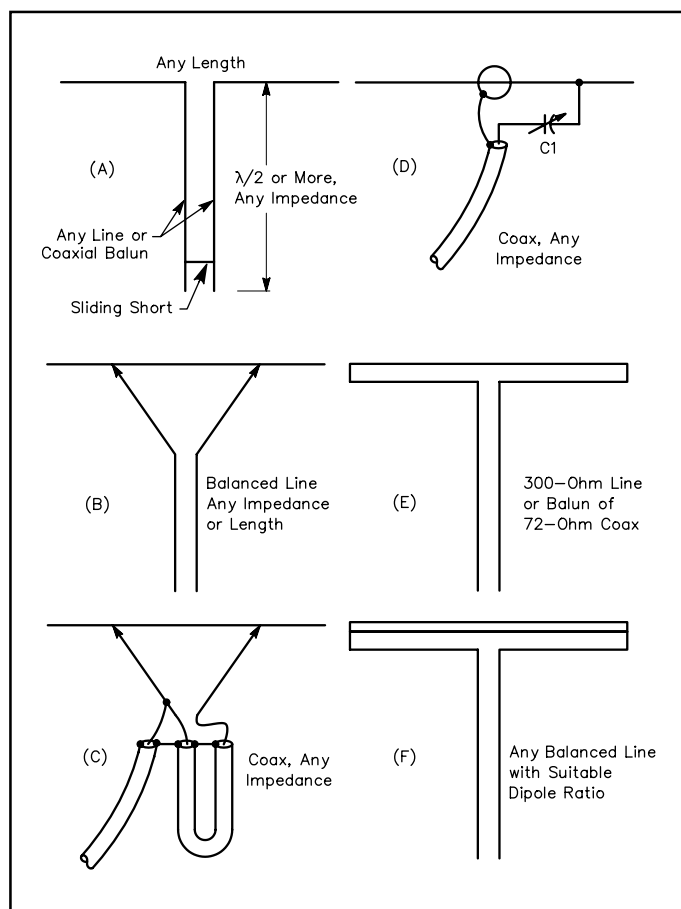


Fig 20.93—Matching methods commonly used in VHF antennas. In the delta match, A and B, the line is fanned out to tap on the dipole at the point of best impedance match. The gamma match, C, is for direct connection of coax. C1 tunes out inductance in the arm. Folded dipole of uniform conductor size, D, 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.

sents 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 20.93B is used from the balanced T-match to the unbalanced coaxial line going to the transmitter. See K1FO's Yagi designs later in this chapter for details.

Folded Dipole

The impedance of a half-wave antenna broken at its center is 72Ω . If a single conductor of uniform size is folded to make a half-wave dipole, as shown in Fig 20.93D, 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 20.93E.

Baluns

Conversion from balanced loads to unbalanced lines, or vice versa, can be performed with electrical circuits, or their equivalents made of coaxial line. A balun made from flexible coax is shown in Fig 20.94A. 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 20.95. The coaxial sleeve, open at the top and connected to the outer conductor of the line at the lower end (A)

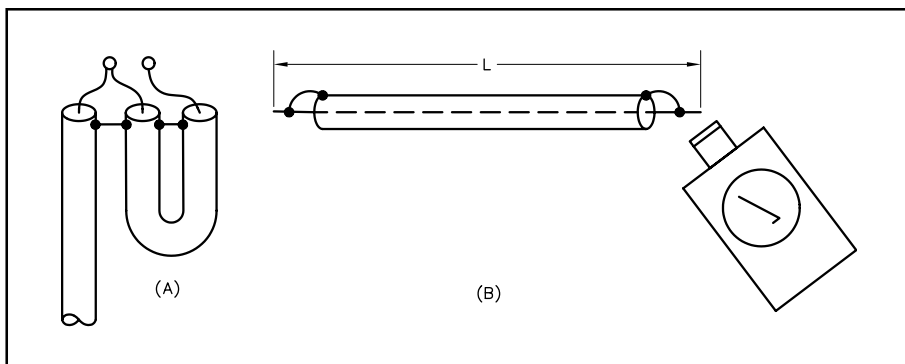


Fig 20.94—Conversion from unbalanced coax to a balanced load can be done with a half-wave coaxial balun, A. Electrical length of the looped section should be checked with a dip meter, with ends shorted, B. The half-wave balun gives a 4:1 impedance step up.

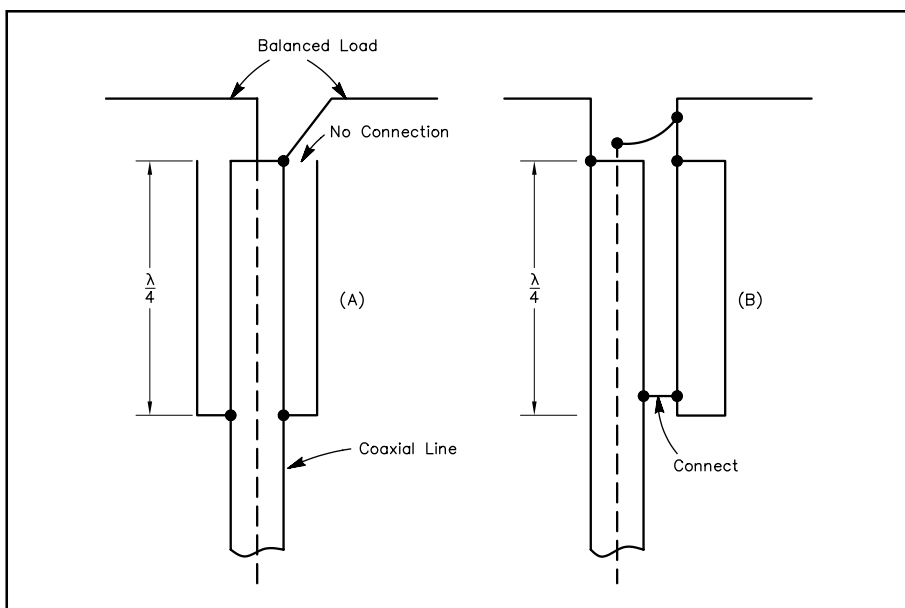


Fig 20.95—The balun conversion function, with no impedance change is accomplished with quarter-wave lines, open at the top and connected to the coax outer conductor at the bottom. The coaxial sleeve, A, is preferred.

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 1λ 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 $\frac{1}{2} \lambda$ (10 ft), but $\frac{5}{8} \lambda$ (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 20.96**. 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 a 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 polarization, 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.

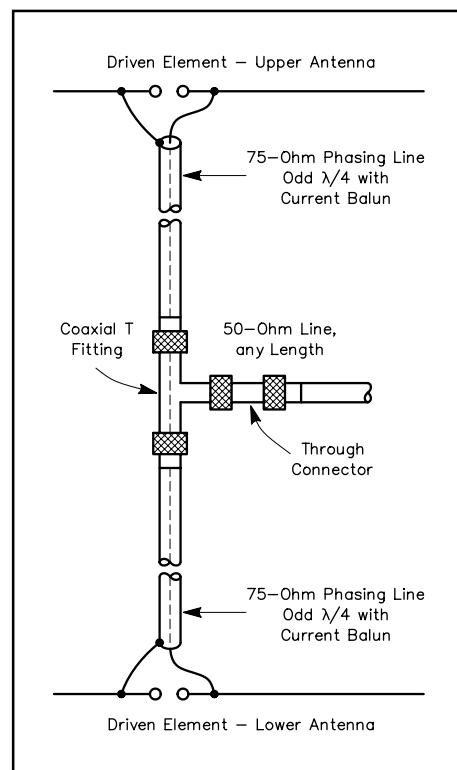


Fig 20.96—A method for feeding a stacked Yagi array. Note that baluns at each antenna are not specifically shown. Modern-day practice is to use current (“choke”) baluns made up of ferrite beads slipped over the outside of the coax and taped to prevent movement. See [Transmission Lines](#) chapter for details.

Hardwood Dowels Strengthen Antenna Elements

There is a very simple and inexpensive way to strengthen your beam antenna prior to hoisting it to the top of the tower. Most well-stocked hardware stores stock assorted sizes of hardwood dowel. Select dowels that can be snugly inserted inside the boom and elements and placed where they are attached to each other. Carefully redrill any holes blocked by the dowels and assemble the beam as instructed. You will then have a more solid attachment point and can really tighten the U-bolts and fittings without fear of deforming the tubing. Lightweight beams can be strengthened by inserting the dowel in the entire length of the boom. This method can be used to straighten elements that have been damaged. These dowels add very little weight to the antenna. I have done this for over 25 years and am completely satisfied with the results.—*H. A. “Tony” Miller, W5BWA, Alexandria, Louisiana*

Car-Engine Heater Keeps Rotator Lubricant Flowing

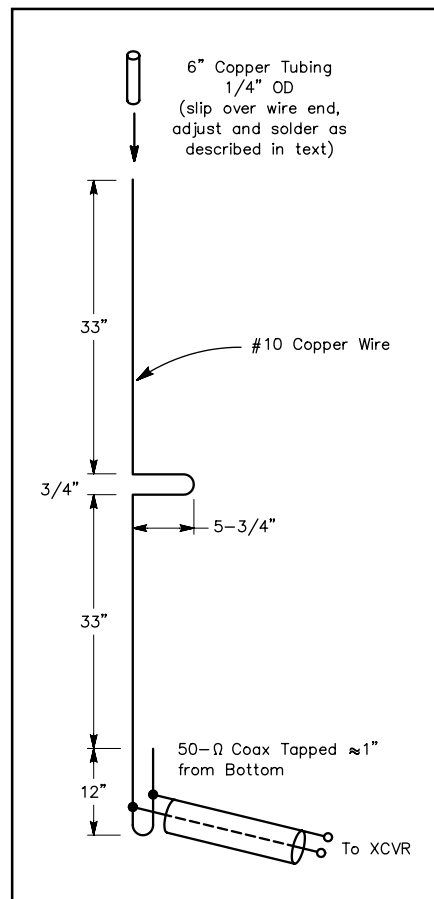
My antenna rotator manual says that the rotator’s lubricant should flow at temperatures below -20°F , but during a -28° spell last winter, nothing moved. I attached a magnetically mounted car engine heater to the bottom of the rotator mounting plate, warmed up the rotator, and got it moving again.—*Richard Mollentine, WA0KKC, Overland Park, Kansas*

A Quick Antenna For 223 MHz

Here is a functional antenna for 223 MHz that you can make in less than an hour (Fig A). To build it, 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’s taps on the antenna’s matching stub (the 12-inch section at the bottom) about an eighth of an inch at a time. My antenna shows an SWR of 1.2 at 223 MHz.—*William Bruce Cameron, WA4UZM, Temple Terrace, Florida*

Fig A—WA4UZM’s quick 223-MHz antenna gets you going on $1\frac{1}{4}$ 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 nylon cable ties.



$\frac{1}{4}\lambda$ ANTENNAS FOR HOME, CAR AND PORTABLE USE

Quarter-wave vertical antennas are useful for local communications when size, cost and ease of construction are important. For theoretical information about quarter-wave vertical antennas see earlier parts of this chapter or *The ARRL Antenna Book*.

Construction Materials

The antennas shown in the following sections are built on a coaxial connector. Use UHF or N connectors for the fixed station antennas. BNC connectors are good for mobile and portable antennas. BNC and N connectors are better than PL-259 connectors for VHF/UHF outdoor use because: (1) they provide a constant impedance over the frequencies of interest, and (2) they are weatherproof when the appropriate connector or cap is attached. The ground-plane antennas require a panel-mount connector (it has mounting holes to hold the radials).

If the antenna is sheltered from weather, copper wire is sufficiently rigid for the element and radials. Antennas exposed to the weather should be made from $\frac{1}{16}$ - to $\frac{1}{8}$ -inch brass or stainless-steel rod.

Radials may be made from $\frac{3}{16}$ -inch aluminum rod or tubing and mounted on an aluminum sheet. Do not use aluminum for the antenna element because it cannot be easily soldered to the coaxial-connector center pin.

Where the figures call for #4-40 hardware, stainless steel or brass is best. Use cadmium-plated hardware if stainless steel or brass is not available.

Fixed-Station Antennas

The ground-plane antenna in **Fig 20.97** uses female chassis-mount connectors to support the element and four radials. If you have chosen large-diameter wire or tubing for the radials refer to **Fig 20.98**. Cut a metal sheet as shown (size is not critical, and the mounting tab is optional). Drill the sheet to accept the coaxial connector on hand (usually $\frac{11}{16}$ inch) and the 4-40 hardware for the radials and connector. Bend the plate or radials as shown with the aid of a bench vise. Mount the coaxial connector and radials to the plate.

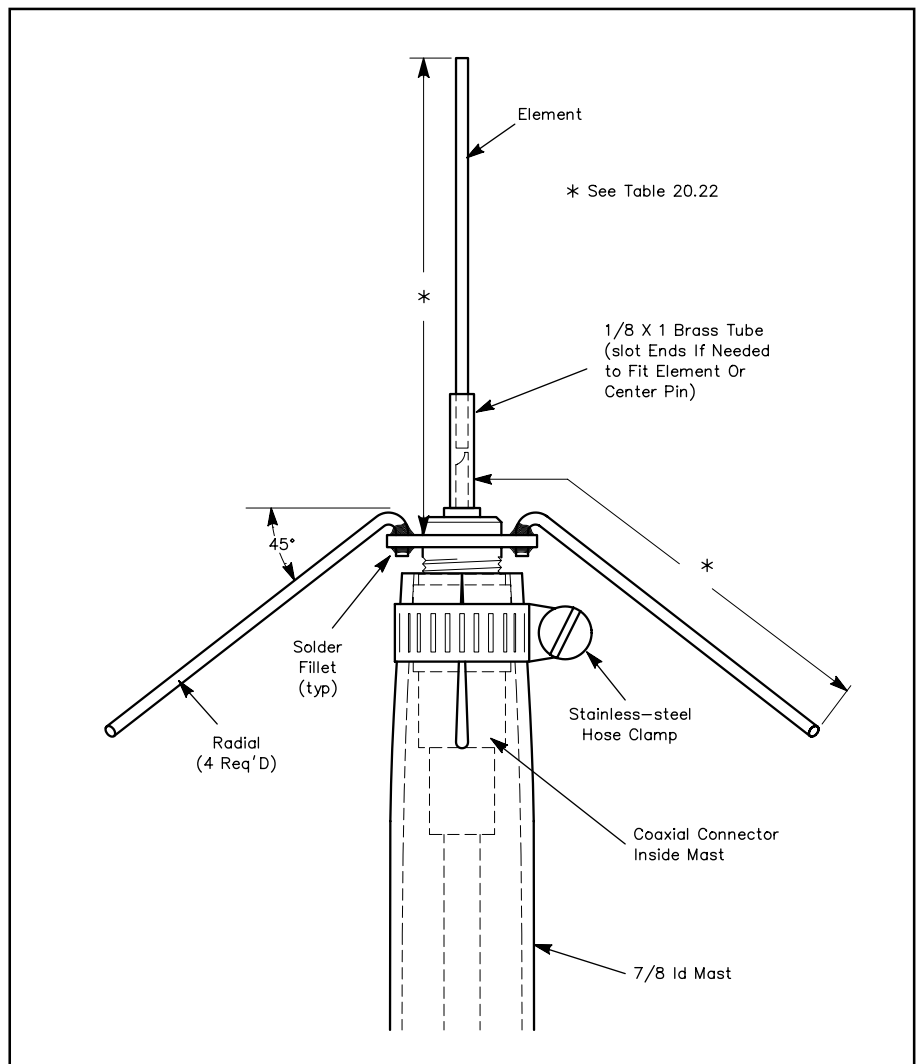


Fig 20.97—A simple groundplane antenna for the 144, 222 and 440-MHz bands. The feed line and connector are inside the mast, and a hose clamp squeezes the slotted mast end to tightly grip the plug body. See **Table 20.22** for element and radial measurements.

