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VHF and UHF Antenna Systems

A good antenna system is one of the most valuable assets available to the VHF/UHF enthusiast. Compared to an antenna of lesser quality, an antenna that is well designed, is built of good quality materials, and is well maintained, will increase transmitting range, enhance reception of weak signals and reduce interference problems. The work itself building antennas is by no means the least attrac-

tive part of the job. Even with high-gain antennas, experimentation is greatly simplified at VHF and UHF because the antennas are a physically manageable size. Setting up a home antenna range is within the means of most amateurs, and much can be learned about the nature and adjustment of antennas. No large investment in test equipment is necessary.

15.1 DESIGN FACTORS AT AND ABOVE VHF

The fundamental principles of antenna systems are the same at VHF and UHF as at HF. There is no magic dividing line at 50 MHz that suddenly changes the way antenna system components operate. However, factors that may be insignificant at HF must be taken into account at higher frequencies as the wavelength of the signals drops, dielectric loss increases, and skin depth shrinks. Similarly, techniques that may be impractical at HF such as dishes and long-boom Yagis with 20 elements can be put to work at VHF and higher frequencies. Instead of repeating the theory presented in other chapters, this section will identify areas that must be treated differently than at HF and give guidelines for how to approach the problem.

15.1.1 ANTENNAS

As on HF, the first step in choosing the right antenna is figuring out what you want it to do. Most VHF/UHF falls into one of two categories — weak-signal and local or regional repeater communication. Weak-signal operating on CW, SSB, and increasingly various digital modes, benefits from horizontally polarized, rotatable antennas with narrow beamwidths and minimum sidelobes. Satellite operation on CW and SSB goes farther and adds elevation control and circular polarization to the list. FM repeater and simplex operation uses vertical polarization for both directional and

omnidirectional antennas. Simple ground-plane and low-gain omnidirectional antennas are common.

Just the polarization issue alone can have a dramatic effect as an antenna cross-polarized to an incoming signal receives up to 20 dB less signal than if the antenna and signal polarization are the same. Similarly, a narrow-beamwidth rotatable antenna can be a poor choice if the goal is to use several nearby repeaters that are located in different directions from the station. As a result, it is not uncommon for an amateur station to include both types — a horizontally polarized beam and a vertically polarized omnidirectional antenna — for VHF and UHF operation.

Gain

At VHF and UHF, it is possible to build Yagi antennas with very high gain — 15 to 20 dBi — on a physically manageable boom. Such antennas then can be combined in arrays of two, four, six, eight or more antennas. These arrays are attractive for EME, tropospheric scatter or other weak-signal communications modes where the path loss is very high.

Collinear antennas such as Franklin arrays become much more manageable at and above 2 meters with gains of 6 to 12 dBi in a single, vertical package similar in size to a 10 meter ground plane antenna. The collinear dipole array is very popular as a repeater antenna (see the **Repeater Antenna**

Systems chapter) with potential gains of up to 9 dBd for eight dipole arrays as described by Belrose. (See Bibliography.)

Reflectors, horns and dishes offer even higher gains (and narrower patterns) at UHF and microwave frequencies. A medium-sized dish can develop up to 30 dBi gain at 10 GHz, for example, turning 1 W of power into an EIRP of 1 kW!

Radiation Patterns

Antenna radiation can be made omnidirectional, bidirectional, practically unidirectional, or anything between these configurations. 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 are greater with such omnidirectional antennas, and omnidirectional antennas having some gain are especially bad in these respects. 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, or where the noise level is high.

Frequency Response

The ability to use an entire VHF band may be important in some types of operation. Modern Yagis can achieve performance over a remarkably wide frequency range, providing that the boom length is long enough and enough elements are used to populate the boom. Modern Yagi designs in fact are competitive with directly driven collinear arrays of similar size and complexity. The primary performance parameters of gain, front-to-rear ratio and SWR can be optimized over all the VHF or UHF amateur bands readily, with the exception of the full 6 meter band from 50.0 to 54.0 MHz, which is an 8% wide bandwidth. A Yagi can be easily designed to cover any 2 MHz portion of the 6 meter band with superb performance.

Height Gain

In general, higher is better in VHF and UHF antenna installations. Raising the antenna over nearby obstructions may make dramatic improvements in coverage. Within reason, greater height is almost always worth its cost, but height gain (see the **Radio Wave Propagation** chapter) must be balanced against increased transmission line loss. This loss can be considerable, and it increases with frequency. The best available line may not be very good if the run is long in terms of wavelengths. Line loss considerations as discussed in the **Transmission Lines** chapter are important in antenna planning.

Physical Size

A given antenna design for 432 MHz has the same gain as the same design for 144 MHz, but being only one-third as large intercepts only one-ninth as much energy in receiving. In other words, the antenna has less pickup efficiency at 432 MHz. To be equal in communication effectiveness, the 432-MHz array should be at least equal in size to the 144-MHz antenna, which requires roughly three times as many elements. With all the extra difficulties involved in

using the higher frequencies effectively, it is best to keep antennas as large as possible for these bands.

Polarization

Whether to position antenna elements vertically or horizontally has been widely debated since early VHF pioneering days. Tests have shown little evidence about which polarization sense is most desirable. On long propagation paths there is no consistent advantage either way. Shorter paths tend to yield higher signal levels with horizontally polarized antennas over some kinds of terrain. Man-made noise, especially ignition interference, also tends to be lower with horizontal antennas. These factors make horizontal polarization somewhat more desirable for weak-signal communications. On the other hand, vertically polarized antennas are much simpler to use in omnidirectional systems and in mobile operation.

Vertical polarization was widely used in early VHF operation, but horizontal polarization gained favor when directional arrays started to become widely used. The major use of FM and repeaters, particularly in the VHF/UHF bands, has tipped the balance in favor of vertical antennas in mobile and repeater use. Horizontal polarization predominates in other communication on 50 MHz and higher frequencies. An additional loss of 20 dB or more can be expected when cross-polarized antennas are used.

15.1.2 TRANSMISSION LINES

Transmission line principles are covered in detail in the **Transmission Lines** chapter. Techniques that apply to VHF and UHF operation are dealt with in greater detail here. As at HF, RF is carried principally via coaxial cables at VHF/UHF although parallel-wire transmission lines (window-line or twin-lead) are used on the VHF and low UHF bands. Certain aspects of these lines characterize them as good or bad for use above 50 MHz. At 10 GHz and higher frequencies, waveguide becomes feasible for amateur use. At VHF and higher frequencies, the primary consideration for transmission lines is loss, which increases dramatically with frequency.

While not in widespread use at VHF/UHF today, properly built parallel-wire line can operate with very low loss in VHF and UHF installations. A total line loss under 2 dB per 100 feet at 432 MHz can easily be obtained. A line made of #12 AWG wire, spaced $\frac{3}{4}$ inch or more with Teflon spreaders and run essentially straight from antenna to station, can be better than anything but the most expensive coax. Such line can be home-made or purchased at a fraction of the cost of coaxial cables, with comparable loss characteristics. Careful attention must be paid to efficient impedance matching if the benefits of this system are to be realized. A similar system for 144 MHz can easily provide a line loss under 1 dB.

Small coax such as RG-58 or RG-59 should never be used in VHF operation if the length of the run is more than a few feet. Lines of $\frac{1}{2}$ -inch diameter (RG-8 or RG-11) work fairly well at 50 MHz, and are acceptable for 144-MHz runs of 50 feet or less. These lines are somewhat better if they employ foam instead of ordinary PE dielectric material but still very lossy.

Aluminum-jacket *hardline* or Heliac coaxial cables with large inner conductors and foam insulation are well worth their cost. Hardline can sometimes be obtained for free from local cable TV operators as “end runs” — pieces at the end of a roll. The most common CATV cable is ½-inch OD 75-Ω hardline. Matched-line loss for this cable is about 1.0 dB/100 feet at 146 MHz and 2.0 dB/100 feet at 432 MHz. Less commonly available from CATV companies is the ¾-inch 75-Ω hardline, sometimes with a black self-healing hard plastic covering. This line has 0.8 dB of loss per 100 feet at 146 MHz, and 1.6 dB loss per 100 feet at 432 MHz. There will be small additional losses for either line if 75-to-50-Ω transformers are used at each end. The **Transmission Line Coupling and Impedance Matching** chapter describes synchronous transmission line transformers for converting between 50- and 75-Ω lines on a single band. Hardline must not be bent too sharply, because it will kink.

Commercial connectors for hardline are expensive but provide reliable connections with full waterproofing. They are often available at very reasonable prices via Internet auction and for-sale sites including adapters to UHF and other connector types. Enterprising amateurs have homebrewed low-cost connectors. If they are properly waterproofed, connectors and hardline can last almost indefinitely. See the **Transmission Lines** chapter for details on hardline connectors.

Beware of any “bargains” in coax for VHF or UHF use. Feed line loss can be compensated to some extent by increasing transmitter power but once lost, a weak signal can never be recovered in the receiver.

Effects of weather on transmission lines should not be ignored. Well-constructed open-wire line works optimally in nearly any weather, and it stands up well. Twinlead is almost useless in heavy rain, wet snow or icing. The best grades of coax are completely impervious to weather — they can be run underground, fastened to metal towers without insulation and bent into any convenient position with no adverse effects on performance.

15.1.3 IMPEDANCE MATCHING

Impedance matching is covered in detail in the **Transmission Line Coupling and Impedance Matching** chapter. The various technical aspects of impedance matching are similar at HF and above 50 MHz but the electrical size of the various components can be a primary factor in the choice of methods. Only the matching devices used in practical construction examples later in this chapter are discussed in detail here. This should not rule out consideration of other methods, however.

Impedance matching at the antenna takes on more importance at VHF and UHF because of feed line loss. At HF, the moderate additional feed line loss caused by an impedance mismatch at the antenna can be tolerated and the impedance matched to 50 Ω at the transmitter with an antenna tuner. At VHF and above, with feed line loss much higher, even moderate SWR can result in unacceptable additional losses. Thus, impedance matching is usually done at the antenna so that

the minimum matched-line loss is obtained. For that reason, antenna tuners are not usually employed on the bands above 50 MHz.

Universal Stub

As its name *universal stub* implies, the double-adjustment stub of **Figure 15.1A** is useful for many matching purposes. The stub length is varied to resonate the system and the transmission line attachment point is varied until the transmission line and stub impedances are equal. In practice this involves moving both the sliding short and the point of line connection for zero reflected power, as indicated on an SWR bridge connected in the line.

The universal stub allows for tuning out any small reactance present in the driven part of the system. It permits matching the antenna to the line without knowledge of the actual impedances involved. The position of the short

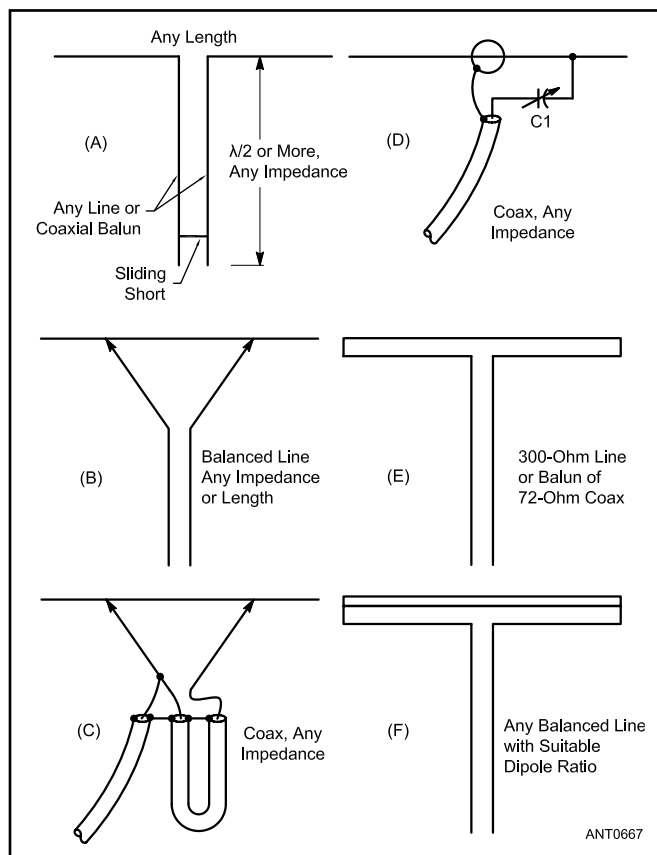


Figure 15.1 — Matching methods commonly used at VHF. The universal stub, A, combines tuning and matching. The adjustable short on the stub and the points of connection of the transmission line are adjusted for minimum reflected power on the line. In the delta match, B and C, the line is fanned out and connected to the dipole at the point of optimum impedance match. Impedances need not be known in A, B or C. The gamma match, D, is for direct connection of coax. C1 tunes out inductance in the arm. A folded dipole of uniform conductor size, E, steps up antenna impedance by a factor of four. Using a larger conductor in the unbroken portion of the folded dipole, F, gives higher orders of impedance transformation.

yielding the best match gives some indication of the amount of reactance present. With little or no reactive component to be tuned out, the stub must be approximately $\frac{1}{2} \lambda$ from the load toward the short.

The stub should be made of stiff bare wire or rod, spaced no more than $\frac{1}{20} \lambda$ apart. Preferably it should be mounted rigidly, on insulators. Once the position of the short is determined, the center of the short can be grounded, if desired, and the portion of the stub no longer needed can be removed.

It is not necessary that the stub be connected directly to the driven element. It can be made part of a parallel-wire line as a device to match coaxial cable to the line. The stub can be connected to the lower end of a delta match or placed at the feed point of a phased array. Examples of these uses are given later.

Delta Match

Probably the most basic impedance matching device is the *delta match*, fanned ends of an parallel-wire line tapped onto a $\frac{1}{2} \lambda$ antenna at the point of the most-efficient power transfer. This is shown in Figure 15.1B. Both the side length and the points of connection either side of the center of the element must be adjusted for minimum reflected power on the line, but as with the universal stub, you needn't know the impedances. The delta match makes no provision for tuning out reactance, so the universal stub is often used as a termination for it.

At one time, the delta match was thought to be inferior for VHF applications because of its tendency to radiate if improperly adjusted. The delta has come back into favor now that accurate methods are available for measuring the effects of matching. It is very handy for phasing multiple-bay arrays with open-wire lines, and its dimensions in this use are not particularly critical. It should be checked out carefully in applications like that of Figure 15.1C, where no tuning device is used.

Gamma and T Matches

An application of the same principle allowing direct connection of coax is the *gamma match*, Figure 15.1D. Because the RF voltage at the center of a $\frac{1}{2} \lambda$ dipole is zero, the outer conductor of the coax is connected to the element at this point. This 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 tuned out by means of C1, resulting in electrical balance. 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 capacitance can be varied until the required value is found, and the variable capacitor replaced with a fixed unit of that value. C1 can be mounted in a waterproof box. The maximum required value should be about 100 pF for 50 MHz and 35 to 50 pF for 144 MHz.

The capacitor and arm can be combined in one coaxial assembly, with the arm connected to the driven element by means of a sliding clamp and the inner end of the arm sliding

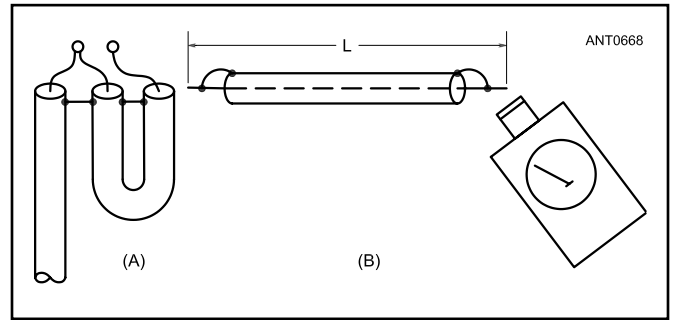


Figure 15.2 — Conversion from unbalanced coax to a balanced load can be done with a $\frac{1}{2}\lambda$, coaxial balun at A. Electrical length of the looped section should be checked with a dip meter, with the ends shorted, as at B. The $\frac{1}{2}\lambda$ balun gives a 4:1 impedance step-up.

inside a sleeve connected to the center conductor of the coax. An assembly of this type can be constructed from concentric pieces of tubing, insulated by a plastic or heat-shrink sleeve. RF voltage across the capacitor is low when the match is adjusted properly, so with a good dielectric, insulation presents no great problem. The initial adjustment should be made with low power. A clean, permanent high-conductivity bond between arm and element is important, since 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 **Figure 15.2** is used from the 200 Ω balanced T-match to the unbalanced 50 Ω coaxial line going to the transmitter. See the K1FO Yagi designs later in this chapter for details on practical use of a T-match. A ferrite bead choke balun as described below can be used with a gamma match to decouple the outer surface of the feed line.

Folded Dipole

As described in the **Dipoles and Monopoles** chapter, if a single conductor of uniform size is folded to make a $\frac{1}{2} \lambda$ dipole as shown in Figure 15.1E, the impedance is stepped up four times. Such a folded dipole can be fed directly with 300- Ω line with no appreciable mismatch. If a 4:1 balun is used, the antenna can be fed with 75- Ω coaxial cable. (See balun information presented below.) Higher step-up impedance transformation can be obtained if the unbroken portion is made larger in cross-section than the fed portion, as shown in Figure 15.1F.

Hairpin Match

The feed point resistance of most multielement Yagi arrays is less than 50 Ω . If the driven element is split and fed at the center, it may be shortened from its resonant length to add capacitive reactance at the feed point. Then, shunting the feed point with a wire loop resembling a *hairpin* causes a step-up of the feed point resistance. The hairpin match (described in

the **Transmission Line Coupling and Impedance Matching** chapter) is used together with a 4:1 coaxial balun in the 50 MHz arrays described later in this chapter.

15.1.4 BALUNS

Conversion from balanced loads to unbalanced lines (or vice versa) can be performed with electrical circuits, or their equivalents made of coaxial cable. A balun made from flexible coax is shown in Figure 15.2A. The looped portion is an electrical $\frac{1}{2} \lambda$. The physical length depends on the velocity factor of the line used, so it is important to check its resonant frequency as shown in Figure 15.2B. 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 (typically 50 to 200 Ω , or 75 to 300 Ω).

Coaxial baluns that yield 1:1 impedance transformations are shown in **Figure 15.3**. The coaxial sleeve, open at the top and connected to the outer conductor of the line at the lower end (A) is the preferred type. At B, a conductor of approximately the same size as the line is used with the outer conductor to form a $\frac{1}{4} \lambda$ stub. 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 flow on the outer surface of the coax shield.

Ferrite bead choke or current baluns become less attractive at VHF and higher frequencies due to the properties of

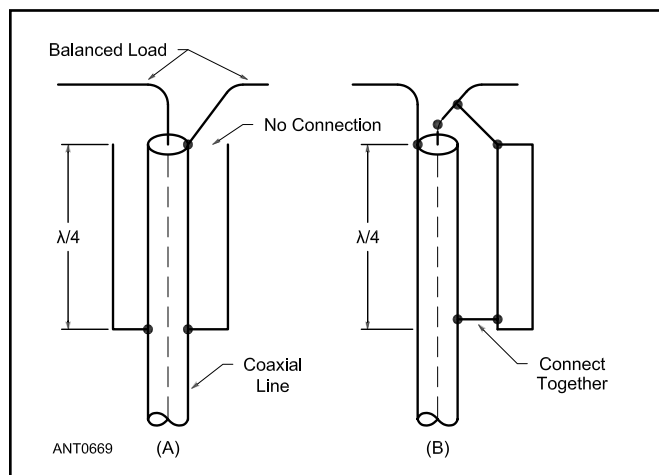


Figure 15.3 — The balun conversion function, with no impedance transformation, can be accomplished with $\frac{1}{4}\lambda$ lines, open at the top and connected to the coax outer conductor at the bottom. The coaxial sleeve at A is preferred.

the ferrite material. However, bead-type choke baluns using type 31, 43, and 61 material can be effective at 50 MHz and even 144 MHz. For 144 MHz and higher frequency bands, coaxial baluns are the usual choice.

15.2 BASIC ANTENNAS FOR VHF AND UHF

Local operation with mobile stations and handheld radios requires an antenna with wide coverage capabilities and a generally omnidirectional pattern. Most mobile operation uses FM and the polarization used with this mode is generally vertical. Some simple vertical systems are described below. Additional material on antennas of this type is presented in the **Mobile VHF and UHF Antennas** chapter.

15.2.1 GROUND-PLANE ANTENNAS

For the FM operator living in the primary coverage area of a repeater, the ease of construction and low cost of a $\frac{1}{4} \lambda$ ground-plane antenna make it an ideal choice. Three different types of construction are detailed in the following section; the choice of construction method depends upon the materials at hand and the desired style of antenna mounting. (Note that while UHF connectors are not generally recommended for use on the upper VHF bands and at UHF, they will work fine as a base for ground-plane antennas. It is their uncontrolled impedance above 100 MHz that causes problems in transmission lines but as part of an antenna, their impedance is accounted for when trimming the antenna for minimum SWR.)

The 144-MHz model shown in **Figure 15.4** uses a flat piece of sheet aluminum, to which radials are connected

with machine screws. A 45° bend is made in each of the radials. This bend can be made with an ordinary bench vise. An SO-239 chassis connector is mounted at the center of the aluminum plate with the threaded part of the connector facing down. The vertical portion of the antenna is made of #12 AWG copper wire soldered directly to the center pin of the SO-239 connector.

The 222-MHz version, **Figure 15.5**, uses a slightly different technique for mounting and sloping the radials. In this case the corners of the aluminum plate are bent down at a 45° angle with respect to the remainder of the plate. The four radials are held to the plate with machine screws, lock washers and nuts. A mounting tab is included in the design of this antenna as part of the aluminum base. A compression type of hose clamp could be used to secure the antenna to a mast. As with the 144-MHz version, the vertical portion of the antenna is soldered directly to the SO-239 connector.

A very simple method of construction, shown in **Figure 15.6** and **Figure 15.7**, requires nothing more than an SO-239 connector and some #4-40 hardware. A small loop formed at the inside end of each radial is used to attach the radial directly to the mounting holes of the coaxial connector. After the radial is fastened to the SO-239 with #4-40 hardware, a large soldering iron or propane torch is used to solder

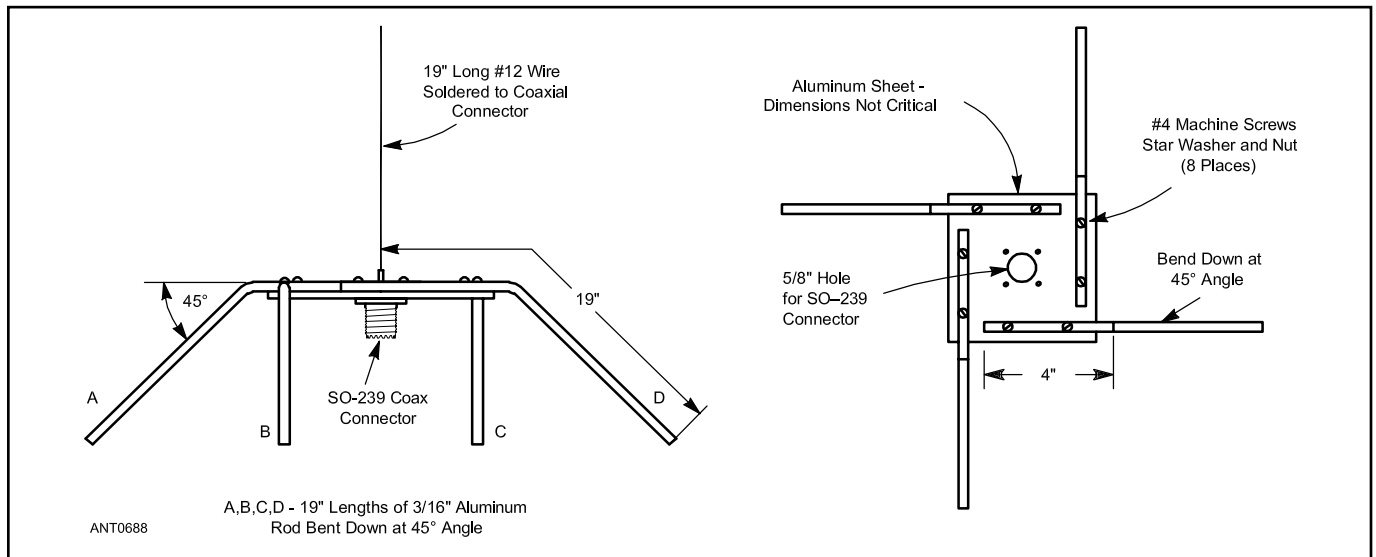


Figure 15.4 — These drawings illustrate the dimensions for the 144-MHz ground-plane antenna. The radials are bent down at a 45° angle.

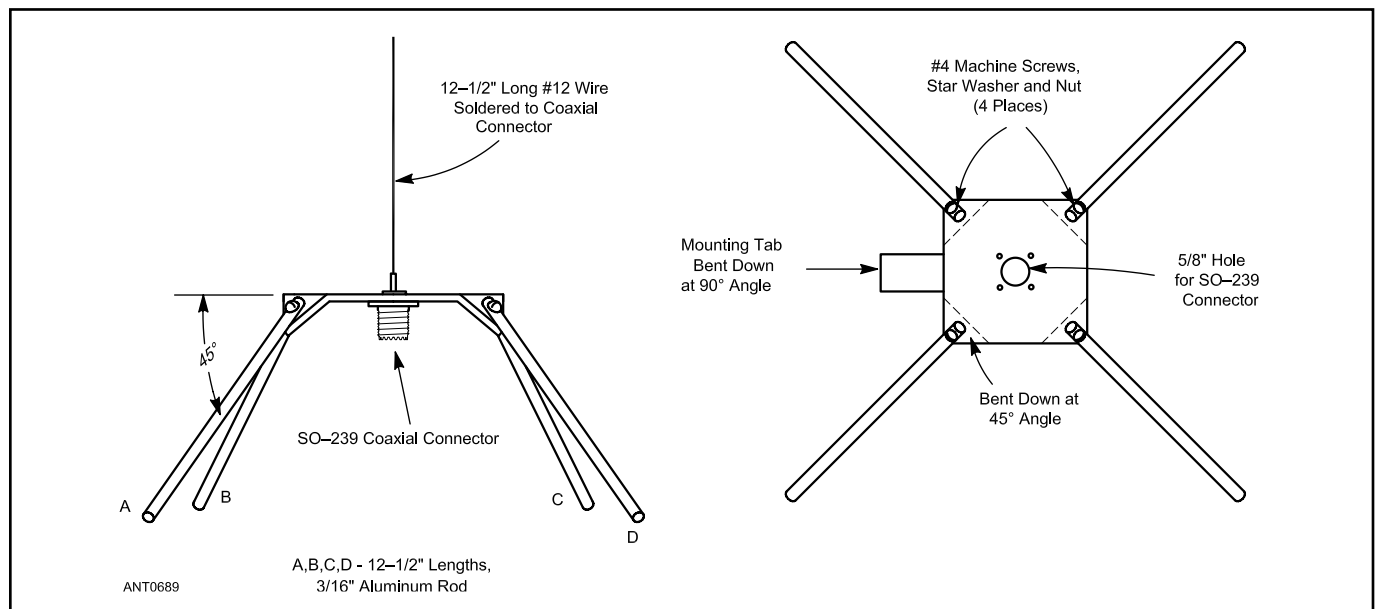


Figure 15.5 — Dimensional information for the 222-MHz ground-plane antenna. Lengths for A, B, C and D are the total distances measured from the center of the SO-239 connector. The corners of the aluminum plate are bent down at a 45° angle rather than bending the aluminum rod as in the 144-MHz model. Either method is suitable for these antennas.

the radial and the mounting hardware to the coaxial connector. The radials are bent to a 45° angle and the vertical portion is soldered to the center pin to complete the antenna. The antenna can be mounted by passing the feed line through a mast of 3/4-inch ID plastic or aluminum tubing. A compression hose clamp can be used to secure the PL-259 connector, attached to the feed line, in the end of the mast. Dimensions for the 144-, 222- and 440-MHz bands are given in Figure 15.6.

If these antennas are to be permanently mounted outside, waterproof the antenna by applying a small amount of sealant around the areas of the center pin of the connector to prevent

the entry of water into the connector and coax line. The coax connector should be waterproofed as well. Techniques and materials for waterproofing are described in the **Building Antenna Systems and Towers** chapter.

15.2.2 THE J-POLE ANTENNA

The J-Pole is a half-wave antenna that is end-fed at its bottom. Since the radiator is longer than that of a 1/4-wave ground-plane antenna, the vertical lobe is compressed down toward the horizon and it has about 1.5 dB of gain compared to the ground-plane configuration. The stub-matching section

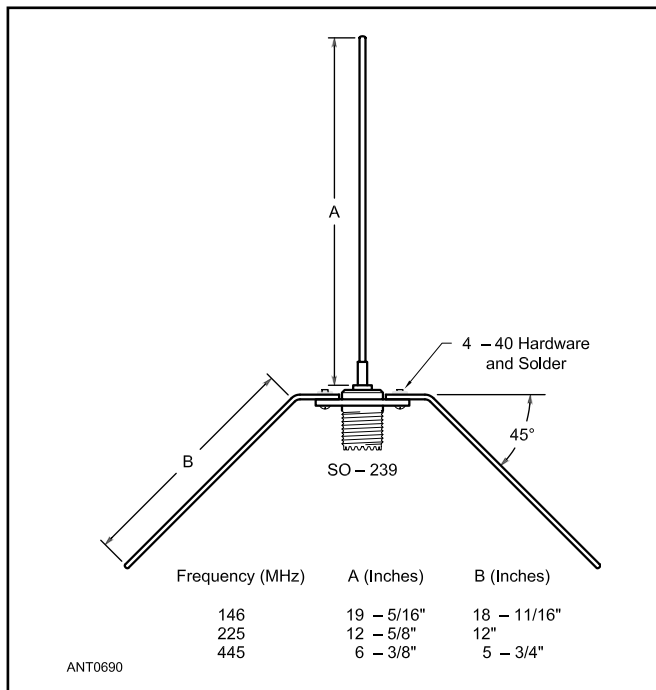


Figure 15.6 — Simple ground-plane antenna for the 144-, 222- and 440-MHz bands. The vertical element and radials are $\frac{3}{32}$ - or $\frac{1}{16}$ -inch brass welding rod. Although $\frac{3}{32}$ -inch rod is preferred for the 144-MHz antenna, #10 or #12 AWG copper wire can also be used.

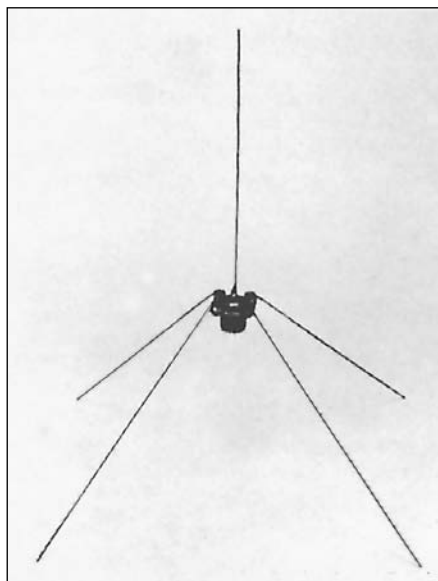


Figure 15.7 — A 440-MHz ground-plane constructed using only an SO-239 connector, no. 4-40 hardware and $\frac{1}{16}$ -inch brass welding rod.

used to transform the high impedance at the end of a half-wave antenna to 50 Ω is shorted at the bottom, making the antenna look like the letter “J,” and giving the antenna its name.

Rigid copper tubing, fittings and assorted hardware can be used to make a rugged J-pole antenna for the VHF bands through 440 MHz. When copper tubing is used, the entire assembly can be soldered together, ensuring electrical integrity, and making the whole antenna weatherproof. A

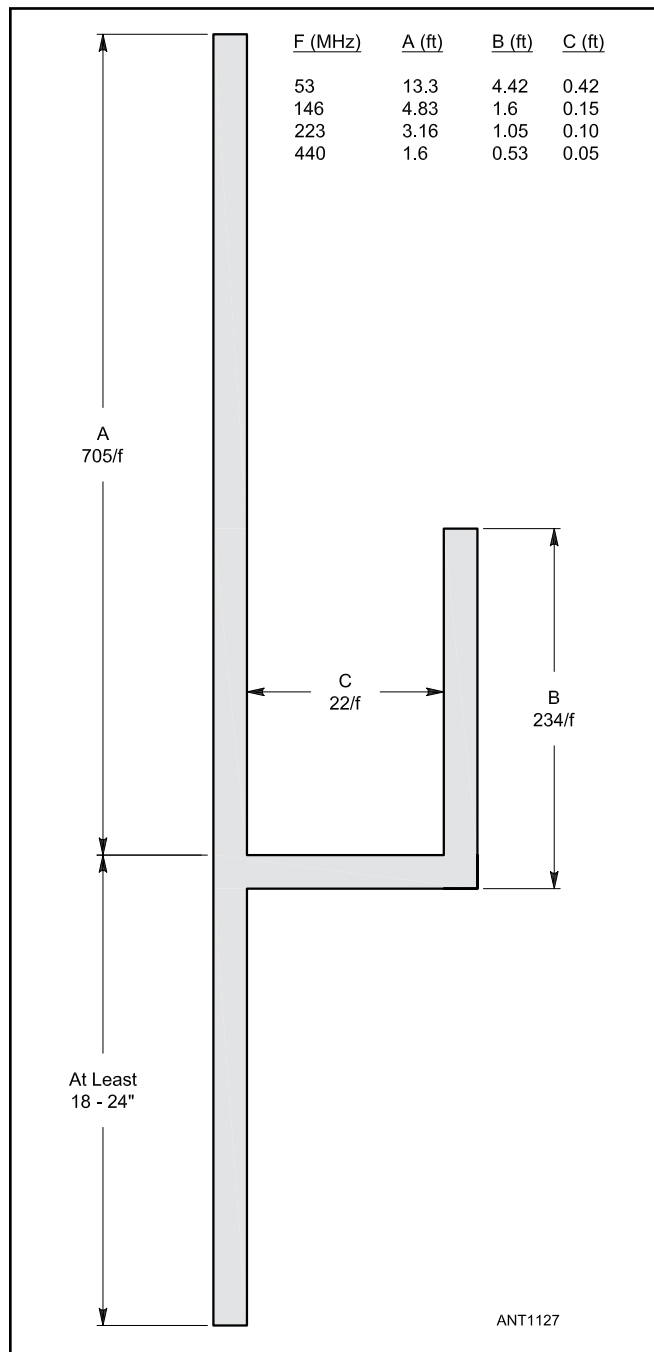


Figure 15.8 — Dimensions for the J-pole.

general-purpose set of dimensions for the J-pole is provided in **Figure 15.8** along with a table of dimensions for 53 MHz, 146 MHz, 223 MHz, and 440 MHz. The 53-MHz version is somewhat large for this construction method and the 440 MHz version a little small. Note that the inside dimensions of the matching section are between the outside surfaces of the tubing, not center-to-center. For placing the feed point, start with the feed point approximately as high above the bottom of the matching section as the tubing spacing.

The J-Pole can be fed directly from 50- Ω coax through a choke balun. The feed line can be made into a choke balun

by forming it into a 3-turn coil about 8 inches in diameter and held together with electrical tape. If the balun is not used, the outer surface of the coaxial cable will become part of the antenna, making tuning difficult and highly dependent on cable placement. In addition, radiation from the current flowing on the feed line can distort the pattern of the antenna, leading to poor performance by breaking up the low-elevation main lobe expected from this design.

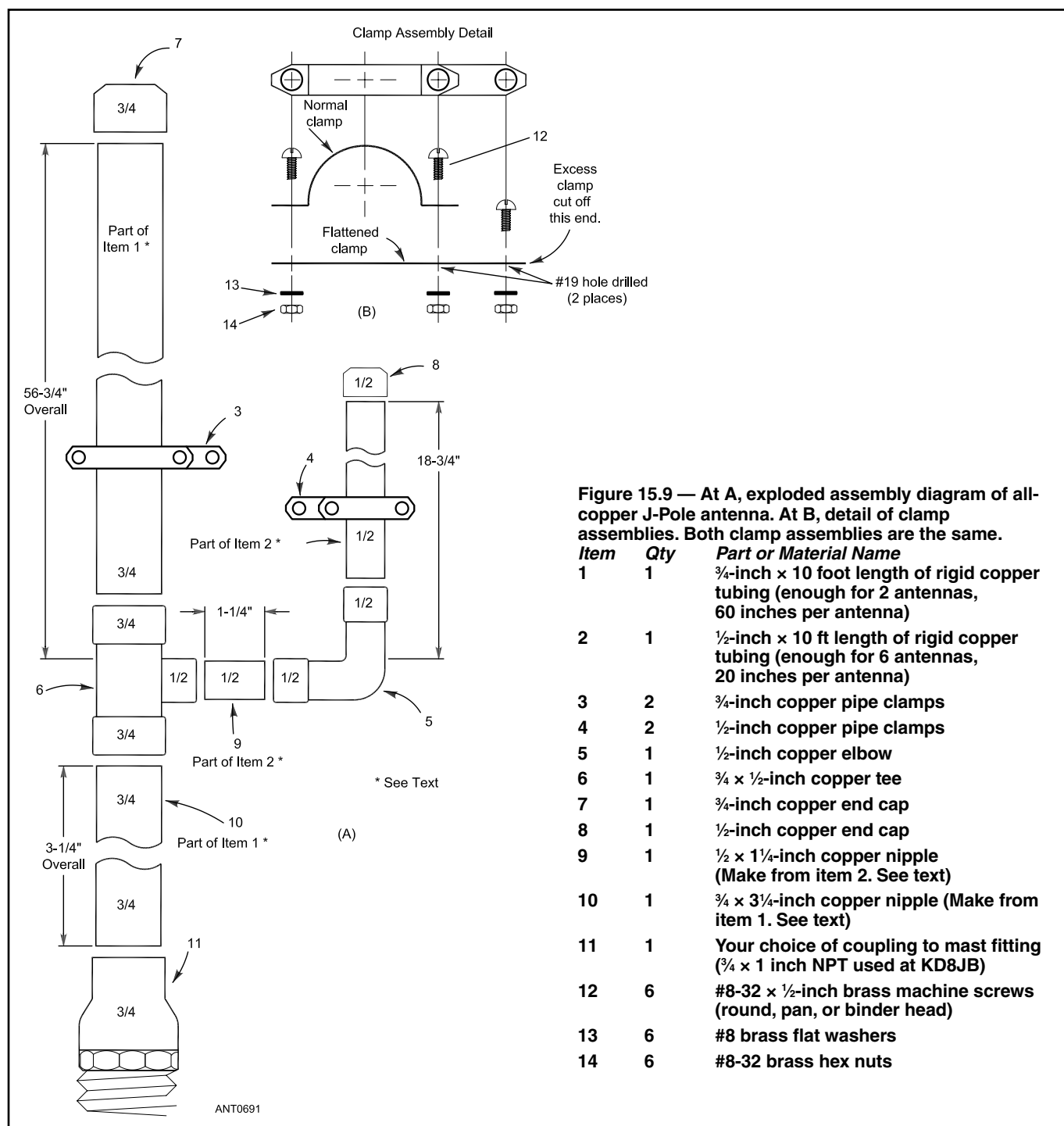
There are many J-pole designs available online and in the ARRL's online archive of *QST* articles at www.arrl.org. One of the more popular variants is known as the "Copper

Cactus" (see Bibliography) and has been adapted to dual- and tri-band designs.

Construction

No special hardware or machined parts are used in this antenna, nor are insulating materials needed, since the antenna is always at dc ground. The following design came from an article by Michael Hood, KD8JB, in *The ARRL Antenna Compendium*, Vol. 4.

Copper and brass is used exclusively in this antenna. These metals get along together, so dissimilar metal cor-



rosion is eliminated. Both metals solder well, too. See **Figure 15.9**. Cut the copper tubing to the lengths indicated. Item 9 is a 1¼-inch nipple cut from the 20-inch length of ½-inch tubing. This leaves 18¾ inches for the ¼-λ matching stub. Item 10 is a 3¼-inch long nipple cut from the 60-inch length of ¾-inch tubing. The ¾-wave element should measure 56¾ 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, end caps 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 ½-inch and ¾-inch pipe clamps. Drill a hole in the flattened clamp as shown in Figure 15.9A. 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 ½-inch clamp around the ¼-wave element and secure with two of the screws, washers, and nuts as shown in Figure 15.9B. Do the same with the ¾-inch clamp around the ¾-wave element. Initially set the clamps 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

Before tuning, mount the antenna vertically, about 5 to 10 feet 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 (¾-wave element or stub) you attach the coaxial center lead. KD8JB 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 a minimum at the desired frequency. The SWR will be close to 1:1. (Stand clear of the antenna when measuring the SWR and include the choke balun in the feed line when making measurements.)

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 noncorrosive 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. Weatherproof this joint as described in the **Building Antenna Systems and Towers** chapter.

15.2.3 COLLINEAR ARRAYS

The information given earlier in this chapter pertains mainly to parasitic arrays, but the collinear array is worthy of consideration in VHF/UHF operation. Two types of collinear arrays are commonly used by amateurs; the *transposed-coaxial array* and the *collinear dipole array*.

Collinear arrays tend to be tolerant of construction tolerances, making them easy to build and adjust for VHF and UHF applications. The use of many collinear driven elements was once popular in very large phased arrays, such as those required in moonbounce (EME) communications, but computer-optimized Yagi arrays have largely replaced them. A collinear array of four dipoles is a popular repeater antenna as described in the chapter **Repeater Antenna Systems**.

Collinear Transposed-Coax Arrays

The most popular collinear array is the omnidirectional array of half-wave dipoles constructed of transposed sections of coaxial cable as shown in **Figure 15.10**. The original array of this type is the Franklin array shown in Figure 15.10A. The phase-reversing stubs allow multiple half-wave sections to operate in phase, creating gain at right angles to the antenna. An example of this array is the popular Cushcraft Ringo Ranger series of omnidirectional VHF and UHF antennas.

While the phasing stubs make the Franklin array inconvenient for vertical stacking of more than two elements, a derivative of this array uses transposed sections of coaxial cable as in Figure 15.10B. The phasing stub is created by the inside of each coaxial section. The outer surface of the coaxial shield forms the radiating element. The resulting antenna can be enclosed in a PVC or fiberglass tube, such as the Comet GP-series of VHF/UHF omnidirectional antennas.

The practical limit for gain in this type of array is about 10 dBi. A choke balun or other method of decoupling such as a set of λ/4 radials is required at the feed point of the array to prevent current from being induced on the outer surface of the coaxial feed line.

Collinear Omnidirectional Array for 70 cm

Figure 15.11 shows the basic construction of a transposed-coax array for the 70 cm band with dimensions in millimeters for accuracy. The λ/4 whip at the end of the array is optional. The gain of this array is approximately 9 dBi (slightly less without the whip). The original design of this antenna is credited to the Radio Amateur Society of Norwich (www.rason.org). More information is available via the “Projects” page of the RASON website.

