TABLE OF CONTENTS

**Chapter 15 —
CD-ROM Content**

Supplemental Articles

- "2 x 3 = 6" by L.B. Cebik, W4RNL
- "A 902-MHz Loop Yagi Antenna" by Don Hilliard, WØPW
- "A Short Boom, Wideband 3 Element Yagi for 6 Meters" by L.B. Cebik, W4RNL
- "A VHF/UHF Discone Antenna" by Bob Patterson, K5DZE
- "An Optimum Design for 432 MHz Yagis – Parts 1 and 2" by Steve Powlishen, K1FO (SK)
- "Building a Medium-Gain, Wide-Band, 2 Meter Yagi" by L.B. Cebik, W4RNL
- "Development and Real World Replication of Modern Yagi Antennas (III) - Manual Optimisation of Multiple Yagi Arrays" by Justin Johnson, GØKSC
- "High-Performance 'Self-Matched' Yagi Antennas" by Justin Johnson, GØKSC
- "High-Performance Yagis for 144, 222 and 432 MHz" by Steve Powlishen, K1FO
- "LPDA for 2 Meters Plus" by L.B. Cebik, W4RNL
- "Making the LFA Loop" by Justin Johnson, GØKSC
- "Microwavelengths - Microwave Transmission Lines" by Paul Wade, W1GHZ
- "RF - A Small 70-cm Yagi" by Zack Lau, W1VT
- "Three-Band Log-Periodic Antenna" by Robert Heslin, K7RTY/2
- "Using LPDA TV Antennas for the VHF Ham Bands" by John Stanley, K4ERO
- "V-Shaped Elements versus Straight Elements" by John Stanley, K4ERO

Support Files

- Model files and sample radiation patterns for Yagi designs by Justin Johnson, GØKSC (require *EZNEC PRO/4* to reproduce the gain and other performance specifications listed)

Chapter 15

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 attractive 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-hird 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. Circular polarization is commonly used for satellite and EME communication with antenna systems that can switch between right-hand and left-hand orientation.

Vertical polarization was widely used in early VHF operation, but horizontal polarization gained favor when directional arrays started to become widely used. The widespread 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 up to 20 dB can be expected when cross-polarized antennas are used over direct paths.

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 ¾ 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 ½-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* coaxial cables with large inner conductors and foam insulation (dielectric) are well worth their cost. Another form of hardline known by its trade name of Heliax has a corrugated outer jacket. Some types of Heliax use foam dielectric, while others are air-insulated with the center conductor supported by a helical plastic strip.

Hardline can sometimes be obtained for free from local cable TV operators as "end runs" — pieces at the end of a roll. A 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. Also 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 System Techniques** 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 more expensive than for flexible cable but provide reliable connections with full waterproofing. They are often available at very reasonable prices via online 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 System Techniques** chapter. While advances in modeling have resulted in more designs featuring 50 Ω feed point impedances for direct connection of coaxial feed lines, impedance matching is still an important technique in antenna system design. 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

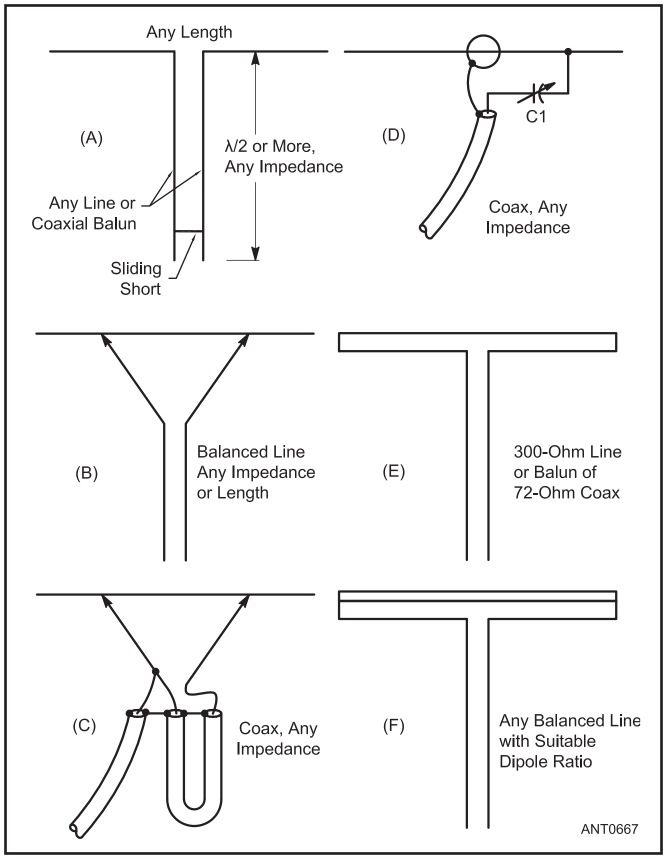


Figure 15.1 — Matching methods commonly used at VHF. The universal stub, A, combines tuning and matching. The adjustable short on the stub and the points of connection of the transmission line are adjusted for minimum reflected power on the line. In the delta match, B and C, the line is fanned out and 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.

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 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 ½ λ from the load toward the short.

The stub should be made of stiff bare wire or rod, spaced no more than $\frac{1}{20}$ λ 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 ½ λ 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 ½ λ 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,

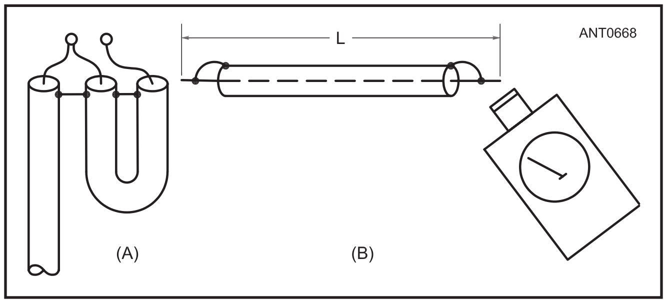


Figure 15.2 — Conversion from unbalanced coax to a balanced load can be done with a ½-λ, coaxial balun at A. Electrical length of the looped section should be checked with a dip meter, with the ends shorted, as at B, or with an antenna analyzer. The ½-λ balun gives a 4:1 impedance

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 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 ½ λ 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 System Techniques** chapter) is used together with a 4:1 coaxial balun in some of the 50 MHz antennas described later in this chapter.

15.1.4 BALUNS

Baluns, circuits and transmission line structures that transfer power while isolating balanced and unbalanced systems are discussed in the **Transmission Line System Techniques** chapter for use at HF and VHF/UHF. An example of a balun made from flexible coax is shown in Figure 15.2A. The looped portion is an electrical ½ λ. 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 ¼ λ 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.

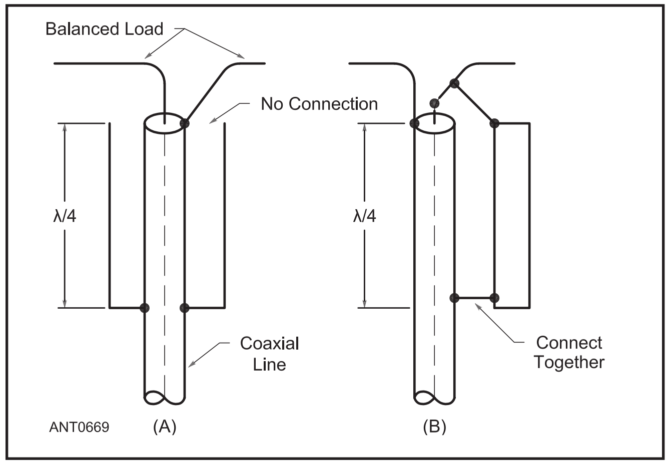


Figure 15.3 — The balun conversion function, with no impedance transformation, can be accomplished with ¼-λ lines, open at the top and connected to the coax outer conductor at the bottom. The coaxial sleeve at A is preferred.

Ferrite bead choke or current baluns become less attractive at VHF and higher frequencies due to the properties of the ferrite material. However, bead-type choke baluns using type 43 and 61 material can be effective at 50 MHz and even 144 MHz. For 144 MHz and higher frequency bands, coiled-coaxial or resonant transmission line 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 ¼ λ 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

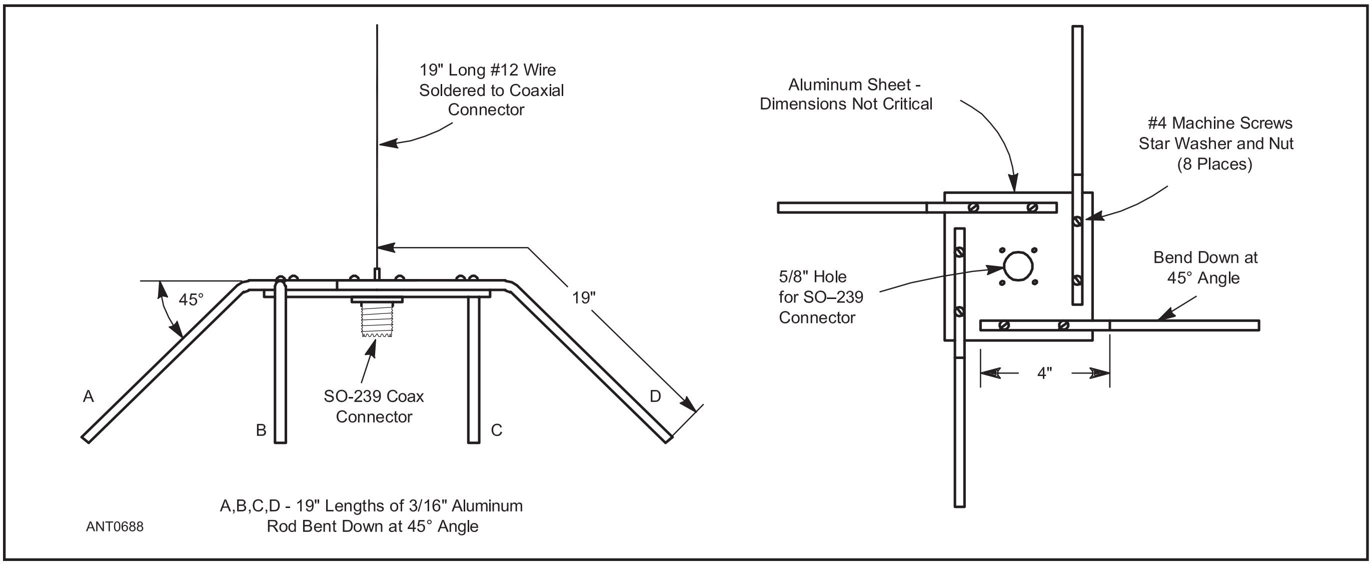


Figure 15.4 — These drawings illustrate the dimensions for the 144-MHz ground-plane antenna. The radials are bent down at a 45° angle.

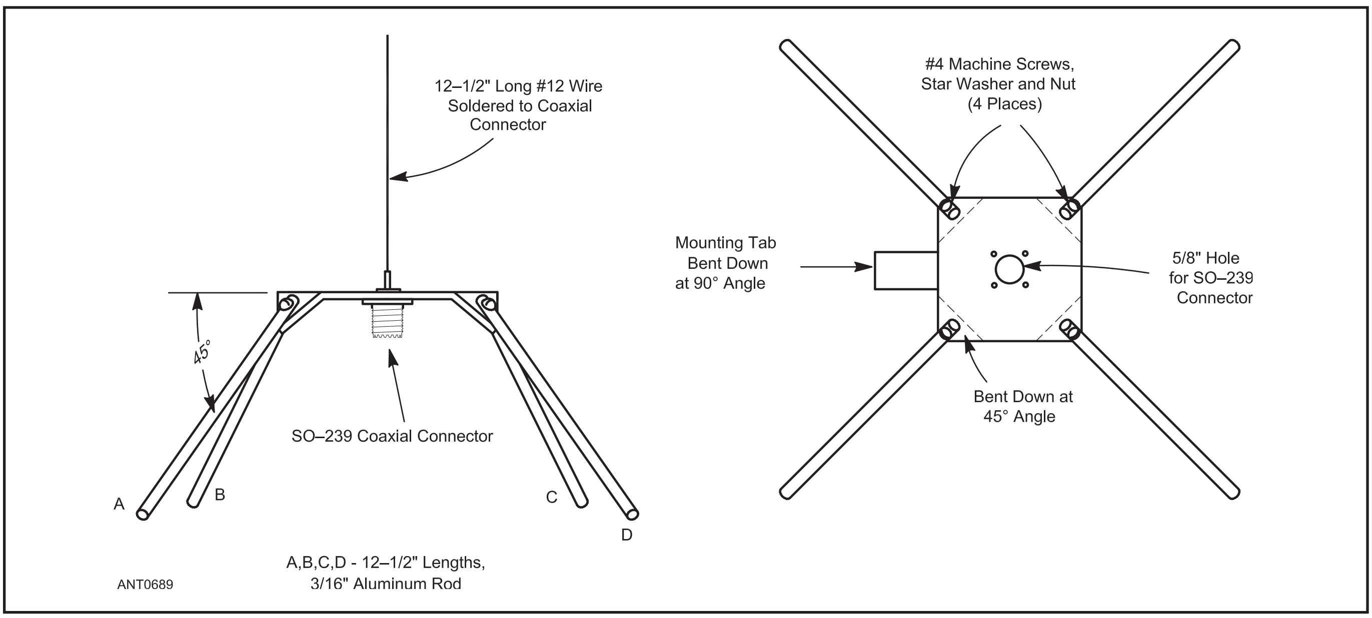


Figure 15.5 — Dimensional information for the 222-MHz ground-plane antenna. Lengths for A, B, C and D are the total distances measured from the center of the SO-239 connector. The corners of the aluminum plate are bent down at a 45° angle rather than bending the aluminum rod as in the 144-MHz model.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

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 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 ¾-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

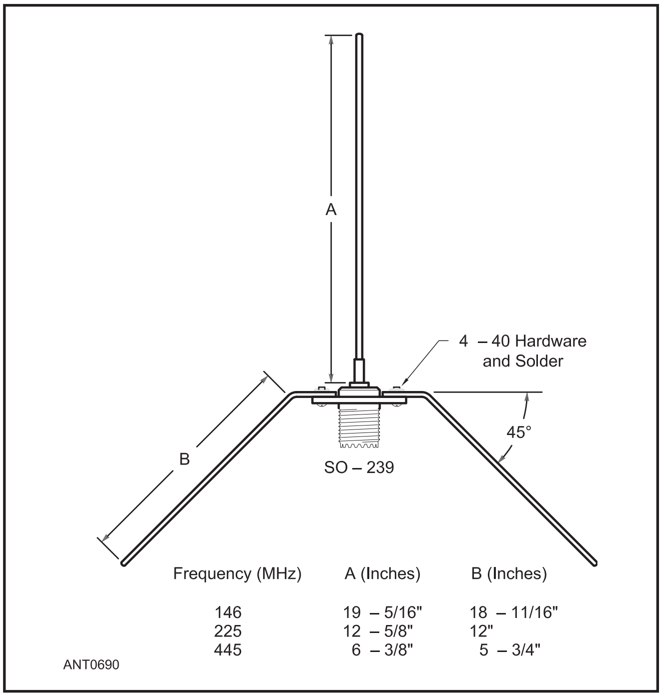


Figure 15.6 — Simple ground-plane antenna for the 144-, 222- and 440-MHz bands. The vertical element and radials are 3⁄32- or 1⁄16-inch brass welding rod. Although 3⁄32-inch rod is preferred for the 144-MHz antenna, #10 or #12 AWG copper wire can also be used.

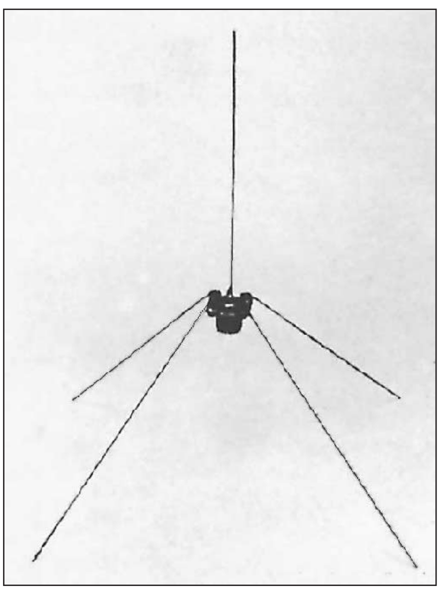


Figure 15.7 — A 440-MHz ground-plane constructed using only an SO-239 connector, no. 4-40 hardware and 1⁄16-inch brass welding rod.

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 ¼-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

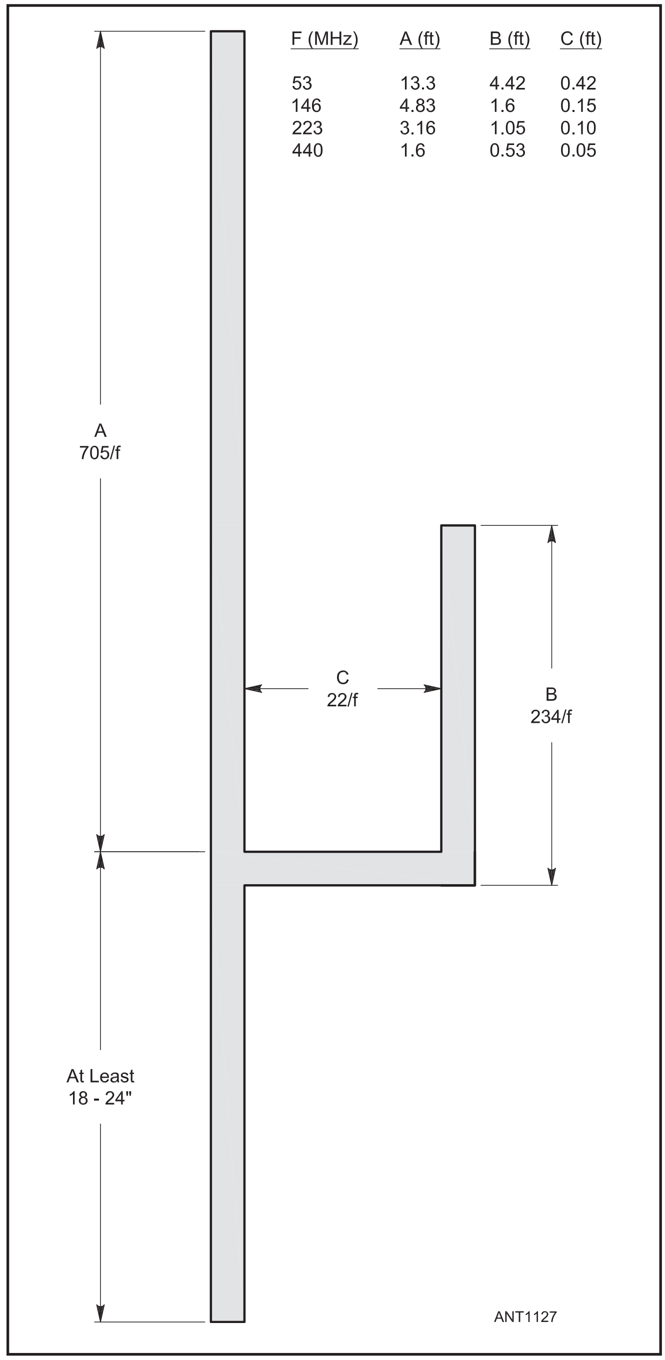


Figure 15.8 — Dimensions for the J-pole.

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 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.

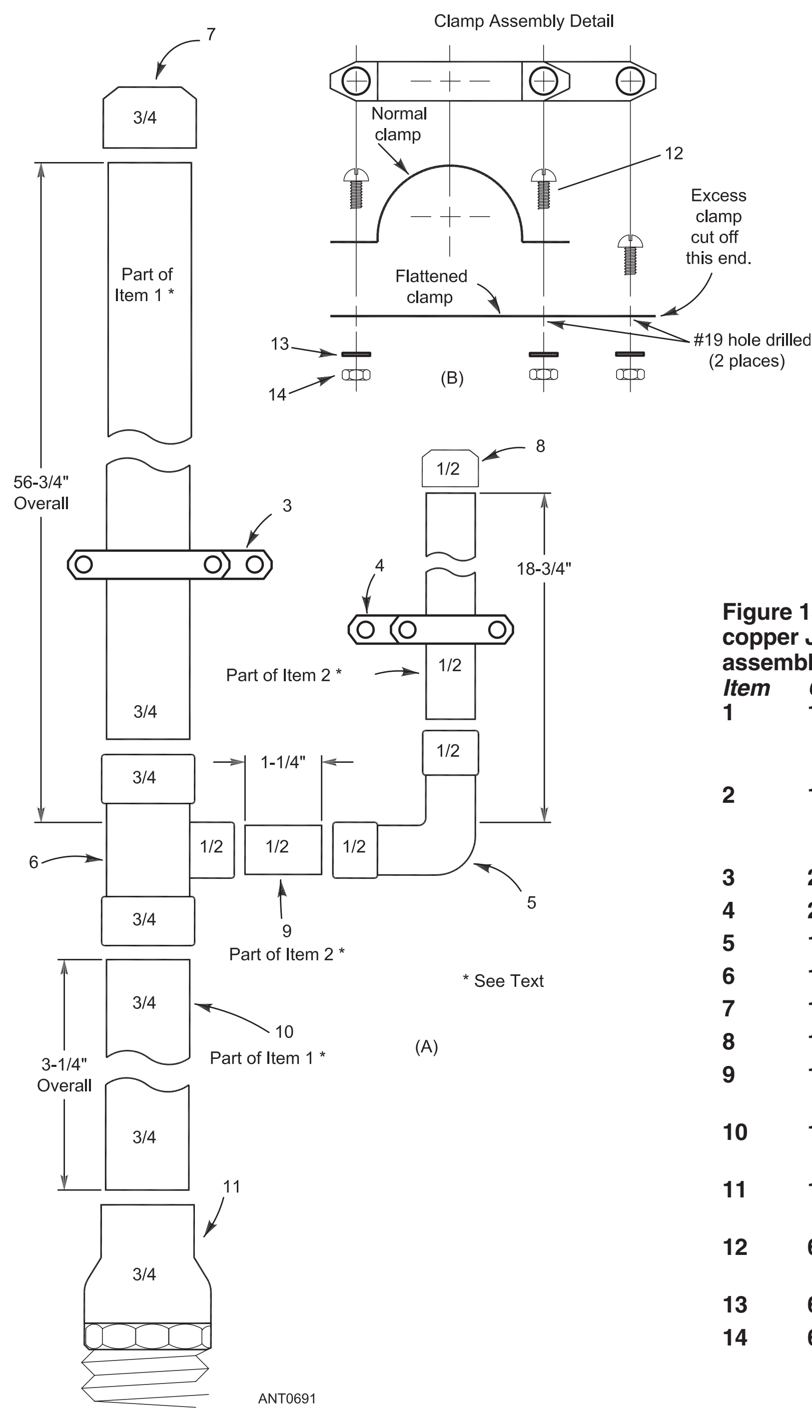


Figure 15.9 — At A, exploded assembly diagram of all-copper J-Pole antenna. At B, detail of clamp assemblies. Both clamp assemblies are the same.

Item	***Qty***	***Part or Material Name***
1	**1**	**¾-inch × 10 foot length of rigid copper tubing (enough for 2 antennas, 60 inches per antenna)**
2	**1**	**½-inch × 10 ft length of rigid copper tubing (enough for 6 antennas, 20 inches per antenna)**
3	**2**	**¾-inch copper pipe clamps**
4	**2**	**½-inch copper pipe clamps**
5	**1**	**½-inch copper elbow**
6	**1**	**¾ × ½-inch copper tee**
7	**1**	**¾-inch copper end cap**
8	**1**	**½-inch copper end cap**
9	**1**	**½ × 1¼-inch copper nipple (Make from item 2. See text)**
10	**1**	**¾ × 3¼-inch copper nipple (Make from item 1. See text)**
11	**1**	**Your choice of coupling to mast fitting (¾ × 1 inch NPT used at KD8JB)**
12	**6**	**#8-32 × ½-inch brass machine screws (round, pan, or binder head)**
13	**6**	**#8 brass flat washers**
14	**6**	**#8-32 brass hex nuts**

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 corrosion 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

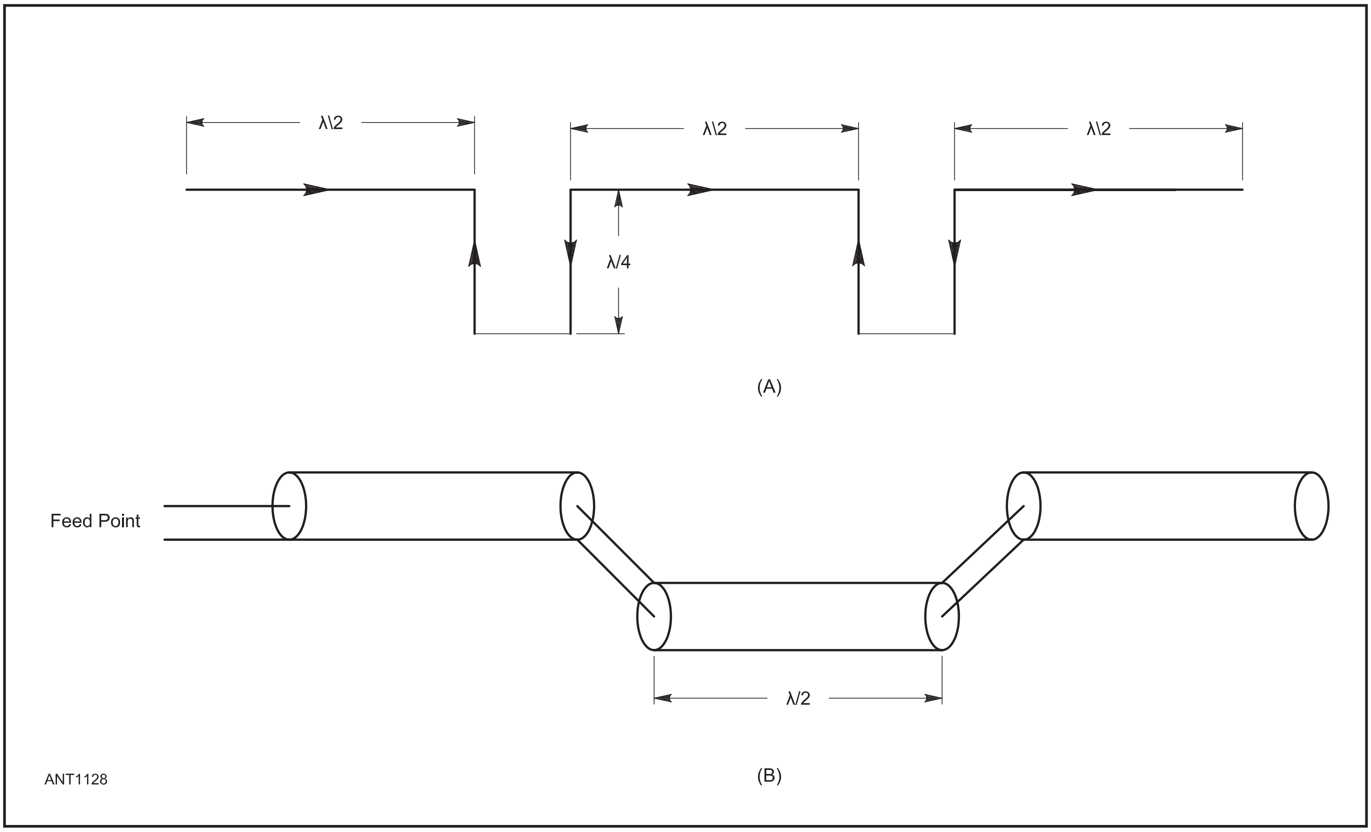


Figure 15.10 — The most popular collinear array is the omnidirectional array of half-wave dipoles constructed of transposed sections of coaxial cable.

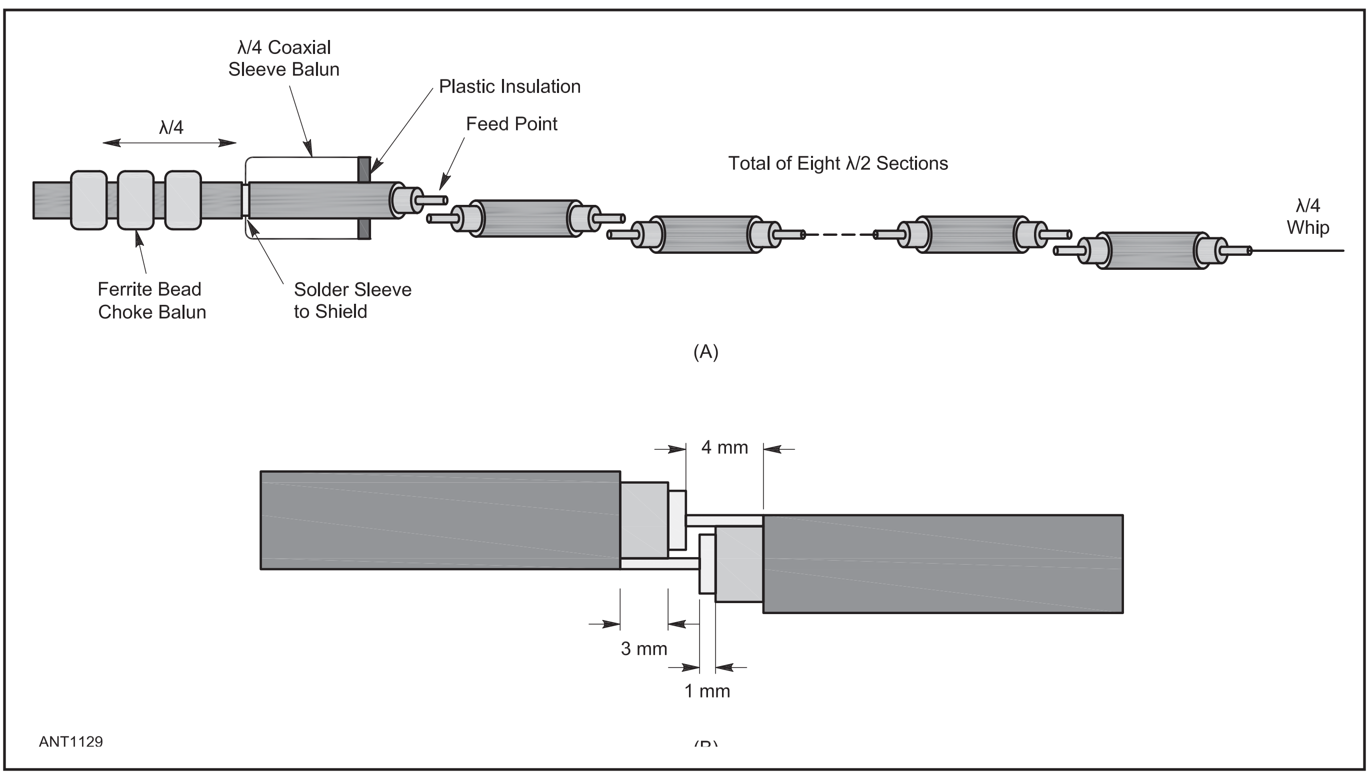


Figure 15.11 — Basic construction of a transposed-coax array for the 70 cm band. Dimensions are given in millimeters for accuracy.