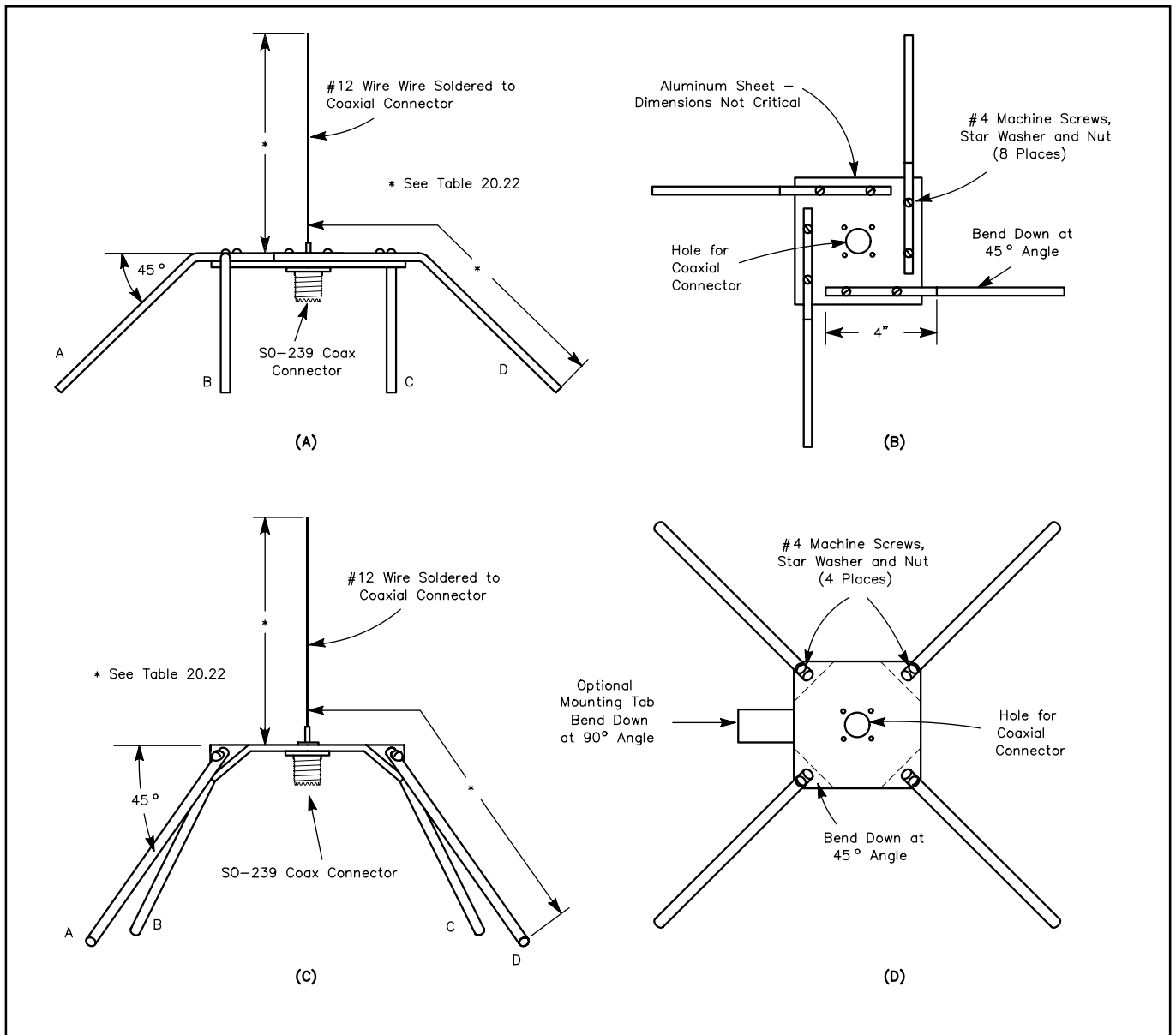


Fig 20.98—Methods of mounting $\frac{3}{16}$ -inch aluminum-rod radials to a VHF/UHF groundplane antenna. At A and B the radials are made approximately $1\frac{1}{2}$ inches longer than l , then bent (45°) and attached to a flat aluminum sheet. At C and D, the radials are somewhat shorter than l , and the corners of the aluminum sheet are bent to provide the 45° angle. In both cases, l is measured from the radial tip to the element. The size of the aluminum sheet is not critical. The mounting tab shown at D is optional; it could be added to the sheet in A and B if desired.

Small diameter ($\frac{1}{16}$ -inch) radials may be attached directly to the mounting lugs of the coaxial connector with 4-40 hardware. To install $\frac{3}{32}$ - or $\frac{1}{8}$ -inch radials, bend a hook at one end of each radial for insertion through the connector lug. (You may need to enlarge the lug holes slightly for $\frac{1}{8}$ -inch rod.) Solder the radials (and hardware, if used) 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 $\frac{1}{8}$ -inch-ID tube will fit over an SO-239 or N-receptacle center pin).

One mounting method for fixed-station antennas appears in Fig 20.97. The method shown is probably the easiest and strongest. Alternatively, a tab (Fig 20.98D) or “L” bracket could be fastened to the side

of a mast with a hose clamp. 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.

Mobile Applications

In order to achieve a perfect omnidirectional radiation pattern, mobile vertical antennas should be located in the center of the vehicle roof. Practically speaking however, vertical antennas work well anywhere on a metal auto body (although the radiation pattern may not be omnidirectional). In the interest of RF safety, antennas that are not mounted on the roof should be placed as far from the vehicle occupants as is practical.

The mobile antenna shown here is based on a mating pair of BNC connectors. (You could use similar techniques with N connectors.) If you plan to remove the antenna element, obtain a matching connector cap to protect the open jack from weather. The jack may be mounted directly through the vehicle body if you wish. If you do so, select a body panel with sufficient strength to support the antenna, and be sure that there is adequate access to both sides of the panel for connector and cable installation.

Most homemade VHF and UHF mobile antennas are mounted on an 1/16-inch-thick aluminum L bracket, which is fastened to the side of the hood or trunk opening (see **Fig 20.99A** and **Fig 20.99B**). If the opening lip slopes at the antenna location, the lower edge of the L bracket should match that slope. Hold the sheet against the inside of the opening lip, orient the sheet so that its top edge is parallel with the ground, and mark where the opening lip crosses the edges. Connect the marks with a straight line, and cut the sheet on that line.

Drill the sheet as required for the coaxial connector, and bend as indicated. Mount the coaxial connector, and install the cable. Hold the bracket against the side of the opening, drill and secure it with two #6 or #8 sheet-metal screws and lock washers.

The antenna shown here was made for the 2-m band. The element is about 19 1/4 inches of 1/8-inch brass rod (from a welding-supply store). Refer to Fig 20.99C and D and follow this procedure to install the element in the male BNC connector:

1) Prepare a special insulator from a 1-inch piece of RG-58 cable by removing all of the jacket and shield. Also remove the center-conductor insulation as shown.

2) File or grind an angle on the end of the brass rod.

3) Place the special insulator against the end of the brass rod and lash them together with fine bare wire.

4) Solder the wire, lashing and BNC center pin in place. (Use a light touch; too much heat causes the insulation to swell and makes it difficult to assemble the connector.)

5) Apply heat-shrink tubing to cover the spe-

Table 20.22
1/4-Wavelength Vertical Antenna Element and Radial Sizes

Lengths	Band		
	144 MHz	222 MHz	440 MHz
ℓ^\dagger	19 1/4"	12 1/2"	6 5/16"
Diameters			
Brass rod	1/8"	3/32"	1/16"
Stainless-steel rod	3/32"	1/16"	1/16"

$$\dagger \ell = \frac{234}{f}$$

where

ℓ = length, in ft

f = frequency, in MHz

Better Adhesion for Suction-Cup Mounted Antennas

I have used a suction-cup-mounted Squalo antenna on my car for over 60,000 miles without the suction cups coming loose—after I put silicone grease on the edge of the suction cups. (Apparently, the grease fills voids in the rubber.) The silicone grease has not damaged my car's finish.—Roger Gibson, K4KLLK, Raleigh, North Carolina

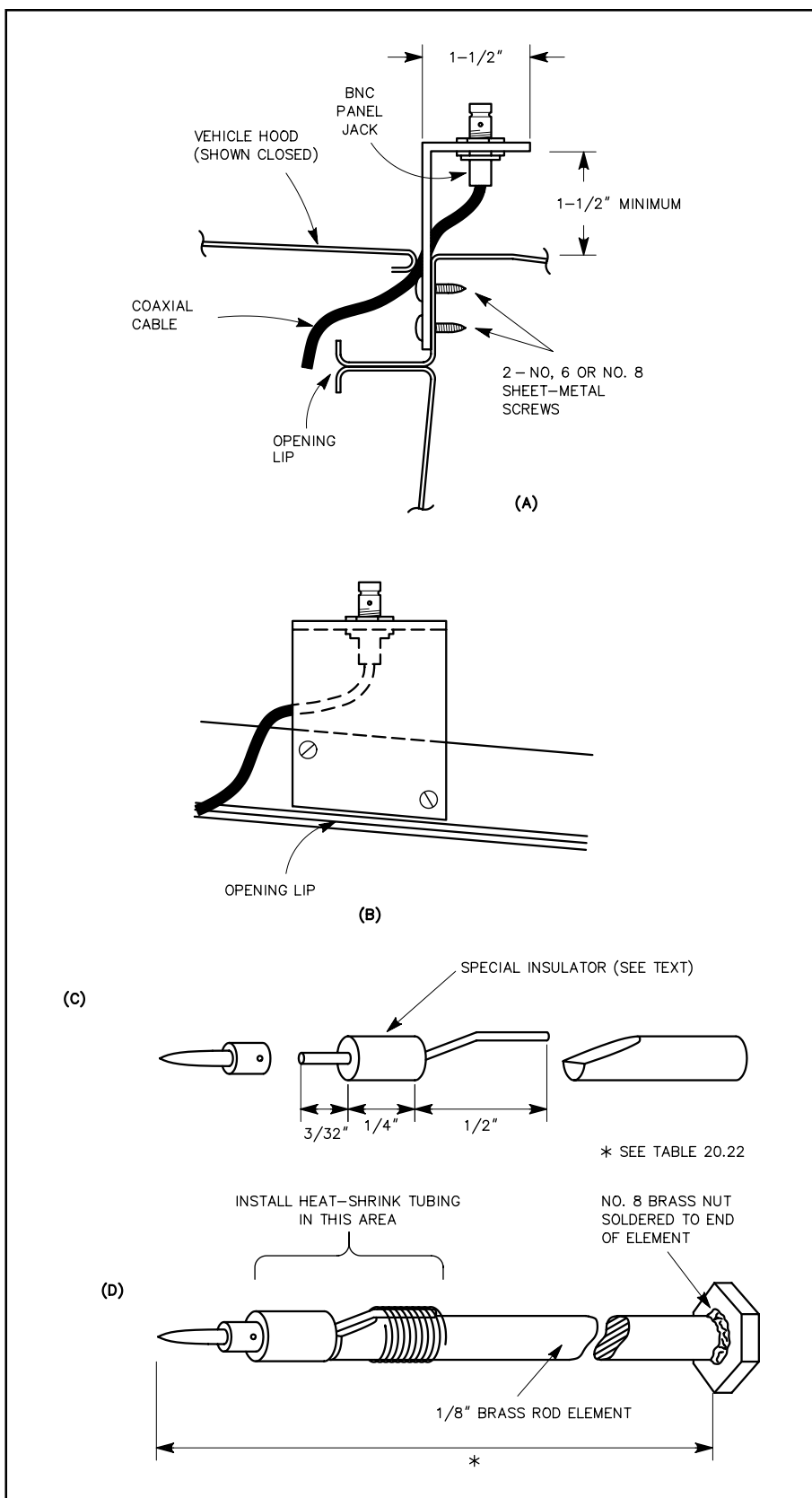
Fig 20.99—Details of the mobile vertical mount and BNC center-pin connection. A shows a cross section of a typical vehicle hood opening with the hood closed. B shows the lower edge of the L bracket trimmed to match the slope of the hood (this ensures that the antenna is plumb). C shows the BNC center pin, the special insulator made from RG-58 and the end of the element shaped for connection. At D, the special insulator has been lashed to the element with fine bare wire and the center pin positioned. The center pin and lashing should be soldered, and the area indicated should be covered with heat-shrink tubing to prevent contact with the plug body when it is installed. The brass nut serves as eye protection.

cial insulator and lashing. Place the tubing so that at least $\frac{1}{8}$ inch of the special insulator remains exposed at the center pin.

6) Place the element in the connector body and fill the back of the connector with epoxy to support the element. Install the BNC nut before the epoxy sets. (The BNC washer, clamp and gasket are discarded.)

7) Solder a #8 brass nut (or other rounded brass object) to the end of the element to serve as eye protection.

This general procedure can be adapted to all of the element materials recommended and to N connectors as well.



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 20.100](#). Cut the copper tubing to the lengths indicated. Item 9 is a 1¹/₄-inch nipple cut from the 20-inch length of 1/2-inch tubing. This leaves 18³/₄ inches for the $\lambda/4$ -matching stub. Item 10 is a 3¹/₄-inch long nipple cut from the 60-inch length of 3/4-inch tubing. The 3/4-wave element should measure 56³/₄ 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 20.100B](#). 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 20.100B](#). 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.

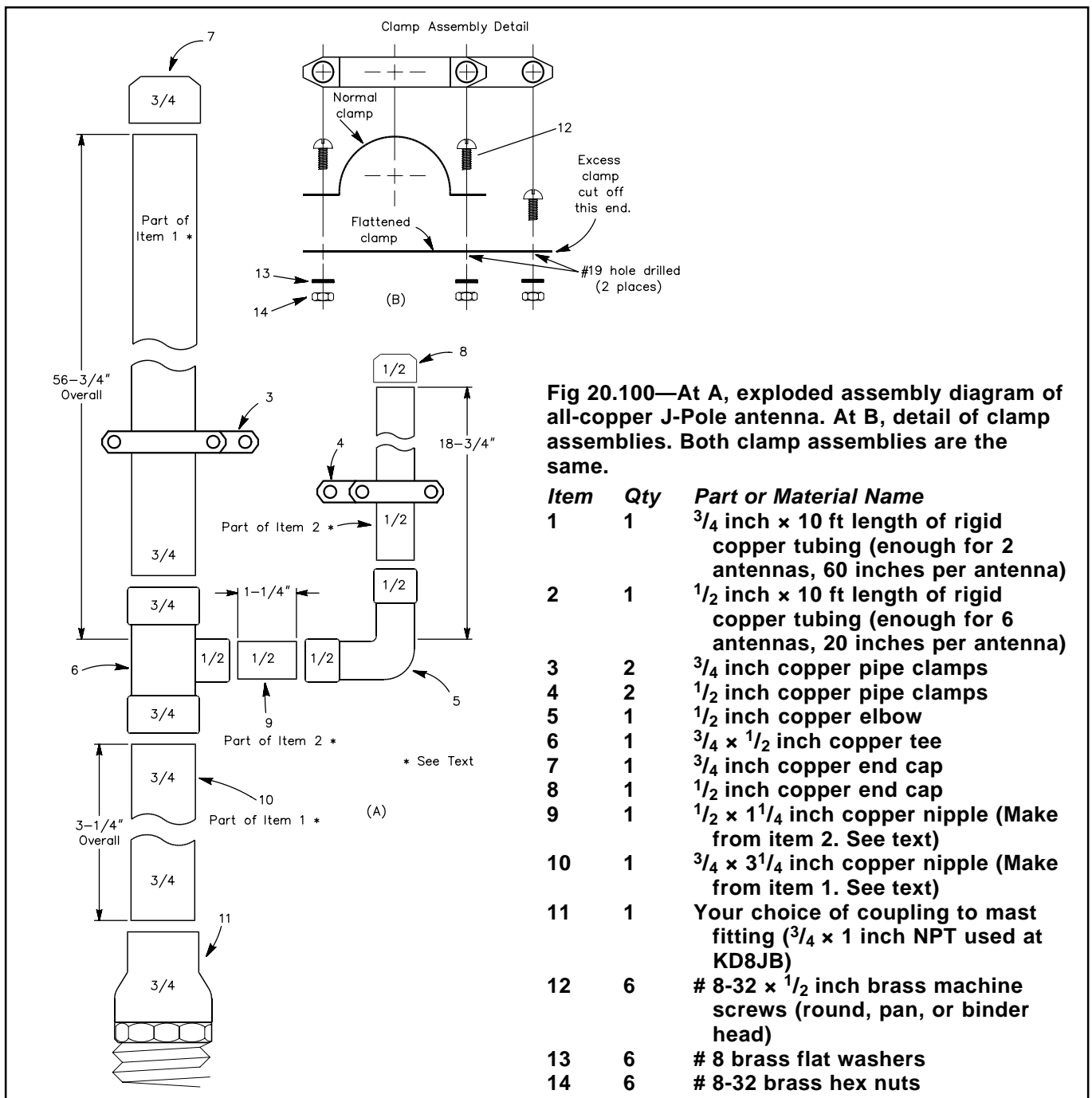
Tuning

The J-Pole can be fed directly from 50 W 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 from 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. The author has done it both ways with no variation in performance. 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 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. Weather-seal this joint with RTV. Otherwise, you may find yourself repairing the feed line after a couple years.

