

# 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 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.

## The Basics

Selecting the best VHF or UHF antenna for a given installation involves much more than scanning gain figures and prices in a manufacturer's catalog. There is no one "best" VHF or UHF antenna design for all purposes. The first step in choosing an antenna is figuring out what you want it to do.

### Gain

At VHF and UHF, it is possible to build Yagi antennas with very high gain—15 to 20 dB—on a physically manageable boom. Such antennas 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 communication modes.

### Radiation Patterns

Antenna radiation can be made omnidirectional, bidirectional, practically unidirectional, or anything between these conditions. A VHF net operator may find an omnidirectional system almost a necessity, but it may be a poor choice otherwise. Noise pickup and other interference problems tend to be greater with such omnidirectional antennas, and such 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 work over an entire VHF band may be important in some types of work. 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 2.0-MHz portion of the 6-meter band with superb performance.

## Height Gain

In general, the higher the better in VHF and UHF antenna installations. If raising the antenna clears its view over nearby obstructions, it may make dramatic improvements in coverage. Within reason, greater height is almost always worth its cost, but height gain (see [Chapter 23](#)) 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 (shown in table form in [Chapter 24](#)) are important in antenna planning.

## Physical Size

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

## DESIGN FACTORS

With the objectives sorted out in a general way, decisions on specifics, such as polarization, type of transmission line, matching methods and mechanical design must be made.

### Polarization

Whether to position antenna elements vertically or horizontally has been widely questioned since early VHF pioneering. Tests have shown little evidence as to which polarization sense is most desirable. On long 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 work.

Vertical polarization was widely used in early VHF work, but horizontal polarization gained favor when directional arrays started to become widely used. The major trend to FM and repeaters, particularly in the 144-MHz band, 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. Additional loss of 20 dB or more can be expected when cross-polarized antennas are used.

## TRANSMISSION LINES

Transmission line principles are covered in detail in [Chapter 24](#). Techniques that apply to VHF and UHF operation are dealt with in greater detail here. The principles of carrying RF from one location to another via a feed line are the same for all radio frequencies. As at HF, RF is carried principally via open-wire lines and coaxial cables at VHF/UHF. Certain aspects of these lines characterize them as good or bad for use above 50 MHz.

Properly built open-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 wire, spaced  $\frac{3}{4}$  inch or more with Teflon spreaders and run essentially straight from antenna to station, can be better than anything but the most expensive coax. Such line can be home-made or purchased at a fraction of the cost of coaxial cables, with comparable loss characteristics. Careful attention must be paid to efficient impedance matching if the benefits of this system are to be realized. A similar system for 144 MHz can easily provide a line loss under 1 dB.

Small coax such as RG-58 or RG-59 should never be used in VHF work if the run is more than a few feet. Lines of  $\frac{1}{2}$ -inch diameter (RG-8 or RG-11) work fairly well at 50 MHz, and are acceptable for 144-MHz runs of 50 feet or less. These lines are somewhat better if they employ foam instead of ordinary PE dielectric material. Aluminum-jacket “Hardline” coaxial cables with large inner conductors and foam insulation are well worth their cost, and can sometimes be obtained for free from local

cable TV operators as “end runs”—pieces at the end of a roll. The most common CATV cable is  $\frac{1}{2}$ -inch OD 75- $\Omega$  Hardline. Matched-line loss for this cable is about 1.0 dB/100 feet at 146 MHz and 2.0 dB/100 feet at 432 MHz. Less commonly available from CATV companies is the  $\frac{3}{4}$ -inch 75- $\Omega$  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- $\Omega$  transformers are used at each end.

Commercial connectors for Hardline are expensive but provide reliable connections with full waterproofing. Enterprising amateurs have “home-brewed” low-cost connectors. If they are properly waterproofed, connectors and Hardline can last almost indefinitely. Hardline must not be bent too sharply, because it will kink.

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. Twin-lead 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.

### G-Line

Conventional two-conductor transmission lines and most coaxial cables are quite lossy in the upper UHF and microwave ranges. If the station and antenna are separated by more than 100 feet, common coaxial cables (such as RG-8) are almost useless for serious work. Unless the very best rigid coax with the proper fittings can be obtained, it is worthwhile to explore alternative methods of carrying RF energy between the station and antenna.

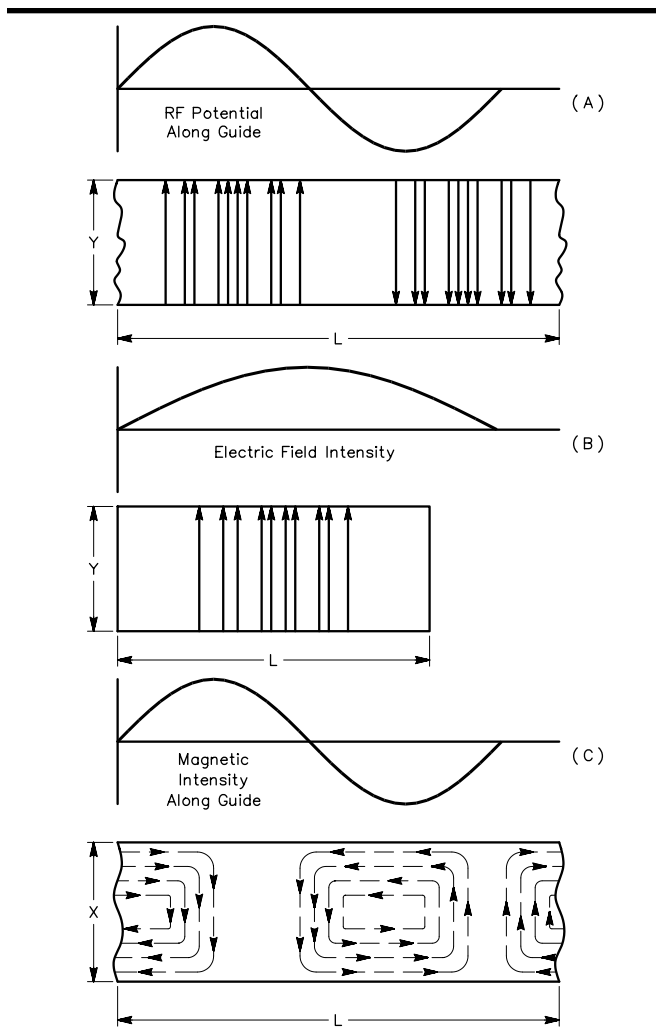
There is a single-conductor transmission line, invented by Georg Goubau (called “G-Line” in his honor), that can be effectively used in this frequency range. Papers by the inventor appeared some years ago, in which seemingly fantastic claims for line loss were made—under 1 dB per 100 feet in the microwave region, for example. (See the [Bibliography](#) at the end of this chapter.) Especially attractive was the statement that the matching device was broadband in nature, making it appear that a single G-Line installation might be made to serve on, say, 432, 903 and 1296 MHz.

The basic idea is that a single conductor can be an almost lossless transmission line at UHF, if a suitable “launching device” is used. A similar “launcher” is placed at the other end. Basically, the launcher is a cone-shaped device that is a flared extension of the coaxial cable shield. In effect, the cone begins to carry the RF as the outer conductor is gradually “removed.” These launch cones should be at least  $3\lambda$  long. The line should be large and heavily insulated, such as #14, vinyl covered.

Propagation along a G-Line is similar to “ground wave,” or “surface wave” propagation over perfectly conducting earth. The dielectric material confines the energy to the vicinity of the wire, preventing radiation. The major drawback of G-Line is that it is very sensitive to deviation from straight lines. If any bends must be made, they should be in the form of a large radius arc. This is preferable to even an obtuse angle change in the direction of the run. The line must be kept several inches away from metal objects and should be supported with as few insulators as possible.

### WAVEGUIDES

Above 2 GHz, coaxial cable is a losing proposition for communication work. 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.



**Fig 1—Field distribution in a rectangular waveguide. The  $TE_{10}$  mode of propagation is depicted.**

**Table 1**

**Waveguide Dimensions**

	<i>Rectangular</i>	<i>Circular</i>
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

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 **Fig 1**. 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 (Fig 1C), 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

Fig 1 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 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 work.

### Waveguide Dimensions

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

Cross-sectional shapes other than the 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 1**, 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 **Fig 2**. 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 on the mode of propagation in the guide or cavity. Coupling is maximum when the coupling device is in the most intense field.

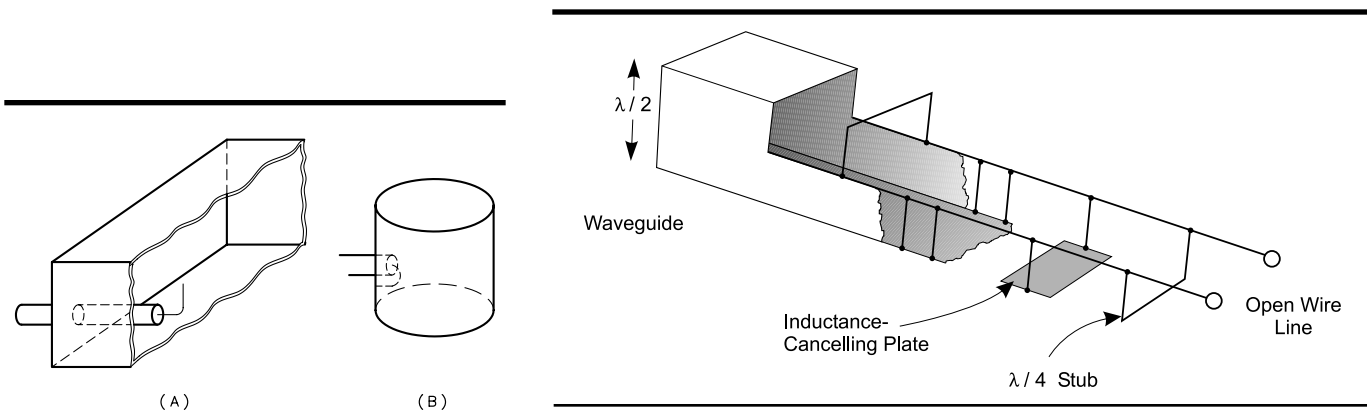
Coupling can be varied by turning the probe or loop through a  $90^\circ$  angle. When the probe is perpendicular to the electric lines the coupling is minimum; similarly, when the plane of the loop is parallel to the magnetic lines the coupling is minimum.

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

## Evolution of a Waveguide

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

An infinite number of these  $\frac{1}{4}\lambda$  stubs may be connected in parallel without affecting the standing waves of voltage 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. **Fig 3** illustrates how a rectangular waveguide evolves from a two-wire parallel transmission line as described. This simplified analysis also shows why the cutoff dimension is  $\frac{1}{2}\lambda$ .



**Fig 2—Coupling coaxial line to waveguide and resonators.**

**Fig 3—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  $\frac{1}{4}\lambda$  stubs.**

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.

## IMPEDANCE MATCHING

Impedance matching is covered in detail in Chapters 25 and 26, and the theory is the same for frequencies above 50 MHz. Practical aspects are similar, but physical size can be a major 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, and a reading of relevant portions of both Chapters 25 and 26 is recommended.