The physical length of each λ/2 section of coax must account for the velocity factor of the cable which should be measured accurately before cutting any cable. Once the

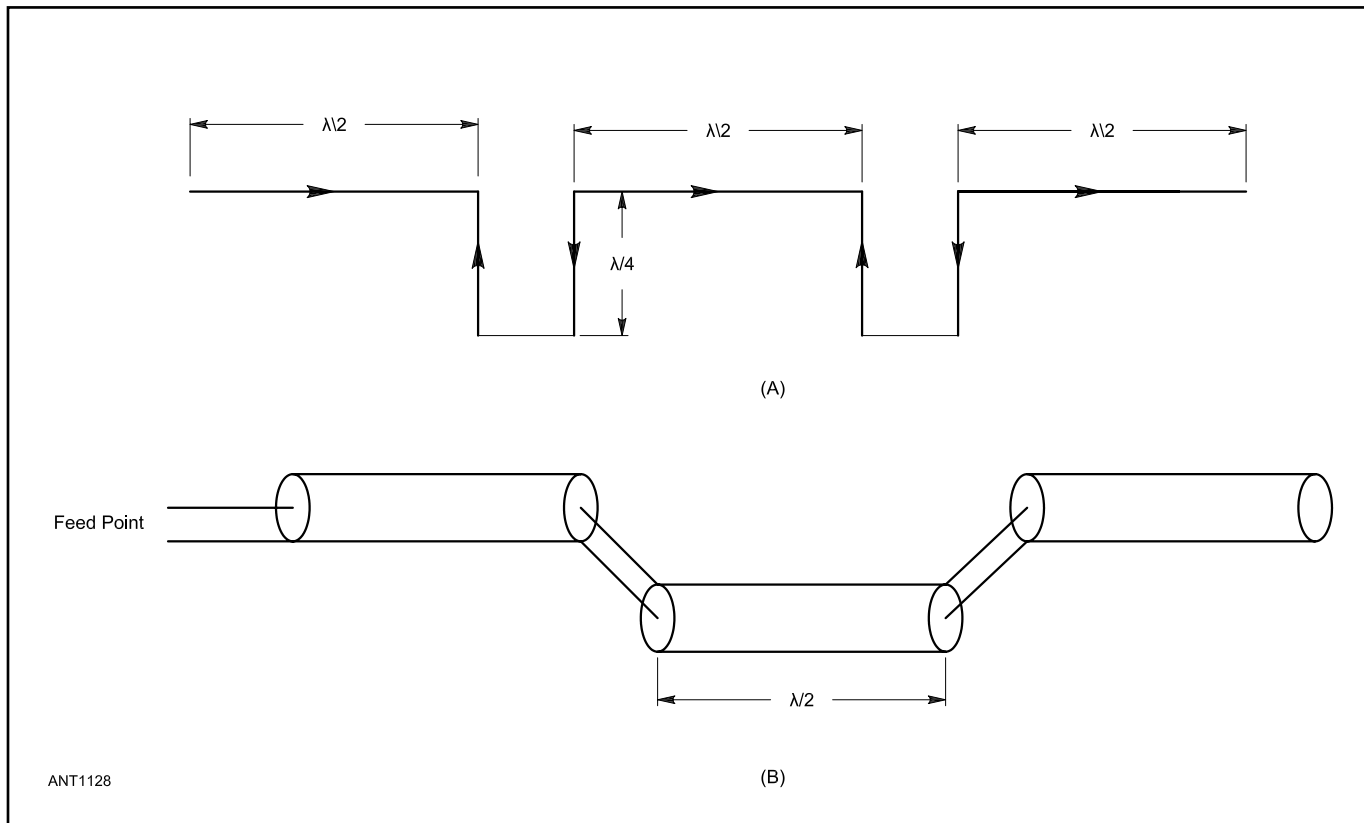


Figure 15.10 — The most popular collinear array is the omnidirectional array of half-wave dipoles constructed of transposed sections of coaxial cable.

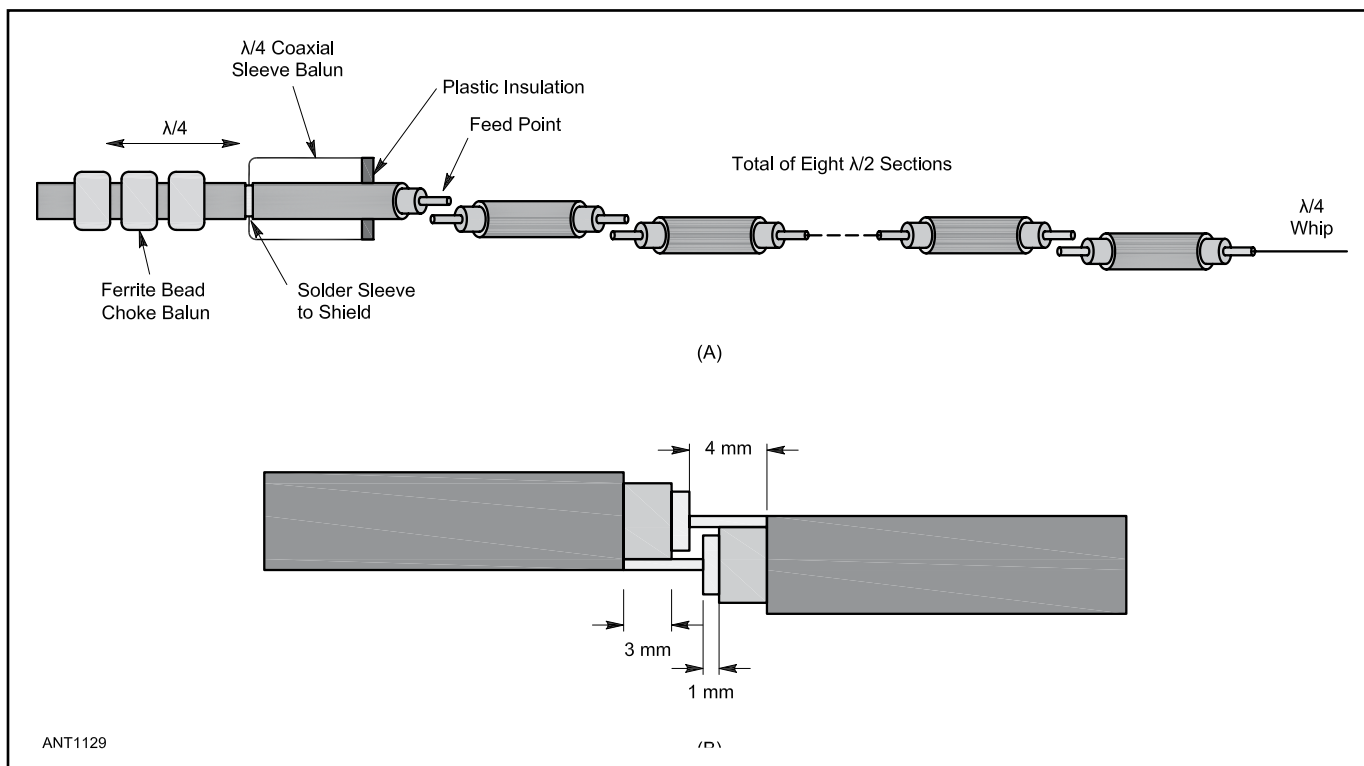


Figure 15.11 — Basic construction of a transposed-coax array for the 70 cm band. Dimensions are given in millimeters for accuracy.

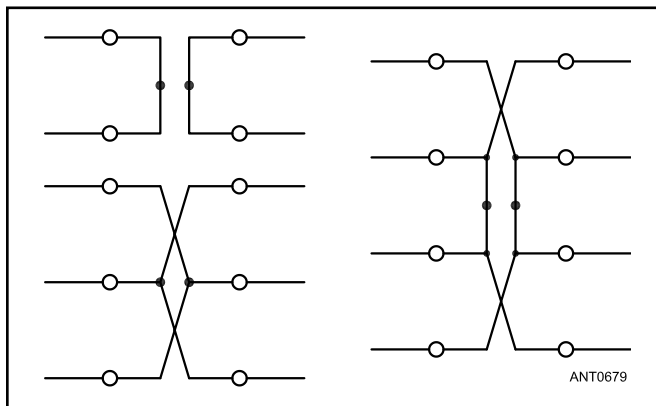


Figure 15.12 — Element arrangements for 8-, 12- and 16-element collinear arrays. Elements are $\frac{1}{2} \lambda$ long and spaced $\frac{1}{2} \lambda$. Parasitic reflectors, omitted here for clarity, are 5% longer and 0.2λ behind the driven elements. Feed points are indicated by black dots. Open circles show recommended support points. The elements can run through wood or metal booms, without insulation, if supported at their centers in this way. Insulators at the element ends (points of high RF voltage) detune and unbalance the system.

physical length of $\lambda/2$ has been determined, add 8 mm to allow for creating the 4 mm connecting surfaces on each end. For a VF = 0.66, the $\lambda/2$ sections should be 223 mm long plus 8 mm for a total of 231 mm. RG-58, RG-8, RG-8X or RG-213 can be used for this antenna. Do not remove the outer jacket from the cable other than at the connecting ends as this will allow the individual braid strands to loosen, reducing the shield's effectiveness as a continuous conductor.

Use a 169 mm segment of #16 AWG copper wire for

the top whip section. A $\lambda/4$ coaxial sleeve balun is attached at the feed point of the antenna. (See the **Transmission Line Coupling and Impedance Matching** chapter.) The balun is made from copper tubing that is soldered to the shield of the feed line using strips of brass or copper shim. If $\frac{5}{8}$ -inch tubing is used, the length should be 160 mm. The feed line should be centered in the balun tubing by using small pieces of plastic inserted between the coax jacket and the tubing's inner surface. Approximately $\lambda/4$ beyond the end of the balun's closed end add an additional choke balun of three type 43 ferrite beads (choose the ID to fit the feed line coax). The entire antenna should be enclosed in a length of PVC or fiberglass tubing to protect it from the weather. If necessary for mechanical stability, support the antenna sections with a length of wooden dowel or plastic rod, secured with electrical tape.

Large Collinear Dipole Arrays

Bidirectional curtain arrays of four, six and eight half waves in phase are shown in **Figure 15.12**. Usually reflector elements are added, normally at about 0.2λ behind each driven element, for more gain and a unidirectional pattern. Such parasitic elements are omitted from the sketch in the interest of clarity.

The feed point impedance of two half waves in phase is high, typically 1000 Ω or more. When they are combined in parallel and parasitic elements are added, the feed impedance is low enough for direct connection to open wire line or twin-lead, connected at the points indicated by black dots. With coaxial line and a balun, it is suggested that the universal stub match, Figure 15.1A, be used at the feed point. All elements should be mounted at their electrical centers, as indicated by

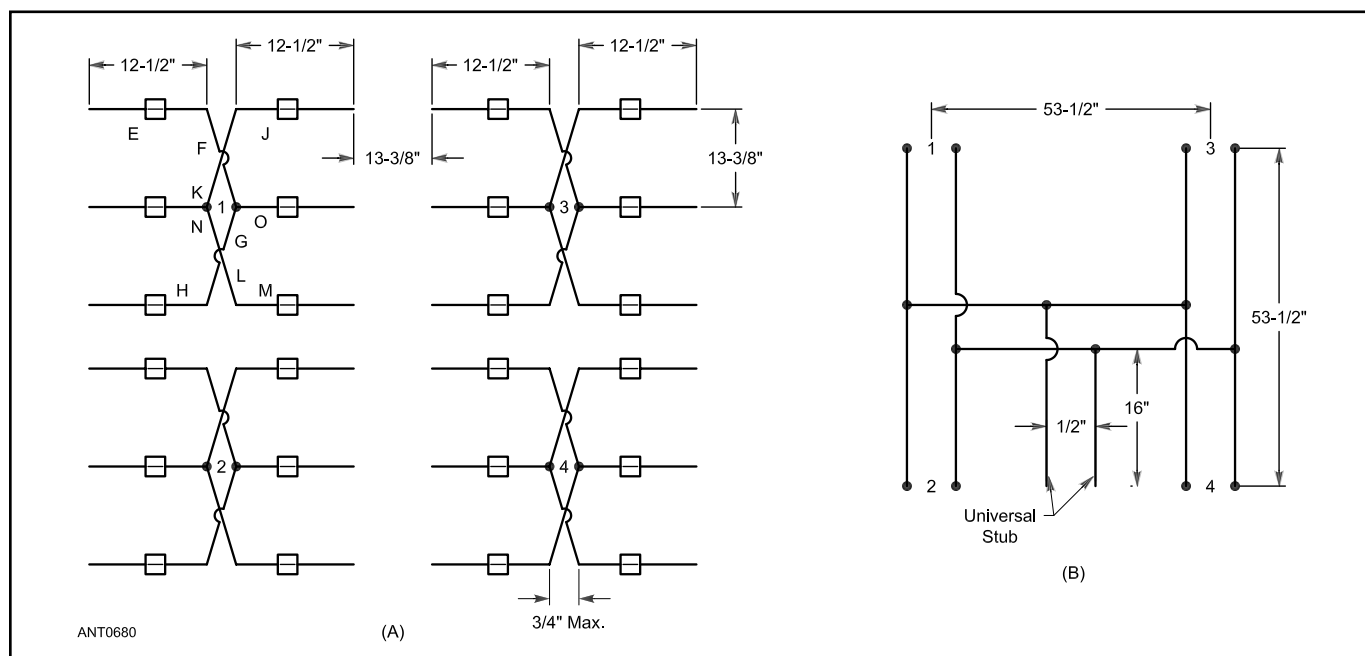


Figure 15.13 — Large collinear arrays should be fed as sets of no more than eight driven elements each, interconnected by phasing lines. This 48-element array for 432 MHz (A) is treated as if it were four 12-element collinear antennas. Reflector elements are omitted for clarity. The phasing harness is shown at B. Squares represent supporting insulators.

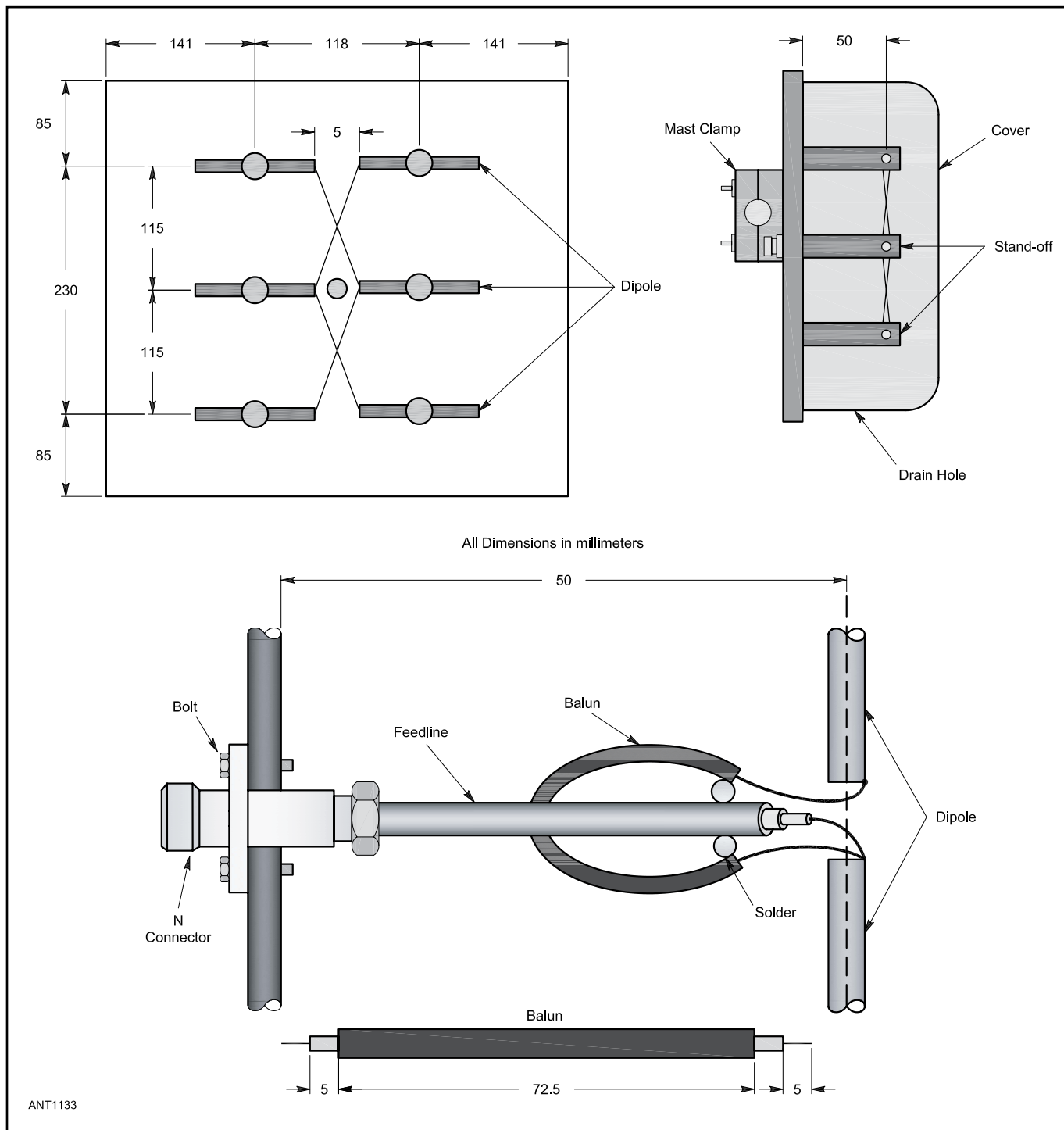


Figure 15.14 — Details of the F5JIO 23 cm collinear array.

Parts list

Reflector — 400 mm × 400 mm (340 mm min), 2.5 mm thick aluminum sheet
 Standoffs — Teflon or PVC, 60 mm L × 20 mm D (qty 6)
 Dipoles — brass, silver plated (opt), 108 mm L × 6 mm D (qty 6)
 Phasing rods — Wire, silver plated (opt), 2 mm D (qty 4)

Connector — N-type receptacle

Feed line — semi-rigid coax 50-Ω approx 4 mm D

Balun — same type as feed line, 92.5 mm L

Bolt — M3 × 8 mm, stainless steel (qty 4)

Cover — plastic food container

Mast clamp from TV antenna

open circles in Figure 15.12. The framework can be metal or insulating material. The metal supporting structure is entirely behind the plane of the reflector elements. Sheet-metal clamps can be cut from scraps of aluminum for this kind of assembly. Collinear elements of this type should be mounted at their centers (where the RF voltage is zero), rather than at their ends, where the voltage is high and insulation losses and detuning can be harmful.

Collinear arrays of 32, 48, 64 and even 128 elements can give outstanding performance. Any collinear array should be fed at the center of the system, to ensure balanced current distribution. This is very important in large arrays, where sets of six or eight driven elements are treated as “sub arrays,” and are fed through a balanced harness. The sections of the harness are resonant lengths, usually of open wire line. The 48-element collinear array for 432 MHz in **Figure 15.13** illustrates this principle.

A reflecting plane, which may be sheet metal, wire mesh, or even closely spaced elements of tubing or wire, can be used in place of parasitic reflectors. To be effective, the plane reflector must extend on all sides to at least $\frac{1}{4} \lambda$ beyond the area occupied by the driven elements. The plane reflector provides high F/B ratio, a clean pattern, and somewhat more gain than parasitic elements, but large physical size limits it to use above 420 MHz. An interesting space-saving possibility lies in using a single plane reflector with elements for two different bands mounted on opposite sides. Reflector spacing from the driven element is not critical. About 0.2λ is common.

Wideband 23 cm Collinear Array

This design for a wideband beam by F5JIO is taken from the RSGB publication *Antennas for VHF and Above*. In the

development of the antenna F5JIO consulted *Rothammel*, the German antenna reference text which gives the following guidelines for the reflector plane:

- For the best F/B ratio, the reflector should extend at least half a wavelength beyond the perimeter of the curtain on all sides.

- If made of wire or mesh instead of solid sheet metal to reduce wind loading surface area, the wire pitch should be 1λ or less.

- A reflector plane spaced $\frac{1}{8} \lambda$ behind the radiator adds a maximum gain of up to 7 dB, but a spacing of 0.1 to 0.3λ provides a better F/B ratio.

- If spaced at least 0.3λ behind the curtain, the reflector plane does not affect the feed point impedance of the array.

Details for the matching of the antenna can be seen in the **Figure 15.14**. With the antenna dimensions given, the feed point impedance of each dipole pair is approximately 600Ω balanced. There are three pairs in parallel which divides this impedance by three to give 200Ω , and a 4:1 coaxial balun transforms this to provide an excellent match to $50\text{-}\Omega$ coax which is unbalanced. Note that as each dipole is supported at its voltage node, the insulators need to be of good quality.

The construction of the antenna is fairly straightforward, although reasonable care and precision are required. Being a 23 cm band antenna, it is quite small and therefore wind loading is not normally a problem and this makes a solid reflector feasible. This then means that the plate used as the reflector can be used as the support for the other components. During construction it is necessary to bend the phasing rods slightly so that they do not touch at the cross-over points. Then, for weather protection, a plastic food container can be used as a radome. This can be used as the RF absorption appears to be negligible and it is much cheaper than a Teflon equivalent.

15.3 YAGIS AND QUADS AT VHF AND UHF

Without doubt, the Yagi is king of home-station VHF and UHF antennas for weak-signal operating and for long-distance repeater and simplex operation. Today's best designs are computer optimized. The **HF Yagi and Quad Antennas** chapter describes the parameters associated with Yagi antennas. Except for somewhat tighter dimensional tolerances needed at VHF and UHF, the properties that make a good Yagi at HF also are needed on the higher frequencies. Conversely, due to the shorter wavelengths above 50 MHz, high-performance designs that would be impractical at HF are easily achievable at VHF and UHF. A variety of designs are presented following the discussion of stacking Yagis.

15.3.1 STACKING YAGIS

Where suitable provision can be made for supporting them, two Yagis mounted one above the other and fed in phase can provide better performance than one long Yagi with

the same theoretical or measured gain. The pair occupies a much smaller turning space for the same gain, and their wider elevation coverage can provide excellent results. The wide azimuthal coverage for a vertical stack often results in QSOs that might be missed with a single narrow-beam long-boom Yagi pointed in a different direction. On long ionospheric paths, a stacked pair occasionally may show an *apparent* gain much greater than the measured 2 to 3 dB of stacking gain. (See also the extensive section on stacking Yagis in the **HF Antenna System Design** chapter.)

Optimum vertical spacing for Yagis with booms longer than 1λ or more is about 1λ ($984/50.1 = 19.64$ feet), but this may be too much for many builders of 50-MHz antennas to handle. Worthwhile results can be obtained with as little as $\frac{1}{2} \lambda$ (10 feet), but $\frac{3}{8} \lambda$ (12 feet) is markedly better. The difference between 12 and 20 feet, however, may not be worth the added structural problems involved in the wider spacing,

at least at 50 MHz. The closer spacings give lower measured gain, but the antenna patterns are cleaner in both azimuth and elevation than with 1λ spacing. Extra gain with wider spacings is usually the objective on 144 MHz and higher-frequency bands, where the structural problems are not as severe.

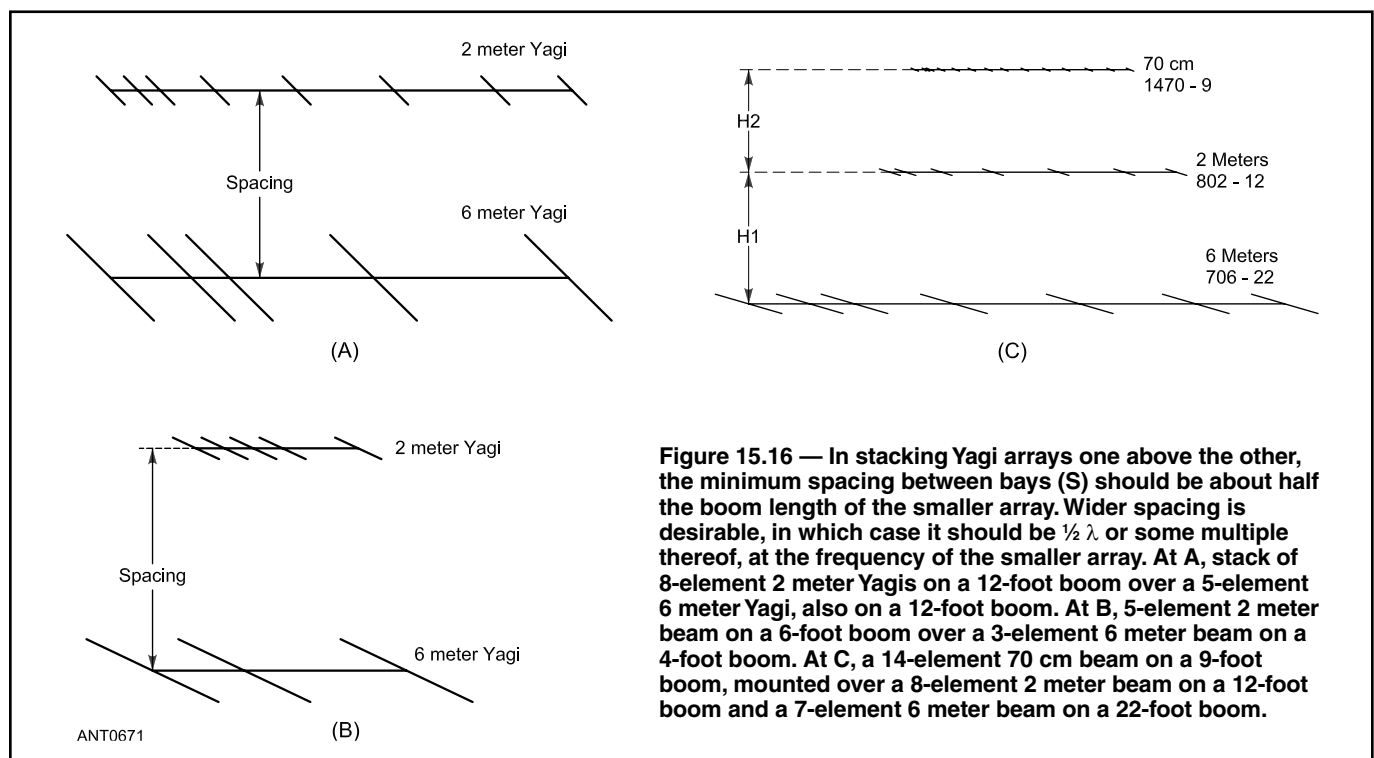
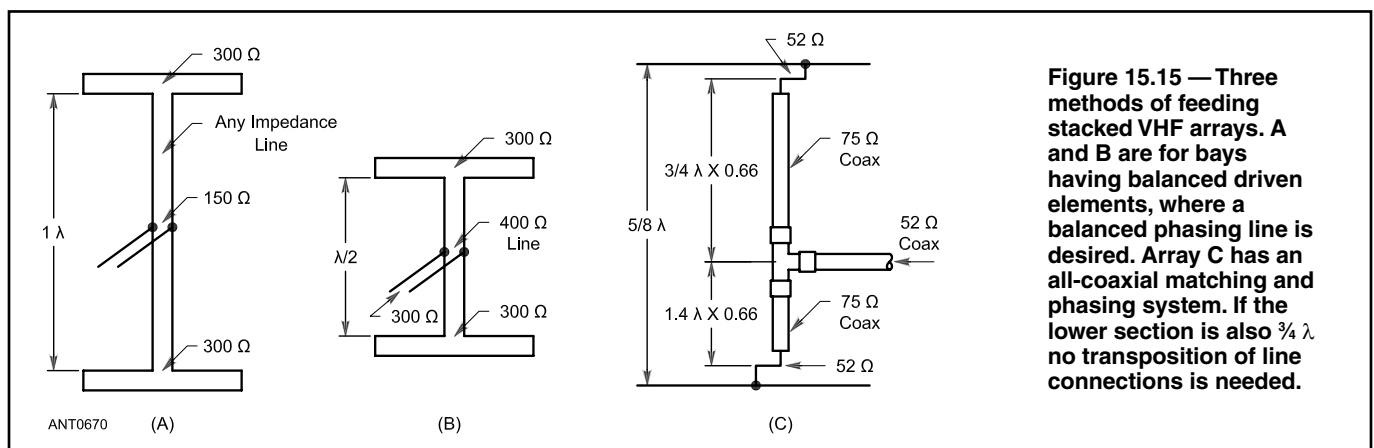
Yagis can also be stacked in the same plane (collinear elements) for sharper azimuthal directivity. A spacing of $\frac{1}{2}\lambda$ between the ends of the inner elements yields the maximum gain within the main lobe of the array.

If individual antennas of a stacked array are properly designed, they look like noninductive resistors to the phasing system that connects them. The impedances involved can thus be treated the same as resistances in parallel.

Three sets of stacked dipoles are shown in **Figure 15.15**.

Whether these are merely dipoles or the driven elements of Yagi arrays makes no difference for the purpose of these examples. Two $300\ \Omega$ antennas at A are 1λ apart, resulting in a paralleled feed point impedance of $150\ \Omega$ at the center. (Actually it is slightly less than $150\ \Omega$ because of coupling between bays, but this can be neglected for illustrative purposes.) This value remains the same regardless of the impedance of the phasing line. Thus, any convenient line can be used for phasing, as long as the *electrical* length of each line is the same.

The velocity factor of the line must be taken into account as well. As with coax, this is subject to so much variation that it is important to make a resonance check on the actual line used. The method for doing this is shown in Figure 15.2B. A $\frac{1}{2}\lambda$ line is resonant both open and shorted, but the shorted



condition (both ends) is usually the more convenient test condition.

The impedance transforming property of a $\frac{1}{4}\lambda$ line section can be used in combination matching and phasing lines, as shown in Figure 15.15B and C. At B, two bays spaced $\frac{1}{2}\lambda$ apart are phased and matched by a 400- Ω line, acting as a double-Q section, so that a 300- Ω main transmission line is matched to two 300- Ω bays. The two halves of this phasing line could also be $\frac{3}{4}\lambda$ or $\frac{5}{4}\lambda$ long, if such lengths serve a useful mechanical purpose. (An example is the stacking of two Yagis where the desirable spacing is more than $\frac{1}{2}\lambda$.)

A double-Q section of coaxial line is illustrated in Figure 15.15C. This is useful for feeding stacked bays that were designed for 50- Ω feed. A spacing of $\frac{5}{8}\lambda$ is useful for small Yagis, and this is the equivalent of a full electrical wavelength of solid-dielectric coax such as RG-11.

If one phasing line is electrically $\frac{1}{4}\lambda$ and $\frac{3}{4}\lambda$ on the other, the connection to one driven element should be reversed with respect to the other to keep the RF currents in the elements in phase — the gamma match is located on opposite sides of the driven elements in Figure 15.15C. If the number of $\frac{1}{4}\lambda$ lengths is the same on either side of the feed point, the two connections should be in the same position, and not reversed. Practically speaking however, you can ensure proper phasing by using exactly equal lengths of line from the same roll of coax. This ensures that the velocity factor for each line is identical.

One marked advantage of coaxial phasing lines is that they can be wrapped around the vertical support, taped or grounded to it, or arranged in any way that is mechanically convenient. The spacing between bays can be set at the most desirable value, and the phasing lines placed anywhere necessary.

Stacking Yagis for Different Frequencies

In stacking horizontal Yagis one above the other on a single rotating support, certain considerations apply when the bays are for different bands. As a very general rule of thumb, the minimum desirable spacing is half the boom length of the higher frequency Yagi.

For example, assume the stacked two-band array of **Figure 15.16A** is for 50 and 144 MHz. This vertical arrangement is commonly referred to as a *Christmas tree*, because it resembles one. The 50 MHz Yagi has 5 elements on a 12-foot boom. It tends to look like “ground” to the 8-element 144 MHz Yagi on a 12-foot boom directly above it. [The exact Yagi designs for the examples used in this section are located on the CD-ROM accompanying this book. They may be evaluated as monoband Yagis using the YW (Yagi for Windows) program also supplied on the CD-ROM. In each case the bottom Yagi in the stack (at the top of the tower) is assumed to be 20 feet high.]

SWR Change in a Multi-Frequency Stack

Earlier editions of *The ARRL Antenna Book* stated that the feed point impedance of the higher-frequency antenna

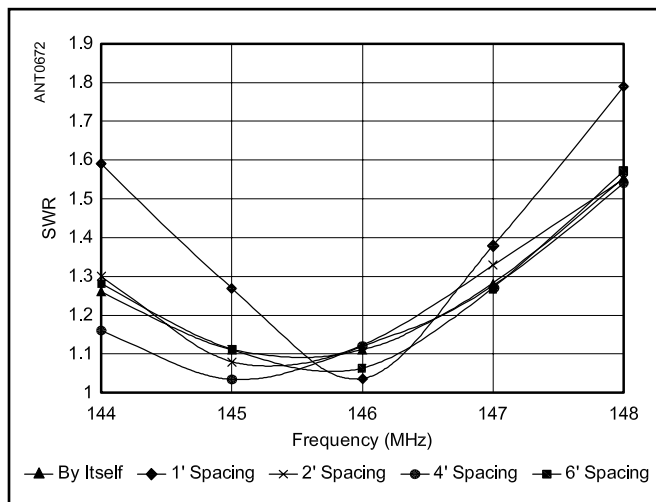


Figure 15.17 — SWR curves for different boom spacing between 8-element 2 meter Yagi on 12-foot boom, over a 5-element 6 meter Yagi on a 12-foot boom. For spacings greater than 1 foot between the booms, differences between the SWR curves are difficult to discern.

would likely be affected the most by the proximity of the lower-frequency Yagi. Modern computer modeling programs reveal that while the feed point SWR can indeed be affected, by far the greatest degradation is in the forward gain and rearward pattern of the higher-frequency Yagi when the booms are closely spaced. In fact, the SWR curve is usually not affected enough to make it a good diagnostic indicator of interaction between the two Yagis.

Figure 15.17 shows an overlay of the SWR curves across the 2 meter band for four configurations: an 8-element 2 meter Yagi by itself, and then over a 5-element 6 meter Yagi with spacings between the booms of 1, 2, 4 and 6 feet. The SWR curves are similar — it would be difficult to see any difference between these configurations using typical amateur SWR indicators for anything but the very closest (1-foot) spacing. For example, the SWR curve for the 2-foot spacing case is virtually indistinguishable from that of the Yagi by itself, while the forward gain has dropped more than 0.6 dB because of interactions with the 6 meter Yagi below it.

Gain and Pattern Degradation Due to Stacking

Figure 15.18 shows four overlaid rectangular plots of the azimuth response from 0° to 180° for the 8-element 2 meter Yagi described above, spaced 1, 2, 4 and 6 feet over a 5-element 6 meter beam. The rectangular presentation gives more detail than a polar plot. The most closely spaced configuration (with 1-foot spacing between the booms) shows the largest degradation in the forward gain, a drop of 1.7 dB. The worst-case front-to-rear ratio for the 6-foot spacing is 29.0 dB, while it is 36.4 dB for the 1-foot spacing — actually better than the F/R for the 8-element 2 meter Yagi by itself. Performance change due to the nearby presence of other Yagis can be enormously complicated (and sometimes is not intuitive as well).

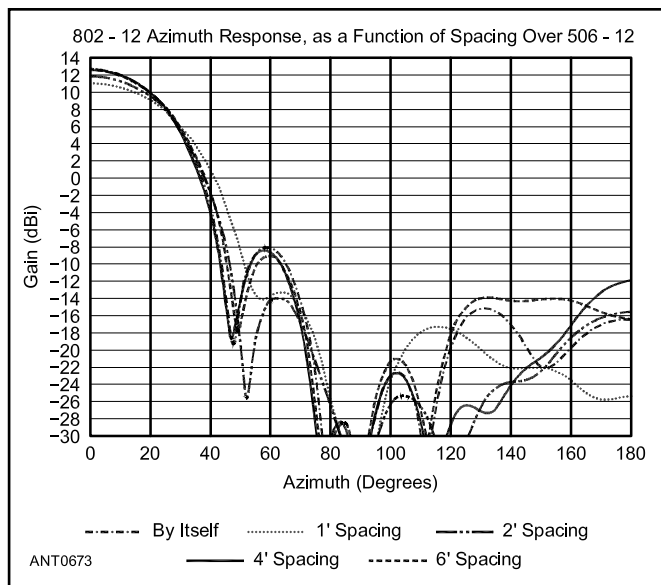


Figure 15.18 — Plots of the 8-element 2 meter Yagi's azimuth response from 0° to 180° for spacing distances from 1 to 6 feet. The sidelobe at about 60° varies about 6 dB over the range of boom spacings, while the shape of worst-case F/R curve varies considerably due to interactions with the lower 6 meter beam. The gain for the 1-foot spacing is degraded by more than 3 dB compared to the 2 meter antenna by itself.

What happens when a different kind of 6 meter Yagi is mounted below the 8-element 2 meter Yagi? **Figure 15.19** compares the change in forward gain and the worst-case F/R performance as a function of spacing between the booms for two varieties of 6 meter Yagis: the 5-element design on a 12-foot boom and a 7-element Yagi on a 22-foot boom. The spacing of "0 feet" represents the 8-element 2 meter Yagi when it is used alone, with no other antenna nearby. This sets the reference expectations for gain and F/R.

The most severe degradation occurs for the 1-foot spacing, as you might imagine, for both the 12 and 22-foot boom lengths. Over the 5-element 6 meter Yagi, the 2 meter gain doesn't recover to the reference level of the 8-element 2 meter beam by itself until the spacing is greater than 9 feet. However, the gain is within 0.25 dB of the reference level for spacings of 3 feet or more. Interestingly, the F/R is higher than that of the 2 meter antenna by itself for the 1, 2 and 5-foot spacings and for spacings greater than 11 feet. The 2 meter F/R in the presence of the 12-foot 5-element 6 meter Yagi remains above 20 dB for spacings beyond 1 foot.

Overall, the 2 meter beam performs reasonably well for spacings of 3 feet or more over the 5-element 6 meter Yagi. Put another way, the 2 meter beam's performance is degraded only slightly for boom spacings greater than 3 feet. A spacing of 3 feet is less than the old rule of thumb that the minimum spacing between booms be greater than one-half the boom length of the higher-frequency Yagi, which in this case is 6 feet long.

For the 7-element 6 meter Yagi, the 2 meter gain recovers

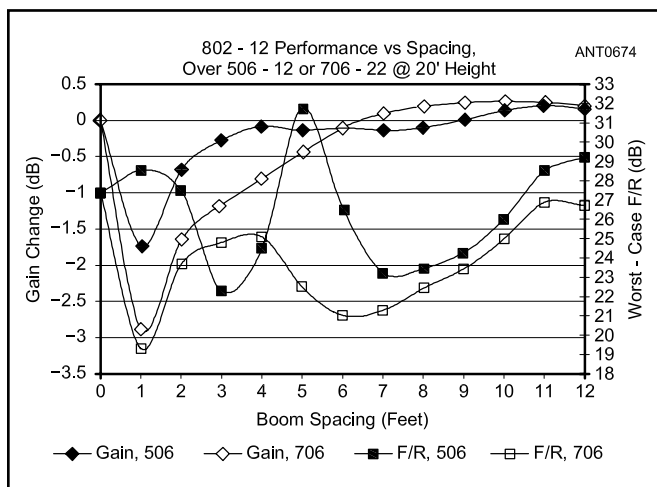


Figure 15.19 — Plot of 8-element 2 meter Yagi's gain and worst-case F/R as a function of distance over two types of 6 meter beams, one on a 12-foot boom and the other on a 22-foot boom. Beyond a spacing of about 5 feet the performance is degraded a minimal amount.

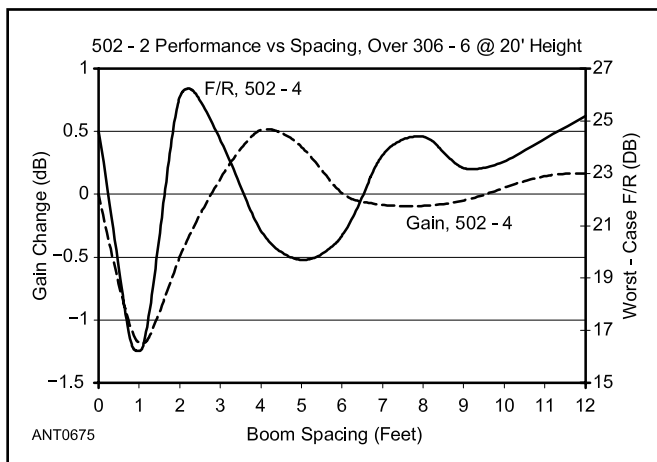


Figure 15.20 — Plot of gain and worst-case F/R of a 5-element 2 meter Yagi on a 4-foot boom as a function of distance over a 3-element 6 meter beam on a 6-foot boom. Beyond a spacing of about 3 feet the performance is degraded a minimal amount.

to the reference level for spacings beyond 7 feet, but the F/R is degraded below the reference level for all spacings shown in Figure 15.19. If we use a gain reduction criterion of less than 0.25 dB and a 20-dB F/R level as the minimum acceptable level, then the spacing must be 5 feet or more over the larger 6 meter Yagi. Again, this is less than the rule of thumb that the minimum spacing between booms be greater than one-half the boom length of the higher-frequency Yagi.

Now, let's try a smaller setup of 2 and 6 meter Yagis stacked vertically in a Christmas-tree configuration to see if the rule of thumb for spacing the booms still holds. **Figure 15.20** shows the performance curves versus boom spacing for a 5-element 2 meter Yagi on a 4-foot boom stacked

over a 3-element 6 meter Yagi on a 6-foot boom. Again, the 1-foot spacing produces a substantial gain reduction of about 1.3 dB compared to the reference gain when the 2 meter Yagi is used by itself. Beyond a boom spacing of 3 feet the 2 meter gain drops less than 0.25 dB from the reference level of the 2 meter Yagi by itself and the F/R remains above about 20 dB. In this example, the simple rule of thumb that the minimum spacing between booms be greater than half the boom length (half of 4 feet) of the higher-frequency Yagi does not hold up. However, the same minimum spacing of 3 feet we found for the larger 2 meter Yagi remains true. Three feet spacing is almost 0.5λ between the booms at the higher frequency.

Adding a 70 cm Yagi to the Christmas Tree

Let's get more ambitious and set up a larger VHF/UHF Christmas tree, with a 14-element 70 cm Yagi on a 9-foot boom at the top, mounted 5 feet over an 8-element 2 meter Yagi on a 12-foot boom. At the bottom of the stack (at the top of the tower) is either the 5-element 6 meter beam on a 12-foot boom, or a 7-element 6 meter beam on a 22-foot boom. See Figure 15.16C. As before, we will vary the spacing between the 70 cm Yagi and the 2 meter Yagi below it to assess the interactions that degrade the 70 cm performance.