On-Air Performance

Years ago, prior to building the first J-Pole antenna for this station, the author used a standard 1/4-wave ground plane vertical antenna. While he had no problem working various repeaters around town with a 1/4-wave antenna, 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 20.23**. 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 20.101**. 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 20.102** 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

Table 20.23
Optimized 6-m Yagi Designs (See page 20.34)

	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 page 20.34 for element details.

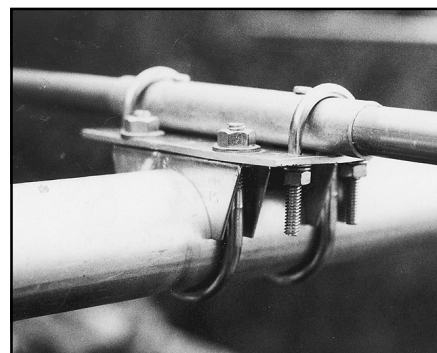


Fig 20.101—The element-to-boom clamp. Galvanized U bolts are used to hold the element to the plate, and 2-inch galvanized muffler clamps hold the plates to the boom.

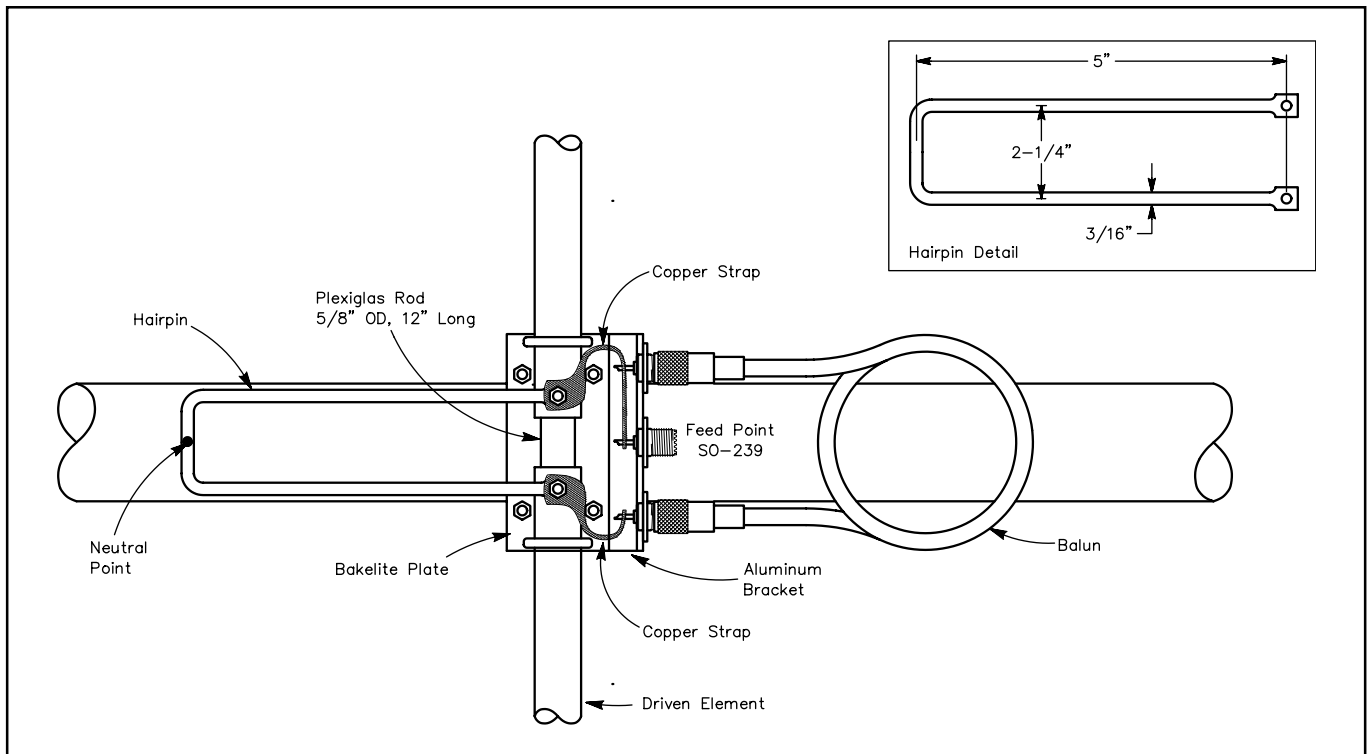


Fig 20.102—Detailed drawing of the feed system used with the 50-MHz Yagi. Balun lengths: For cable with 0.80 velocity factor—7 ft, $10^{3/8}$ in. For cable with 0.66 velocity factor—6 ft, $5^{3/4}$ in.

50 Ω at the center connector. Note that the electrical length of the balun is $\lambda/2$, but the physical length 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 PORTABLE 3-ELEMENT 2-M BEAM

In April 1993 *QST*, Nathan Loucks, WBOCMT, described the 2-m beam shown in **Fig 20.103**. The boom and mast are made from $\frac{3}{4}$ -inch PVC plumber's pipe. The three pieces of PVC pipe are held together with a PVC T joint and secured by screws. Elements can be made from brass brazing or hobby rods. (If you can't find a 40-inch rod for the reflector, you can solder wire extensions to obtain the full length.)

Drill holes that provide a snug fit to the elements approximately $\frac{1}{4}$ inch or so from the boom ends. Epoxy the director and reflector in place after centering them in these holes. A pair of holes spaced $\frac{1}{4}$ inch and centered 16 inches from the reflector hold the two-piece driven element. The short ends of the element halves should extend about $\frac{1}{4}$ inch through the boom. Solder the 50- Ω feed line to the driven element as shown in **Fig 20.104**.

Loucks used a pair of 4-inch pieces held in place by #12 or #14 jam screws (electrical connectors) to extend and adjust the driven element to allow for operation in various parts of the 2-m band. You can trim the driven element to length for operation in the desired portion of the band if you prefer.

The figures show the beam assembled for vertical polarization. You may want to turn the boom pieces 90° for horizontal polarization for SSB or CW operation.

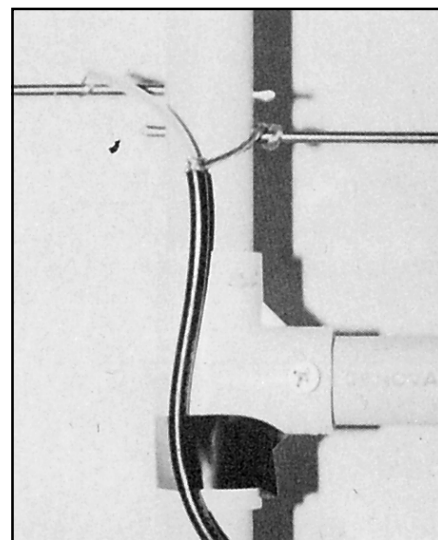
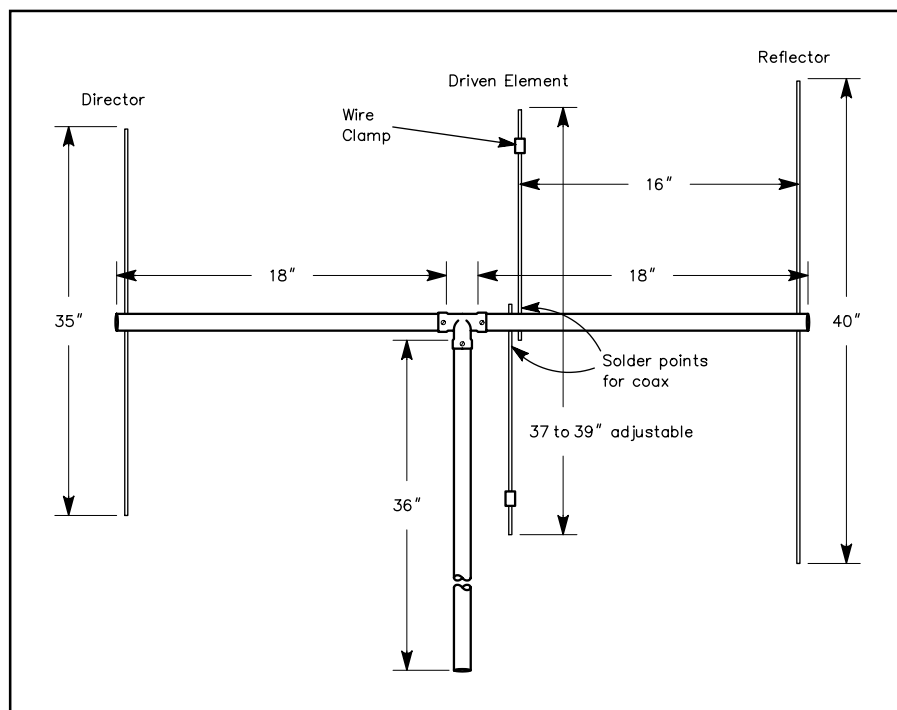


Fig 20.104—Solder the coaxial cable to the driven element pieces as shown.

Fig 20.103—Construction diagram for the 2-m beam antenna. See text for details.

High-Performance VHF/UHF Yagis

This construction information is presented as an introduction to the three high-performance VHF/UHF Yagis that follow. All were designed and built by Steve Powlishen, K1FO.

For years the design of long Yagi antennas seemed to be a mystical black art. The problem of simultaneously optimizing 20 or more element spacings and element lengths presented an almost unsolvable set of simultaneous equations. With the unprecedented increase in computer power and widespread availability of antenna analysis software, we are now able to quickly examine many Yagi designs and determine which approaches work and which designs to avoid.

At 144 MHz and above, most operators desire Yagi antennas two or more wavelengths in length. This length (2λ) is where most classical designs start to fall apart in terms of gain per boom length, bandwidth and pattern quality. Extensive computer and antenna range analysis has proven that the best possible design is a Yagi that has both varying element spacings and varying element lengths.

This logarithmic-design approach (pioneered by Gunter Hoch, DL6WU, and others) starts with closely spaced directors. The director spacings gradually increase until a constant spacing of about 0.4λ is reached. Conversely, the director lengths start out longest with the first director and decrease in length in a decreasing rate of change until they are virtually constant in length. This method of construction results in a wide gain bandwidth. A bandwidth of 7% of the center frequency at the -1 dB forward-gain points is typical for these Yagis even when they are longer than 10λ . The log-taper design also reduces the rate of change in driven-element impedance vs frequency. This allows the use of simple dipole driven elements while still obtaining acceptable driven-element SWR over a wide frequency range. Another benefit is that the resonant frequency of the Yagi changes very little as the boom length is increased. The driven-element impedance also changes moderately with boom length. The tapered approach creates a Yagi with a very clean radiation pattern. Typically, first side lobe levels of ≈ 17 dB in the E plane, ≈ 15 dB in the H plane, and all other lobes at ≈ 20 dB or more are possible on designs from 2λ to more than 14λ .

The actual rate of change in element lengths is determined by the diameter of the elements (in wavelengths). The spacings can be optimized for an individual boom length or chosen as a best compromise for most boom lengths.

The gain of long Yagis has been the subject of much debate. Recent measurements and computer analysis by both amateurs and professionals indicates that given an optimum design, doubling a Yagi's boom length will result in a maximum theoretical gain increase of about 2.6 dB. In practice, the real gain increase may be less because of escalating resistive losses and the greater possibility of construction error. **Fig 20.105** shows the

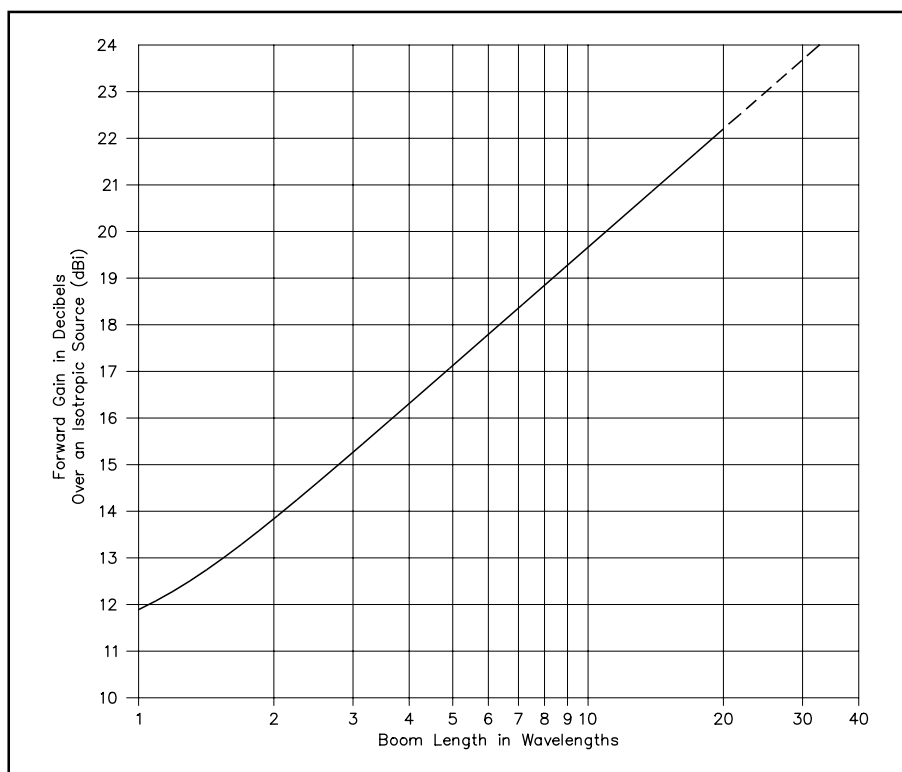


Fig 20.105—This chart shows maximum gain per boom length for optimally designed long Yagi antennas.

maximum possible gain per boom length expressed in decibels, referenced to an isotropic radiator. The actual number of directors does not play an important part in determining the gain vs boom length as long as a reasonable number of directors are used. The use of more directors per boom length will normally give a wider gain bandwidth; however, a point exists where too many directors will adversely affect all performance aspects.

While short antennas ($< 1.5 \lambda$) may show increased gain with the use of quad or loop elements, long Yagis ($> 2 \lambda$) will not exhibit measurably greater forward gain or pattern integrity with loop type elements. Similarly, loops used as driven elements and reflectors will not significantly change the properties of a long log-taper Yagi. Multiple-dipole driven-element assemblies will also not result in any significant gain increase per given boom length when compared to single-dipole feeds.

Once a long-Yagi director string is properly tuned, the reflector becomes relatively noncritical. Reflector spacings between 0.15λ and 0.2λ are preferred. The spacing can be chosen for best pattern and driven-element impedance. Multiple-reflector arrangements will not significantly increase the forward gain of a Yagi that has its directors properly optimized for forward gain. Many multiple-reflector schemes such as trireflectors and corner reflectors have the disadvantage of lowering the driven-element impedance compared to a single optimum-length reflector. The plane or grid reflector, shown in **Fig 20.106**, may however reduce the intensity of unwanted rear lobes. This can be used to reduce noise pickup on EME or satellite arrays. This type of reflector will usually increase the driven-element impedance compared to a single reflector. This sometimes makes driven-element matching easier. Keep in mind that even for EME, a plane reflector will add considerable wind load and weight for only a few tenths of a decibel of receive signal-to-noise improvement.

Yagi Construction

Normally, aluminum tubing or rod is used for Yagi elements. Hard-drawn enamel-covered copper wire can also be used on Yagis above 420 MHz. Resistive losses are inversely proportional to the square of the element diameter and the square root of its conductivity.

Element diameters of less than $\frac{3}{16}$ inch or 4 mm should not be used on any band. The size should be chosen for reasonable strength. Half-inch diameter is suitable for 50 MHz, $\frac{3}{16}$ to $\frac{3}{8}$ inch for 144 MHz and $\frac{3}{16}$ inch is recommended for the higher bands. Steel, including stainless steel and unprotected brass or copper wire, should not be used for elements.

Boom material may be aluminum tubing, either square or round. High-strength aluminum alloys such as 6061-T6 or 6063-T651 offer the best strength-to-weight advantages. Fiberglass poles have been used (where available as surplus). Wood is a popular low-cost boom material. The wood should be well seasoned and free from knots. Clear pine, spruce and Douglas fir are often used. The wood should be well treated to avoid water absorption and warping.