### Universal Stub

As its name implies, the double adjustment stub of Fig 4A is useful for many matching purposes. The stub length is varied to resonate the system, and the transmission line attachment point is varied until the transmission line and stub impedances are equal. In practice this involves moving both the sliding short and the point of line connection for zero reflected power, as indicated on an SWR bridge connected in the line.

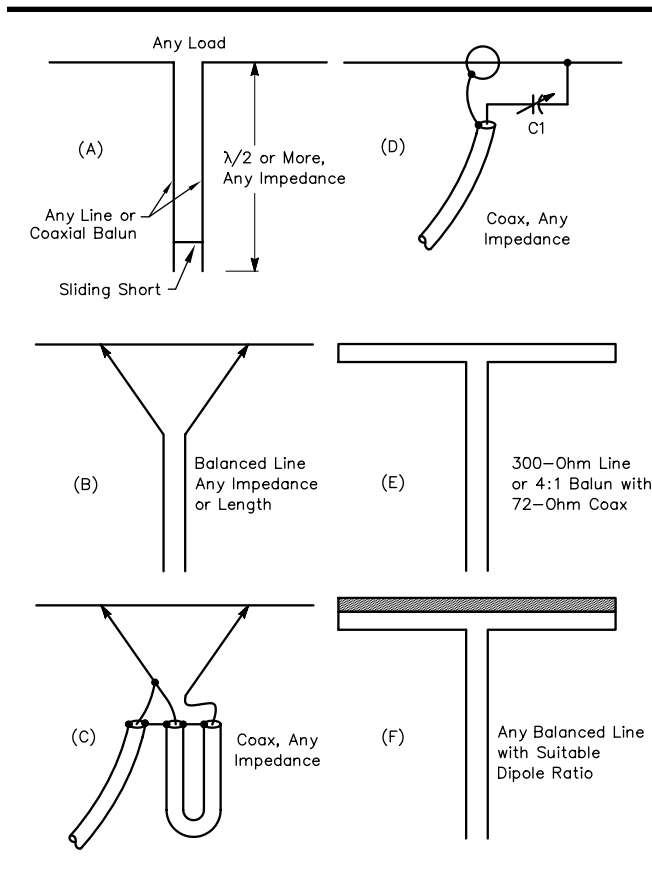
The universal stub allows for tuning out any small reactance present in the driven part of the system. It permits matching the antenna to the line without knowledge of the actual impedances involved. The position of the short yielding the best match gives some indication of the amount of reactance present. With little or no reactive component to be tuned out, the stub must be approximately  $\frac{1}{2} \lambda$  from load toward the short.

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

It is not necessary that the stub be connected directly to the driven element. It can be made part of an open 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 open wire line tapped onto a  $\frac{1}{2} \lambda$  antenna at the point of most efficient power transfer. This is shown in Fig 4B. Both the side length and the points of con-



**Fig 4—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.



nection either side of the center of the element must be adjusted for minimum reflected power on the line, but as with the universal stub, the impedances need not be known. The delta match makes no provision for tuning out reactance, so the universal stub is often used as a termination for it, to this end.

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 [Fig 4C](#), 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, [Fig 4D](#). Because the RF voltage at the center of a  $1/2\text{-}\lambda$  dipole is zero, the outer conductor of the coax is connected to the element at this point. This may also be the junction with a metallic or wooden boom. The inner conductor, carrying the RF current, is tapped out on the element at the matching point. Inductance of the arm is tuned out by means of C1, resulting in electrical balance. Both the point of contact with the element and the setting of the capacitor are adjusted for zero reflected power, with a bridge connected in the coaxial line.

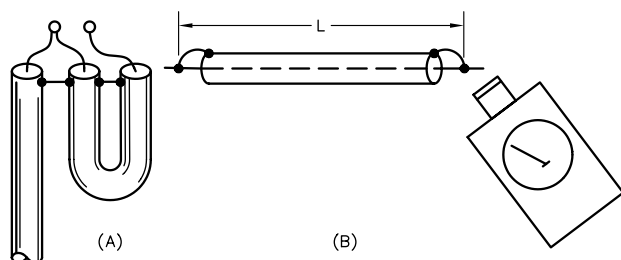
The capacitance can be varied until the required value is found, and the variable capacitor replaced with a fixed unit of that value. C1 can be mounted in a waterproof box. The maximum required value should be about 100 pF for 50 MHz and 35 to 50 pF for 144 MHz.

The capacitor and arm can be combined in one coaxial assembly with the arm connected to the driven element by means of a sliding clamp, and the inner end of the arm sliding 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 plastic or heat-shrink sleeving. 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, as the RF current is high at this point.

Because it is inherently somewhat unbalanced, the gamma match can sometimes introduce pattern distortion, particularly on long-boom, highly directive Yagi arrays. The T match, essentially two gamma matches in series creating a balanced feed system, has become popular for this reason. A coaxial balun like that shown in [Fig 5](#) is used from the 200- $\Omega$  balanced T match to the unbalanced 50- $\Omega$  coaxial line going to the transmitter. See [K1FO Yagi designs](#) later in this chapter for details.

### Folded Dipole

The impedance of a  $1/2\text{-}\lambda$  antenna broken at its center is about 70  $\Omega$ . If a single conductor of uniform size is folded to make a  $1/2\text{-}\lambda$  dipole as shown in [Fig 4E](#), the impedance is stepped up four times. Such a folded dipole can be fed directly with 300- $\Omega$  line with no appreciable mismatch. If a 4:1 balun is used, the antenna can be fed with 75- $\Omega$  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 [Fig 4F](#).



**Fig 5—Conversion from unbalanced coax to a balanced load can be done with a  $1/2\text{-}\lambda$  coaxial balun at A. Electrical length of the looped section should be checked with a dip meter, with the ends shorted, as at B. The  $1/2\text{-}\lambda$  balun gives a 4:1 impedance step-up.**

## Hairpin Match

The feed-point resistance of most multi-element Yagi arrays is less than  $50\ \Omega$ . 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 is used together with a 4:1 coaxial balun in the **50-MHz arrays** described later in this chapter.

## BALUNS AND TRANSMATCHES

Conversion from balanced loads to unbalanced lines (or vice versa) can be performed with electrical circuits, or their equivalents made of coaxial cable. A balun made from flexible coax is shown in **Fig 5A**. The looped portion is an electrical  $\frac{1}{2}\lambda$ . The physical length depends on the velocity factor of the line used, so it is important to check its resonant frequency as shown in **Fig 5B**. 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  $\Omega$ , or 75 to 300  $\Omega$ ).

Coaxial baluns that yield 1:1 impedance transformations are shown in **Fig 6**. The coaxial sleeve, open at the top and connected to the outer conductor of the line at the lower end (A) is the preferred type. At B, a conductor of approximately the same size as the line is used with the outer conductor to form a  $\frac{1}{4}\lambda$  stub. Another piece of coax, using only the outer conductor, will serve this purpose. Both baluns are intended to present an infinite impedance to any RF current that might otherwise flow on the outer conductor of the coax.

The functions of the balun and the impedance transformer can be handled by various tuned circuits. Such a device, commonly called an *antenna tuner* or *Transmatch*, can provide a wide range of impedance transformations. Additional selectivity inherent in the Transmatch can reduce RFI problems.

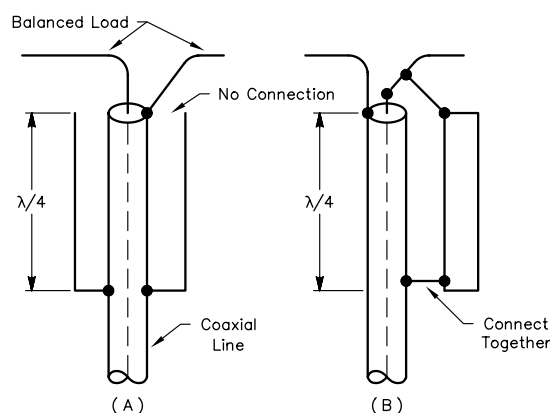
## THE YAGI AT VHF AND UHF

Without doubt, the Yagi is king of home-station antennas these days. Today's best designs are computer optimized. For years amateurs as well as professionals designed Yagi arrays experimentally. Now we have powerful (and inexpensive) personal computers and sophisticated software for antenna modeling. These have brought us antennas with improved performance, with little or no element pruning required. The chapter on **HF Yagis** in this handbook describes the parameters associated with Yagi-Uda arrays. Except for somewhat tighter dimensional tolerances needed at VHF and UHF, the properties that make a good Yagi at HF also are needed on the higher frequencies. See the end of this chapter for practical Yagi designs.

## STACKING YAGIS

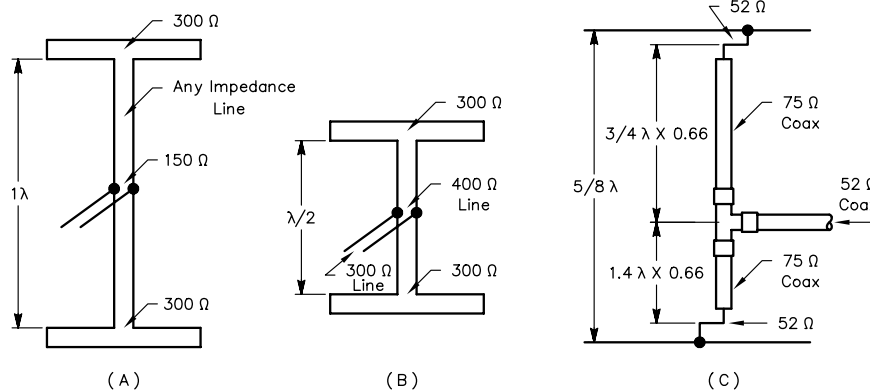
Where suitable provision can be made for supporting them, two Yagis mounted one above the other and fed in phase can provide better performance than one long Yagi with the same theoretical or measured gain. The pair occupies a much smaller turning space for the same gain, and their lower radiation angle can provide excellent results. The wider azimuthal coverage for a vertical stack often results in QSOs that might be missed with a single narrow-beam long-boom Yagi pointed in a different direction. On long ionospheric paths, a stacked pair occasionally may show an *apparent* gain much greater than the measured 2 to 3 dB of stacking gain.

Optimum vertical spacing for Yagis with boom longer than  $1\lambda$  or more is about  $1\lambda$  ( $984/50.1 =$



**Fig 6—The balun conversion function, with no impedance transformation, can be accomplished with  $\frac{1}{4}\lambda$  lines, open at the top and connected to the coax outer conductor at the bottom. The coaxial sleeve at A is preferred.**





**Fig 7—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  $3/4\lambda$  no transposition of line connections is needed.**

19.64 feet), but this may be too much for many builders of 50-MHz antennas to handle. Worthwhile results can be obtained with as little as  $1/2\lambda$  (10 feet), but  $5/8\lambda$  (12 feet) is markedly better. The difference between 12 and 20 feet 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  $1\lambda$  spacing. Extra gain with wider spacings is usually the objective on 144 MHz and the higher frequency bands, where the structural problems are not as severe.

Yagis can also be stacked in the same plane (collinear elements) for sharper azimuthal directivity. A spacing of  $5/8\lambda$  between the ends of the inner elements yields the maximum gain within the main lobe of the array.