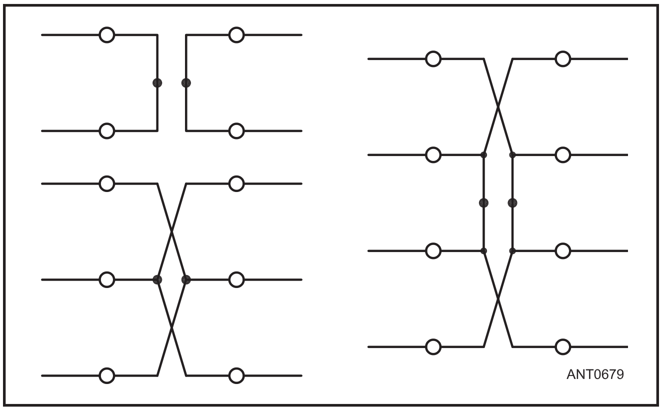


Figure 15.12 — Element arrangements for 8-, 12- and 16-element collinear arrays. Elements are ½ λ long and spaced ½ λ. Parasitic reflectors, omitted here for clarity, are 5% longer and 0.2 λ behind the driven elements. Feed points are indicated by black dots. Open circles show recommended support points. 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.

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 physical length of λ/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 λ/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 λ/4 coaxial sleeve balun is attached at the feed point of the antenna. (See the **Transmission Line System Techniques** 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 ⅝-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 λ/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 0.2 λ 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

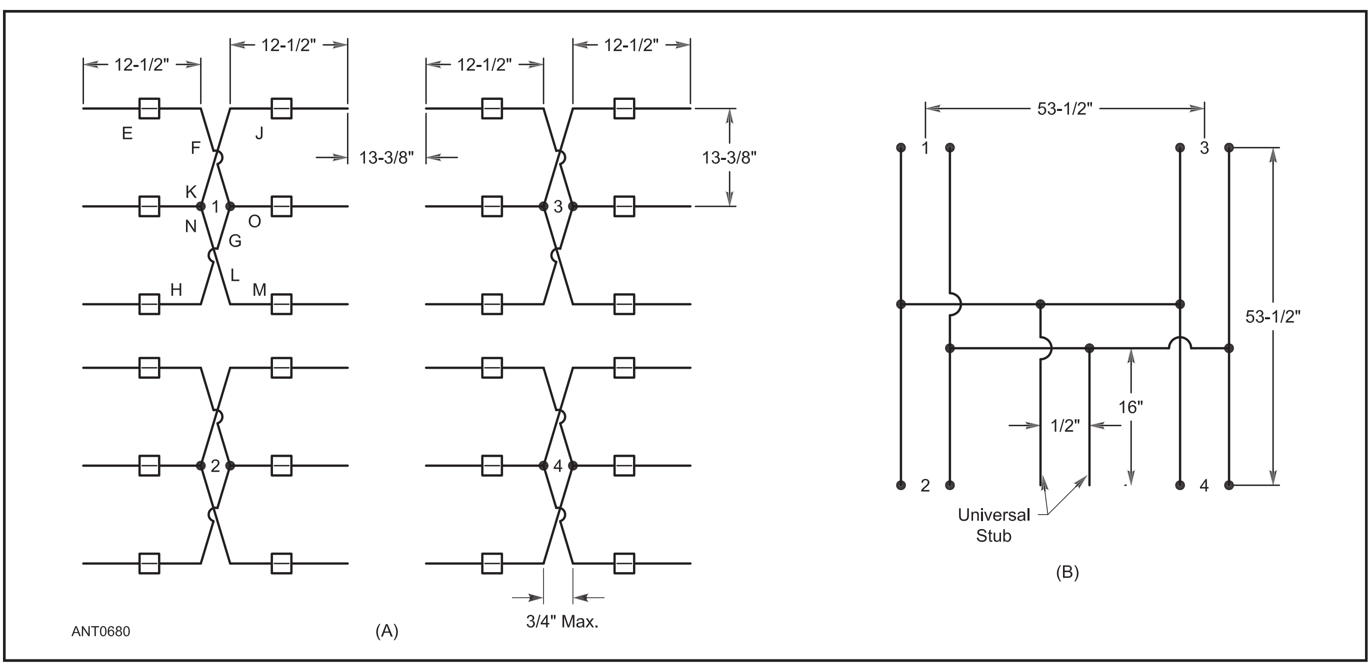


Figure 15.13 — Large collinear arrays should be fed as sets of no more than eight driven elements each, interconnected by phasing lines. This 48-element array for 432 MHz (A) is treated as if it were four 12-element collinear antennas. Reflector elements are omitted for clarity. The phasing harness is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

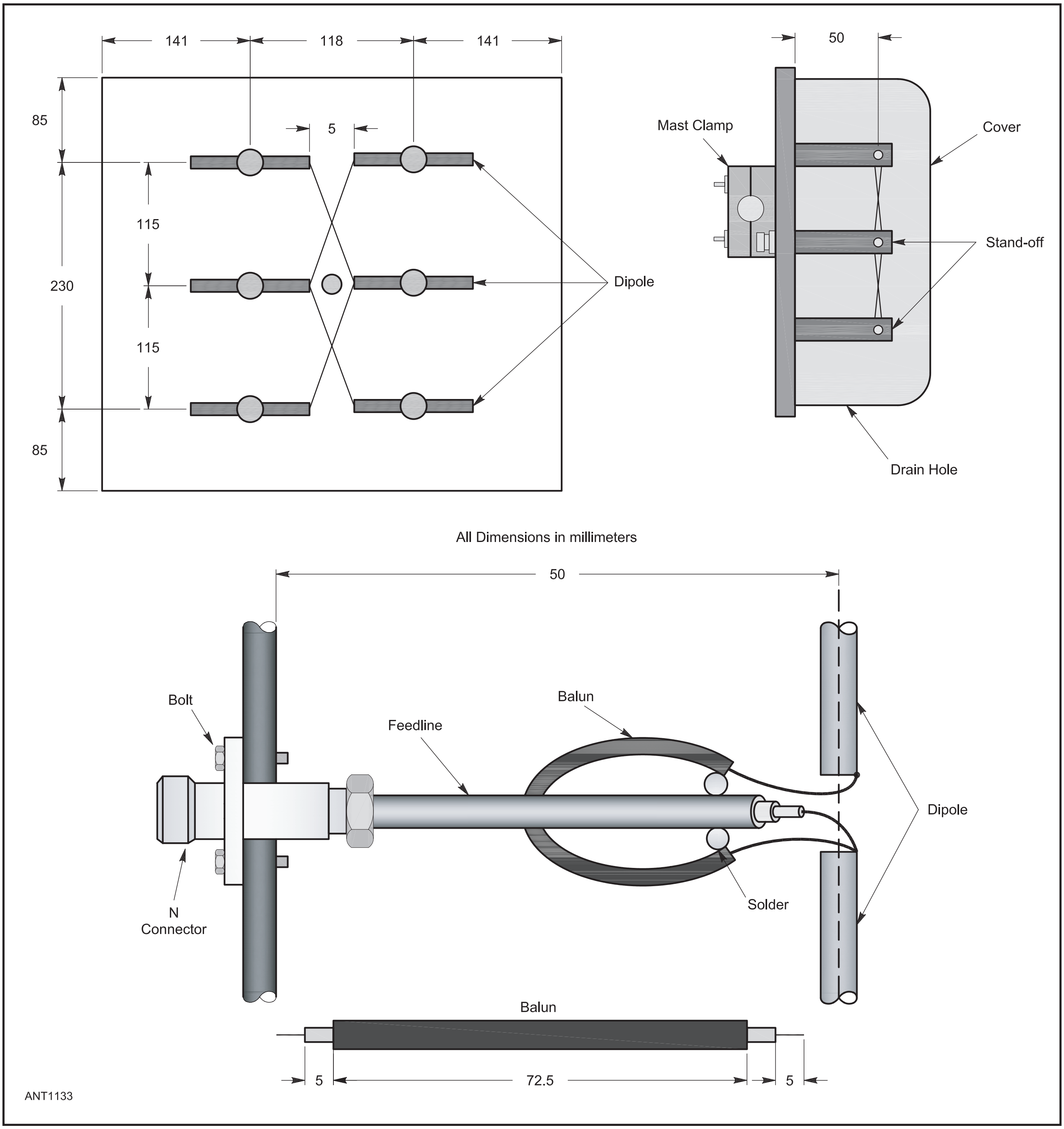


Figure 15.14 — Details of the F5JIO 23 cm collinear array.

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

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 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 ¼ λ 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 0.2 λ 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 1 λ or less.
- A reflector plane spaced ⅝ λ behind the radiator adds a maximum gain of up to 7 dB, but a spacing of 0.1 to 0.3 λ provides a better F/B ratio.
- If spaced at least 0.3 λ 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 600 Ω balanced. There are three pairs in parallel which divides this impedance by three to give 200 Ω, and a 4:1 coaxial balun transforms this to provide an excellent match to 50-Ω 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 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. 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 for 50 through 432 MHz.

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 (El) coverage can provide excellent results. The wide azimuth (Az) 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.)

The fundamentals of Yagi stacking are laid out by Ian White, GM3SEK, in the VHF/UHF Long Yagi Workshop section of his website (**www.ifwtech.co.uk/g3sek/index.htm**). The goal is to separate the antennas just enough that their capture areas (or *effective aperture*) do not overlap. This allows each antenna to fully contribute to the overall performance without creating additional sidelobes. The capture area of the Yagi can be thought of as an ellipse centered on the elements of the antenna.

Assuming horizontally-polarized Yagis, as stacking distance increases beyond optimum, the El pattern sidelobes will increase. This narrows the main lobe and more noise to be received from outside the main beam of the antenna. Stacking distances narrower than optimum ("under-stacking") allow a tradeoff between less gain and smaller vertical sidelobes. The tradeoff of a small amount of gain in order to gain improvements in reduced noise may be worthwhile.

It should be noted that vertical stacking of horizontally-polarized Yagis (H-plane stacking) does not narrow the Az beamwidth, only the El beamwidth. Horizontal stacking of the same antennas (E-plane stacking) narrows the Az beamwidth but not the El beamwidth. To narrow both beamwidths requires stacking in both the E- and H-planes, usually implemented as a four-antenna "H-frame" array.

Optimum vertical spacing for Yagis with booms longer than 1 λ or more is about 1 λ (984/50.1 = 19.64 feet), but this may be too much for many builders of 50-MHz antennas to handle. Worthwhile results for 50-MHz stacks can be obtained with as little as ½ λ (10 feet), but ⅝ λ (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 1 λ 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 Az directivity. A spacing of ⅝ λ between the ends of the inner elements yields approximately the maximum gain within the main lobe of the array.

DL6WU Stacking Formula

For antennas on the same band and assuming "long-boom" antennas, a formula developed by DL6WU gives excellent results that are close to optimum.

$$D = \lambda / (2 \times \sin (B/2))$$

where

D = the stacking distance
λ = the wavelength (D and λ must be in the same units)
B = the –3 dB beamwidth of the antenna.

For vertical stacking distance use the antenna's El beamwidth and for horizontal stacking distance, use the Az beamwidth. (A calculator for the DL6WU formula is available online at **dg7ybn.de/Stacking/6WU_online_calc.htm**.)

The formula is approximate. For E-plane stacking (in the plane of the elements) the antennas should have a boom length greater than 0.7 λ and for H-plane stacking, a boom length greater than 2 λ. It is safest to restrict the formula's use to Yagis of at least 2 λ boom length.

If individual antennas of a stacked array are properly designed, they look like non-inductive 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 Ω antennas at A are 1 λ apart, resulting in a paralleled feed point impedance of 150 Ω at the center. (Actually it is slightly less than 150 Ω 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.

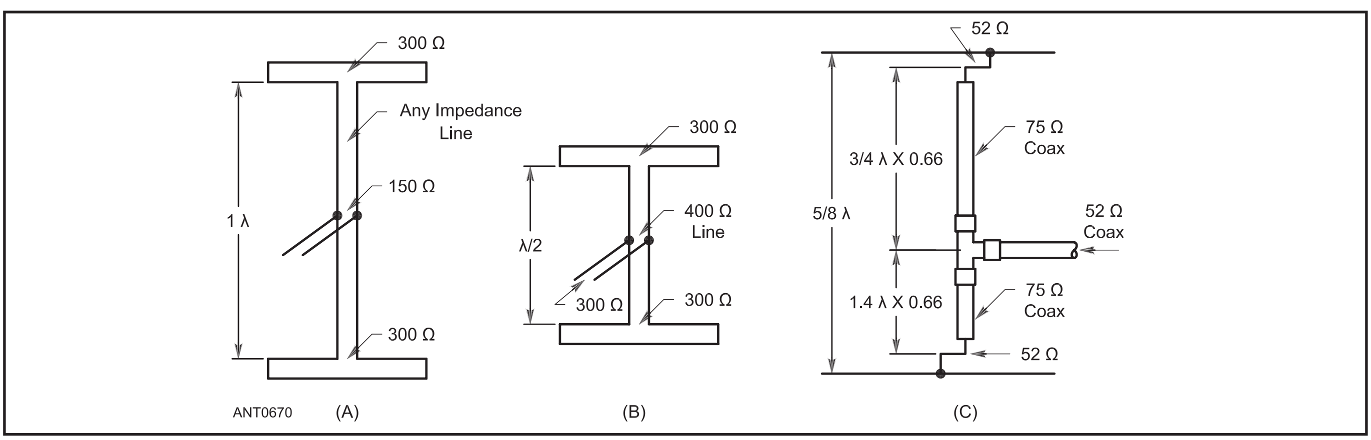


Figure 15.15 — Three methods of feeding stacked VHF arrays. A and B are for bays having balanced driven elements, where a balanced phasing line is desired. Array C has an all-coaxial matching and phasing system. If the lower section is also ¾ λ no transposition of line connections is needed.

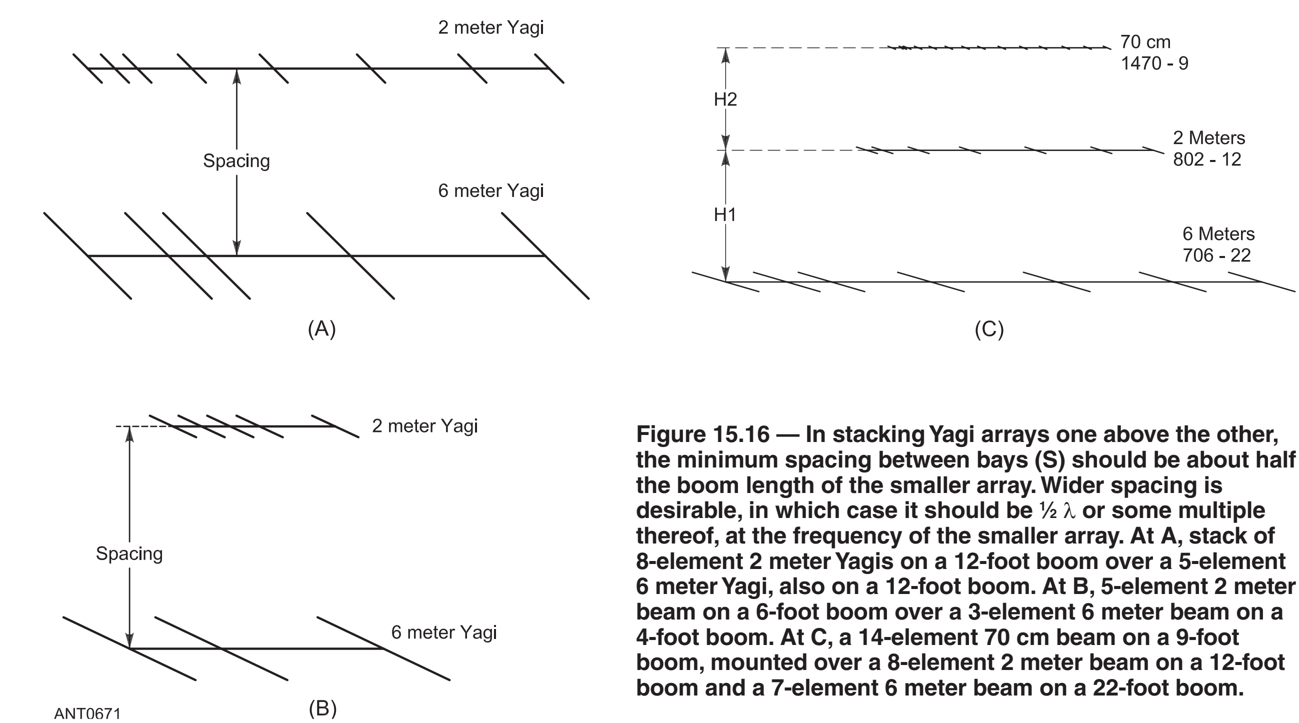


Figure 15.16 — In stacking Yagi arrays one above the other, the minimum spacing between bays (S) should be about half the boom length of the smaller array. Wider spacing is desirable, in which case it should be ½ λ or some multiple thereof, at the frequency of the smaller array. At A, stack of 8-element 2 meter Yagis on a 12-foot boom over a 5-element 6 meter Yagi, also on a 12-foot boom. At B, 5-element 2 meter beam on a 6-foot boom over a 3-element 6 meter beam on a 4-foot boom. At C, a 14-element 70 cm beam on a 9-foot boom, mounted over a 8-element 2 meter beam on a 12-foot boom and a 7-element 6 meter beam on a 22-foot boom.

The method for doing this is shown in Figure 15.2B. A ½ λ 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 ¼-λ line section can be used in combination matching and phasing lines, as shown in Figure 15.15B and C. At B, two bays spaced ½ λ 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 ¾-λ or 5⁄4-λ long, if such lengths serve a useful mechanical purpose. (An example is the stacking of two Yagis where the desirable spacing is more than ½ λ.)

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 ⅝ λ 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 ¼ λ and ¾ λ 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 ¼ λ 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 although computer modeling or manufacturer recommendations for equivalent antennas give better results.

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.]

The tables of antenna performance by VE7BQH (also called the VH list, see the sidebar) also include recommend stacking distances. Comparable antennas can be used as approximations for a homebuilt or unlisted antenna. For antennas on different bands, separate the antennas by at least one-half the recommended stacking distance for the higher-frequency antenna.

VE7BQH Antenna Performance Tables

Similar to the Sherwood Engineering receiver performance tables (**www.sherweng.com/table.html**) that show dynamic range and other performance metrics for popular transceivers, Lionel Edwards, VE7BQH, has compiled the performance data of a large number of antennas for 50, 144, and 432 MHz. (a.k.a. – the VH List) The tables are maintained online at **www.dxmaps.com/VE7BQH.html** and are also available as downloadable spreadsheet files from **www.bigskyspaces.com/w7gj/6mTable.htm**.

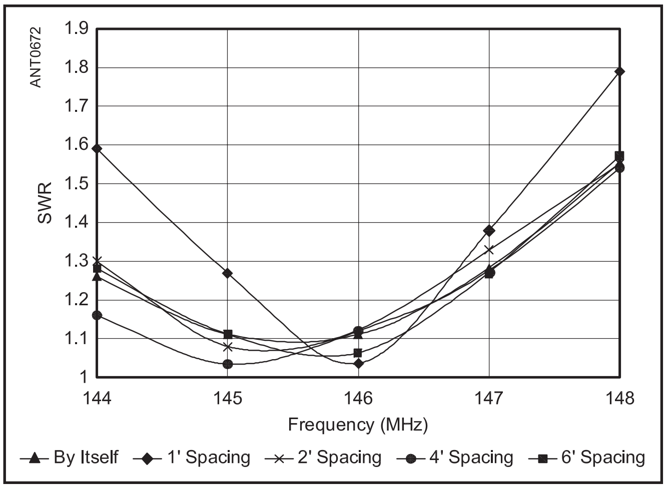


Figure 15.17 — SWR curves for different boom spacing between 8-element 2 meter Yagi on 12-foot boom, over a 5-element 6 meter Yagi on a 12-foot boom. For spacings greater than 1 foot between the booms, differences between the SWR curves are difficult to discern.

SWR Change in a Multi-Frequency Stack

Modern computer modeling programs reveal that while the feed point SWR can indeed be affected from nearby lower-frequency antennas, 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).

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 feet.

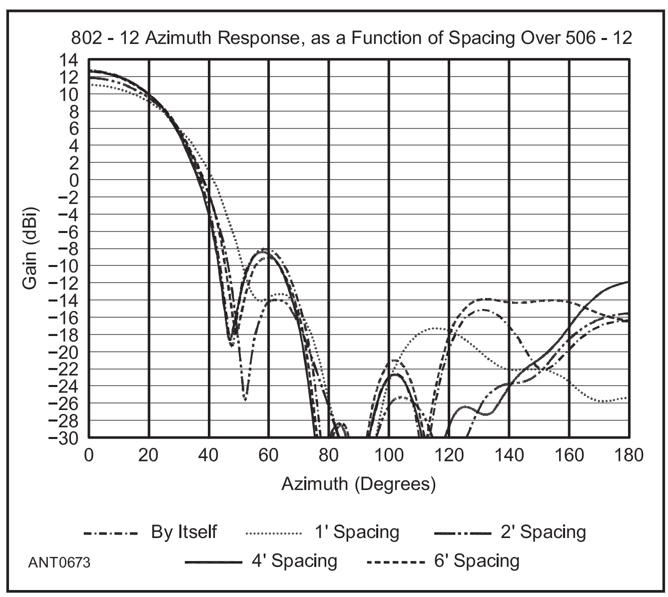


Figure 15.18 — Plots of the 8-element 2 meter Yagi's azimuth response from 0° to 180° for spacing distances from 1 to 6 feet. The sidelobe at about 60° varies about 6 dB over the range of boom spacings, while the shape of worst-case F/R curve varies considerably due to interactions with the lower 6 meter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

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 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.

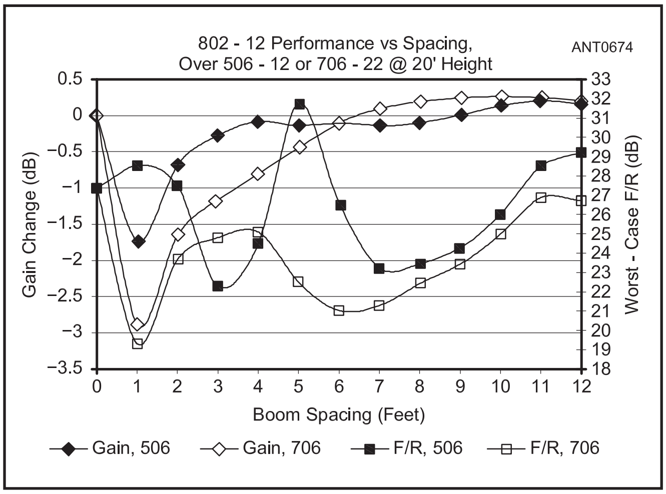


Figure 15.19 — Plot of 8-element 2 meter Yagi's gain and worst-case F/R as a function of distance over two types of 6 meter beams, one on a 12-foot boom and the other on a 22-foot boom. Beyond a spacing of about 5 feet the performance is degraded a minimal amount.

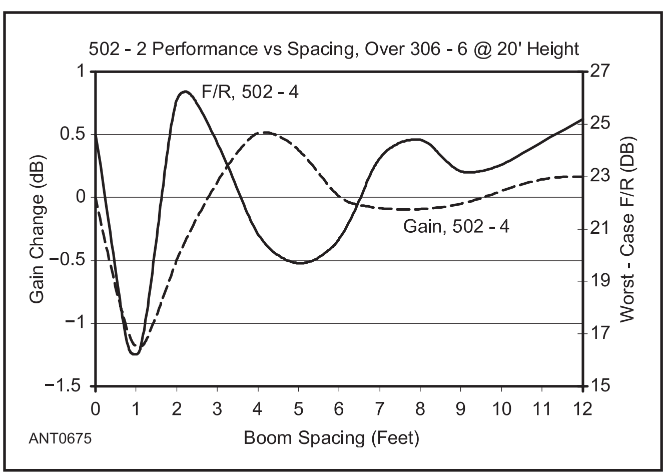


Figure 15.20 — Plot of gain and worst-case F/R of a 5-element 2 meter Yagi on a 4-foot boom as a function of distance over a 3-element 6 meter beam on a 6-foot boom. Beyond a spacing of about 3 feet the performance is degraded a minimal amount.

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 0.5 λ 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

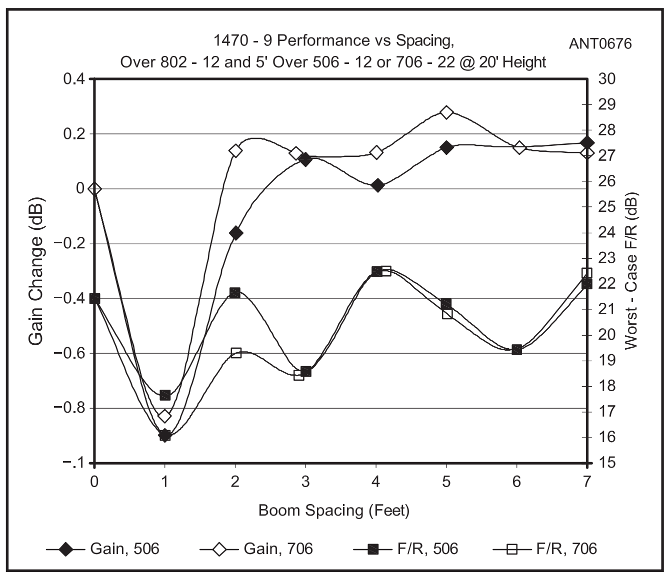


Figure 15.21 — Performance of a 14-element 70 cm Yagi on a 9-foot boom, mounted a variable distance over an 8-element 2 meter Yagi on a 12-foot boom, which is mounted 5 feet above either a 5-element 6 meter Yagi on a 12-foot boom or a 7-element 6 meter Yagi on a 22-foot boom. Beyond a spacing of about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

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 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.

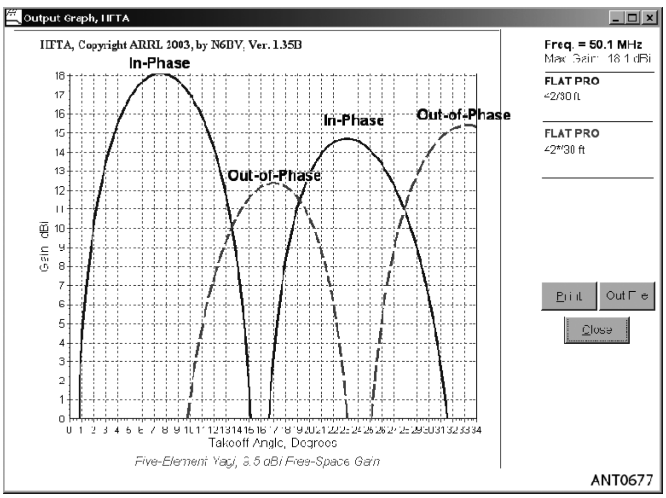


Figure 15.22 — *HFTA* comparison plots of the elevation responses for two 5-element 6 meter Yagis mounted at 42 and 30 feet above flat ground, when they are fed in-phase and out-of-phase. By switching the phasing (adding a half-wavelength of coax to one of the antennas), the elevation angle can be controlled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

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.

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

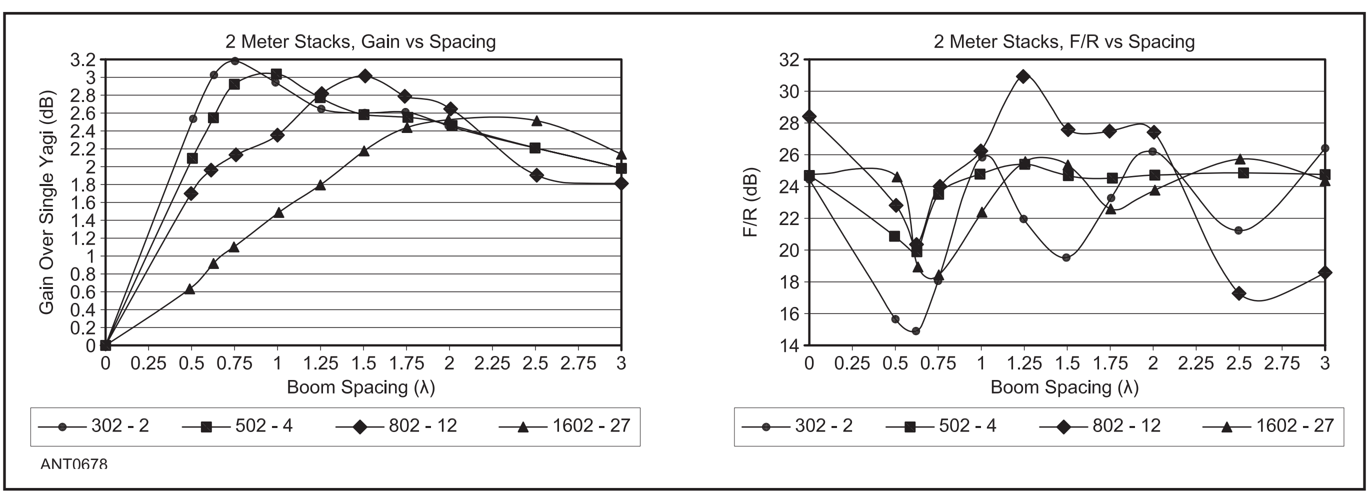


Figure 15.23 — Performance of two different 2 meter Yagis (5 elements on 4-foot boom and 8 elements on 12-foot boom) fed in-phase, as a function of spacing between the booms. Note that the distance is measured in wavelengths.

2-foot boom (occupying 0.28 λ of that boom). The 5-element Yagi is on a 4-foot boom (0.51 λ of the boom), while the 8-element Yagi is on a 12-foot boom (1.72 λ of boom). The biggest antenna in the group has 16 elements, on a 27-foot boom (4.0 λ 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 0.75 λ 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 1.7 λ, where the gain has fallen about 0.6 dB from the peak possible gain. A boom spacing of 1.7 λ 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 1 λ (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 1.5 λ (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 2.25 λ (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 1 λ, the F/R pattern holds well for Yagi designs with booms longer than about 0.5 λ, 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 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.

Optimizing Yagi Stacks at VHF and Above

Starting with the DL6WU stacking formula discussed at the beginning of this section, further optimization of stacking distances is required in order to achieve the cleanest, tightest symmetrical patterns, maximizing front to rear (F/R) and front to back (F/B), and eliminating any "spike" lobes appearing in the elevation or azimuth patterns.

For a detailed discussion of the issues involved at this level of optimization, see the article "Development and Real World Replication of Modern Yagi Antennas (III) — Manual Optimisation of Multiple Yagi Arrays" by Justin Johnson, GØKSC, available as a PDF document on this book's CD-ROM. It is important to note that this optimization described in the article is not being carried out for absolute best sky temperature and/or G/T although the results prove not to be too far away from optimum in these areas.

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 Yagis is 12 feet (1.78 λ). We'll assume a boom length of 12 feet (0.61 λ) for the 5-element 6 meter Yagis.

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

The boom spacing for two 5-element 6 meter beams is 1 λ for peak stacking gain, but a compromise of 0.625 λ (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 0.625 λ 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 CONSTRUCTING VHF AND UHF YAGIS

Before discussing materials, it is important to note that high-performance, especially at and above 144 MHz, requires that design specifications be followed very closely. Measurement or machining errors that can be ignored at HF become more significant at short wavelengths. The antenna designs in this chapter are fairly tolerant of deviations in the final assembly dimensions from those specified by the model and in the dimension tables. Good performance will be obtained using standard building practices and paying attention to details. However, accurate assembly is required if maximum performance is required or to duplicate the modeled performance.