Elements may be mounted insulated or uninsulated, above or through the boom. Mounting uninsulated elements through a metal boom is the least desirable method unless the elements are welded in place. The Yagi elements will oscillate, even in moderate winds. Over several years this element oscillation will work open the boom holes. This will allow the elements to move in the boom and create noise (in your receiver) when the wind blows. Eventually the element-to-boom junction will corrode (aluminum oxide is a good insulator). This loss of electrical contact between the boom

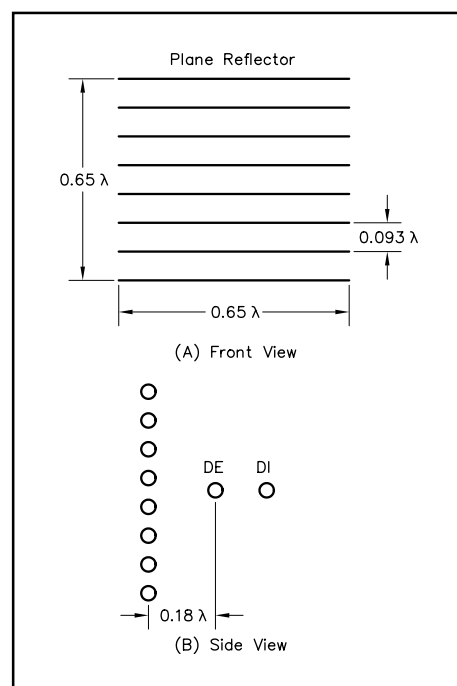


Fig 20.106—Front and side views of a plane-reflector antenna.

and element will reduce the boom's effect and change the resonant frequency of the Yagi.

Noninsulated elements mounted above the boom will perform fine as long as a good mechanical connection is made. Insulating blocks mounted above the boom will also work, but they require additional fabrication. One of the most popular construction methods is to mount the elements through the boom using insulating shoulder washers. This method is lightweight and durable. Its main disadvantage is difficult disassembly, making this method of limited use for portable arrays.

If a conductive boom is used, element lengths must be corrected for the mounting method used. The amount of correction is dependent upon the boom diameter in wavelengths. See **Fig 20.107**. Elements mounted through the boom and not insulated require the greatest correction. Mounting on top of the boom or through the boom on insulated shoulder washers requires about half of the through-the-boom correction. Insulated elements mounted at least one element diameter above the boom require no correction over the free-space length.

The three following antennas have been optimized for typical boom lengths on each band.

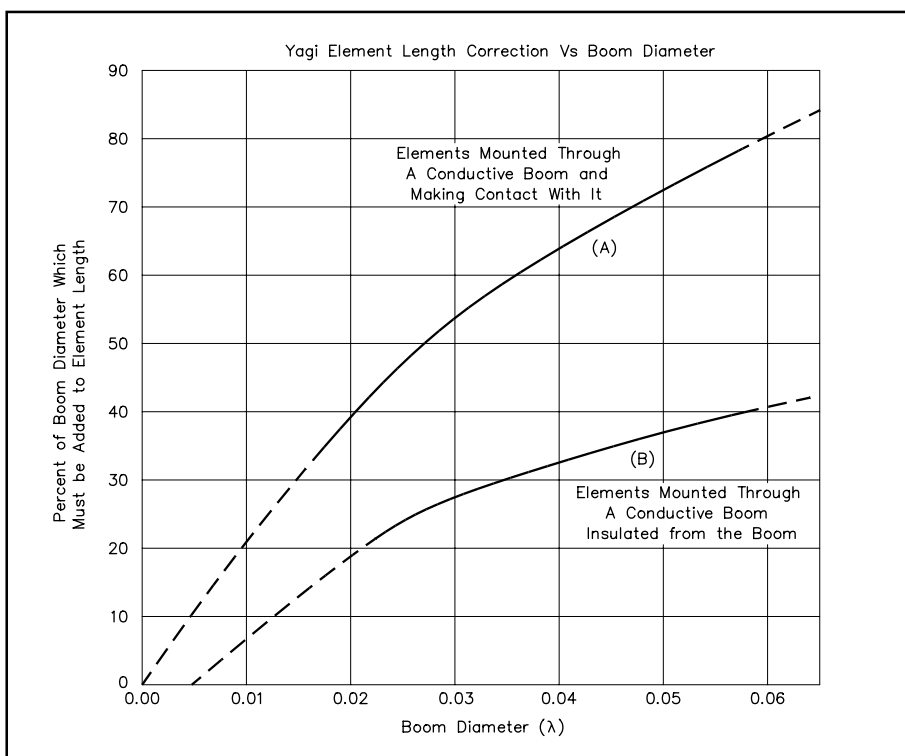


Fig 20.107—Yagi element correction vs boom diameter. Curve A is for elements mounted through a round or square conductive boom, with the elements in mechanical contact with the boom. Curve B is for insulated elements mounted through a conductive boom, and for elements mounted on top of a conductive boom (elements make electrical contact with the boom). The patterns were corrected to computer simulations to determine Yagi tuning. The amount of element correction is not affected by element diameter.

A HIGH-PERFORMANCE 432-MHz YAGI

This 22-element, 6.1λ , 432-MHz Yagi was originally designed for use in a 12-Yagi EME array built by K1FO. A lengthy evaluation and development process preceded its construction. Many designs were considered and then analyzed on the computer. Next, test models were constructed and evaluated on a home-made antenna range. The resulting design is based on WIEJ's computer-optimized spacings.

The attention paid to the design process has been worth the effort. The 22-element Yagi not only has exceptional forward gain (17.9 dBi), but has an unusually "clean" radiation pattern. The measured E-plane pattern is shown in **Fig 20.108**. Note that a 1-dB-per-division axis is used to show pattern detail. A complete description of the design process and construction methods appears in December 1987 and January 1988 *QST*.

Like other log-taper Yagi designs, this one can easily be adapted to other boom lengths. Versions of this Yagi have been built by many amateurs. Boom lengths ranged between 5.3λ (20 elements) and 12.2λ (37 elements).

The size of the original Yagi (169 inches long, 6.1λ) was chosen so the antenna could be built from small-diameter boom material ($7/8$ inch and 1 inch round 6061-T6 aluminum) and still survive high winds and ice loading. The 22-element Yagi weighs about 3.5 pounds and has a wind load of approximately 0.8 square ft. This allows a high-gain EME array to be built with manageable wind load and weight. This same low wind load and weight lets the tropo operator add a high-performance 432-MHz array to an existing tower without sacrificing antennas on other bands.

Table 20.24 lists the gain and stacking specifications for the various length Yagis. The basic Yagi dimensions are shown in

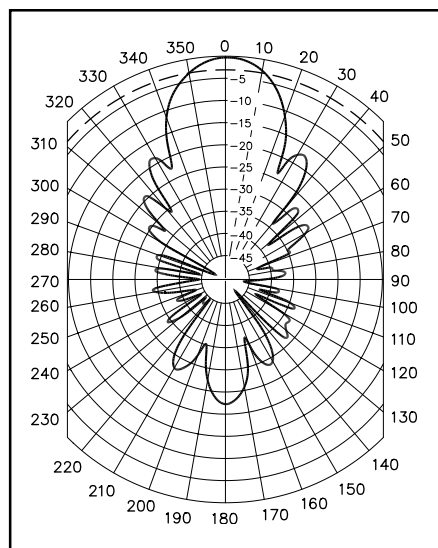


Fig 20.108—Measured E-plane pattern for the 22-element Yagi. Note: This antenna pattern is drawn on a linear dB grid, rather than on the standard ARRL log-periodic grid, to emphasize low sidelobes.

Table 20.24

Specifications for 432-MHz Yagi Family

No. of El	Boom Length (λ)	Gain (dBi)*	FB Ratio (dB)	DE Impd (Ω)	Beamwidth E / H ($^\circ$)	Stacking E / H (in.)
15	3.4	15.67	21	23	30 / 32	53 / 49
16	3.8	16.05	19	23	29 / 31	55 / 51
17	4.2	16.45	20	27	28 / 30	56 / 53
18	4.6	16.8	25	32	27 / 29	58 / 55
19	4.9	17.1	25	30	26 / 28	61 / 57
20	5.3	17.4	21	24	25.5 / 27	62 / 59
21	5.7	17.65	20	22	25 / 26.5	63 / 60
22	6.1	17.9	22	25	24 / 26	65 / 62
23	6.5	18.15	27	30	23.5 / 25	67 / 64
24	6.9	18.35	29	29	23 / 24	69 / 66
25	7.3	18.55	23	25	22.5 / 23.5	71 / 68
26	7.7	18.8	22	22	22 / 23	73 / 70
27	8.1	19.0	22	21	21.5 / 22.5	75 / 72
28	8.5	19.20	25	25	21 / 22	77 / 75
29	8.9	19.4	25	25	20.5 / 21.5	79 / 77
30	9.3	19.55	26	27	20 / 21	80 / 78
31	9.7	19.7	24	25	19.6 / 20.5	81 / 79
32	10.2	19.8	23	22	19.3 / 20	82 / 80
33	10.6	19.9	23	23	19 / 19.5	83 / 81
34	11.0	20.05	25	22	18.8 / 19.2	84 / 82
35	11.4	20.2	27	25	18.5 / 19.0	85 / 83
36	11.8	20.3	27	26	18.3 / 18.8	86 / 84
37	12.2	20.4	26	26	18.1 / 18.6	87 / 85
38	12.7	20.5	25	25	18.9 / 18.4	88 / 86
39	13.1	20.6	25	23	18.7 / 18.2	89 / 87
40	13.5	20.8	26	21	17.5 / 18	90 / 88

*Gain is approximate real gain based upon gain measurements made on six different-length Yagis.

Table 20.25. These are free-space element lengths for $3/16$ -inch-diameter elements. Boom corrections for the element mounting method must be added in. The element-length correction column gives the length that must be added to keep the Yagi's center frequency optimized for use at 432 MHz. This correction is required to use the same spacing pattern over a wide range of boom lengths. Although any length Yagi will work well, this design is at its best when made with 18 elements or more (4.6λ). Element material of less than $3/16$ -inch diameter is not recommended because resistive losses will reduce the gain by about 0.1 dB, and wet-weather performance will be worse.

Quarter-inch-diameter elements could be used if all elements are shortened by 3 mm. The element lengths are intended for use with a slight chamfer (0.5 mm) cut into the element ends. The gain peak of the array is centered at 437 MHz. This allows acceptable wet-weather performance, while reducing the gain at 432 MHz by only 0.05 dB.

The gain bandwidth of the 22-element Yagi is 31 MHz (at the -1 dB points). The SWR of the Yagi is less than 1.4: 1 between 420 and 440 MHz. **Fig 20.109** is a network analyzer plot of the driven-element SWR vs frequency. These numbers indicate just how wide the frequency response of a log-taper Yagi can be, even with a simple dipole driven element. In fact, at one antenna gain

contest, some ATV operators conducted gain vs frequency measurements from 420 to 440 MHz. The 22-element Yagi beat all entrants including those with so-called broadband feeds.

To peak the Yagi for use on 435 MHz (for satellite use), you may want to shorten all the elements by 2 mm. To peak it for use on 438 MHz (for ATV applications), shorten all elements by 4 mm. If you want to use the Yagi on FM between 440 MHz and 450 MHz, shorten all the elements by 10 mm. This will provide 17.6 dBi gain at 440 MHz, and 18.0 dBi gain at 450 MHz. The driven element may have to be adjusted if the element lengths are shortened.

Table 20.25
Free-Space Dimensions for 432-MHz Yagi Family

Element lengths are for $3/16$ -inch-diameter material.

<i>EI</i> No.	<i>Element Position</i> (mm from rear of boom)	<i>Element</i> <i>Length</i> (mm)	<i>Element</i> <i>Correction*</i>
REF	0	340	
DE	104	334	
D1	146	315	
D2	224	306	
D3	332	299	
D4	466	295	
D5	622	291	
D6	798	289	
D7	990	287	
D8	1196	285	
D9	1414	283	
D10	1642	281	-2
D11	1879	279	-2
D12	2122	278	-2
D13	2373	277	-2
D14	2629	276	-2
D15	2890	275	-1
D16	3154	274	-1
D17	3422	273	-1
D18	3693	272	0
D19	3967	271	0
D20	4242	270	0
D21	4520	269	0
D22	4798	269	0
D23	5079	268	0
D24	5360	268	+1
D25	5642	267	+1
D26	5925	267	+1
D27	6209	266	+1
D28	6494	266	+1
D29	6779	265	+2
D30	7064	265	+2
D31	7350	264	+2
D32	7636	264	+2
D33	7922	263	+2
D34	8209	263	+2
D35	8496	262	+2
D36	8783	262	+2
D37	9070	261	+3
D38	9359	261	+3

*Element correction is the amount to shorten or lengthen all elements when building a Yagi of that length.

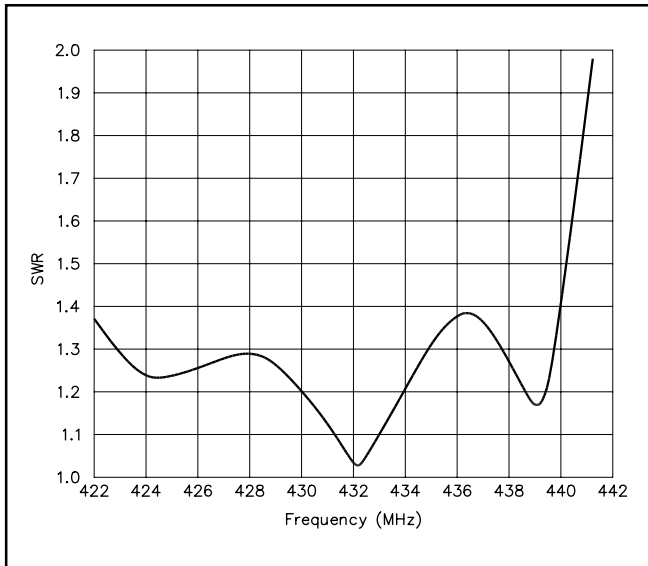


Fig 20.109—SWR performance of the 22-element Yagi in dry weather.

made with black Delryn insulators, available from Rutland Arrays in New Cumberland, Pennsylvania.

The driven element uses a UG-58 connector mounted on a small bracket. The UG-58 should be the type with the press-in center pin. UG-58s with center pins held in by “C” clips will usually leak water. Some connectors use steel retaining clips, which will rust and leave a conductive stripe across the insulator. The T-match wires are supported by the UT-141 balun. RG-303 or RG-142 Teflon-insulated cable could be used if UT-141 cannot be obtained. **Fig 20.111** shows details of the driven-element construction. Driven element dimensions are given in **Fig 20.112**.

Dimensions for the 22-element Yagi are listed in **Table 20.26**. **Fig 20.113** details the Yagi’s boom

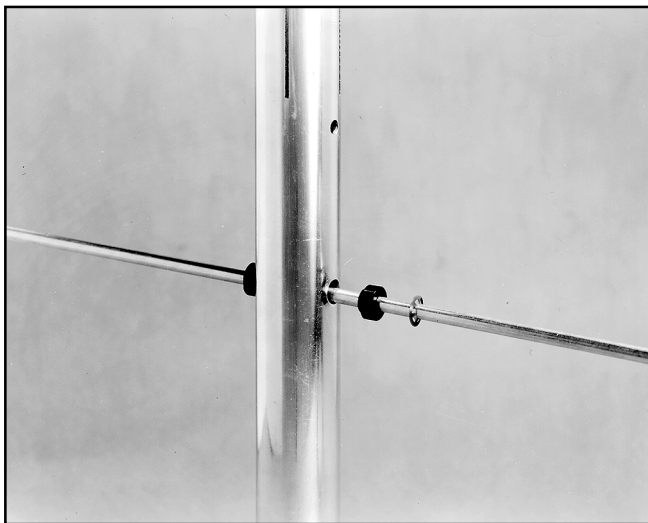


Fig 20.110—Element-mounting detail. Elements are mounted through the boom using plastic insulators. Stainless steel push-nut retaining rings hold the element in place.

Although this Yagi design is relatively broadband, pay close attention to copying the design exactly. Metric dimensions are used because they are convenient for a Yagi sized for 432 MHz. Element holes should be drilled within ± 2 mm. Element lengths should be kept within ± 0.5 mm. Elements can be accurately constructed if they are first rough cut with a hack saw and then held in a vise and filed to the exact length.

Larger arrays require more attention to making all Yagis identical. Elements are mounted on shoulder insulators and run through the boom (see **Fig 20.110**). The element retainers are stainless-steel push nuts. These are made by several companies, including Industrial Retaining Ring Co in Irvington, New Jersey, and AuVeco in Ft Mitchell, Kentucky.