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

Three sets of stacked dipoles are shown in **Fig 7**. Whether these are merely dipoles or the driven elements of Yagi arrays makes no difference for the purpose of these examples. Two  $300\text{-}\Omega$  antennas at A are  $1\lambda$  apart, resulting in a feed-point impedance of approximately  $150\ \Omega$  at the center. (Actually it is slightly less than  $150\ \Omega$  because of coupling between bays, but this can be neglected for illustrative purposes.) This value remains the same regardless of the impedance of the phasing line. Thus, any convenient line can be used for phasing, as long as the *electrical* length of each line is the same.

The velocity factor of the line must be taken into account as well. As with coax, this is subject to so much variation that it is important to make a resonance check on the actual line used. The method for doing this is shown in **Fig 5B**. A  $1/2\text{-}\lambda$  line is resonant both open and shorted, but the shorted condition (both ends) is usually the more convenient test condition.

The impedance transforming property of a  $1/4\text{-}\lambda$  line section can be used in combination matching and phasing lines, as shown in **Fig 7B** and **C**. At B, two bays spaced  $1/2\lambda$  apart are phased and matched by a  $400\text{-}\Omega$  line, acting as a double Q section, so that a  $300\ \Omega$  main transmission line is matched to two  $300\text{-}\Omega$  bays. The two halves of this phasing line could also be  $3/4\lambda$  or  $5/4\lambda$  long, if such lengths serve a useful mechanical purpose. (An example is the stacking of two Yagis where the desirable spacing is more than  $1/2\lambda$ .)

A double Q section of coaxial line is illustrated in **Fig 7C**. This is useful for feeding stacked bays that were designed for  $50\text{-}\Omega$  feed. A spacing of  $5/8\lambda$  is useful for small Yagis, and this is the equivalent of a full electrical wavelength of solid-dielectric coax such as RG-11.

If one phasing line is electrically  $1/4\lambda$  and  $3/4\lambda$  on the other, the connection to one driven element should be reversed with respect to the other to keep the RF currents in the elements in phase—the gamma match is located on opposite sides of the driven elements in **Fig 7C**. If the number of  $1/4\lambda$  lengths is the same on either side of the feed point, the two connections should be in the same position, and not reversed. Practically speaking, however, you can ensure proper phasing by using exactly equal lengths of line from the same roll of coax. This ensures that the velocity factor for each line is identical.

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

In stacking horizontal Yagis one above the other on a single support, certain considerations apply whether the bays are for different bands or for the same band. As a rule of thumb, the minimum desirable spacing is half the boom length for two bays on the same band, or half the boom length of the higher frequency array where two bands are involved.

Assume the stacked two-band array of **Fig 8** is for 50 and 144 MHz. The 50-MHz, 4-element Yagi is going to tend to look like “ground” to the 7-element 144-MHz Yagi above it, if it has any effect at all. It is well known that the impedance of an antenna varies with height above ground, passing through the free-space value at  $\frac{1}{4}\lambda$  and multiples thereof. At  $\frac{1}{4}\lambda$  and at the *odd* multiples thereof, ground also acts like a reflector, causing considerable radiation straight up. This effect is least at the  $\frac{1}{2}\lambda$  points, where the impedance also passes through the free-space value. Preferably, then, the spacing  $S$  should be  $\frac{1}{2}\lambda$ , or multiple thereof, at the frequency of the smaller antenna. The “half the boom length” rule gives about the same answer in this example. For this size 144-MHz antenna, 40 inches is the minimum desirable spacing, but 80 inches would be better.

The effect of spacing on the larger (lower frequency) array is usually negligible. If spacing closer than half the boom length or  $\frac{1}{2}\lambda$  must be used, the principal concern is variation in feed impedance of the higher frequency antenna. If this antenna has an adjustable matching device, closer spacings can be used in a pinch, if the matching is adjusted for best SWR. Very close spacing and interlacing of elements should be avoided unless the builder is prepared to go through an extensive program of adjustments of both matching and element lengths.

## QUADS FOR VHF

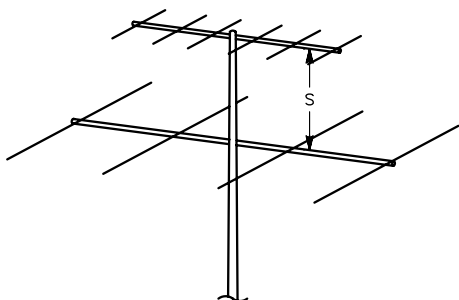
The quad antenna can be built of very inexpensive materials, yet its performance is comparable to other arrays of its size. Adjustment for resonance and impedance matching can be accomplished readily. Quads can be stacked horizontally and vertically to provide high gain, without sharply limiting frequency response. Construction of **quad antennas for VHF** use is covered later in this chapter.

### Stacking Quads

Quads can be mounted side by side or one above the other, or both, in the same general way as other antennas. Sets of driven elements can also be mounted in front of a screen reflector. The recommended spacing between adjacent element sides is  $\frac{1}{2}\lambda$ . Phasing and feed methods are similar to those employed with other antennas described in this chapter.

### Adding Directors

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



**Fig 8**—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  $\frac{1}{2}\lambda$ , or some multiple thereof, at the frequency of the smaller array. If the beams shown are for 50 and 144 MHz,  $S$  should be at least 40 inches, but 80 inches is preferred. Similar conditions apply for stacking antennas for a single band.

are similar to those for conventional Yagis. In an experimental model the reflector was spaced  $0.25 \lambda$  and the director  $0.15 \lambda$ . A square array using four 3-element bays worked extremely well.

## VHF AND UHF QUAGIS

At higher frequencies, especially 420 MHz and above, Yagi arrays using dipole-driven elements are 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. Construction details and examples are given in the projects later in this chapter.

## COLLINEAR ANTENNAS

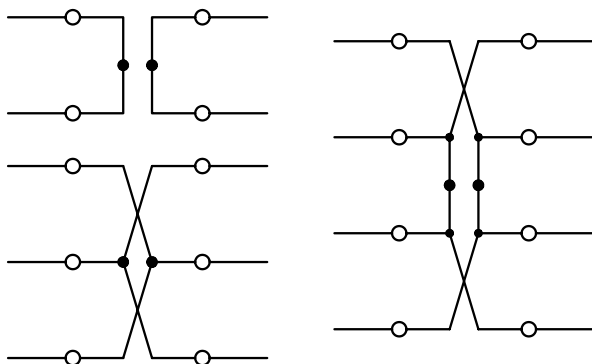
The information given earlier in this chapter pertains mainly to parasitic arrays, but the collinear array is worthy of consideration in VHF/UHF operations. This array tends to be tolerant of construction tolerances, making it easy to build and adjust for VHF applications. The use of many collinear driven elements was once popular in very large phased arrays, such as those required in moonbounce (EME) communication, but the advent of computer-optimized Yagis has changed this in recent years.

### Large Collinear Arrays

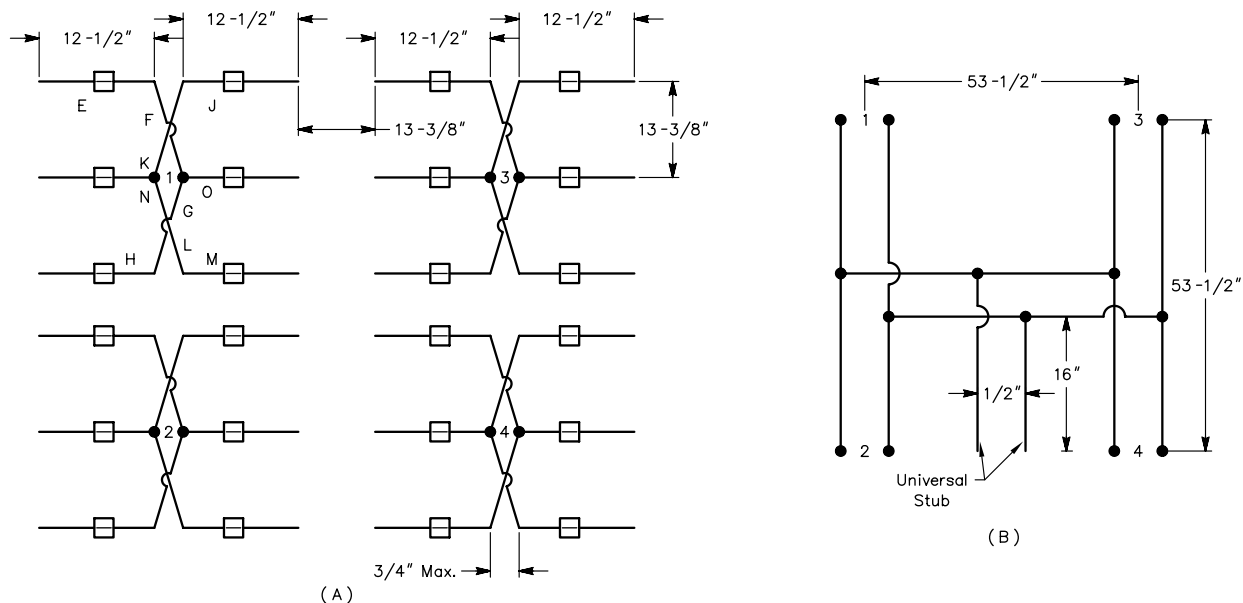
Bidirectional curtain arrays of four, six, and eight half waves in phase are shown in **Fig 9**. Usually reflector elements are added, normally at about  $0.2 \lambda$  behind each driven element, for more gain and a unidirectional pattern. Such parasitic elements are omitted from the sketch in the interest of clarity.

The feed-point impedance of two half waves in phase is high, typically  $1000 \Omega$  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, [Fig 4A](#), be used at the feed point. All elements should be mounted at their electrical centers, as indicated by open circles in Fig 9. 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,”



**Fig 9—Element arrangements for 8, 12 and 16-element collinear arrays. Elements are  $\frac{1}{2} \lambda$  long and spaced  $\frac{1}{2} \lambda$ . Parasitic reflectors, omitted here for clarity, are 5% longer and  $0.2 \lambda$  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.**



**Fig 10—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.**

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 **Fig 10** illustrates this principle.

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

## THE CORNER REFLECTOR

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 reflector can be used at 144 MHz, though usually at much less than optimum size. For a given aperture, the corner reflector does not equal a parabola in gain, but it is simple to construct, broadbanded, and offers gains from about 10 to 15 dB, depending on the angle and size. This section was written by Paul M. Wilson, W4HHK.