Materials

Normally, aluminum tubing or rod is used for Yagi elements. Brass tubing is also used and has the additional advantage of being solderable. Hard-drawn 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 3⁄16 inch or 4 mm should not be used on any band. The size should be chosen for reasonable strength. Half-inch diameter elements are the minimum suitable for 50 MHz (use a tempered alloy) and should be used at 144 MHz. One-quarter to three-sixteenths inch elements are acceptable for higher frequencies. Steel, including stainless steel and unprotected brass or copper wire, should not be used for elements.

When developing a Yagi at VHF and up, it is important to make the driven elements adjustable. This allows the builder to compensate for minor variations in feed line attachments and slight variations in element placement. See the note regarding connections in the section on Feed Point Construction below.

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. If the original design uses a metal boom, use the same size and shape metal boom when you duplicate it. Larger or smaller conductive booms may require an adjustment in element length. If the design calls for a wood boom, use a nonconductive material. Fiberglass tubes or poles are also good for booms but may need painting for UV protection.

Wood is popular for temporary or portable antennas, such as those in the section Cheap Yagis by WA5VJB elsewhere in this chapter. Suitable sizes of lumber include 1 × 3 (up to 15 feet long), 1 × 2 or ¾ × 1¼ pine molding stock, or even strips of ½-inch exterior plywood for very short antennas. 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. If varnished well, wood can outlast aluminum in salt air and marine environments.

Insulated and Non-insulated Elements

Elements may be mounted insulated or non-insulated, above or through the boom. Insulating the elements from the boom reduces interaction between the elements and boom which becomes increasingly important in high-performance designs.

Non-insulated elements as in **Figure 15.24** are mechanically convenient and are at dc ground, assuming the boom of the antenna is also grounded. 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.

Computer modeling can apply a correction for the connection of the element with the boom — make sure you account for that interaction when designing the antenna as it is significant at VHF and higher frequencies! (Correction

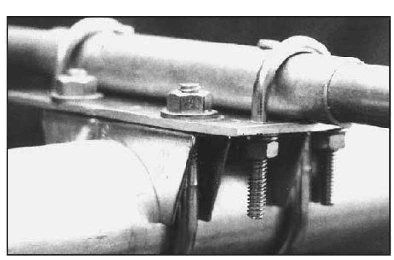


Figure 15.24 — The element to boom clamp. U bolts are used to hold the element to the plate, and 2-inch galvanized muffler clamps hold the plates to the boom.

tables are available on the DG7YBN and YU7EF websites referenced in the sidebar later in this chapter.)

Insulated elements can be mounted on shoulder insulators and run through the boom as in **Figure 15.25**. The stainless-steel element retainers are usually referred to as push-on retainers or "pushnuts" such as those made by Auveco Products (**www.auveco.com/product/nuts.html**). The insulating shoulder washers should be UV-resistant Teflon or Delrin, such as are available from Unicorp (**www.unicorpinc.com/insulating_washers.htm**). Directive Systems & Engineering (**www.directivesystems.com**) can supply small quantities of both parts.

Mounting non-insulated 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 or loosen connecting hardware. This will allow the elements to move in the boom, creating noise (in the receiver) when the wind blows, as the element contact changes. (Rope or string inside the element helps damp this movement.) 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.

One of the most popular construction methods for insulated elements 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 impractical for portable antennas.

Stauff clamps (**www.us.stauff.com**) can be used to hold the elements on the boom as shown in **Figure 15.26**. These clamps are relatively new to US antenna builders but solve several problems with the traditional plate-and-U-bolt construction and are rated for industrial and outdoor use. The clamps for reflector and director elements are typically mounted directly to the boom. Various brackets and supports are also available from Stauff. Be sure to use clamps with polypropylene (PP) insulation at VHF and above as other plastics exhibit excessive loss.

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. (A change in boom diameter also requires element length adjustment.) See **Figure 15.27** for an example of the effect of element mounting. 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. When using a model or design plans for a Yagi, be sure to note whether the elements are in contact with a conductive boom and whether corrections are incorporated into the model and design.

Feed Point Construction

The following applies especially to high-performance antennas at VHF and above. Modeling software assumes that at the antenna feed point, the coax stops and the driven element starts and there are no wires or pigtails or connectors between them. This means that when an antenna is built from a software model, the driven element will need to be shorter than the model suggests when built, in order to account for the connections that will indeed need to exist between the coax and the antenna feed point in the real world.

RF does not wait until it arrives at the element itself to radiate. At the exact point at which the coax cable is no longer coaxial, the radiating element begins and this includes any wires or pigtails. It is for this reason that a driven element will always need to be shorter than model, assuming that the antenna is built correctly and any correction factors have been appropriately applied. Additionally, this highlights the fact that tail length should be reduced to an absolute minimum and more T shaped across the feed point as in **Figure 15.28** rather than Y shaped in order for the software model can be replicated as closely as possible. Similar considerations apply to the use of connectors. The higher the frequency, the more relevant this rule becomes.

Leads from a feed line or balun to the feed point (or coax pigtails) should be as short as possible and spread apart parallel to the driven element. Once no longer inside the

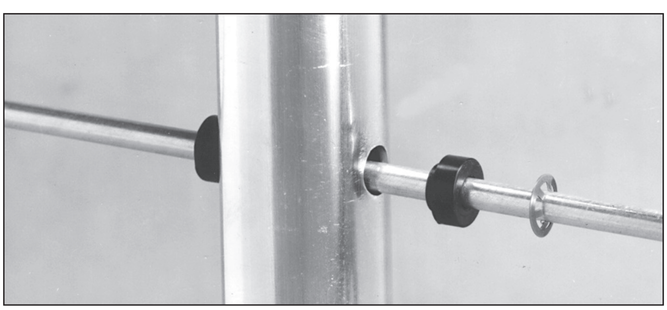


Figure 15.25 — Insulated elements up to ⅜ inch in diameter can be mounted through the boom using plastic insulators. Stainless-steel push-nut retaining rings hold the element in place.

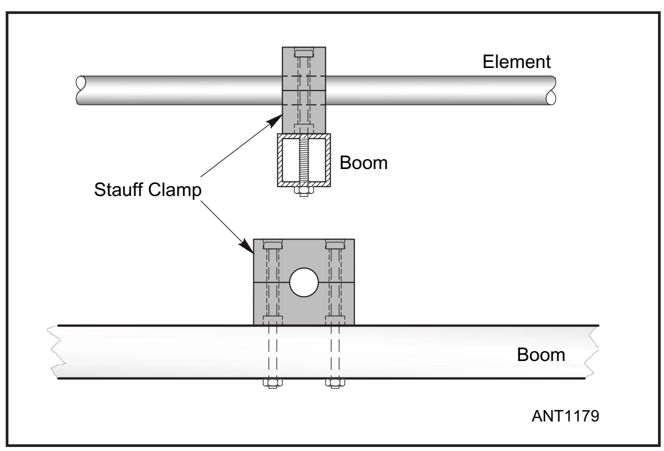


Figure 15.26 — Using a Stauff clamp to mount an insulated element on a square boom.

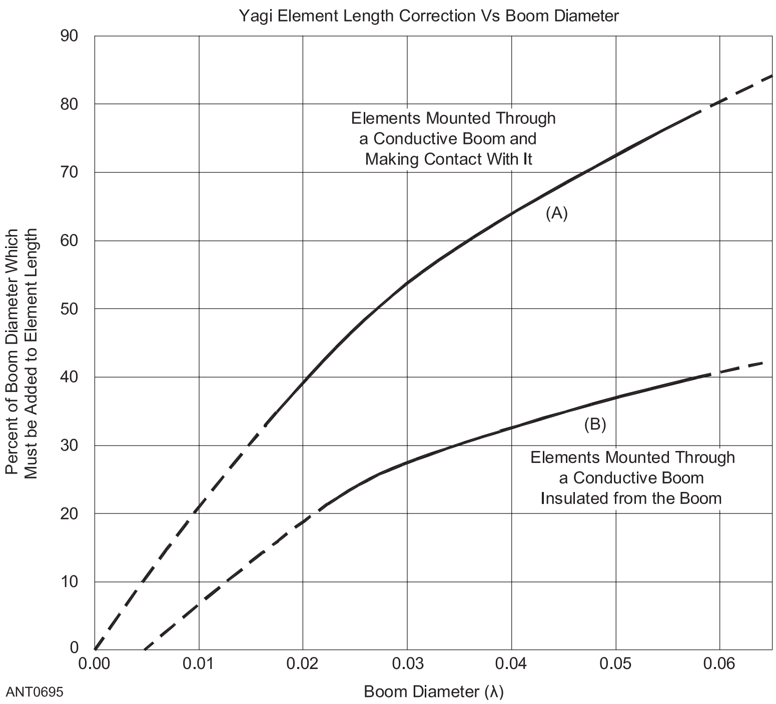


Figure 15.27 — Typical Yagi element correction vs boom diameter. Curve A is for elements mounted through a round or square conductive boom, with the elements in mechanical contact with the boom. Curve B is for insulated elements mounted through a conductive boom, and for elements mounted on top of a 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. This graph is an example of typical element length corrections and should not be applied in all circumstances.

Figure 15.28 — A close-up of the feed line connection showing proper technique for creating and attaching coaxial cable to a driven element. The configuration should be as close to T-shaped as possible and in line with the element to avoid affecting performance at VHF and higher frequencies

coaxial cable, the leads form part of the driven element and if they are excessively long it will affect antenna performance.

Choke Baluns for VHF/UHF Yagis

A choke balun should be used at the feed point to prevent interaction between the antenna and the feed line shield's outer surface. Alternately, resonant transmission line baluns are commonly used at VHF and UHF. See the **Transmission Line System Techniques** chapter for design and construction information on choke and transmission line baluns. At VHF and UHF, the most consistent performance from bead baluns requires using an appropriate ferrite mix such as 43 or 61.

If a choke balun at the feed point is used, feed line length between the balun and the feed point should be as short as possible to limit interaction between the feed line's outer surface and the antenna.

15.3.3 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 high-performance OWL (Optimized Wideband Low Impedance) design for 50 MHz by Justin Johnson, GØKSC, is included in the High-Performance Yagi Design section of this chapter.

A beam designed for FM operation higher in the band is described by the August 2007 *QST* article "A Short 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, "2 x 3 = 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. 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.

Table 15.1
Optimized 6 Meter Yagi Designs
(Lengths are for half elements)

	Spacing Between Elements (inches)	*Seg1 OD Length (inches)*	*Seg2 OD Length (inches)*	*Midband Gain F/R*
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	

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 15.29** 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.

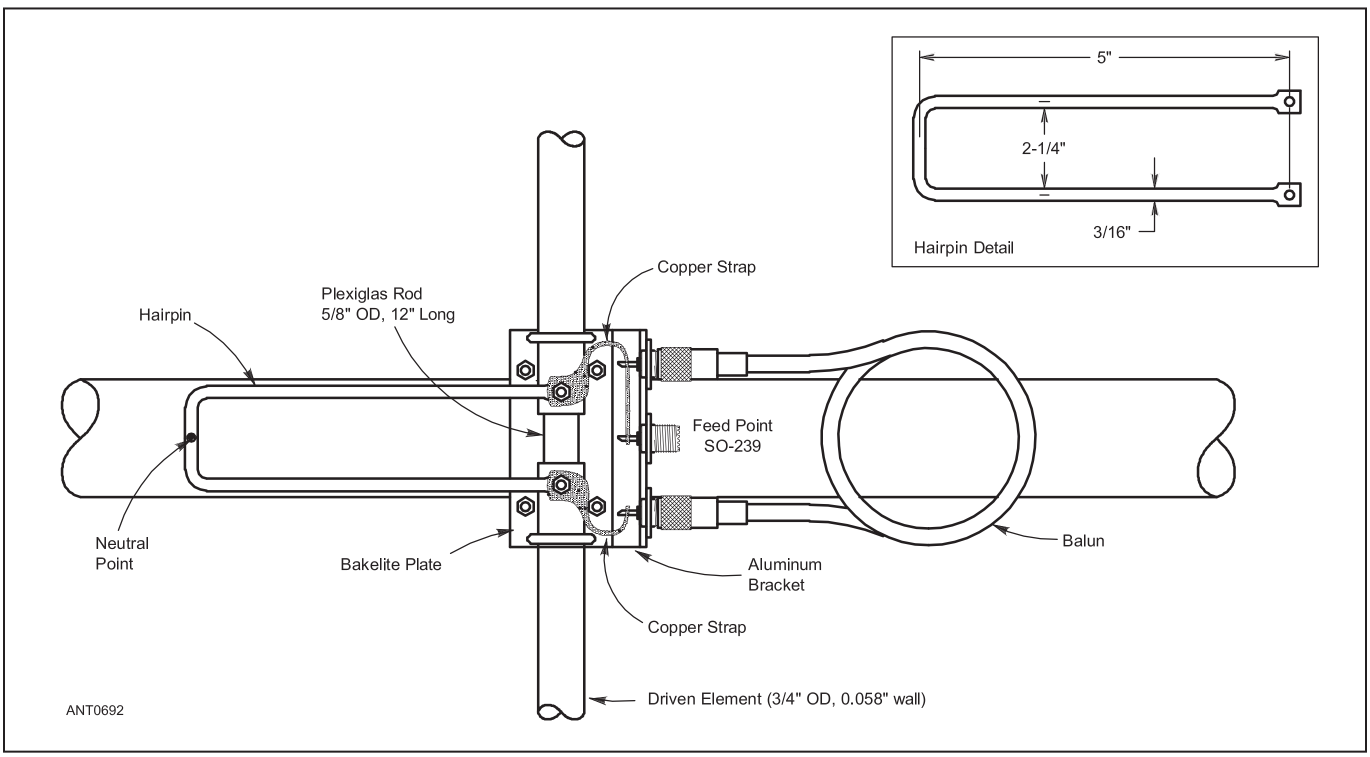


Figure 15.29 — This shows how the driven element and feed system are attached to the boom. The phasing line is coiled and taped to the boom. The center of the hairpin loop may be connected to the boom electrically and mechanically if desired.
Phasing-line lengths:
For cable with 0.80 velocity factor — 7 ft, 10⅜ inches
For cable with 0.66 velocity factor — 6 ft, 5¾ 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*

15.3.4 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 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 15.30** shows the general structure of the beam and **Figure 15.31** 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.

Table 15.2
2 Meter OWA Yagi Dimensions
(Lengths are for full elements)

Element	*Element Length (inches)*	*Spacing from Reflector (inches)*	*Element Diameter (inches)*
Reflector	40.52	—	3⁄16
Driven Ele.	39.70	10.13	½
Director 1	37.36	14.32	3⁄16
Director 2	36.32	25.93	3⁄16
Director 3	36.32	37.28	3⁄16
Director 4	34.96	54.22	3⁄16

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 ½-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 System Techniques** chapter) is desirable. The SWR as shown in **Figure 15.32** is very flat across

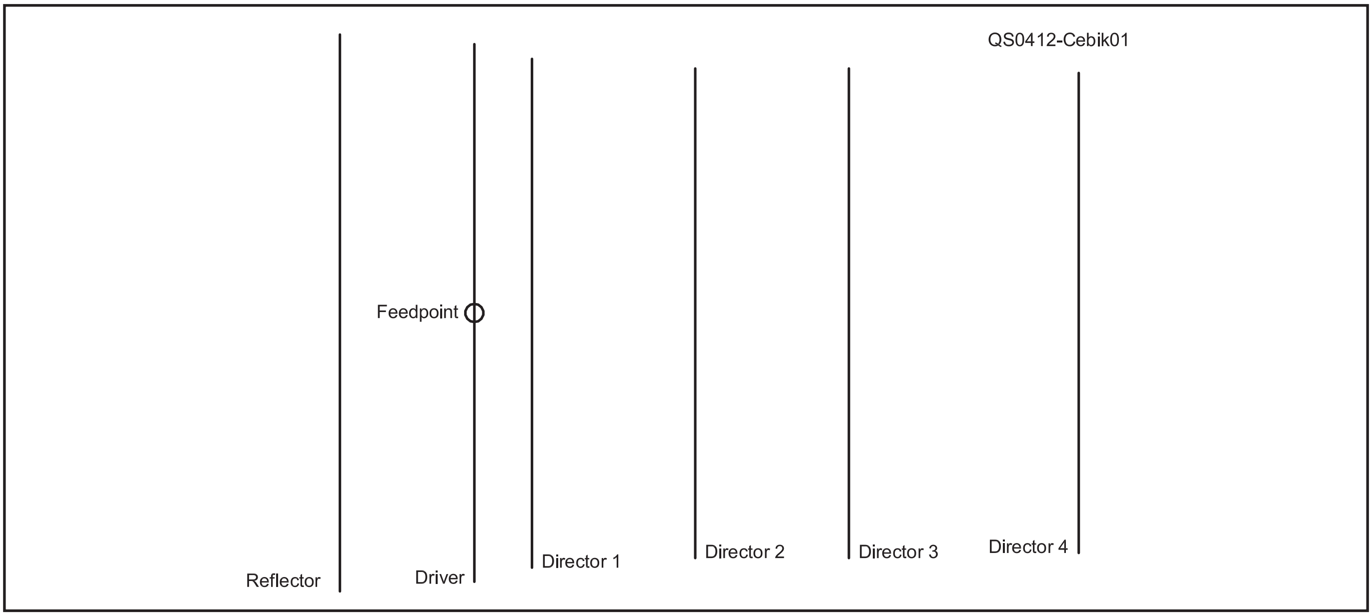


Figure 15.30 — The general structure of the 2 meter, 6-element OWA Yagi. See Table 15.2 for dimensions.

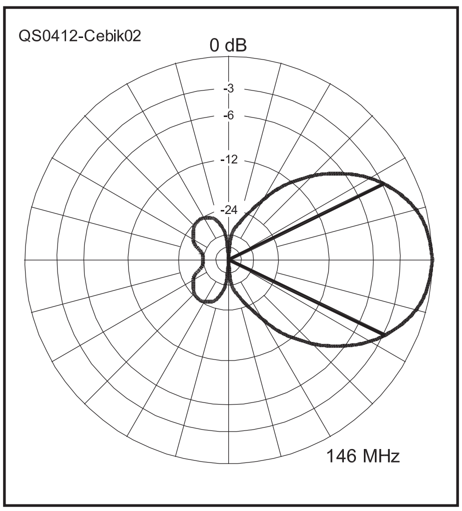


Figure 15.31 — E-plane (horizontal azimuth) pattern of the 2 meter, 6-element OWA Yagi in free space at mid-band — 146 MHz. The antenna exhibits a gain of about 10.2 dBi, consistent across the 2 meter band.

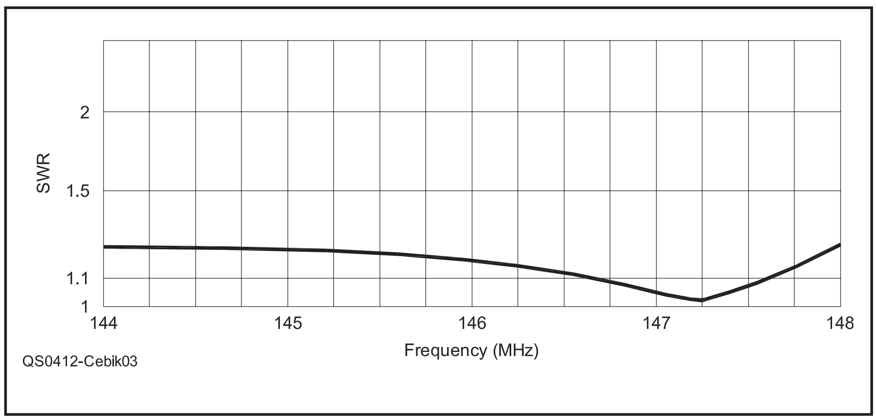


Figure 15.32 — The SWR for the OWA 2 meter Yagi from 144 to 148 MHz as modeled by *NEC-4*.

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 15.33**. The short 30-inch boom is small enough to fit in the trunk of a compact 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 15.34** and the

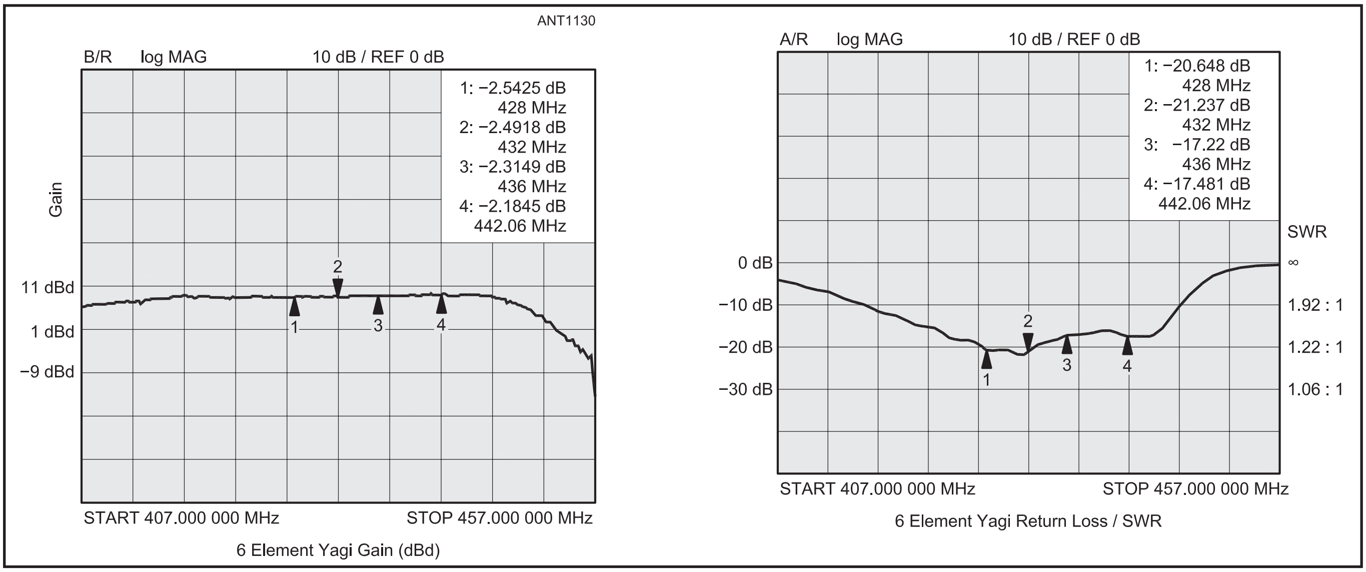


Figure 15.33 — Gain and SWR measurements for the 70 cm Yagi.

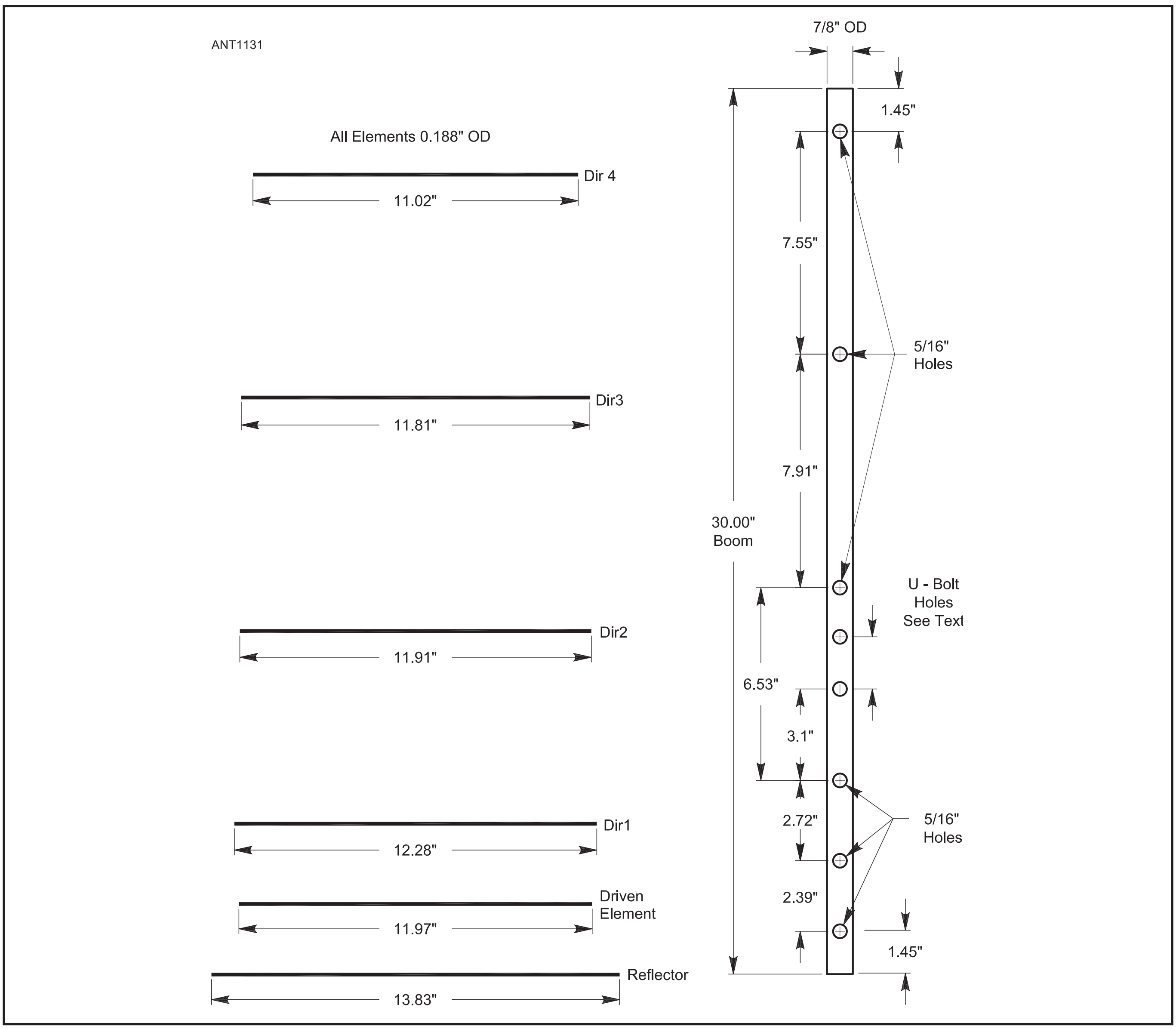


Figure 15.34 — Rough scale drawing of the 70 cm Yagi boom and elements.

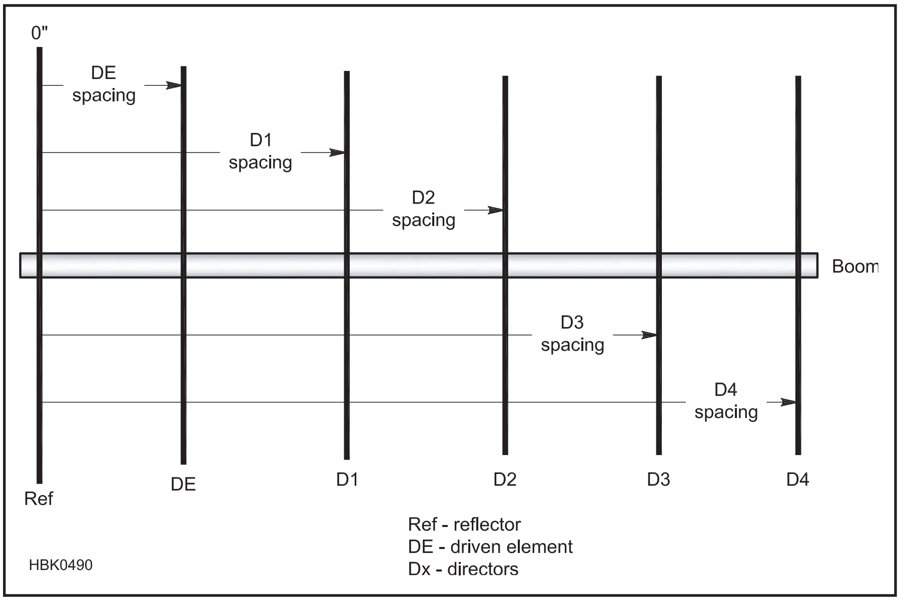


Figure 15.35 — Element spacing for the Cheap Yagis. Refer to Tables 15-4 to 15-10 for exact dimensions for the various bands.

Table 15.3
432-MHz Yagi Dimensions

	Spacing Between Ele. (inches)	*Spacing from Reflector (inches)*	*Full Element Length (inches)*
Reflector	0	—	13.832
Driven Ele.	2.394	2.394	11.968
Dir. 1	2.715	5.109	12.284
Dir. 2	6.528	11.637	11.908
Dir. 3	7.907	19.544	11.810
Dir. 4	7.546	27.09	11.01

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, he T match steps up the impedance of the driven element to 200 Ω.

15.3.5 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 ¾-inch square, or ½-inch by ¾-inch wood. To 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 15.35 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 15.36 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 15.37** 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!

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 ³⁄₁₆-inch aluminum rod and the driven element is made from ⅛-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 ³⁄₁₆-inch aluminum rod and the driven element is made from ⅛-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 ⅛-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 ¾-inch square wood for the boom makes it easy to build two antennas on the same boom for cross-polarization. Offset the two antennas 6½ 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 ⅛-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,

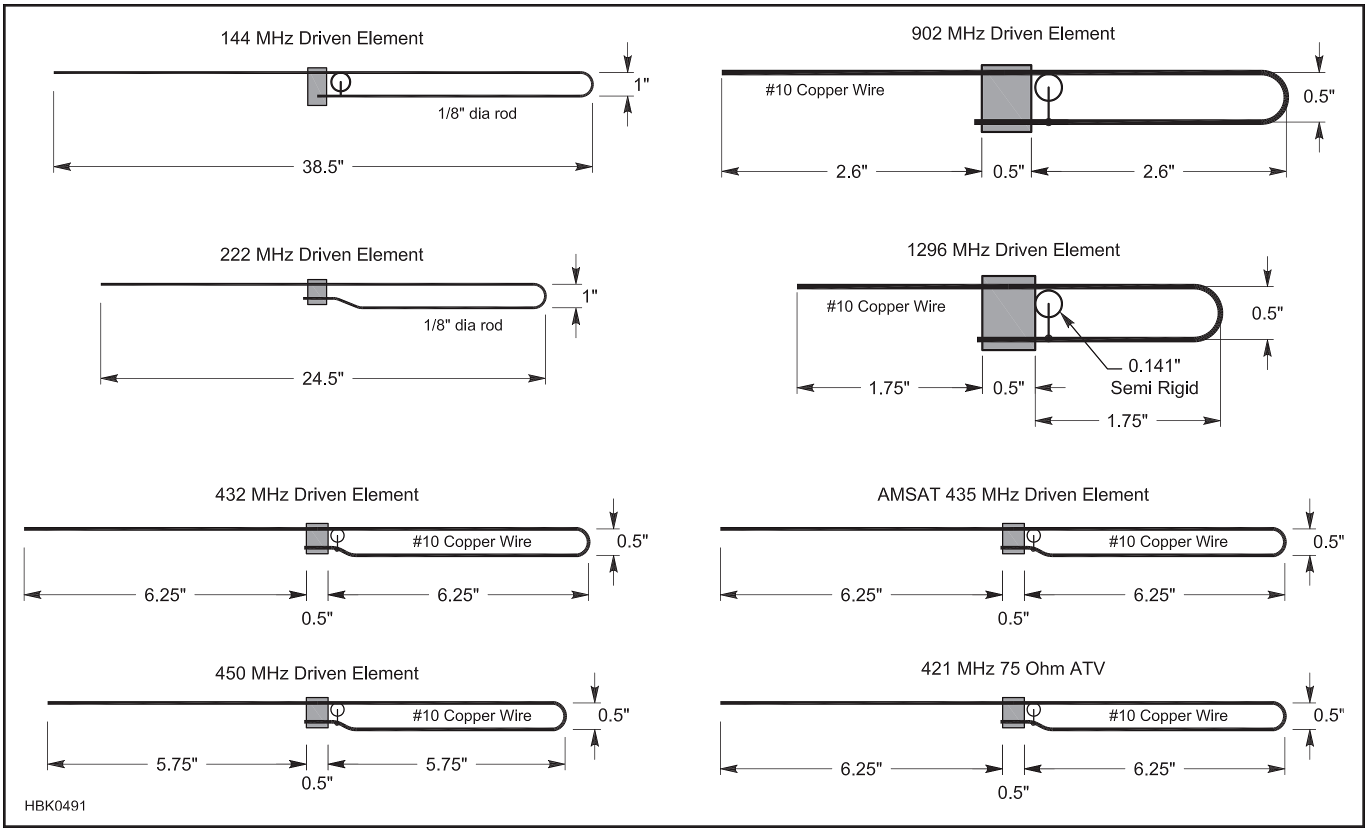


Figure 15.36 — Driven element dimensions for the Cheap Yagis. Attaching the coax shield to the center of the driven element is appropriate because that is the lowest impedance point of the element.