Local industrial hardware distributors can usually order them for you. The element insulators are not critical. Teflon or black polyethylene are probably the best materials. The Yagi in the photographs is

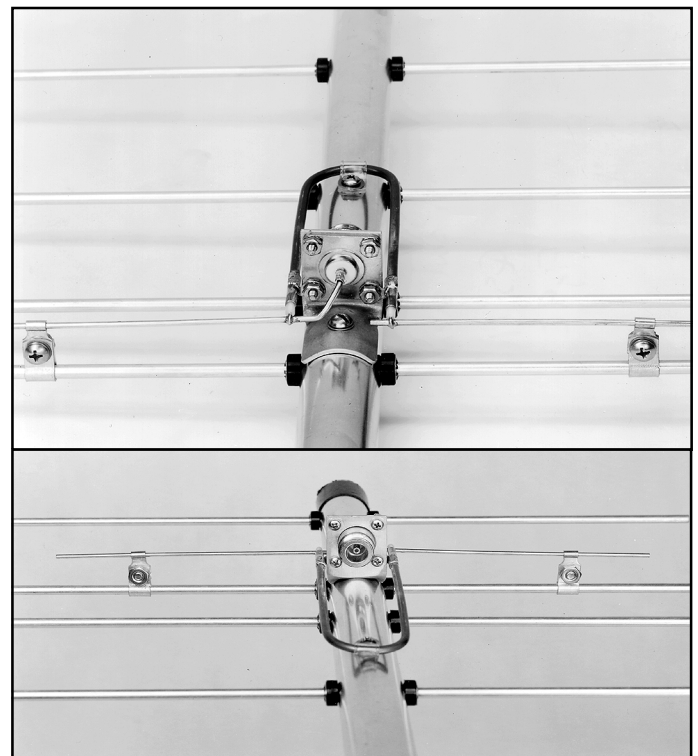


Fig 20.111—Several views of the driven element and T match.

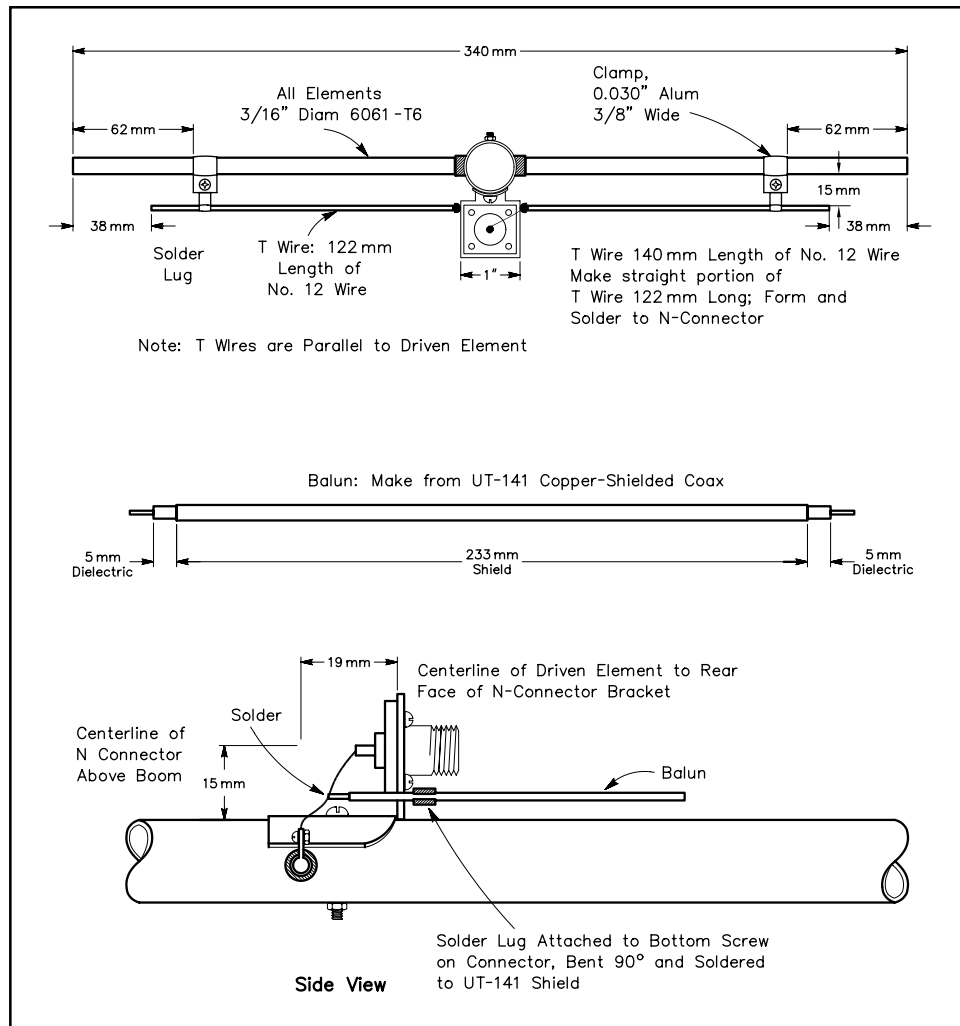


Fig 20.112—Details of the driven element and T match for the 22-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna. See text. Use care soldering to connector center pin to prevent damage.

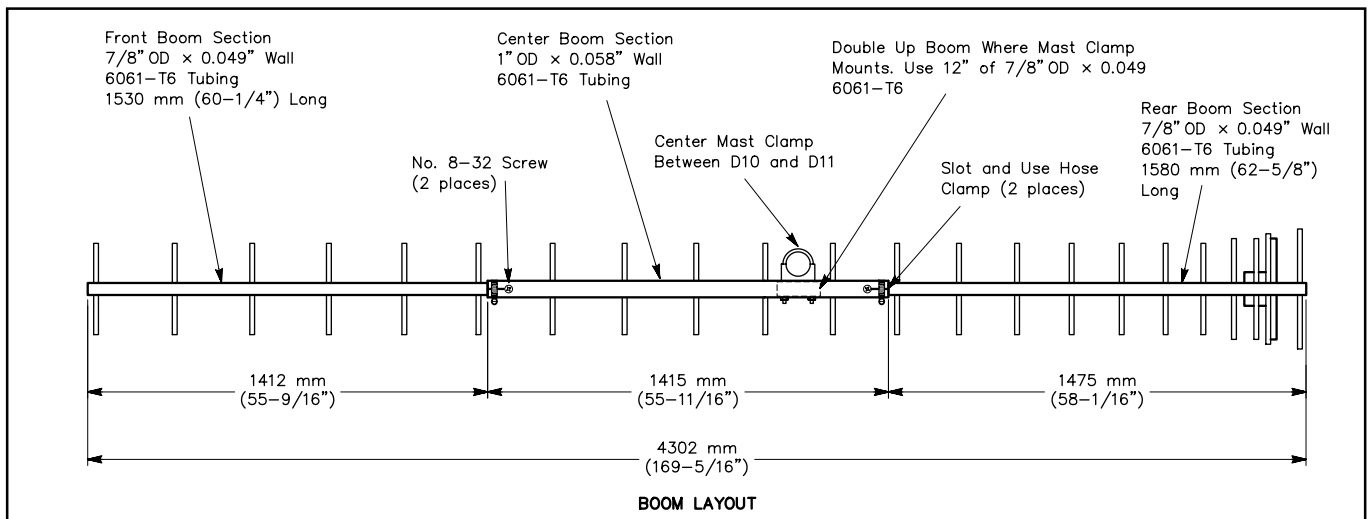


Fig 20.113—Boom-construction information for the 22-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna. See text.

layout. Element material can be either $3/16$ -inch 6061-T6 aluminum rod or hard aluminum welding rod.

A 24-ft-long, 10.6λ , 33-element Yagi was also built. The construction methods used were the same as the 22-element Yagi. Telescoping round boom sections of 1, $1\frac{1}{8}$, and $1\frac{1}{4}$ inches in diameter were used. A boom support is required to keep boom sag acceptable. At 432 MHz, if boom sag is much more than two or three inches, H-plane pattern distortion will occur. Greater amounts of boom sag will reduce the gain of a Yagi. **Table 20.27** lists the proper dimensions for the antenna when built with the previously given boom diameters. The boom layout is shown in **Fig 20.114**, and the driven element is described in **Fig 20.115**. The 33-element Yagi exhibits the same clean pattern traits as the 22-element Yagi (see **Fig 20.116**). Measured gain of the 33-element Yagi is 19.9 dBi at 432 MHz. A measured gain sweep of the 33-element Yagi gave a ≈ 1 dB gain bandwidth of 14 MHz with the ≈ 1 dB points at 424.5 MHz and 438.5 MHz.

Table 20.26
Dimensions for the 22-Element 432-MHz Yagi

Element Number	Element Position (mm from rear of boom)	Element Length (mm)	Boom Diam (in.)
REF	30	346	7/8
DE	134	340	
D1	176	321	
D2	254	311	
D3	362	305	
D4	496	301	
D5	652	297	
D6	828	295	
D7	1020	293	
D8	1226	291	
D9	1444	289	1
D10	1672	288	
D11	1909	286	
D12	2152	285	
D13	2403	284	
D14	2659	283	7/8
D15	2920	281	
D16	3184	280	
D17	3452	279	
D18	3723	278	
D19	3997	277	
D20	4272	276	

Table 20.27
Dimensions for the 33-Element 432-MHz Yagi

Element Number	Element Position (mm from rear of boom)	Element Length (mm)	Boom Diam (in.)
REF	30	348	1
DE	134	342	
D1	176	323	
D2	254	313	
D3	362	307	
D4	496	303	
D5	652	299	
D6	828	297	
D7	1020	295	
D8	1226	293	
D9	1444	291	1 1/8
D10	1672	290	
D11	1909	288	
D12	2152	287	
D13	2403	286	
D14	2659	285	1 1/4
D15	2920	284	
D16	3184	284	
D17	3452	283	
D18	3723	282	
D19	3997	281	1 1/8
D20	4272	280	
D21	4550	278	
D22	4828	278	
D23	5109	277	
D24	5390	277	
D25	5672	276	1
D26	5956	275	
D27	6239	274	
D28	6524	274	
D29	6809	273	
D30	7094	273	
D31	7380	272	

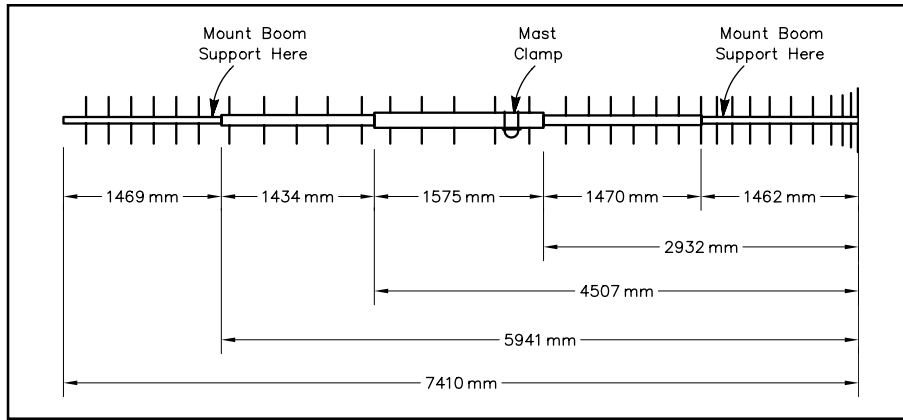


Fig 20.114—Boom-construction information for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

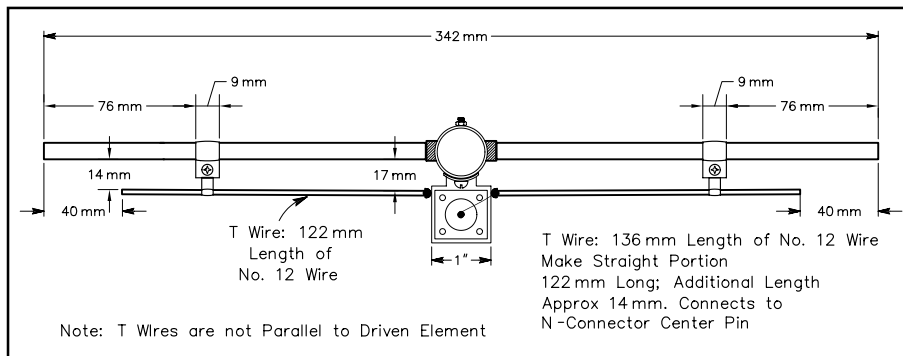


Fig 20.115—Details of the driven element and T match for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

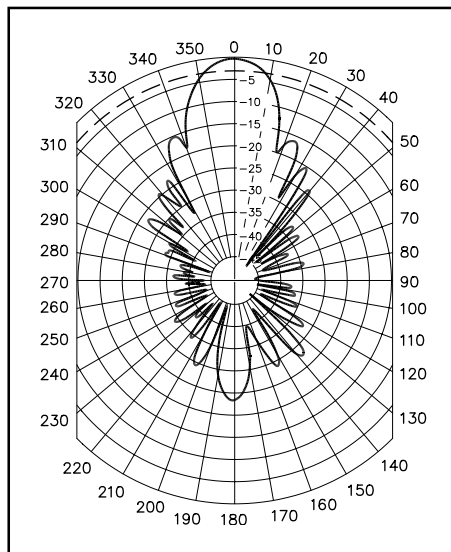


Fig 20.116—E-plane pattern for the 33-element Yagi. This pattern is drawn on a linear dB grid scale, rather than the standard ARRL log-periodic grid, to emphasize low sidelobes.

A HIGH-PERFORMANCE 144-MHz YAGI

This 144-MHz Yagi design uses the latest log-tapered element spacings and lengths. It offers near-theoretical gain per boom length, an extremely clean pattern and wide bandwidth. The design is based upon the spacings used in a 4.5λ 432-MHz computer-developed design by W1EJ. It is quite similar to the 432-MHz Yagi described elsewhere in this chapter. Refer to that project for additional construction diagrams and photographs.

Mathematical models do not always directly translate into real working examples. Although the computer design provided a good starting point, the author, Steve Powlisken, K1FO, built several test models before the final working Yagi was obtained. This hands-on tuning included changing the element-taper rate in order to obtain the flexibility that allows the Yagi to be built with different boom lengths.

The design is suitable for use from 1.8λ (10 elements) to 5.1λ (19 elements). When elements are added to a Yagi, the center frequency, feed impedance and front-to-back ratio will range up and down. A modern tapered design will minimize this effect and allow the builder to select any desired boom length. This Yagi's design capabilities per boom length are listed in **Table 20.28**.

The gain of any Yagi built around this design will be within 0.1 to 0.2 dB of the maximum theoretical gain at the design frequency of 144.2 MHz. The design is intentionally peaked high in frequency (calculated gain peak is about 144.7 MHz). It has been found that by doing this, the SWR bandwidth and pattern at 144.0 to 144.3 MHz will be better, the Yagi will be less affected by weather and its performance in arrays will be more predictable. This design starts to drop off in performance if built with fewer than 10 elements. At less than 2λ , more traditional designs perform well.

Table 20.29 gives free-space element lengths for $1/4$ -inch-diameter elements. The use of metric notation allows for much easier dimensional changes during the design stage. Once you

Table 20.28
Specifications for the 144-MHz Yagi Family

No. of El	Boom Length (λ)	Gain (dBd)	DE Impd (Ω)	FB Ratio (dB)	Beamwidth E / H ($^\circ$)	Stacking E / H (ft)
10	1.8	11.4	27	17	39 / 42	10.2 / 9.5
11	2.2	12.0	38	19	36 / 40	11.0 / 10.0
12	2.5	12.5	28	23	34 / 37	11.7 / 10.8
13	2.9	13.0	23	20	32 / 35	12.5 / 11.4
14	3.2	13.4	27	18	31 / 33	12.8 / 12.0
15	3.6	13.8	35	20	30 / 32	13.2 / 12.4
16	4.0	14.2	32	24	29 / 30	13.7 / 13.2
17	4.4	14.5	25	23	28 / 29	14.1 / 13.6
18	4.8	14.8	25	21	27 / 28.5	14.6 / 13.9
19	5.2	15.0	30	22	26 / 27.5	15.2 / 14.4

Table 20.29
Free-Space Dimensions for the 144-MHz Yagi Family

Element Diameter is $1/4$ -inch.

El No.	Element Position (mm from rear of boom)	Element Length (mm)
REF	0	1038
DE	312	955
D1	447	956
D2	699	932
D3	1050	916
D4	1482	906
D5	1986	897
D6	2553	891
D7	3168	887
D8	3831	883
D9	4527	879
D10	5259	875
D11	6015	870
D12	6786	865
D13	7566	861
D14	8352	857
D15	9144	853
D16	9942	849
D17	10744	845

become familiar with the metric system, you'll probably find that construction is easier without the burden of cumbersome English fractional units. For $\frac{3}{16}$ -inch-diameter elements, lengthen all parasitic elements by 3 mm. If $\frac{3}{8}$ -inch-diameter elements are used, shorten all of the directors and the reflector by 6 mm. The driven element will have to be adjusted for the individual Yagi if the 12-element design is not adhered to.