Figure 15.21 compares the change in gain and F/R curves as a function of boom spacings between the 70 cm and 2 meter Yagis for the two different 6 meter Yagis (with a fixed distance of 5 feet between the 2 meter and 6 meter Yagis). In this example, the 70 cm Yagi was designed to be an intrinsic 50- Ω feed, where the F/R has been compromised

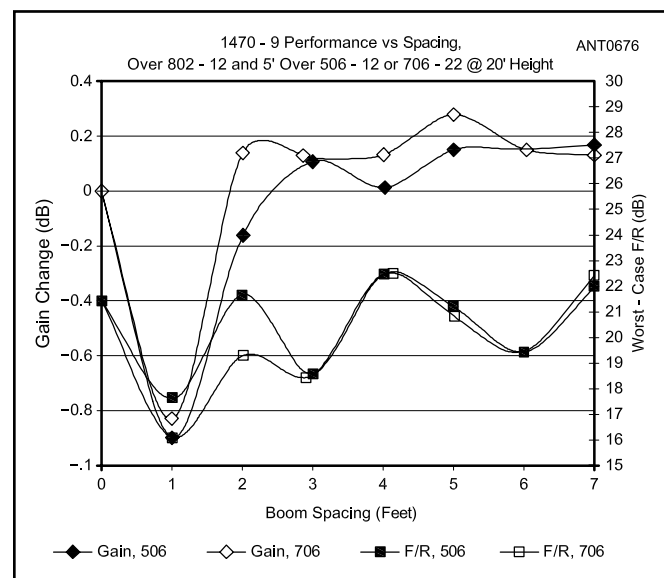


Figure 15.21 — Performance of a 14-element 70 cm Yagi on a 9-foot boom, mounted a variable distance over an 8-element 2 meter Yagi on a 12-foot boom, which is mounted 5 feet above either a 5-element 6 meter Yagi on a 12-foot boom or a 7-element 6 meter Yagi on a 22-foot boom. Beyond a spacing of about 4 feet, the performance of the 70 cm beam is degraded a minimal amount.

to some extent. Still, the F/R is greater than 20 dB when the 70 cm Yagi is used by itself.

For spacings greater than 4 feet between the 70 cm and 2 meter booms, the 70 cm gain is equal to or even slightly greater than that of the 70 cm antenna by itself. The increase of gain indicates that the elevation pattern of the 70 cm antenna is slightly compressed by the presence of the other Yagis below it. The F/R stays above at 19.5 dB for spacings greater than or equal to 4 feet. This falls just below our desired lower limit of 20 dB, but it is highly doubtful that anyone would notice this 0.5-dB drop in actual operation. A spacing of 4 feet between booms falls under the rule of thumb that the minimum spacing be at least half the boom length of the higher-frequency Yagi, which in this case is 9 feet.

What should be obvious in this discussion is that you should model the exact configuration you plan to build to avoid unnecessary performance degradation.

Stacking Same-Frequency Yagis

This subject has been examined in some detail in the **HF Antenna System Design** chapter. The same basic principles hold at VHF and UHF as they do on HF. That is, the gain increases gradually with increasing spacing between the booms, and then falls off gradually past a certain spacing distance.

At HF, you should avoid nulls in the antenna's elevation response — so that you can cover all the angles needed for geographic areas of interest. At VHF/UHF, propagation is usually at low elevation angles for most propagation modes, and signals are often extremely weak. Thus, achieving maximum gain is the most common design objective for a VHF/UHF stack. Of secondary importance is the cleanliness of the beam pattern, to discriminate against interference and noise sources.

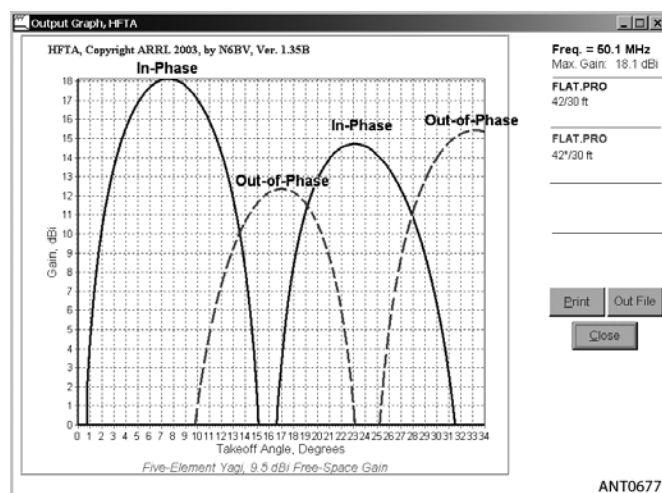


Figure 15.22 — HFTA comparison plots of the elevation responses for two 5-element 6 meter Yagis mounted at 42 and 30 feet above flat ground, when they are fed in-phase and out-of-phase. By switching the phasing (adding a half-wavelength of coax to one of the antennas), the elevation angle can be controlled to enhance performance when a sporadic-E cloud is nearly overhead.

Six meter sporadic-E can sometimes occur at high elevation angles, especially if the E_s cloud is overhead, or nearly overhead. Since sporadic-E is exactly that, *sporadic*, it's not a good design practice to try to cover a wide range of elevation angles, as you must often do at HF to cover large geographic areas. On 6 meters, you can change to high-angle coverage when necessary. For example, you might switch to a separate Yagi mounted at a low height, or you might provide means to feed stacked antennas out-of-phase. **Figure 15.22** shows an *HFTA* (HF Terrain Assessment) plot of two 5-element 6 meter Yagis, fed either in-phase or out-of-phase to cover a much wider range of elevation angles than the in-phase stack alone.

Figure 15.23A shows the change in gain for four 2 meter stacked designs, as a function of the spacing in wavelengths between the booms. The 3-element Yagi is mounted on a 2-foot boom (occupying 0.28λ of that boom). The 5-element Yagi is on a 4-foot boom (0.51λ of the boom), while the 8-element Yagi is on a 12-foot boom (1.72λ of boom). The biggest antenna in the group has 16 elements, on a 27-foot boom (4.0λ of boom). This range of boom lengths pretty much covers the practical range of antennas used by hams.

The stack of two 3-element Yagis peaks at 3.2 dB of additional gain over a single Yagi for 0.75λ spacing between the booms. Further increases in spacing see the gain change gradually drop off. Figure 15.23B shows the worst-case F/R of the four stacks, again as a function of boom length. The F/R of a single 3-element Yagi is just over 24 dB, but in the presence of the second 3-element Yagi in the stack, the F/R of the pair oscillates between 15 to 26 dB, finally remaining consistently over the desired 20-dB level for spacings greater than about 1.7λ , where the gain has fallen about 0.6 dB from the peak possible gain. A boom spacing of 1.7λ at 146 MHz is 11.5 feet. Thus you must compromise in choosing the boom spacing between achieving maximum gain and the best pattern.

The increase in gain of the stack of two 5-element Yagis peaks at a spacing of about 1λ (6.7 feet), where the F/R is an excellent 25 dB. Having more elements on a particular length

of boom aids in holding a more consistent F/R in the presence of the second antenna.

The gain increase for the bigger stack of 8-element Yagis peaks at a spacing of about 1.5λ (10.1 feet), where the F/R is more than 27 dB. The 16-element Yagi's gain increase is 2.6 dB for a spacing of about 2.25λ (15.2 feet), where the F/R remains close to 25 dB. The stacking distance of 15.2 feet for an antenna with a 27-foot long boom may be a real challenge physically, requiring a very sturdy rotating mast to withstand wind pressures without bending.

These examples show that the exact spacing between booms is not overly critical, since the gain varies relatively slowly around the peak. Figure 15.23A shows that the boom spacing needed to achieve peak gain from a stack increases when higher-gain (longer-boom) individual antennas are used in that stack. It also shows that the increase in maximum gain from stacking decreases for long-boom antennas. Figure 15.23B shows that beyond boom spacings of about 1λ , the F/R pattern holds well for Yagi designs with booms longer than about 0.5λ , which is about 4 feet at 146 MHz.

The plots in Figure 15.23 are representative of typical modern Yagis. You could simply implement these designs as is, and you'll achieve good results. However, we recommend that you model any specific stack you design, just to make sure. Since the boom spacings are displayed in terms of wavelength, you can extend the results for 2 meters to other bands, provided that you use properly scaled Yagi designs to the other bands too.

You can even tweak the element dimensions and spacings of each Yagi used in a stack to optimize the rearward pattern for a particular stacking distance. This strategy can work out well at VHF/UHF, where stacks are often configured for best gain (and pattern) and are "hard-wired" with fixed lengths of feed lines permanently joined together at the junctions.

This is in contrast to the situation at HF (and even on 6 meters). The HF operator usually wants flexibility to select individual Yagis (or combinations of Yagis) from the stack, to match the array's takeoff angle with ionospheric propagation

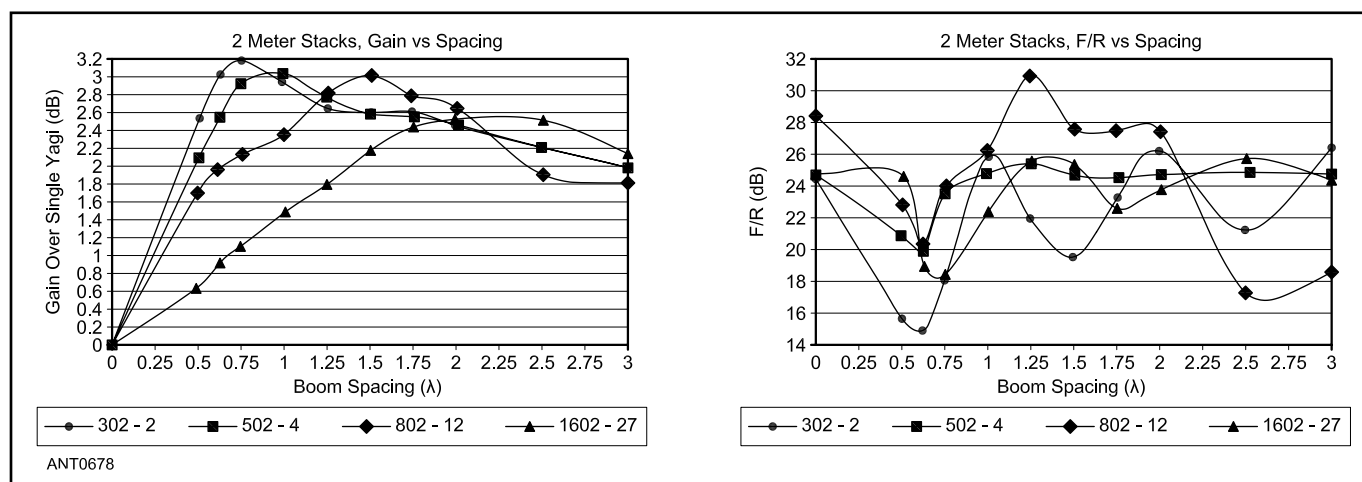


Figure 15.23 — Performance of two different 2 meter Yagis (5 elements on 4-foot boom and 8 elements on 12-foot boom) fed in-phase, as a function of spacing between the booms. Note that the distance is measured in wavelengths.

conditions. The designer of a flexible HF stack thus usually doesn't try to redo the element lengths and spacings of the Yagis to optimize a particular stack.

Stacking Stacks of Different-Frequency Yagis

The investment in a tower is usually substantial, and most hams want to put as many antennas as possible on a tower, provided that interaction between the antennas can be held to a reasonable level. Really ambitious weak-signal VHF/UHF enthusiasts may want "stacked stacks" — sets of stacked Yagis that cover different bands. For example, a VHF contester might want a stack of two 8-element 2 meter Yagis mounted on the same rotating mast as a stack of two 5-element 6 meter Yagis. Let's assume that the boom length of the 8-element 2 meter Yagi is 12 feet (1.78λ). We'll assume a boom length of 12 feet (0.61λ) for the 5-element 6 meter Yagi.

From Figure 15.23, we find the stacking distance between the 8-element 2 meter beams for peak gain and good pattern is 1.5λ , or 10 feet, but adequate performance can be had for a boom spacing of 0.75λ , which is 5 feet on 2 meters.

The boom spacing for two 5-element 6 meter beams is 1λ for peak stacking gain, but a compromise of 0.625λ (12 feet) still yields an acceptable gain increase of 2 dB over a single Yagi. The overall height of the rotating mast sticking out of the top of the tower is thus set by the 0.625λ stacking distance on 6 meters, at 12 feet. In-between the 6 meter Yagis at the bottom and top of the rotating mast we will mount the 2 meter Yagi stack. With only 12 feet available on the mast, the spacing for symmetric placement of the two 2 meter Yagis in-between the 6 meter Yagis dictates a distance of only 4 feet between the 2 meter beams. This is less than optimal.

The performance of the 2 meter stack in this "stack within a stack" is affected by the close spacing, but the interactions are not disastrous. The stacking gain is 1.62 dB more than the gain for a single 8-element 2 meter Yagi and the F/R remains above 20 dB across the 2 meter band.

On 6 meters, the stacking gain for two 5-element 6 meter Yagis spaced 12 feet apart is 2.2 dB more than the gain of a single Yagi, while the F/R pattern remains about 20 dB over the weak-signal portion of the 6 meter band. As described in the **HF Antenna System Design** chapter, stacking gives more advantages than merely a gain increase, and 6 meter propagation does require coverage of a range of elevation angles because much of the time ionospheric modes are involved.

Increasing the length of the rotating mast to 18 feet sticking out of the top of the tower will increase performance, particularly on 2 meters. The stacking gain on 6 meters will increase to 2.3 dB while the F/R decreases to 18.5 dB, modest changes both. The 18-foot mast allows the 2 meter Yagis to be spaced 6 feet from each other and 6 feet away from both top and bottom 6 meter antennas. The stacking gain goes to 2.14 dB and the F/R approaches 27 dB in the weak-signal portion of the 2 meter band.

Whether the modest increase in stacking gain is worth the cost and mechanical complexity of stacking two 2 meter

Yagis between a stack of 6 meter Yagis is a choice left to the operator. Certainly the cost and weight of a rotating mast that is 20 feet long (18 feet out of the top of the tower and 2 feet down inside the tower), a mast that must be sturdy enough to support the antennas in high winds without bending, should give pause to even the most enthusiastic 6 meter weak-signal operator.

15.3.2 YAGIS FOR 50 MHZ

Boom length often proves to be the deciding factor when one selects a Yagi design. **Table 15-1** shows three 6 meter Yagis designed for convenient boom lengths (6, 12 and 22 feet). The 3-element, 6-foot boom design has 8.0 dBi gain in free space; the 12 foot boom, 5-element version has 10.1 dBi gain, and the 22-foot, 7 element Yagi has a gain of 11.3 dBi. All antennas exhibit better than 22 dB front-to-rear ratio and cover 50 to 51 MHz with better than 1.7:1 SWR.

A beam designed for FM operation higher in the band is described by the August 2007 *QST* article "A Short Boom,

Table 15-1
Optimized 6 Meter Yagi Designs

	<i>Spacing Between Elements (inches)</i>	<i>Seg1 OD Length (inches)</i>	<i>Seg2 OD Length (inches)</i>	<i>Midband Gain F/R</i>
306-06				
OD		0.750	0.625	
Refl.	0	36	23.500	7.9 dBi
D.E.	24	36	16.000	27.2 dB
Dir. 1	42	36	15.500	
506-12				
OD		0.750	0.625	
Refl.	0	36	24.000	10.1 dBi
D.E.	24	36	17.125	24.7 dB
Dir. 1	12	36	19.375	
Dir. 2	44	36	18.250	
Dir. 3	58	36	15.375	
706-22				
OD		0.750	0.625	
Refl.	0	36	25.000	11.3 dBi
D.E.	27	36	17.250	29.9 dB
Dir. 1	16	36	18.500	
Dir. 2	51	36	15.375	
Dir. 3	54	36	15.875	
Dir. 4	53	36	16.500	
Dir. 5	58	36	12.500	



Figure 15.24 — The element to boom clamp. U bolts are used to hold the element to the plate, and 2-inch galvanized muffer clamps hold the plates to the boom.

Wideband 3 Element Yagi for 6 Meters,” by L.B. Cebik, W4RNL (SK). Cebik describes two additional 3-element Yagis for 6 meters — one optimized for gain and F/B and the other optimized for bandwidth — in the February 2000 *QST* article, “2X3 = 6.” Both articles are included on this book’s CD-ROM.

Half-element lengths and spacings are given in the table. Elements can be mounted to the boom as shown in **Figure 15.24**. Two muffler clamps hold each aluminum plate to the boom, and two U bolts fasten each element to the plate, which is 0.25 inch thick and 4 × 4 inches square. Stainless steel is the best choice for hardware, but 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. Please note that the element lengths shown in Table 15-1 are half the overall element lengths. See the **Antenna Materials and Construction** chapter for practical details of telescoping aluminum elements.

The driven element is mounted to the boom on a Bakelite or G-10 fiberglass 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 **Figure 15.25** for driven-element and hairpin match details. A bracket made from a piece of aluminum is used to mount the three SO-239 connectors to the driven

element plate. A 4:1 transmission line balun connects the two element halves, transforming the 200 Ω resistance at the hairpin match to 50 Ω at the center connector. Note that the electrical length of the balun is $\lambda/2$, 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 all antennas.

15.3.3 UTILITY YAGIS FOR 144 MHZ AND 432 MHZ

There are many applications for Yagis on 144 MHz that do not require high gain or tightly-controlled pattern. In fact, for casual operating, a beamwidth that is too narrow can actually prevent a station from hearing weak signals not in the main lobe of the antenna. For meteor scatter and other applications (see the sidebar, “Meteor Scatter: How Much Antenna is Too Much?”) where the opening comes from an unknown azimuth, a wider beamwidth is preferred. Rover

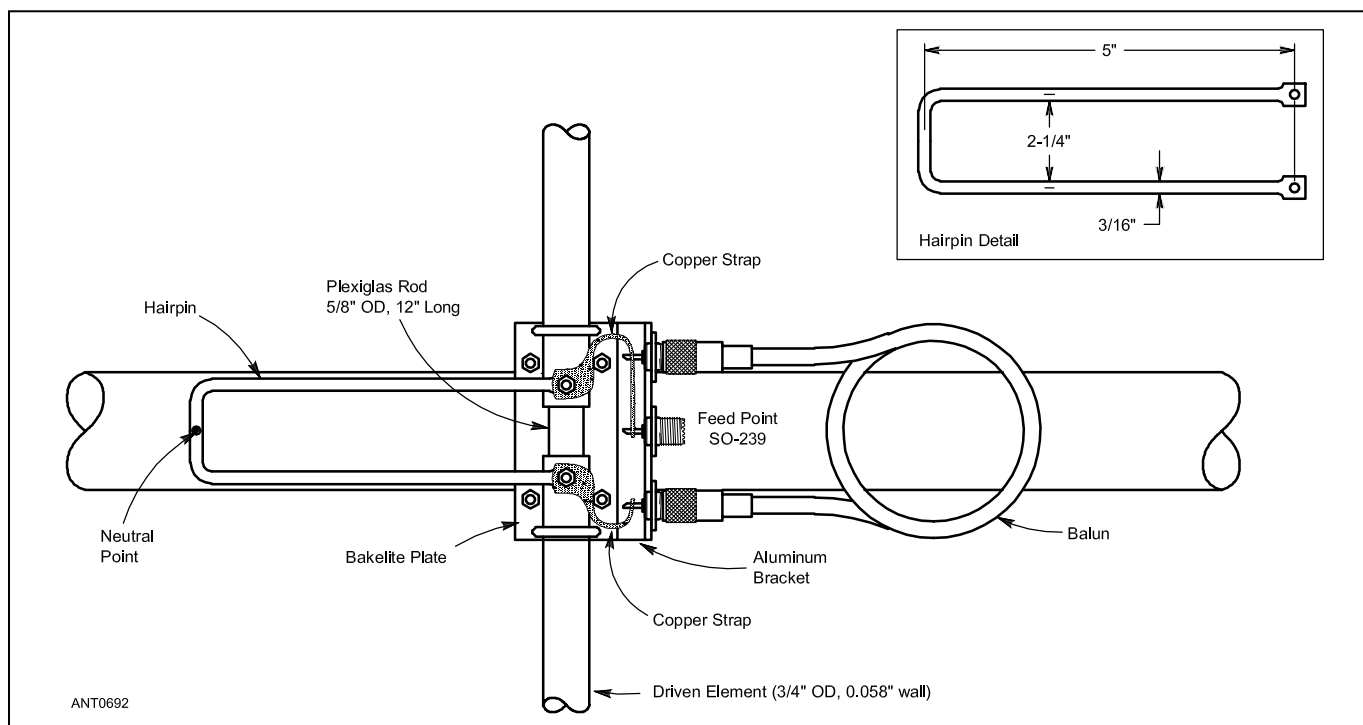


Figure 15.25 — This shows how the driven element and feed system are attached to the boom. The phasing line is coiled and taped to the boom. The center of the hairpin loop may be connected to the boom electrically and mechanically if desired.

Phasing-line lengths:

For cable with 0.80 velocity factor — 7 ft, 10 $\frac{5}{8}$ inches

For cable with 0.66 velocity factor — 6 ft, 5 $\frac{3}{4}$ inches

Meteor Scatter: How Much Antenna is Too Much?

Can an antenna be too big or have too much gain? Perhaps surprisingly, in some circumstances the answer is a definite “Yes.”

High gain means narrow beamwidth. Even supposing that a sharp beam can be directed just as desired, you may sometimes want your transmitter to illuminate a larger range of directions, or to receive signals with reasonable gain over a larger range. Such situations can exist even for point-to-point communication — for example, when station A tries to work station B, at a known location some 800 to 1200 km away, on a VHF band using meteor scatter.

The most probable path geometries for random meteor scatter are offset by angles of about 8° to 16° either side of the great circle path. Smaller offsets apply to the longest paths, on the order of 2200 to 2400 km; paths less than 1000 km have optimum offsets near the high end of the range. The largest number of meteor-scatter reflections will occur when stations A and B use antenna beamwidths that overlap throughout most of the potentially useful scattering volume. This implies beamwidths at least twice the offset angle: around 32° for 800 km paths, or 16° for the longest feasible paths. Of course, antennas with higher gain and narrower beams may yield stronger signals, when they produce any at all; but for efficient completion of their desired contact, A and B may be interested in getting *more* meteor

reflections, rather than *stronger* ones.

A Yagi antenna with 30° beamwidth has boom length of about 3 wavelengths and gain of 13 dBd. Three wavelengths at 50 MHz is nearly 60 feet, so few if any amateur antennas for this band are likely to be “too large” for effective meteor-scatter use. At 144 MHz, however, Yagis of 5 wavelengths and more are quite practical. Their beamwidths will be significantly less than 30°, so they will be sub-optimal for meteor-scatter contacts at moderate distances.

Real-world amateur meteor scatter experience confirms the picture outlined above. For meteor scatter out to 1600 km on the 2 meter band, an optimized 10 to 12 element Yagi (length 1.8 to 2.5 λ) is probably close to the optimum antenna. Takeoff angles for meteor scatter are no more than about 15°, so a vertical stack of two such Yagis (which would have the same beamwidth in azimuth) would be even better. Horizontal stacking of a pair, or a 2 × 2 box of four such Yagis, would work well beyond about 1600 km, but would be sub-optimal at shorter distances. On the longest feasible meteor-scatter paths, beyond about 1800 km, the rule-of-thumb once again becomes “bigger is better.” Note that for these long paths the optimum takeoff angle has fallen to less than 3°, so antenna height in excess of 5 λ (about 35 feet at 144 MHz) is also important. — *Joe Taylor, K1JT*

Table 15-2
2 Meter OWA Yagi Dimensions

Element	Element Length (inches)	Reflector Spacing (inches)	Element Diameter (inches)
Reflector	40.52	—	0.1875
Driver	39.70	10.13	0.5000
Director 1	37.36	14.32	0.1875
Director 2	36.32	25.93	0.1875
Director 3	36.32	37.28	0.1875
Director 4	34.96	54.22	0.1875

and portable stations often find the lighter weight and shorter boom length of the smaller antennas easier to handle.

Utility Yagi for 144 MHz

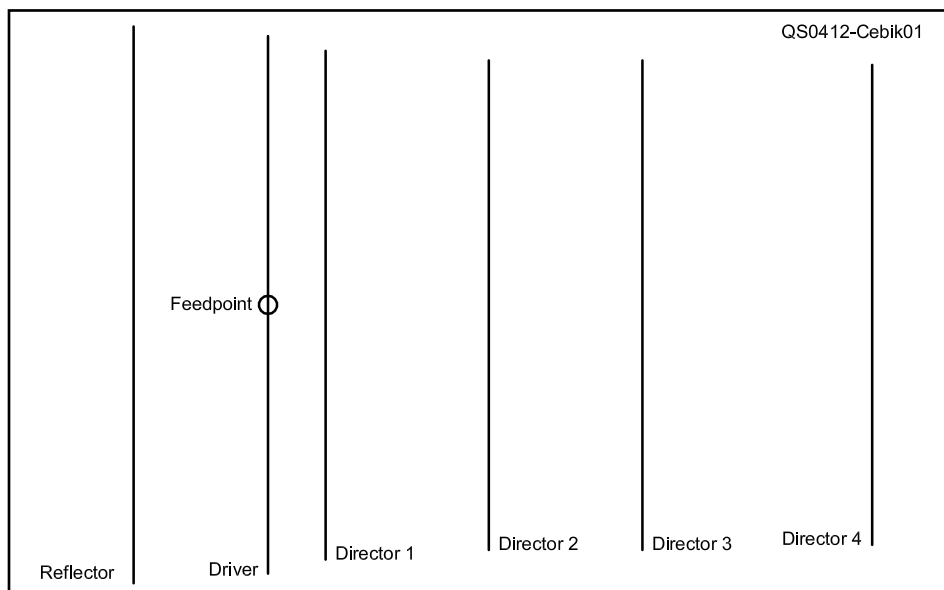
The following material is a summary of the design presented by L.B. Cebik, W4RNL (SK) in the December 2004 *QST* article “Building a Medium-Gain, Wide-Band, 2 Meter Yagi.” (The complete article is included on this book’s CD-ROM.)

The 6-element Yagi presented here is a derivative of the “optimized wideband antenna” (OWA) designs developed for HF use by NW3Z and WA3FET.

Figure 15.26 shows the general structure of the beam and **Figure 15.27** gives the free-space E-plane pattern. If mounted with the elements horizontal, the E-plane pattern would be the azimuthal pattern.

Oversimplifying the design somewhat, the reflector and first director largely set the feed point impedance. The next two directors contribute to setting the operating bandwidth. The final director sets the gain.

Figure 15.26 — The general structure of the 2 meter, 6-element OWA Yagi. See Table 15-2 for dimensions.



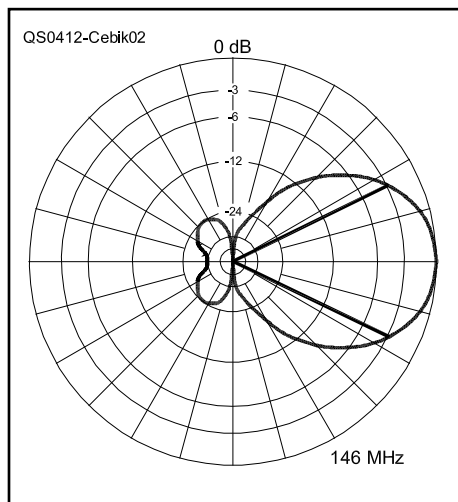


Figure 15.27 — E-plane (horizontal azimuth) pattern of the 2 meter, 6-element OWA Yagi in free space at mid-band — 146 MHz. The antenna exhibits a gain of about 10.2 dBi, consistent across the 2 meter band.

Designed using *NEC-4*, the antenna's six elements are arranged on a 56-inch boom **Table 15-2** gives the specific dimension for the antenna. The parasitic elements are all 3/16-inch aluminum rod while the driver uses 1/2-inch aluminum tubing for reasons of construction. Dimensions for the beam with an alternate driver or the use of 1/8-inch elements is given in the original article.

The OWA design provides about 10.2 dBi of free-space gain with better than 20 dB F/B across the entire 2 meter band. The horizontal beamwidth is considerably wider if the beam is mounted with the elements vertical for use on FM.

One significant feature of the OWA design is its direct 50-Ω feed point impedance that requires no matching network. Of course, a common-mode choke balun (see the **Transmission Line Coupling and Impedance Matching** chapter) is desirable. The SWR as shown in **Figure 15.28** is very flat across the band and never exceeds 1.3:1. The SWR and pattern consistency together create a very useful utility antenna for 2 meters.

Utility Yagi for 432 MHz

The following design was developed by Zack Lau, W1VT and described in his "RF" column "A Small 70-cm Yagi" in the July/August 2001 *QEX*. The complete article is included on this book's CD-ROM.

This six-element Yagi was designed for a wide bandwidth — in gain, F/B and SWR. Its gain was measured at 8.5 dBd during the 1995 Eastern States VHF/UHF Conference — with little gain variation between 417 and 446 MHz. The SWR is almost as broad, with better than 1.4:1 SWR between 422 and 446 MHz. The measured gain and return loss curves are shown in **Figure 15.29**. The short 30-inch boom is small enough to fit in the trunk of a compact

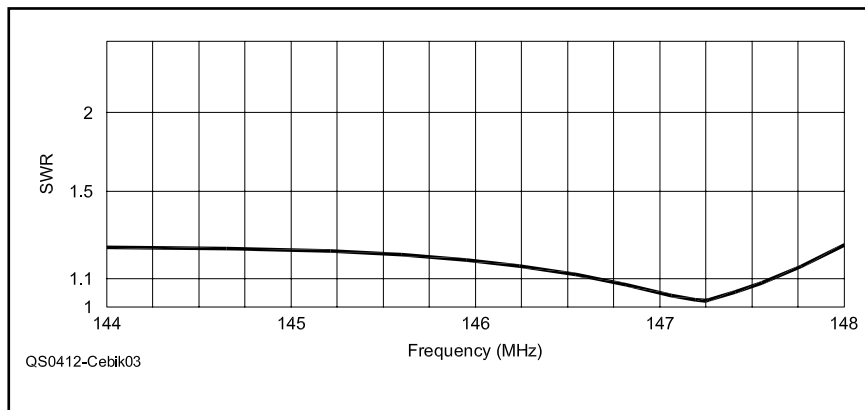


Figure 15.28 — The SWR for the OWA 2 meter Yagi from 144 to 148 MHz as modeled by *NEC-4*.

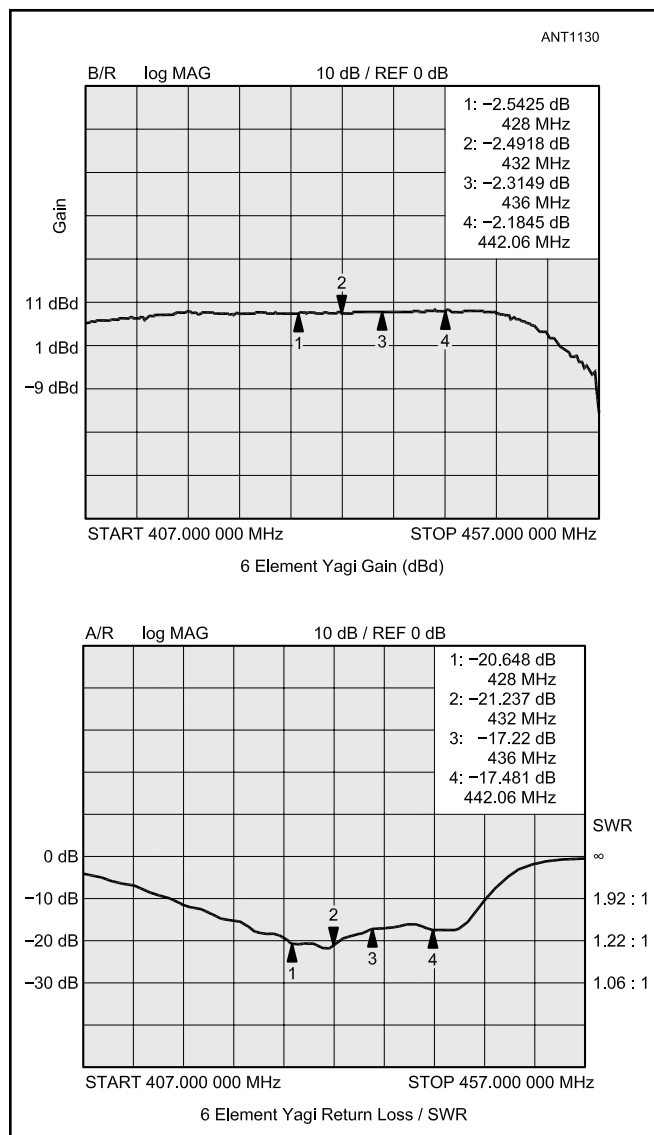


Figure 15.29 — Gain and SWR measurements for the 70 cm Yagi.

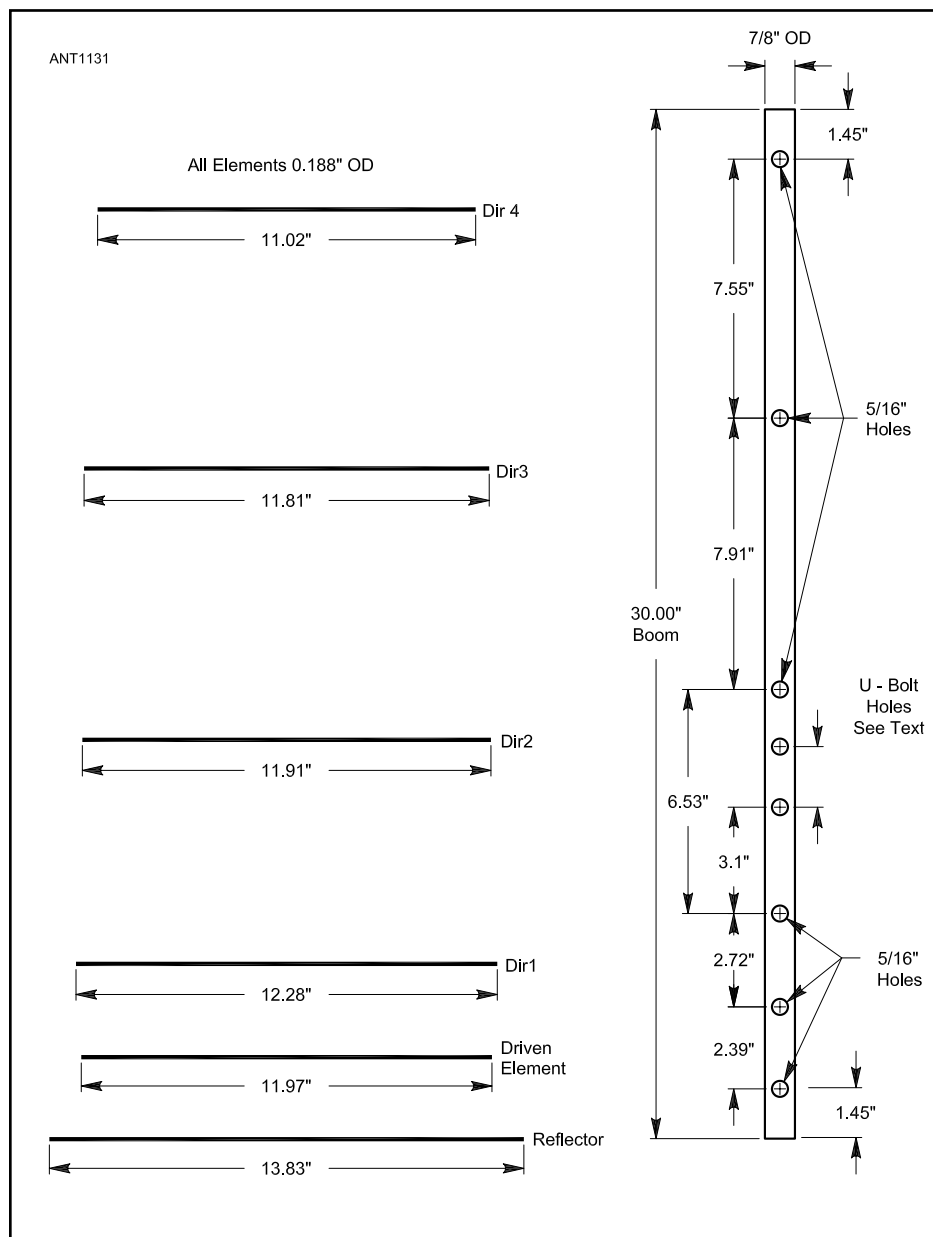


Figure 15.30 — Rough scale drawing of the 70 cm Yagi boom and elements.

sedan, perfect for portable or emergency operation. The F/B bandwidth is also very good, with over 20 dB of F/B between 424 and 450 MHz, according to a *Yagi Analyzer* computer model.

Even if you only intend to use this antenna for 432-MHz SSB or 436-MHz satellite operation, the extra bandwidth is useful when it rains. Heavy rain causes antenna elements to resonate lower in frequency. This is much worse if the antenna is tweaked for maximum gain. Yagis typically have a low-pass gain response. The gain falls off rapidly past the maximum-gain point. Thus, while the maximum gain is around 442 MHz, the gain is significantly lower at 457 MHz, while only a little bit lower at 427 MHz.

The optimized design is shown in **Figure 15.30** and the element lengths and placement are given in **Table 15-3**. The element lengths are adjusted to work with a particular boom and mounting arrangement. Changing the boom or element mounting may require adjusting the element lengths. The antenna uses a simple T-match, as simpler gamma matches have a poor reputation on this band. A T-matched Yagi is more likely to have a symmetrical radiation pattern. The feed system shown in the complete article on the CD-ROM is a copy of that used in the K2RIW Yagi. A half-wave balun made out of semi-rigid UT-141 coax steps up the impedance to 200 Ω . Similarly, the T match steps up the impedance of the driven element to 200 Ω .

Table 15-3
432-MHz Yagi Dimensions

Spacing	Cumulative Boom Length	Element Length
0		13.832
2.394	2.394	11.968
2.715	5.109	12.284
6.528	11.637	11.908
7.907	19.544	11.810
7.546	27.09	11.01

Dimensions in inches.

15.3.4 CHEAP YAGIS BY WA5VJB

The following material is adapted from an online paper by Kent Britain, WA5VJB, entitled “Controlled Impedance ‘Cheap’ Antennas.” The paper is available from www.wa5vjb.com/references.html. The simplified feed uses the structure of the antenna itself for impedance matching. The antennas were designed with *YagiMax*, tweaked in *NEC*, and the driven elements experimentally determined on the antenna range. The result is a family of Yagis with good performance that can be built very inexpensively.

Construction of the antennas is straightforward. The boom is $\frac{3}{4}$ -inch square, or $\frac{1}{2}$ -inch by $\frac{3}{4}$ -inch wood. To

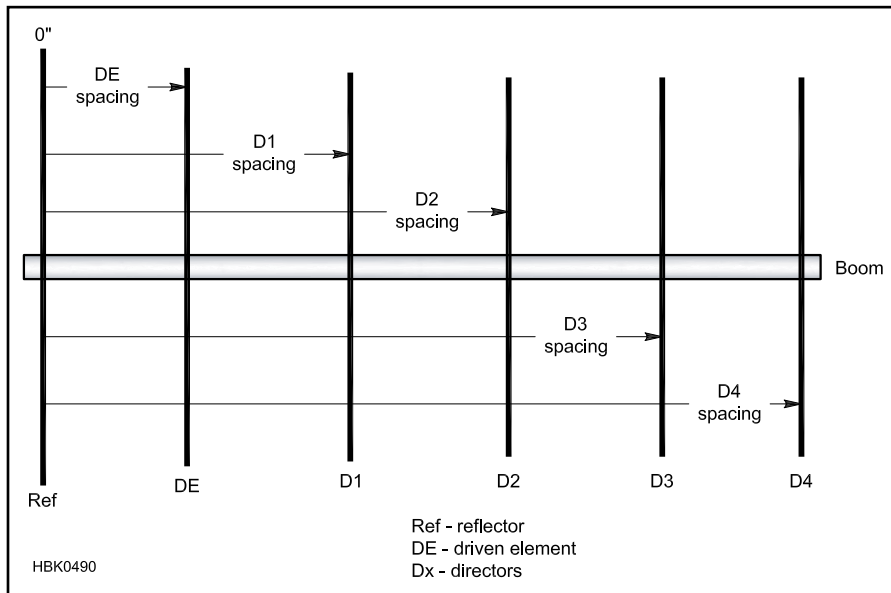


Figure 15.31 — Element spacing for the Cheap Yagis. Refer to Tables 15-4 to 15-10 for exact dimensions for the various bands.

install an element, drill a hole through the boom and insert the element. A drop of cyanoacrylate “super glue,” epoxy, or silicone adhesive is used to hold the elements in place. There is no boom-to-mast plate — drill holes in the boom and use a U-bolt to attach it to the mast! The life of the antenna

is determined by what you coat it with. The author had a 902-MHz version in the air varnished with polyurethane for two years with little deterioration.

The parasitic elements on prototypes have been made from silicon-bronze welding rod, aluminum rod, brass hobby tubing, and #10 or #12 AWG solid copper ground wire. So that you can solder to the driven element, use the welding rod, hobby tubing or copper wire. The driven element is folded at one end with its ends inserted through the boom.

Figure 15.31 shows the basic plan for the antenna and labels the dimensions that are given in the table for each band. All table dimensions are given in inches.

Figure 15.32 shows how the driven element is constructed for each antenna. Trim the free end of the driven element to tune it for minimum SWR at the desired

frequency. **Figure 15.33** shows how to attach coaxial cable to the feed point. Sliding a quarter-wave sleeve along the coax had little effect, so there’s not much RF on the outside of the coax. You may use a ferrite bead choke balun if you like, but these antennas are designed for minimum expense!