Table 15.4
WA5VJB 144 and 222 MHz Yagi Dimensions

144 MHz Yagi

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*
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

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*
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.

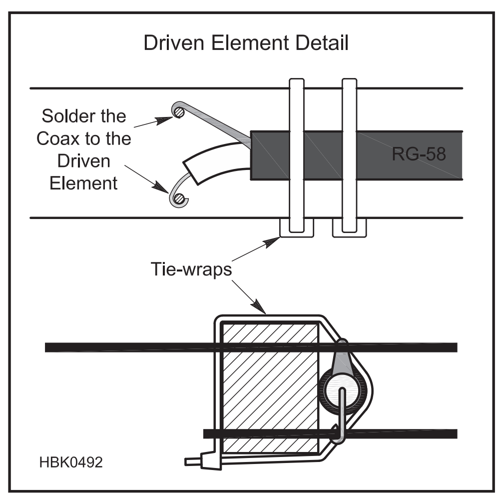


Figure 15.37 — Construction details and feed line attachment for the Cheap Yagi driven element.

cheap antenna to get a newcomer into a repeater or make a simplex-FM QSO during a contest. RadioShack ⅛-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 ⅛-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 ⅛-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 ⅛-inch silicon-bronze welding rod for the elements, but any ⅛-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

Table 15.5
WA5VJB 432 MHz Yagi Dimensions

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*
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

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*
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.

Table 15.7
WA5VJB 450 MHz Yagi Dimensions

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*
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

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*
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

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*
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

		Ref	*DE*	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*
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.

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 ⅛-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.

15.3.6 HIGH-PERFORMANCE YAGI DESIGN

This section was primarily updated and extended by Justin Johnson, GØKSC, based on his articles in *DUBUS* and from material on his website at **www.g0ksc.co.uk** (see Bibliography). In addition to the summarized information here and references in the Bibliography, several articles by Justin are included on the CD-ROM accompanying this book. The CD-ROM also includes the classic Yagi designs by Steve Powlishen, K1FO (SK), featured in several recent editions of this book. For those who wish to construct antennas based on DL6WU's work, a Javascript calculator by K7MEM is available online at **www.k7mem.com/Electronic_Notebook/antennas/yagi_vhf.html** and a family of designs is available at the article referenced in the Bibliography.

The treatment of high-performance Yagi design in this edition takes advantage of high-precision modeling developed over the past few years to achieve better control of antenna pattern through manual and automatic optimization. In addition, construction techniques that can have a significant effect on performance across a band and susceptibility to noise pickup are discussed.

New techniques pioneered by YU7EF, DG7YBN, UA9TC, RA3AQ, and others (see the sidebar Yagi Designs Online for web URLs) have contributed to the development of Yagis optimized for wideband (flat) performance, consideration of elevation plane lobes, self-matching radiating elements, close-spaced "driver cell" (first three elements), and other key performance indicators, particularly gain/noise temperature performance as described in the sidebar Gain/Noise Temperature (G/T). It should be understood that not all of the antenna designs found online take into account the

Yagi Designs Online

Many designers have been creating high-performance Yagis for EME and VHF+ contesting. Here are a few of the active designers websites:

DG7YBN — **dg7ybn.de/index.htm**
DK7ZB — **www.qsl.net/d/dk7zb**
GØKSC — **www.g0ksc.co.uk**
G4CQM — **g4cqm.www.idnet.com**
UA9TC — **www.vhfdx.ru/faylyi/view-details/shemyi-i-opisaniya/ant-ua9tc**
YU7EF — **www.yu7ef.com**
YU7XL— **www.qslnet.de/member/yu7xl**
DUBUS Magazine — **www.dubus.org**

Gain/Noise Temperature (G/T)

This parameter is a figure of merit for evaluating the antenna's ability to receive weak signals. That ability is particularly important at VHF/UHF/microwave where signals can be very weak, such as for EME operation and in contests. G represents the antenna gain in dB and T_a is the equivalent noise temperature of the antenna in degrees Kelvin. (See T. Milligan, *Modern Antenna Design, 2nd Edition,* IEEE Press, p. 32.)

For the purposes of this discussion:

$$G/T = (G + 2.15) - (10 \log T_a)$$

where more positive values indicate better performance. T_a includes noise received from all directions including side lobes.

An alternative calculation of G/T for the entire receiving system includes the noise produced by the antenna and receiving system, which includes the feed line, any preamplifiers, and the receiver itself.

Optimizing G/T is similar to optimizing signal-to-noise ratio (SNR) in that the goal is optimizing the quality of the received signal and not necessarily absolute signal level or noise level.

G/T may be calculated directly from the Far Field radiation pattern tables produced by *EZNEC* or *4nec2* by using *TANT*, a DOS utility program developed by Sinisa Miloskjovic, YU1NT, originally for use in developing EME antenna systems. It imports the far field data from the file and computes G/T in 5-degree increments from elevation angles of 0 to 90 degrees. *TANT* may be downloaded at **www.dg7ybn.de/Ant_Temp/Ant_Temp.htm#TANT** with instructions for use and sample input and output files.

It is important to note that while this is a good method of comparison between antennas, it is intended for use in EME systems and the calculations are performed assuming an antenna elevation fixed at 30°. With any given set of Yagis pointed at the horizon or at elevation angles greater than 30° very different comparative results may be seen.

entire set of considerations in the following discussion while being optimized.

Building on the current state of computer-optimized antenna design, this section details some additional attributes that contribute to the "ideal" Yagi. In addition, reasons are presented and discussed as to why Yagis for UHF and microwave bands sometimes do not perform at the level predicted by software models.

On a philosophical note, recent advances in modeling and optimization of antenna performance have led to some exciting new advances, all pioneered by amateurs. The combination of sophisticated design tools, inexpensive materials, and the manageable weight and size for Yagis above 50 MHz, make it possible for any amateur so inclined to construct their own state of the art antennas.

High-Performance At and Above 144 MHz

At 144 MHz and above, most high-performance operation requires Yagi antennas two or more wavelengths in length. Before computer-based optimization became practical for amateurs, a boom length of 2 wavelengths was the point at which classic Yagi performance started to fall apart in terms of gain per boom length, bandwidth, and pattern quality. Careful optimization techniques have extended the range of high-performance Yagi designs considerably beyond the 2-wavelength limit. This is discussed in the sections Optimization and Bandwidth followed by Optimizing to Minimize Real-World Noise.

The Classic Design Approach

As described in previous editions of this book, classic high-performance Yagi design approaches start with closely spaced directors. The spacings gradually increase until a constant spacing of about 0.4 λ 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 10 λ. The driven-element impedance also changes moderately with boom length.

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.

Measurements and computer analysis by both amateurs and professionals indicates that given an optimum classic design, doubling a Yagi's boom length will result in a maximum theoretical gain increase of about 2.6 dB. (This value is not exact and varies with optimization technique and element construction.) In practice, the real gain increase may be less because of escalating resistive losses and the greater possibility of construction error. **Figure 15.38** shows the maximum theoretically 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, but a point exists where too many directors will adversely affect all performance aspects.

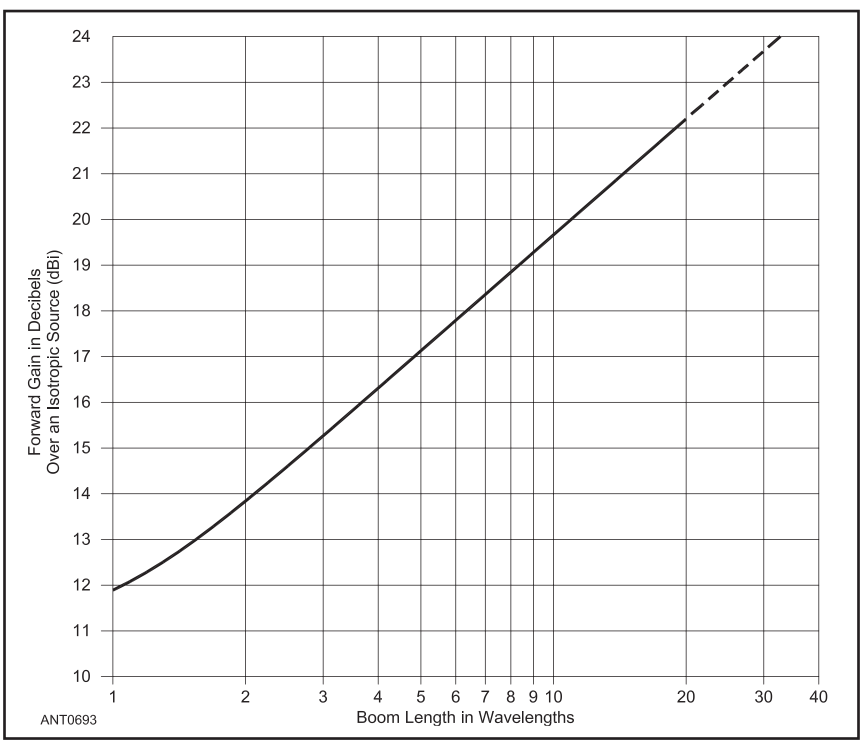


Figure 15.38 — This chart shows maximum gain per boom length for optimally designed long Yagi antennas using the classic design approach.

While short antennas (< 1.5 λ) may show increased gain with the use of quad or loop elements, long Yagis (> 2 λ) 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 0.15 λ and 0.2 λ 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.

Bent-Element Yagis

By bending elements in the most active part of the Yagi (the reflector, driven element, and first director) a variety of improvements can be made to antenna performance with a variety of additional construction complexity.

UA9TC first experimented with bending the reflector in a right angle at the ends, similar to the Moxon designs, resulting in improved bandwidth and less noise pickup but gain was reduced. GØKSC then changed the design to bend the tips of the driven element back toward the reflector. (OP-DES designs)

Another early experimenter was K6STI who developed designs with V-shaped driven elements to raise the feed point impedance. (The V opens rearward toward the reflector.) A five-element version of this design for FM broadcast has been published at **www.ham-radio.com/k6sti/five.htm**. This approach was extended by DG7YBN and others.

LFA Yagis

The LFA Yagi (Loop Fed Array) replaces the bent tips of the driven element with an extended folded-dipole type feed laid flat on the boom. Thus, both sides of the driven loop are in line with the parasitic elements, rather than extending above or below the boom. Unlike a traditional folded dipole driven element, the feed point of the LFA design is in line with the boom and all elements as shown in **Figure 15.39** with the feed point toward the front of the antenna. (LFA Yagis are available commercially only from InnovAntennas — **www.innovantennas.com**.)

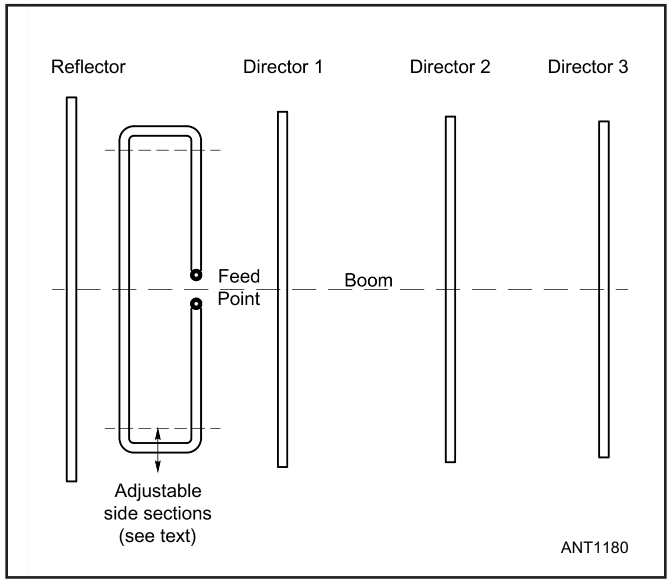


Figure 15.39 — Typical construction for an LFA Yagi with the loop driven element laying along the boom in the same plane as the elements.

The LFA design leads to a symmetrical pattern in both the E and H planes. However, this mechanical arrangement adds certain construction complications. With all elements in line, the feed point lies at the boom, centered on its axis. Workable construction options include using a metallic boom, although for optimum long-term performance the elements must be welded to the boom. Insulated elements passing through a metallic boom are another option, but this practice can lead to eddy currents in the boom, detuning the antenna and causing deterioration of both pattern and system temperature. With these problems in mind, a hollow fiberglass boom is recommended.

OWA, OWL, and OWM Yagis

Optimized Wideband Low Impedance (OWL) Yagis are a modification of the Optimized Wideband Array (OWA) Yagi designs developed by WA3FET and NW3Z (**www.naic.edu/~angel/kp4ao/ham/owa.html**). The OWA Yagi has a feed point impedance of 50 Ω for direct feed and wide bandwidth but as a tradeoff has lower peak gain and F/B. A benefit of the OWA design at VHF and higher frequencies is that the OWA design is less sensitive to small impedance shifts from weather or interaction with surrounding objects such as trees, buildings, and most importantly, other antennas.

The OWL Yagi has a conventional, split-dipole driven element, is designed to have a 12.5 Ω feed point impedance, and can be easily matched to 50 Ω with a λ/4 section of 25 Ω transmission line made from two parallel sections of 50 Ω coax. (See the **Transmission Lines** and **Transmission Line System Techniques** chapters for information on coaxial impedance transformers.) This enables good performance over a wider bandwidth than was previously available.

An alternate implementation of the OWL is to use a folded dipole for the driven element. This conveys the benefits of closed-loop feed systems, including that the feed point impedance is transformed to 50 Ω for direct connection to feed lines. This is the type of driven element used in the 144 MHz OWL designs later in this chapter.

The OWM (Optimized Wideband Medium Impedance) Yagi is designed for 28 Ω feed point impedance. This impedance can be matched to 50 Ω with a λ/4 section of 37.5 Ω transmission line made from two parallel sections of 75 Ω coax or a matching device can be used. (See the section on 144 MHz and 222 MHz Yagis for more information on building these coaxial cable transformer sections.)

Self-Matched Yagis

"Self-matched" Yagis are those that have the driven element constructed in such a way as to increase the impedance to 50 Ω for direct connection to 50 Ω feed lines. Rearranging the driven element can include bending the element, using folded dipoles as in the OWL designs in this chapter, or using a loop as for the Loop-Fed Array (LFA).

There are a number of advantages of doing so, not the least of which is that the Yagi can be modeled, optimized and viewed exactly as it will be built with no additional structure (matching device) being added outside the model during the build-phase. This added structure and connections, including the feed line, can and do affect and change performance parameters in the real world. At the same time, direct feed can reduce the susceptibility to man-made noise and drastically increase the power levels of that can fed to the antenna system without problems.

Optimizing and Bandwidth

Figure 15.40 shows a graph of gain versus (F/R – F/B) in a "typical" Yagi with a single point (frequency) of optimization that is focused on maximum gain within the optimization parameter setup. (F/R is the ratio of forward to gain averaged over the entire rear-ward hemisphere — the "rear bubble" — and F/B is the ratio of forward gain to that at the exact opposite direction to the main lobe.) This is not a real plot of any Yagi and is very much exaggerated in order that the point can be illustrated.

The problem with optimizing metrics at a single frequency and to single parameters is the potential impact on real-world performance in changing conditions and from variations in materials used to build these antennas which could result in a shift of performance (and ultimately G/T) away from the specified frequency toward the band edges. For example, as the center of frequency on the VH list (the list of antennas in the VE7BQH Antenna Performance Tables, see sidebar earlier in this chapter) is 144.1 MHz and the bandwidth of each antenna is measured between 144 MHz and 145 MHz, the potential issue of the antenna's performance shifting within or even outside of its operating range is plain to see in Figure 15.40.

Often, the presented usable bandwidth is simply specified as the frequencies between which SWR is below a certain threshold (1.5:1 for example) rather than an average of all performance parameters over a given range. When correctly optimized, a good Yagi will have characteristics similar to a bandpass filter (BPF) in terms of performance with stable and consistent performance up to several hundred kHz (at VHF) or several MHz (at UHF) on either side of its center frequency. It's not just a nice flat SWR curve over a good range — gain and F/R will remain fairly constant, too.

What stands out clearly in Figure 15.40 is the best F/B (and/or F/R) and best forward gain are typically at opposite ends of the bandwidth of the antenna. Gain is highest at the top of this bandwidth (naturally) because of the increasing boom length (in terms of λ). F/B and F/R drop off very quickly in the same direction, usually because the Yagi is too long for the number of elements the modeler has selected for this given boom length, or the modeler has optimized for an exceedingly long boom length. In that case the Yagi cannot be optimized for a balance of gain and F/B (F/R) across the desired range. This "ski sloping" of performance parameters in opposite directions is very common and often the reason why gain and F/B figures are quoted as being "peak gain, peak F/B."

In Figure 15.40, the vertical line denotes the performance of this hypothetical antenna at 144.1 MHz and the corresponding gain and F/B results. Shifting frequency up and down just 50 kHz or so will show very different gain – F/B combinations which will result in a large variation in antenna temperature and G/T as well. Furthermore, it is important to note how close the center of operation (144.1 MHz) is to the band edge. Taking into account the desired BPF-type characteristics, the center of activity for any 144 MHz Yagi should more likely be focused around 144.300 MHz if modes other than just EME will be practiced by the end user. It would not take too much for narrower-band antennas to move well out of their peak performance characteristic range in real-world conditions (wet weather, ice, other antennas close by, and so on) if they were optimized between 144 and 145 MHz and were being used at 144.100 MHz. While the focus of the VH list is G/T performance at 144.1 MHz for EME applications, the comparison of G/T at three points (perhaps 144.0, 144.1 and 144.2 MHz) may give a much more accurate indication as to what the user might expect for day-to-day or contest use.

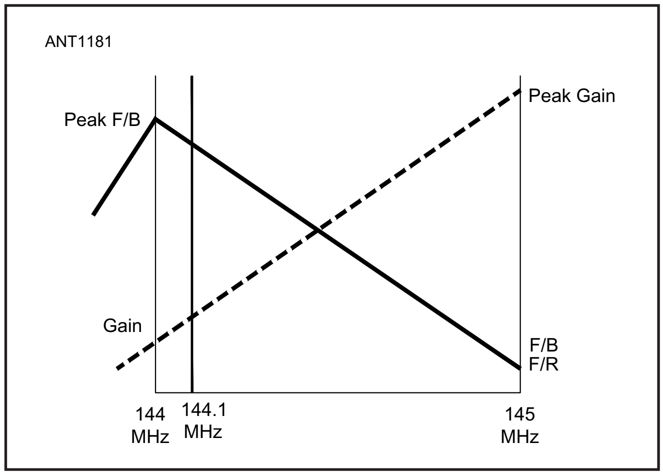


Figure 15.40 — Hypothetical performance of a typical Yagi across the 2 meter weak-signal band.

Because performance tends to fall off toward the edge of an antenna's design bandwidth, optimizing should be performed with 144.300 MHz, for example, as the true center of operation with a guided bandwidth of 500 kHz either side of that point (143.800 to 144.800 MHz). Doing this ensures very constant performance either side of the center frequency rather than perhaps experiencing the typical tail-off of performance at the band edges as discussed above. This leads to less impressive table values across 144-145 MHz but a more stable design to be used in varying weather conditions. An antenna which yields the most consistent results across a range centered on the most likely frequencies of use is likely to be the most stable for day to day use and/or use in extreme environments and not just for EME applications either!

Optimizing to Minimize Real-World Noise

The collection and pick-up of real world noise is dependent on the lack of side lobes in the elevation (El) plane. If lobes in the El plane are prominent and down-facing, regardless of how quiet a location is believed to be, higher levels of noise will be received in certain directions (direction of the shack and/or house, for example) than if any such lobes were more highly suppressed. When measuring and comparing G/T, rear-facing lobes in back of the 90°-270° line are what are considered for calculation and measurement. (See the sidebar Gain/Noise Temperature (G/T).) However, real-world operation by hams requires us to pay equal consideration to more forward and down facing lobes in this plane. At this point optimization starts to become more complicated — generally speaking, optimizing on one band then scaling to another will not show the same improvements in performance.

Different considerations and attributes must be taken into account during the design phase when switching from designing a Yagi on one band and then looking to repeat the results on another band. Quiet Yagis are very much band-specific — note that what is being discussed here is relevant only when optimizing on 144 MHz.

Take a look at **Figure 15.41** and the design considerations taken in order to not just show a good G/T figure (assume G/T is based on T_a unless noted otherwise), but to also reduce the likelihood of man-made noise pick-up to an absolute minimum from beneath the antenna within its near-field. This particular antenna used a closed-loop driven element to allow direct-feed (50 Ω feed point impedance) and lower noise pickup.

Within Figure 15.41 are two bars marked T1 and T2. T1 shows a sharp taper from the back towards the front. This level of taper right at the back of the antenna and forward is important to ensure good G/T results as tighter suppression from the 90° line backward will yield much better results. However, to continue this level of taper for the first side lobes would be disastrous for near-field noise pick-up. From having very wide side lobes in the azimuth (Az) plane (not much more than 12 dB below the main lobe) additional noise sources could be detected and interfere with signals in the desired capture direction from noise sources either side of center. The ability for this antenna to hear weak signals (real-world) would be greatly reduced by having what in effect would be three forward lobes in both planes, all receiving whatever was beneath or either side of the antenna. It is for this reason that an amount of suppression has been applied to the first lobe to arrive at the best compromise between the overall size of the "rear bubble" and outright forward gain.

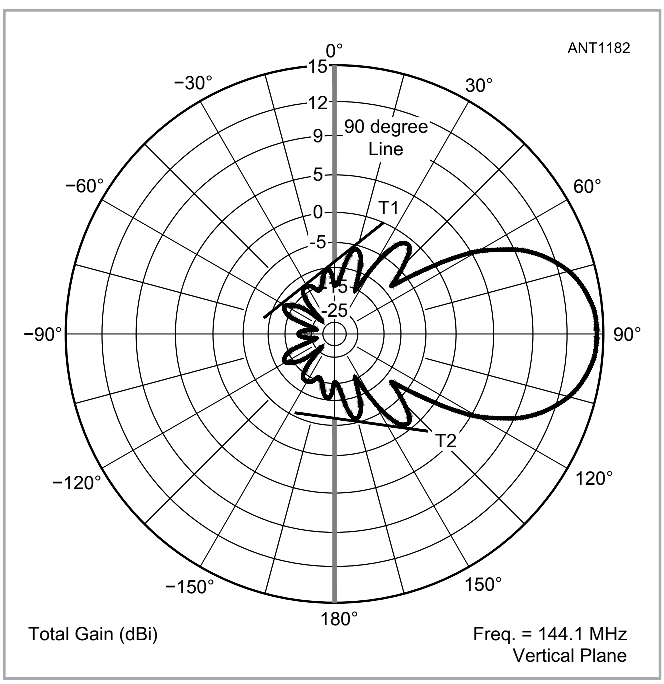


Figure 15.41 — Elevation plot of a 9 element Yagi showing the side lobe taper both in the rear hemisphere (T1) and between the rear hemisphere and the main lobe (T2).

The challenge is to achieve the best from the antenna in terms of performance while at the same time, keeping the El pattern as clean as possible. During optimization, GØKSC uses a maximum limit or "marker" for side lobes. Basically, this is a parameter that can be controlled during software optimization that is not so easily achieved when optimizing manually. Some software packages allow the starting point at which F/R is measured (normally 90°) to be moved forward towards the forward lobe. The advantage of so doing is this starting point can be moved forward until it covers the angle from the forward lobe where forward lobes would start to increase in size. While this sounds simple, in practice, getting excellent results take a lot of time and work.

Antennas of typical length up to around six elements tend not to produce side lobes of any consequence, at least not in the Az plane. For weak signal and EME work, the desire is to have much longer antennas than six elements and normally they would have booms of multiple wavelengths. If uncontrolled, the natural course of gain-focused optimization would see very large side lobes at large angles away from the center of the forward lobe upon optimization completion. Simply moving the starting point (within software) further forward than the point of these lobes will result in two side-effects: First, a reduction in forward gain and the second, a "blown" rear bubble with odd small lobes or spikes that cause F/R to be much worse than the starting point.

As the boom gets longer, the forward lobe becomes narrower and in-turn, the side lobes get closer to one another either side of the main forward lobe but exactly how close they sit to the main lobe can be controlled, to a point.

In order to achieve the best overall gain results and to ensure the rear bubble can be minimized, an antenna is best optimized (assuming computer optimization now) with F/B parameters being set just behind the Az side lobe position as in **Figure 5.42**. For example, if the side lobes on a subject antenna are at 50°, the F/B point would be set at 55°. The antenna can then be optimized for bandwidth and gain several times until no further improvements can be made. (At 144 MHz and higher, optimization should be performed in 1° increments.)

At this point, move the optimization point from 55° to 54° and re-optimize then 53° then 52° and so on. Improvements should be seen in terms of gain and bandwidth by doing this method of controlling the elevation lobes in addition to (hopefully) pushing the side lobes closer to the main lobes resulting in less significance or negative consequences. (For best results, computer optimization/controlling of side lobes should only be done in the El plane, so doing will see the Az lobes kept in-check automatically. The same does not happen in reverse should you optimize in the Az plane.)

Each time the optimization results should be saved individually as there will become a point where the gain starts

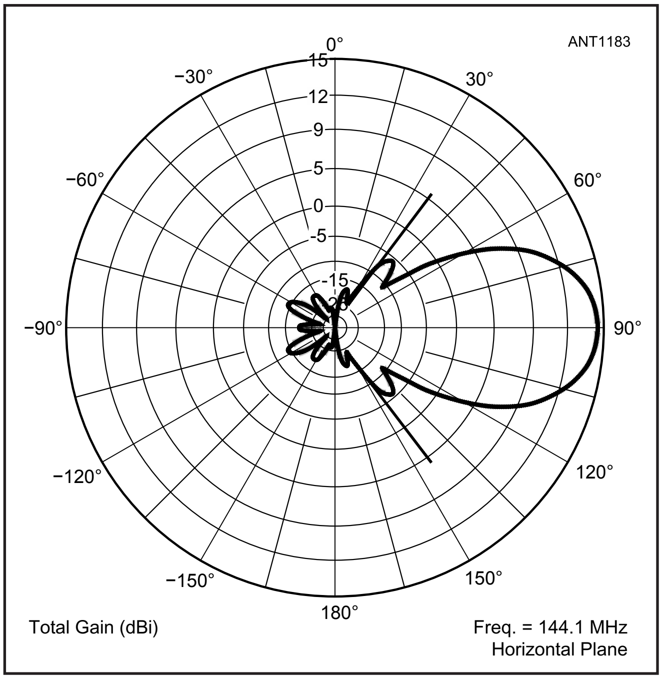


Figure 15.42 — Same elevation plot as in Figure 15.41 showing where optimization limits can be placed to move side lobes closer to the main lobe. This helps minimize pickup of noise from nearby sources.

to drop and the rear bubble starts to "blow" (rear lobes growing quickly with further changes). At this point you know you are trying to compress the side lobes too tightly and you should go back to your last improvement optimization for your best usable result. The whole optimization process is much more detailed than the explanation given in these few lines but at least now an understanding of the levels of attention and time taken to optimize this antenna can be perhaps much more appreciated.

High-Performance LFA and OWL VHF/UHF Yagi Designs

The antenna designs by GØKSC and listed in **Table 15.11** are new designs not previously published or made available as products. Justin is a primary designer of HF, VHF, and UHF antennas for InnovAntennas (**www.innovantennas.com**). He has published a number of articles featuring innovative and high-performance antennas, including discussions of what makes a design successful, issues for competitive and high-performance antennas, and helpful information on the construction details for these designs. Model files and sample radiation patterns for all of the Yagis are available on the book's CD-ROM but require *EZNEC PRO/4* to reproduce the gain and other performance specifications listed.

The Stauff clamps (**www.us.stauff.com**) recommended for these designs are industrial pipe clamps designed for rugged, outdoor service. The standard series part numbers (DIN 3015, Part 1) in **Table 15.12** are sufficiently rated for these designs. Stauff clamps are easiest to use with booms of square tubing although adapters for round booms are available.

Table 15.12
Stauff Clamps

Standard Series (DIN 3015-1)

¼ in elements:	106,4APP (1 per element)
½ in loop:	212,7PP (3 per loop - 1 for DE1, 2 for DE2)
Angled weld plate	WSP 1A U W1 (2 per loop at DE2)

-PP part numbers are polypropylene material
(replace with –AL for aluminum)
Available from **www.us.stauff.com**

Constructing the Loop Driven Element

The loop driven element may be unfamiliar. GØKSC has created a detailed description of the construction process at **www.g0ksc.co.uk/making-the-lfa-loop.html** which is also available as a PDF file on this book's CD-ROM. The following set of instructions are summarized from that document.