For the 12-element Yagi, $\frac{1}{4}$ -inch-diameter elements were selected because smaller-diameter elements become rather flimsy at 2 m. Other diameter elements can be used as described previously. The $2.5\text{-}\lambda$ boom was chosen because it has an excellent size and wind load vs gain and pattern trade-off. The size is also convenient; three 6-ft-long pieces of aluminum tubing can be used without any waste. The relatively large-diameter boom sizes ($1\frac{1}{4}$ and $1\frac{3}{8}$ inches) were chosen, as they provide an extremely rugged Yagi that does not require a boom support. The 12-element 17-ft-long design has a calculated wind survival of close to 120 mi/h! The absence of a boom support also makes vertical polarization possible.

Longer versions could be made by telescoping smaller-size boom sections into the last section. Some sort of boom support will be required on versions longer than 22 ft. The elements are mounted on shoulder insulators and mounted through the boom. However, elements may be mounted, insulated or uninsulated, above or through the boom, as long as appropriate element length corrections are made. Proper tuning can be verified by checking the depth of the nulls between the main lobe and first side lobes. The nulls should be 5 to 10 dB below the first side-lobe level at the primary operating frequency. The boom layout for the 12-element model is shown in **Fig 20.117**. The actual corrected element dimensions for the 12-element $2.5\text{-}\lambda$ Yagi are shown in **Table 20.30**.

The design may also be cut for use at 147 MHz. There is no need to change element spacings. The element lengths should be shortened by 17 mm for best operation between 146 and 148 MHz. Again, the driven element will have to be adjusted as required.

The driven-element size ($\frac{1}{2}$ -inch diameter) was chosen to allow easy impedance match-

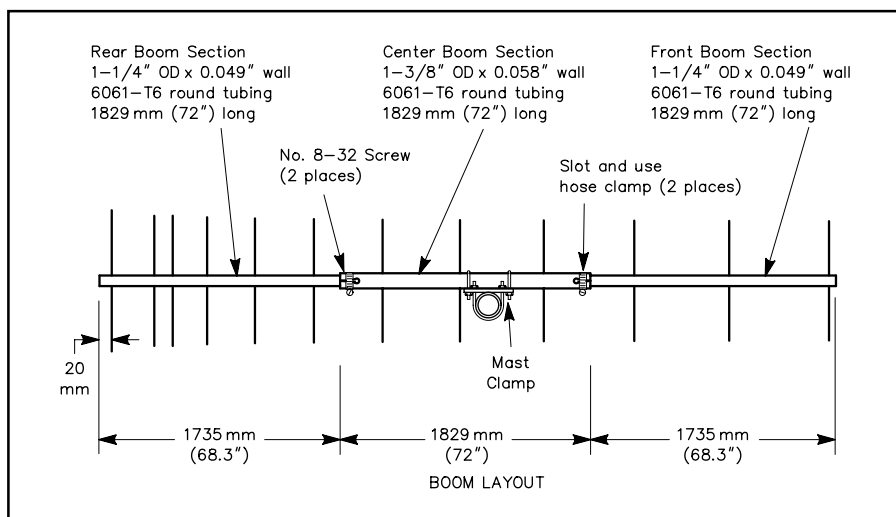


Fig 20.117—Boom layout for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication.

**Table 20.30
Dimensions for the 12-Element $2.5\text{-}\lambda$ Yagi**

Element Number	Element Position (mm from rear of boom)	Element Length (mm)	Boom Diam (in.)
REF	0	1044	1 $\frac{1}{4}$
DE	312	955	
D1	447	962	
D2	699	938	
D3	1050	922	
D4	1482	912	1 $\frac{3}{8}$
D5	1986	904	
D6	2553	898	
D7	3168	894	1 $\frac{1}{4}$
D8	3831	889	
D9	4527	885	
D10	5259	882	

ing. Any reasonably sized driven element could be used, as long as appropriate length and T-match adjustments are made. Different driven-element dimensions are required if you change the boom length. The calculated natural driven-element impedance is given as a guideline. A balanced T-match was chosen because it's easy to adjust for best SWR and provides a balanced radiation pattern. A 4:1 half-wave coaxial balun is used, although impedance-transforming quarter-wave sleeve baluns could also be used. The calculated natural impedance will be useful in determining what impedance transformation will be required at the 200- Ω balanced feedpoint. *The ARRL Antenna Book* contains information on calculating folded-dipole and T-match driven-element parameters. A balanced feed is important for best operation on this antenna. Gamma matches can severely distort the pattern balance. Other useful driven-element arrangements are the Delta match and the folded dipole, if you're willing to sacrifice some flexibility. **Fig 20.118** details the driven-element dimensions.

A noninsulated driven element was chosen for mounting convenience. An insulated driven element may also be used. A grounded driven element may be less affected by static build-up. On the other hand, an insulated driven element allows the operator to easily check his feed lines for water or other contamination by the use of an ohmmeter from the shack.

Fig 20.119 shows computer-predicted E- and H-plane radiation patterns for the 12-element Yagi. The patterns are plotted on a 5-dB-per-division linear scale instead of the usual ARRL polar plot graph. This expanded scale plot is used to show greater pattern detail. The pattern for the 12-element Yagi is so clean that a plot done in the standard ARRL format would be almost featureless, except for the main lobe and first sidelobes.

The excellent performance of the 12-element Yagi is demonstrated by the reception of Moon echoes from several of the larger 144-MHz EME stations with only one 12-element Yagi. Four of the 12-element Yagis will make an excellent starter EME array, capable of working many EME QSOs while being relatively small in size. The advanced antenna builder can use the information in **Table 20.28** to design a "dream" array of virtually any size.

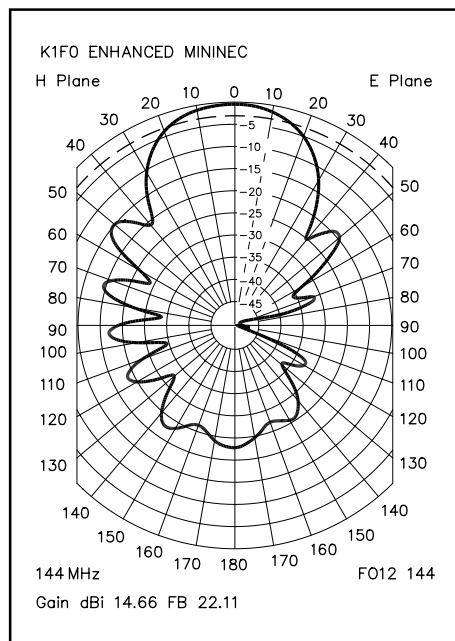


Fig 20.119—H- and E-plane pattern for the 12-element 144-MHz Yagi.

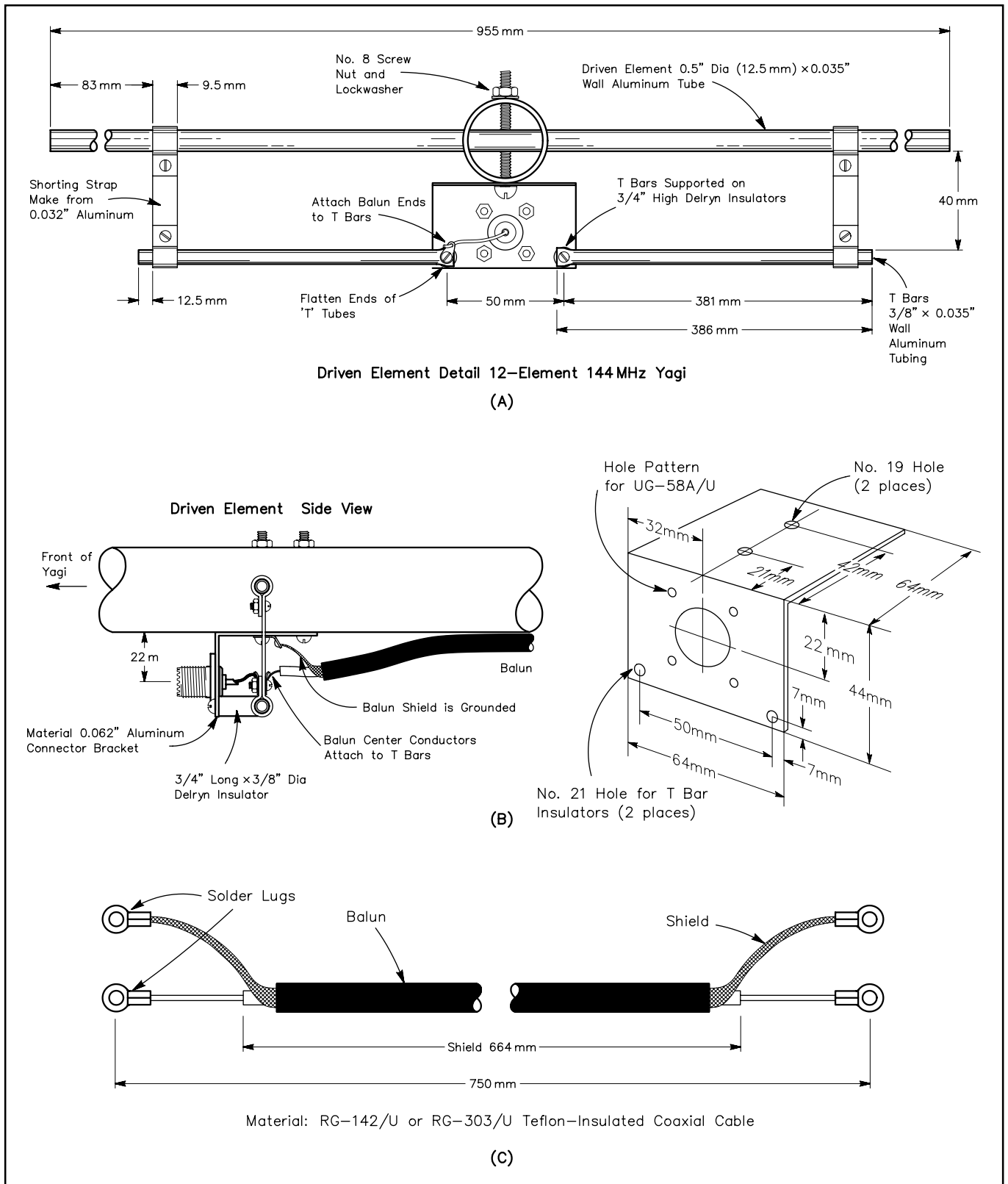


Fig 20.118—Driven-element detail for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication. Use care soldering to connector center to prevent pin damage.

SWR Analyzer Tips, Tricks and Techniques

Hand-held SWR analyzers have become popular tools. Several hams modified their analyzers and put them to work doing tasks that are not found in the analyzer's instruction manual. In the September and October 1996 issues of *QST*, they reported on their experiences.

SWR ANALYZER HINTS

LINE-CORD ISOLATION

When using internal battery power, an MFJ-249 makes good unambiguous antenna measurements. Used with its ac-operated power supply, however, measurements become confused because of the RF path to ground through the power supply and 120-V line. W6TC solved this problem by wrapping 15 turns of the power-supply lead on a ferrite toroid core. Be sure the toroid ID is large enough so that the dc plug can make 15 turns through the core. Locate the toroid near the dc plug end of the cord.

BALUN FOR BALANCED-LOAD MEASUREMENTS

When the MFJ-249 is used with a balanced load, hand-capacitance effects make consistent measurements difficult. A balun, made from a short length of RG-174 coaxial cable connected to a PL-259 at the measurement terminal, is one solution to this problem. Ten turns of cable wrapped on a ferrite core make a good current balun, isolating the MFJ-249's cabinet from the balanced load. Now you can handle the instrument without affecting readings.

MEASURING ANTENNA RF RESISTANCE AND BANDWIDTH

The included RF resistance meter brings the MFJ-259 a cut above the MFJ-249, but it has a small handicap. It's desirable to be able to measure antenna bandwidth at a wide range of load resistances. The RF resistance meter in the MFJ-259 (which basically measures the voltage across the load) gives a true indication of SWR bandwidth *but only if the load is 50 Ω*. To overcome this restriction, W6TC modified his MFJ-249 by changing one of the 50-Ω resistors in the RF bridge circuit to a 500-Ω potentiometer. Calibrated the dial so that when the bridge is balanced (minimum SWR), the resistance can be read by the potentiometer's dial calibration. Then, by simply rocking the FREQUENCY control between the 2:1 SWR points (or whatever SWR criteria for bandwidth you choose), you can measure the bandwidth of the device under test. The bridge-balancing resistor must be a miniature potentiometer, such as an Allen Bradley Type W (Model WA2G056S501UA).

Bring the potentiometer's shaft through the cabinet's bottom, add legs to the cabinet and install a calibrated bezel. Calibrate the bezel using external resistors of various values. Because of the potentiometer's capacitance and inductance, the bridge circuit does not work well in the VHF range. This modification is, therefore, primarily useful below 30 MHz.

REMOTE INDICATION OF SWR PATTERN

A particularly welcome characteristic of the MFJ-249 is that the self-excited oscillator frequency is affected by the load. Further, the oscillator signal is easily identified because of the modulation generated by the frequency counter gate. When working with open-wire transmission line, it's easy to determine the position of the voltage nodes.

Excite the transmission line with the MFJ-249, listen to the signal in a receiver and walk alongside the transmission line while touching it with your hand or a metal rod. (This is the modern-day version of the tried-and-true neon-bulb indicator.) At voltage nodes, there'll be no frequency change when you

touch the line. At current nodes, however, the tone you hear in the receiver will change substantially, and is roughly proportional to SWR. Be sure to use a receiver with a BFO.

ANTENNA VOLTAGE/CURRENT NODE DETECTION

When working with wire antennas such as loops, watching the '249's SWR indication or listening to the tone shift in a receiver can also be used to determine the location of current maxima (maximum radiation) on the antenna. W6TC suggests using a long, thin aluminum tube and touch the antenna at various points (the '249 is connected to the feed line, not the rig!). Where the voltage is a minimum, there is no effect on SWR or audio tone, whereas at voltage maxima, the SWR increases and the frequency shifts. Thus, the positions of maximum radiation (and maximum voltage) on various shapes of wire antennas, including loops and elevated radials, is easily determined.

AN RF SOURCE FOR THE ANTENNASCOPE

Years ago, Bill Scherer, W2AEF, developed the famous Antennascope.¹ The RF power output of an MFJ-249 is sufficient to drive an Antennascope to a useful level provided the Antennascope null indicator is changed to a 50- μ A meter (such as a RadioShack 270-1754).² With this combination, antenna resistance at resonance from a few ohms to 1 kW is measured easily.

A SIMPLE, LOW-COST WAY TO MEASURE ANTENNA RESISTANCE

Another way to determine antenna resistance at resonance with the '249 is to use a resistor connected in parallel, or in series, with the load. First, find the minimum SWR, then place a 100- Ω resistor in parallel with the load. If the SWR *decreases*, you know that the load is *greater* than 50 Ω . Now, put the 100- Ω resistance *in series* with the load, and the SWR should *increase*, confirming that the resistance of the load is greater than 50 Ω .

Calculate the antenna resistance by *multiplying* 50 W by the original SWR. Conversely, when the 100- Ω resistor is placed across the load (in shunt) and the SWR *increases*, you know that the load resistance is *less than* 50 Ω . In this case, the antenna resistance is determined by simply *dividing* 50 W by the original SWR.

An alternate—and perhaps more accurate—way to make this measurement is to use a small 50- Ω potentiometer in series or in parallel with the load. If the load is less than 50 Ω , put the variable resistor in series with the load and adjust the frequency and the resistor for a match. Measure the variable resistor with an ohmmeter. The load resistance is then equal to 50 Ω minus the ohmmeter reading.

The same procedure can be used if the load is more than 50 Ω by placing a variable 1-k Ω resistor across the load. Adjust the resistor for a match, measure the resistor's value, and calculate the load resistance, using the parallel resistance formula.

ADJUSTING A TETRODE PASSIVE-INPUT CIRCUIT

W6TC modified his 8877 linear to use one of the inexpensive Svetlana tetrodes.³ The 50- Ω passive-input circuit used with tetrodes eliminates nine tuned circuits and presents a flat load to the driving transceiver. On 10 meters, the input capacitance of the 4CX1600B tetrode across the 50- Ω input resistor causes the input SWR to be excessive. With a mock-up and a MFJ-249, you can adjust lead lengths in series with the 50- Ω resistor to compensate for the tetrode input capacitance. In addition, the lead from the linear RF input connector to the grid should be routed *through the center* of the 50- Ω Global resistor. Passing the wire through the center of the resistor evidently forms a sort of lossy coax line, reducing lumped reactances. With this configuration, adjust the lead lengths in until the SWR on 10 meters is 1:1. The reactance of the leads disappears on the other bands, so the input SWR on all bands (including 12, 17 and 30 meters) is a very satisfying 1:1.