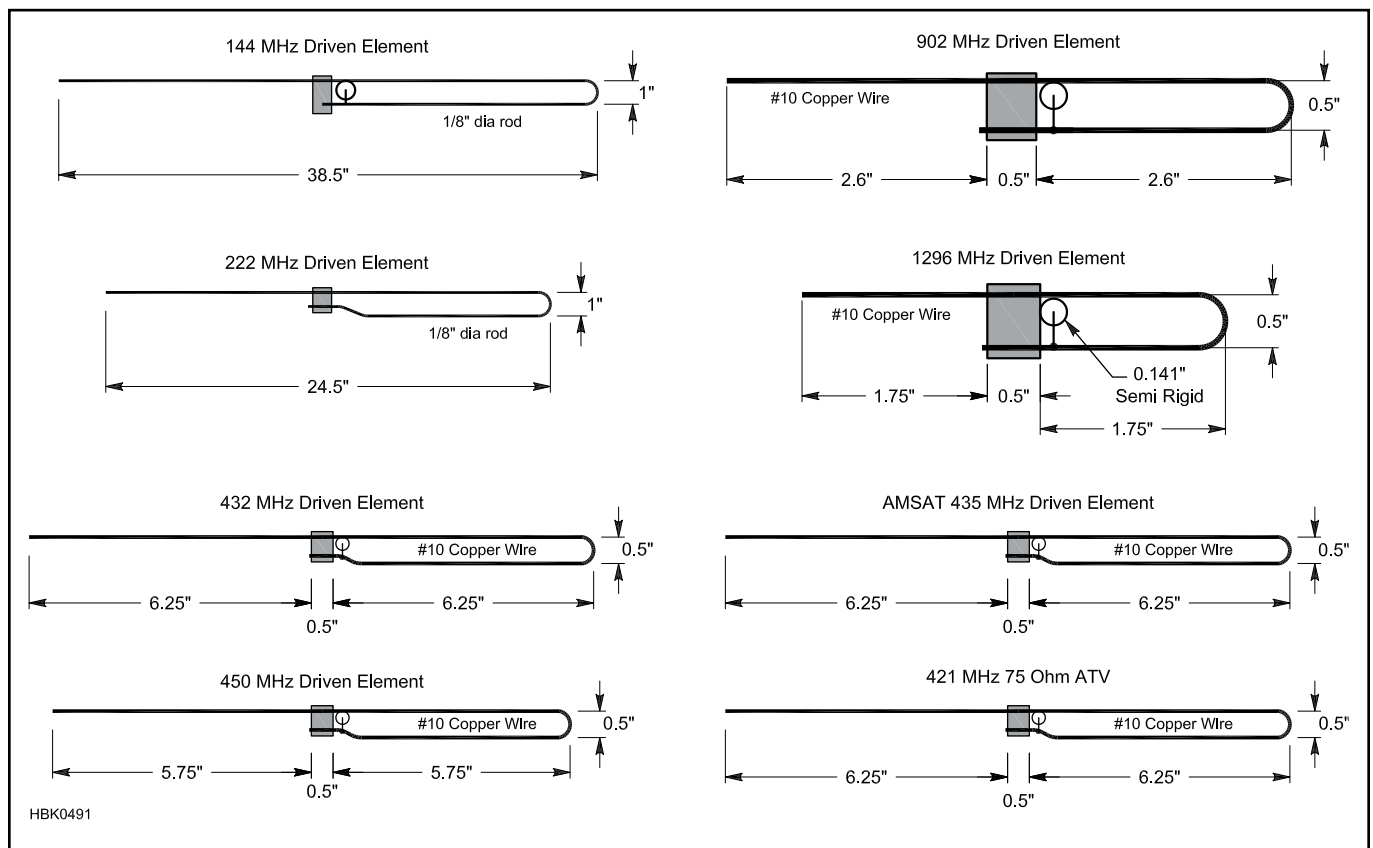


Figure 15.32 — Driven element dimensions for the Cheap Yagis. Attaching the coax shield to the center of the driven element is appropriate because that is the lowest impedance point of the element.

Table 15-4
WA5VJB 144 and 222 MHz Yagi Dimensions
144 MHz Yagi

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>
3-element	Length	41.0	—	37.0			
	Spacing	0	8.5	20.0			
4-element	Length	41.0	—	37.5	33.0		
	Spacing	0	8.5	19.25	40.5		
6-element	Length	40.5	—	37.5	36.5	36.5	32.75
	Spacing	0	7.5	16.5	34.0	52.0	70.0

222 MHz Yagi

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>
3-element	Length	26.0	—	23.75			
	Spacing	0	5.5	13.5			
4-element	Length	26.25	—	24.1	22.0		
	Spacing	0	5.0	11.75	23.5		
6-element	Length	26.25	—	24.1	23.5	23.5	21.0
	Spacing	0	5.0	10.75	22.0	33.75	45.5

Dimensions in inches.

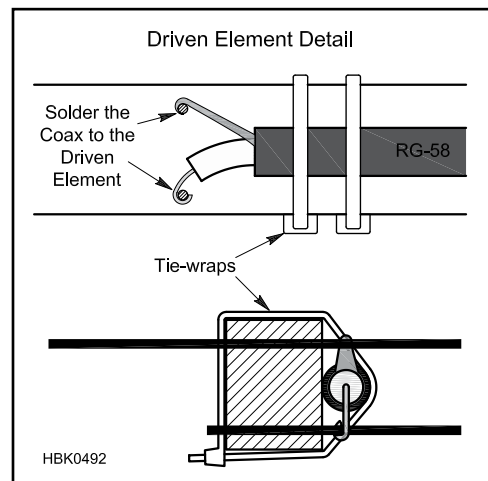


Figure 15.33 — Construction details and feed line attachment for the Cheap Yagi driven element.

Table 15-5
WA5VJB 432 MHz Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>	<i>D5</i>	<i>D6</i>	<i>D7</i>	<i>D8</i>	<i>D9</i>
6-element	Length	13.5	—	12.5	12.0	12.0	11.0					
	Spacing	0	2.5	5.5	11.25	17.5	24.0					
8-element	Length	13.5	—	12.5	12.0	12.0	12.0	12.0	11.25			
	Spacing	0	2.5	5.5	11.25	17.5	24.0	30.75	38.0			
11-element	Length	13.5	—	12.5	12.0	12.0	12.0	12.0	12.0	11.75	11.75	11.0
	Spacing	0	2.5	5.5	11.25	17.5	24.0	30.75	38.0	45.5	53.0	59.5

Dimensions in inches.

Table 15-6
WA5VJB 435 MHz Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>	<i>D5</i>	<i>D6</i>	<i>D7</i>	<i>D8</i>	<i>D9</i>
6-element	Length	13.4	—	12.4	12.0	12.0	11.0					
8-element	Length	13.4	—	12.4	12.0	12.0	12.0	12.0	11.1			
10-element	Length	13.4	—	12.4	12.0	12.0	12.0	12.0	11.75	11.75	11.1	
11-element	Length	13.4	—	12.4	12.0	12.0	12.0	12.0	11.75	11.75	11.75	11.1
	Spacing	0	2.5	5.5	11.25	17.5	24.0	30.5	37.75	45.0	52.0	59.5

Dimensions in inches.

144 MHz Yagi: While others have reported good luck with 16-element long-boom wood antennas, six elements was about the maximum for most rovers. The design is peaked at 144.2 MHz, but performance is still good at 146.5 MHz. All parasitic elements are made from $\frac{3}{16}$ -inch aluminum rod and the driven element is made from $\frac{1}{8}$ -inch rod. Lengths and spacings are given in **Table 15-4**.

222 MHz Yagi: This antenna is peaked at 222.1 MHz, but performance has barely changed at 223.5 MHz. You can drill the mounting holes to mount it with the elements horizontal or vertical. All parasitic elements are made from $\frac{3}{16}$ -inch aluminum rod and the driven element is made from $\frac{1}{8}$ -inch rod. Lengths and spacings are given in **Table 15-4**.

432 MHz Yagi: At this band the antenna is getting very

practical and easy to build. All parasitic elements are made from $\frac{1}{8}$ -inch diameter rod and the driven element is made from #10 AWG solid copper wire. Lengths and spacings are given in **Table 15-5**.

435 MHz Yagi for AMSAT: Ed Krome, K9EK, provided help and motivation for these antennas. A high front-to-back ratio (F/B) was a major design consideration of all versions. The model predicts 30 dB F/B for the six-element and over 40 dB for the others. For gain, *NEC* predicts 11.2 dBi for the six-element, 12.6 dBi for the eight-element, and 13.5 dBi for the 10-element, and 13.8 dBi for the 11-element.

Using $\frac{3}{4}$ -inch square wood for the boom makes it easy to build two antennas on the same boom for cross-polarization.

Table 15-7
WA5VJB 450 MHz Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>
6-element	Length	13.0	—	12.1	11.75	11.75	10.75
	Spacing	0	2.5	5.5	11.0	18.0	28.5

Dimensions in inches.

Table 15-8
WA5VJB 902 MHz Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>	<i>D5</i>	<i>D6</i>	<i>D7</i>	<i>D8</i>
10-element	Length	6.2	—	5.6	5.5	5.5	5.4	5.3	5.2	5.1	5.1
	Spacing	0	2.4	3.9	5.8	9.0	12.4	17.4	22.4	27.6	33.0

Dimensions in inches.

Table 15-9
WA5VJB 1296 MHz Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>	<i>D5</i>	<i>D6</i>	<i>D7</i>	<i>D8</i>
10-element	Length	4.3	—	3.9	3.8	3.75	3.75	3.65	3.6	3.6	3.5
	Spacing	0	1.7	2.8	4.0	6.3	8.7	12.2	15.6	19.3	23.0

Dimensions in inches.

Table 15-10
WA5VJB 421.25 MHz 75- Ω Yagi Dimensions

		<i>Ref</i>	<i>DE</i>	<i>D1</i>	<i>D2</i>	<i>D3</i>	<i>D4</i>	<i>D5</i>	<i>D6</i>	<i>D7</i>	<i>D8</i>	<i>D9</i>
6-element	Length	14.0	—	12.5	12.25	12.25	11.0					
9-element	Length	14.0	—	12.5	12.25	12.25	12.0	12.0	11.25			
11-element	Length	14.0	—	12.5	12.25	12.25	12.0	12.0	12.0	11.75	11.75	11.5
	Spacing	0	3.0	6.5	12.25	17.75	24.5	30.5	36.0	43.0	50.25	57.25

Dimensions in inches.

Offset the two antennas 6-1/2 inch along the boom and feed them in-phase for circular polarization, or just use one for portable operations. All parasitic elements are made from 1/8-inch diameter rod and the driven element is made from #10 AWG solid copper wire. Lengths and spacings are given in **Table 15-6**. The same element spacing is used for all four versions of the antenna.

450 MHz Yagi for FM: this six-element Yagi is a good, cheap antenna to get a newcomer into a repeater or make a simplex-FM QSO during a contest. RadioShack 1/8-inch diameter aluminum ground wire was used in the prototype for all the elements except the driven element, which is made from #10 AWG solid copper wire. Other 1/8-inch diameter material could be used. Lengths and spacings are given in **Table 15-7**.

902 MHz Yagi: The 2.5-ft length has proven very practical. All parasitic elements are made from 1/8-inch-diameter rod and the driven element is made from #10 AWG solid copper wire. Lengths and spacings are given in **Table 15-8**.

1296 MHz Yagi: This antenna is the veteran of several “Grid-peditions” and has measured 13.5 dBi on the Central States VHF Society antenna range. Dimensions must be followed with great care. The driven element is small enough to allow 0.141-inch semi-rigid coax to be used. The prototype antennas use 1/8-inch silicon-bronze welding rod for the elements, but any 1/8-inch-diameter material can be used. The driven element is made from #10 AWG solid copper wire. Lengths and spacings are given in **Table 15-9**.

421.25 MHz 75- Ω Yagi for ATV: 421 MHz vestigial sideband video is popular in North Texas for receiving the FM video input repeaters. These antennas are made for 421 MHz use and the driven element is designed for 75 Ω . RG-59 or an F adapter to RG-6 can be directly connected to a cable-TV converter or cable-ready TV on channel 57. All parasitic elements are made from 1/8-inch diameter rod and the driven element is made from #10 AWG solid copper wire. Lengths and spacings are given in **Table 15-10**. The same spacing is used for all versions.

15.3.5 HIGH-PERFORMANCE YAGIS FOR 144, 222 AND 432 MHZ

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. A Yagi designer from Europe, Gunter Hoch, DL6WU, has produced a family of alternative high-performance designs that can be found in the article referenced in the Bibliography.

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 design approach 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 sidelobe 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. 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. **Figure 15.34** shows the 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 non critical. 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 which has its directors properly optimized for forward gain. Many multiple-reflector schemes such as tri-reflectors 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 **Figure 15.35**, 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

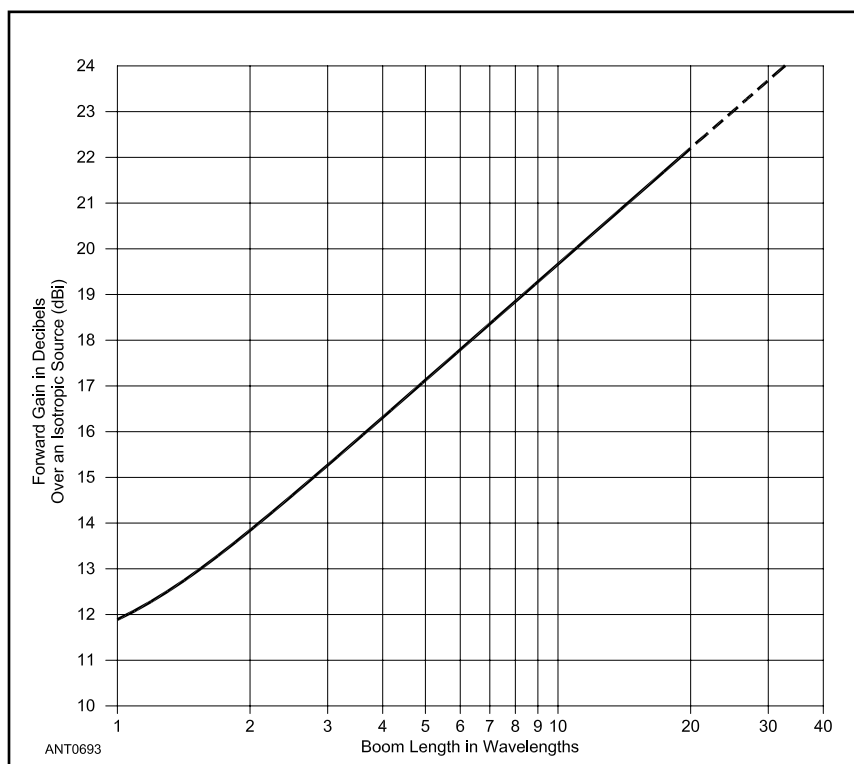


Figure 15.34 — This chart shows maximum gain per boom length for optimally designed long Yagi antennas.

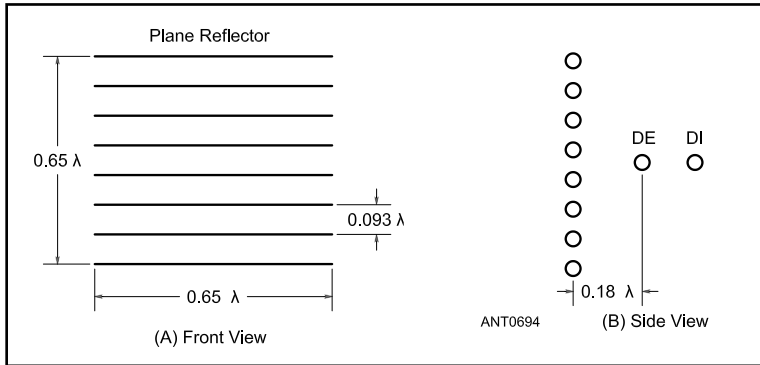


Figure 15.35 — Front and side views of a plane-reflector antenna.

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.

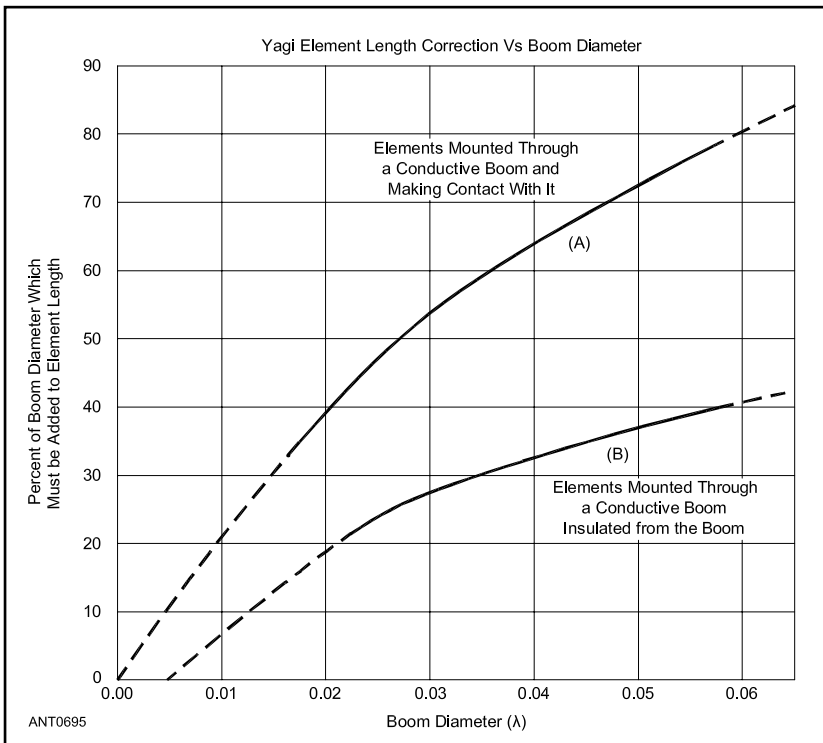
Element diameters of less than $\frac{3}{16}$ inch or 4 mm should not be used on any band. The size should be chosen for reasonable strength. Half-inch diameter is suitable for 50 MHz, $\frac{3}{16}$ to $\frac{3}{8}$ inch for 144 MHz and $\frac{3}{16}$ inch is recommended for the higher bands. Steel,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

ess 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. This will create noise (in your receiver) when the wind blows, as the element contact changes. Eventually the element-to-boom junction will corrode (aluminum oxide is a good insulator). This loss of electrical contact between the boom 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 **Figure 15.36**. 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

Figure 15.36 — 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.

Table 15-11
Specifications for the 144-MHz Yagi Family

No. of Ele.	Boom Length (λ)	Gain (dBd)	DE Impedance (Ω)	F/B Ratio (dB)	Beamwidth E/H ($^\circ$)	Stacking E/H ($^\circ$)
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 15-12
Free-Space Dimensions for the 144-MHz Yagi Family

Element diameter is $\frac{1}{4}$ inch

Element No.	Element Position (mm from reflector)	Element Length
Refl.	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

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.

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 4.5- λ 432-MHz computer-developed design by Tom Kirby, W1EJ (SK). 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 Powlisen, 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 1.8 λ (10 elements) to 5.1 λ (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 15-11**.

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 2 λ , more traditional designs perform well.

Table 15-12 gives free-space element lengths for $\frac{1}{4}$ -inch-diameter elements. The use of metric notation allows for much easier dimensional changes during the design stage. Once you 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 meters. Other diameter elements can be used as described previously. The 2.5- λ boom was chosen because it has an excellent size and wind load versus gain and pattern trade-off. The size is also convenient; three 6-foot-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-foot-long design has a calculated wind survival of close to 120 mph! 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 feet. The elements are mounted on shoulder insulators and mounted through the boom. However, elements may be mounted,

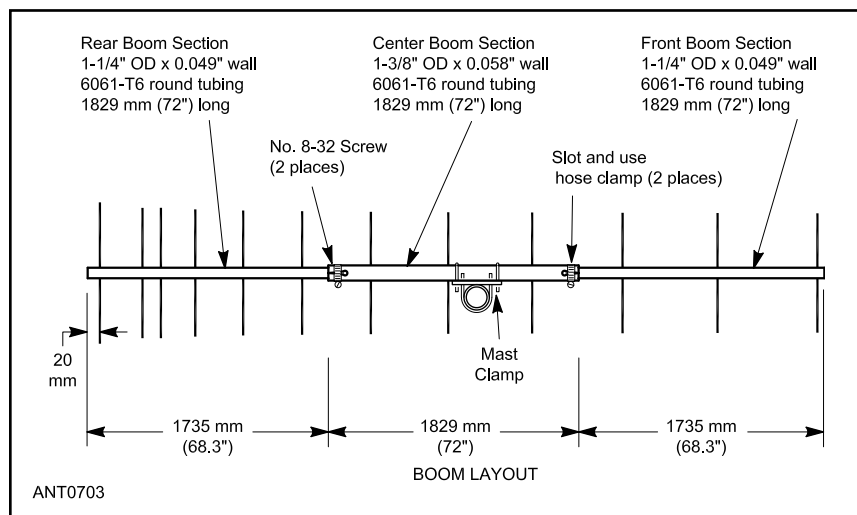


Figure 15.37 — Boom layout for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication.

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 sidelobes. 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 **Figure 15.37**. The actual corrected element dimensions for the 12-element 2.5- λ Yagi are shown in **Table 15-13**.

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 matching. 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 feed point. Information on calculating folded-dipole and T-match driven-element parameters is available in the **Transmission Line Coupling and Impedance Matching** chapter. 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. **Figure 15.38** 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.

Figure 15.39 shows computer-predicted E- and H-plane radiation patterns for the 12-element Yagi. The patterns are plotted on a 1-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 15-11 to design a dream array of virtually any size.

A High-Performance 222 MHz Yagi

Modern tapered Yagi designs are easily applied to 222 MHz. This design uses a spacing progression that is in between the 12-element 144-MHz design, and the 22-element 432-MHz design. The result is a design with maximum gain per boom length, a clean, symmetrical radiation pattern, and wide bandwidth. Although it was designed for weak-signal operation (tropospheric scatter and EME), the design is suited to all modes of 222-MHz operation, such as

Table 15-13
Dimensions for the 12-Element 2.5- λ Yagi

Element Number	Element Position (mm from reflector)	Element Length (mm)	Boom Diam (inches)
Refl.	0	1044	
DE	312	955	
D1	447	962	1 1/4
D2	699	938	
D3	1050	922	
D4	1482	912	
D5	1986	904	
D6	2553	898	1 3/8
D7	3168	894	
D8	3831	889	
D9	4527	885	1 1/4
D10	5259	882	



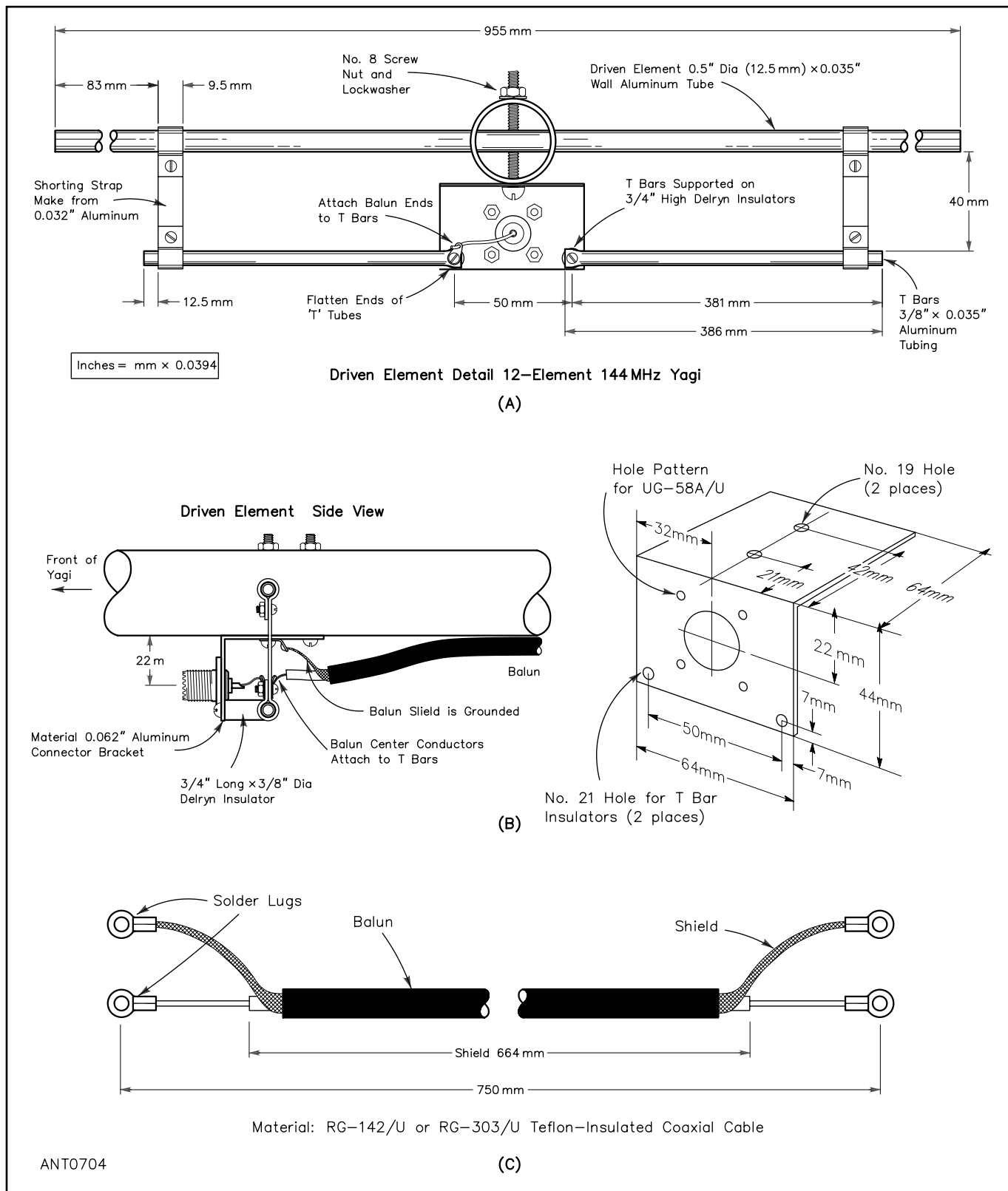


Figure 15.38 — Driven-element detail for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication.

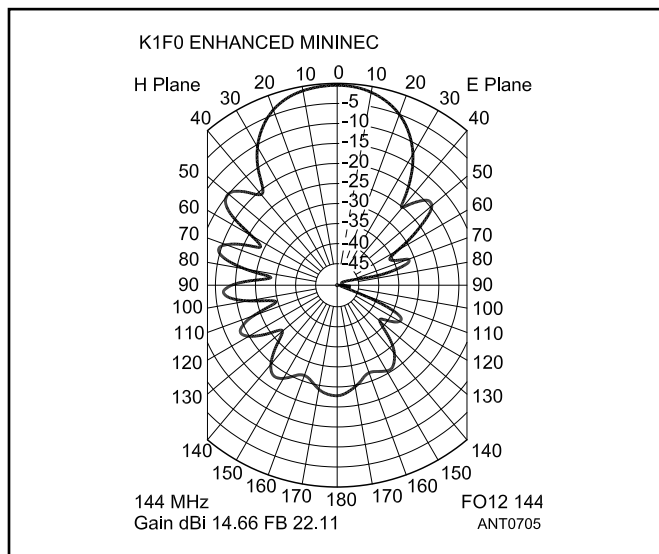


Figure 15.39 — H- and E-plane pattern for the 12-element 144-MHz Yagi.

packet radio, FM repeater operation and control links.

The spacings were chosen as the best compromise for a 3.9λ 16-element Yagi. The 3.9λ design was chosen, like the 12-element 144-MHz design, because it fits perfectly on a boom made from three 6-foot-long aluminum tubing sections. The design is quite extensible, and models from 12 elements (2.4λ) to 22 elements (6.2λ) can be built from the dimensions given in **Table 15-14**. Note that free-space lengths are given. They must be corrected for the element-mounting method. Specifications for various boom lengths are shown in **Table 15-15**.

Construction

Large-diameter ($1\frac{1}{4}$ and $1\frac{3}{8}$ inch diameter) boom construction is used, eliminating the need for boom supports. The Yagi can also be used vertically polarized. Three-sixteenths-inch-diameter aluminum elements are used. The exact alloy is not critical; 6061-T6 was used, but hard aluminum welding

Table 15-14
Free-Space Dimensions for the 222-MHz Yagi Family
Element diameter is $\frac{3}{16}$ -inch.

Element No.	Element Position (mm from reflector)	Element Length (mm)
Refl.	0	676
DE	204	647
D1	292	623
D2	450	608
D3	668	594
D4	938	587
D5	1251	581
D6	1602	576
D7	1985	573
D8	2395	569
D9	2829	565
D10	3283	562
D11	3755	558
D12	4243	556
D13	4745	554
D14	5259	553
D15	5783	552
D16	6315	551
D17	6853	550
D18	7395	549
D19	7939	548
D20	8483	547

rod is also suitable. Quarter-inch-diameter elements could also be used if all elements are shortened by 3 mm. Three-eighths-inch-diameter elements would require 10-mm shorter lengths. Elements smaller than $\frac{3}{16}$ inch-diameter are not recommended. The elements are insulated and run through the boom. Plastic shoulder washers and stainless steel retainers are used to hold the elements in place. The various pieces needed to build the Yagi may be obtained from Directive Systems (www.directivesystems.com). **Figure 15.40** details the boom layout for the 16-element Yagi. **Table 15-16** gives the dimensions for the 16-element Yagi as built. The driven element is fed with a T match and a 4:1 balun. See **Figure 15.41** for construction details. See the 432-MHz Yagi project elsewhere in this chapter for additional photographs and construction diagrams.

The Yagi has a relatively broad gain and SWR curve, as is typical of a tapered design, making it usable over a wide frequency range. The example dimensions are intended for use at 222.0 to 222.5 MHz. The 16-element Yagi is quite usable to more than 223 MHz. The best compromise for covering the entire band is to shorten all parasitic elements by 4 mm. The driven element will have to be adjusted in length for best match.

Figure 15.40 — Boom layout for the 16-element 222-MHz Yagi. Lengths are given in millimeters to allow precise duplication.

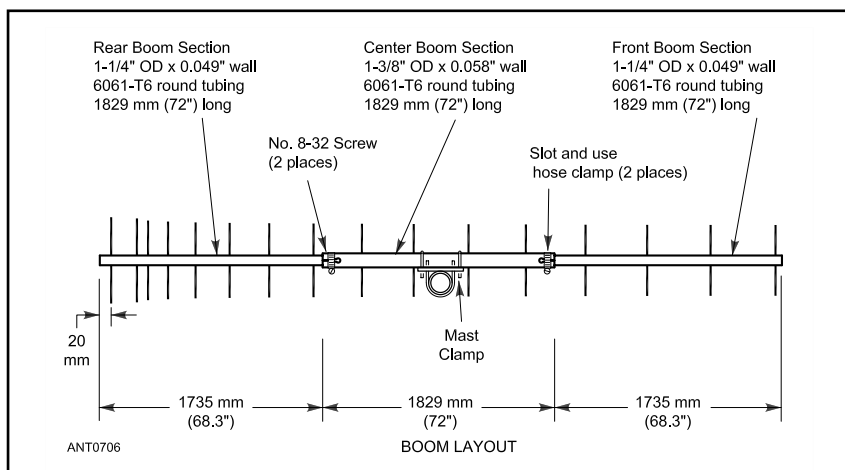


Table 15-15
Specifications for the 222-MHz Yagi Family

No of Ele.	Boom Length (λ)	Gain (dBd)	F/B Ratio (dB)	DE Impedance (Ω)	Beamwidth E/H ($^\circ$)	Stacking E/H (feet)
12	2.4	12.3	22	23	37/39	7.1/6.7
13	2.8	12.8	19	28	33/36	7.8/7.2
14	3.1	13.2	20	34	32/34	8.1/7.6
15	3.5	13.6	24	30	30/33	8.6/7.8
16	3.9	14.0	23	23	29/31	8.9/8.3
17	4.3	14.35	20	24	28/30.5	9.3/8.5
18	4.6	14.7	20	29	27/29	9.6/8.9
19	5.0	15.0	22	33	26/28	9.9/9.3
20	5.4	15.3	24	29	25/27	10.3/9.6
21	5.8	15.55	23	24	24.5/26.5	10.5/9.8
22	6.2	15.8	21	23	24/26	10.7/10.2

Table 15-16
Dimensions for 16-Element 3.9- λ 222-MHz Yagi

Element Number	Element Position (mm from reflector)	Element Length (mm)	Boom Diam (inches)
Refl.	0	683	
DE	204	664	
D1	292	630	
D2	450	615	
D3	668	601	1 $\frac{1}{4}$
D4	938	594	
D5	1251	588	
D6	1602	583	
D7	1985	580	
D8	2395	576	
D9	2829	572	1 $\frac{3}{8}$
D10	3283	569	
D11	3755	565	
D12	4243	563	
D13	4745	561	1 $\frac{1}{4}$
D14	5259	560	



The position of the T-wire shorting straps may also have to be moved.

The aluminum boom provides superior strength, is lightweight, and has a low wind-load cross section. Aluminum is doubly attractive, as it will long outlast wood and fiberglass. Using state-of-the-art designs, it is unlikely that significant performance increases will be achieved in the next few years. Therefore, it's in your best interest to build an antenna that will last many years. If suitable wood or fiberglass poles are readily available, they may be used without any performance degradation, at least when the wood is new and dry. Use the free-space element lengths given in Table 15-16 for insulated-boom construction.

The pattern of the 16-element Yagi is shown in **Figure 15.42**. Like the 144-MHz Yagi, a 1-dB-per-division plot is used to detail the pattern accurately. This 16-element design makes a good building block for EME or tropo DX arrays. Old-style narrow-band Yagis often perform

unpredictably when used in arrays. The theoretical 3.0-dB stacking gain is rarely observed. The 16-element Yagi (and other versions of the design) reliably provides stacking gains of nearly 3 dB. (The spacing dimensions listed in Table 15-15 show just over 2.9 dB stacking gain.) This has been found to be the best compromise between gain, pattern integrity and array size. Any phasing line losses will subtract from the possible stacking gain. Mechanical misalignment will also degrade the performance of an array.

A High-Performance 432 MHz Yagi

This 22-element, 6.1- λ , 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 homemade antenna range. The resulting design is based on the W1EJ (SK) 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 **Figure 15.43**. 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*. (See Bibliography.)

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 5.3 λ (20 elements) and 12.2 λ (37 elements).

The size of the original Yagi (169 inches long, 6.1 λ) was chosen so the antenna could be built from small-diameter boom material ($\frac{7}{8}$ -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 feet. 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

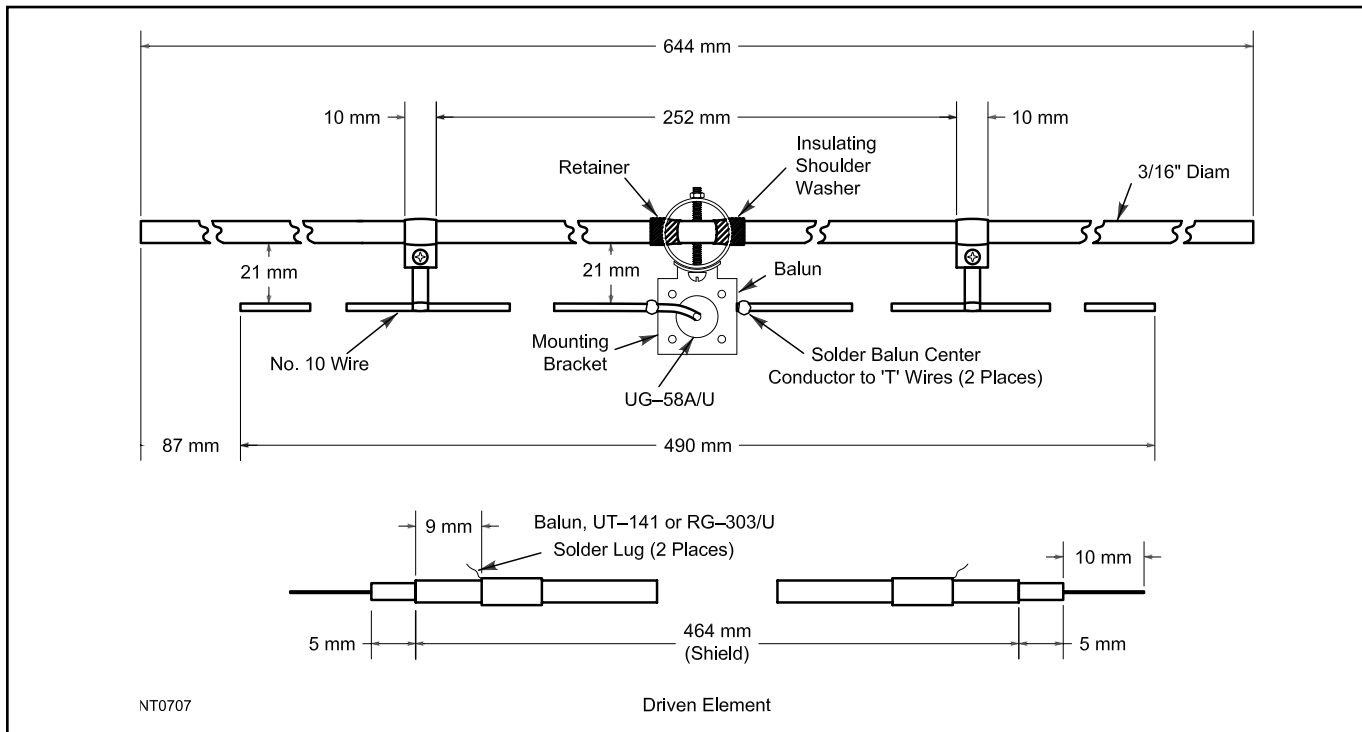


Figure 15.41 — Driven-element detail for the 16-element 222-MHz Yagi. Lengths are given in millimeters to allow precise duplication.

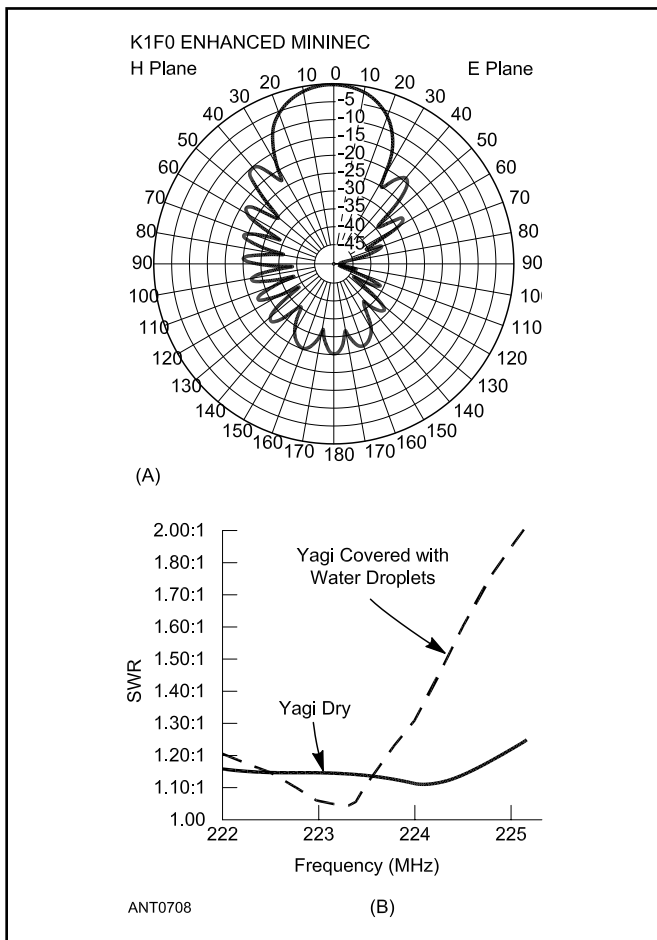


Figure 15.42 — H- and E-plane patterns for the 16-element 222-MHz Yagi at A. The driven-element T-match dimensions were chosen for the best SWR compromise between wet and dry weather conditions. The SWR vs frequency curve shown at B demonstrates the broad frequency response of the Yagi design.

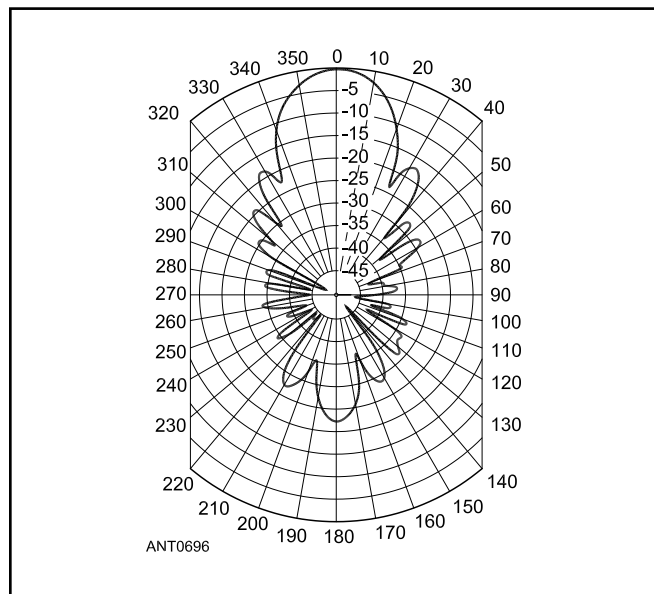


Figure 15.43 — Measured E-plane pattern for the 22-element Yagi. Note: This antenna pattern is drawn on a linear dB grid, rather than on the standard ARRL log-periodic grid, to emphasize low sidelobes.

Table 15-17
Specifications for 432-MHz Yagi Family

No. of Ele.	Boom Length (λ)	Gain (dBi)*	F/B Ratio (dB)	DE Impedance (Ω)	Beamwidth E/H ($^\circ$)	Stacking E/H (inches)
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 on gain measurements made on six different-length Yagis.

without sacrificing antennas on other bands.

Table 15-17 lists the gain and stacking specifications for the various length Yagis. The basic Yagi dimensions are shown in **Table 15-18**. These are free-space element lengths for $\frac{3}{16}$ -inch-diameter elements. Boom corrections for the element mounting method must be added

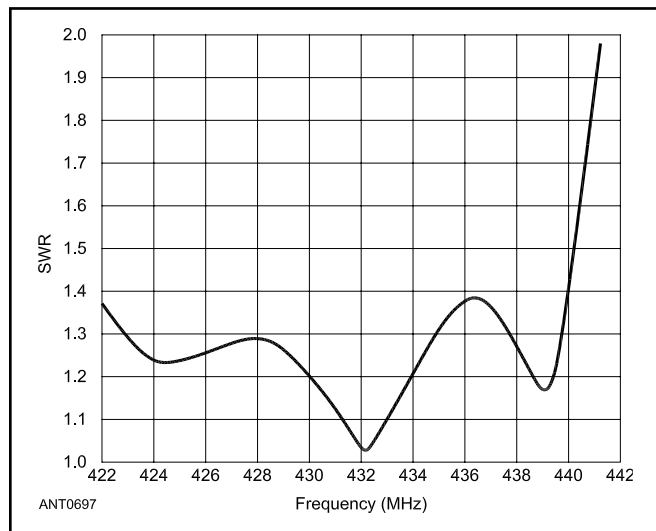


Figure 15.44 — SWR performance of the 22-element Yagi in dry weather.

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 $\frac{3}{16}$ -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. **Figure 15.44** 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.

Although this Yagi design is relatively broadband, it is suggested that close attention be paid to copying the design exactly as built. 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.

The larger the array, the more attention you should pay to making all Yagis identical. Elements are mounted on shoulder insulators and run through the boom (see **Figure 15.45**). The element retainers are stainless-steel push nuts. These are made by several companies, including Industrial Retaining Ring Co (www.truarc.com) and Auveco Products (www.auveco.com).