Figure 15.39 shows the orientation of the loop on the boom with the feed point located on the forward side. **Figure 15.43** shows the overall construction and adjustment of the LFA Yagi's loop driven element. LFA driven elements are constructed with straight sections (DE1 and DE2, parallel to the other elements) and side sections of slightly smaller diameter that are adjustable "trombone-style" by sliding in and out of the straight sections. This allows SWR to be

Table 15.11
High-Performance LFA and OWL Yagis

Freq (MHz)	*No. Elements*	*Boom Length*	*Peak Gain) (dBi)*	*Peak F/B (dB)*	*E-plane Beamwidth (degrees)*	*H-plane Beamwidth (degrees)*
50	4	12' 8" (3.86 m)	10.6	31.9	42	67
144	9	17' 3" (5.26 m)	14.8	24.7	34	37
144	14	32' 4" (9.86 m)	17.0	33.0	27	29
222	10	11' 5" (3.48 m)	14.5	34.6	37	41
222	19	29' 2" (8.88 m)	18.1	39.7	24	25
432	10	6' 7" (2.01 m)	14.5	25.6	36	40
432	20	17' 0" (5.18 m)	18.6	37.0	23	24

Note: All parameters are free-space

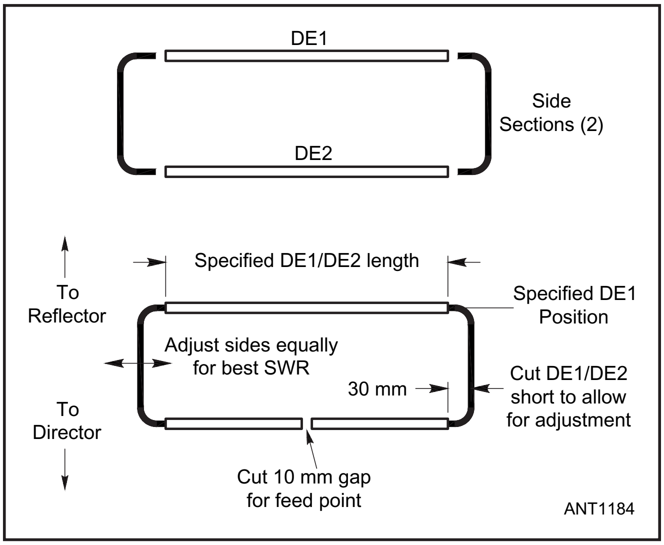
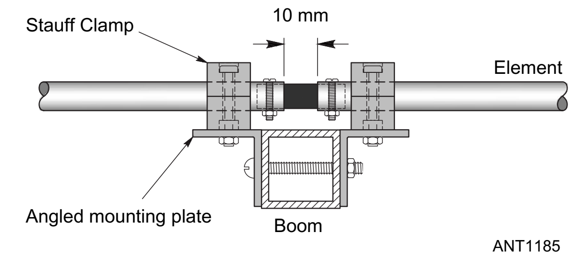


Figure 15.43 — Construction of the LFA loop driven-element showing the sliding end sections and how loop dimensions are measured.



(B)

Figure 15.44 — Figure A illustrates mounting the driven element feed point on a square boom using Stauff clamps and angled mounting plate. At B, the driven element loop is mounted using through-the-boom construction.

adjusted without a separate impedance-matching structure and to compensate for feed point construction variations.

Once the SWR is satisfactory, the sliding sections are secured to the straight sections with a stainless-steel screw (be sure to use anti-corrosion compound), an aluminum rivet, or a hose clamp (the straight section would require a short slot to allow compression by the clamp). The screw and rivet are convenient but have limited contact area. Spot welding the tubing sections together also works very well. If brass tubing is used, the sliding and fixed sections should be soldered together.

The tubing for DE1 and DE2 should be cut 50 mm short of the model's full dipole length in the tables. Measure 30 mm from the end of the remaining straight ½ inch section to the inside of the loop end as in the figure. This additional width provides a correction for the radius at the corners of the loop. The additional 5 mm of width remains fairly constant on all bands since the radius becomes more like a 90° bend at lower frequencies as modeled. (This assumes use of the same bending tool to create all bends.) Absolute accuracy here is not essential; this is a starting point from where the antenna is adjusted for best SWR.

After cutting and deburring the loop's straight sections, cut the side section tubing such that it has approximately 80 mm of extra length beyond the difference between the DE1 and DE2 positions. For example, if the positions of DE1 and DE2 are 0.128 m and 0.235 m, respectively, cut the side section tubing to be (0.235 – 0.128) + 0.080 = 0.107 + 0.080 = 0.187 m long. Use an automotive brake line bending tool (see the PDF instructions for photographs) to bend approximately 40 mm of the section length at a right angle. Insert the bent section into either the DE1 section. Bend the other end of the side section tubing so that the DE2 section is 0.107 m from DE1. Repeat for the remaining side section.

Cut the DE2 section to leave a feed point gap of approximately 10 mm. To support the loop at the feed point (see **Figure 15.44A**), insert a short section of fiberglass, polycarbonate, or Teflon rod approximately 25 mm longer than the gap on each side. Drill through the element and supporting rod. Use stainless steel #8 hardware to hold the element and supporting rod together and create attachment points for the feed line. Use Stauff clamps with angled mounting plates as in Figure 15.44 to support the feed point assembly.

Note that the exact center of the loop driven element opposite the feed point is at an RF-neutral point and can be connected directly to the boom by using an aluminum clamp. (Substitute –AL for –PP in the Stauff clamp part number or fabricate your own mounting bracket.) Doing so will place the driven element at dc ground for static protection and it will also cause the driven element impedance to increase rapidly away from the design frequency.

In Figure 15.44B, the driven element loop for a 10-element 432 MHz LFA Yagi is shown with a through-the-boom construction option that eliminates the need for extra clamps with the smaller driven element.

Following construction, temporarily mount the beam at least 1 wavelength above ground or pointed at the sky with the reflector at least ½ wavelength above ground, Adjust each of the loop sliding sections in equal increments starting from a symmetrical position until SWR is satisfactory. Following adjustment, secure the sliding sections to the fixed sections as described above.

Table 15.13
4-element 50 MHz LFA Yagi

Peak Gain:	10.6 dBi @ 50.150 MHz
Peak F/B:	31.9 dB @ 50.150 MHz
Beamwidth (E-plane):	42 dB @ 50.150 MHz
Beamwidth (H-plane):	67 dB @ 50.150 MHz
SWR:	Below 1.3.1 from 50 MHz to 50.400 MHz

Note: All parameters are free-space

Half-element dimensions and placement (lengths are for half elements)

	Element	*----Section 1 (Middle)----*		*---------Section 2---------*		*--------Section 3--------*	
	Position (m)	*OD (in/mm)*	*Length (m)*	*OD (in/mm)*	*Length (m)*	*OD (in/mm)*	*Length (m)*
Reflector	0.030 (1)	⅝ / 16	0.415	½ / 13	0.315	⅜ / 10	0.788
DE1 (loop)	0.694	⅝ / 16	0.415	½ / 13	0.84 (2)		
DE2 (loop)	1.157	⅝ / 16	0.415	½ / 13	0.84 (2)		
D1	2.213	⅝ / 16	0.415	½ / 13	0.315	⅜ / 10	0.674
D2	3.963	⅝ / 16	0.415	½ / 13	0.84	⅜ / 10	0.610

Note 1— End of boom is zero (0) reference.
Note 2 — The ends of DE1 and DE2 are connected together with ⅜ inch / 10 mm tube.

50 MHz LFA Yagi

The 4-element design in **Table 15.13** is an illustration of what can be achieved by careful optimization on a fairly short boom (12 feet 8 inches). The design is well suited for stacking and can be handled by small rotators. It is ideal for portable and rover station use as well as at a home station.

The reflector and both directors have three segments of tubing per half-element — one center segment and a pair of segments on each half-element. The driven element loop's DE1 and DE2 section both have two segments per half-element. Element lengths assume a conductive boom with insulated elements.

144 MHz OWL Yagis

Common dimensions and notes for the high-performance 144, 222, and 432 MHz Yagis are listed in **Table 15.14**. Two designs are presented in this section — a 9-element in **Table 15.15** and a 14-element antenna in **Table 15.16**. Performance is specified at 144.2 MHz. The E-plane pattern for the 14-element antenna is shown in **Figure 15.45**.

Element lengths assume a conductive 1.25 inch square boom with insulated elements. If a non-conductive boom is used, subtract 1 mm from all element lengths. If a 1.5 inch square conductive boom is used, add 1 mm to all element lengths.

A folded-dipole driven element is used on both antennas. Construction is similar to that of the LFA loop driven-element. Two methods of mounting the driven element are shown in **Figure 15.46**. The feed point's insulating rod is mounted through a short mounting section of boom material which is, in turn, attached to the top of the main boom. The feed point thus straddles the mounting section — be sure to minimize coax-to-feed point leads lengths.

As with the LFA driven element, the point on the folded dipole directly opposite the feed point is a neutral point at

Table 15.14
Common Dimensions and Notes for the High-Performance 144, 222, and 432 MHz Yagis

Boom is 1.25" square aluminum unless otherwise specified
Element diameter is ¼" unless otherwise specified
DE1, DE2 diameter ½" (sliding sections are ⅜" diameter)

Note 1– End of boom is zero (0) reference.
Note 2 – DE1 position dimension is the centerline of the rear-most loop tubing
Note 3 – DE1 and DE2 width are the outside edge of the loop.

Table 15.15
9-element 144 MHz OWL Yagi

Gain:	14.8 dBi
SWR:	Less than 1.1:1
F/B:	24.7 dB
Beamwidth (E-plane):	34 degrees
Beamwidth (H-plane):	37 degrees

Performance specified at 144.2 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.514	1.028
DE (Note)	0.1625	0.4765	0.953
DIR1	0.453	0.4705	0.941
DIR2	1.009	0.455	0.910
DIR3	1.7275	0.444	0.888
DIR4	2.533	0.437	0.874
DIR5	3.358	0.432	0.864
DIR6	4.222	0.427	0.854
DIR7	4.9685	0.429	0.858

Note: All elements are ½" diameter
Note: DE is 0.953 m wide and 0.026 m high, measured on outside edges

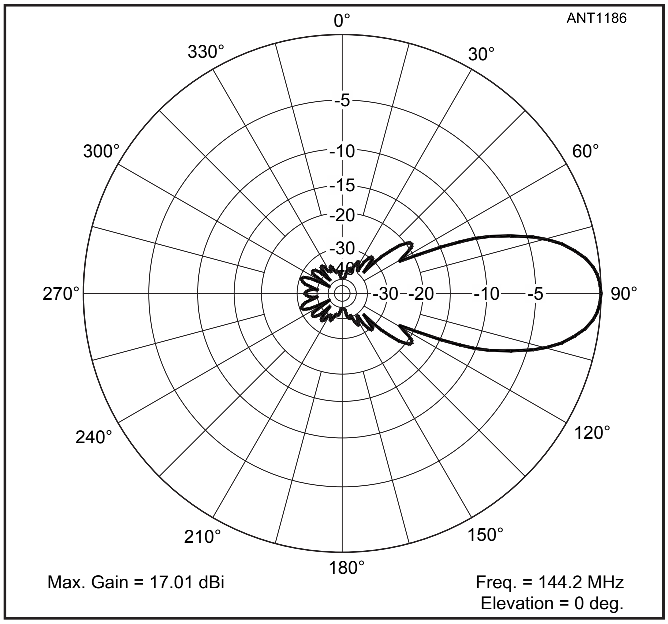


Figure 15.45 — E-plane pattern, 14-element 144 MHz LFA Yagi.

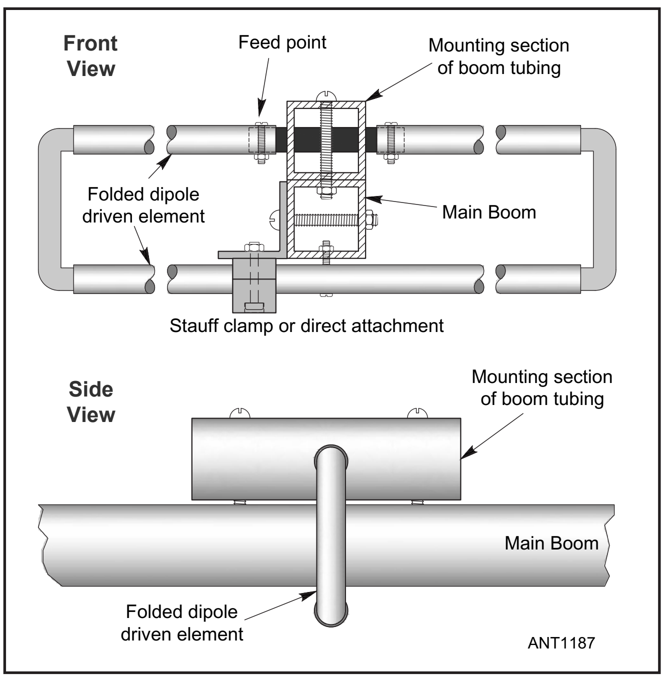


Figure 15.46 — Construction and mounting of an OWL Yagi's loop driven-element. The plane of the loop is perpendicular to the boom.

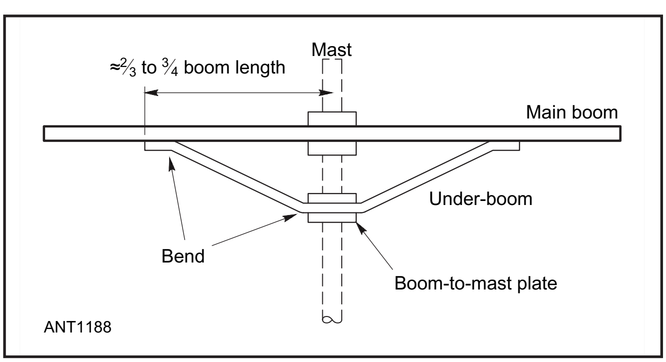


Figure 15.47 — Use of an under-boom to support the long-boom Yagis. The same material is used for both the boom and under-boom. Alternatively, boom guying can be employed.

Table 15.16
14-element 144 MHz OWL Yagi

Gain:	17.0 dBi
SWR:	Less than 1.1:1
F/B:	33.0 dB
Beamwidth (E-plane):	27 degrees
Beamwidth (H-plane):	29 degrees

Performance specified at 144.2 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.5115	1.023
DE (Note)	0.253	0.469	0.938
DIR1	0.5785	0.4805	0.961
DIR2	1.156	0.4665	0.933
DIR3	1.8525	0.457	0.914
DIR4	2.686	0.4495	0.899
DIR5	3.526	0.4435	0.887
DIR6	4.4265	0.4395	0.879
DIR7	5.3365	0.436	0.872
DIR8	6.254	0.433	0.866
DIR9	7.1735	0.4295	0.859
DIR10	8.108	0.425	0.850
DIR11	9.060	0.416	0.832
DIR12	9.8625	0.427	0.854

Note: All elements are ½" diameter
Note: DE is 0.948 m wide and 0.026 m high, measured on outside edges

Table 15.17
10-element 222 MHz LFA Yagi

Gain:	14.5 dBi
SWR:	Less than 1.1:1
F/B:	34.6 dB
Beamwidth (E-plane):	37 degrees
Beamwidth (H-plane):	41 degrees

Performance specified at 222.1 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.3315	0.6630
DE1 (loop)	0.128	0.233	0.566
DE2 (loop)	0.235	0.233	0.233
DIR1	0.390	0.3075	0.6150
DIR2	0.626	0.292	0.584
DIR4	1.316	0.289	0.578
DIR5	1.819	0.2835	0.567
DIR6	2.358	0.277	0.554
DIR7	2.939	0.2675	0.535
DIR8	3.455	0.2645	0.529

RF and can be attached directly to the boom as shown in the figure's front view. The same caution applies regarding rapid impedance change away from the design frequency. An insulating support such as a Stauff clamp can be used, as well.

The boom is assumed to be made from 1.25 inch square tubing. If a ¾ inch square boom is used, an under-boom support will be required as in **Figure 15.47**. Alternatively, boom guying could also be used.

222 MHz LFA Yagis

Two designs are presented in this section — a 10-element in **Table 15.16** and a 19-element antenna in **Table 15.17**. Performance is specified at 222.1 MHz. The E-plane pattern for the 19-element antenna is shown in **Figure 15.48**.

See the notes on constructing the LFA driven element above. The 19-element antenna will require boom guying or an under-boom as in Figure 15.47.

Element lengths assume a conductive boom with insulated elements. If a non-conductive boom is used, subtract 1 mm from all element lengths.

432 MHz LFA Yagis

Two designs are presented in this section — a 10-element broadband LFA in **Table 15.18** and a 20-element antenna in **Table 15.19**. Performance is specified at 432.1 MHz.

The broadband 10-element design provides a flat, low SWR across a 6 MHz bandwidth as shown in **Figure 15.49**. The broad-banded nature of this antenna makes it more accepting of measurement variations in both boom and element lengths.

The 20-element design is optimized for use in stacked arrays, allowing some forward side lobes to appear in exchange for a highly suppressed rear bubble. The forward side lobes are kept close to the main lobe, however, and elevation plane lobes are highly suppressed, as well. As a result, when stacked with the correct separation, no odd "spike-lobes" should appear and the pattern should remain clear. E- and H-plane patterns for the 20-element antenna are

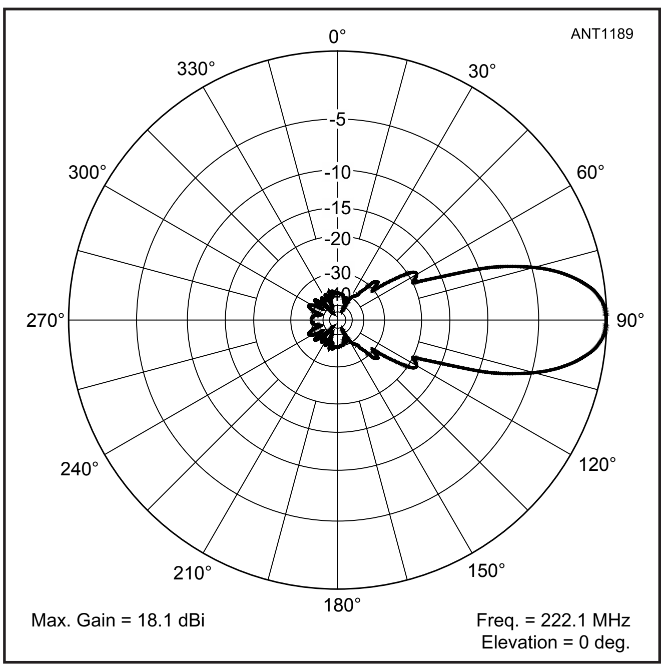


Figure 15.48 — E-plane pattern, 19-element 222 MHz LFA Yagi.

Table 15.18
19-element 222 MHz LFA Yagi

Peak Gain:	18.1 dBi
SWR:	Less than 1.1:1
F/B:	39.7 dB
Beamwidth (E-plane):	24 degrees
Beamwidth (H-plane):	25 degrees

Performance specified at 222.1 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.3325	0.665
DE1 (loop)	0.145	0.285	0.570
DE2 (loop)	0.251	0.285	0.285
DIR1	0.411	0.3095	0.619
DIR2	0.676	0.288	0.576
DIR3	0.902	0.2945	0.589
DIR4	1.320	0.2925	0.585
DIR5	1.836	0.2885	0.577
DIR6	2.380	0.285	0.570
DIR7	2.946	0.282	0.564
DIR8	3.536	0.280	0.560
DIR9	4.123	0.2775	0.555
DIR10	4.725	0.2755	0.551
DIR11	5.330	0.273	0.546
DIR12	5.940	0.2715	0.543
DIR13	6.5415	0.2705	0.541
DIR14	7.1385	0.2685	0.537
DIR15	7.7255	0.266	0.532
DIR16	8.3105	0.2545	0.509
DIR17	8.8545	0.2505	0.501

Table 15.19
10-element 432 MHz LFA Yagi

Peak Gain:	14.5 dBi
SWR:	Less than 1.1:1
F/B:	25.6 dB
Beamwidth (E-plane):	36 degrees
Beamwidth (H-plane):	40 degrees

Performance specified at 432.1 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.1685	0.337
DE1 (loop)	0.078	0.150	0.300
DE2 (loop)	0.1495	0.150	0.300
DIR1	0.212	0.157	0.314
DIR2	0.3425	0.150	0.300
DIR3	0.494	0.146	0.292
DIR4	0.6845	0.1445	0.289
DIR5	0.9215	0.143	0.286
DIR6	1.1785	0.1405	0.281
DIR7	1.470	0.1365	0.273
DIR8	1.716	0.1355	0.271

shown in **Figures 15.50** and **15.51**.

See the notes on constructing the LFA driven element above. All element lengths are based on a metal boom. If a non-conducting boom, such as fiberglass, is used, subtract 1.5 mm from all element lengths.

Both antennas can be constructed using Stauff clamps and a 1.25 inch square boom as for the 144 and 222 MHz Yagis.

For the 10-element antenna, a much lighter version (3 lbs versus 6 lbs) with less wind load can be constructed using a ¾ inch square boom and mounting the elements through the boom, secured by a stainless steel screw. The loop driven element is also mounted through the boom, requiring a wider feed point gap. The non-conductive rod is extended through the boom as shown in Figure 15.44B. The lighter version of the antenna can be mounted to the mast using a single U-bolt through the boom.

For the 20-element antenna, boom guys are required if the 1.25 inch square boom and Stauff clamps are used for construction. If the ¾ inch square boom technique is used, an under-boom is required as in Figure 15.47.

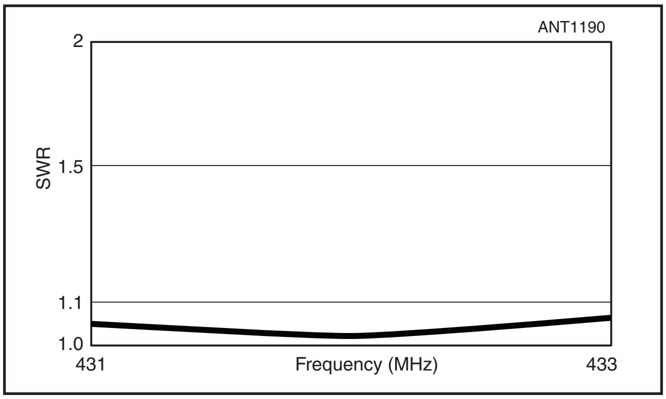


Figure 15.49 — SWR versus frequency, 10-element 432 MHz LFA Yagi.

Table 15.20
20-element 432 MHz LFA Yagi

Peak Gain:	18.6 dBi
SWR:	Less than 1.1:1
F/B:	37.0 dB
Beamwidth (E-plane):	23 degrees
Beamwidth (H-plane):	24 degrees

Performance specified at 432.1 MHz
Note: All parameters are free-space

Element	*Element Position (m)*	*Half-Element Length (m)*	*Element Length (m)*
REF	0.030	0.167	0.334
DE1 (loop)	0.117	0.153	0.306
DE2 (loop)	0.189	0.153	0.306
DIR1	0.2445	0.15775	0.3155
DIR2	0.4015	0.151	0.302
DIR3	0.556	0.14525	0.2905
DIR4	0.7305	0.14425	0.2885
DIR5	0.959	0.14325	0.2865
DIR6	1.2275	0.14125	0.2825
DIR7	1.5135	0.1395	0.2790
DIR8	1.314	0.138	0.276
DIR9	2.120	0.1365	0.273
DIR10	2.4315	0.13525	0.2705
DIR11	2.750	0.13425	0.2685
DIR12	3.0655	0.13425	0.2685
DIR13	3.378	0.135	0.270
DIR14	3.682	0.13525	0.2705
DIR15	3.982	0.13425	0.2685
DIR16	4.2835	0.13075	0.2615
DIR17	4.598	0.12425	0.2485
DIR18	4.879	0.120	0.240

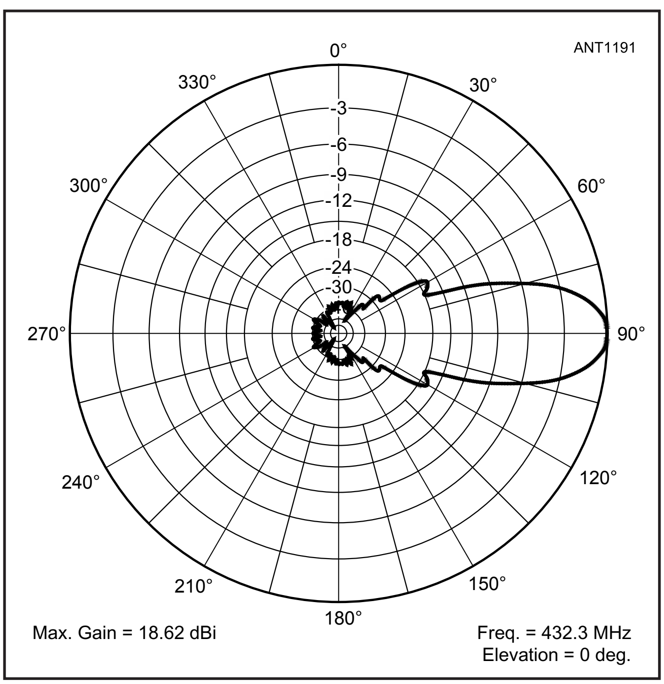


Figure 15.50 — E-plane pattern, 20-element 432 MHz LFA Yagi.

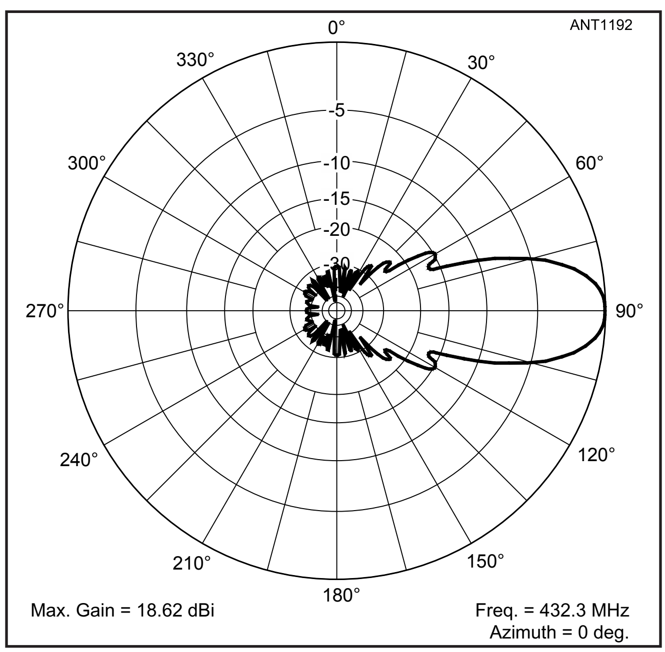


Figure 15.51 — H-plane pattern, 20-element 432 MHz LFA Yagi.

15.3.7 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. Information was first published on this antenna in 1977. (See Bibliography.)

Quagi Construction

There are a few tricks to Quagi building, but nothing very difficult or complicated is involved. **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. See the information on materials in the previous section on Yagi Construction. 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. At 222 MHz the boom is under 10 feet long, requiring 1 × 2 or (preferably) ¾ × 1¼ inch pine molding stock. At 432 MHz, except for long-boom versions, the boom should be ½ inch thick or less.

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

Table 15.22
432-MHz, 15-Element, Long Boom Quagi Construction Data

Element Lengths (Inches)	*Interelement Spacing (Inches)*
R — 28	R-DE — 7
DE — 26⅝	DE-D1 — 5¼
D1 — 11¾	D1-D2 — 11
D2 — 11¹¹⁄₁₆	D2-D3 — 5⅞
D3 — 11⅝	D3-D4 — 8¾
D4 — 11⁹⁄₁₆	D4-D5 — 8¾
D5 — 11½	D5-D6 — 8¾
D6 — 11⁷⁄₁₆	D6-D7 — 12
D7 — 11⅜	D7-D8 — 12
D8 — 11⁵⁄₁₆	D8-D9 — 11¼
D9 — 11⁵⁄₁₆	D9-D10 — 11½
D10 — 11¼	D10-D11 — 9³⁄₁₆
D11 — 11³⁄₁₆	D11-D12 — 12⅜
D12 — 11⅛	D12-D13 — 13¾
D13 — 11¹⁄₁₆	

Boom: 1 × 2 inch × 12-ft Douglas fir, tapered to ⅝ 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: ⅛ inch rod passing through boom.

Table 15.21
Dimensions, Eight-Element Quagi

Element Lengths	*144.5 MHz*	*147 MHz*	*Frequency 222 MHz*	*432 MHz*	*446 MHz*
Reflector[1]	86⅝"	85"	56⅜"	28"	27⅛"
Driven[2]	82"	80"	53½"	26⅝"	25⅞"
Directors	35¹⁵⁄₁₆" to 35" in ³⁄₁₆" steps	35⁵⁄₁₆" to 34⅜" in ³⁄₁₆" steps	23⅜" to 23¾" in ⅛" steps	11¾" to 11⁷⁄₁₆" in ¹⁄₁₆" steps	11⅜" to 11¹⁄₁₆" in ¹⁄₁₆" steps
Spacing					
R-DE	21"	20½"	13⅝"	7"	6.8"
DE-D1	15¾"	15⅜"	10¼"	5¼"	5.1"
D1-D2	33"	32½"	21½"	11"	10.7"
D2-D3	17½"	17⅛"	11⅜"	5.85"	5.68"
D3-D4	26.1"	25⅝"	17"	8.73"	8.46"
D4-D5	26.1"	25⅝"	17"	8.73"	8.46"
D5-D6	26.1"	25⅝"	17"	8.73"	8.46"
Stacking Distance Between Bays					
	11'	10' 10"	7' 1½"	3'7"	3' 5 ⅝"

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

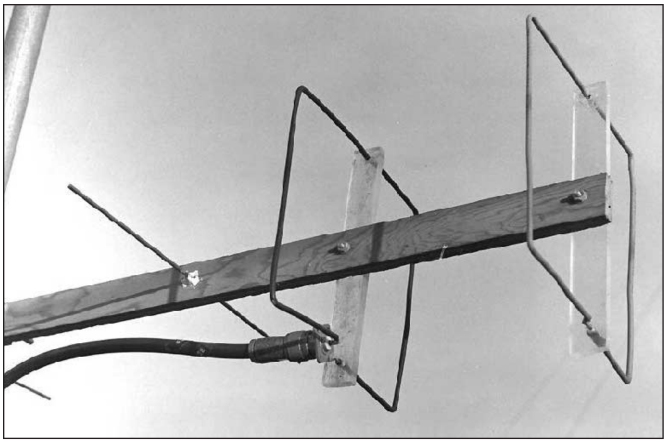


Figure 15.52 — A close-up view of the feed method used on a 432-MHz Quagi. This arrangement produces a low SWR and gain in excess of 13 dBi with a 4-ft 10-inch boom! The same basic arrangement is used on lower frequencies, but wood may be substituted for the Plexiglas spreaders. The boom is ½-inch exterior plywood.

be made of almost any metal rod or wire of about ⅛-inch diameter. Welding rod or aluminum clothesline wire works well if straight. (The designer uses ⅛-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.

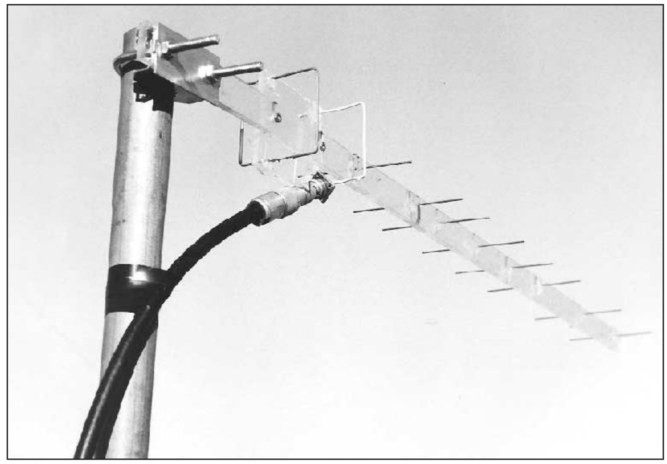
Based on the experiences of Quagi builders, the following hints are offered. First, remember that at 432 MHz even a ⅛-inch measurement error results in performance deterioration. Cut the loops and elements as carefully as possible. No precision tools are needed, but accuracy is necessary. Also make sure 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 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.