CHECKING OPEN-WIRE-LINE RF BALANCE

You can check for balance on open-wire lines by touching a screwdriver to each side of the transmission line (again, the '249 is connected to the feed line, not your rig). If the circuit is balanced, touching the screwdriver to each side of the transmission line causes the SWR to rise the same amount on either side. The same technique will determine the balance of voltage baluns.

USING THE MFJ-249 FOR ANTENNA-PATTERN MEASUREMENTS

The MFJ-249 is handy as a signal source for rotary antenna pattern measurements. The oscillator is reasonably stable and there is enough signal so that, with a short dipole, good pattern measurements can be made. Put the MFJ-249 into a tree, as high as possible, several wavelengths from the antenna you're measuring.

Battery operation makes the MFJ-249 particularly useful because pattern measurements can be affected by wires feeding power to the oscillator. A word to the wise: The MFJ-249 eats batteries! I measured the total battery current at 175 mA. With the counter disconnected, only 75 mA is consumed. By cutting the +5-V trace to the counter and adding a jumper to disconnect the counter and digital readout from the battery supply your batteries will last longer.

IN-CIRCUIT FREQUENCY MEASUREMENT OF TOROIDAL TUNED CIRCUITS

The resonant frequency of a toroidal tuned circuit is difficult to measure with a dip meter because there is little field outside of the core. Using the MFJ-249, you can measure the resonant frequency by threading one turn through the toroid. Connect one end of the loop to the coax outer conductor (ground) and connect the other end of the loop through a 100- Ω resistor to the center conductor. The SWR meter should read 2, and should deflect upward at the resonant frequency. If it doesn't, put another loop through the toroid and connect it to a sensitive RF indicator, such as a field-strength meter (any sensitive RF meter will do). The RF indicator meter peaks as you tune the MFJ-249 through the toroid-tuned circuit resonant frequency.

THE MFJ-249

INCREASED SENSITIVITY

AG4R purchased an MFJ-249 SWR Analyzer and found that its otherwise excellent frequency counter was not sensitive enough to pick up the various oscillator check points that he wanted to measure in his transceiver. His solution was to connect an RF amplifier module using a Motorola hybrid wide-band amplifier (MHW591).⁴ This device produces an average gain of 35 dB over the frequency range of 1 to 250 MHz and requires a 13-V supply (see (A) in **Fig 20.120**). Inserting the amplifier in line with the FC input of the '249 did the trick! If a little less gain will suffice, the low-noise RF amplifier he described in Hints and Kinks⁵ can also perk up the frequency counter.

You can also use your MFJ-249 to check the quality of other ham-shack components such as coaxial switches and relays. All you need is a noninductive 50- Ω load and some interconnecting coax. You should know the characteristics of your 50- Ω load before you start checking other equipment. By testing the equipment at frequencies of 10 MHz and up, you'll be able to evaluate overall performance and spot trouble should it arise.

CHECKING A FILTER'S CUT-OFF FREQUENCY

You can use your MFJ SWR Analyzer to check a 50- Ω filter's cut-off frequency. Connect a 50- Ω dummy load to one end of the filter and the Analyzer to the other end. (See B in Fig 20.120.) Within the filter's passband, you'll get an SWR of 1 and an SWR increase beyond the filter's upper and lower cut-off frequencies. How closely the SWR approaches 1 depends on the filter losses. The sharpness of the rise in SWR beyond the filter cut-off points gives you an indication of the filter quality.

Although this filter-checking method isn't as good as having a spectrum analyzer, it does provide a reasonable bench check of filters used in amateur equipment.

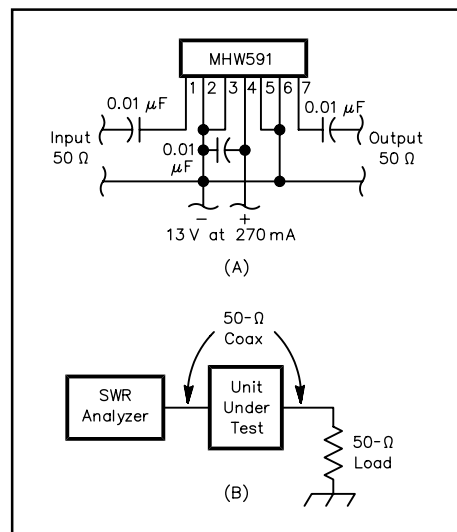


Fig 20.120—There's not much to do to get the broadband amplifier going! At A, just add three capacitors, a power source and you're up and running. At B, coupling your SWR analyzer through the device under test to a known load can help you identify troublespots and evaluate overall performance equipment.

MFJ-247 HINTS

Early MFJ-247s exhibited two problems right from the start. First, the LCD intermittently locked up when band-switching. Generally, the display would unlock and return to normal if you quickly turned the power on and off. To solve this problem, install an SPST toggle switch on the front panel directly below the GATE pushbutton and wire it in series with the positive battery lead to allow easy on/off switching when that lock-up occurs. MFJ has a factory fix for this problem (a replacement band-selector switch), but adding the toggle switch was easier and less expensive than returning the unit to MFJ.

Stock MFJ-247s don't provide continuous coverage of the HF bands. So, directly to the left of the main tuning knob, you can install another SPST switch. It switches in a 75-pF ceramic capacitor to fill in the band-coverage voids. This capacitor can be selected any time you need to extend the frequency coverage below the analyzer's normal range; this provides additional coverage and better centering within any band. Connect one lead of the capacitor to the main tuning capacitor's *high side* and the other end to one of the switch terminals. The other switch terminal goes to circuit ground via the shortest path. Because the '247 has the built-in LCD frequency counter, no recalibration was needed; the counter simply reads the RF oscillator output.

Since the '247 doesn't cover the 2-meter band, you can couple an MFJ-208 analyzer (140 to 160-MHz) to the '247 by using an adapter spanning the rear of each unit (see **Fig 20.121**). It's a 6¹/₄-inch-wide, 4¹/₄-inch-high, 1/8-inch-thick black aluminum plate that holds the two units together via a single #8 sheet metal screw in the back of each analyzer. This makes the docking adapter plate easy to remove when the batteries in either analyzer need replacing. The **FREQ OUT** connector of the '208 loops to the **FREQ IN** connector of the '247 via a short length of coaxial cable for reading the frequency of the '208 on the B input of the '247's counter. (The counter in the '247 operates well beyond 2 meters even though the analyzer itself doesn't.) For carrying ease, NZ9E attached a husky handle to the left side of the '247.

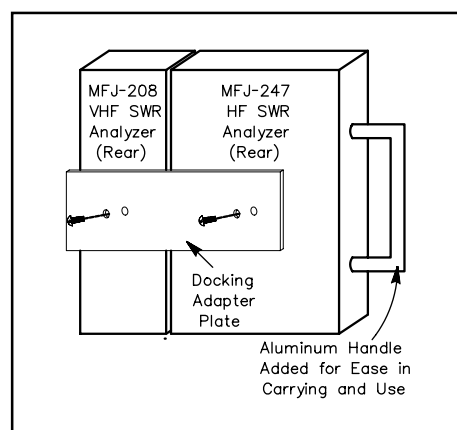


Fig 20.121—NZ9E's docking adapter and carry handle allow easy transport of his MFJ-247 and MFJ-208.

A QRP ACCESSORY PACK FOR THE MFJ-259

To check the crystals he uses and to align his home-brewed QRP rig, KB6WB combined his MFJ-259 SWR Analyzer and the ancillary equipment he needed in an accessory pack (see **Figs 20.122** and **20.123**). The pack contains an eight-position, switchable 81-dB attenuator⁶ for receiver alignment; four crystal sockets to accommodate different-size crystal holders for crystal checks, and a 50- Ω L pad for testing and tuning stubs and transmission lines and checking transmitter alignment using an MFJ SWR Analyzer's frequency counter.

CW OFFSET

For QRP transmitter CW-offset calibration, connect a UHF T to the transmitter's RF output jack. Using short pieces of coaxial cable, connect one side of the T to a 50- Ω dummy load and the other side to J4. Connect J6 to the analyzer's Frequency Counter input. Note: The transmitter's output must be reduced to an acceptable level at the input to the SWR analyzer—see the analyzer's operating manual. (The resistive network between J4 and J6 can handle transmitter power-output levels of up to 5 W.) Then you can key the transmitter and check and adjust the CW offset using the frequency counter, comparing the received and transmitted frequencies.

CRYSTAL CHECKING

Connect the analyzer to J3 of the Accessory Pack using a double-male coaxial adapter. Carefully adjust the TUNE knob around the frequency of the crystal under test until you note a dip in the SWR reading. At that point, the crystal is oscillating. Slow and careful tuning is required to avoid bypassing the crystal's resonant frequency. You may want to install a larger knob on your MFJ-259 to allow for better tuning control.

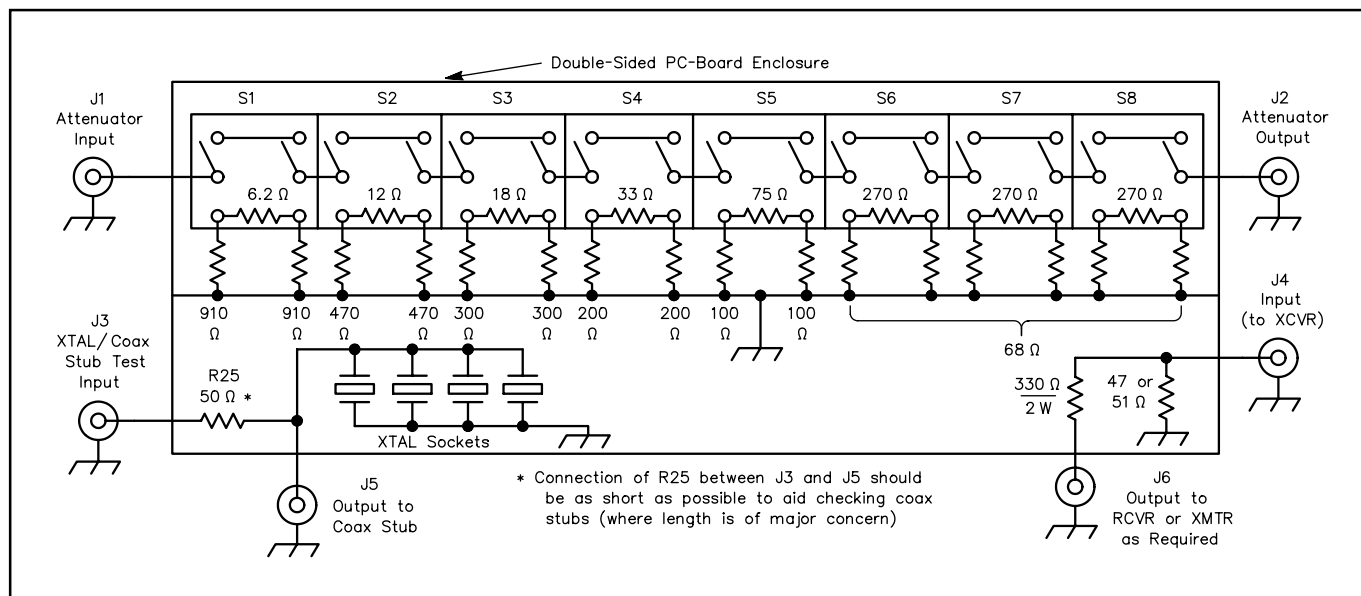
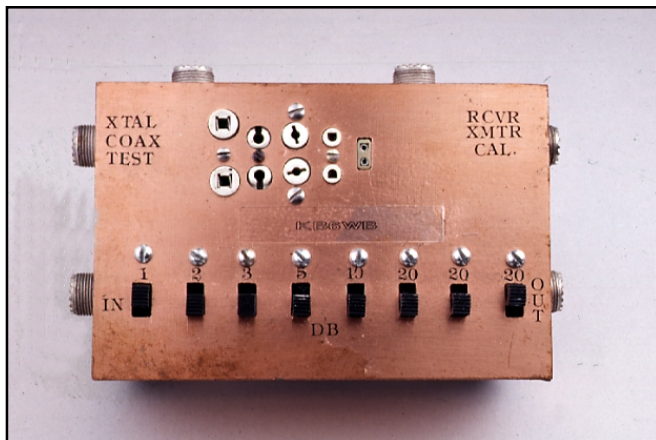
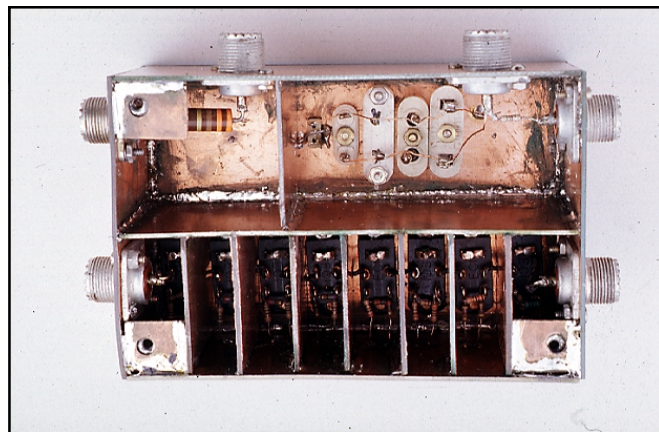


Fig 20.122—Schematic of KB6WB's QRP Accessory Pack. J1-J6, SO-239; J1—attenuator input; J2—attenuator output; J3—input for crystal and coaxial stub testing. Attach J3 to the MFJ-249 through a double-male coaxial connector adapter. J4 is the input to the resistive network used for transceiver checking. Interconnect J2 and J4 for receiver testing. For transmitter testing, connect J4 to the MFJ-249's Frequency Counter connector. J5 is the coaxial stub-test output; connect the stub under test to this jack. J6, the resistive network output, is connected to a receiver or transmitter for their specific checks. Resistors are $\frac{1}{4}$ W, 5%-tolerance units except for the 330- Ω resistor, which is a 2-W unit. Remember: The attenuator is a low-power unit. S1-S8 are DPDT slide switches.



(A)



(B)

Fig 20.123—KB6WB’s QRP Accessory Pack is constructed in a 2¹/₂ × 4 × 6-inch enclosure made of double-sided PC board. In A, you can see the four crystal sockets that accept crystals in different-size holders. The attenuator section switches are below. The bottom/inside view of the Pack (B) reveals the shielding between the attenuator sections and the compartments.

CHECKING COAXIAL STUBS AND TRANSMISSION LINES

Connect the SWR analyzer to J3 using a double-male coaxial adapter. Attach the coax under test to J5. Follow the instructions in the analyzer’s operating manual under “Testing and Tuning Stubs and Transmission Lines.”

AN ETHERNET ANALYZER

Several months ago, AA0QX's computer network went down. It's a Novell network connected with thin Ethernet cable. Intermittent cabling and connection problems that were hard to locate are not uncommon in networks.

Since thin Ethernet uses 50- Ω termination—in essence, a “dummy load,” an MFJ analyzer enabled him to locate the bad connection immediately, without bringing down the network and disconnecting all users. To find a fault, connect the analyzer to the T connector. Because the cable is terminated at both ends, the resistance reads as 25 Ω at 10 MHz (an SWR of 2). If the analyzer's needle jumps when you wiggle the connector, you know it's bad. Occasionally you may have to disconnect the T connector to determine which connector is the problem. In that event, the SWR drops to 1, as the impedance is now 50 Ω .

Commercial-grade network analyzers cost \$1500 to \$4500. Continuity testers require that the network be brought down to test a connection, since a break in either end could still show continuity. The MFJ analyzer proved successful and costs a lot less!

DETERMINING COMPLEX IMPEDANCE WITH AN AUTEK RESEARCH RF-1

Since the earliest Autek Research RF-1 owned by K4ERO did not include instructions to determine $R \pm jX$, he devised his own system of finding $R \pm jX$ by using SWR and Z. The SWR/Z chart of Fig 20.124⁸ is the same size as a standard Smith Chart. When the SWR and Z have been located (and the sign ambiguity resolved), the SWR/Z chart can be laid over the Smith Chart and the R and jX read or matched.

You may prefer his graphical method to that of using a formula because it gives you a picture of what's happening and an idea of the accuracy to be expected from the measurements. The formula is simple enough, but it's accompanied by a number of warnings about when it will deliver inaccurate results. With the graphical method, the approximate accuracy to be expected is quite obvious. If an "error circle" is mentally placed around the points SWR and Z, you can quickly see what possible values of R and X can be expected. Of course, for those not familiar with the use of the Smith Chart, the formula is probably the way to go. The graphical method also has finite accuracy, but it is probably as accurate as the measurements themselves, and would not, therefore, give a false idea of having greater accuracy than is justified.