Table 15-18
Free-Space Dimensions for 432-MHz Yagi Family

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

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

<i>Ele. No.</i>	<i>Element Position (mm from reflector)</i>	<i>Element Length (mm)</i>	<i>Element Correction*</i>
Refl	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

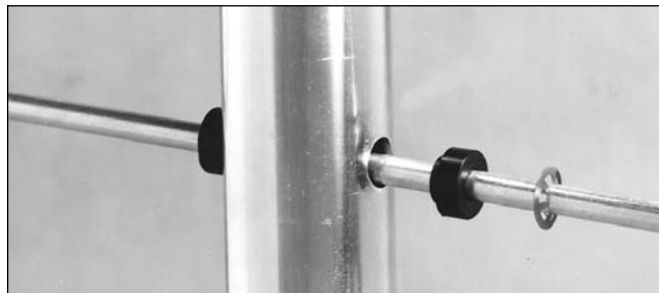


Figure 15.45 — Element-mounting detail. Elements are mounted through the boom using plastic insulators. Stainless steel push-nut retaining rings hold the element in place.

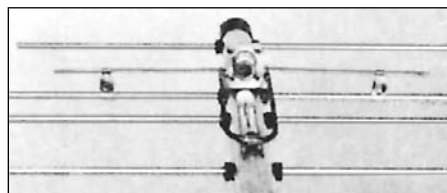
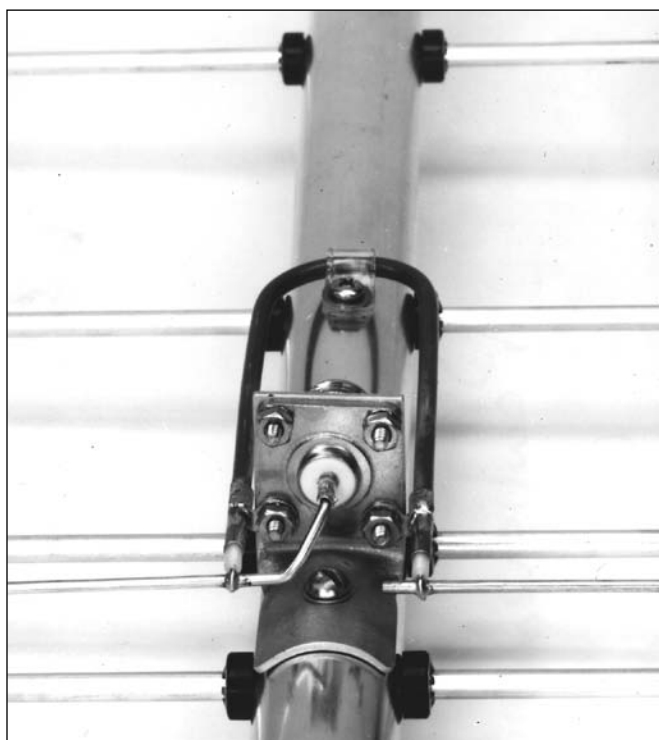


Figure 15.46 — Several views of the driven element and T match.

com). 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 made with black Delrin insulators. Suitable insulators and retainers (“keepers”) are available from Directive Systems (www.directive-systems.com).

The driven element uses a UG-58A/U connector mounted on a small bracket. The UG58A/U 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/U or RG-142/U Teflon-insulated cable could be used if UT-141 cannot be obtained. **Figure 15.46** shows details of the driven-element construction. Driven element dimensions are given in **Figure 15.47**.

Dimensions for the 22-element Yagi are listed in

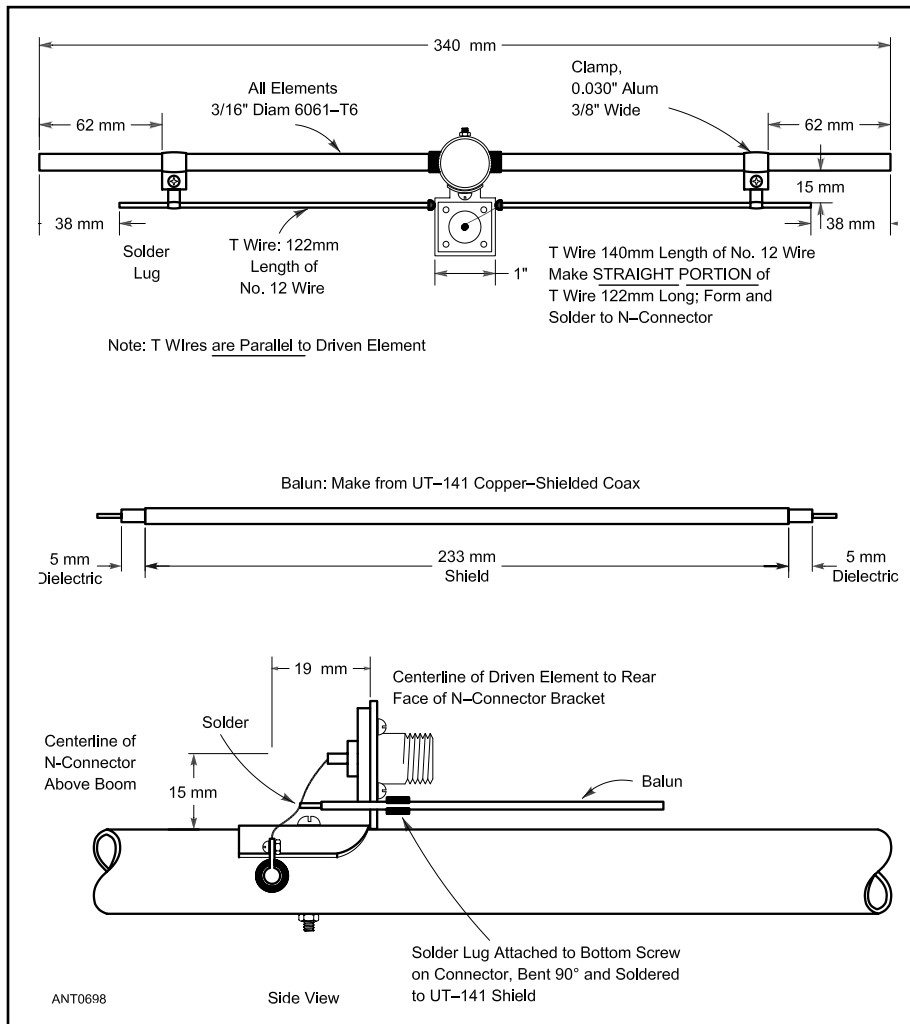


Figure 15.47 — Details of the driven element and T match for the 22-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna. See text.

Table 15-19. Figure 15.48 details the Yagi's boom layout. Element material can be either $\frac{3}{16}$ inch 6061-T6 aluminum rod or hard aluminum welding rod.

A 24-foot-long, 10.6λ , 33-element Yagi was also built. The construction method used were the same as for 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 15-20** lists the proper dimensions for the antenna when built with the previously given boom diameters. The boom layout is shown in **Figure 15.49**, and the driven element is described in **Figure 15.50**. The 33-element Yagi exhibits the same clean pattern traits as the 22-element Yagi (see **Figure 15.51**). 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.

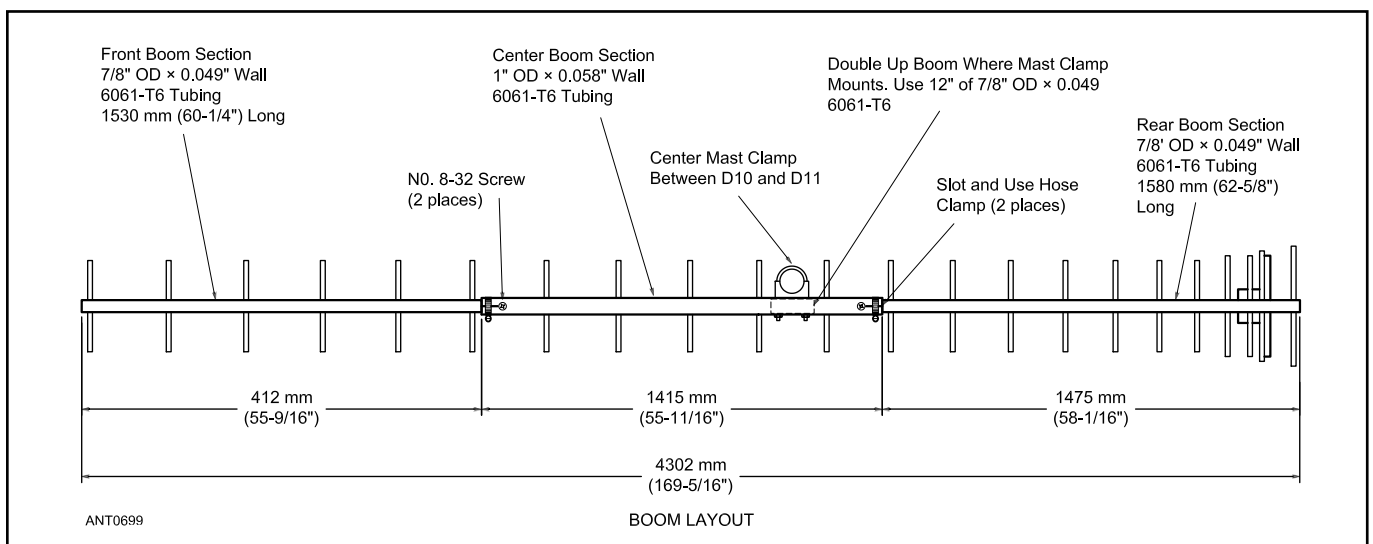


Figure 15.48 — Boom-construction information for the 22-element Yagi Lengths are given in millimeters to allow precise duplication of the antenna. See text.

Table 15-19
Dimensions for the 22-Element 432-MHz Yagi

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

Table 15-20
Dimensions for the 33-Element 432-MHz Yagi

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

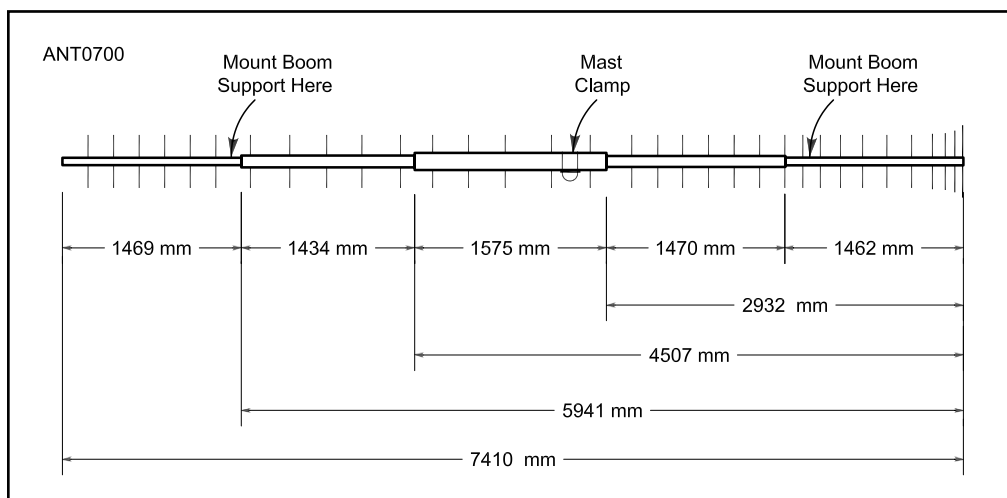


Figure 15.49 — Boom-construction information for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

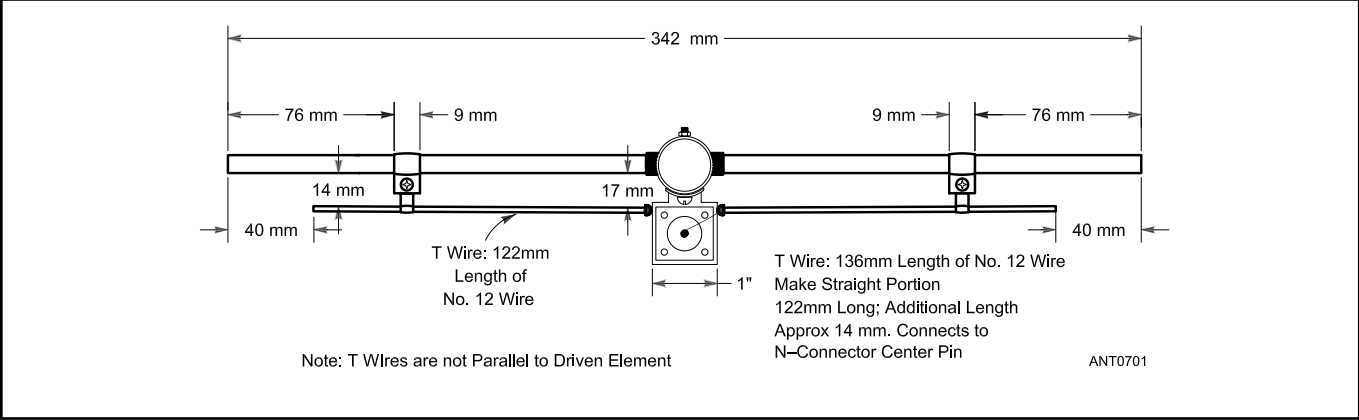


Figure 15.50 — Details of the driven element and T match for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

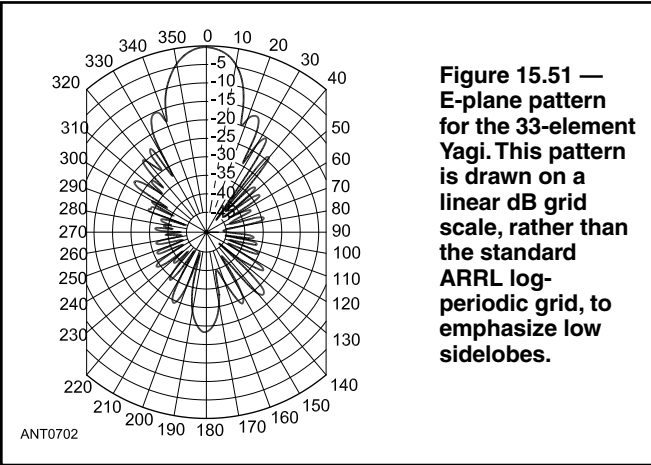


Figure 15.51 — E-plane pattern for the 33-element Yagi. This pattern is drawn on a linear dB grid scale, rather than the standard ARRL log-periodic grid, to emphasize low sidelobes.

15.3.6 QUAGI ANTENNAS

At higher frequencies, especially 420 MHz and above, Yagi arrays using dipole-driven elements can be difficult to feed and match, unless special care is taken to keep the feed point impedance relatively high by proper element spacing and tuning. The cubical quad described earlier overcomes the feed problems to some extent. When many parasitic elements are used, however, the loops are not nearly as convenient to assemble and tune as are straight cylindrical ones used in conventional Yagis. The *Quagi*, designed and popularized by Wayne Overbeck, N6NB, is an antenna having a full-wave loop driven element and reflector, and Yagi type straight rod directors. He first published information on this antenna in 1977. (See Bibliography.)

**Table 15-21
Dimensions, Eight-Element Quagi**

Element Lengths	144.5 MHz	147 MHz	Frequency 222 MHz	432 MHz	446 MHz
Reflector ¹	86 ⁵ / ₈ "	85"	56 ³ / ₈ "	28"	27 ¹ / ₈ "
Driven ²	82"	80"	53 ¹ / ₂ "	26 ⁵ / ₈ "	25 ⁷ / ₈ "
Directors	35 ¹⁵ / ₁₆ " to 35" in ³ / ₁₆ " steps	35 ⁵ / ₁₆ " to 34 ³ / ₈ " in ³ / ₁₆ " steps	23 ³ / ₈ " to 23 ³ / ₄ " in ¹ / ₈ " steps	11 ³ / ₄ " to 11 ¹ / ₂ " in ¹ / ₁₆ " steps	11 ³ / ₈ " to 11 ¹ / ₁₆ " in ¹ / ₁₆ " steps
Spacing					
R-DE	21"	20 ¹ / ₂ "	13 ⁵ / ₈ "	7"	6.8"
DE-D1	15 ³ / ₄ "	15 ³ / ₈ "	10 ¹ / ₄ "	5 ¹ / ₄ "	5.1"
D1-D2	33"	32 ¹ / ₂ "	21 ¹ / ₂ "	11"	10.7"
D2-D3	17 ¹ / ₂ "	17 ¹ / ₈ "	11 ⁵ / ₈ "	5.85"	5.68"
D3-D4	26.1"	25 ⁵ / ₈ "	17"	8.73"	8.46"
D4-D5	26.1"	25 ⁵ / ₈ "	17"	8.73"	8.46"
D5-D6	26.1"	25 ⁵ / ₈ "	17"	8.73"	8.46"
Stacking Distance Between Bays	11'	10' 10"	7' 1 ¹ / ₂ "	3'7"	3' 5 ⁵ / ₈ "

¹All #12 AWG TW (electrical) wire, closed loops.
²All #12 AWG TW wire loops, fed at bottom.

Quagi Construction

There are a few tricks to Quagi building, but nothing very difficult or complicated is involved. In fact, Overbeck mass produced as many as 16 in one day. **Table 15-21** and **Table 15-22** give the dimensions for Quagis for various frequencies up to 446 MHz.

For the designs of Tables 15-21 and 15-22, the boom is *wood* or any other nonconductor (such as, fiberglass or Plexiglas). If a metal boom is used, a new design and new element lengths will be required. Many VHF antenna builders

Table 15-22
432-MHz, 15-Element, Long Boom Quagi
Construction Data

<i>Element Lengths</i> <i>(Inches)</i>	<i>Interelement Spacing</i> <i>(Inches)</i>
R — 28	R-DE — 7
DE — $26\frac{5}{8}$	DE-D1 — $5\frac{1}{4}$
D1 — $11\frac{3}{4}$	D1-D2 — 11
D2 — $11\frac{1}{16}$	D2-D3 — $5\frac{7}{8}$
D3 — $11\frac{5}{8}$	D3-D4 — $8\frac{3}{4}$
D4 — $11\frac{9}{16}$	D4-D5 — $8\frac{3}{4}$
D5 — $11\frac{1}{2}$	D5-D6 — $8\frac{3}{4}$
D6 — $11\frac{7}{16}$	D6-D7 — 12
D7 — $11\frac{3}{8}$	D7-D8 — 12
D8 — $11\frac{5}{16}$	D8-D9 — $11\frac{1}{4}$
D9 — $11\frac{5}{16}$	D9-D10 — $11\frac{1}{2}$
D10 — $11\frac{1}{4}$	D10-D11 — $9\frac{3}{16}$
D11 — $11\frac{3}{16}$	D11-D12 — $12\frac{3}{8}$
D12 — $11\frac{1}{8}$	D12-D13 — $13\frac{3}{4}$
D13 — $11\frac{1}{16}$	

Boom: 1 × 2 inch × 12-ft Douglas fir, tapered to $\frac{5}{8}$ inch at both ends.

Driven element: #12 AWG TW copper wire loop in square configuration, fed at bottom center with type N connector and 52-Ω coax.

Reflector: #12 AWG TW copper wire loop, closed at bottom.

Directors: $\frac{1}{8}$ inch rod passing through boom.

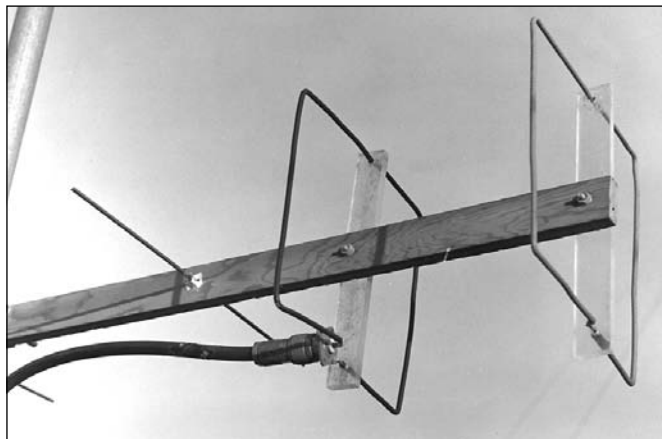


Figure 15.52 — A close-up view of the feed method used on a 432-MHz Quagi. This arrangement produces a low SWR and gain in excess of 13 dBi with a 4-ft 10-inch boom! The same basic arrangement is used on lower frequencies, but wood may be substituted for the Plexiglas spreaders. The boom is $\frac{1}{2}$ -inch exterior plywood.

go wrong by failing to follow this rule: If the original uses a metal boom, use the same size and shape metal boom when you duplicate it. If it calls for a wood boom, use a nonconductor. Many amateurs dislike wood booms, but in a salt air environment they outlast aluminum (and surely cost less). Varnish the boom for added protection.

The 144-MHz version is usually built on a 14 foot, 1 × 3 inch boom, with the boom tapered to 1 inch at both ends. Clear pine is best because of its light weight, but construction grade Douglas fir works well. At 222 MHz the boom is under 10 feet long, and most builders use 1 × 2 or (preferably) $\frac{3}{4}$ × $1\frac{1}{4}$ inch pine molding stock. At 432 MHz, except for long-boom versions, the boom should be $\frac{1}{2}$ inch thick or less. Most builders use strips of $\frac{1}{2}$ -inch exterior plywood for 432 MHz.

The quad elements are supported at the current maxima (the top and bottom, the latter beside the feed point) with Plexiglas or small strips of wood. See **Figure 15.52**. The quad elements are made of #12 AWG copper wire, commonly used in house wiring. Some builders may elect to use #10 AWG wire on 144 MHz and #14 AWG wire on 432 MHz, although this changes the resonant frequency slightly. Solder a type N connector (an SO-239 is often used at 144 MHz) at the midpoint of the driven element bottom side, and close the reflector loop.

The directors are mounted through the boom. They can be made of almost any metal rod or wire of about $\frac{1}{8}$ -inch diameter. Welding rod or aluminum clothesline wire works well if straight. (The designer uses $\frac{1}{8}$ -inch stainless-steel rod obtained from an aircraft surplus store.)

A TV type U bolt mounts the antenna on a mast. A single machine screw, washers and a nut are used to secure the spreaders to the boom so the antenna can be quickly “flattened” for travel. In permanent installations two screws are recommended.

Based on the experiences of Quagi builders, the following hints are offered. First, remember that at 432 MHz even a $\frac{1}{8}$ -inch measurement error results in performance deterioration. Cut the loops and elements as carefully as possible. No precision tools are needed, but accuracy is necessary. Also make sure to get the elements in the right order. The longest director goes closest to the driven element.

Finally, remember that a balanced antenna is being fed with an unbalanced line. Every balun the designer tried introduced more trouble in terms of losses than the feed imbalance caused. Some builders have tightly coiled several turns of the feed line near the feed point to limit line radiation. In any case, the feed line should be kept at right angles to the antenna. Run it from the driven element directly to the supporting mast and then up or down perpendicularly for best results.

A Quagi for 1296 MHz

This Quagi is designed for the 1296-MHz band, where good performance is extremely difficult to obtain from homemade conventional Yagis. **Figure 15.53** shows the construction and **Table 15-23** gives the design information for antennas with 10, 15 and 25 elements.

At 1296 MHz, even slight variations in design or building

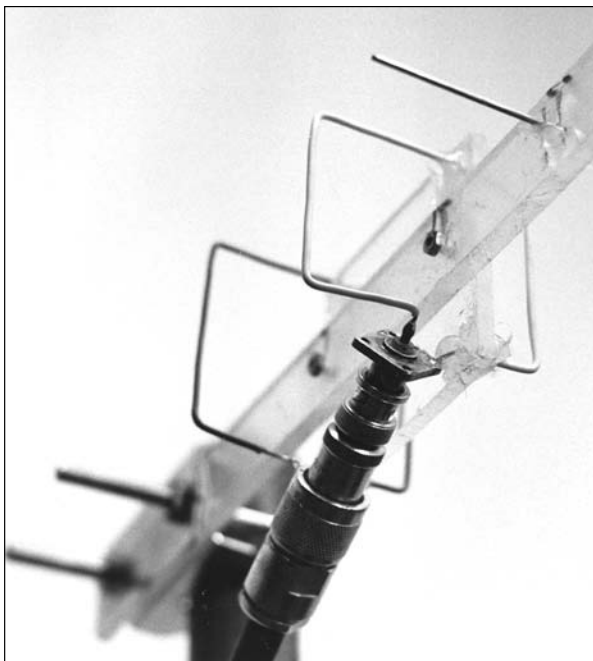
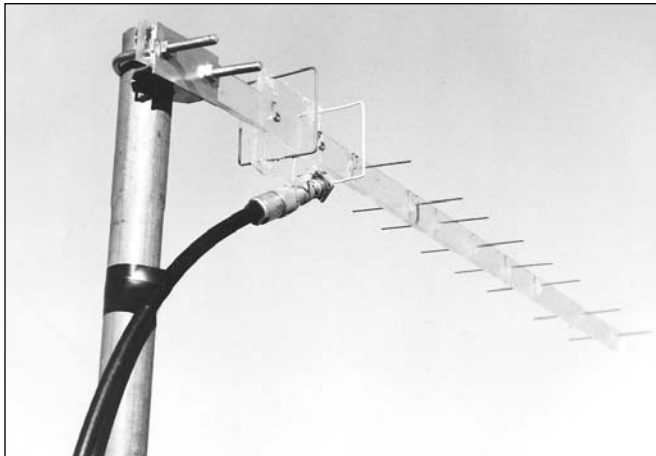


Figure 15.53 — A view of the 10-element version of the 1296-MHz Quagi. It is mounted on a 30-inch Plexiglas boom with a 3 x 3-inch square of Plexiglas to support the driven element and reflector. Note how the driven element is attached to a standard UG-290 BNC connector. The elements are held in place with silicone sealing compound.

materials can cause substantial changes in performance. The 1296 MHz antennas described here work every time — but only if the same materials are used and the antennas are built *exactly* as described. This is not to discourage experimentation, but if modifications to these 1296-MHz antenna designs are contemplated, consider building one antenna as described here, so a reference is available against which variations can be compared.

The Quagis (and the cubical quad) are built on ¼-inch thick Plexiglas booms. The driven element and reflector (and also the directors in the case of the cubical quad) are made of insulated #18 AWG solid copper bell wire, available at hardware and electrical supply stores. Other types and sizes

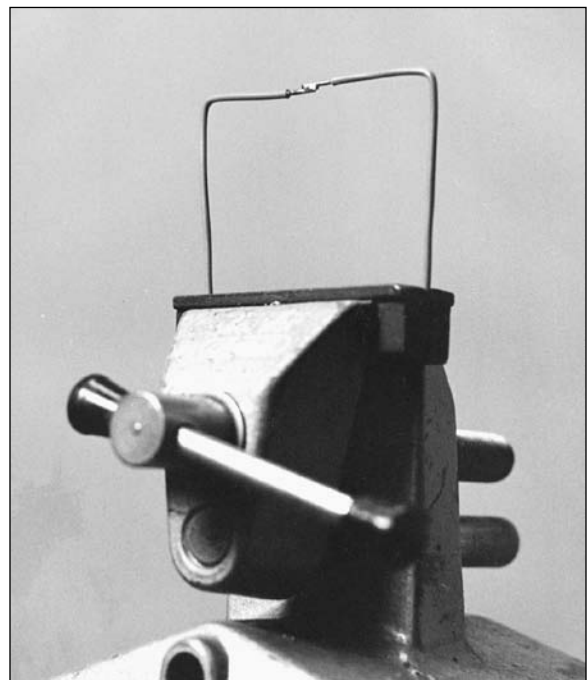
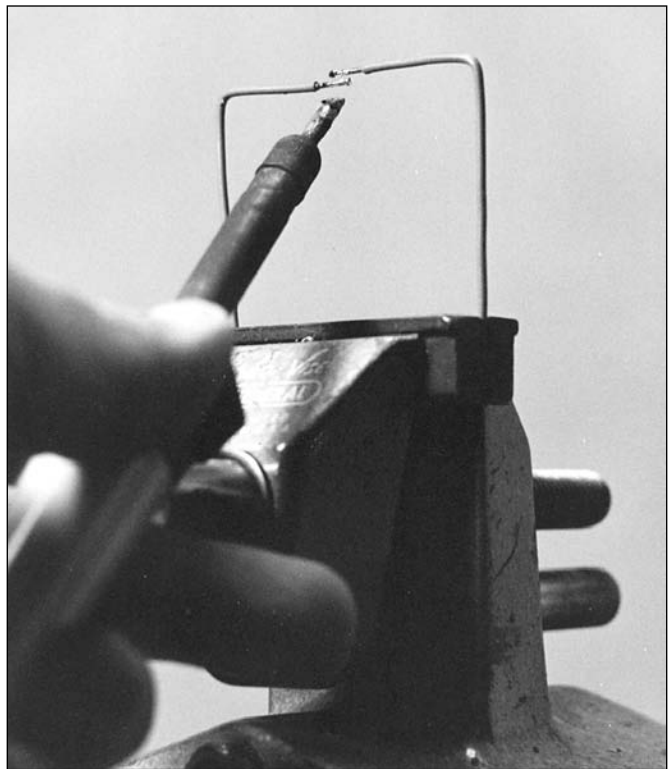


Figure 15.54 — These photos show the construction method used for the 1296-MHz quad type parasitic elements. The two ends of the #18 AWG bell wire are brought together with an overlap of 1/8 inch and soldered.

of wire work equally well, but the dimensions vary with the wire diameter. Even removing the insulation usually necessitates changing the loop lengths.

Quad loops are approximately square (**Figure 15.54**), although the shape is relatively uncritical. The element lengths,

Table 15-23
Dimensions, 1296-MHz Quagi Antennas

Note: All lengths are gross lengths. See text and photos for construction technique and recommended overlap at loop junctions. All loops are made of #18 AWG solid-covered copper bell wire. The Yagi type directors are 1/16-inch brass brazing rod. See text for a discussion of director taper.

Feed: Direct with 52-Ω coaxial cable to UG-290 connector at driven element; run coax symmetrically to mast at rear of antenna.

Boom: 1 1/4-inch thick Plexiglas, 30 inches long for 10-element quad or Quagi and 48 inches long for 15-element Quagi; 84 inches for 25-element Quagi.

10-Element Quagi for 1296 MHz

<i>Element</i>	<i>Length (Inches)</i>	<i>Construction</i>	<i>Element</i>	<i>Interelement Spacing (inches)</i>
Reflector	9.5625	Loop	R-DE	2.375
Driven	9.25	Loop	DE-D1	2.0
Director 1	3.91	Brass rod	D1-D2	3.67
Director 2	3.88	Brass rod	D2-D3	1.96
Director 3	3.86	Brass rod	D3-D4	2.92
Director 4	3.83	Brass rod	D4-D5	2.92
Director 5	3.80	Brass rod	D5-D6	2.92
Director 6	3.78	Brass rod	D6-D7	4.75
Director 7	3.75	Brass rod	D7-D8	3.94
Director 8	3.72	Brass rod		

15-Element Quagi for 1296 MHz

The first 10 elements are the same lengths as above, but the spacing from D6 to D7 is 4.0 inches; D7 to D8 is also 4.0 inches.

Director 9	3.70	D8-D9	3.75
Director 10	3.67	D9-D10	3.83
Director 11	3.64	D10-D11	3.06
Director 12	3.62	D11-D12	4.125
Director 13	3.59	D12-D13	4.58

25-Element Quagi for 1296 MHz

The first 15 elements use the same element lengths and spacings as the 15-element model. The additional directors are evenly spaced at 3.0-inch intervals and taper in length successively by 0.02 inch per element. Thus, D23 is 3.39 inches.

however, *are* critical. At 1296 MHz, variations of 1/16 inch alter the performance measurably, and a 1/8 inch departure can cost several decibels of gain. The loop lengths given are *gross* lengths. Cut the wire to these lengths and then solder the two ends together. There is a 1/8-inch overlap where the two ends of the reflector (and director) loops are joined, as shown in Figure 15.54.

The driven element is the most important of all. The #18 AWG wire loop is soldered to a standard UG-290 chassis-mount BNC connector as shown in the photographs. This exact type of connector must be used to ensure uniformity in construction. Any substitution may alter the driven element electrical length. One end of the 9 1/4 inch driven loop is pushed as far as it can go into the center pin, and is soldered in that position. The loop is then shaped and threaded through small holes drilled in the Plexiglas support. Finally, the other end is fed into one of the four mounting holes on the BNC connector and soldered. In most cases, the best SWR is obtained if the end of the wire just passes through the hole so it is flush with the opposite side of the connector flange.

15.3.7 LOOP YAGIS

The loop Yagi fits into the quad family of antennas, as each element is a closed loop with a length of approximately 1 λ. Several versions are described, so the builder can choose the boom length and frequency coverage desired for the task at hand. Mike Walters, G3JVL, brought the original loop-Yagi design to the amateur community in the 1970s in the out-of-print RSGB *VHF/UHF Manual*. Since then, many versions have been developed with different loop and boom dimensions. G3JVL's *Loopquad* software is available online at g3jvl.com/programPages/loopQuad.php to design loop Yagis. Along with the 1296-MHz version described below construction articles for a 902-MHz and 2304-MHz are included on this book's CD-ROM.

A Loop Yagi for 1296 MHz

Described here are loop Yagis for the 1296-MHz band designed by Chip Angle, N6CA. Three sets of dimensions are given. Good performance can be expected if the dimensions are carefully followed. Check all dimensions before

cutting or drilling anything. The 1296-MHz version is intended for weak-signal operation, while the 1270-MHz version is optimized for FM and mode L satellite operation. The 1283-MHz antenna provides acceptable performance from 1280 to 1300 MHz.

These antennas have been built on 6- and 12-foot booms. Results of gain tests at VHF conferences and by individuals around the country show the gain of the 6-foot model to be about 18 dBi, while the 12-foot version provides about 20.5 dBi. Swept measurements indicate that gain is about 2 dB down from maximum gain at ± 30 MHz from the design frequency. The SWR, however, deteriorates within a few megahertz on the low side of the design center frequency.

The Boom

The dimensions given here apply only to a $\frac{3}{4}$ -inch OD boom. If a different boom size is used, the dimensions must be scaled accordingly. Many hardware stores carry aluminum

tubing in 6- and 8-foot lengths, and that tubing is suitable for a short Yagi. If a 12-foot antenna is planned, find a piece of more rugged boom material, such as 6061-T6 grade aluminum. Do not use anodized tubing. The 12-foot antenna must have additional boom support to minimize boom sag. The 6-foot version can be rear mounted. For rear mounting, allow $4\frac{1}{2}$ inches of boom behind the last reflector to eliminate SWR effects from the support.

The antenna is attached to the mast with a gusset plate. This plate mounts at the boom center. See **Figure 15.55**. Drill the plate mounting holes perpendicular to the element mounting holes (assuming the antenna polarization is to be horizontal).

Elements are mounted to the boom with no. 4-40 machine screws, so a series of no. 33 (0.113 inch) holes must be drilled along the center of the boom to accommodate this hardware. **Figure 15.56** shows the element spacings for different parts of the band. Dimensions should be followed as closely as possible.

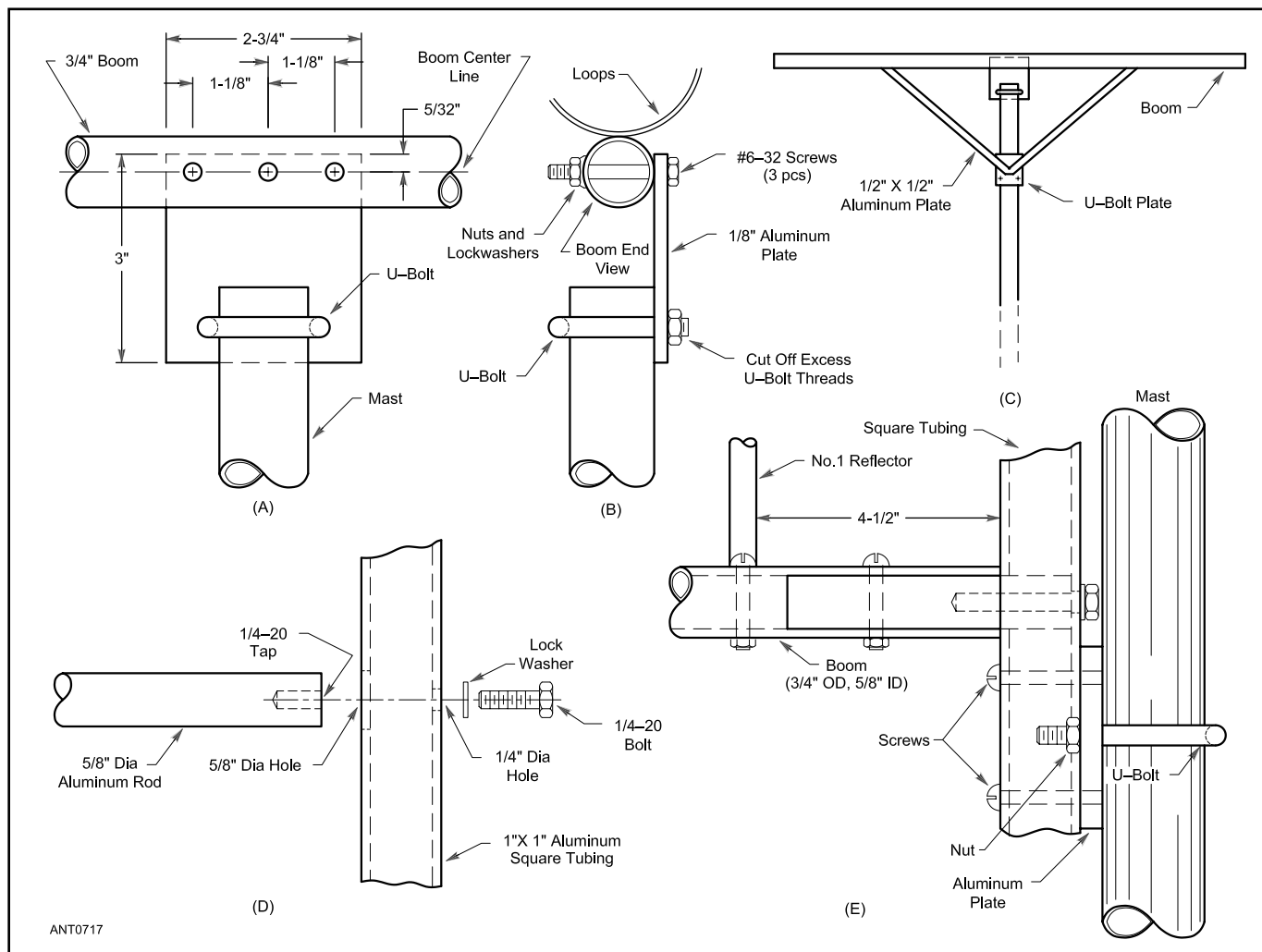
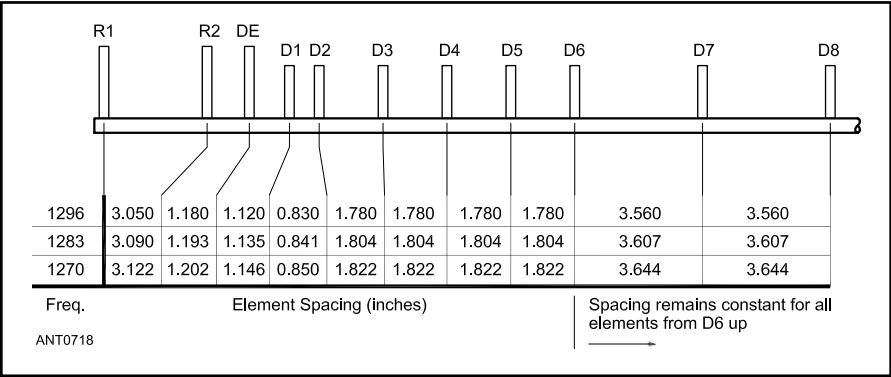


Figure 15.55 — Loop Yagi boom-to-mast plate details are given at A. At B, the mounting of the antenna to the mast is detailed. A boom support for long antennas is shown at C. The arrangement shown in D and E may be used to rear-mount antennas up to 6 or 7 ft long.

Figure 15.56 — Boom drilling dimensions. These dimensions must be carefully followed and the same materials used if performance is to be optimum. Element spacings are the same for all directors after D6 — use as many as necessary to fill the boom.



Parasitic Elements

The reflectors and directors are cut from 0.032-inch thick aluminum sheet and are ¼ inch wide. Figure 15.57 indicates the lengths for the various elements. These lengths apply only to elements cut from the specified material. For best results,

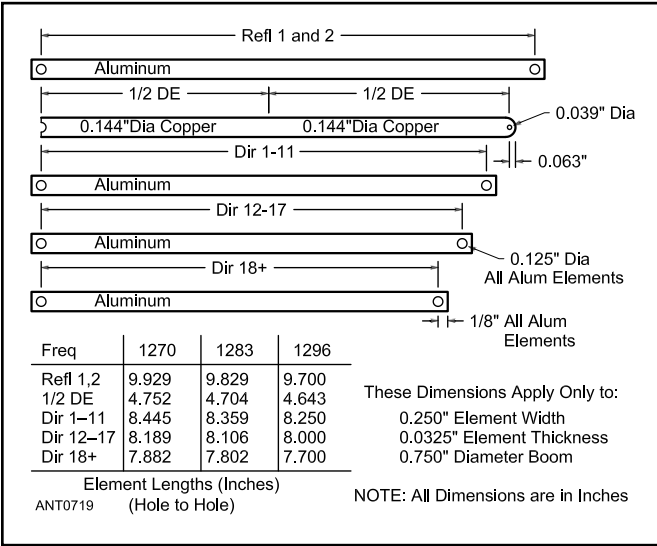


Figure 15.57 — Parasitic elements for the loop Yagi are made from aluminum sheet, the driven element from copper sheet. The dimensions given are for ¼-inch wide by 0.0325-inch thick elements only. Lengths specified are hole to hole distances; the holes are located ⅛ inch from each element end.

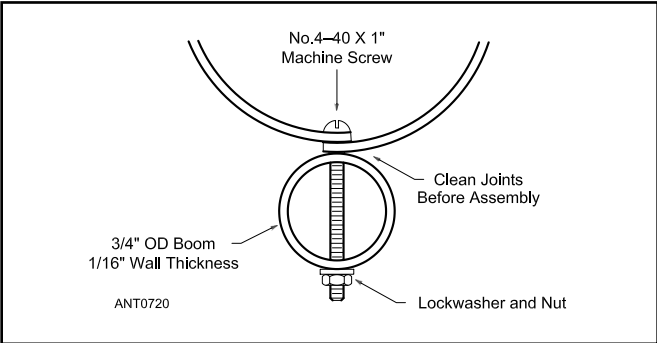


Figure 15.58 — Element-to-boom mounting details.

the element strips should be cut with a shear. If the edges are left sharp, birds won't sit on the elements.

Drill the mounting holes as shown in Figure 15.57 after carefully marking their locations. After the holes are drilled, form each strap into a circle. This is easily done by wrapping the element around a round form. (A small juice can works well.)