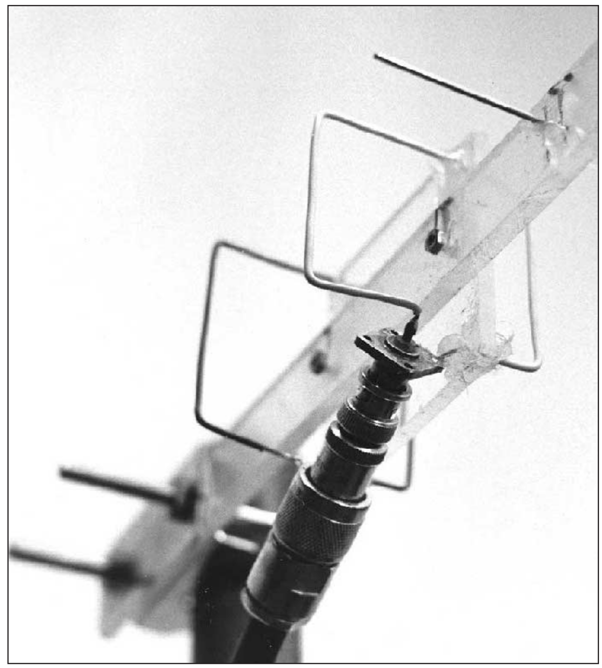


Figure 15.53 — A view of the 10-element version of the 1296-MHz Quagi. It is mounted on a 30-inch Plexiglas boom with a 3 × 3-inch square of Plexiglas to support the driven element and reflector. Note how the driven element is attached to a standard UG-290 BNC connector. The elements are held in place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

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 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: 1¼-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

Element	*Length (Inches)*	*Construction*	*Element*	*Interelement Spacing (inches)*
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.

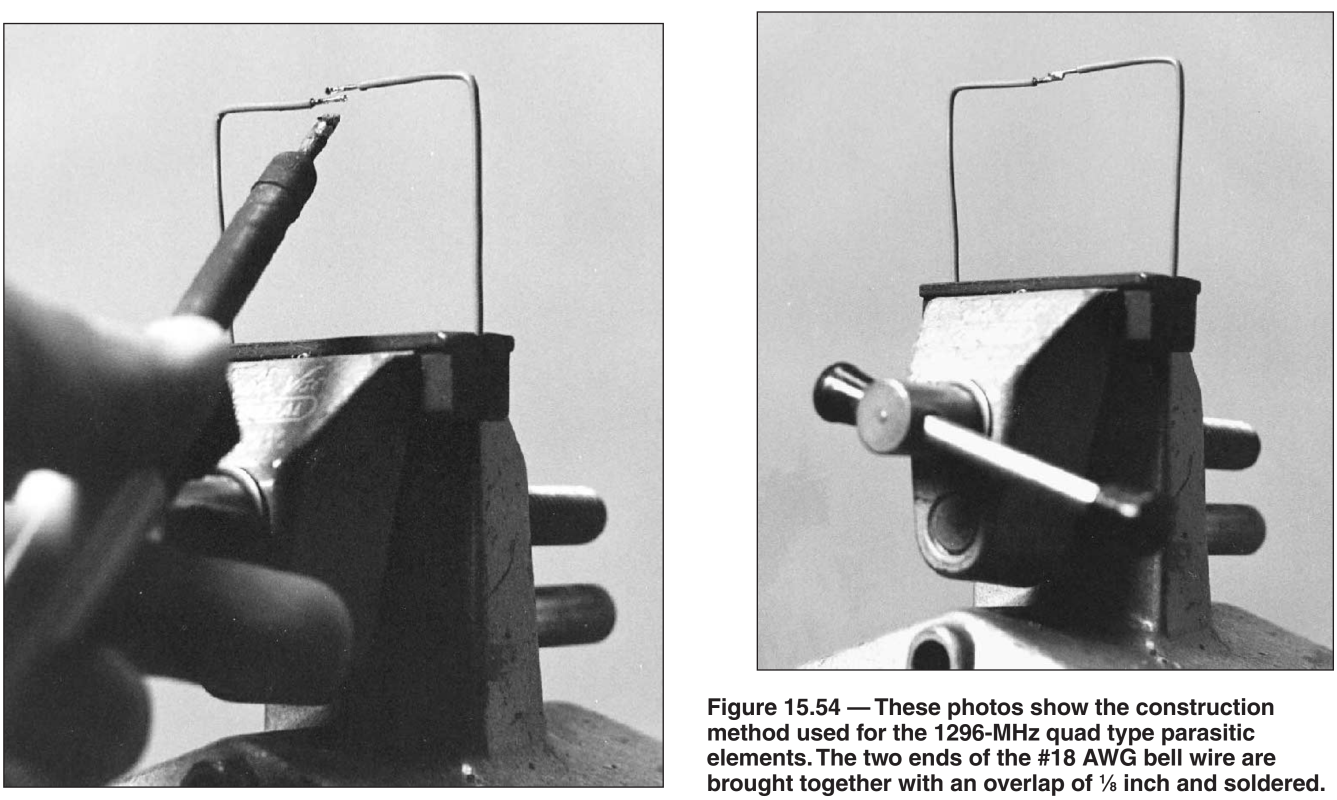


Figure 15.54 — These photos show the construction method used for the 1296-MHz quad type parasitic elements. The two ends of the #18 AWG bell wire are brought together with an overlap of ⅛ inch and soldered.

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 9¼ 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.

15.3.8 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

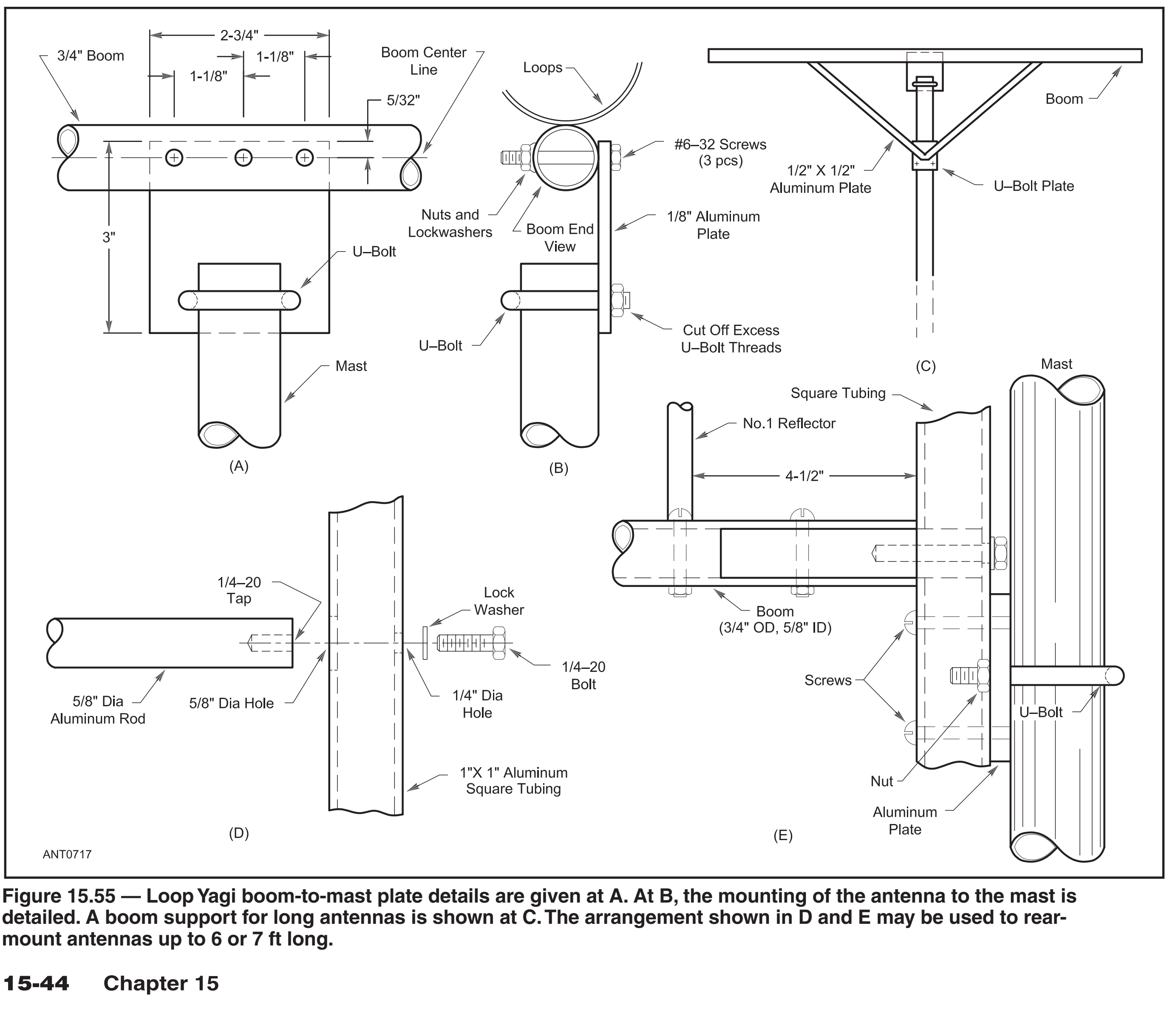


Figure 15.55 — Loop Yagi boom-to-mast plate details are given at A. At B, the mounting of the antenna to the mast is detailed. A boom support for long antennas is shown at C. The arrangement shown in D and E may be used to rear-mount antennas up to 6 or 7 ft long.

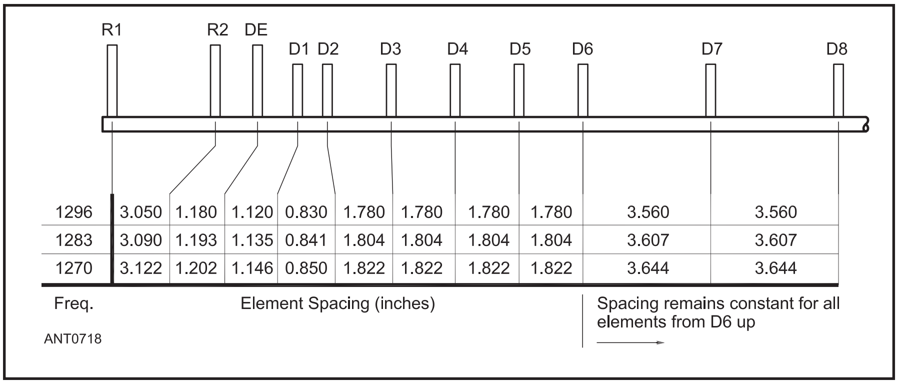


Figure 15.56 — Boom drilling dimensions. These dimensions must be carefully followed and the same materials used if performance is to be optimum. Element spacings are the same for all directors after D6 — use as many as necessary to fill the boom.

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 ¾-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 4½ 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.

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, 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**.

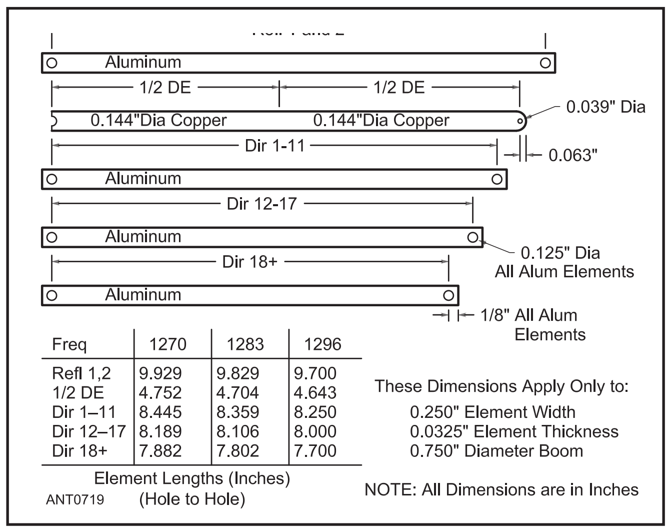


Figure 15.57 — Parasitic elements for the loop Yagi are made from aluminum sheet, the driven element from copper sheet. The dimensions given are for ¼-inch wide by 0.0325-inch thick elements only. Lengths specified are hole to hole distances; the holes are located ⅛ inch from each element end.

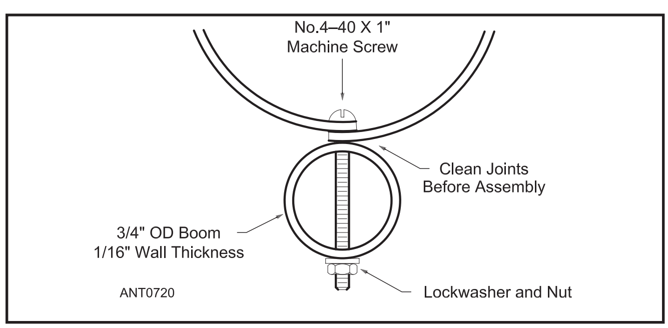


Figure 15.58 — Element-to-boom mounting details.

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.

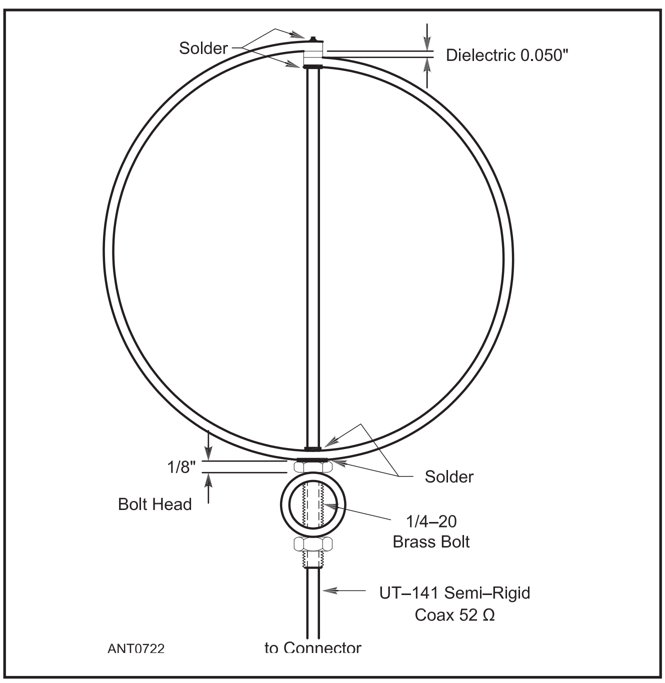


Figure 15.59 — Driven-element details. See Figure 15.57 and the text for additional information.

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.

15.3.9 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 ½ λ. 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 0.25 λ and the director 0.15 λ. 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 0.14 λ to 0.25 λ. 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.

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.

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

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

Directors (ft) = $937.3/f_{MHz}$ (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. (See the previous section on Yagi Construction for more information about wood boom material.) 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.

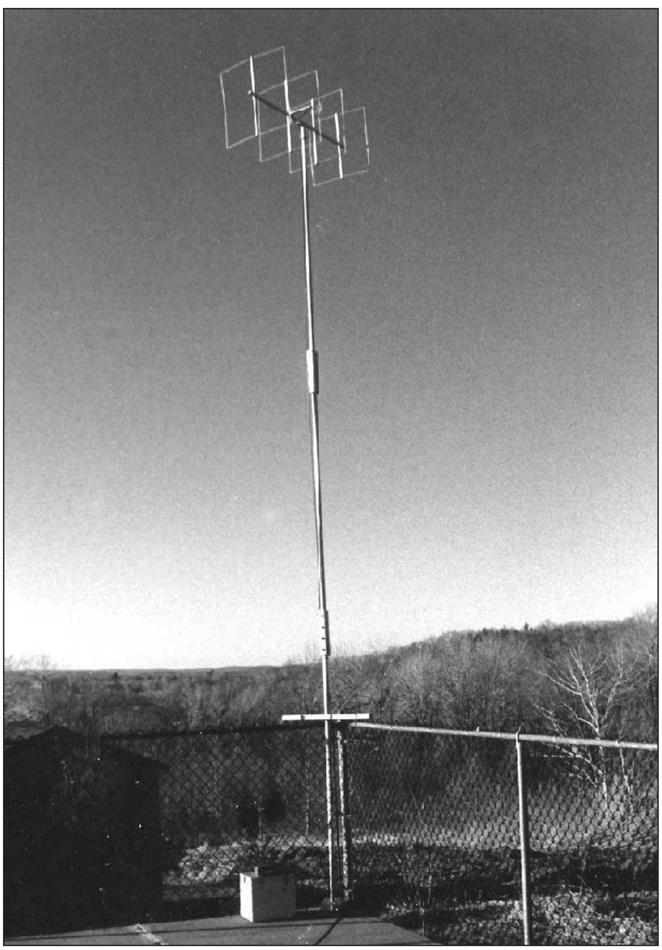


Figure 15.60 — The 4-element 144-MHz portable quad, assembled and ready for operation. Sections of clothes closet poles joined with pine strips make up the mast. (W1MPO photo)

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.

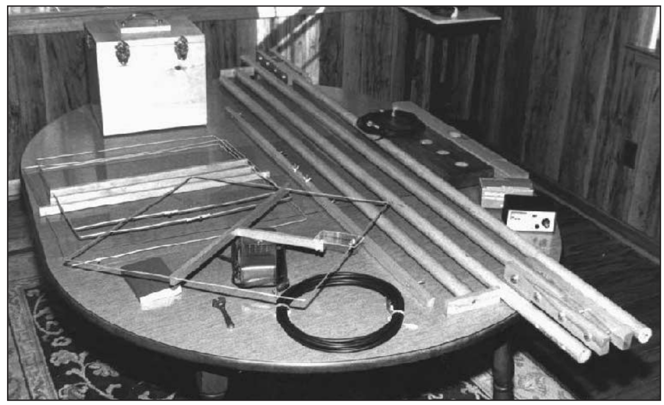


Figure 15.61 — The complete portable quad, broken down for travel. Visible in the foreground is the driven element. The pine box in the background is a carrying case for equipment and accessories. A hole in the lid accepts the mast, so the box doubles as a base for a short mast during portable operation.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

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 × 1⅝ × 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: 1 5/16 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

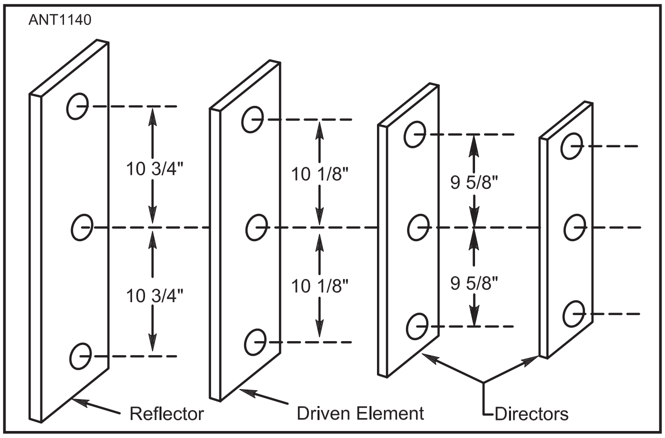


Figure 15.62 — Dimensions for the pine element spreaders for the 144-MHz 4-element quad.

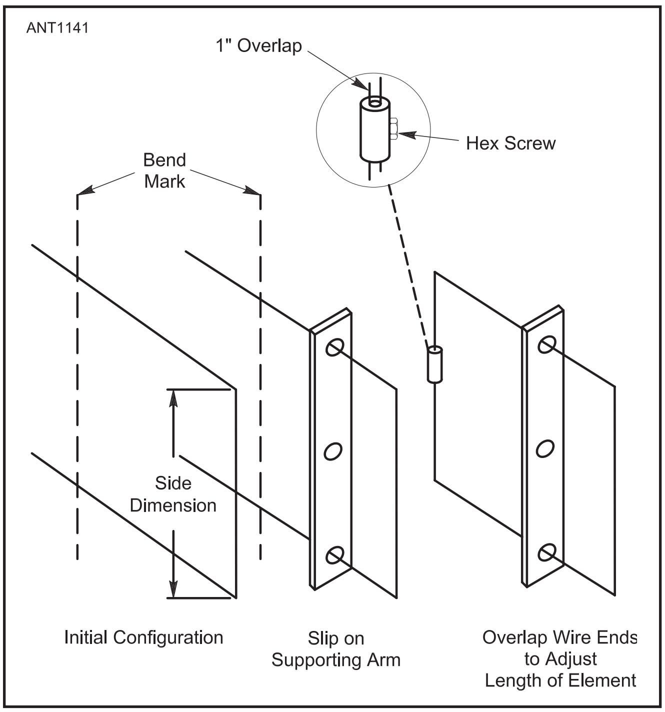


Figure 15.63 — Illustration showing how the aluminum element wires are bent. The adjustment clamp and its location are also shown.

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.

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

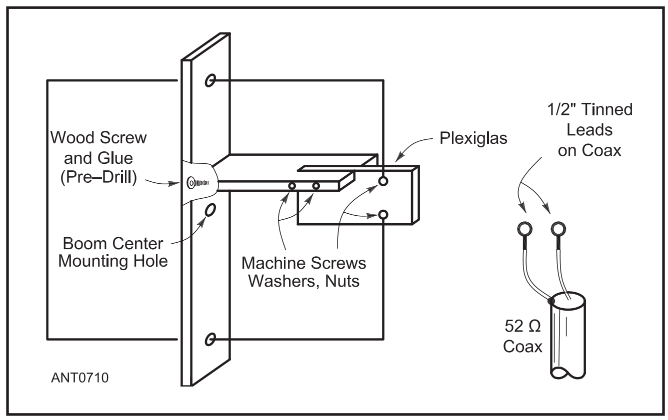


Figure 15.64 — Layout of the driven element of the 144-MHz quad. The leads of the coaxial cable should be stripped to ½ inch and solder lugs attached for easy connection and disconnection. See text regarding impedance at loop support points.

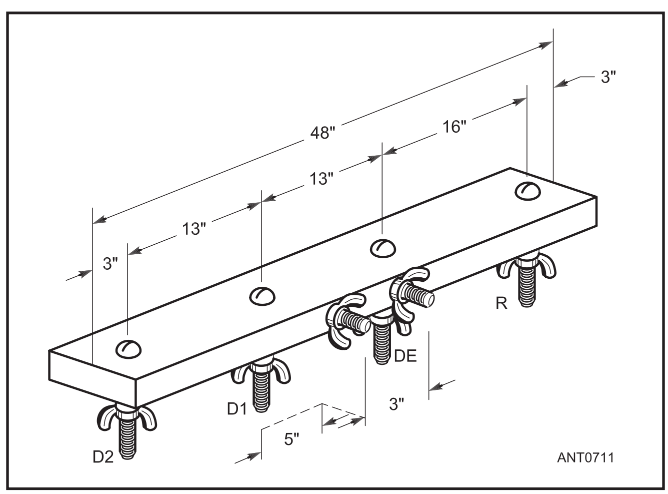


Figure 15.65 — Detail of the boom showing hole center locations and boom to mast connection points.

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 ¾ 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 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 3½ × ¼-inch hex bolts, washers and nuts, sections may be attached as needed, for a 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**).

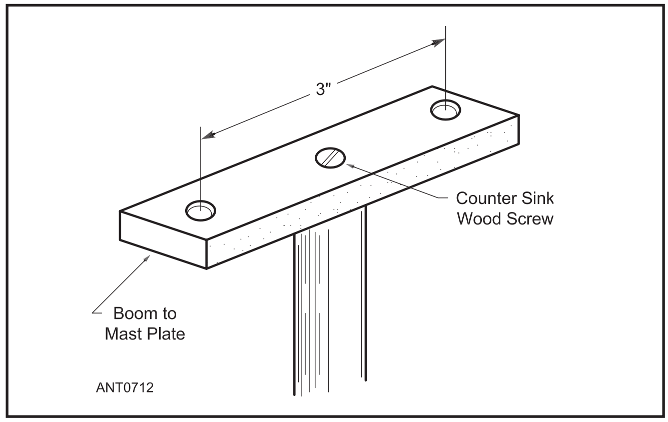


Figure 15.66 — Boom to mast plate for the 144-MHz quad. The screw hole in the center of the plate should be countersunk so the wood screw attaching it to the mast does not interfere with the fit of the boom.

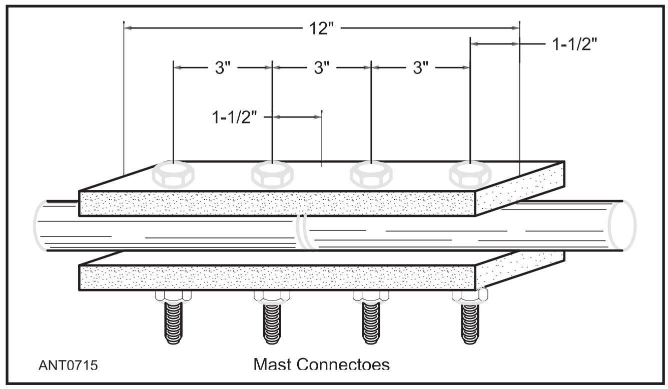


Figure 15.67 — Mast coupling connector details for the portable quad. The plates should be drilled two at a time to ensure the holes line up.

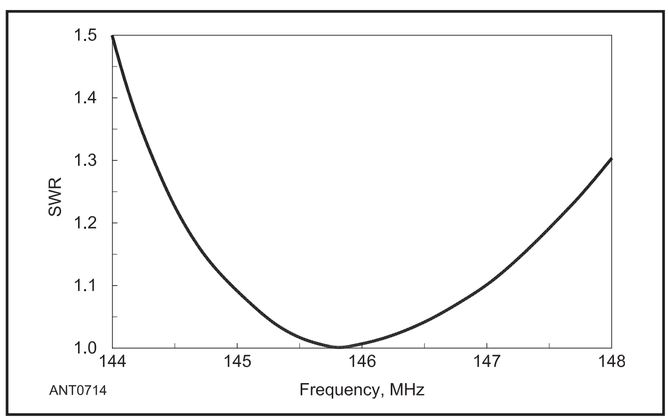


Figure 15.68 — Typical SWR curve for the 144-MHz portable quad. The large wire diameter and the quad design provide excellent bandwidth.

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

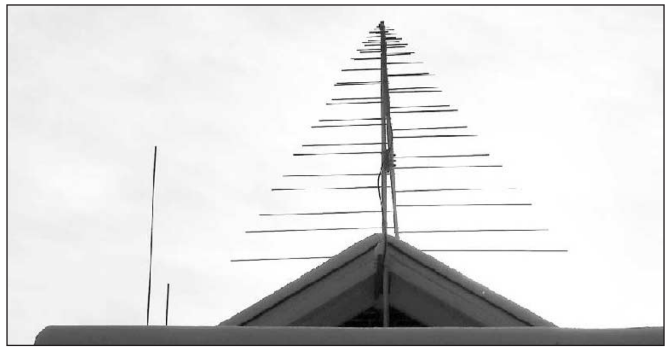
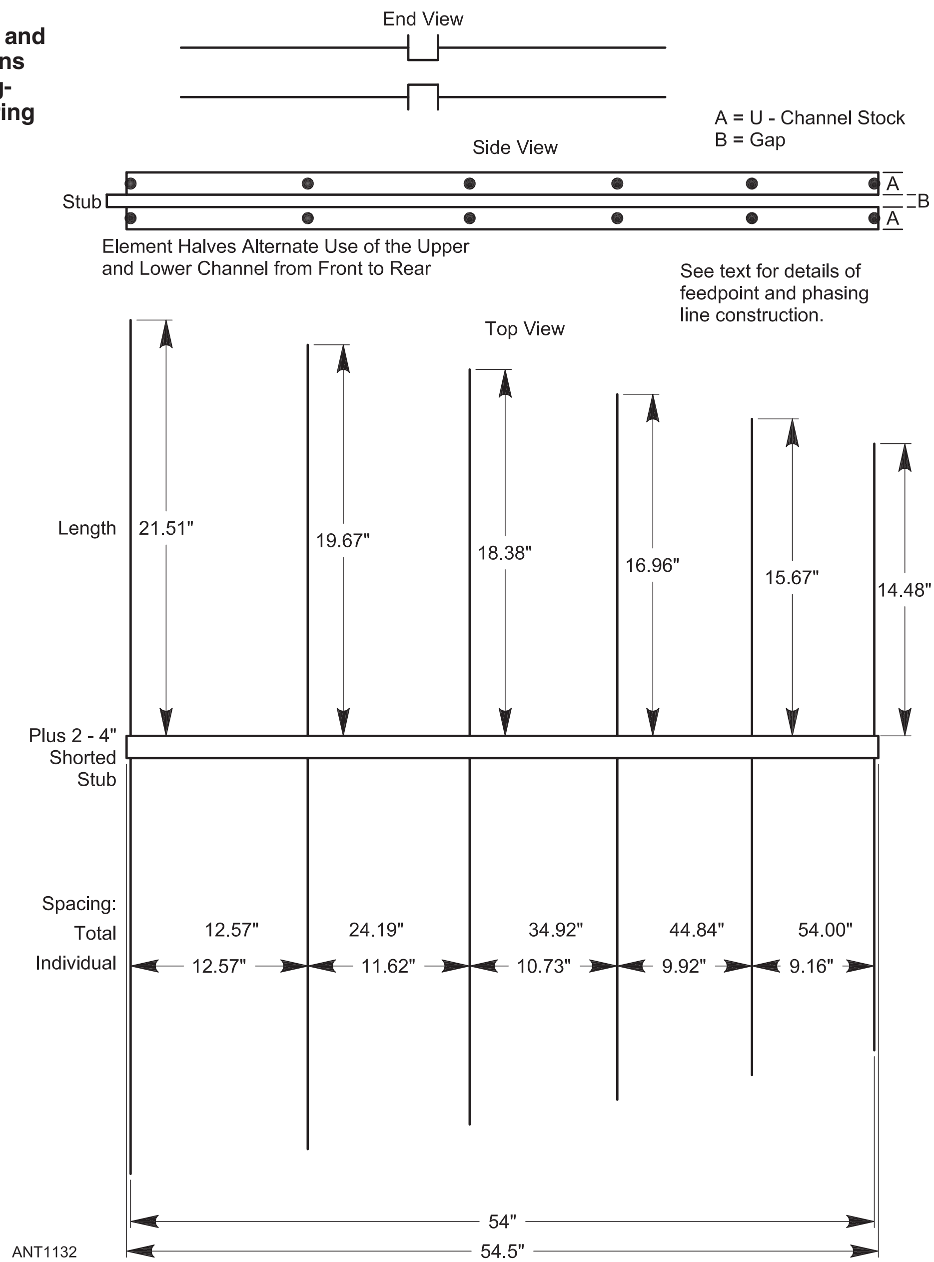


Figure 15.69 — The Tennadyne T-28 covers 50-1300 MHz with boom length of 12 feet.

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



covers 50 to 1300 MHz with a boom length of only 12 feet. 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 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 omni-directional antenna for scanner use at VHF and above with numerous commercial models available. (Discone design is discussed in the **Multiband HF 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!

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"!