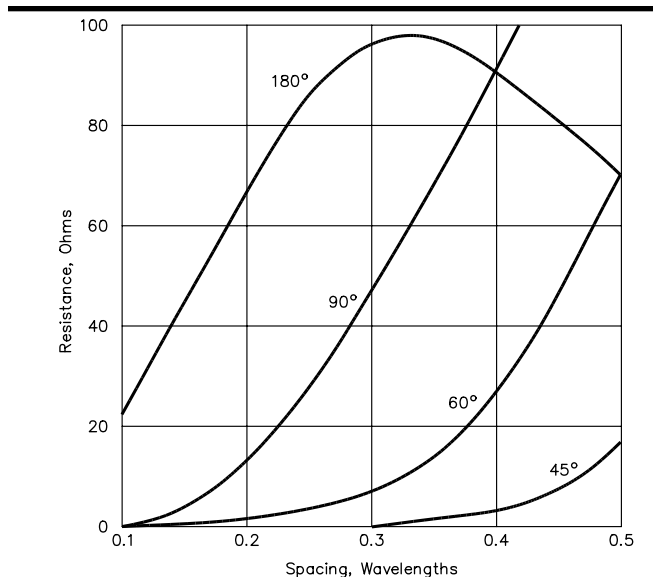
The corner angle can be 90, 60 or 45°, but the side length must be increased as the angle is narrowed. For a 90° corner, the driven element spacing can be anything from  $0.25$  to  $0.7\lambda$ ,  $0.35$  to  $0.75\lambda$  for 60°, and  $0.5$  to  $0.8\lambda$  for 45°. In each case the gain variation 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 **Fig 11**. The maximum gain obtained with minimum spacing is the primary mode (the one generally used at 144, 222 and 432 MHz to maintain

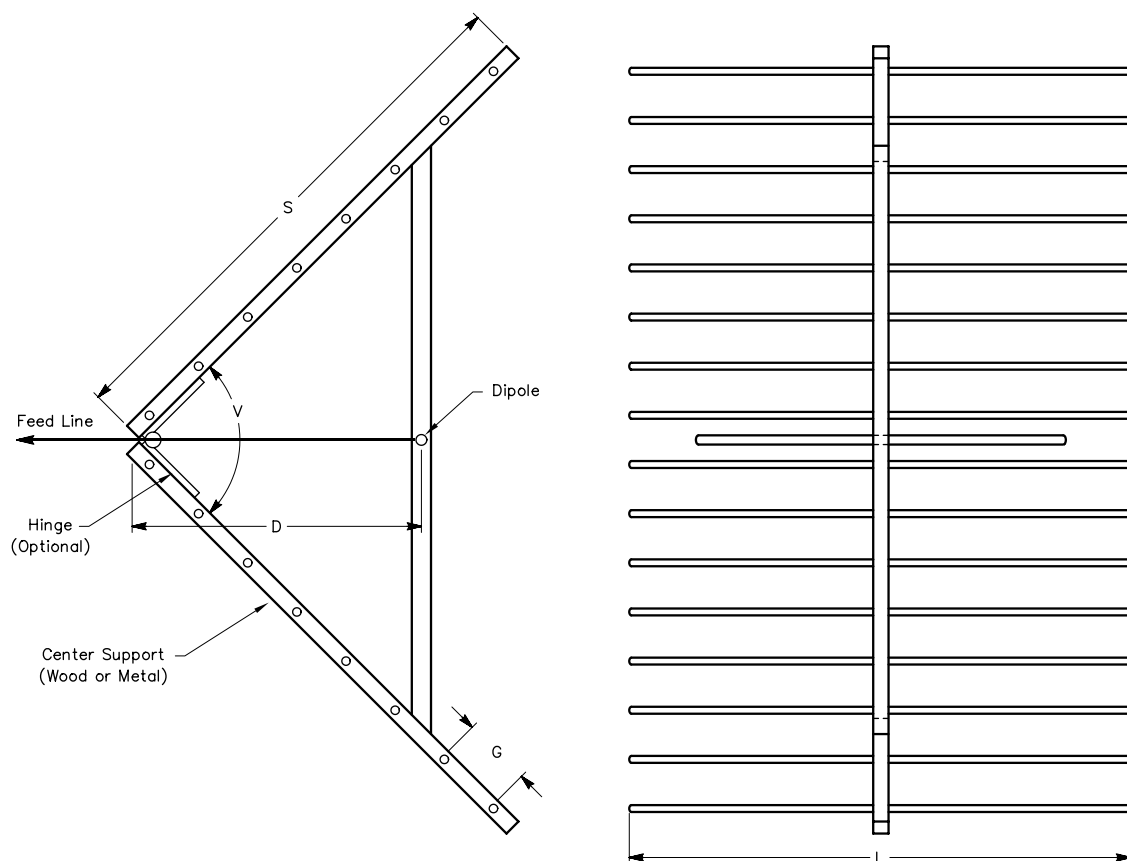
reasonable side lengths). A  $90^\circ$  corner, for example, should have a minimum side length ( $S$ , **Fig 12**) equal to twice the dipole spacing, or  $1\lambda$  long for  $0.5\lambda$  spacing. A side length greater than  $2\lambda$  is ideal. Gain with a  $60^\circ$  or  $90^\circ$  corner reflector with  $1\lambda$  sides is about 10 dB. A  $60^\circ$  corner with  $2\lambda$  sides has about 12 dB gain, and a  $45^\circ$  corner with  $3\lambda$  sides has about 13 dB gain.

Reflector length ( $L$ , **Fig 12**) should be a minimum of  $0.6\lambda$ . Less than that spacing causes radiation to increase to the sides and rear, and decreases gain.

Spacing between reflector rods ( $G$ , **Fig 12**) should not exceed  $0.06\lambda$  for best results. A spacing of  $0.06\lambda$  results 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 construc-



**Fig 11—Radiation resistance of the driven element in a corner reflector array for corner angles of  $180^\circ$  (flat sheet),  $90^\circ$ ,  $60^\circ$  and  $45^\circ$  as a function of spacing  $D$ , as shown in Fig 12.**



**Fig 12—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 2. 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.**

tion. A spacing of  $0.06 \lambda$  at 1296 MHz, for example, requires mounting reflector rods about every  $\frac{1}{2}$ -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 Fig 12. The frame may be made of wood or metal, with a hinge at the corner to facilitate portable work or assembly atop a tower. A hinged corner is also useful in experimenting with different angles. **Table 2** gives the principal dimensions for corner reflector arrays for 144 to 2300 MHz. The arrays for 144, 222 and 420 MHz have side lengths of twice to four times the driven element spacing. The 915-MHz corner reflectors use side lengths of three times the element spacing, 1296-MHz corners use side lengths of four times the spacing, and 2304-MHz corners employ side lengths of six times the spacing. Reflector lengths of 2, 3, and 4 wavelengths are used on the 915, 1296 and 2304-MHz reflectors, respectively. A  $4 \times 6\text{-}\lambda$  reflector closely approximates a sheet of infinite dimensions.

A corner reflector may be used for several bands, or for UHF television reception, as well as amateur UHF work. 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  $\lambda/\text{dia}$  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

**Table 2**  
**Dimensions of Corner Reflector Arrays for VHF and UHF**

<i>Freq, MHz</i>	<i>Side Length S, in.</i>	<i>Dipole to Vertex Distance D, in.</i>	<i>Reflector Length L, in.</i>	<i>Reflector Spacing G, in.</i>	<i>Corner Angle, V°</i>	<i>Radiation Resistance, <math>\Omega</math></i>
144*	65	$27\frac{1}{2}$	48	$7\frac{3}{4}$	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	$8\frac{3}{4}$	$16\frac{1}{4}$	$2\frac{5}{8}$	90	70
420	54	$13\frac{1}{2}$	$16\frac{1}{4}$	Screen	60	70
915	20	$6\frac{1}{2}$	$25\frac{3}{4}$	0.65	90	70
915	51	$16\frac{3}{4}$	$25\frac{3}{4}$	Screen	60	65
915	78	$25\frac{3}{4}$	$25\frac{3}{4}$	Screen	45	70
1296	18	$4\frac{1}{2}$	$27\frac{1}{2}$	$\frac{1}{2}$	90	70
1296	48	$11\frac{3}{4}$	$27\frac{1}{2}$	Screen	60	65
1296	72	$18\frac{1}{4}$	$27\frac{1}{2}$	Screen	45	70
2304	$15\frac{1}{2}$	$2\frac{1}{2}$	$20\frac{1}{2}$	$\frac{1}{4}$	90	70
2304	40	$6\frac{3}{4}$	$20\frac{1}{2}$	Screen	60	65
2304	61	$10\frac{1}{4}$	$20\frac{1}{2}$	Screen	45	70

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

**Notes:**

*915 MHz*

Wavelength is 12.9 in.

Side length S is  $3 \times D$ , dipole to vertex distance

Reflector length L is  $2.0 \lambda$

Reflector spacing G is  $0.05 \lambda$

*1296 MHz*

Wavelength is 9.11 in.

Side length S is  $4 \times D$ , dipole to vertex distance

Reflector length L is  $3.0 \lambda$

Reflector spacing G is  $0.05 \lambda$

*2304 MHz*

Wavelength is 5.12 in.

Side length S is  $6 \times D$ , dipole to vertex distance

Reflector length L is  $4.0 \lambda$

Reflector spacing G is  $0.05 \lambda$

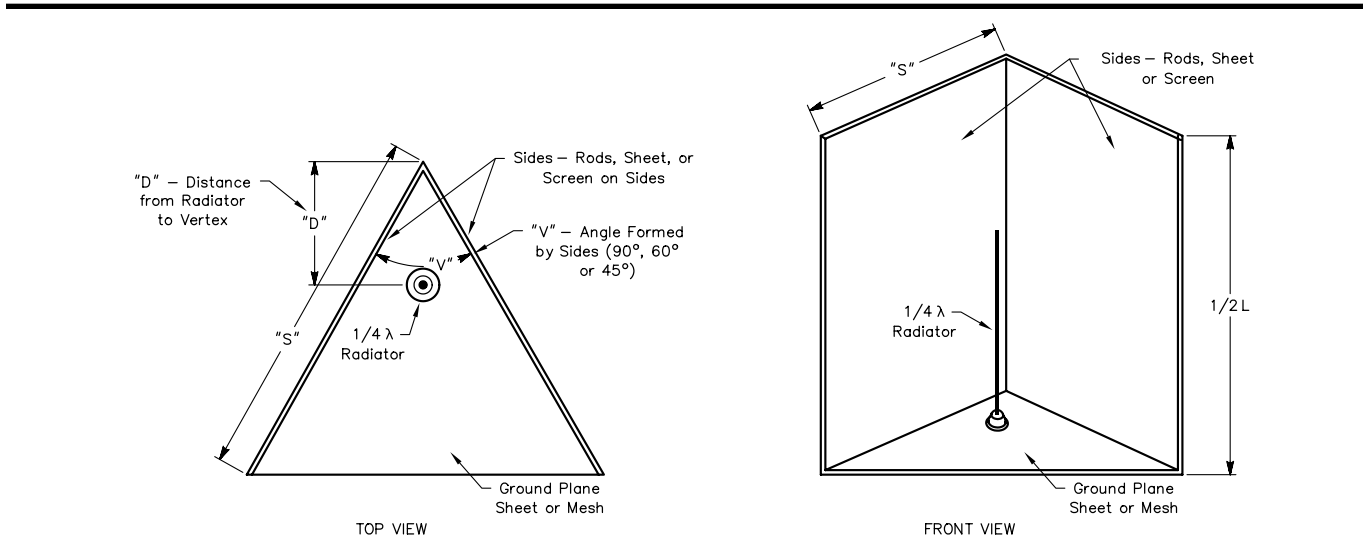


for vertical polarization. A ground-plane corner with monopole driven element is shown in **Fig 13**. The corner reflector and a  $\frac{1}{4}\lambda$  radiator are mounted on the ground plane, permitting direct connection to a coaxial line if the proper spacing is used. The effective aperture is reduced, but at the higher frequencies, second or third-mode radiator spacing and larger reflectors can be employed to obtain more gain and offset the loss in effective aperture. A J antenna could be used to maintain the aperture area and provide a match to a coaxial line.