Mount the loops to the boom with no. 4-40 × 1-inch machine screws, lock washers and nuts. See **Figure 15.58**. It is best to use only stainless steel or plated-brass hardware. Although the initial cost is higher than for ordinary plated-steel hardware, stainless or brass hardware will not rust and need replacement after a few years. Unless the antenna is painted, the hardware will definitely deteriorate.

Driven Element

The driven element is cut from 0.032-inch copper sheet and is ¼ inch wide. Drill three holes in the strap as detailed in Figure 15.56. Trim the ends as shown and form the strap into a loop similar to the other elements. This antenna is like a quad; if the loop is fed at the top or bottom, it is horizontally polarized.

Driven element mounting details are shown in **Figure 15.59**. A mounting fixture is made from a ¼-20 × 1¼ inch brass bolt. File the bolt head to a thickness of ⅛ inch. Bore a 0.144-inch (no. 27 drill) hole lengthwise through the center of the bolt. A piece of 0.141 inch semi-rigid hardline (UT-141 or equivalent) mounts through this hole and is soldered to the driven loop feed point. The point at which the UT-141 passes through the copper loop and brass mounting fixture should be left unsoldered at this time to allow for matching adjustments when the antenna is completed, although the range of adjustment is not very large.

The UT-141 can be any convenient length. Attach the connector of your choice (preferably type N). Use a short piece of low-loss RG-8 size cable (or ½-inch Hardline) for the run down the boom and mast to the main feed line. For best results, the main feed line should be the lowest loss 50-Ω cable obtainable. Good ⅞-inch hardline has 1.5 dB of loss per 100 feet and virtually eliminates the need for remote mounting of the transmit converter or amplifier.

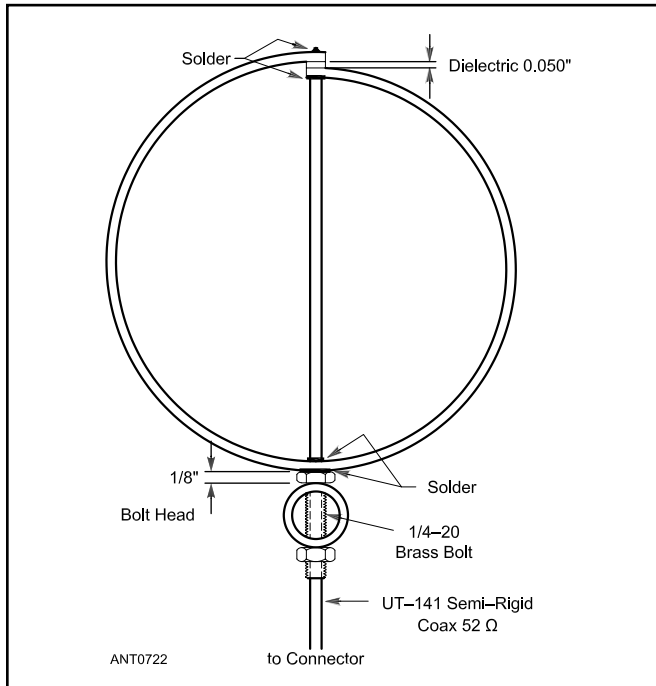


Figure 15.59 — Driven-element details. See Figure 15.57 and the text for additional information.

Tuning the Driven Element

If the antenna is built carefully to the dimensions given, the SWR should be close to 1:1. Just to be sure, check the SWR if you have access to test equipment. Be sure the signal source is clean, however; wattmeters respond to “dirty” signals and can give erroneous readings. If problems are encountered, recheck all dimensions. If they look good, a minor improvement may be realized by changing the shape of the driven element. Slight bending of reflector 2 may also improve the SWR. When the desired match has been obtained, solder the point where the UT-141 jacket passes through the loop and brass bolt.

15.3.8 QUADS FOR VHF

The quad antenna can be built with inexpensive materials, yet its performance is comparable to other arrays of its size. Adjustment for resonance and impedance matching can be accomplished readily.

Quads can be stacked horizontally and vertically to provide high gain, without sharply limiting frequency response. Quads can be mounted side by side or one above the other, or both, in the same general way as other beam antennas. Sets of driven elements can also be mounted in front of a screen reflector. The recommended spacing between adjacent element sides is $\frac{1}{2} \lambda$. Phasing and feed methods are similar to those employed with other antennas described in this chapter.

Parasitic elements ahead of the driven element work in a manner similar to those in a Yagi array. Closed loops can be used for directors by making them 5% shorter than the driven element. Spacings are similar to those for conventional Yagis. In an experimental model the reflector was spaced 0.25λ and

the director 0.15λ . A square array using four 3-element bays worked extremely well.

Because of the small size of the quad at VHF and UHF, many of the mechanical issues associated with HF quads are no longer significant. PVC pipe, fiberglass rod, and wood are all acceptable materials for booms and spreaders.

Quad antennas are best suited for the 6 meter and 2 meter bands. They are very popular for portable and backpacking operation. A quad design for 144 MHz is presented below. See the **Portable Antennas** chapter for a 2-element, 6 meter quad design.

A 144-MHz 4-Element Quad

Element spacing for quad antennas found in the literature ranges from 0.14λ to 0.25λ . Factors such as the number of elements in the array and the parameters to be optimized (F/B ratio, forward gain, bandwidth, etc), determine the optimum element spacing within this range. The 4-element quad antenna described here was designed for portable use, so a compromise between these factors was chosen. This antenna, pictured in **Figure 15.60**, was designed and built by Philip D’Agostino, W1KSC.

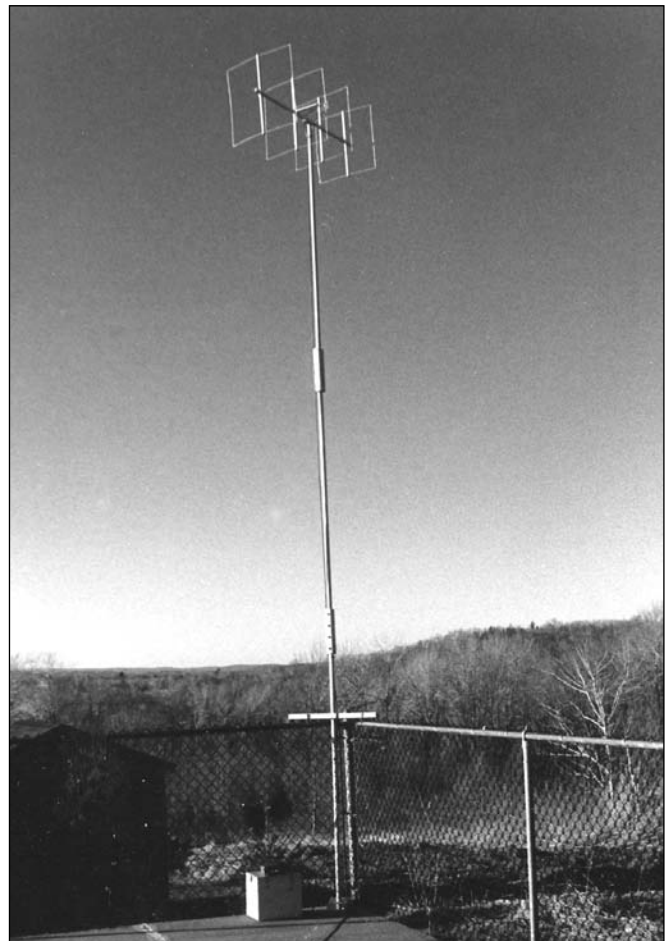


Figure 15.60 — The 4-element 144-MHz portable quad, assembled and ready for operation. Sections of clothes closet poles joined with pine strips make up the mast. (W1MPO photo)

Based on several experimentally determined correction factors related to the frequency of operation and the wire size, optimum design dimensions were found to be as follows.

$$\text{Reflector length (ft)} = 1046.8/f_{\text{MHz}} \quad (\text{Eq } 1)$$

$$\text{Driven element length (ft)} = 985.5/f_{\text{MHz}} \quad (\text{Eq } 2)$$

$$\text{Directors (ft)} = 937.3/f_{\text{MHz}} \quad (\text{Eq } 3)$$

Cutting the loops for 146 MHz provides satisfactory performance across the entire 144-MHz band.

Materials

The quad was designed for quick and easy assembly and disassembly, as illustrated in **Figure 15.61**. Wood (clear trim pine) was chosen as the principal building material because of its light weight, low cost and ready availability. Pine is used for the boom and element supporting arms. Round wood clothes closet poles comprise the mast material. Strips connecting the mast sections are made of heavier pine trim. Elements are made of #8 AWG aluminum wire. Plexiglas is used to support the feed point. **Table 15-24** lists the hardware and other parts needed to duplicate the quad.

Construction

The elements of the quad are assembled first. The mounting holes in the boom should be drilled to accommodate 1½ inch #8 hardware. Measure and mark the locations where the holes are to be drilled in the element spreaders, **Figure 15.62**. Drill the holes in the spreaders just large enough to accept the #8 AWG wire elements. It is important to drill all the holes straight so the elements line up when the antenna is assembled.

Construction of the wire elements is easiest if the directors are made first. A handy jig for bending the elements can be made from a piece of 2 × 3-inch wood cut to the side length of the directors. It is best to start with about 82 inches

of wire for each director. The excess can be cut off when the elements are completed. (The total length of each director is 77 inches.) Two bends should initially be made so the directors can be slipped into the spreaders before the remaining corners are bent. See **Figure 15.63**. Electrician's copper-wire clamps can be used to join the wires after the final bends are made, and they facilitate adjustment of element length. The reflector is made the same way as the directors, but the total length is 86 inches.

Table 15-24

Parts List for the 144 MHz 4-element Quad

Boom: ¾ × ¾ × 48-inch pine
 Driven element support (spreader): ½ × ¾ × 21¼ inch pine
 Driven element feed point strut: ½ × ¾ × 7½ inch pine
 Reflector support (spreader): ½ × ¾ × 22½ inch pine
 Director supports (spreaders): ½ × ¾ × 20¼ inch pine, 2 req'd
 Mast brackets: ¾ × 1½ × 12 inch heavy pine trim, 4 req'd
 Boom to mast bracket: ½ × 1½ × 5 inch pine
 Element wire: Aluminum ground wire (Radio Shack no. 15-035)
 Wire clamps: ¼ inch electrician's copper or zinc plated steel clamps, 3 req'd

Boom hardware:

6 no. 8-32 × 1½ inch stainless steel machine screws
 6 no. 8-32 stainless steel wing nuts
 12 no. 8 stainless steel washers

Mast hardware:

8 hex bolts, ¼-20 × 3½ inch
 8 hex nuts, ¼-20
 16 flat washers

Mast material: 1⅞ inch × 6 ft wood clothes closet poles, 3 req'd

Feed point support plate: 3½ × 2½ inch Plexiglas sheet

Wood preparation materials: Sandpaper, clear polyurethane, wax

Feed line: 52-Ω RG-8 or RG-58 cable

Feed line terminals: Solder lugs for no. 8 or larger hardware, 2 req'd

Miscellaneous hardware: 4 small machine screws, nuts, washers; 2 flat-head wood screws

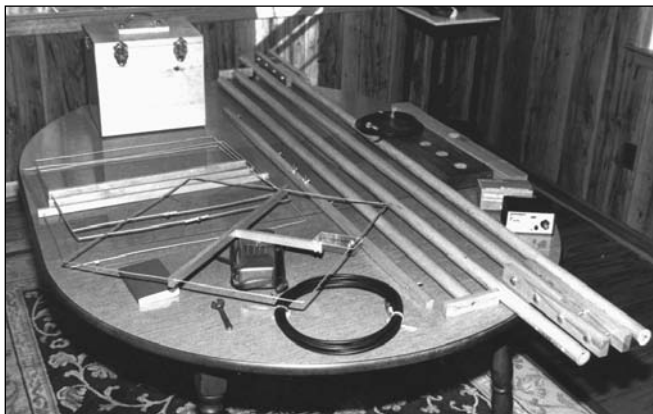


Figure 15.61 — The complete portable quad, broken down for travel. Visible in the foreground is the driven element. The pine box in the background is a carrying case for equipment and accessories. A hole in the lid accepts the mast, so the box doubles as a base for a short mast during portable operation. (W1MPO photo)

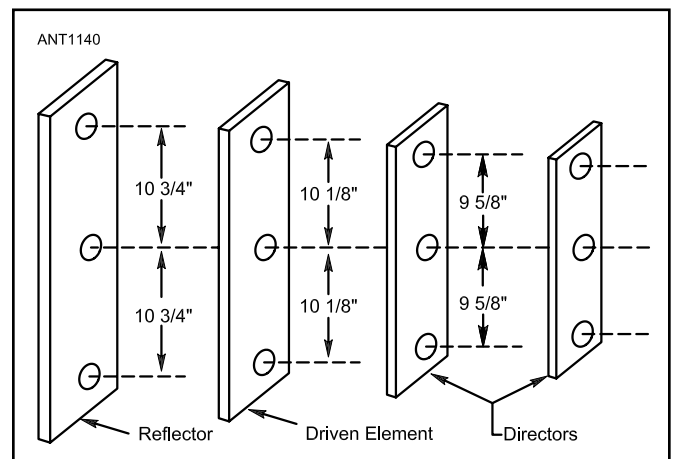


Figure 15.62 — Dimensions for the pine element spreaders for the 144-MHz 4-element quad.

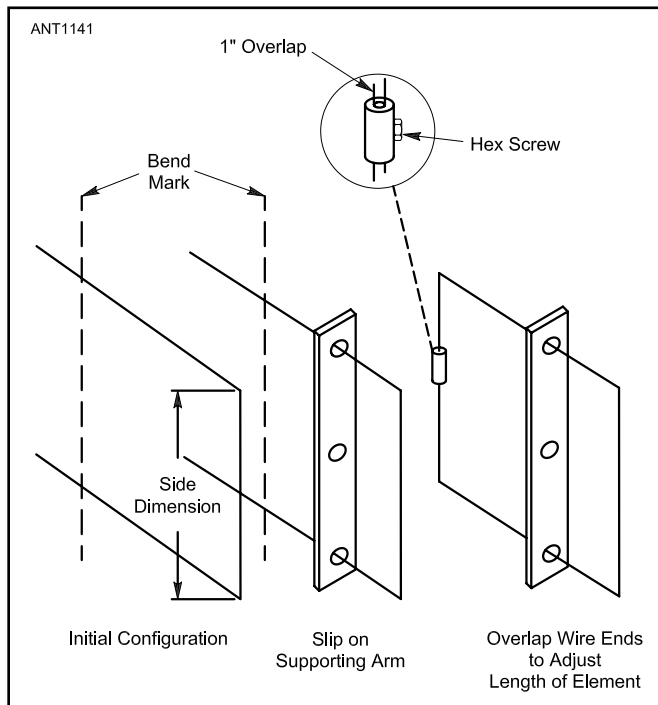


Figure 15.63 — Illustration showing how the aluminum element wires are bent. The adjustment clamp and its location are also shown.

The driven element, total length 81 inches, requires special attention, as the feed attachment point needs to be adequately supported. An extra hole is drilled in the driven element spreader to support the feed point strut, as shown in **Figure 15.64**. A Plexiglas plate is used at the feed point to support the feed point hardware and the feed line. The feed point support strut should be epoxied to the spreader, and a wood screw used for extra mechanical strength.

For vertical polarization, locate the feed point in the center of one side of the driven element, as shown in Figure 15.64. Although this arrangement places the spreader supports at voltage maxima points on the four loop conductors, D'Agostino reports no adverse effects during operation. However, if the antenna is to be left exposed to the weather, the builder may wish to modify the design to provide support for the loops at current maxima points, such as shown in Figure 15.64. (The element of Figure 15.64 should be rotated 90° for horizontal polarization.)

Orient the driven element spreader so that it mounts properly on the boom when the antenna is assembled. Bend the driven element the same way as the reflector and directors, but do not leave any overlap at the feed point. The ends of the wires should be $\frac{3}{4}$ inch apart where they mount on the Plexiglas plate. Leave enough excess that small loops can be bent in the wire for attachment to the coaxial feed line with stainless steel hardware.

Drill the boom as shown in **Figure 15.65**. It is a good idea to use hardware with wing nuts to secure the element spreaders to the boom. After the boom is drilled, clean all the wood parts with denatured alcohol, sand them, and give them two coats of glossy polyurethane. After the polyurethane

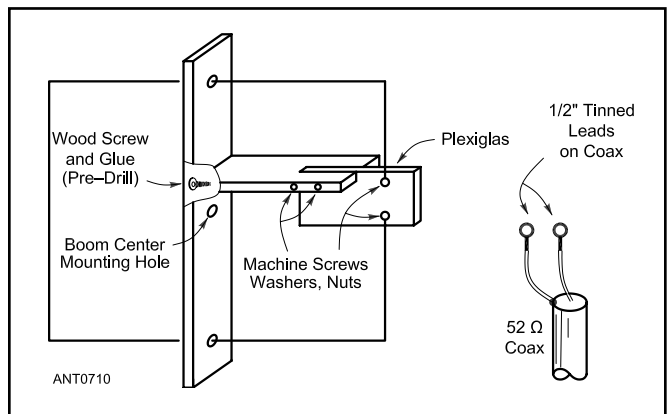


Figure 15.64 — Layout of the driven element of the 144-MHz quad. The leads of the coaxial cable should be stripped to $\frac{1}{2}$ inch and solder lugs attached for easy connection and disconnection. See text regarding impedance at loop support points.

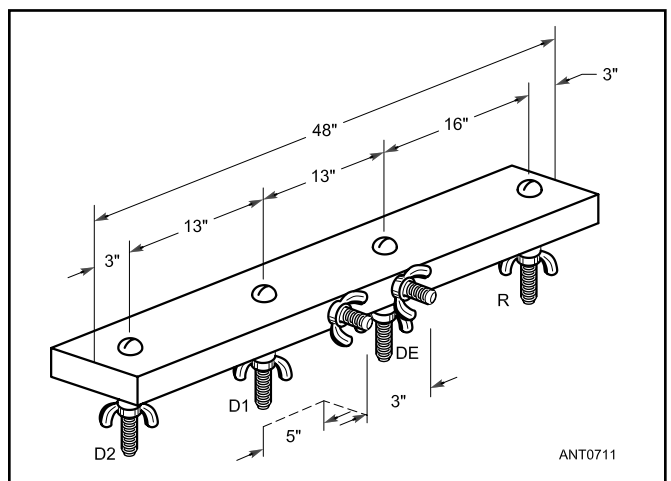


Figure 15.65 — Detail of the boom showing hole center locations and boom to mast connection points.

dries, wax all the wooden parts.

The boom to mast attachment is made next. Square the ends of a 6-foot section of clothes closet pole (a miter box is useful for this). Drill the center holes in both the boom attachment piece and one end of the mast section (**Figure 15.66**). Make certain that the mast hole is smaller than the flat-head screw to be used to ensure a snug fit. Accurately drill the holes for attachment to the boom as shown in Figure 15.66.

Countersink the hole for the flat-head screw to provide a smooth surface for attachment to the boom. Apply epoxy cement to the surfaces and screw the boom attachment piece securely to the mast section. One 6 foot mast is used for attachment to the other mast sections.

Two additional 6-foot mast sections are prepared next. This brings the total mast height to 18 feet. It is important to square the ends of each pole so the mast stands straight when assembled. Mast-section connectors are made of pine as shown in **Figure 15.67**. Using $3\frac{1}{2} \times \frac{1}{4}$ -inch hex bolts, washers and nuts, sections may be attached as needed, for a

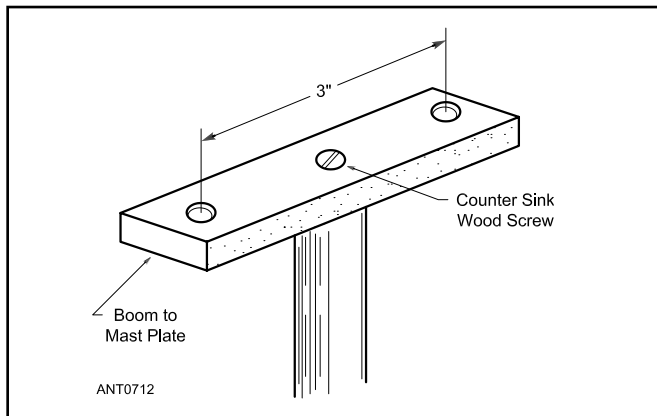


Figure 15.66 — Boom to mast plate for the 144-MHz quad. The screw hole in the center of the plate should be countersunk so the wood screw attaching it to the mast does not interfere with the fit of the boom.

total height of 6, 12 or 18 feet. Drill the holes in two connectors at a time. This ensures good alignment of the holes. A drill press is ideal for this job, but with care a hand drill can be used if necessary.

Line up two mast sections end to end, being careful that they are perfectly straight. Use the predrilled connectors to maintain pole straightness, and drill through the poles, one at a time. If good alignment is maintained, a straight 18-foot mast section can be made. Label the connectors and poles immediately so they are always assembled in the same order.

When assembling the antenna, install all the elements on the boom before attaching the feed line. Connect the coax to the screw connections on the driven element support plate and run the cable along the strut to the boom. From there, the cable should be routed directly to the mast and down. Assemble the mast sections to the desired height. The antenna provides good performance, and has a reasonable SWR curve over the entire 144 MHz band (**Figure 15.68**).

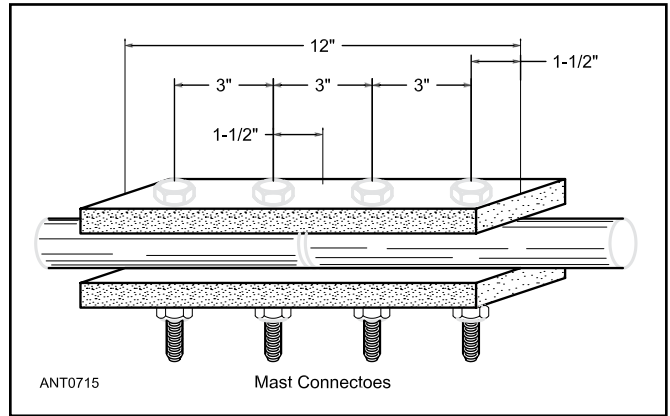


Figure 15.67 — Mast coupling connector details for the portable quad. The plates should be drilled two at a time to ensure the holes line up.

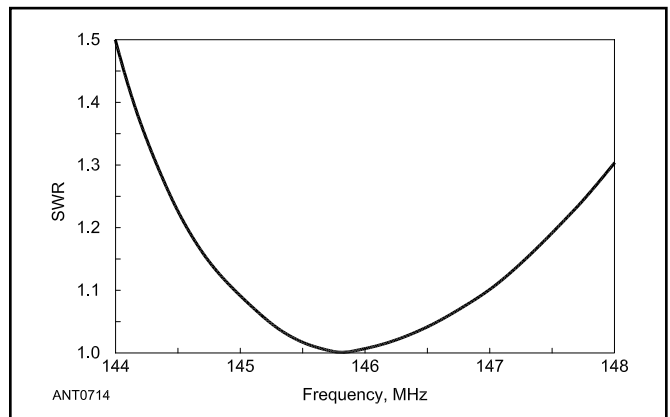


Figure 15.68 — Typical SWR curve for the 144-MHz portable quad. The large wire diameter and the quad design provide excellent bandwidth.

15.4. LOG-PERIODIC AND DISCONE ANTENNAS

Log-periodic antennas designed for use on single VHF or UHF bands have largely been displaced by Yagi designs that can be used across an entire band. The shorter wavelengths at VHF and above make “heavily filled” designs practical that can cover wide frequency ranges. (The design of log-periodic antennas was presented in the **Log-Periodic Dipole Arrays** chapter. See also the short article “V-Shaped Elements versus Straight Elements” by K4ERO on this book’s CD-ROM.)

Operation on several bands with a single antenna makes the log-periodic antenna a popular choice for the amateur with limited antenna options. An example of such a design is the Tennadyne T-28 shown in **Figure 15.69**. This antenna covers 50 to 1300 MHz with a boom length of only 12 feet.



Figure 15.69 — The Tennadyne T-28 covers 50-1300 MHz with boom length of 12 feet.

Yes, That's a TV Antenna!

If you have noticed the similarities between TV-receive antennas and the log-periodic antennas that cover the amateur VHF and lower UHF bands, you are not alone! In an article included on this book's CD-ROM, John Stanley, K4ERO, shows how to modify a mid-sized log-periodic originally designed for receiving TV broadcasts into a stealthy, yet effective ham antenna covering 50 through 222 MHz. For hams limited to TV-antennas only, this might be a good solution to getting on at least a few of the ham bands and you can answer truthfully when asked about your new "TV antenna"!

In addition, the antenna looks very much like a TV-receive antenna, attracting much less attention than a stack of mono-band Yagis for the same frequency range!

Two VHF log-periodic designs are presented by reprints of *QST* articles included on this book's CD-ROM. The first is a single-band design covering 2 meters, "An LPDA for 2 Meter Plus," by L.B. Cebik, W4RNL (SK). The antenna, described in **Figure 15.70**, covers 130-170 MHz and can be used for listening to air band and public safety channels along with transmit and receive operation across 2 meters.

The second design is a three-band log-periodic covering the 144, 222, and 432 MHz bands, "A Three-Band Log-Periodic Antenna," by Robert Heslin, K7RTY, from

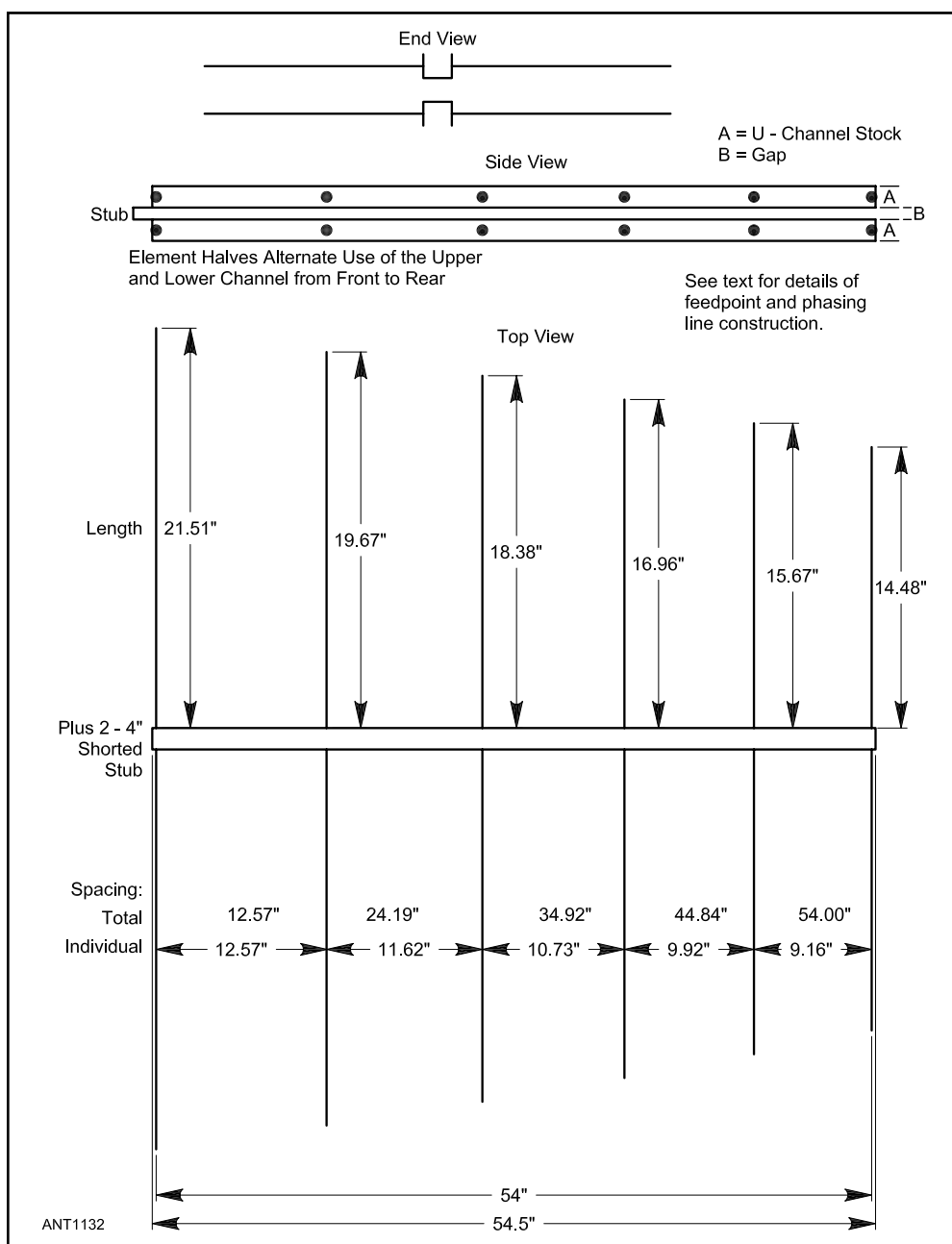


Figure 15.70 — Outline and sketch of the dimensions for the 2 meter Plus log-periodic antenna covering 130 to 170 MHz.

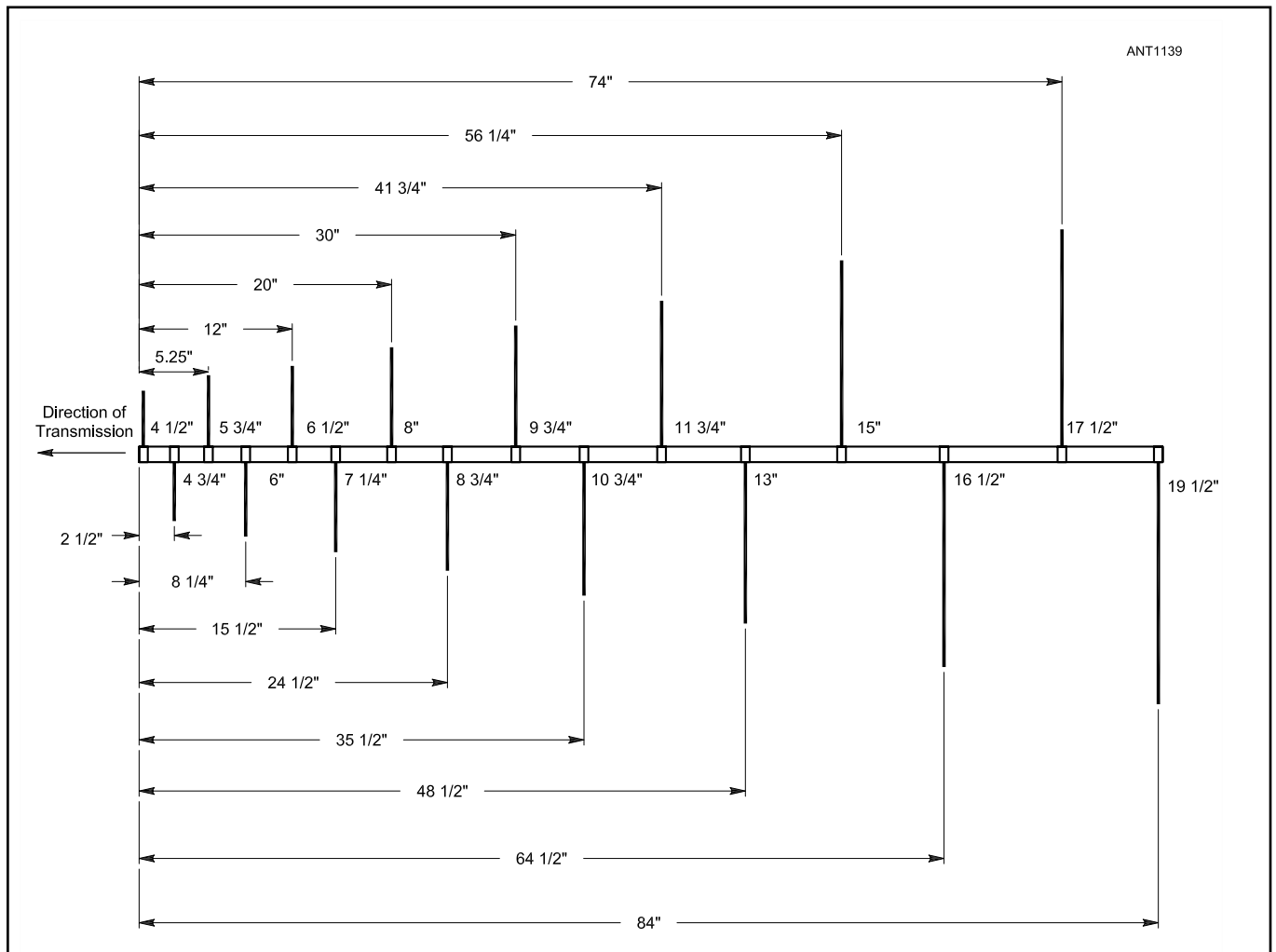


Figure 15.71 — Outline and sketch of the dimensions for the log-periodic antenna covering the 144, 222, and 432 MHz bands.

June 1963 *QST*. This antenna is shown in **Figure 15.71**. The design is based on the same principles used today and the antenna is similar to that of commercial models covering the same frequency range.

The wideband discone antenna is a very popular omnidirectional antenna for scanner use at VHF and above with numerous commercial models available. (Discone design is discussed in the **Multiband Antennas** chapter.) Discones

for VHF and UHF coverage are fairly simple to build, such as the design shown in **Figure 15.72** from the May 2003 *QST* article, “A VHF/UHF Discone Antenna,” by Bob Patterson, K5DZE. The antenna is constructed from wire-mesh hardware cloth but sheet metal or heavy screen can be used. As the author mentions in the article, even aluminum foil on cardboard worked fine as an indoor receive antenna!

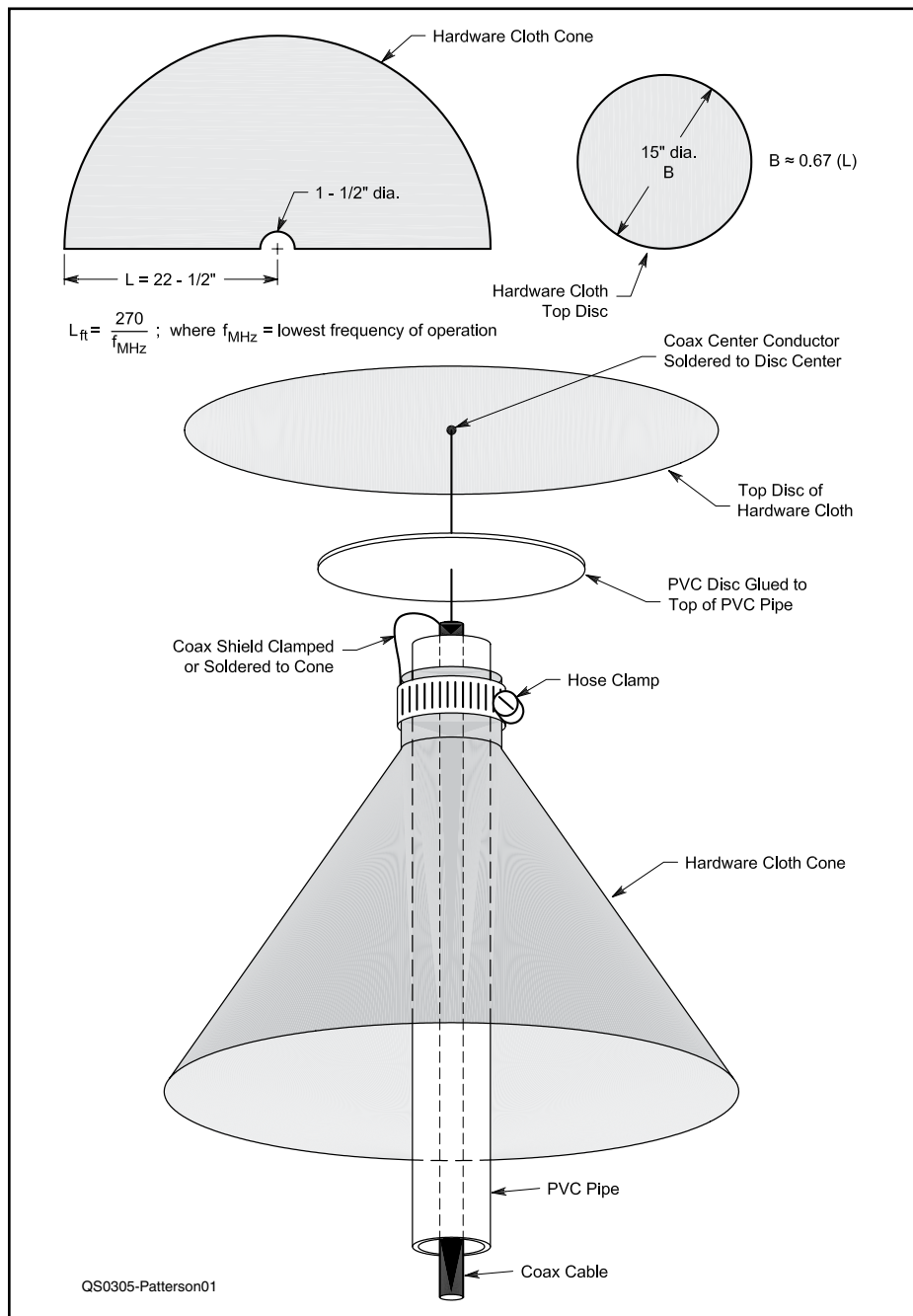


Figure 15.72 — Construction details for a VHF/UHF discone antenna. The largest dimension of the discone is determined by the lowest frequency of use.

15.5 REFLECTOR ANTENNAS

When a single driven element is used, the reflector screen may be bent to form an angle, giving an improvement in the radiation pattern and gain. At 222 and 420 MHz its size assumes practical proportions, and at 902 MHz and higher, practical reflectors can approach ideal dimensions (very large in terms of wavelengths), resulting in more gain and sharper patterns. The corner can be used at 144 MHz, though usually at much less than optimum size. For a given aperture, the

reflector does not equal a parabola in gain, but it is simple to construct, broadband, and offers gains from about 9 to 14 dBi, depending on the angle and size. This section was written by Paul M. Wilson, W4HHK (SK).

15.5.1 CORNER REFLECTORS

The corner angle can be 90, 60 or 45°, but the side length must be increased as the angle is narrowed. For a 90° corner,

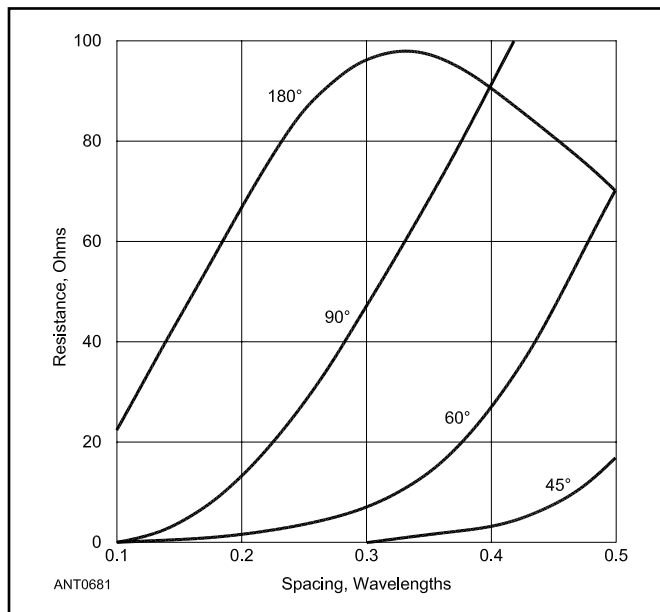


Figure 15.73 — Radiation resistance of the driven element in a corner reflector array for corner angles of 180° (flat sheet), 90°, 60° and 45° as a function of spacing D , as shown in Figure 15.74.

the driven element spacing can be anything from 0.25 to 0.7λ , 0.35 to 0.75λ for 60° , and 0.5 to 0.8λ for 45° . In each case the gain variation over the range of spacings given is about 1.5 dB. Because the spacing is not very critical to gain, it may be varied for impedance-matching purposes. Closer spacings yield lower feed point impedances, but a folded dipole radiator could be used to raise this to a more convenient level.

Radiation resistance is shown as a function of spacing in **Figure 15.73**. The maximum gain obtained with minimum spacing is the primary mode (the one generally used at 144, 222 and 432 MHz to maintain reasonable side lengths). A 90° corner, for example, should have a minimum side length (S , **Figure 15.74**) equal to twice the dipole spacing, or 1λ long for $0.5\text{-}\lambda$ spacing. A side length greater than 2λ is ideal. Gain with a 60° or 90° corner reflector with $1\text{-}\lambda$ sides is about 10 dB. A 60° corner with $2\text{-}\lambda$ sides has about 13 dBi gain, and a 45° corner with $3\text{-}\lambda$ sides has about 14 dBi gain.

Reflector length (L , **Figure 15.74**) should be a minimum of 0.6λ . Less than that spacing causes radiation to increase to the sides and rear, and decreases gain.