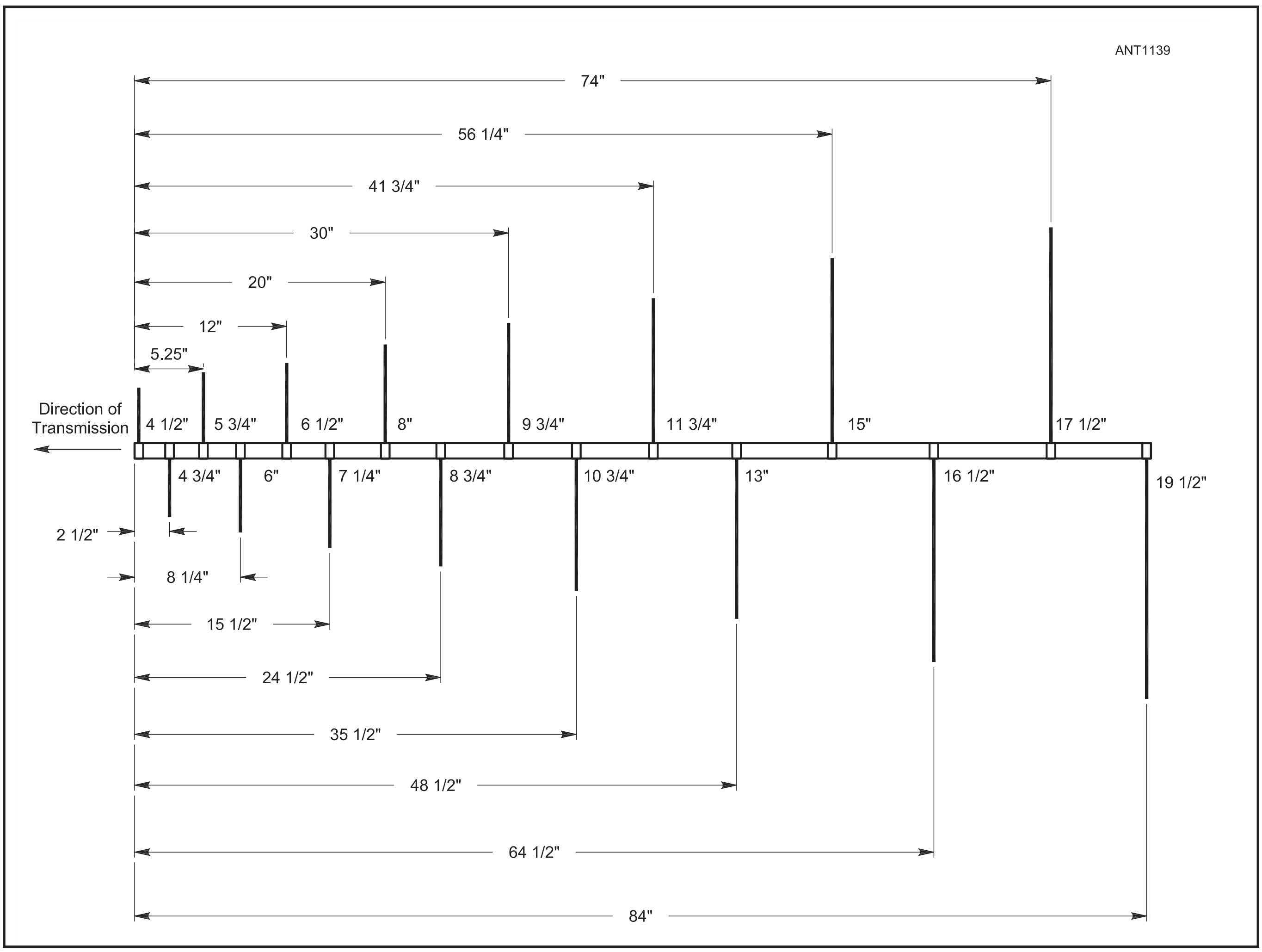


Figure 15.71 — Outline and sketch of the dimensions for the log-periodic antenna covering the 144, 222, and 432 MHz bands.

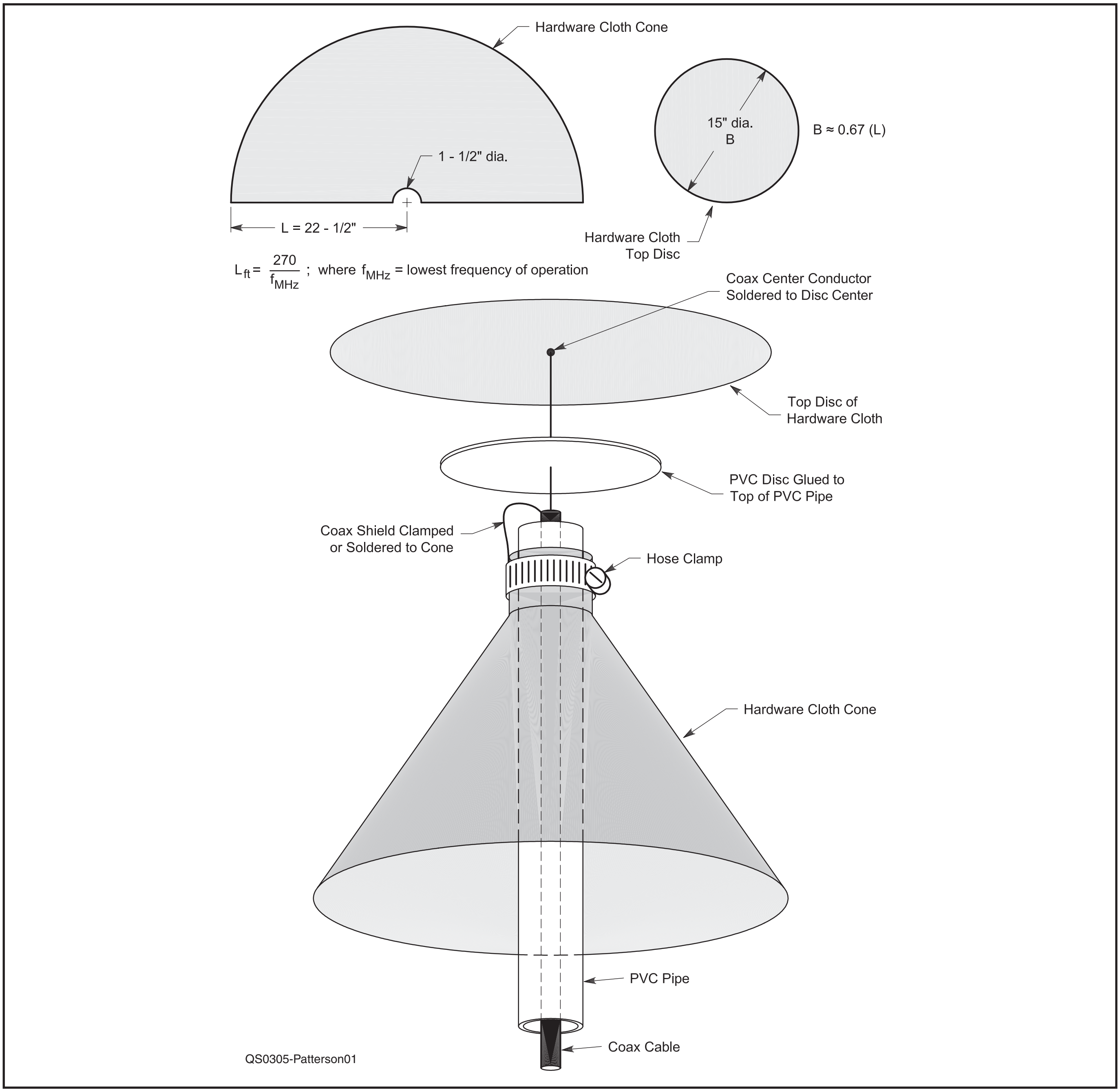


Figure 15.72 — Construction details for a VHF/UHF discone antenna. The largest dimension of the discone is determined by the lowest frequency of use.

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,

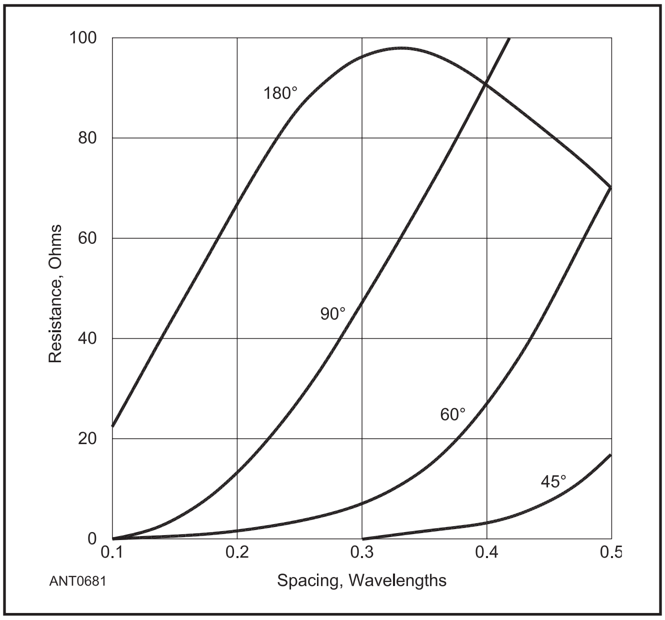


Figure 15.73 — Radiation resistance of the driven element in a corner reflector array for corner angles of 180° (flat sheet), 90°, 60° and 45° as a function of spacing D, as shown in Figure 15.74.

the driven element spacing can be anything from 0.25 to 0.7 λ, 0.35 to 0.75 λ for 60°, and 0.5 to 0.8 λ 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 1 λ long for 0.5-λ spacing. A side length greater than 2 λ is ideal. Gain with a 60° or 90° corner reflector with 1-λ sides is about 10 dB. A 60° corner with 2-λ sides has about 13 dBi gain, and a 45° corner with 3-λ sides has about 14 dBi gain.

Reflector length (L, Figure 15.74) should be a minimum of 0.6 λ. 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 0.06 λ for best results. A spacing of 0.06 λ results

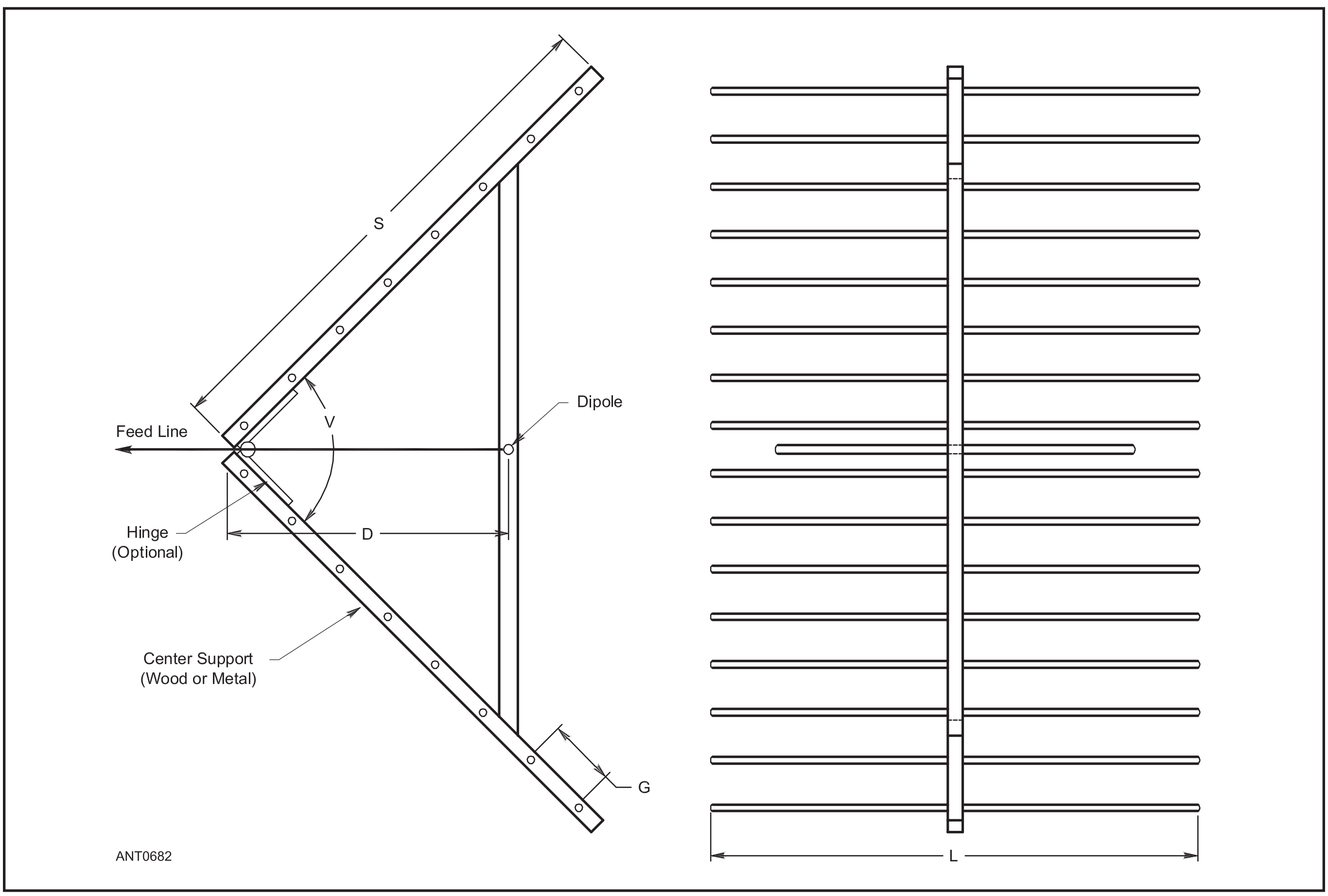


Figure 15.74 — Construction of a corner reflector array. The frame can be wood or metal. Reflector elements are stiff wire or tubing. Dimensions for several bands are given in Table 15.25. Reflector element spacing, G, is the maximum that should be used for the frequency; closer spacings are optional. 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 × D, dipole to vertex distance
Reflector length L is 2.0 λ
Reflector spacing G is 0.05 λ

1296 MHz
Wavelength is 9.11 inches
Side length S is 4 × D, dipole to vertex distance
Reflector length L is 3.0 λ
Reflector spacing G is 0.05 λ

2304 MHz
Wavelength is 5.12 inches
Side length S is 6 × D, dipole to vertex distance
Reflector length L is 4.0 λ
Reflector spacing G is 0.05 λ

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 0.06 λ 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

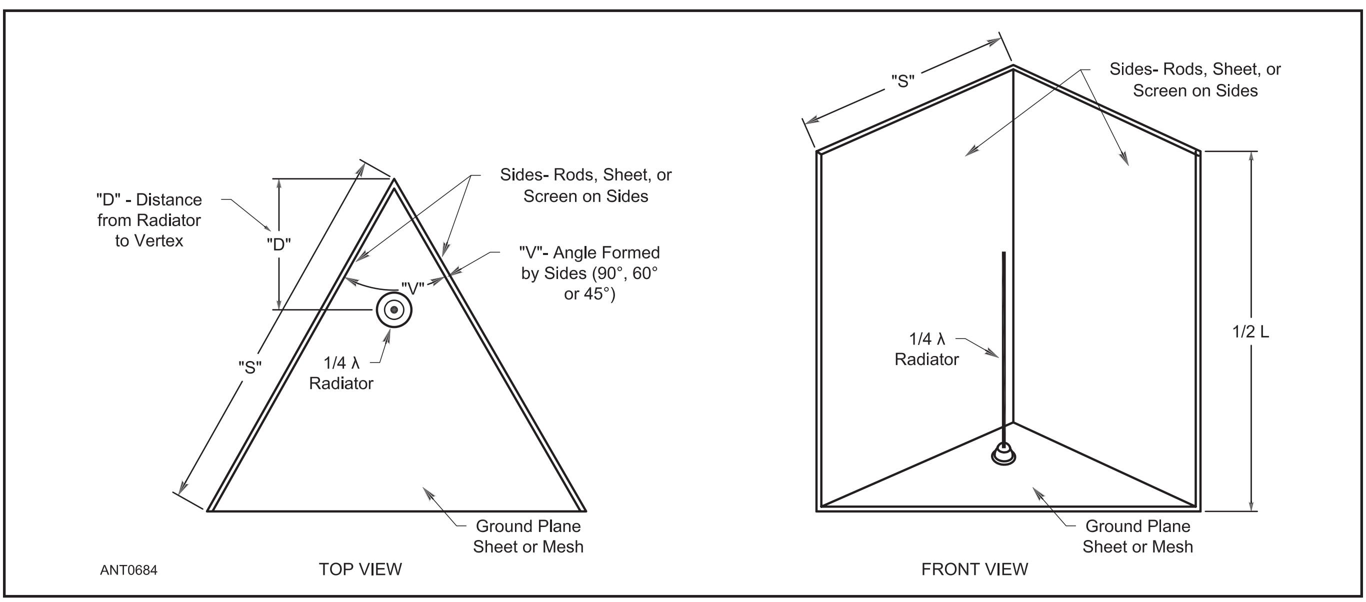


Figure 15.75 — A ground-plane corner reflector antenna for vertical polarization, such as FM communications or packet radio. The dimension ½ L in the front view refers to data in Table 15.25.

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 × 6 λ 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.

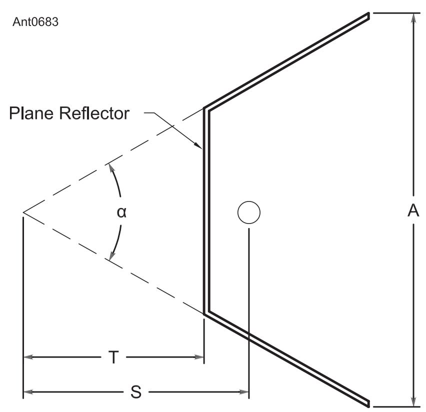
A dipole radiator is usually employed with a corner reflector. This requires a balun between the coaxial line and the balanced feed point impedance of the antenna. Baluns are easily constructed of coaxial line on the lower VHF bands, but become more difficult at the higher frequencies. This problem may 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 ¼ λ 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



Angle α	*Value of S for maximum gain*	*Gain*	*Value of T*
90°	1.5 λ	13.5 dB	1λ - 1.25 λ
60°	1.75 λ	15 dB	1.0 λ
45°	2.0 λ	16 dB	1.9 λ

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.

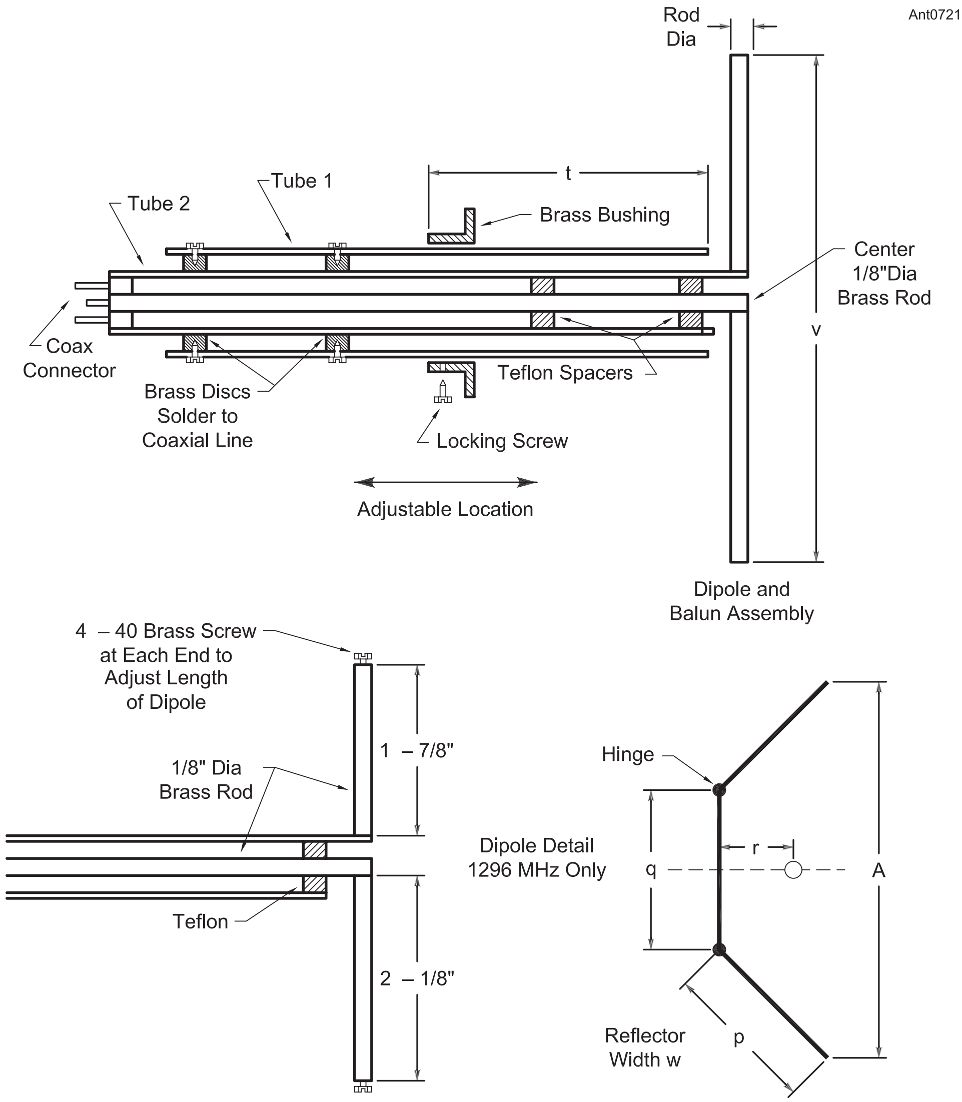
dipoles (fed in phase) within a wider reflector. Not more than two or three radiating units should be used, because the great virtue of the simple feeder arrangement would then be lost.

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.



Dimensions in Inches

Band	A	p	q	r	w	t	u	v	Tube 1 Brass or Copper	Tube 2 Brass or Copper	Gain
432	120	100	50	7–1/2	60	6–1/2	1/4	12–3/4	1–1/2" ID 1/16" Wall	5/8" OD 1/16" Wall	16 dBi
1296	45	36	9–1/2	2–1/2	20	2–1/8	1/8	4–1/4	3/4" ID	3/8" OD 20 s.w.g.	15 dBi

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: ¼ λ 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
½ inch foam/copper hardline: 4 dB
⅞ 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

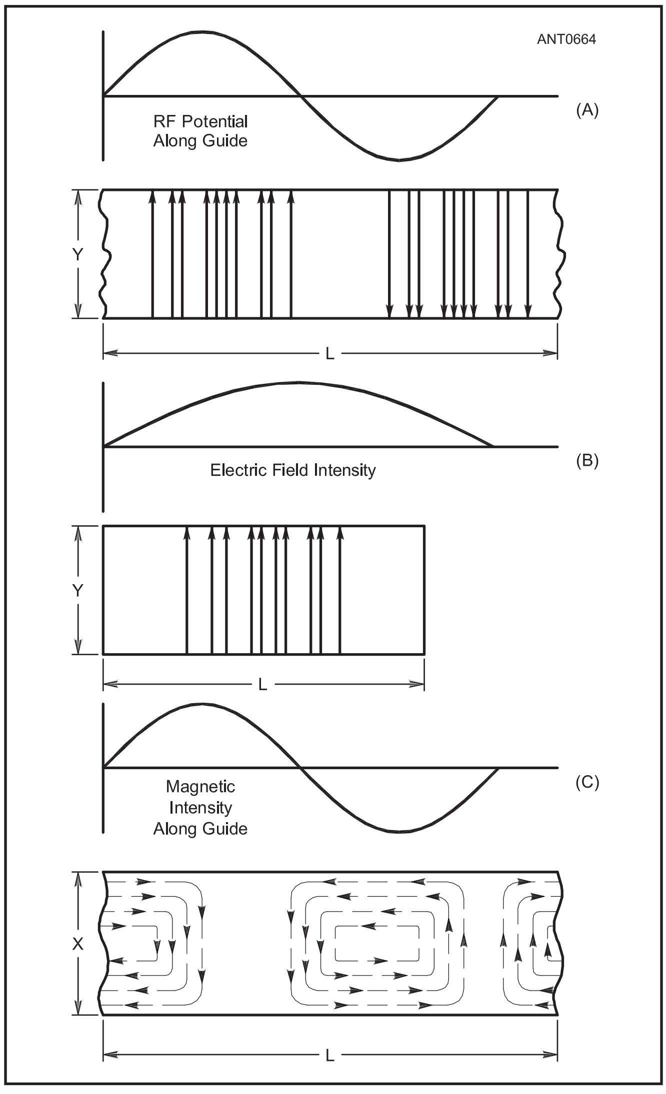


Figure 15.78 — Field distribution in a rectangular waveguide. The TE10 mode of propagation is depicted.

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 ½ λ at the lowest frequency to be transmitted. In practice, the Y dimension usually is made about equal to ½ 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.

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

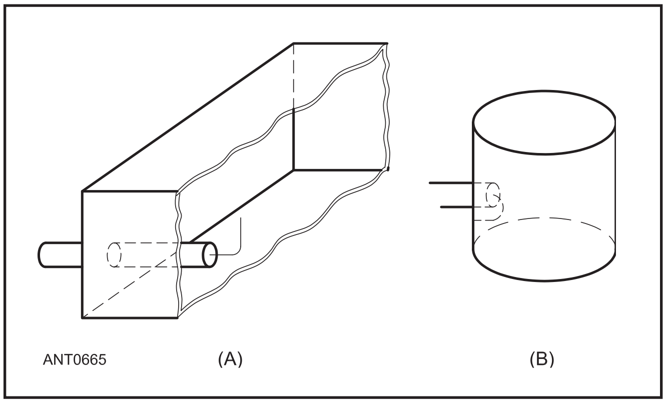


Figure 15.79 — Coupling coaxial line to waveguide and resonators.

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 ½ λ 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 ¼ λ 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 ¼ λ stubs may be connected in parallel without affecting the standing waves of voltage

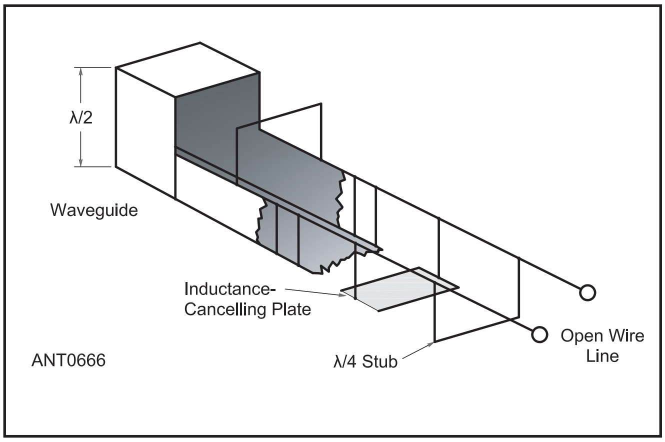


Figure 15.80 — At its cutoff frequency a rectangular waveguide can be thought of as a parallel two-conductor transmission line supported from top and bottom by an infinite number of ¼-λ stubs.

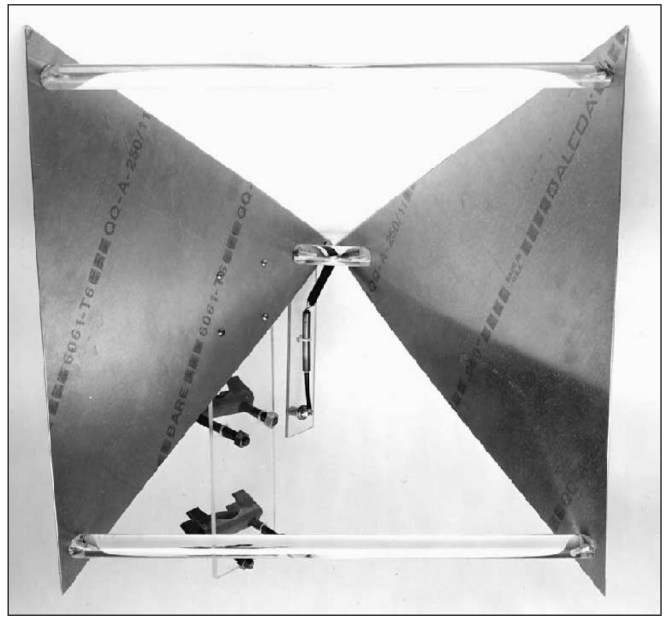


Figure 15.81 — An experimental two-sided pyramidal horn constructed in the ARRL laboratory. A pair of muffler clamps allow mounting the antenna on a mast. This model has sheet-aluminum sides, although window screen would work as well. Temporary elements could be made from cardboard covered with aluminum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

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 ½ λ.

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 ¼ λ, 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

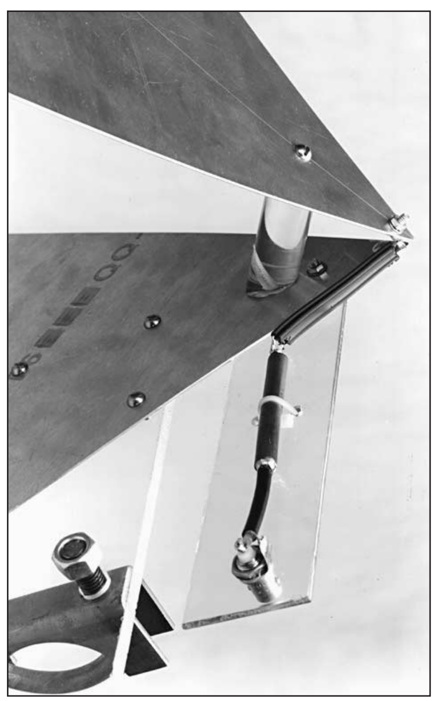


Figure 15.82 — Matching system used to test the horn. Better performance would be realized with open wire line. See text.

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

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

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

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

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 ⅛ λ in amateur operation. At 430 MHz ⅛ λ 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 $\frac{1}{12}$ λ. 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

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

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.

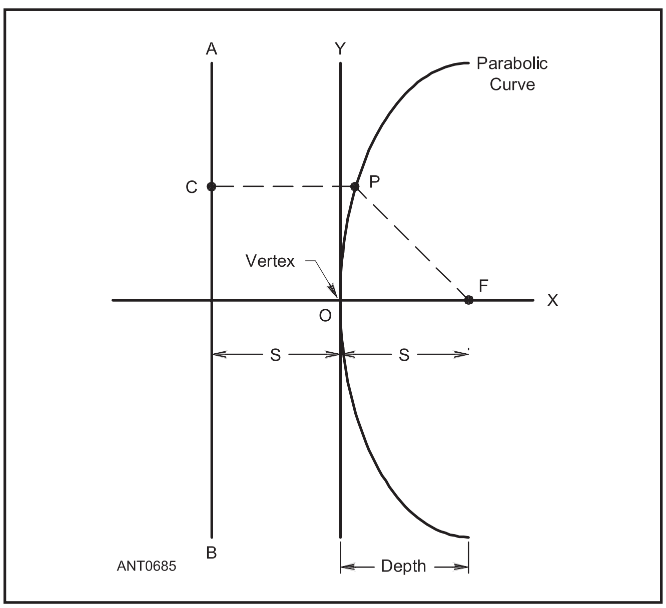


Figure 15.83 — Details of the parabolic curve, Y^2 = 4SX. This curve is the locus of points that are equidistant from a fixed point, the focus (F), and a fixed line (AB) that is called the *directrix*. Hence, FP = PC. The focus (F) is located at coordinates S,0.