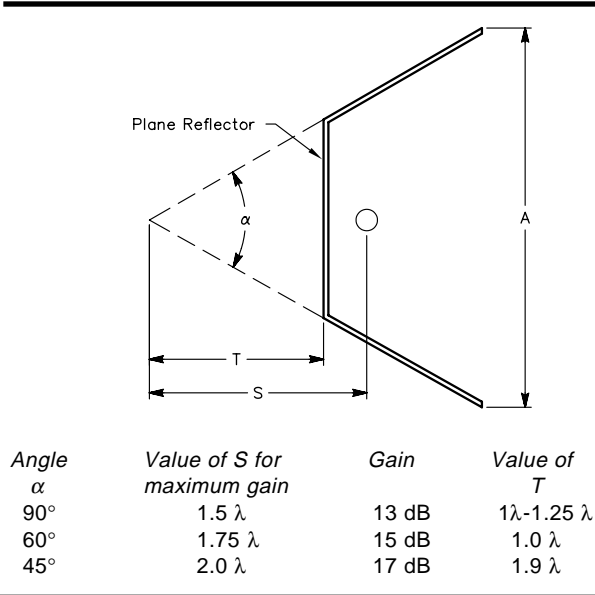
For vertical polarization work, four 90° corner reflectors built back-to-back (with common reflectors) could be used for scanning 360° of horizon with modest gain. Feed-line switching could be used to select the desired sector.

### 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 **Fig 14**. Performance similar to that of the large corner reflector can thereby be had, provided that the dimensions of S and T



**Fig 13—A ground-plane corner reflector antenna for vertical polarization, such as FM communications or packet radio. The dimension  $\frac{1}{2} L$  in the front view refers to data in [Table 2](#).**



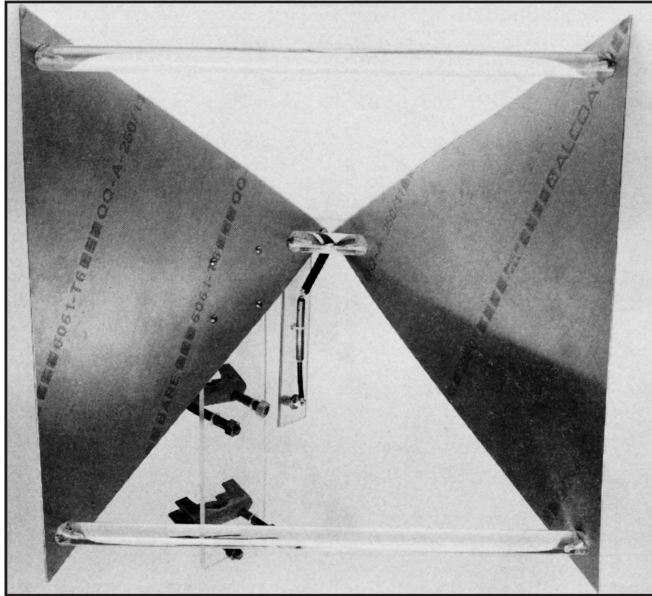
**Fig 14—The trough reflector. This is a useful modification of the corner reflector. The vertex has been cut off and replaced by a simple plane section. The tabulated data shows the gain obtainable for greater values of S than those covered in [Table 2](#), assuming that the reflector is of adequate size.**

as shown in Fig 14 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.

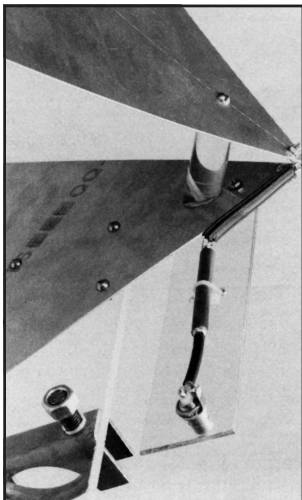
The gain of both corner reflectors and trough reflectors may be increased by stacking two or more and arranging them to radiate in phase, or alternatively by adding further collinear dipoles (fed in phase) within a wider reflector. Not more than two or three radiating units should be used, because the great virtue of the simple feeder arrangement would then be lost.

## HORN ANTENNAS FOR THE MICROWAVE BANDS

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.



**Fig 15—**An experimental two-sided pyramidal horn constructed in the ARRL laboratory. A pair of muffer clamps allows 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.



**Fig 16—**Matching system used to test the horn. Better performance would be realized with open wire line. See text.

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  $\Omega$ . A 60° two-sided pyramidal horn with 18-inch sides is shown in Fig 15. This antenna has a theoretical gain of 15 dBi at 1296 MHz, although the feed system detailed in Fig 16 probably degrades this value somewhat. A  $\frac{1}{4} \lambda$ , 150- $\Omega$  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 was assembled strictly for the purpose of demonstrating the two-sided horn in a 50- $\Omega$  system. In a practical installation the horn would be fed with open wire line and matched to 50  $\Omega$  at the station equipment.

## PARABOLIC 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.

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

$$G = 10 \log k \left( \frac{\pi D}{\lambda} \right)^2 \quad (\text{Eq 1})$$

where

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

k = efficiency factor, usually about 55%

D = dish diameter in feet

$\lambda$  = wavelength in feet

See **Table 3** for parabolic antenna gain for the bands 420 MHz through 10 GHz and diameters of 2 to 30 feet.

A close approximation of beamwidth may be found from

$$\Psi = \frac{70 \lambda}{D} \quad (\text{Eq 2})$$

where

$\Psi$  = beamwidth in degrees at half-power points (3 dB down)

D = dish diameter in feet

$\lambda$  = wavelength in feet

At 420 MHz and higher, the parabolic dish becomes a practical antenna. A simple, single feed point eliminates phasing harnesses and balun requirements. Gain is dependent on good surface accuracy, which is more difficult to achieve with increasing frequency. Surface errors should not exceed  $\frac{1}{8} \lambda$  in amateur work. At 430 MHz  $\frac{1}{8} \lambda$  is 3.4 inches, but at 10 GHz it is 0.1476 inch! Mesh can be used for the reflector surface to reduce weight and wind loading, but hole size should be less than  $\frac{1}{12} \lambda$ . At 430 MHz the use of 2-inch hole diameter poultry netting (chicken wire) is acceptable. Fine mesh aluminum screening works well as high as 10 GHz.

A support form may be fashioned to provide the proper parabolic shape by plotting a curve (**Fig 17**) from  $Y^2 = 4SX$  as shown in the figure.

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

The focal length of a dish may be found from

$$f = \frac{D^2}{16d} \quad (\text{Eq 3})$$

where

f = focal length

D = diameter

d = depth distance from plane at mouth of dish to vertex (see Fig 17)

The units of focal length f are the same as those used to measure the depth and diameter.

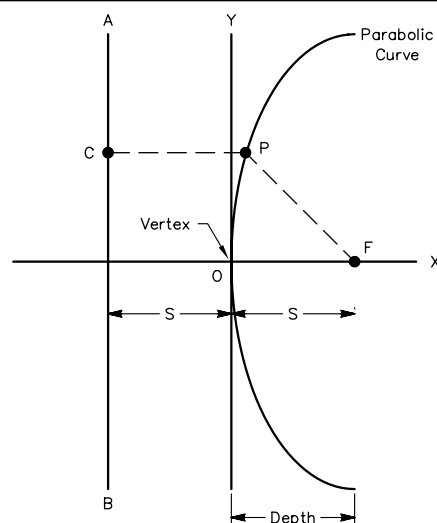
**Table 4** gives the subtended angle at focus for dish f/D ratios from 0.2 to 1.0. A dish, for example,

**Table 3**

**Gain, Parabolic Antennas\***

Frequency	Dish Diameter (Feet)						
	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.



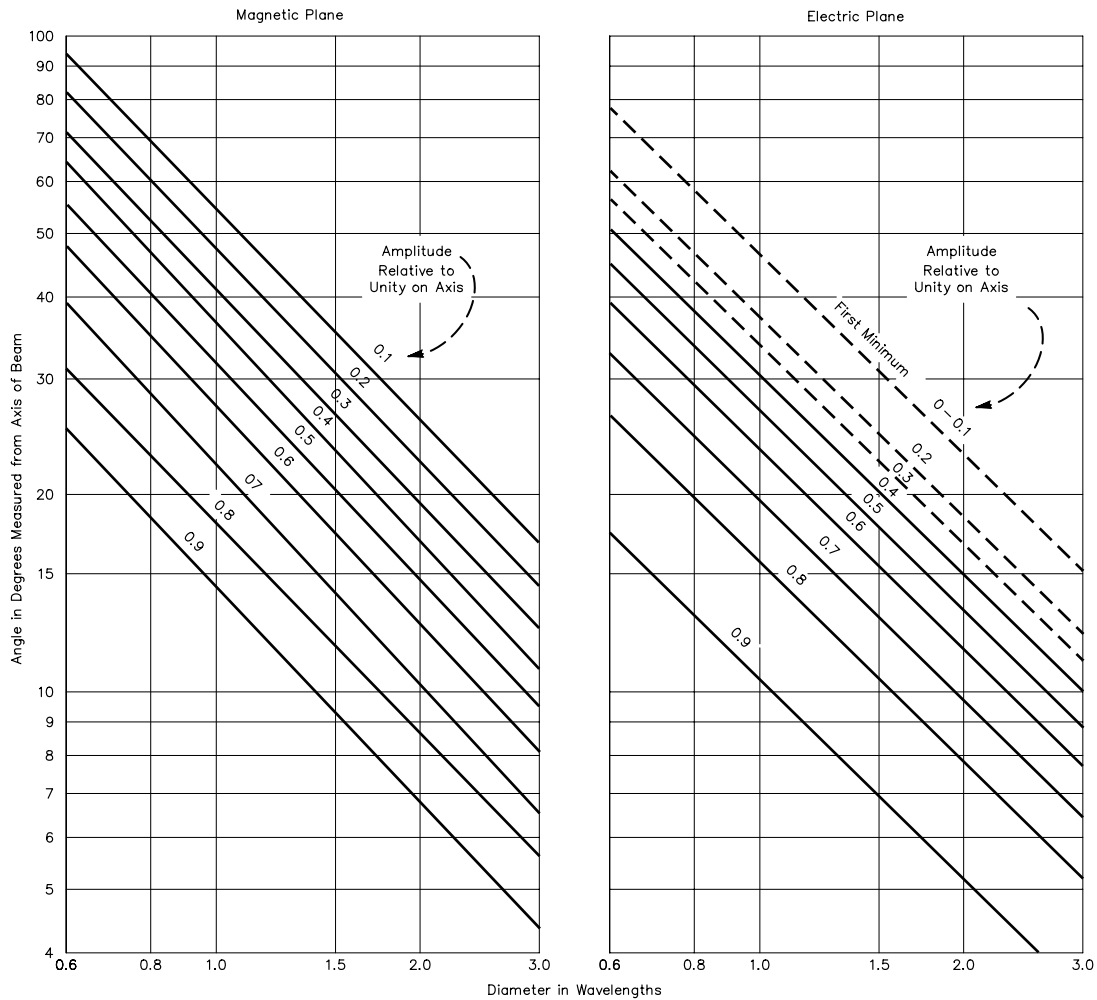
**Fig 17—Details of the parabolic curve,  $Y^2 = 4SX$ . This curve is the locus of points which are equidistant from a fixed point, the focus (F), and a fixed line (AB) which is called the directrix. Hence,  $FP = PC$ . The focus (F) is located at coordinates S,0.**