Spacing between reflector rods (G , **Figure 15.74**) should not exceed 0.06λ for best results. A spacing of 0.06λ results

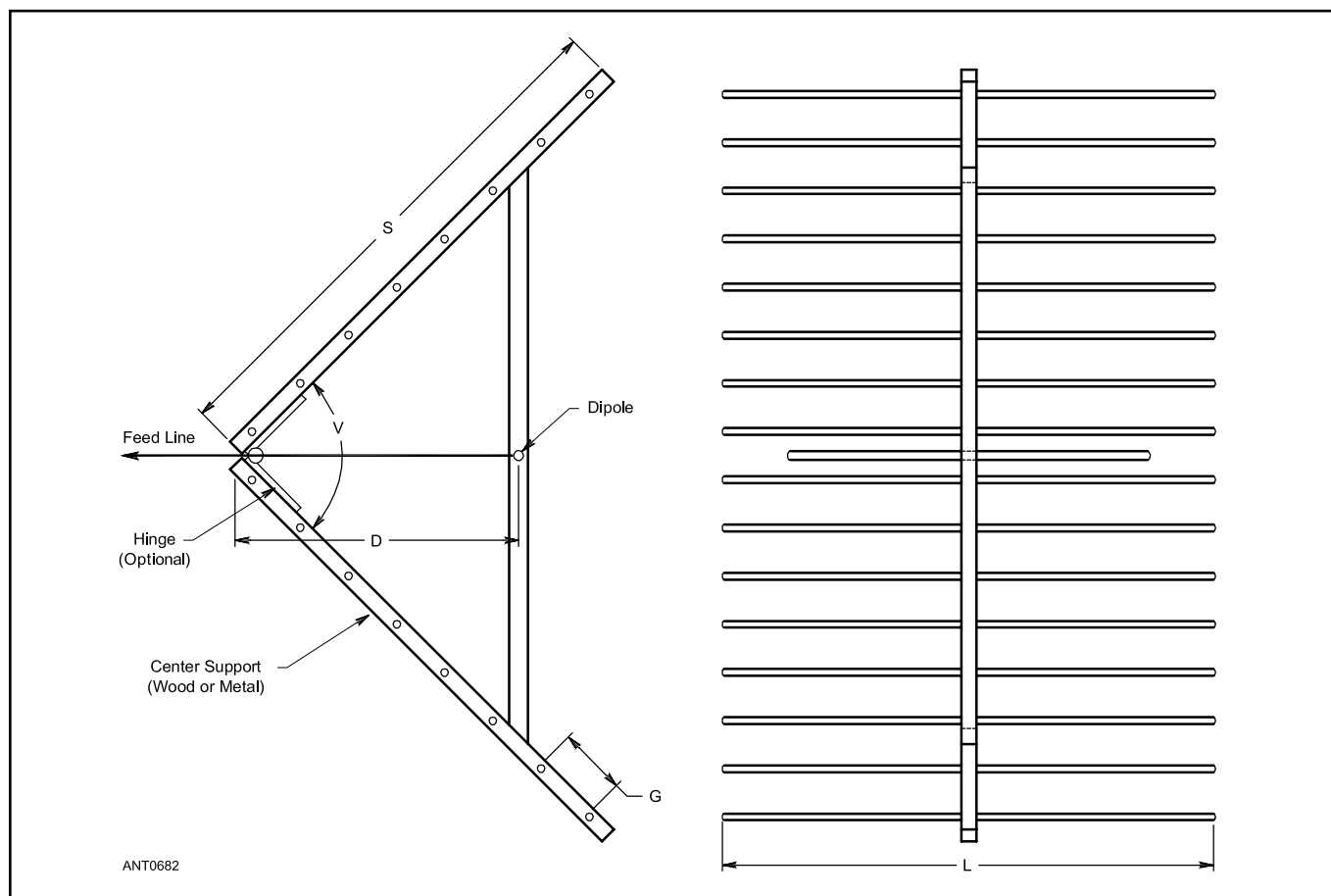


Figure 15.74 — Construction of a corner reflector array. The frame can be wood or metal. Reflector elements are stiff wire or tubing. Dimensions for several bands are given in Table 15-25. Reflector element spacing, G , is the maximum that should be used for the frequency; closer spacings are optional. The hinge permits folding for portable use.

Table 15-25
Dimensions of Corner Reflector Arrays for VHF and UHF

Freq (MHz)	Side Length, S (inches)	Dipole to Vertex, D (inches)	Reflector Length, L (inches)	Reflector Spacing, G (inches)	Corner Angle, Vo	Radiation Resistance (Ω)
144*	65	27½	48	7¾	90	70
144	80	40	48	4	90	150
222*	42	18	30	5	90	70
222	52	25	30	3	90	150
222	100	25	30	Screen	60	70
420	27	8¾	16¼	2⅝	90	70
420	54	13½	16¼	Screen	60	70
915	20	6½	25¾	0.65	90	70
915	51	16¾	25¾	Screen	60	65
915	78	25¾	25¾	Screen	45	70
1296	18	4½	27½	½	90	70
1296	48	11¾	27½	Screen	60	65
1296	72	18¼	27½	Screen	45	70
2304	15½	2½	20½	¼	90	70
2304	40	6¾	20½	Screen	60	65
2304	61	10¼	20½	Screen	45	70

*Side length and number of reflector elements somewhat below optimum — slight reduction in gain.

Notes:

915 MHz

Wavelength is 12.9 inches
Side length S is $3 \times D$, dipole
to vertex distance
Reflector length L is 2.0λ
Reflector spacing G is 0.05λ

1296 MHz

Wavelength is 9.11 inches
Side length S is $4 \times D$, dipole
to vertex distance
Reflector length L is 3.0λ
Reflector spacing G is 0.05λ

2304 MHz

Wavelength is 5.12 inches
Side length S is $6 \times D$, dipole
to vertex distance
Reflector length L is 4.0λ
Reflector spacing G is 0.05λ

in a rear lobe that is about 6% of the forward lobe (down 12 dB). A small mesh screen or solid sheet is preferable at the higher frequencies to obtain maximum efficiency and highest F/B ratio, and to simplify construction. A spacing of 0.06λ at 1296 MHz, for example, requires mounting reflector rods about every ½ inch along the sides. Rods or spines may be used to reduce wind loading. The support used for mounting

the reflector rods may be of insulating or conductive material. Rods or mesh weave should be parallel to the radiator.

A suggested arrangement for a corner reflector is shown in Figure 15.74. The frame may be made of wood or metal, with a hinge at the corner to facilitate portable operation or assembly atop a tower. A hinged corner is also useful in experimenting with different angles. **Table 15-25** gives the

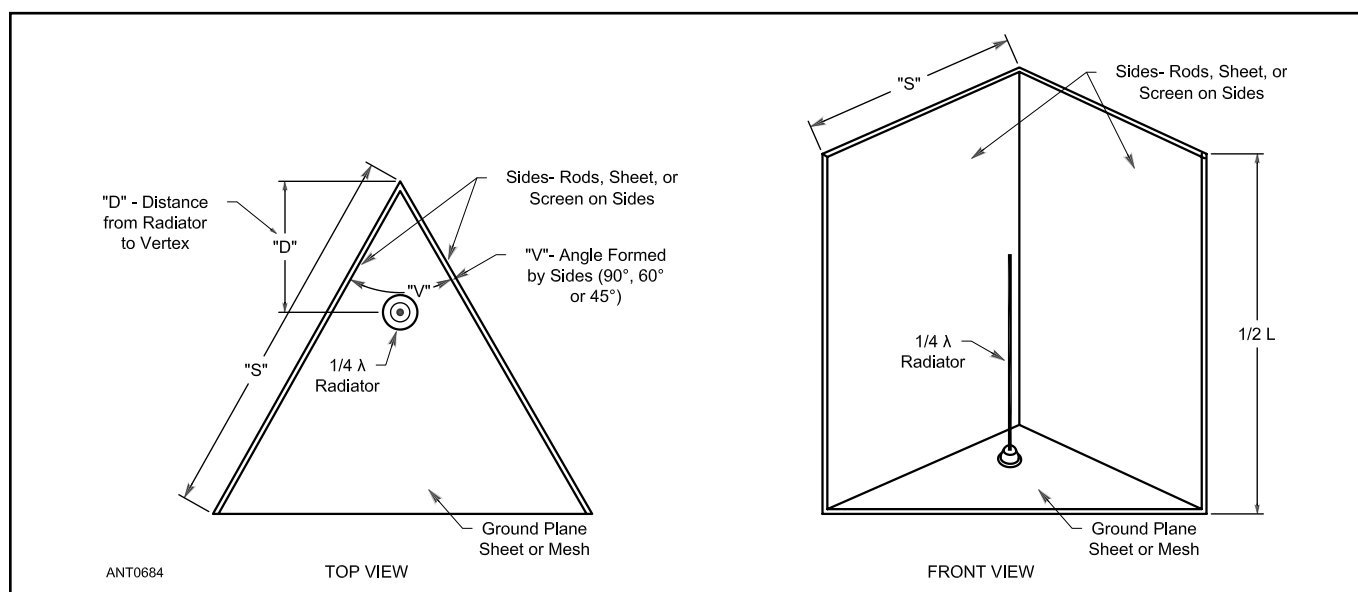


Figure 15.75 — A ground-plane corner reflector antenna for vertical polarization, such as FM communications or packet radio. The dimension ½ L in the front view refers to data in Table 15-25.

principal dimensions for corner reflector arrays for 144 to 2300 MHz. The arrays for 144, 222 and 420 MHz have side lengths of twice to four times the driven element spacing. The 915 MHz corner reflectors use side lengths of three times the element spacing, 1296 MHz corners use side lengths of four times the spacing, and 2304 MHz corners employ side lengths of six times the spacing. Reflector lengths of 2, 3, and 4 wavelengths are used on the 915, 1296 and 2304 MHz reflectors, respectively. A $4 \times 6 \lambda$ reflector closely approximates a sheet of infinite dimensions.

A corner reflector may be used for several bands, or for UHF television reception, as well as amateur UHF operation. For operation on more than one frequency, side length and reflector length should be selected for the lowest frequency, and reflector spacing for the highest frequency. The type of driven element plays a part in determining bandwidth, as does the spacing to the corner. A fat cylindrical element (small λ/dia ratio) or triangular dipole (bow tie) gives more bandwidth than a thin driven element. Wider spacings between driven element and corner give greater bandwidths. A small increase in gain can be obtained for any corner reflector by mounting collinear elements in a reflector of sufficient size, but the simple feed of a dipole is lost if more than two elements are used.

A dipole radiator is usually employed with a corner reflector. This requires a balun between the coaxial line and the balanced feed point impedance of the antenna. Baluns are easily constructed of coaxial line on the lower VHF bands, but become more difficult at the higher frequencies. This problem may be overcome by using a ground-plane corner reflector, which can be used for vertical polarization. A ground-plane corner with monopole driven element is shown in **Figure 15.75**. The corner reflector and a $\frac{1}{4} \lambda$ radiator are mounted on the ground plane, permitting direct connection to a coaxial line if the proper spacing is used. The effective aperture is reduced, but at the higher frequencies, second- or third-mode radiator spacing and larger reflectors can be employed to obtain more gain and offset the loss in effective aperture. A J antenna could be used to maintain the aperture area and provide a match to a coaxial line.

For vertical polarization operation, four 90° corner reflectors built back-to-back (with common reflectors) could be used for scanning 360° of horizon with modest gain. Feed line switching could be used to select the desired sector.

15.5.2 TROUGH REFLECTORS

To reduce the overall dimensions of a large corner reflector the vertex can be cut off and replaced with a plane reflector. Such an arrangement is known as a *trough reflector*. See **Figure 15.76**. Performance similar to that of the large corner reflector can thereby be had, provided that the dimensions of S and T as shown in Figure 15.76 do not exceed the limits indicated in the figure. This antenna provides performance very similar to the corner reflector, and presents fewer mechanical problems because the plane center portion is relatively easy to mount on the mast. The sides are considerably shorter, as well.

The gain of both corner reflectors and trough reflectors may be increased by stacking two or more and arranging them to radiate in phase, or alternatively by adding further collinear

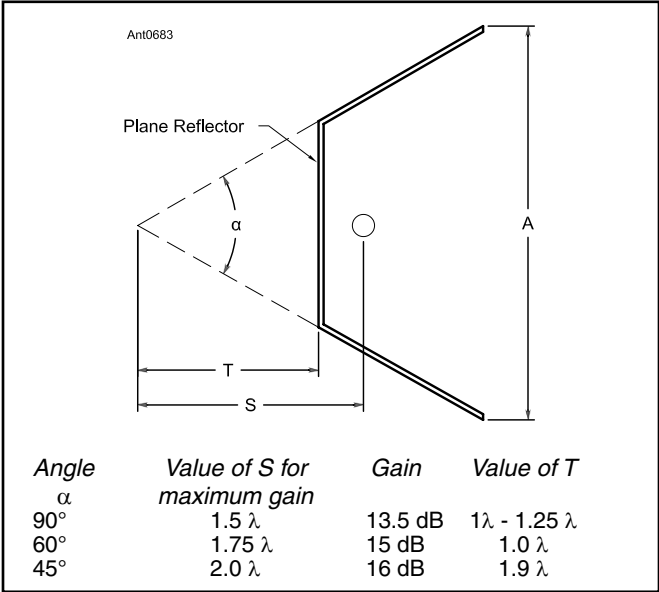


Figure 15.76 — The trough reflector. This is a useful modification of the corner reflector. The vertex has been cut off and replaced by a simple plane section. The tabulated data shows the gain obtainable for greater values of S than those covered in Table 15-25, assuming that the reflector is of adequate size.

dipoles (fed in phase) within a wider reflector. Not more than two or three radiating units should be used, because the great virtue of the simple feeder arrangement would then be lost.

Trough Reflectors for 432 and 1296 MHz

Dimensions are given in **Figure 15.77** for 432- and 1296-MHz trough reflectors. The gain to be expected is 16 dBi and 15 dBi, respectively. A very convenient arrangement, especially for portable operation, is to use a metal hinge at each angle of the reflector. This permits the reflector to be folded flat for transit. It also permits experiments to be carried out with different apex angles.

A housing is required at the dipole center to prevent the entry of moisture and, in the case of the 432-MHz antenna, to support the dipole elements. The dipole may be moved in and out of the reflector to get either minimum SWR or, if this cannot be measured, maximum gain. If a two-stub tuner or other matching device is used, the dipole may be placed to give optimum gain and the matching device adjusted to give optimum match. In the case of the 1296-MHz antenna, the dipole length can be adjusted by means of the brass screws at the ends of the elements. Locking nuts are essential.

The reflector should be made of sheet aluminum for 1296 MHz, but can be constructed of wire mesh (with twists parallel to the dipole) for 432 MHz. To increase the gain by 3 dB, a pair of these arrays can be stacked so the reflectors are barely separated (to prevent the formation of a slot radiator by the edges). The radiating dipoles must then be fed in phase, and suitable feeding and matching must be arranged. A two-stub tuner can be used for matching either a single- or double-reflector system.

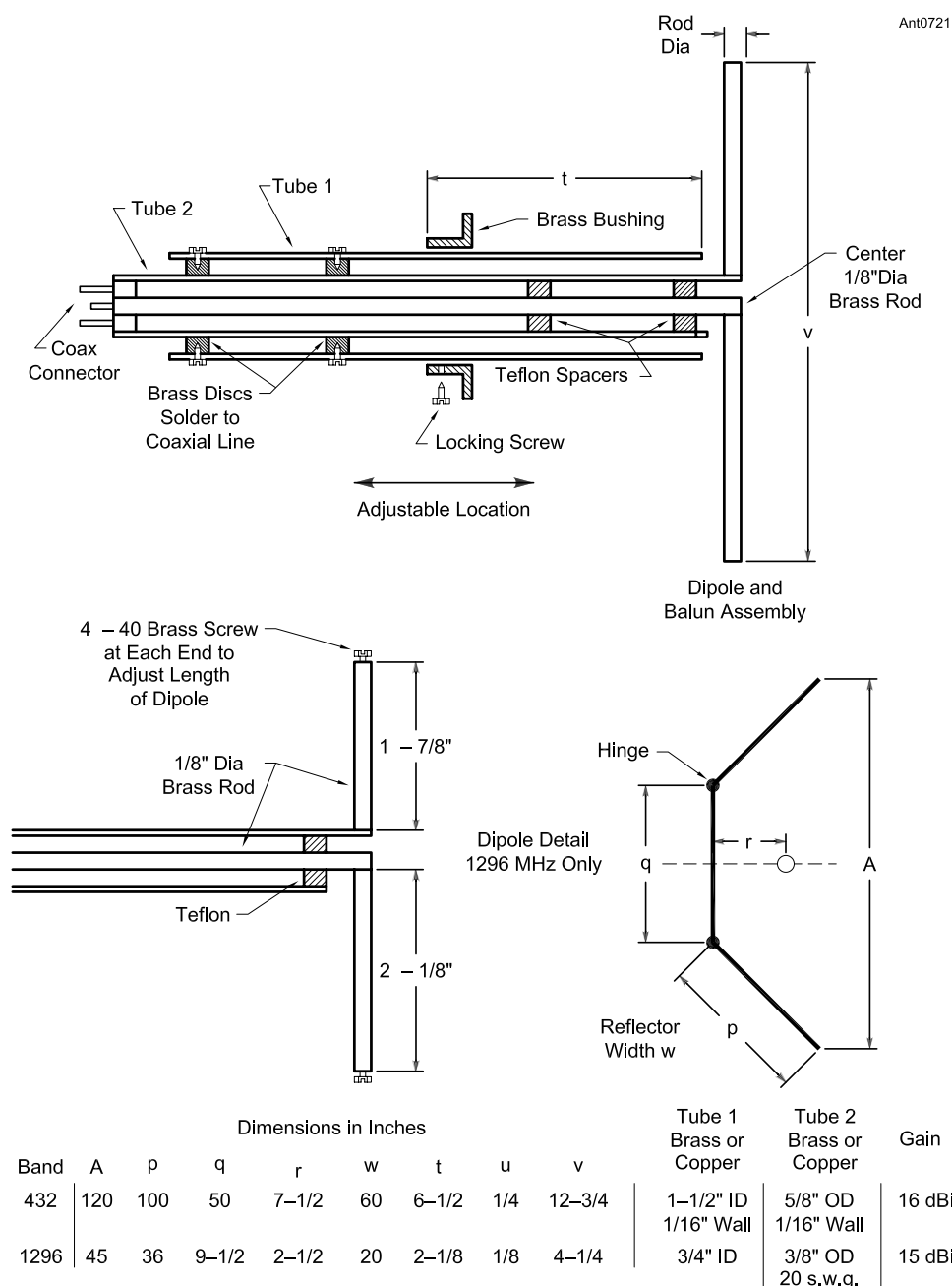


Figure 15.77 — Practical construction information for trough reflector antennas for 432 and 1296 MHz.

15.6 MICROWAVE ANTENNAS

The domain of amateur microwaves begins at 902 MHz and includes all higher frequency bands. (The 10 GHz and higher bands are also referred to as mm-wave bands.) The short wavelength of microwaves enables a wide range of interesting designs quite different from the antennas based on discrete linear and loop elements popular at lower frequencies. At microwaves, surfaces and shapes are used in ways that are impractical at longer wavelengths. This section surveys several common microwave antenna types but the interested reader is encouraged to obtain copies of the RSGB texts listed in the Bibliography for a more complete treatment of amateur microwave antennas.

A caveat for the amateur interested in microwaves — many antenna construction practices that are common on lower frequencies cannot be used at microwave frequencies. This is the most important reason why all who venture to microwaves are not equally successful. When a proven antenna design is used, copy it exactly; don't change *anything*.

Do not allow the mast to pass through the elements, as is common on antennas for lower frequencies. Avoid any unnecessary metal around the antenna: $\frac{1}{4}\lambda$ at 1296 MHz is only a little over 2 inches. Cut all U-bolts and mounting hardware to the minimum length needed so that no resonant or near-resonant conductors are present to couple to the antenna's field.

After antenna performance, feed line loss is the next most important aspect of antenna system design. Mount the antennas to keep feed line losses to an absolute minimum. Antenna height is less important than keeping the line losses low.

Use the best feed line you can get. As an example of why this is important, here are some realistic measurements of common coaxial cables at 1296 MHz (loss per 100 feet):

RG-8, 213, 214 coaxial cable: 11 dB

$\frac{1}{2}$ inch foam/copper hardline: 4 dB

$\frac{7}{8}$ inch foam/copper hardline: 1.5 dB

Preamps should be mounted at the antenna wherever practical and only connectors designed for frequency of operation should be used.

15.6.1 WAVEGUIDES

Above 2 GHz, coaxial cable is a losing proposition for communications operation. Fortunately, at this frequency the wavelength is short enough to allow practical, efficient energy transfer by an entirely different means. A *waveguide* is a conducting tube through which energy is transmitted in the form of electromagnetic waves. The tube is not considered as carrying a current in the same sense that the wires of a two-conductor line do, but rather as a *boundary* that confines the waves in the enclosed space. Skin effect prevents any electromagnetic effects from being evident outside the guide. The energy is injected at one end, either through capacitive or inductive coupling or by radiation, and is removed from the other end in a like manner. Waveguide merely confines the energy of the fields, which are propagated through it to the

receiving end by means of reflections against its inner walls.

Analysis of waveguide operation is based on the assumption that the guide material is a perfect conductor of electricity. Typical distributions of electric and magnetic fields in a rectangular guide are shown in **Figure 15.78**. The intensity of the electric field is greatest (as indicated by closer spacing of the lines of force) at the center along the X dimension (Figure 15.78C), diminishing to zero at the end walls. The fields must diminish in this manner, because the existence of any electric field parallel to the walls at the surface would cause an infinite current to flow in a perfect conductor. Waveguides, of course, cannot carry RF in this fashion.

Modes of Propagation

Figure 15.78 represents the most basic distribution of the electric and magnetic fields in a waveguide. There are an infinite number of ways in which the fields can arrange

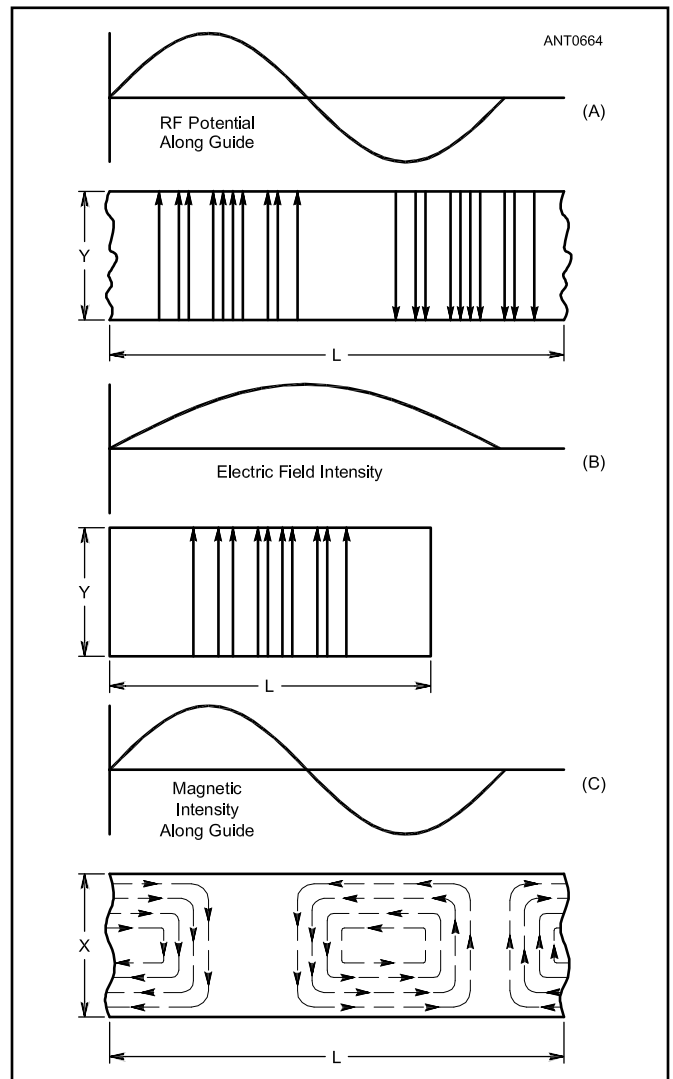


Figure 15.78 — Field distribution in a rectangular waveguide. The TE₁₀ mode of propagation is depicted.

themselves in a waveguide (for frequencies above the low cutoff frequency of the guide in use). Each of these field configurations is called a *mode*.

The modes may be separated into two general groups. One group, designated *TM* (transverse magnetic), has the magnetic field entirely transverse to the direction of propagation, but has a component of the electric field in that direction. The other type, designated *TE* (transverse electric) has the electric field entirely transverse, but has a component of magnetic field in the direction of propagation. *TM* waves are sometimes called *E waves*, and *TE* waves are sometimes called *H waves*, but the *TM* and *TE* designations are preferred.

The mode of propagation is identified by the group letters followed by two subscript numerals. For example, TE_{10} , TM_{11} , etc. The number of possible modes increases with frequency for a given size of guide, and there is only one possible mode (called the *dominant mode*) for the lowest frequency that can be transmitted. The dominant mode is the one generally used in amateur operation.

Waveguide Dimensions

In a rectangular guide the critical dimension is *X* in Figure 15.78. This dimension must be more than $\frac{1}{2} \lambda$ at the lowest frequency to be transmitted. In practice, the *Y* dimension usually is made about equal to $\frac{1}{2} X$ to avoid the possibility of operation in other than the dominant mode.

Cross-sectional shapes other than a rectangle can be used, the most important being the circular pipe. Much the same considerations apply as in the rectangular case.

Wavelength dimensions for rectangular and circular guides are given in **Table 15-26**, where *X* is the width of a rectangular guide and *r* is the radius of a circular guide. All figures apply to the dominant mode.

Coupling to Waveguides

Energy may be introduced into or extracted from a waveguide or resonator by means of either the electric or magnetic field. The energy transfer frequently is through a coaxial line. Two methods for coupling to coaxial line are shown in **Figure 15.79**. The probe shown at *A* is simply a short extension of the inner conductor of the coaxial line, oriented so that it is parallel to the electric lines of force. The loop shown at *B* is arranged so that it encloses some of the magnetic lines of force. The point at which maximum coupling is obtained depends upon the mode of propagation in the guide or cavity.

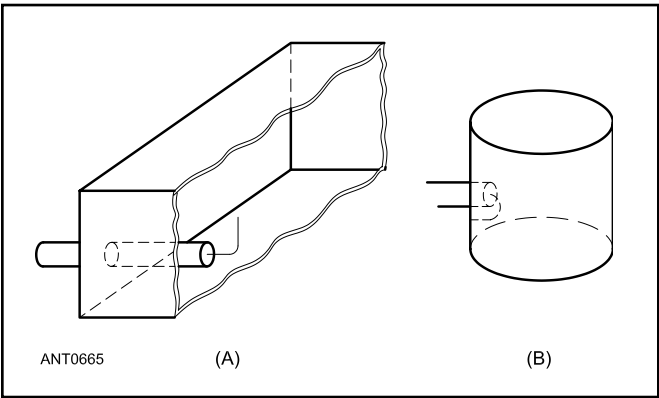


Figure 15.79 — Coupling coaxial line to waveguide and resonators.

Coupling is maximum when the coupling device is in the most intense field.

Coupling can be varied by turning the probe or loop through a 90° angle. When the probe is perpendicular to the electric lines the coupling is minimum. Similarly, when the plane of the loop is parallel to the magnetic lines the coupling is minimum.

If a waveguide is left open at one end it will radiate energy. This radiation can be greatly enhanced by flaring the waveguide to form a pyramidal horn antenna. The horn acts as a transition between the confines of the waveguide and free space. To effect the proper impedance transformation the horn must be at least $\frac{1}{2} \lambda$ on a side. A horn of this dimension (cutoff) has a unidirectional radiation pattern with a null toward the waveguide transition. The gain at the cutoff frequency is 3 dB, increasing 6 dB with each doubling of frequency. Horns are used extensively in microwave operation, both as primary radiators and as feed elements for more elaborate focusing systems. Details for constructing 10-GHz horn antennas are given later in this chapter.

Evolution of a Waveguide

Suppose an open-wire line is used to carry RF energy from a generator to a load. If the line has any appreciable length it must be mechanically supported. The line must be well insulated from the supports if high losses are to be avoided. Because high-quality insulators are difficult to construct at microwave frequencies, the logical alternative is to support the transmission line with $\frac{1}{4} \lambda$ stubs, shorted at the end opposite the feed line. The open end of such a stub presents an infinite impedance to the transmission line, provided the shorted stub is nonreactive. However, the shorting link has a finite length, and therefore some inductance. The effect of this inductance can be removed by making the RF current flow on the surface of a plate rather than a thin wire. If the plate is large enough, it will prevent the magnetic lines of force from encircling the RF current.

An infinite number of these $\frac{1}{4} \lambda$ stubs may be connected in parallel without affecting the standing waves of voltage

Table 15-26
Waveguide Dimensions

	Rectangular	Circular
Cutoff wavelength	2X	3.41r
Longest wavelength transmitted with little attenuation	1.6X	3.2r
Shortest wavelength before next mode becomes possible	1.1X	2.8r

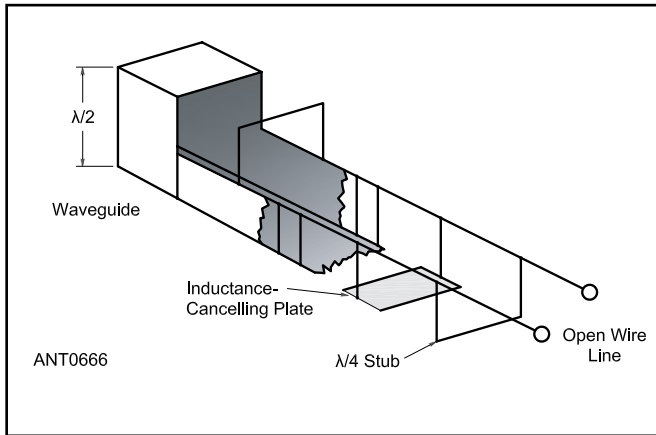


Figure 15.80 — At its cutoff frequency a rectangular waveguide can be thought of as a parallel two-conductor transmission line supported from top and bottom by an infinite number of $\lambda/4$ stubs.

and current. The transmission line may be supported from the top as well as the bottom, and when an infinite number of supports are added, they form the walls of a waveguide at its cutoff frequency. **Figure 15.80** illustrates how a rectangular waveguide evolves from a two-wire parallel transmission line as described. This simplified analysis also shows why the cutoff dimension is $\frac{1}{2} \lambda$.

While the operation of waveguides is usually described in terms of fields, current does flow on the inside walls, just as on the conductors of a two-wire transmission line. At the waveguide cutoff frequency, the current is concentrated in the center of the walls, and disperses toward the floor and ceiling as the frequency increases.

15.6.2 HORNS AND DISHES

Two forms of antenna that are only used at microwave frequencies are the horn antenna and the parabolic reflector or dish antenna.

Horn Antennas

Horn antennas were briefly introduced in the section on coupling energy into and out of waveguides. For amateur purposes, horns begin to show usable gain with practical dimensions in the 902 MHz band.

It isn't necessary to feed a horn with waveguide. If only two sides of a pyramidal horn are constructed, the antenna may be fed at the apex with a two-conductor transmission line. The impedance of this arrangement is on the order of 300 to 400 Ω . A 60° two-sided pyramidal horn with 18 inch sides is shown in **Figure 15.81**. This antenna has a theoretical gain of 15 dBi at 1296 MHz, although the feed system detailed in **Figure 15.82** probably degrades this value somewhat. A $\frac{1}{4} \lambda$, 150- Ω matching section made from two parallel lengths of twin-lead connects to a bazooka balun made from RG-58 cable and a brass tube. This matching system

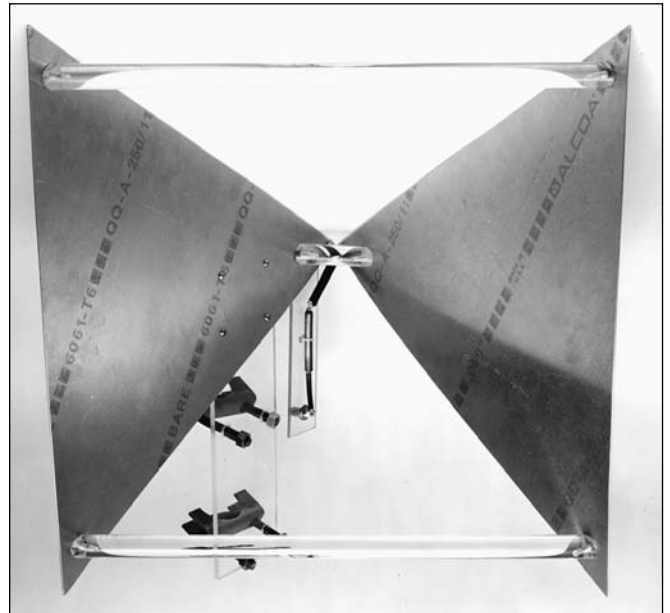


Figure 15.81 — An experimental two-sided pyramidal horn constructed in the ARRL laboratory. A pair of muller clamps allow mounting the antenna on a mast. This model has sheet-aluminum sides, although window screen would work as well. Temporary elements could be made from cardboard covered with aluminum foil. The horizontal spreaders are Plexiglas rod. Oriented as shown here, the antenna radiates horizontally polarized waves.

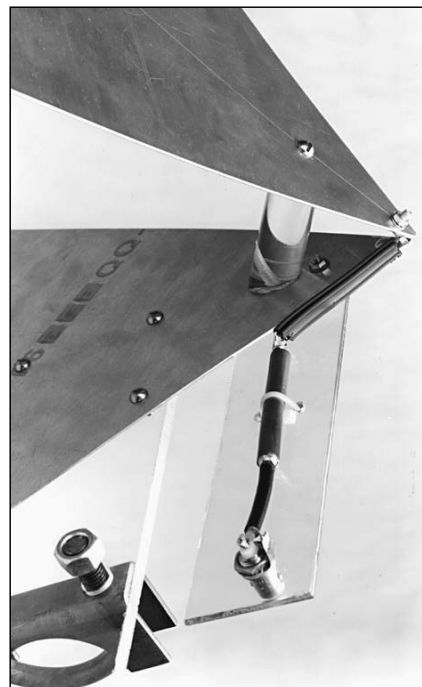


Figure 15.82 — Matching system used to test the horn. Better performance would be realized with open wire line. See text.

was assembled strictly for the purpose of demonstrating the two-sided horn in a 50-Ω system. In a practical installation the horn would be fed with open-wire line and matched to 50 Ω at the station equipment.

Parabolic Reflector Antennas

When an antenna is located at the focus of a parabolic reflector (dish), it is possible to obtain considerable gain. Furthermore, the beamwidth of the radiated energy will be very narrow, provided all the energy from the driven element is directed toward the reflector. This section was written by Paul M. Wilson, W4HHK (SK).

Gain is a function of parabolic reflector diameter, surface accuracy and proper illumination of the reflector by the feed. Gain may be found from

$$G = 10 \log k \left(\frac{\pi D}{\lambda} \right)^2 \quad (\text{Eq 4})$$

where

G = gain over an isotropic antenna, dBi (subtract 2.15 dB for gain over a dipole)

k = efficiency factor, usually about 55%

D = dish diameter in feet

λ = wavelength in feet

See **Table 15-27** for parabolic antenna gain for the bands 420 MHz through 10 GHz and diameters of 2 to 30 feet.

A close approximation of beamwidth may be found from

$$\psi = \frac{70\lambda}{D} \quad (\text{Eq 5})$$

where

ψ = beamwidth in degrees at half-power points (3 dB down)

D = dish diameter in feet

λ = wavelength in feet

At 420 MHz and higher, the parabolic dish becomes a practical antenna. A simple, single feed point eliminates phasing harnesses and balun requirements. Gain is dependent on good surface accuracy, which is more difficult to achieve

with increasing frequency. Surface errors should not exceed $\frac{1}{8} \lambda$ in amateur operation. At 430 MHz $\frac{1}{8} \lambda$ is 3.4 inches, but at 10 GHz it is 0.1476 inch! Mesh can be used for the reflector surface to reduce weight and wind loading, but hole size should be less than $\frac{1}{2} \lambda$. At 430 MHz the use of 2-inch hole diameter poultry netting (chicken wire) is acceptable. Fine mesh aluminum screening works well as high as 10 GHz.

A support form may be fashioned to provide the proper parabolic shape by plotting a curve (**Figure 15.83**) from

$$Y^2 = 4SX$$

as shown in the figure.

Optimum illumination occurs when power at the reflector edge is 10 dB less than that at the center. A circular waveguide feed of correct diameter and length for the frequency and correct beamwidth for the dish focal length to diameter (f/D) ratio provides optimum illumination at 902 MHz and higher. This, however, is impractical at 432 MHz, where a dipole and plane reflector are often used. An f/D ratio between 0.4 and 0.6 is considered ideal for maximum gain and simple feeds.

The focal length of a dish may be found from

$$f = \frac{D^2}{16d} \quad (\text{Eq 6})$$

where

f = focal length

D = diameter

d = depth distance from plane at mouth of dish to vertex

Table 15-27
Gain, Parabolic Antennas*

	Dish Diameter (Feet)						
Frequency	2	4	6	10	15	20	30
420 MHz	6.0	12.0	15.5	20.0	23.5	26.0	29.5
902	12.5	18.5	22.0	26.5	30.0	32.5	36.0
1215	15.0	21.0	24.5	29.0	32.5	35.0	38.5
2300	20.5	26.5	30.0	34.5	38.0	40.5	44.0
3300	24.0	30.0	33.5	37.5	41.5	43.5	47.5
5650	28.5	34.5	38.0	42.5	46.0	48.5	52.0
10 GHz	33.5	39.5	43.0	47.5	51.0	53.5	57.0

*Gain over an isotropic antenna (subtract 2.1 dB for gain over a dipole antenna). Reflector efficiency of 55% assumed.

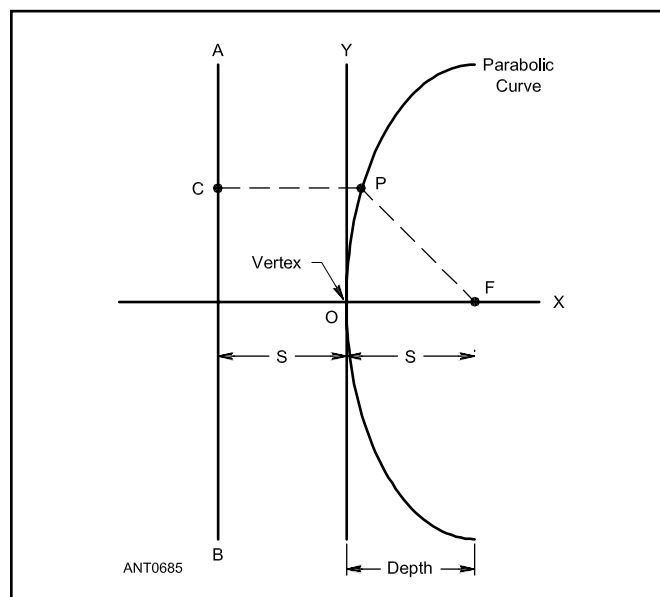


Figure 15.83 — Details of the parabolic curve, $Y^2 = 4SX$. This curve is the locus of points that are equidistant from a fixed point, the focus (F), and a fixed line (AB) that is called the *directrix*. Hence, $FP = PC$. The focus (F) is located at coordinates S,0.

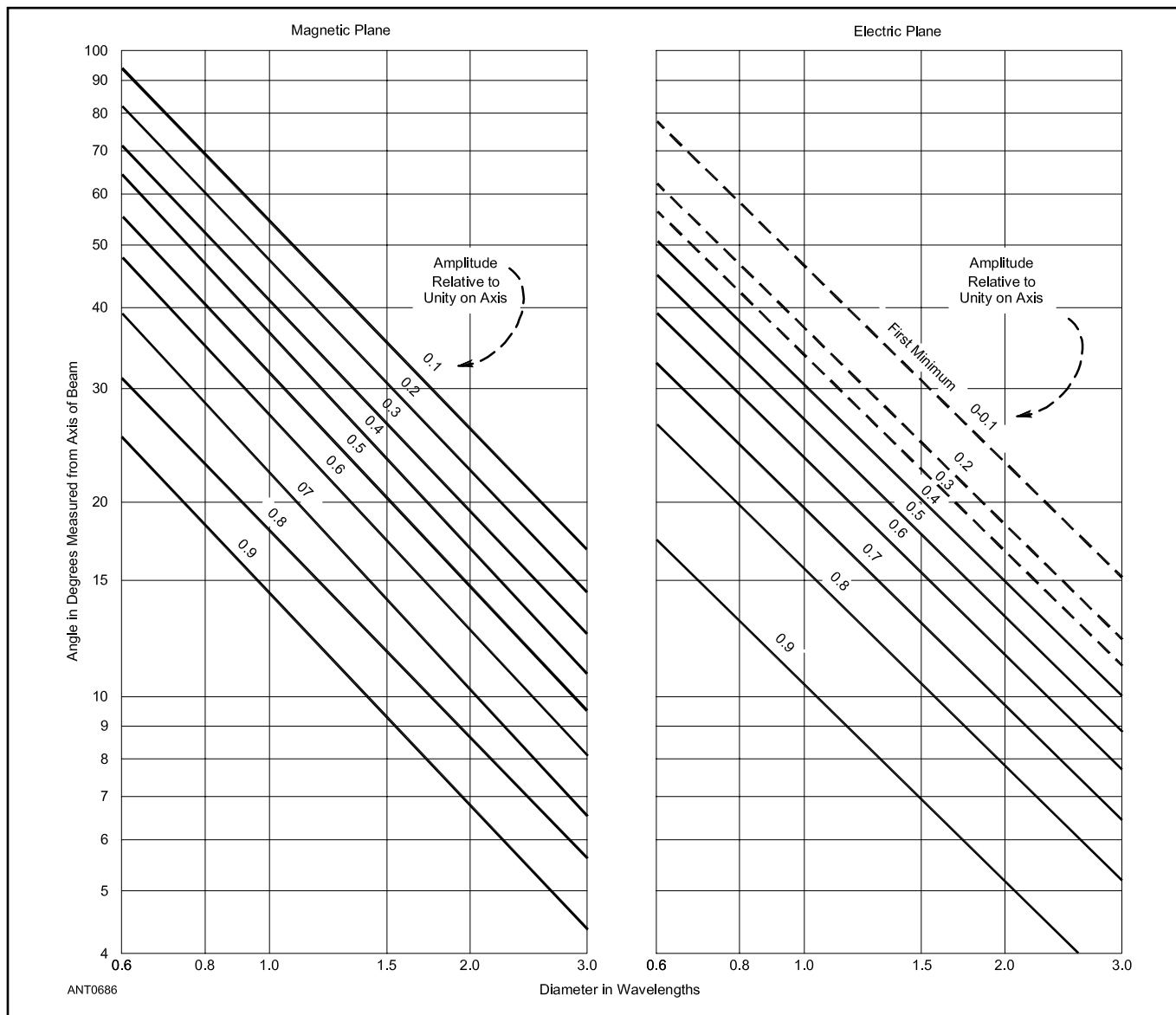


Figure 15.84 — This graph can be used in conjunction with Table 15-28 for selecting the proper diameter waveguide to illuminate a parabolic reflector.

Table 15-28
f/D Versus Subtended Angle at Focus of a Parabolic Reflector Antenna

f/D	Subtended Angle (Deg.)	f/D	Subtended Angle (Deg.)
0.20	203	0.65	80
0.25	181	0.70	75
0.30	161	0.75	69
0.35	145	0.80	64
0.40	130	0.85	60
0.45	117	0.90	57
0.50	106	0.95	55
0.55	97	1.00	52
0.60	88		

Taken from graph "f/D vs Subtended Angle at Focus," page 170 of the 1966 *Microwave Engineers' Handbook and Buyers Guide*. Graph courtesy of K. S. Kelleher, Aero Geo Astro Corp, Alexandria, Virginia

The units of focal length f are the same as those used to measure the depth and diameter. **Table 15-28** gives the subtended angle at focus for dish f/D ratios from 0.2 to 1.0. A dish, for example, with a typical f/D of 0.4 requires a 10-dB beamwidth of 130° . A circular waveguide feed with a diameter of approximately 0.7λ provides nearly optimum illumination, but does not uniformly illuminate the reflector in both the magnetic (TM) and electric (TE) planes. **Figure 15.84** shows data for plotting radiation patterns from circular guides. The waveguide feed aperture can be modified to change the beamwidth.