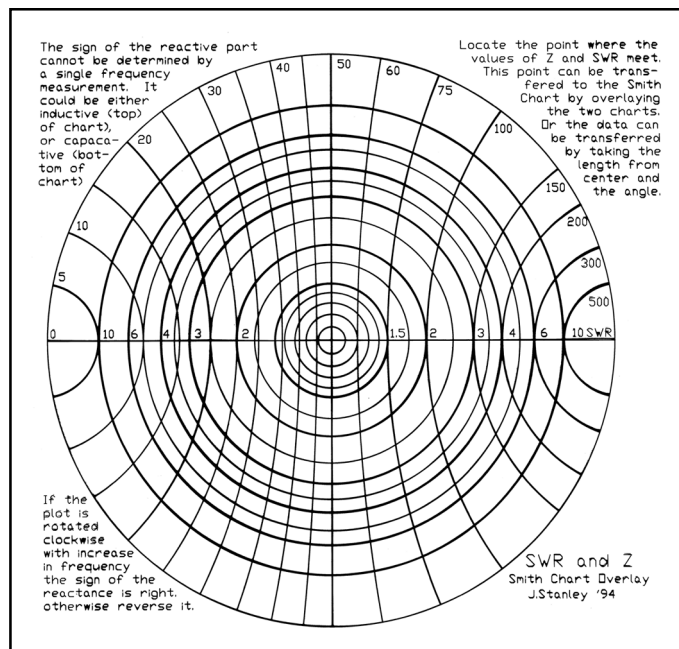


Fig 20.124—K4ERO devised a Smith Chart overlay to graphically convert SWR and Z measurements to the $R \pm jX$ format. It can be used with instruments such as the Autek RF-1 to provide complex impedance information for matching purposes. A full-size, transparent overlay is available from the ARRL (see Note 8).

THE "GADGET"

Soon after he bought an MFJ-249, W3NZ built a copy of Dave (AF6S) Barton's dip-meter attachment as described in *QST*.⁹ After that, came the inspiration for a multipurpose "Gadget." The Gadget is simple to build—its base is a piece of double-sided PC board.¹⁰ Refer to **Figs 20.125** through **20.127**. Remove a rectangular section of foil from the mirror location on both sides of the board, leaving a "lazy-L" shaped section of foil common to both sides. Secure three red binding posts (A, B, C) to the bare section of board; attach three black binding posts (D, E, F) directly opposite each of the red posts on the board's foil section. A notch at one end of the board accepts the shell of a PL-259 connector that's soldered directly to the foil on both sides.

Before installing the PL-259, solder a piece of insulated wire to its center pin. Connect the other end

of the wire to the red binding post A nearest the PL-259. On the bottom of the board, connect the diode, capacitor and resistors to their proper binding posts by means of solder lugs secured to the posts. (See Fig 20.127A) Prepare four accessory items: three short lengths of wire configured as shown in Fig 20.127B, and a 50-Ω load resistor. These accessories come in handy when using the Gadget to make various measurements.

Next, measure the Analyzer's RF-output voltage. You should perform this step before conducting any tests in which the SWR Analyzer's output voltage is part of an equation. (It often takes about 18 minutes after turn-on for the RF-output voltage to stabilize.) You may also decide it's best to use an ac-operated supply for the Analyzer because by the time the RF-output voltage settles down, the battery shows signs of tiring. To measure the Analyzer's RF-output voltage, connect the Gadget's PL-259 to the SWR Analyzer's output connector and attach a digital voltmeter (DVM) to binding posts C and D. A short piece of wire (Item 3) connects post A to post B. The DVM reads the dc voltage produced by the rectified RF output voltage of the analyzer presented across the 200-kΩ resistor. As a typical example, W3NZ recorded 0.43

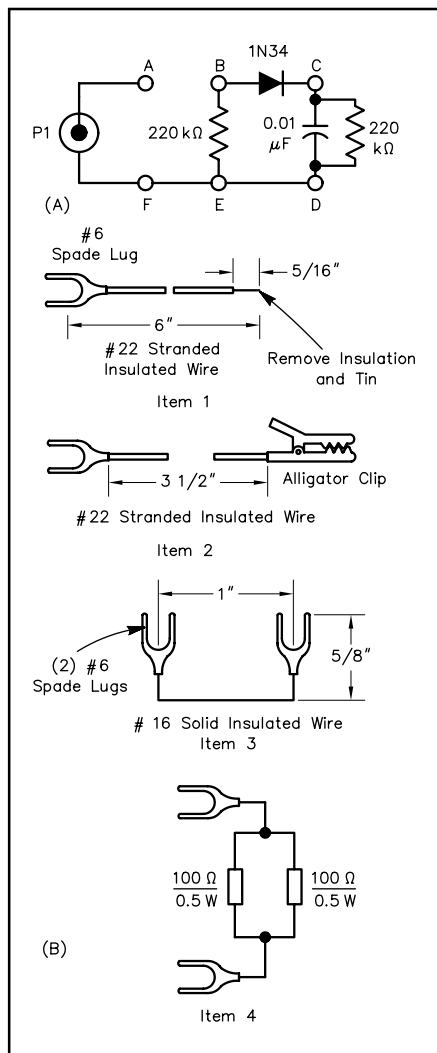


Fig 20.125—Schematic of the Gadget (A). Terminals A through F are binding posts. P1 is a PL-259 coaxial plug. Be sure to use a germanium diode (such as the 1N34 specified), not a silicon diode. Resistors can be 1/4 or 1/2-W units. Four accessory items are made as shown at (B).

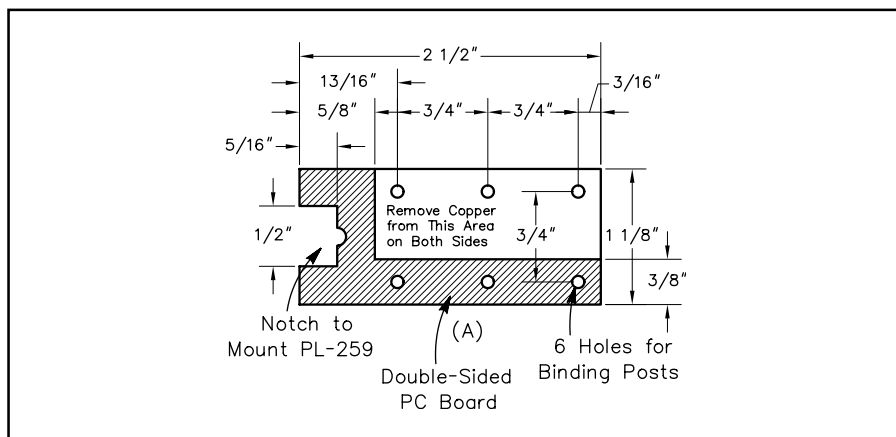
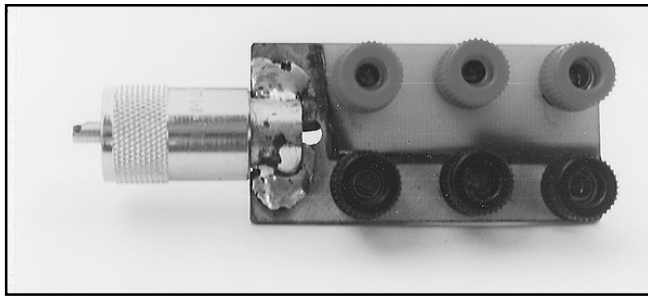
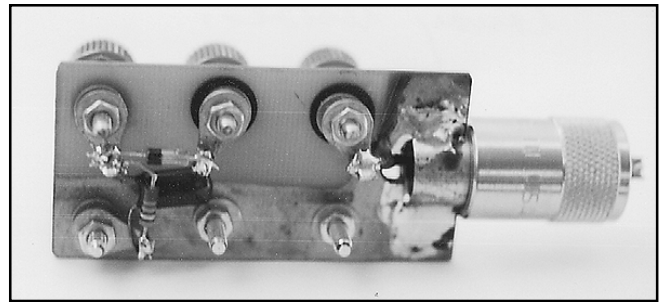


Fig 20.126—Physical layout of the Gadget; dimensions are not critical. Remove a "lazy-L" area of foil from both sides of a piece of double-sided PC board. A 1/2-inch-wide notch at one end of the board accepts the PL-259 shell, which is soldered to the foil on both sides of the board. Six holes accept the binding posts (Radio Shack #274-661).



(A)



(B)

Fig 20.127—At A, the top side of the Gadget. Three red binding posts are mounted on the *nonfoil* section of the board. Three black binding posts are secured to the *foil* area. Beneath the board, B, the diode, resistor and capacitor are secured to the binding posts by means of solder lugs. The red binding post nearest the PL-259 connector connects to the center conductor of the coaxial plug.

V at 1.8 MHz. Because the Analyzer's output voltage varies with frequency, you should measure and record its output voltage at the bottom end of each of the HF amateur bands.

Be aware of the Sun's effect on the Gadget's 1N34 diode. In bright sunlight and with a temperature of 82°, the output of the diode changed considerably as it became warmer. You may want to provide some means of shading the Gadget from sunlight and drafts.

USING THE GADGET TO CHECK RF CHOKES

W3NZ needed two RF chokes to separate a dc relay voltage from RF, both being supplied to a remote point by a coaxial feed line. From his junk box, he inserted a likely candidate (a two-pie choke) between posts A and B. What an eye opener! At 4 MHz, the meter read 0.09 V, at 5 MHz it was down to 0.004 V and at 5.795 MHz the reading was zero. That choke was okay for use above 7 MHz, but certainly wouldn't perform well on the 80 or 160-meter bands. The lower the voltage at and above the frequency of interest, the better the RF choke is suited for use at those frequencies.

THE GADGET AS A SUPER DIPPER

To dip a circuit that used a very small toroid inductor, thread a length of wire (Accessory Item 1) through the small toroid. Next attach the wire's spade lug to post A and the tinned end to post E (ground). A very sharp dip should be seen! Now you won't need a separate dip meter and its plug-in coils, nor need to hunt for the dip meter's oscillator signal in the receiver for an accurate confirmation of the resonant frequency. The SWR Analyzer does the trick.

CHECKING TUNED-CIRCUIT Q

To check the Q of a tuned circuit, disconnect the 220-kΩ resistor connected between binding posts B and E. Connect the tuned circuit under test between posts B and E, with a single loop of wire (use Item 1) passing through the toroid core (to create a one-turn loop). Attach a DVM to Gadget posts C and D. Measure the resonant-frequency output voltage ($V_{OUT(RES)}$) and the voltage at the high and low-frequency 3-dB points ($V_{OUT(RES)} \propto 0.707$). Then, calculate the tuned circuit's Q by using the equation

$$Q = \frac{f_{RES}}{f_{HIGH} - f_{LOW}} \quad (\text{Eq 1})$$

where

f_{RES} = Resonant frequency

f_{HIGH} = -3 dB high frequency

f_{LOW} = -3 dB low frequency

OTHER USES

You can use the Gadget/SWR Analyzer combination to find lossy coaxial cable and a bad low-pass filter. See **Fig 20.128**. To check a piece of coax, connect a 50- Ω , 1/4-W resistor between posts A and F. This resistor is the load resistance for the cable under test. Connect a shorting jumper between posts A and B and attach your DVM to posts C and D. Record the Analyzer's output voltage; this is V_{IN} . Because the RF-output voltage is frequency dependent, also record the measurement frequency. (I was mostly interested in the frequencies between 3.6 and 21 MHz.) Next, connect the Gadget to one end of the line under test and attach the SWR Analyzer to the other end of the line. Set the Analyzer to the frequency of interest. (Before proceeding, be sure the SWR is 1:1.) Record the voltage at the frequency of interest and label it V_{OUT} . To calculate the line loss in decibels, use the following formulas:

$$\text{Loss(dB)} = 20 \log \frac{V_{IN}}{V_{OUT}} \quad (\text{Eq 2})$$

where

$$P = \frac{E^2}{R} P_{IN} = \frac{V_{IN}^2}{50} P_{OUT} = \frac{V_{OUT}^2}{50} \quad (\text{Eq 3-Eq 5})$$

The percentage of loss is calculated by

$$\text{Loss(\%)} = \frac{P_{IN} - P_{OUT}}{\frac{P_{IN}}{100}} \quad (\text{Eq 6})$$

Use the same approach to check your low-pass filter, substituting the filter for the coaxial cable section. By sweeping the Analyzer frequency higher (past 30 MHz), the upper cut-off frequency of the filter is indicated by the DVM voltage reading dipping toward zero.

Notes

- 1 Wilfred Scherer, W2AEF, "Building and Using the Antennascope," CQ, Sep 1950, pp 13-18 and 59-63.
- 2 Although the meter is sold as a 0 to 15-V dc voltmeter, the meter movement is a 50- μ A unit.—*Ed.*

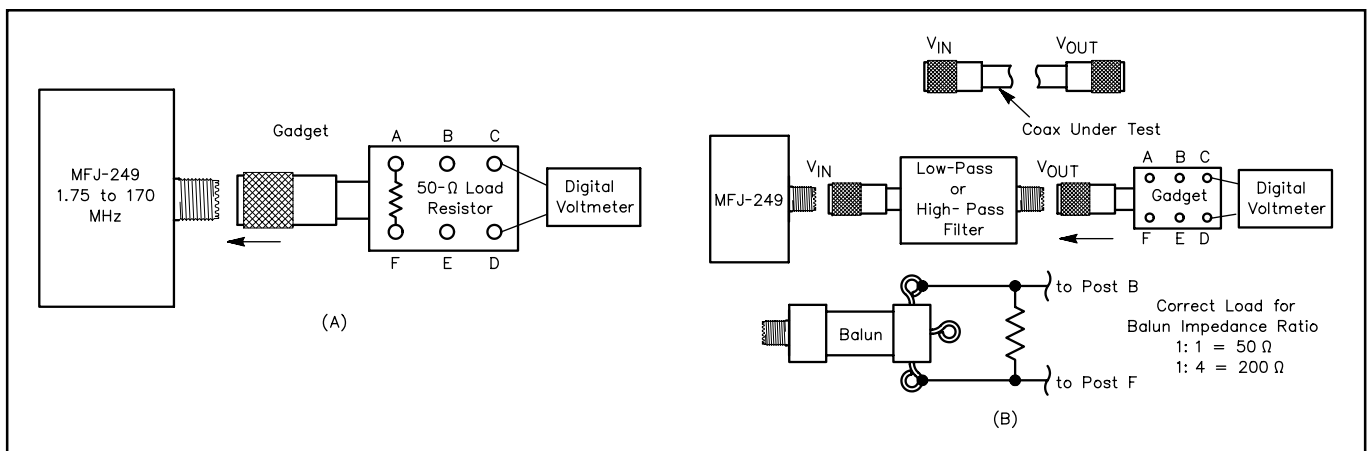


Fig 20.128—At A, measuring the output of the antenna analyzer across a 50- Ω resistor at the test frequency. A jumper wire is needed between posts A and B, with a digital voltmeter connected between posts C and D. At B, a few ideas on how to measure coaxial-cable loss and the characteristics of low-pass and high-pass filters and baluns. Be sure to terminate the load end of the balun with a resistor of the proper value. At some time, you're sure to need one or more adapters (such as a double-female coaxial connector) to make required equipment interconnections.

- ³ See *QST Congratulates...* George Badger, W6TC, as President of Svetlana Electron Devices, *QST*, Jul 1995, p 116.
- ⁴ The MHW591 is available from Newark Electronics; it costs about \$50. A less-expensive replacement to consider is one of the Motorola MWA-series amplifiers; those units have a gain of about 15 dB and cost about \$10 each (Newark's minimum order is \$25). See **References** chapter Address List for contact information.
- ⁵ Wayne Cooper, AG4R, "A One-Transistor RF Amplifier," Hints and Kinks, *QST*, Aug 1984, pp 46-47.
- ⁶ A suitable attenuator is described in The 1995 *ARRL Handbook* on pages 26.40 to 26.41. Materials for a PC-board enclosure are available from FAR Circuits. See **References** chapter Address List for contact information.
- ⁷ Andrew S. Griffith, W4ULD, "The 1/3-Wavelength Multiband Dipole," *QST*, Sep 1993, pp 33-35.
- ⁸ Full-size SWR/Z transparent overlays are available in the **References** chapter.
- ⁹ David M. Barton, AF6S, "An Accurate Dip Meter Using the MFJ-249 SWR Analyzer," *QST*, Nov 1993, pp 45-46.
- ¹⁰ A PC board for this project is available from FAR Circuits. See the **References** chapter Address List for contact information.

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