**Table 4**

**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.

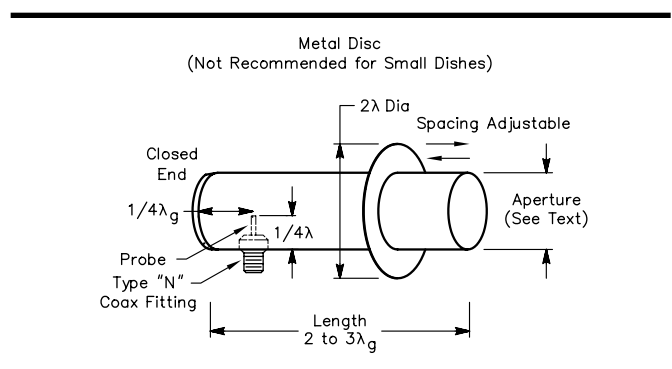


**Fig 18—**This graph can be used in conjunction with **Table 4** for selecting the proper diameter waveguide to illuminate a parabolic reflector.

with a typical  $f/D$  of 0.4 requires a 10-dB beamwidth of  $130^\circ$ . A circular waveguide feed with a diameter of approximately  $0.7 \lambda$  provides nearly optimum illumination, but does not uniformly illuminate the reflector in both the magnetic (TM) and electric (TE) planes. **Fig 18** 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 **Fig 19**. 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  $2 \lambda$  in diameter appears to be as effective as a 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



**Fig 19—**Details of a circular waveguide 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 TE<sub>11</sub> mode. The guide must be large enough to pass the TE<sub>11</sub> mode with no attenuation, but smaller than the diameter that permits the next higher TM<sub>01</sub> mode to propagate. To support the desirable TE<sub>11</sub> mode in circular waveguide, the cutoff frequency, F<sub>C</sub>, is given by

$$F_C\text{ (TE}_{11}\text{)}=\frac{6917.26}{d(\text{inches})}\tag{Eq 4}$$

where

f<sub>C</sub> = cutoff frequency in MHz for TE<sub>11</sub> mode

d = waveguide inner diameter

A circular waveguide will support the TM<sub>01</sub> mode having a cutoff frequency

$$F_C\text{ (TM}_{01}\text{)}=\frac{9034.85}{d(\text{inches})}\tag{Eq 5}$$

The wavelength in a waveguide always exceeds the free-space wavelength and is called guide wavelength, λ<sub>g</sub>. It is related to the cutoff frequency and operating frequency by the equation

$$\lambda_g=\frac{11802.85}{\sqrt{f_0^2-f_C^2}}\tag{Eq 6}$$

where

λ<sub>g</sub> = guide wavelength, inches

f<sub>0</sub> = operating frequency, MHz

f<sub>C</sub> = TE<sub>11</sub> 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 5** 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 1/4 λ long and spaced from the closed end of the guide by 1/4 guide wavelength. The length of the feed should be two to three guide wavelengths. The latter is preferred if a second probe is to be mounted for polarization change or for polaplexer work 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 work should be spaced 3/4 guide wavelength from the closed end and mounted at right angles to the first probe.

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

**Table 5**  
**Circular Waveguide Dish Feeds**

<i>Freq</i> <i>(MHz)</i>	<i>Inside Diameter</i> <i>Circular Waveguide</i> <i>Range (in.)</i>
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



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 W). The US Government has set a limit of 10 mW/cm<sup>2</sup> 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<sup>2</sup> is reached in the near field of a parabolic antenna if the level at  $2D^2/\lambda$  is 0.242 mW/cm<sup>2</sup>. The equation for power density is

$$\text{Power density} = \frac{3\lambda P}{64D^2} = \frac{158.4P}{D^2} \text{ mW/cm}^2 \quad (\text{Eq 7})$$

where

P = average power in kilowatts

D = antenna diameter in feet

$\lambda$  = wavelength in feet

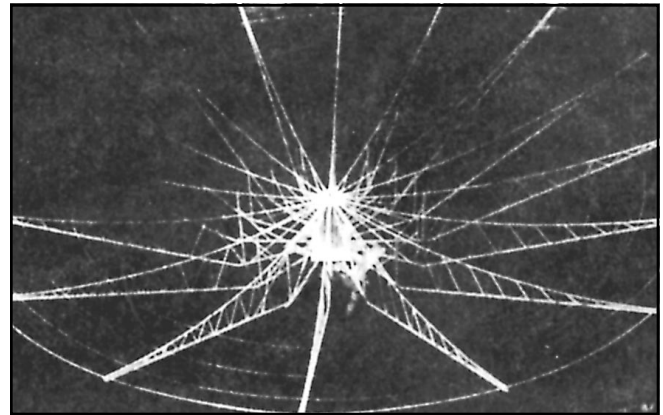
New commercial dishes are expensive, but surplus ones can often be purchased at low cost. Some amateurs build theirs, while others modify UHF TV dishes or circular metal snow sleds for the amateur bands. **Fig 20** shows a dish using the homemade feed just described. Photos showing a highly ambitious dish project under construction by ZL1BJQ appear in **Figs 21** and **22**. Practical details for constructing this type of antenna are given in [Chapter 19](#). Dick Knadle, K2RIW, described modern UHF antenna test procedures in February 1976 *QST* (see Bibliography).

### OMNIDIRECTIONAL ANTENNAS FOR VHF AND UHF

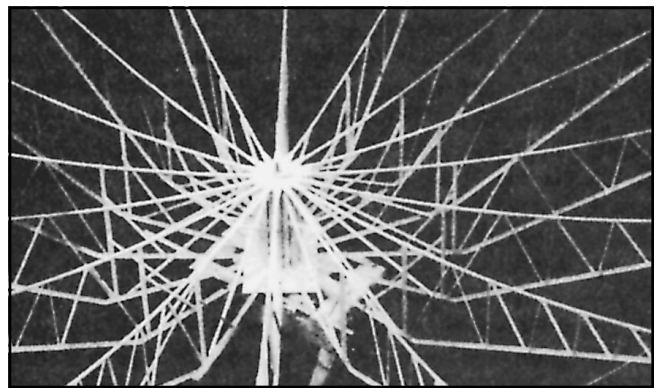
Local work with mobile stations requires an antenna with wide coverage capabilities. Most mobile work is on FM, and the polarization used with this mode is generally vertical. Some simple vertical systems are described below. Additional material on antennas of this type is presented in [Chapter 16](#).



**Fig 20—**Coffee-can 2304-MHz feed described in text and [Fig 19](#) mounted on a 4-foot dish.



**Fig 21—**Aluminum framework for a 23-foot dish under construction by ZL1BJQ.



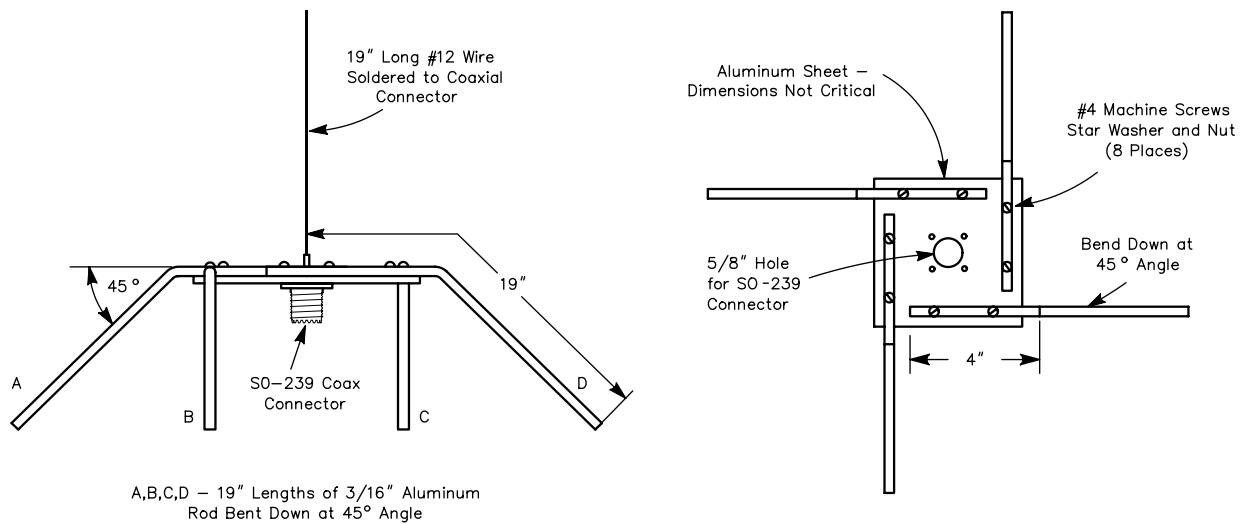
**Fig 22—**Detailed look at the hub assembly for the ZL1BJQ dish. Most of the structural members are made from 3/4-inch T section.



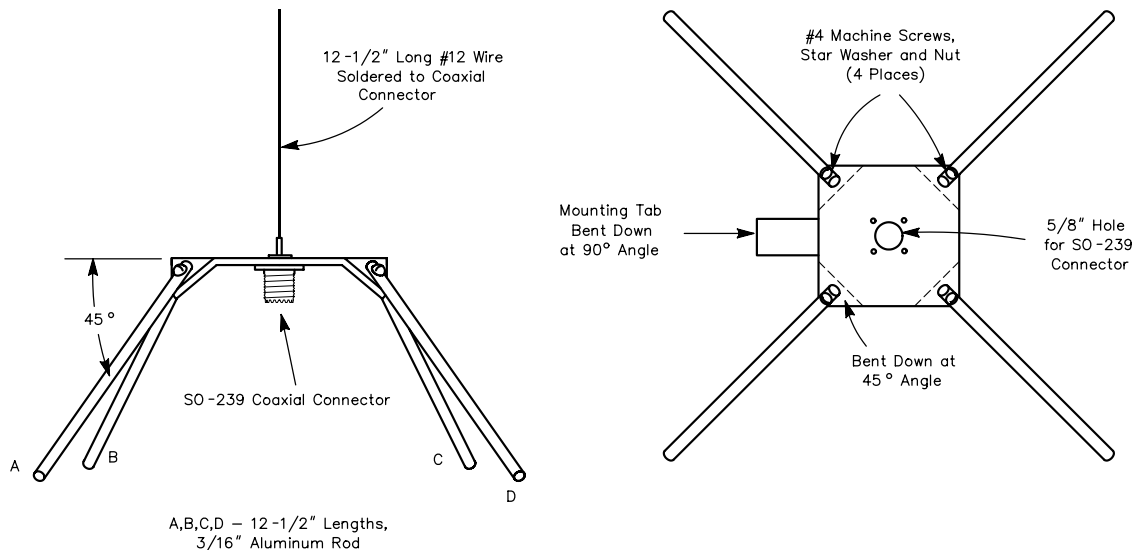
# Ground-plane Antennas for 144, 222 and 440 MHz

For the FM operator living in the primary coverage area of a repeater, the ease of construction and low cost of a  $\frac{1}{4}\lambda$  ground-plane antenna make it an ideal choice. Three different types of construction are detailed in **Figs 23 through 26**; the choice of construction method depends on the materials at hand and the desired style of antenna mounting.