One approach used successfully by some experimenters is the use of a disc at a short distance behind the aperture as shown in **Figure 15.85**. As the distance between the aperture and disc is changed, the TM plane patterns become alternately broader and narrower than with an unmodified aperture. A disc about 2λ in diameter appears to be as effective as a

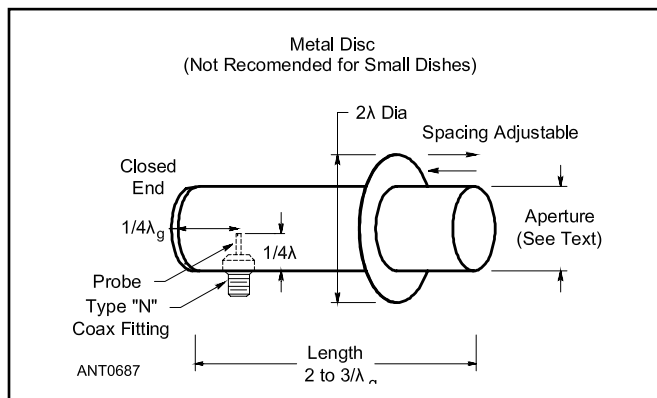


Figure 15.85 — Details of a circular waveguide feed.

much larger one. Some experimenters have noted a 1 to 2 dB increase in dish gain with this modified feed. Rectangular waveguide feeds can also be used, but dish illumination is not as uniform as with round guide feeds.

The circular feed can be made of copper, brass, aluminum or even tin in the form of a coffee or juice can, but the latter must be painted on the outside to prevent rust or corrosion. The circular feed must be within a proper size (diameter) range for the frequency being used. This feed operates in the dominant circular waveguide mode known as the *mode*. The guide must be large enough to pass the mode with no attenuation, but smaller than the diameter that permits the next higher mode to propagate. To support the desirable mode in circular waveguide, the cutoff frequency, F_C , is given by

$$F_C (TE_{11}) = \frac{6917.26}{d \text{ (inches)}} \quad (\text{Eq } 7)$$

where

F_C = cutoff frequency in MHz for mode
 d = waveguide inner diameter

Circular waveguide will support the mode having a cutoff frequency

$$F_C (TM_{01}) = \frac{9034.85}{d \text{ (inches)}} \quad (\text{Eq } 8)$$

The wavelength in a waveguide always exceeds the free-space wavelength and is called guide wavelength, λ_g . It is related to the cutoff frequency and operating frequency by the equation

$$\lambda_g = \frac{11802.85}{\sqrt{f_0^2 - f_C^2}} \quad (\text{Eq } 9)$$

where

λ_g = guide wavelength, inches
 f_0 = operating frequency, MHz
 f_C = waveguide cutoff frequency, MHz

An inside diameter range of about 0.66 to 0.76 λ is suggested. The lower frequency limit (longer dimension) is dictated by proximity to the cutoff frequency. The higher frequency limit (shorter dimension) is dictated by higher order

Table 15-29
Circular Waveguide Dish Feeds

Freq. (MHz)	Inside Diameter Circular Waveguide Range (inches)
915	8.52-9.84
1296	6.02-6.94
2304	3.39-3.91
3400	2.29-2.65
5800	1.34-1.55
10,250	0.76-0.88

waves. See **Table 15-29** for recommended inside diameter dimensions for the 902- to 10,000-MHz amateur bands.

The probe that excites the waveguide and makes the transition from coaxial cable to waveguide is $\frac{1}{4} \lambda$ long and spaced from the closed end of the guide by $\frac{1}{4}$ guide wavelength. The length of the feed should be two to three guide wavelengths. The latter is preferred if a second probe is to be mounted for polarization change or for polaplexer operation where duplex communication (simultaneous transmission and reception) is possible because of the isolation between two properly located and oriented probes. The second probe for polarization switching or polaplexer operation should be spaced $\frac{3}{4}$ guide wavelength from the closed end and mounted at right angles to the first probe. (A polaplexer is a polarization-based diplexer antenna, or antenna feed, which supports two simultaneous inputs or outputs that are independent and isolated from each other by use of orthogonal (at right angles) linear polarization. See the article by Munn listed in the Bibliography.)

The feed aperture is located at the focal point of the dish and aimed at the center of the reflector. The feed mounts should permit adjustment of the aperture either side of the focal point and should present a minimum of blockage to the reflector. Correct distance to the dish center places the focal point about 1 inch inside the feed aperture. The use of a non-metallic support minimizes blockage. PVC pipe, fiberglass and Plexiglas are commonly used materials. A simple test by placing a material in a microwave oven reveals if it is satisfactory up to 2450 MHz. PVC pipe has tested satisfactorily and appears to work well at 2300 MHz. A simple, clean looking mount for a 4-foot dish with 18 inches focal length, for example, can be made by mounting a length of 4-inch PVC pipe using a PVC flange at the center of the dish. At 2304 MHz the circular feed is approximately 4 inches ID, making a snug fit with the PVC pipe. Precautions should be taken to keep rain and small birds from entering the feed.

Never look into the open end of a waveguide when power is applied, or stand directly in front of a dish while transmitting. Tests and adjustments in these areas should be done while receiving or at extremely low levels of transmitter power (less than 0.1 watt). The US Government has set a limit of 10 mW/cm² averaged over a 6-minute period as the safe maximum. Other authorities believe even lower levels should be used. Destructive thermal heating of body tissue results from excessive exposure. This heating effect is especially

dangerous to the eyes. The accepted safe level of 10 mW/cm^2 is reached in the near field of a parabolic antenna if the level at $2D^2/\lambda$ is 0.242 mW/cm^2 . The equation for power density at the far-field boundary is

$$\text{Power density} = \frac{137.8 P}{D^2} \text{ mW / cm}^2 \quad (\text{Eq 10})$$

where

P = average power in kilowatts

D = antenna diameter in feet

λ = wavelength in feet

New commercial dishes are expensive, but surplus ones can often be purchased at low cost. Some amateurs build theirs, while others modify UHF TV dishes or circular metal snow sleds for the amateur bands. **Figure 15.86** shows a dish using the homemade feed just described. Practical details for dish antennas are given in the **Antennas for Space Communications** chapter. A number of horn and dish designs, including conversion of surplus offset-feed satellite TV receive dishes are presented in the RSGB publication *Antennas for VHF and Above*. (See Bibliography.)

A Horn Antenna for 10 GHz

The horn antenna is the easiest antenna for the beginner on 10 GHz to construct. It can be made out of readily available flat sheet brass. Because it is inherently a broadband structure, minor constructional errors can be tolerated. The one drawback is that horn antennas become physically cumbersome at gains over about 25 dBi, but for most line-of-sight operation this much gain is rarely necessary. This antenna was designed by Bob Atkins, KA1GT, and appeared in *QST* for April and May 1987.



Figure 15.86 — Coffee-can 2304 MHz feed described in text and Figure 15.85 mounted on a 4-foot dish.

Horn antennas are usually fed by waveguide. When operating in its normal frequency range, waveguide propagation is in the TE_{10} mode. This means that the electric (E) field is across the short dimension of the guide and the magnetic (H) field is across the wide dimension. This is the reason for the E-plane and H-plane terminology shown in **Figure 15.87**.

There are many varieties of horn antennas. If the waveguide is flared out only in the H-plane, the horn is called an H-plane sectoral horn. Similarly, if the flare is only in the E-plane, an E-plane sectoral horn results. If the flare is in both planes, the antenna is called a pyramidal horn.

For a horn of any given aperture, directivity (gain along the axis) is maximum when the field distribution across the aperture is uniform in magnitude and phase. When the fields are not uniform, sidelobes that reduce the directivity of the antenna are formed. To obtain a uniform distribution, the horn should be as long as possible with minimum flare angle. From a practical point of view, however, the horn should be as short as possible, so there is an obvious conflict between performance and convenience.

Figure 15.88 illustrates this problem. For a given flare

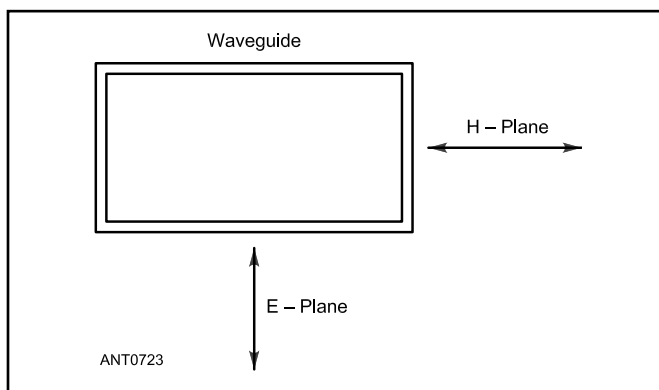


Figure 15.87 — 10-GHz antennas are usually fed with waveguide. See text for a discussion of waveguide propagation characteristics.

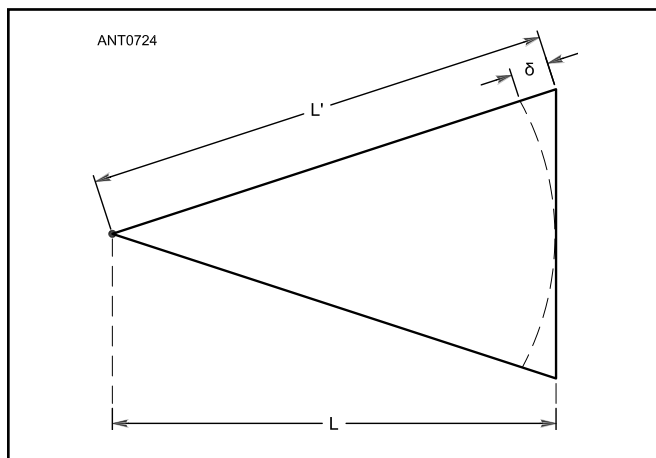


Figure 15.88 — The path-length (phase) difference between the center and edge of a horn antenna is δ .

angle and a given side length, there is a path-length difference from the apex of the horn to the center of the aperture (L), and from the apex of the horn to the edge of the aperture (L'). This causes a phase difference in the field across the aperture, which in turn causes formation of sidelobes, degrading directivity (gain along the axis) of the antenna. If L is large this difference is small, and the field is almost uniform. As L decreases however, the phase difference increases and directivity suffers. An optimum (shortest possible) horn is constructed so that this phase difference is the maximum allowable before sidelobes become excessive and axial gain markedly decreases.

The magnitude of this permissible phase difference is different for E-plane and H-plane horns. For the E-plane horn, the field intensity is quite constant across the aperture. For the H-plane horn, the field tapers to zero at the edge. Consequently, the phase difference at the edge of the aperture in the E-plane horn is more critical and should be held to less than 90° ($\frac{1}{4} \lambda$). In an H-plane horn, the allowable phase difference is 144° (0.4λ). If the aperture of a pyramidal horn exceeds one wavelength in both planes, the E-plane and H-plane patterns are essentially independent and can be analyzed separately.

The usual direction for orienting the waveguide feed is with the broad face horizontal, giving vertical polarization. If this is the case, the H-plane sectoral horn has a narrow horizontal beamwidth and a very wide vertical beamwidth. This is not a very useful beam pattern for most amateur applications. The E-plane sectoral horn has a narrow vertical beamwidth and a wide horizontal beamwidth. Such a radiation pattern could be useful in a beacon system where wide coverage is desired.

The most useful form of the horn for general applications is the optimum pyramidal horn. In this configuration the two beamwidths are almost the same. The E-plane (vertical) beamwidth is slightly less than the H-plane (horizontal), and also has greater sidelobe intensity.

Building the Antenna

A 10-GHz pyramidal horn with 18.5 dBi gain is shown in **Figure 15.89**. The first design parameter is usually the required gain, or the maximum antenna size. These are of course related, and the relationships can be approximated by the following:

$$L = \text{H-plane length } (\lambda) = 0.0654 \times \text{gain} \quad (\text{Eq 11})$$

$$A = \text{H-plane aperture } (\lambda) = 0.0443 \times \text{gain} \quad (\text{Eq 12})$$

$$B = \text{E-plane aperture } (\lambda) = 0.81 A \quad (\text{Eq 13})$$

where gain is expressed as a *ratio*; 20 dBi gain = 100, and L, A and B are dimensions shown in **Figure 15.90**.

From these equations, the dimensions for a 20-dBi gain horn for 10.368 GHz can be determined. One wavelength at 10.368 GHz is 1.138 inches. The length (L) of such a horn is $0.0654 \times 100 = 6.54 \lambda$. At 10.368 GHz, this is

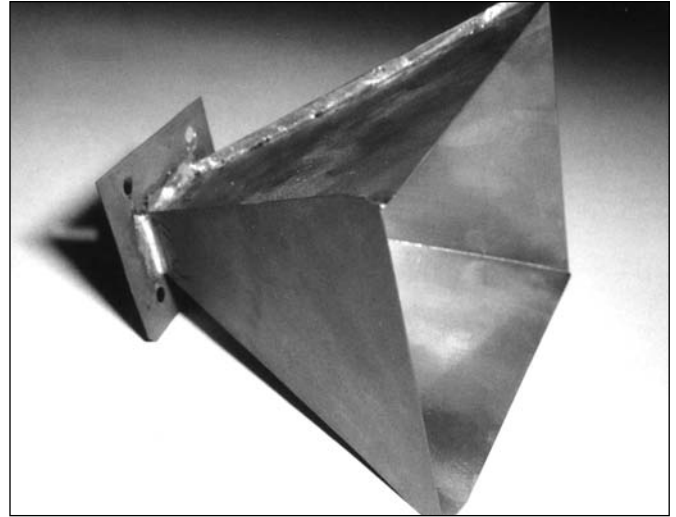


Figure 15.89 — This pyramidal horn has 18.5 dBi gain at 10 GHz. Construction details are given in the text.

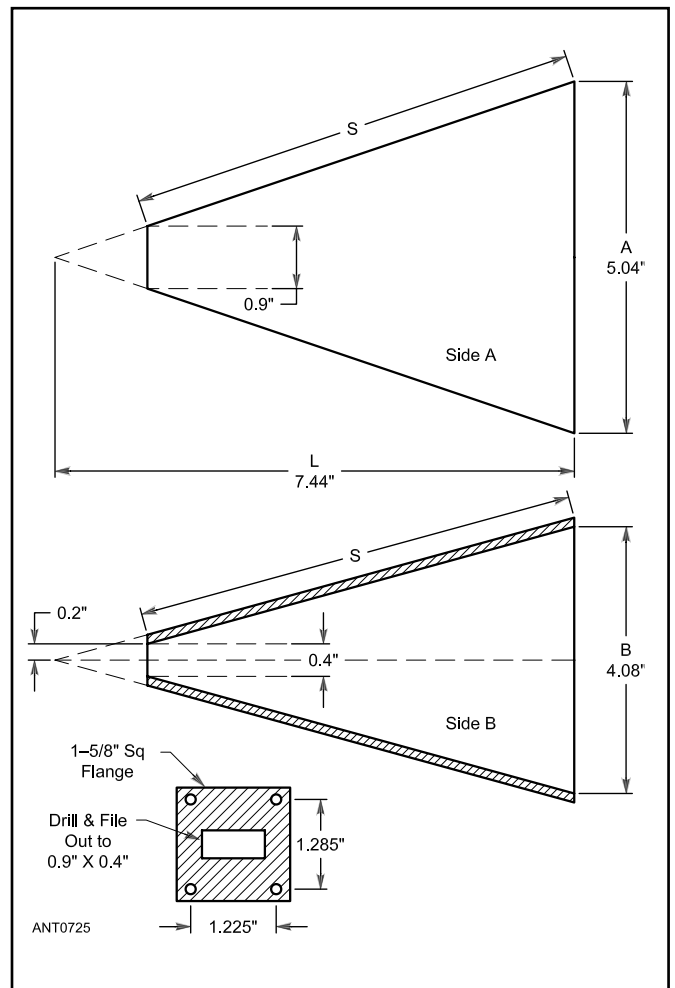


Figure 15.90 — Dimensions of the brass pieces used to make the 10-GHz horn antenna. Construction requires two of each of the triangular pieces (side A and side B).

7.44 inches. The corresponding H-plane aperture (A) is 4.43λ (5.04 inches), and the E-plane aperture (B), 4.08 inches.

The easiest way to make such a horn is to cut pieces from brass sheet stock and solder them together. Figure 15.90 shows the dimensions of the triangular pieces for the sides and a square piece for the waveguide flange. (A standard commercial waveguide flange could also be used.) Because the E-plane and H-plane apertures are different, the horn opening is not square. Sheet thickness is unimportant; 0.02 to 0.03 inch works well. Brass sheet is often available from hardware or hobby shops.

Note that the triangular pieces are trimmed at the apex to fit the waveguide aperture (0.9×0.4 inch). This necessitates that the length, from base to apex, of the smaller triangle (side B) is shorter than that of the larger (side A). Note that the length, S, of the two different sides of the horn must be the same if the horn is to fit together! For such a simple looking object, getting the parts to fit together properly requires careful fabrication.

The dimensions of the sides can be calculated with simple geometry, but it is easier to draw out templates on a sheet of cardboard first. The templates can be used to build a mock antenna to make sure everything fits together properly before cutting the sheet brass.

First, mark out the larger triangle (side A) on cardboard. Determine at what point its width is 0.9 inch and draw a line parallel to the base as shown in Figure 15.90. Measure the length of the side S; this is also the length of the sides of the smaller (side B) pieces.

Mark out the shape of the smaller pieces by first drawing a line of length B and then constructing a second line of length S. One end of line S is an end of line B, and the other is 0.2 inch above a line perpendicular to the center of line B as shown in Figure 15.89. (This procedure is much more easily followed than described.) These smaller pieces are made slightly oversize (shaded area in Figure 15.90) so you can construct the horn with solder seams on the outside of the horn during assembly.

Cut out two cardboard pieces for side A and two for side B and tape them together in the shape of the horn. The aperture at the waveguide end should measure 0.9×0.4 inch and the aperture at the other end should measure 5.04×4.08 inches.

If these dimensions are correct, use the cardboard templates to mark out pieces of brass sheet. The brass sheet should be cut with a bench shear if one is available, because scissors type shears tend to bend the metal. Jig the pieces together and solder them on the *outside* of the seams. It is important to keep both solder and rosin from contaminating the inside of the horn; they can absorb RF and reduce gain at these frequencies.

Assembly is shown in **Figure 15.91**. When the horn is completed, it can be soldered to a standard waveguide flange, or one cut out of sheet metal as shown in Figure 15.90. The transition between the flange and the horn must be smooth. This antenna provides an excellent performance-to-cost ratio (about 20 dBi gain for about five dollars in parts).

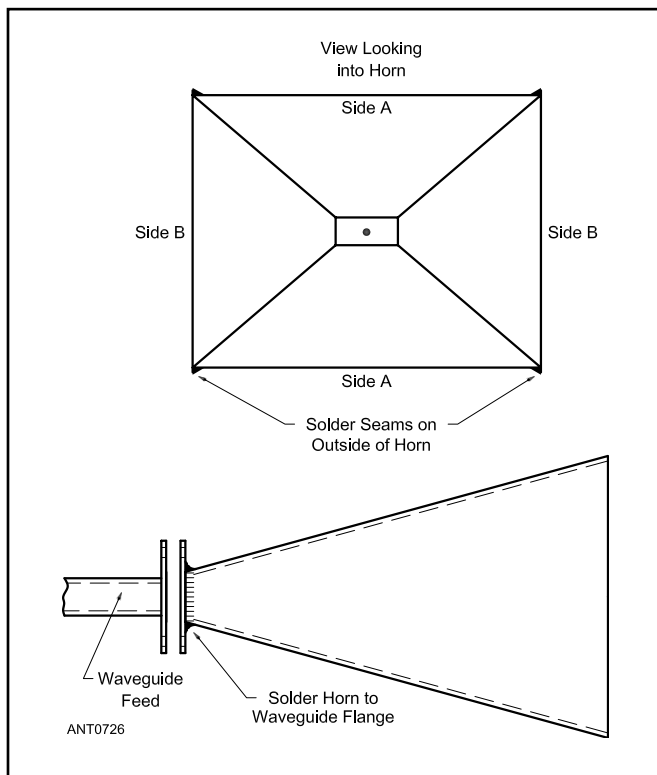


Figure 15.91 — Assembly of the 10-GHz horn antenna.

15.6.3 VIVALDI ANTENNAS

The following material is reprinted from the RSGB publication *Microwave Know-How*. (See Bibliography.) The Vivaldi antenna in **Figure 15.92** is an exponential antenna from the same family as V-beams and Rhombics (see the **Long-Wire and Traveling-Wave Antennas** chapter). They have exceptionally wide bandwidth. The lowest frequency is determined by the width of the opening.

The higher frequency of operation is determined by how accurately the slot is formed. As an example, the 75 mm PCB version has an excellent return loss from 5 GHz to 18 GHz and is usable from 2 GHz. (See www.wa5vjb.com/pcb-pdfs/10-25GHzSweep.pdf for additional construction information.)

All versions start with the template shown in Figure 15.92. Place the template on a photocopy machine and enlarge or reduce to the desired frequency range as shown in **Table 15-30**. Cut out the template and mark your material

Table 15-30 Scaling for the Vivaldi Antenna Template	
Opening	Low End Frequency Response
40 mm	10 GHz
75 mm	5 GHz
150 mm	2 GHz
200 mm	1 GHz

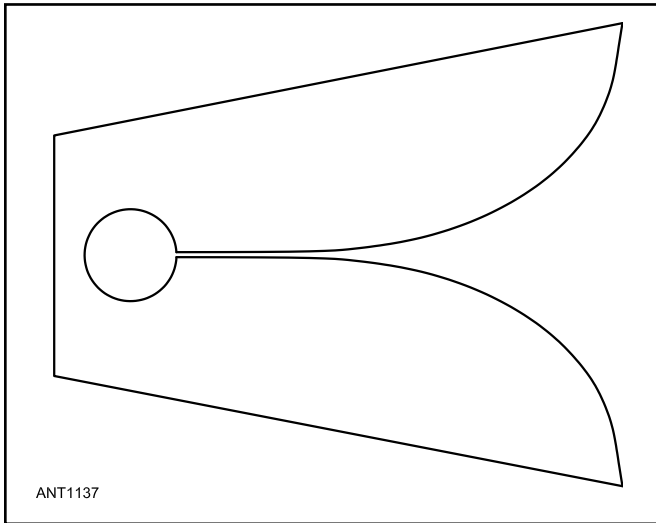


Figure 15.92 — The template for a Vivaldi antenna. Scale as shown in Table 15-30.

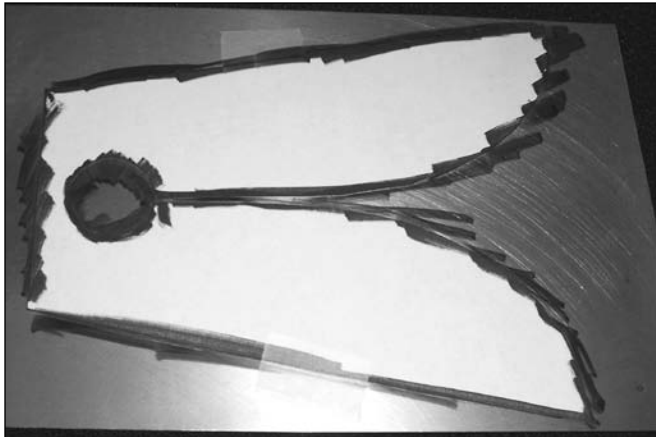


Figure 15.93 — Marking out a Vivaldi antenna using the template placed on your chosen material.

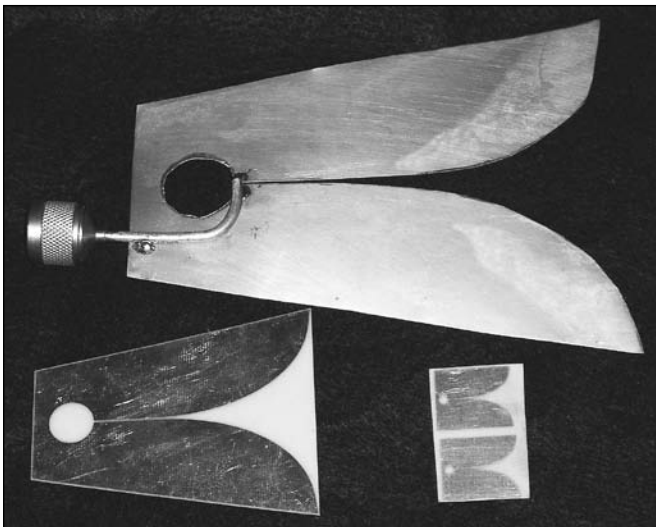


Figure 15.94 — A complete Vivaldi antenna.

as shown in **Figure 15.93**. Thin brass, tin plate, or PC board material have all been used.

Cut out the antenna using sharp scissors or a band saw. The feed line shield should be soldered to one side of the slot and the center conductor to the other side as close to the circle as possible. (See **Figure 15.94**.) Both semi-rigid and Teflon braided coax types can be used.

Vivaldi antennas make excellent test antennas for use with a test instrument or can be used as dish feeds over several bands. The phase center of the Vivaldi does move back and forth in the narrow region of the slot, but when the dish is focused at the highest frequency of planned use, the lower bands will be very close. Mount the narrow area of the slot at the focus of the dish.

15.6.4 PATCH ANTENNAS

The following material is adapted from the RSGB publication *Microwave Know-How*. (See Bibliography for additional articles by Kraus and Krug.) Patch antennas (also called *microstrip antennas*) are a good example of how an antenna's shape is used at microwave frequencies in ways not possible at 70 cm and longer wavelengths. Patch antennas become practical at and above the 902 MHz band and are very common in commercial microwave applications such as GPS reception, wireless telephony, and wireless data links. As more amateurs investigate operation at microwave frequencies, the patch antenna should receive more attention.

The patch, an example of which is shown in **Figure 15.95**, consists of a radiating surface mounted over a ground plane although there are many variations of the basic design. The patch is approximately $\lambda/2$ on a side for a square patch. Patch antenna gain is on the order of 7 to 9 dBi.

Some patches are constructed of double-sided PCB material with the patch etched on one side and the unetched side acting as the ground plane. The shape of the patch is such that when excited by a signal, the resulting currents form patterns that create a useful radiation pattern. It works the same as an arrangement of discrete elements. The closest electrical analogy is that the square patch acts similarly to a pair of slot antennas fed in phase and approximately $\lambda/2$ apart.

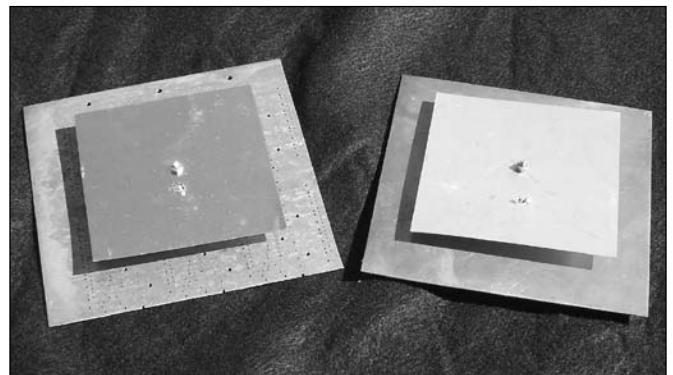


Figure 15.95 — Two patch antennas for the 23 cm band. The patch on the left is constructed from sheet metal and the one on the right from PCB material.

Since the impedance of the patch is high at the edges where current is low (just as in a linear element), the feed point is usually close to the center of the patch. Placement of the feed point determines the feed point impedance and also influences the pattern of current on the surface of the patch. An alternate method of feeding the patch is to create a 50- Ω microstrip or stripline transmission line from a location with a 50- Ω impedance to the edge of the structure where a feed line can be attached.

It is not necessary for the patch to be rectangular in shape and could conveniently be round or polygon shaped. A rectangular patch with its opposite corners cut off will produce circular polarization.

A Patch Antenna for 23 cm

This simple patch antenna for the middle range of the 23 cm band was designed by Kent Britain, WA5VJB. The antenna works for use as a dish feed as well as for point-to-point communication such as for D-STAR, ATV, or satellite contacts.

The antenna can be made from almost any sheet metal. The base can be made from sheet aluminum, brass, copper, or PCB material. It is probably easier to assemble if the patch is made from something that can be soldered. Figure 15.95 shows two patches. The one on the right is made from PCB material and the one on the left from galvanized sheet steel. **Figure 15.96** shows the dimensions for the 23 cm band patch.

Since the very center of the patch is electrically neutral, similar to the center of a dipole, you can use a metal screw to support the patch over the conductive plate or ground plane. This provides a dc ground for the antenna and dissipates any static charge. A #4 or #6 brass or similar screw can be used. The diameter of the screw is not important but the height at which it holds the patch above the ground plane is. Adjust the height of the patch above the ground plane for the best impedance match. If swept frequency measurements are not possible, adjustment at a single frequency is acceptable.

Coaxial feed line is attached to the patch 23 mm from the mounting screw as shown in Figure 15.96 and **Figure 15.97**. The orientation of the line from the feed point to the center of the patch determines the antenna's polarization. If the antenna is placed with the feed point below the center, the antenna will be vertically polarized.

An SMA connector is used for this design, but coax can be soldered directly to the patch. The center conductor attaches to the patch and the shield to the ground plane. Ground plane size is not critical and 150 mm $\times$ 150 mm or larger will work well.

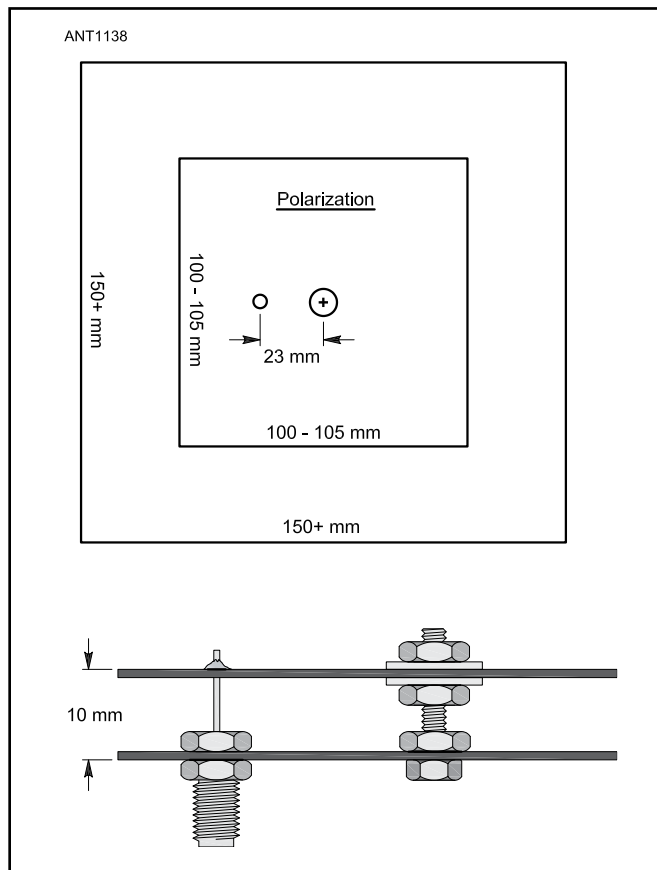


Figure 15.96 — Dimensions for the 23 cm patch antenna. The size of the patch determines the frequency range of the antenna (see text). The orientation of the feed point determines the antenna's polarization.

The typical patch will have a bandwidth of 50 MHz at this frequency. To use the 1240-1280 MHz portion of the band, increase the patch to 105 mm $\times$ 105 mm. For 1280-1325 MHz reduce the patch size to 100 mm $\times$ 100 mm.

15.6.5 PERISCOPE ANTENNA SYSTEMS

One problem common to all who use microwaves is that of mounting an antenna at the maximum possible height while trying to minimize feed line losses. The higher the frequency, the more severe this problem becomes, as feeder losses increase with frequency. Because parabolic dish reflectors are most often used on the higher bands, there is also the difficulty of waterproofing feeds (particularly waveguide feeds). Inaccessibility of the dish is also a problem when

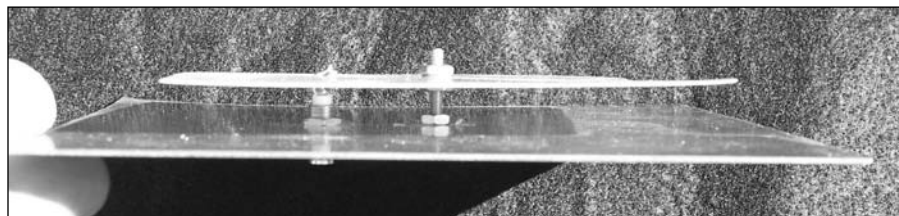


Figure 15.97 — An illustration showing how the patch is mounted above the ground plane using the center screw and, in this case, the SMA connector.

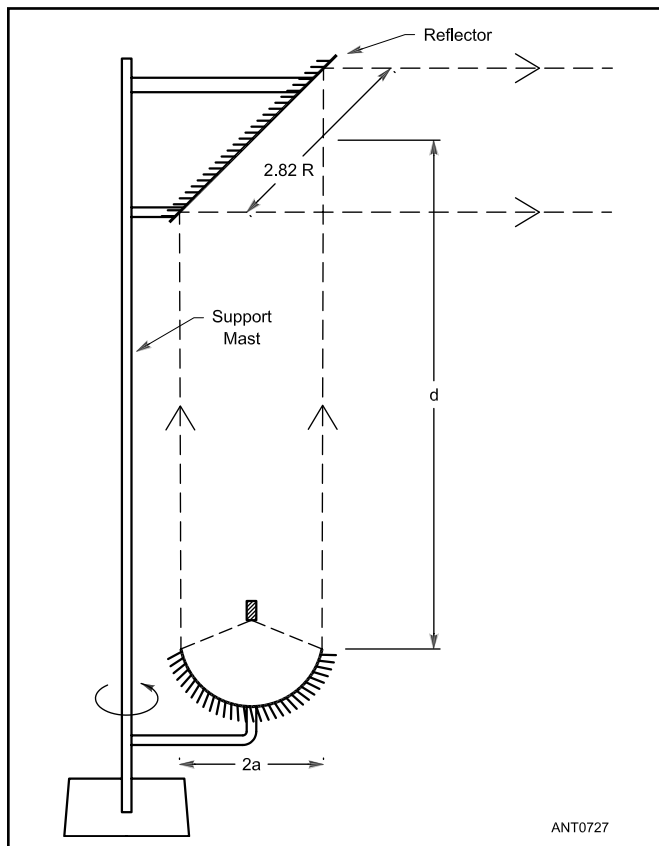


Figure 15.98 — The basic periscope antenna. This design makes it easy to adjust the feed antenna.

changing bands. Unless the tower is climbed every time and the feed changed, there must be a feed for each band mounted on the dish. One way around these problems is to use a periscope antenna system (sometimes called a “fly-swatter antenna”).

The material in this section was prepared by Bob Atkins, KA1GT, and appeared in *QST* for January and February 1984. **Figure 15.98** shows a schematic representation of a periscope antenna system. A plane reflector is mounted at the top of a rotating tower at an angle of 45°. This reflector can be elliptical with a major to minor axis ratio of 1.41, or rectangular. At the base of the tower is mounted a dish or other type of antenna such as a Yagi, pointing straight up. The advantage of such a system is that the feed antenna can be changed and worked on easily. Additionally, with a correct choice of reflector size, dish size, and dish to reflector spacing, feed losses can be made small, increasing the effective system gain. In fact, for some particular system configurations, the gain of the overall system can be greater than that of the feed antenna alone.

Gain of a Periscope System

Figure 15.99 shows the relationship between the effective gain of the antenna system and the distance between the reflector and feed antenna for an elliptical reflector. At first sight, it is not at all obvious how the antenna system can have a higher gain than the feed alone. The reason lies in the fact that, depending on the feed to reflector spacing, the reflector may be in the near field (Fresnel) region of the antenna,

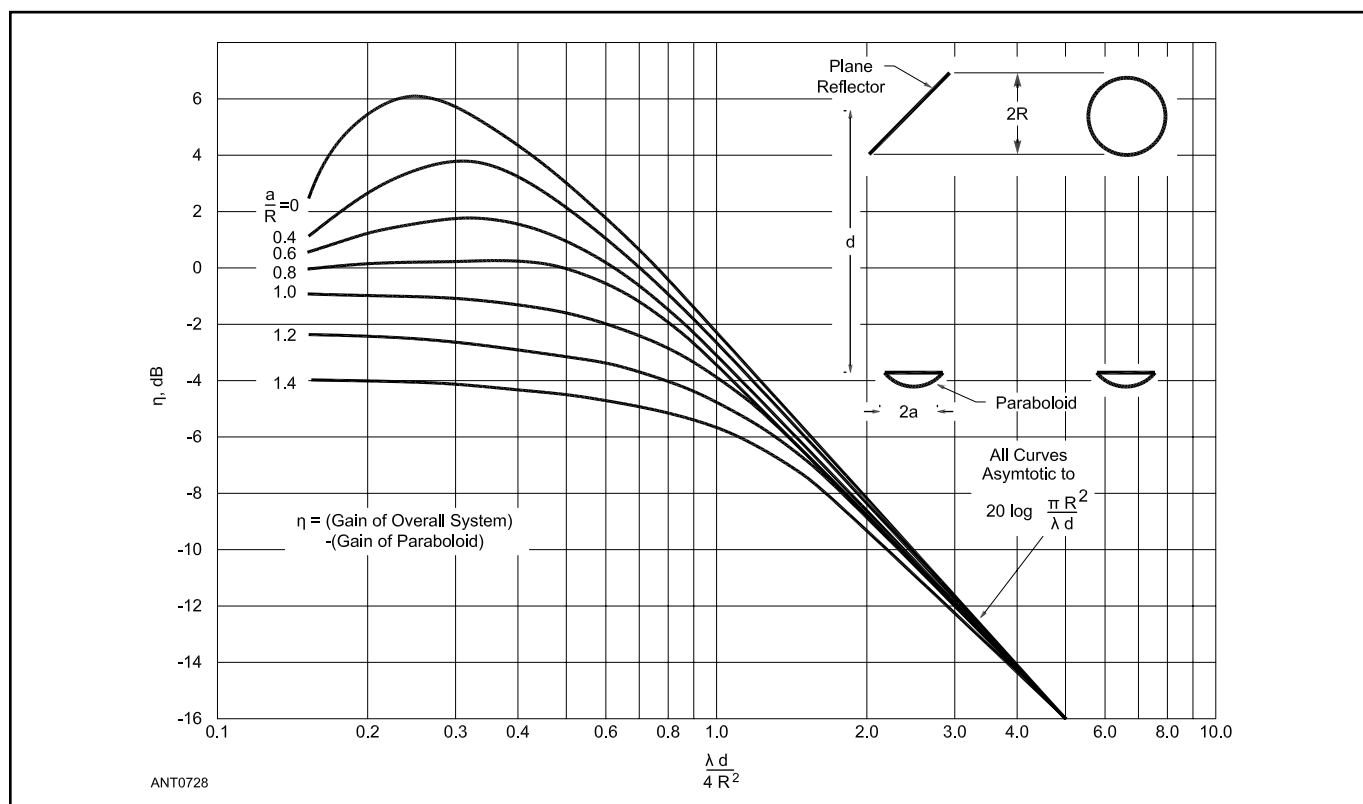


Figure 15.99 — Gain of a periscope antenna using a plane elliptical reflector (after Jasik — see Bibliography).

the far field (Fraunhöffer) region, or the transition region between the two.

In the far field region, the gain is proportional to the reflector area and inversely proportional to the distance between the feed and reflector. In the near field region, seemingly strange things can happen, such as decreasing gain with decreasing feed to reflector separation. The reason for this gain decrease is that, although the reflector is intercepting more of the energy radiated by the feed, it does not all contribute in phase at a distant point, and so the gain decreases.

In practice, rectangular reflectors are more common than elliptical. A rectangular reflector with sides equal in length to the major and minor axes of the ellipse will, in fact, normally give a slight gain increase. In the far field region, the gain will be proportional to the area of the reflector. To use Figure 15.99 with a rectangular reflector, R^2 may be replaced by A / π , where A is the projected area of the reflector. The antenna pattern depends in a complicated way on the system parameters (spacing and size of the elements), but **Table 15-31** gives an approximation of what to expect. R is the radius of the projected circular area of the elliptical reflector (equal to the minor axis radius), and b is the length of the side of the projected square area of the rectangular reflector (equal to the length of the short side of the rectangle).

For those wishing a rigorous mathematical analysis of this type of antenna system, several references are given in the Bibliography at the end of this chapter.

Mechanical Considerations

There are some problems with the physical construction of a periscope antenna system. Since the antenna gain of a microwave system is high and, hence, its beamwidth narrow, the reflector must be accurately aligned. If the reflector does not produce a beam that is horizontal, the useful gain of the system will be reduced. From the geometry of the system, an angular misalignment of the reflector of X degrees in the vertical plane will result in an angular misalignment of $2X$ degrees in the vertical alignment of the antenna system pattern. Thus, for a dish pointing straight up (the usual case), the reflector must be at an angle of 45° to the vertical and should not fluctuate from factors such as wind loading.

The reflector itself should be flat to better than $\frac{1}{10} \lambda$ for the frequency in use. It may be made of mesh, provided that the holes in the mesh are also less than $\frac{1}{10} \lambda$ in diameter. A second problem is getting the support mast to rotate about a truly vertical axis. If the mast is not vertical, the resulting beam will swing up and down from the horizontal as the system is rotated, and the effective gain at the horizon will fluctuate. Despite these problems, amateurs have used periscope antennas successfully on the bands through 10 GHz. Periscope antennas are used frequently in commercial service, though usually for point-to-point transmission. Such a commercial system is shown in **Figure 15.100**.

Circular polarization is not often used for terrestrial

Table 15-31
Radiation Patterns of Periscope Antenna Systems

	<i>Elliptical Reflector</i>	<i>Rectangular Reflector</i>
3-dB beamwidth, degrees	60 $\lambda/2R$	52 λ/b
6-dB beamwidth, degrees	82 $\lambda/2R$	68 λ/b
First minimum, degrees from axis	73 $\lambda/2R$	58 λ/b
First maximum, degrees from axis	95 $\lambda/2R$	84 λ/b
Second minimum, degrees from axis	130 $\lambda/2R$	116 λ/b
Second maximum, degrees from axis	156 $\lambda/2R$	142 λ/b
Third minimum, degrees from axis	185 $\lambda/2R$	174 λ/b



Figure 15.100 — Commercial periscope antennas, such as this one, are often used for point-to-point communication.

operation, but if it is used with a periscope system there is an important point to remember. The circularity sense changes when the signal is reflected. Thus, for right hand circularity with a periscope antenna system, the feed arrangement on the ground should produce left hand circularity. It should also be mentioned that it is possible (though more difficult for amateurs) to construct a periscope antenna system using a parabolically curved reflector. The antenna system can then be regarded as an offset fed parabola. More gain is available from such a system at the added complexity of constructing a parabolically curved reflector, accurate to $\frac{1}{10} \lambda$.

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