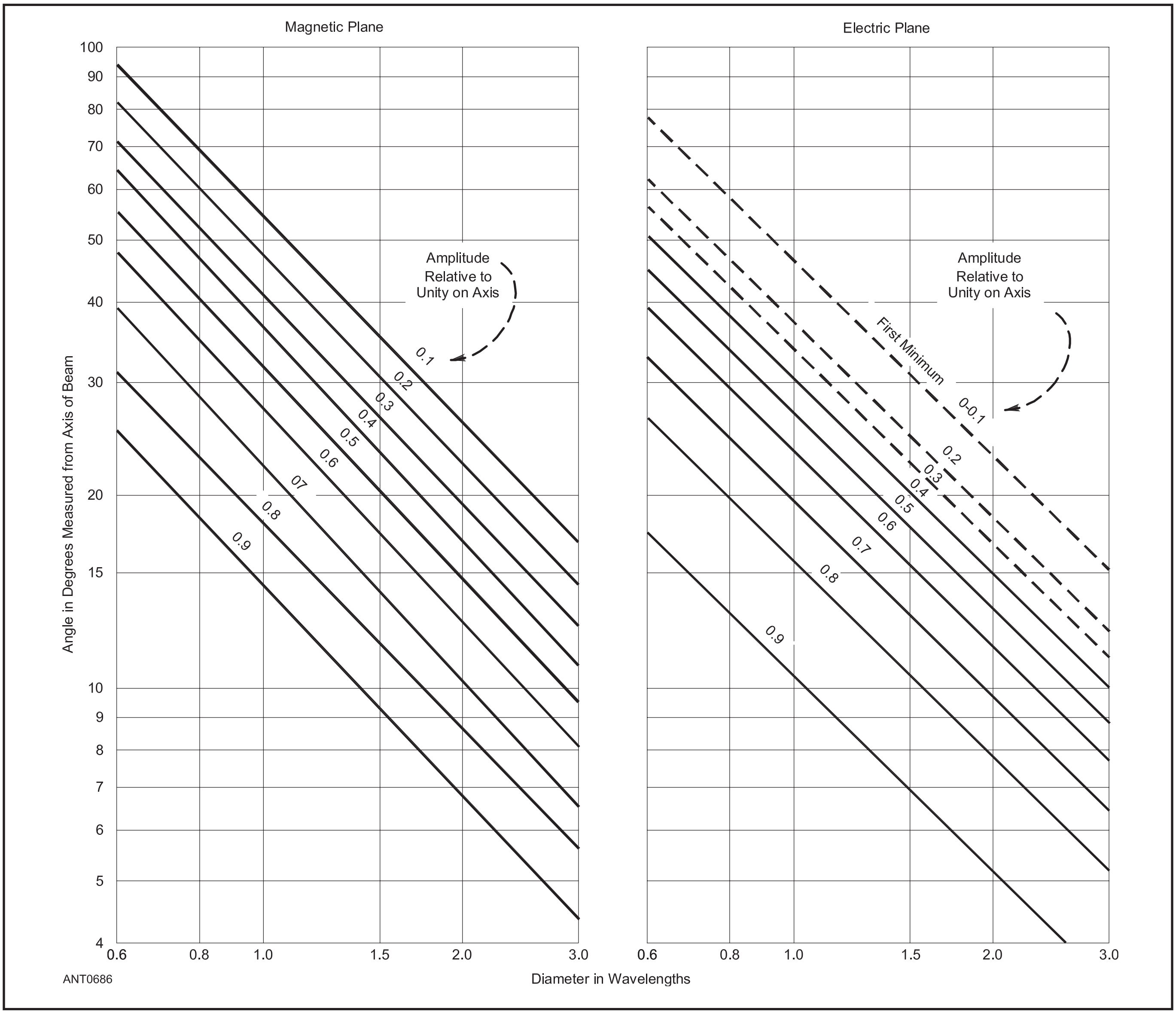


Figure 15.84 — This graph can be used in conjunction with Table 15.28 for selecting the proper diameter waveguide to illuminate a parabolic reflector.

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 0.7 λ 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 2 λ in diameter appears to be as effective as a

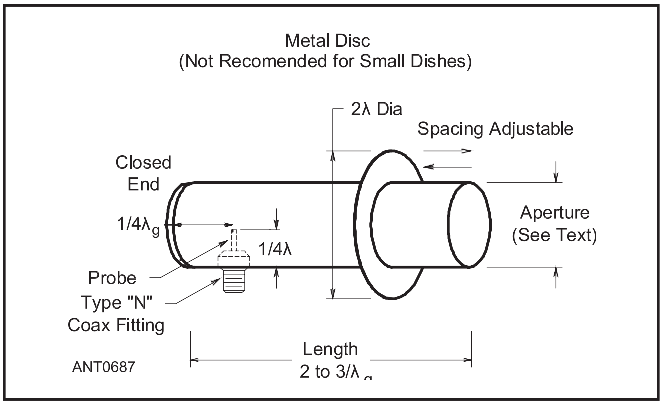


Figure 15.85 — Details of a circular waveguide feed.

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

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

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

where

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

Circular waveguide will support the mode having a cutoff frequency

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

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

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

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 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 ¼ λ long and spaced from the closed end of the guide by ¼ 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 ¾ 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 nonmetallic 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/cm^2 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

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

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

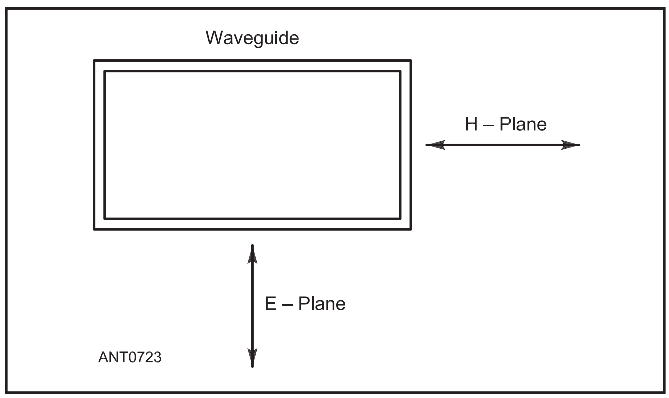


Figure 15.87 — 10-GHz antennas are usually fed with waveguide. See text for a discussion of waveguide propagation characteristics.

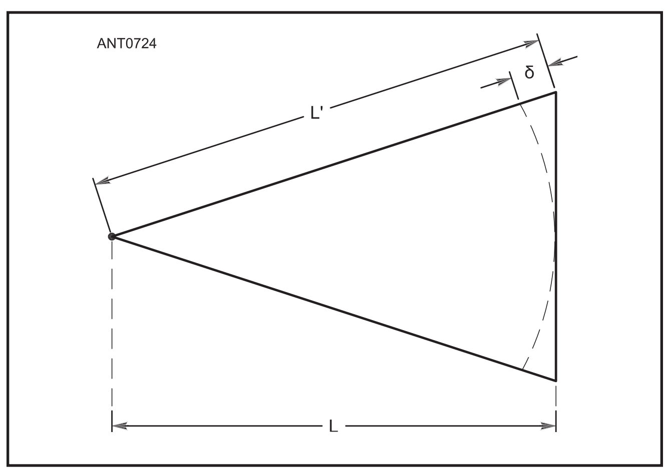


Figure 15.88 — The path-length (phase) difference between the center and edge of a horn antenna is δ.

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° (¼ λ). In an H-plane horn, the allowable phase difference is 144° (0.4 λ). 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 = H-plane length (λ) = 0.0654 × gain (Eq 11)

A = H-plane aperture (λ) = 0.0443 × gain (Eq 12)

B = E-plane aperture (λ) = 0.81 A (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 × 100 = 6.54 λ. At 10.368 GHz, this is

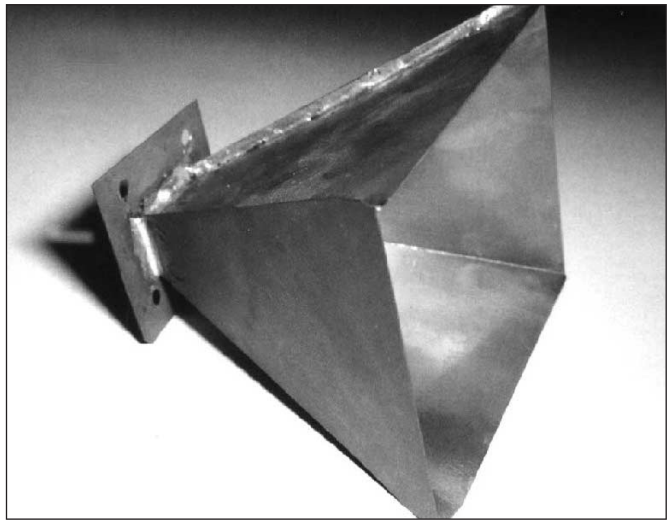


Figure 15.89 — This pyramidal horn has 18.5 dBi gain at 10 GHz. Construction details are given in the text.

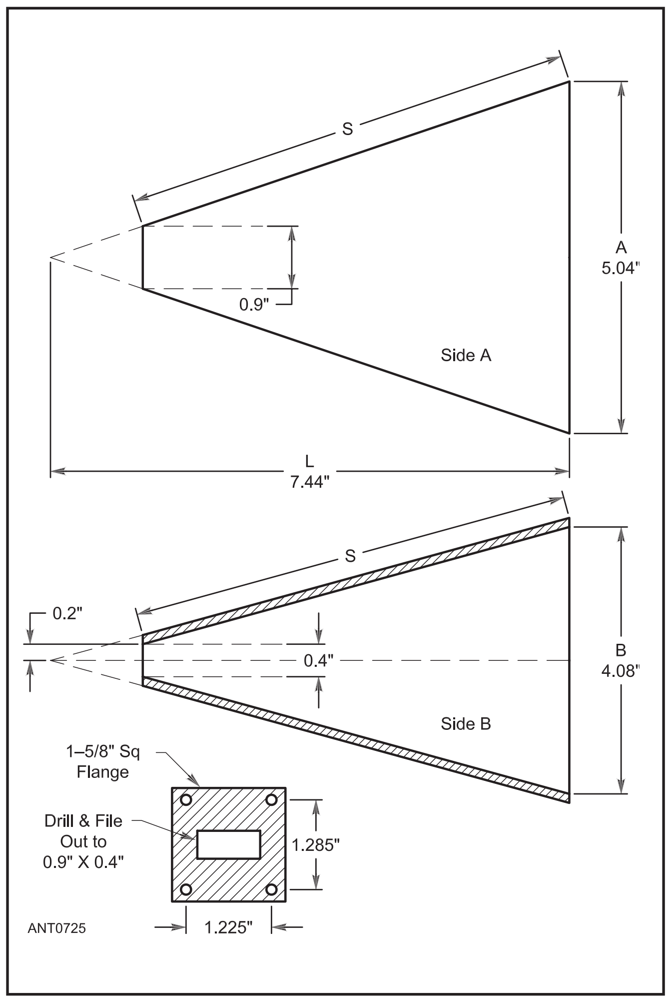


Figure 15.90 — Dimensions of the brass pieces used to make the 10-GHz horn antenna. Construction requires two of each of the triangular pieces (side A and side B).

7.44 inches. The corresponding H-plane aperture (A) is 4.43 λ (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).

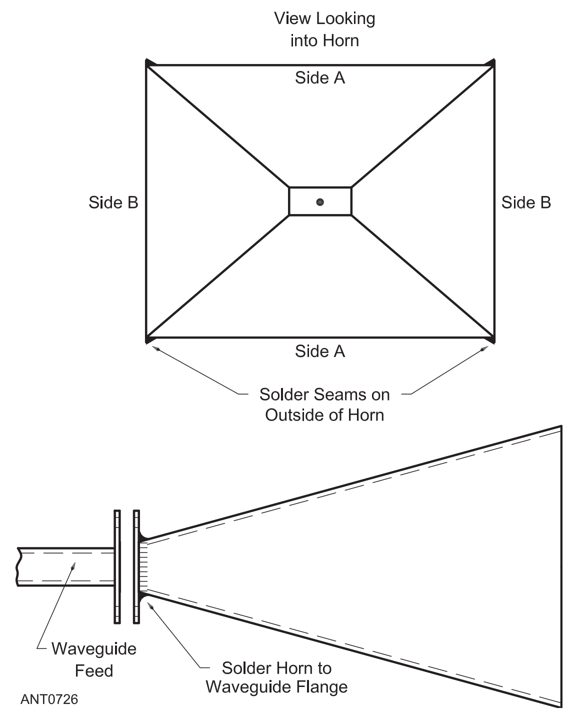


Figure 15.91 — Assembly of the 10-GHz horn antenna.

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

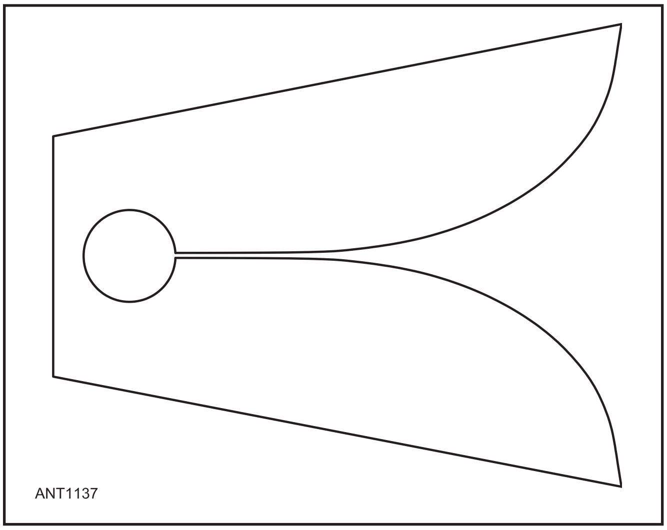


Figure 15.92 — The template for a Vivaldi antenna. Scale as shown in Table 15.30.

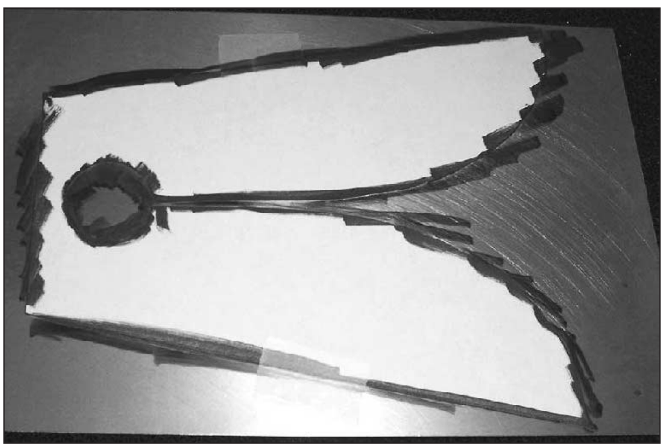


Figure 15.93 — Marking out a Vivaldi antenna using the template placed on your chosen material.

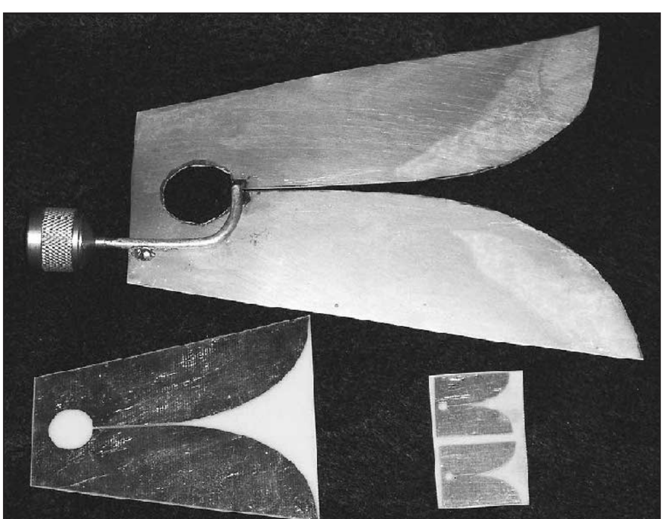


Figure 15.94 — A complete Vivaldi antenna.

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 antenna make excellent test antennas for use with a test instruments 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.

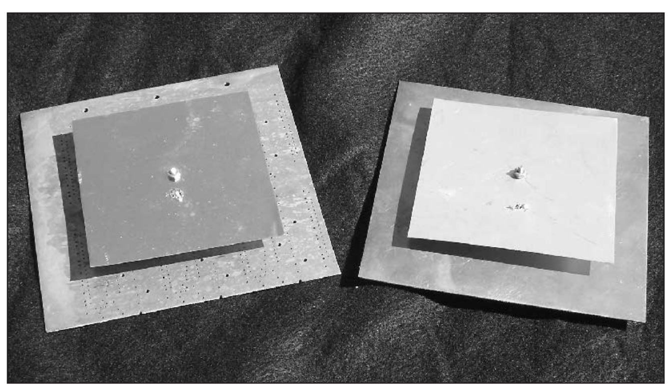


Figure 15.95 — Two patch antennas for the 23 cm band. The patch on the left is constructed from sheet metal and the one on the right from PCB material.

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 × 150 mm or larger will work well.

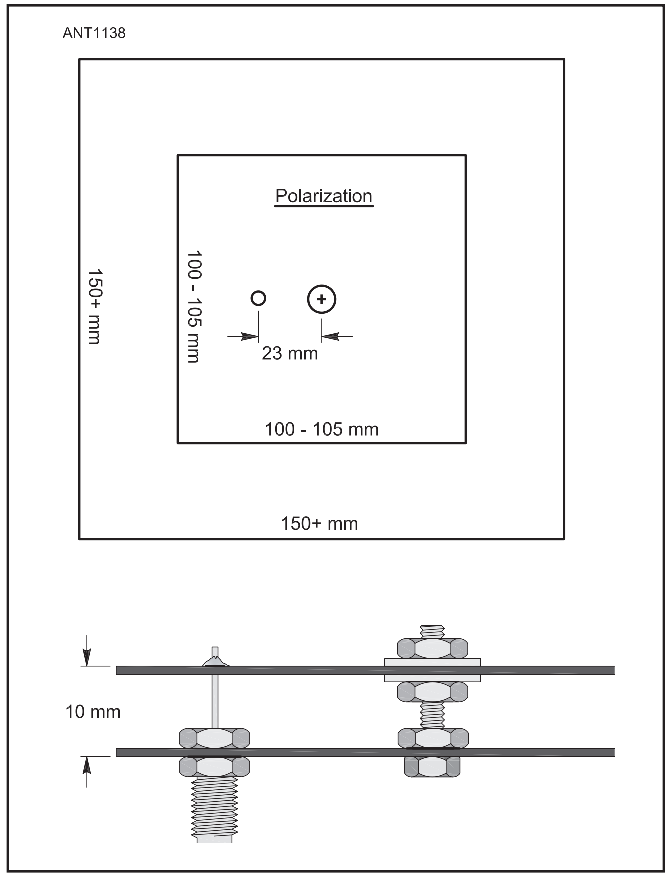


Figure 15.96 — Dimensions for the 23 cm patch antenna. The size of the patch determines the frequency range of the antenna (see text). The orientation of the feed point determines the antenna's polarization.

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 × 105 mm. For 1280-1325 MHz reduce the patch size to 100 mm × 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

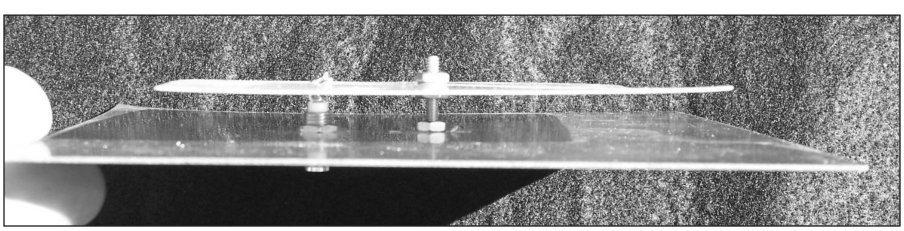


Figure 15.97 — An illustration showing how the patch is mounted above the ground plane using the center screw and, in this case, the SMA connector.

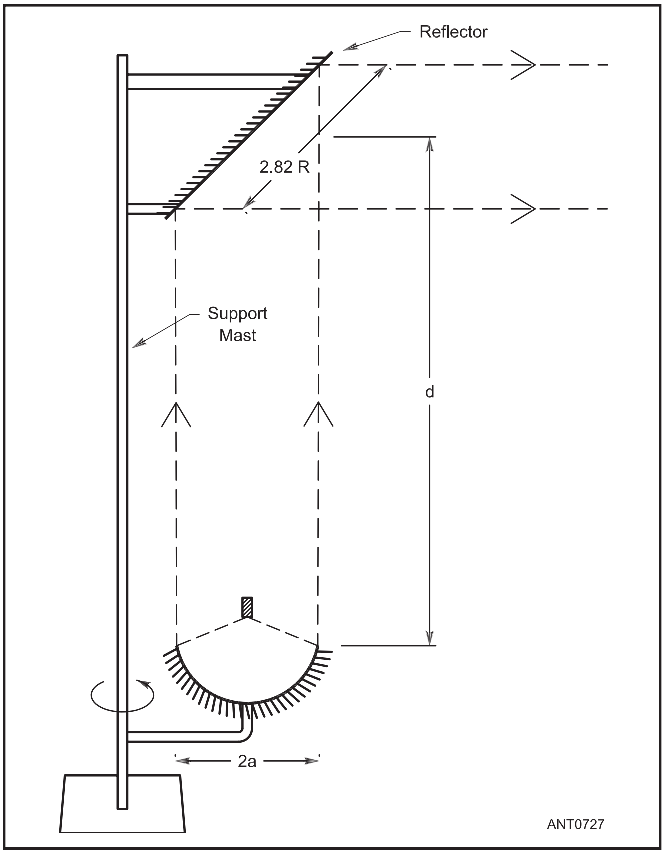


Figure 15.98 — The basic periscope antenna. This design makes it easy to adjust the feed antenna.

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,

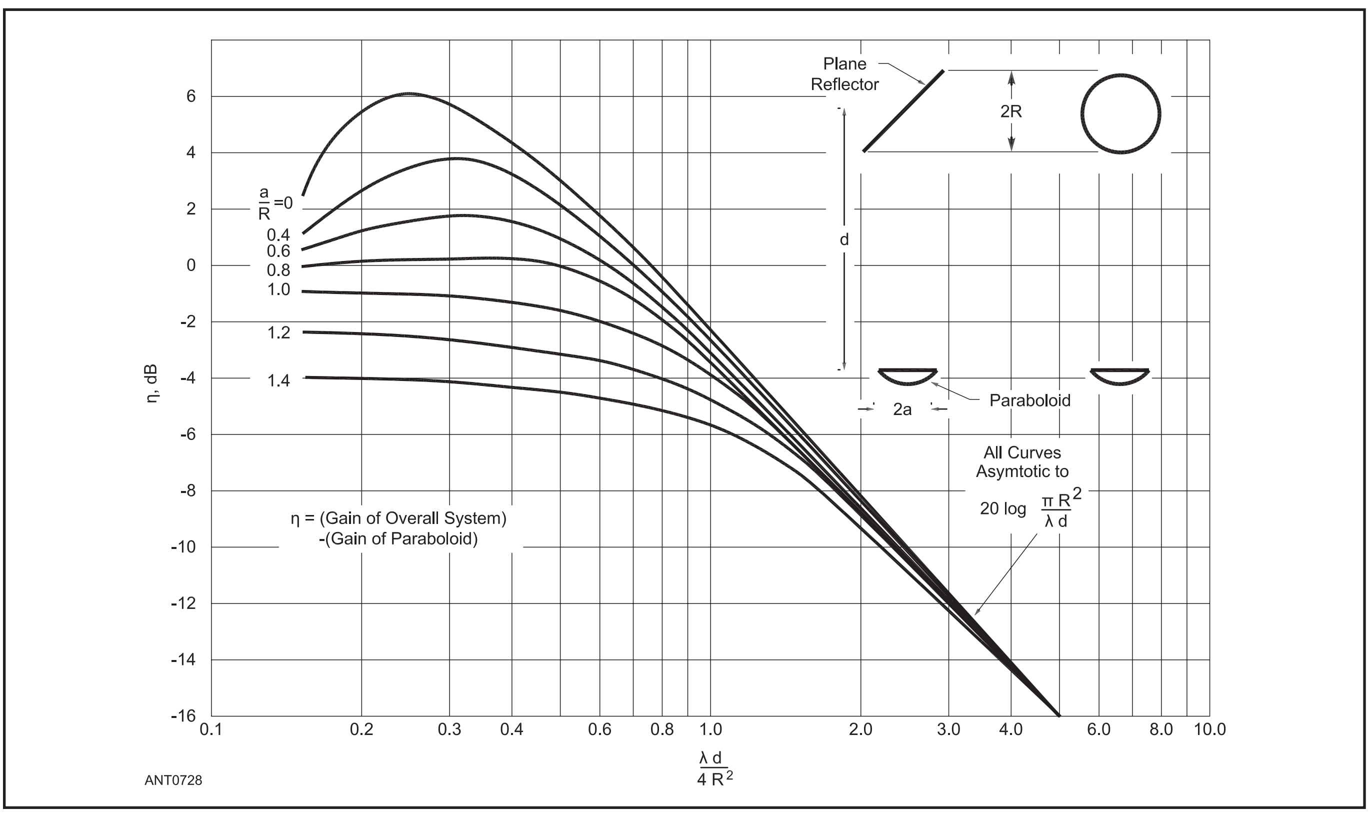


Figure 15.99 — Gain of a periscope antenna using a plane elliptical reflector (after Jasik — see Bibliography).

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.

Table 15.31
Radiation Patterns of Periscope Antenna Systems

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

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**.

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

Circular polarization is not often used for terrestrial 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 $\frac{1}{10}\,\lambda$.

15.7 BIBLIOGRAPHY

Source material and more extended discussion of topics covered in this chapter can be found in the references given below and in the textbooks listed at the end of the **Antenna Fundamentals** chapter.

RSGB Books

Antennas for VHF and Above, (Potters Bar: RSGB, 2008).

International Microwave Handbook (Potters Bar: RSGB, 2008).

Microwave Know-How for the Radio Amateur (Potters Bar: RSGB, 2010).

Radio Communication Handbook, 10th ed. (Potters Bar: RSGB, 2009).

Other Publications

B. Atkins, "Periscope Antenna Systems," The New Frontier, *QST*, Jan 1984, p 70 and Feb 1984, p 68.

B. Atkins, "Horn Antennas for 10 GHz," The New Frontier, *QST*, Apr 1987, p 80 and May 1987, p 63.

B. Atkins, "The New Frontier: Loop Yagi for 2304 MHz," *QST*, Sep 1981, p 76.

R. Bancroft, *Microstrip and Printed Antenna Design (2nd Edition)* (Raleigh, NC: SciTech Publishing, 2009)

J. Belrose, "Technical Correspondence: Gain of Vertical Collinear Antennas," *QST*, Oct 1982, pp 40-41.

L.B. Cebik, "A Short Boom, Wideband 3 Element Yagi for 6 Meters," *QST*, Aug 2007, pp 41-45.

L.B. Cebik, "2X3=6," *QST*, Feb 2000, p 34-36.

L.B. Cebik, "Building a Medium-Gain, Wide-Band, 2 Meter Yagi," *QST*, Dec 2004, pp 33-37.

L.B. Cebik, "Notes on the OWA Yagi," *QEX*, Jul/Aug 2002, pp 22-34.

L.B. Cebik, "An LPDA for 2 Meters Plus," *QST*, Oct 2001, pp 42-46.

J. Drexler, "An Experimental Study of a Microwave Periscope," *Proc. IRE*, Correspondence, Vol 42, Jun 1954, p 1022.

D. Evans and G. Jessop, *VHF-UHF Manual*, 3rd ed. (London: RSGB), 1976.

N. Foot, "WA9HUV 12 foot Dish for 432 and 1296 MHz," The World Above 50 Mc., *QST*, Jun 1971, pp 98-101, 107.

N. Foot, "Cylindrical Feed Horn for Parabolic Reflectors," *Ham Radio*, May 1976, pp 16-20.

G. Gobau, "Single-Conductor Surface-Wave Transmission Lines," *Proc. IRE*, Vol 39, Jun 1951, pp 619-624; also see *Journal of Applied Physics*, Vol 21 (1950), pp 1119-1128.

R. E. Greenquist and A. J. Orlando, "An Analysis of Passive Reflector Antenna Systems," *Proc. IRE*, Vol 42, Jul 1954, pp 1173-1178.

G. A. Hatherell, "Putting the G Line to Work," *QST*, Jun 1974, pp 11-15, 152, 154, 156.

R. Heslin, "Three-Band Log Periodic Antenna," *QST*, Jun 1963, pp 50-52.

D. L. Hilliard, "A 902 MHz Loop Yagi Antenna," *QST*, Nov 1985, pp 30-32.

G. Hoch, "Extremely Long Yagi antennas," *VHF Communications Magazine*, Mar 1982, pp 131-138.

G. Hoch, "More Gain from Yagi Antennas," *VHF Communications Magazine*, Apr 1997, pp 204-211.

W. C. Jakes, Jr., "A Theoretical Study of an Antenna-Reflector Problem," *Proc. IRE*, Vol 41, Feb 1953, pp 272-274.

H. Jasik, *Antenna Engineering Handbook*, 2nd ed. (New York: McGraw-Hill, 1984).

J. Johnson, "The Optimised Wideband Low Impedance (OWL) Yagi," **antennex.com**, April 2010.

J. Johnson, "How do I model an OWL Yagi?," **antennaex.com**, May 2010.

J. Johnson, "Matching and feeding the OWL Yagi," **antennex.com**, June 2010.

R. T. Knadle, "UHF Antenna Ratiometry," *QST*, Feb 1976, pp 22-25.

G. Kraus, "Modern Patch Antenna Design," *VHF Communications Magazine*, Jan 2001, pp 49-63.

F. Krug, "Micro-Stripline Antennas," *VHF Communications Magazine,* Apr 1985, pp 194-207.

Z. Lau, "RF: A Small 70-cm Yagi," *QEX*, Jul 2001, p 55.

T. Moreno, *Microwave Transmission Design Data* (New York: McGraw-Hill, 1948).

E. Munn, "The Polaplexer Revisited," **www.ham-radio.com/sbms/sd/ppxrdsgn.htm**.

W. Overbeck, "The VHF Quagi," *QST*, Apr 1977, pp 11-14.

W. Overbeck, "The Long-Boom Quagi," *QST*, Feb 1978, pp 20-21.

W. Overbeck, "Reproducible Quagi Antennas for 1296 MHz," *QST*, Aug 1981, pp 11-15.

J. Post, "The Copper Cactus," *73*, Feb 1992, p 9.

S. Powlishen, "An Optimum Design for 432 MHz Yagis – Parts 1 and 2," *QST*, Dec 1987, pp 20-24, and Jan 1988, pp 24-30.

J. Reisert, "VHF/UHF World: Designing and Building Loop Yagis," *Ham Radio*, Sep 1985, pp 56-62.

G. Southworth, *Principles and Applications of Waveguide Transmission* (New York: D. Van Nostrand Co, 1950).

P. P. Viezbicke, "Yagi Antenna Design," *NBS Technical Note 688* (U. S. Dept. of Commerce/National Bureau of Standards, Boulder, CO), Dec 1976.

D. Vilardi, "Easily Constructed Antennas for 1296 MHz," *QST*, Jun 1969, pp 47-49.

D. Vilardi, "Simple and Efficient Feed for Parabolic Antennas," *QST*, Mar 1973, pp 42-44.