The 144-MHz model shown in Fig 23 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 copper wire soldered directly to the center pin of the SO-239 connector.



**Fig 23—These drawings illustrate the dimensions for the 144-MHz ground-plane antenna.**



**Fig 24—Dimensional information for the 222-MHz ground-plane antenna. Lengths for A, B, C and D are the total distances measured from the center of the SO-239 connector. The corners of the aluminum plate are bent down at a 45° angle rather than bending the aluminum rod as in the 144-MHz model. Either method is suitable for these antennas.**

The 222-MHz version, Fig 24, uses a slightly different technique for mounting and sloping the radials. In this case the corners of the aluminum plate are bent down at a 45° angle with respect to the remainder of the plate. The four radials are held to the plate with machine screws, lock washers and nuts. A mounting tab is included in the design of this antenna as part of the aluminum base. A compression type of hose clamp could be used to secure the antenna to a mast. As with the 144-MHz version, the vertical portion of the antenna is soldered directly to the SO-239 connector.

A very simple method of construction, shown in Figs 25 and 26, 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 3/4-inch ID plastic or aluminum tubing. A compression hose clamp can be used to secure the PL-259 connector, attached to the feed line, in the end of the mast. Dimensions for the 144, 222 and 440-MHz bands are given in Fig 25.

If these antennas are to be mounted outside it is wise to apply a small amount of RTV sealant or similar material around the areas of the center pin of the connector to prevent the entry of water into the connector and coax line.

## Practical 6-Meter Yagis

Boom length often proves to be the deciding factor when one selects a Yagi design. Table 6 shows three 6-meter Yagis designed for convenient boom lengths (6, 12 and 22 feet). The 3-element, 6-foot boom design has 8 dBi gain in free space; the 12-foot boom, 5-element version has 10 dBi gain, and the 22-foot, 7-element Yagi has a gain of 11.4 dBi. All antennas exhibit better than 22 dB front-to-rear ratio and cover 50 to 51 MHz with better than 1.6:1 SWR.

Element half lengths and spacings are given in the table. Elements can be mounted to the boom as shown in Fig 27. Two muffler clamps hold each aluminum plate to the boom, and two U bolts fasten each

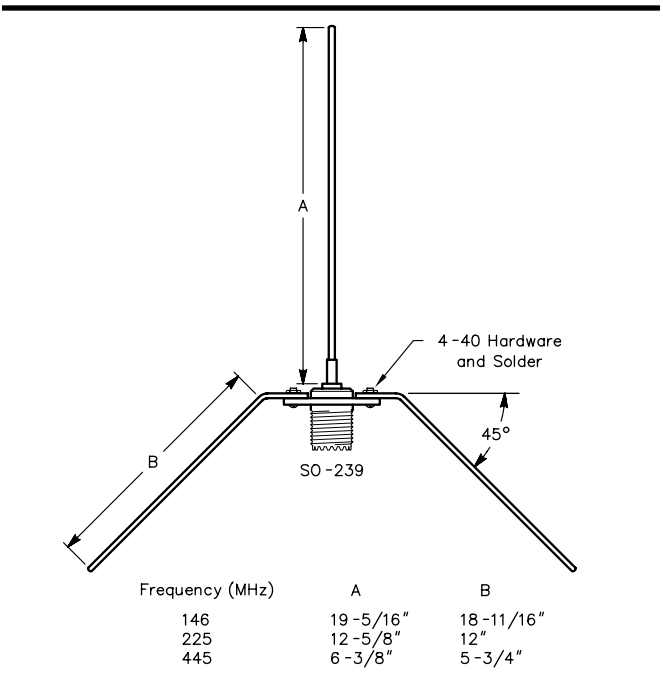


Fig 25—Simple ground-plane antenna for the 144, 222 and 440-MHz bands. The vertical element and radials are 3/32 or 1/16-inch brass welding rod. Although 3/32-inch rod is preferred for the 144-MHz antenna, #10 or #12 copper wire can also be used.

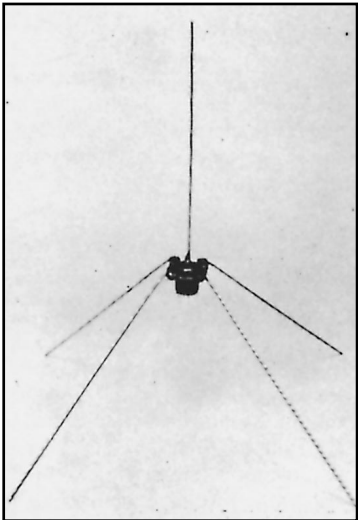


Fig 26—A 440-MHz ground-plane constructed using only an SO-239 connector, #4-40 hardware and 1/16-inch brass welding rod.

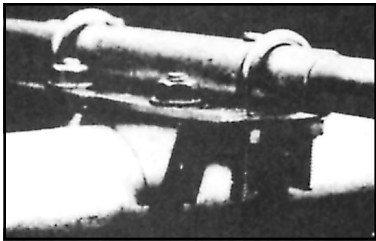


Fig 27—The element to boom clamp. U bolts are used to hold the element to the plate, and 2-inch galvanized muffler clamps hold the plates to the boom.

element to the plate, which is 0.25 inches thick and 4 × 4 inches square. Stainless steel is the best choice for hardware; however, galvanized hardware can be substituted. Automotive muffler clamps do not work well in this application, because they are not galvanized and quickly rust once exposed to the weather.

The driven element is mounted to the boom on a Bakelite 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.

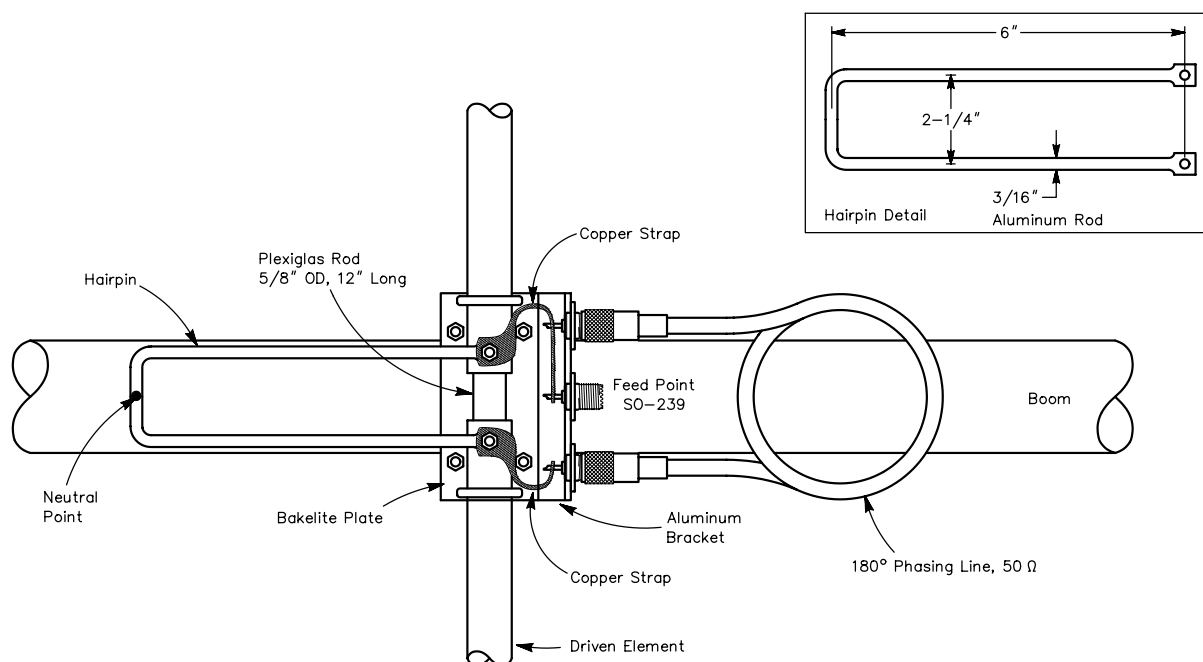
Refer to **Fig 28** for driven element and hairpin match details. A bracket made from a piece of aluminum is used to mount the three SO-239 connectors to the driven element plate. A 4:1 transmission-line balun connects the two element halves, transforming the 200- $\Omega$  resistance at the hairpin match to 50  $\Omega$  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

**Table 6**

**Optimized 6-Meter Yagi Designs**

	<i>Spacing Between Elements inches</i>	<i>Seg 1 OD* Length inches</i>	<i>Seg 2 OD* Length inches</i>	<i>Midband Gain F/R</i>
<b>306-06</b>				
OD		0.750	0.625	
Refl.	0	36	22.500	8.1 dBi
D.E.	24	36	16.000	28.3 dB
Dir. 1	42	36	15.500	
<b>506-12</b>				
OD		0.750	0.625	
Refl.	0	36	23.625	10.0 dBi
D.E.	24	36	17.125	26.8 dB
Dir. 1	12	36	19.375	
Dir. 2	44	36	18.250	
Dir. 3	58	36	15.375	
<b>706-22</b>				
OD		0.750	0.625	
Refl.	0	36	24.750	11.4 dBi
D.E.	27	36	15.625	24.3 dB
Dir. 1	16	36	17.250	
Dir. 2	51	36	15.250	
Dir. 3	54	36	15.500	
Dir. 4	53	36	15.750	
Dir. 5	58	36	12.750	

\* See pages 20-6 to 20-10 for telescoping aluminum tubing details.



**Fig 28**—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 feet, 10<sup>3</sup>/<sub>8</sub> inches

For cable with 0.66 velocity factor—6 feet, 5<sup>3</sup>/<sub>4</sub> inches

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.

## High-Performance Yagis for 144, 222 and 432 MHz

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

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

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

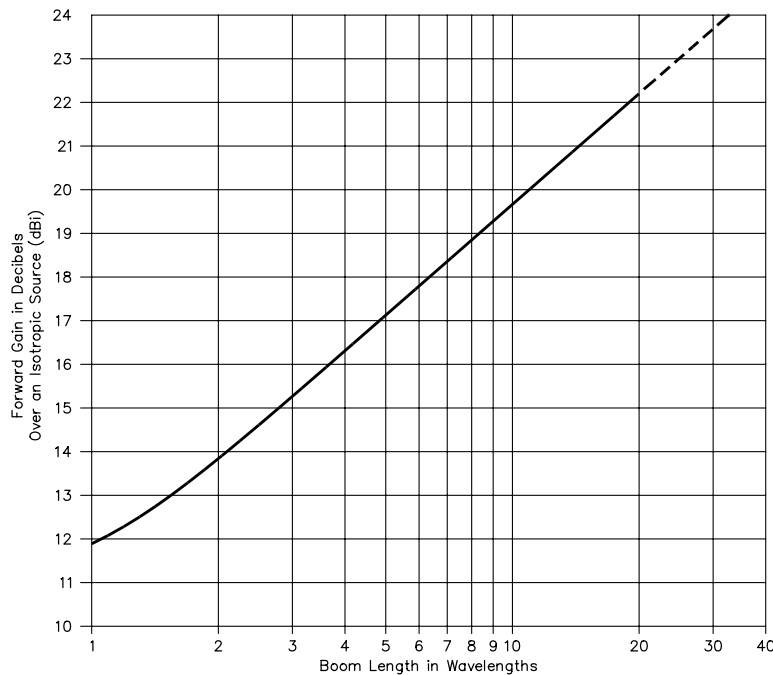
This design approach starts with closely spaced directors. The director spacings gradually increase until a constant spacing of about  $0.4\lambda$  is reached. Conversely, the director lengths start out longest with the first director and decrease in length in a decreasing rate of change until they 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  $10\lambda$ . The log-taper design also reduces the rate of change in driven-element impedance vs frequency. This allows the use of simple dipole driven elements while still obtaining acceptable driven-element SWR over a wide frequency range. Another benefit is that the resonant frequency of the Yagi changes very little as the boom length is increased. The driven-element impedance also changes moderately with boom length. The tapered approach creates a Yagi with a very clean radiation pattern. Typically, first side lobe levels of  $-17$  dB in the E plane,  $-15$  dB in the H plane, and all other lobes at  $-20$  dB or more are possible on designs from  $2\lambda$  to more than  $14\lambda$ .

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

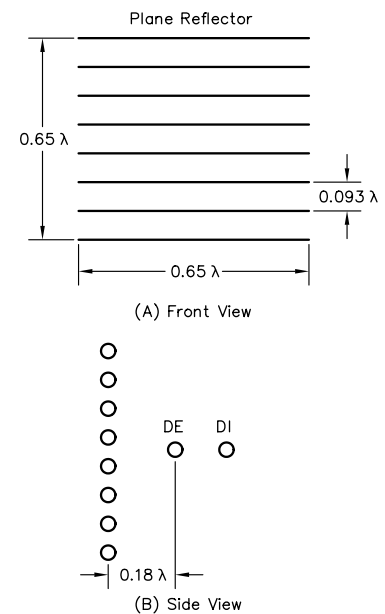
The gain of long Yagis has been the subject of much debate. Recent measurements and computer analysis by both amateurs and professionals indicates that given an optimum design, doubling a Yagi's boom length will result in a maximum theoretical gain increase of about 2.6 dB. In practice, the real gain increase may be less because of escalating resistive losses and the greater possibility of construction error. **Fig 29** shows the maximum possible gain per boom length expressed in decibels, referenced to an isotropic radiator. The actual number of directors does not play an important part in determining the gain vs boom length as long as a reasonable number of directors are used. The use of more directors per boom length will normally give a wider gain bandwidth, however, a point exists where too many directors will adversely affect all performance aspects.

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

Once a long-Yagi director string is properly tuned, the reflector becomes relatively noncritical.



**Fig 29—This chart shows maximum gain per boom length for optimally designed long Yagi antennas.**



**Fig 30—Front and side views of a plane-reflector antenna.**

Reflector spacings between  $0.15 \lambda$  and  $0.2 \lambda$  are preferred. The spacing can be chosen for best pattern and driven element impedance. Multiple-reflector arrangements will not significantly increase the forward gain of a Yagi which has its directors properly optimized for forward gain. Many multiple-reflector schemes such as tri-reflectors and corner reflectors have the disadvantage of lowering the driven element impedance compared to a single optimum-length reflector. The plane or grid reflector, shown in **Fig 30**, may however reduce the intensity of unwanted rear lobes. This can be used to reduce noise pickup on EME or satellite arrays. This type of reflector will usually increase the driven-element impedance compared to a single reflector. This sometimes makes driven-element matching easier. Keep in mind that even for EME, a plane reflector will add considerable wind load and weight for only a few tenths of a decibel of receive signal-to-noise improvement.

### Yagi Construction

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

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

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

Elements may be mounted insulated or uninsulated, above or through the boom. Mounting uninsulated elements through a metal boom is the least desirable method unless the elements are welded in place. The Yagi elements will oscillate, even in moderate winds. Over several years this element oscillation will work open the boom holes. This will allow the elements to move in the boom. This will

create noise (in your receiver) when the wind blows, as the element contact changes. Eventually the element-to-boom junction will corrode (aluminum oxide is a good insulator). This loss of electrical contact between the boom and element will reduce the boom's effect and change the resonant frequency of the Yagi.

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

If a conductive boom is used, element lengths must be corrected for the mounting method used. The amount of correction is dependent on the boom diameter in wavelengths. See **Fig 31**. Elements mounted through the boom and not insulated require the greatest correction. Mounting on top of the boom or through the boom on insulated shoulder washers requires about half of the through-the-boom correction. Insulated elements mounted at least one element diameter above the boom require no correction over the free-space length.

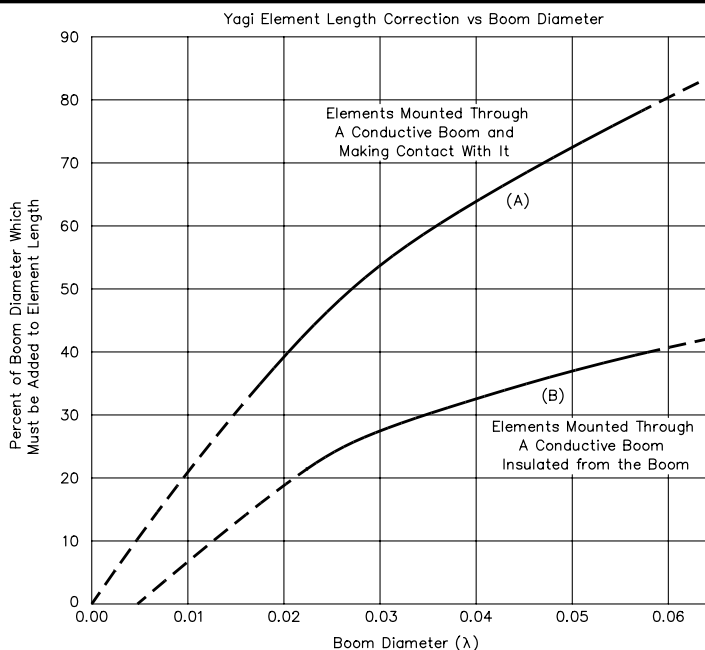
The three following antennas have been optimized for typical boom lengths on each band.

### A HIGH-PERFORMANCE 432-MHz YAGI

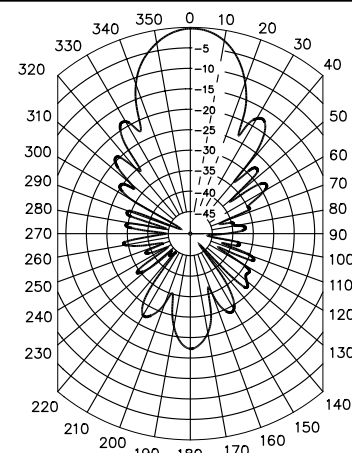
This 22-element,  $6.1\lambda$ , 432-MHz Yagi was originally designed for use in a 12-Yagi EME array built by K1FO. A lengthy evaluation and development process preceded its construction. Many designs were considered and then analyzed on the computer. Next, test models were constructed and evaluated on a homemade antenna range. The resulting design is based on W1EJ's computer-optimized spacings.

The attention paid to the design process has been worth the effort. The 22-element Yagi not only has exceptional forward gain (17.9 dBi), but has an unusually "clean" radiation pattern. The measured E-plane pattern is shown in **Fig 32**. Note that a 1-dB-per-division axis is used to show pattern detail. A complete description of the design process and construction methods appears in December 1987 and January 1988 *QST*.

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



**Fig 31—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.



**Fig 32—Measured E-plane pattern for the 22-element Yagi.** Note: This antenna pattern is drawn on a linear dB grid, rather than on the standard ARRL log-periodic grid, to emphasize low sidelobes.



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

**Table 7** lists the gain and stacking specifications for the various length Yagis. The basic Yagi dimensions are shown in **Table 8**. These are free-space element lengths for  $3/16$ -inch-diameter elements. Boom corrections for the element mounting method must be added in. The element-length correction column gives the length that must be added to keep the Yagi's center frequency optimized for use at 432 MHz. This correction is required to use the same spacing pattern over a wide range of boom lengths. Although any length Yagi will work well, this design is at its best when made with 18 elements or more ( $4.6 \lambda$ ). Element material of less than  $3/16$ -inch diameter is not recommended because resistive losses will reduce the gain by about 0.1 dB, and wet-weather performance will be worse.

**Table 7**  
**Specifications for 432-MHz Family**

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

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

**Table 8**  
**Free-Space Dimensions for 432-MHz Yagi Family**

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

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

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

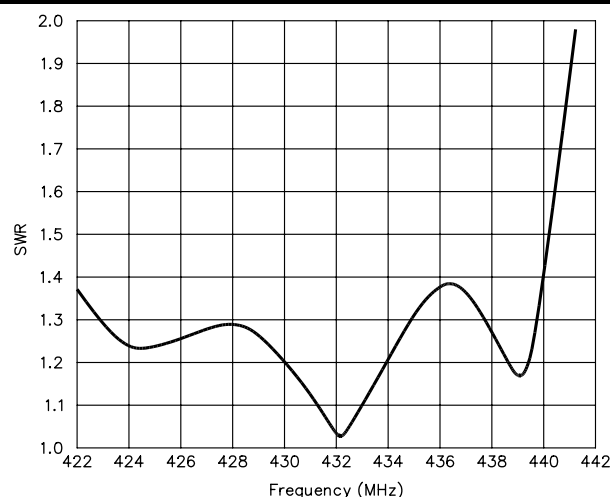
Quarter-inch-diameter elements could be used if all elements are shortened by 3 mm. The element lengths are intended for use with a slight chamfer (0.5 mm) cut into the element ends. The gain peak of the array is centered at 437 MHz. This allows acceptable wet-weather performance, while reducing the gain at 432 MHz by only 0.05 dB. The gain bandwidth of the 22-element Yagi is 31 MHz (at the  $-1$  dB points). The SWR of the Yagi is less than 1.4:1 between 420 and 440 MHz. **Fig 33** is a network analyzer plot of the driven-element SWR vs frequency. These numbers indicate just how wide the frequency response of a log-taper Yagi can be, even with a simple dipole driven element. In fact, at one antenna gain contest, some ATV operators conducted gain vs frequency measurements from 420 to 440 MHz. The 22-element Yagi beat all entrants including those with so-called broadband feeds.

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

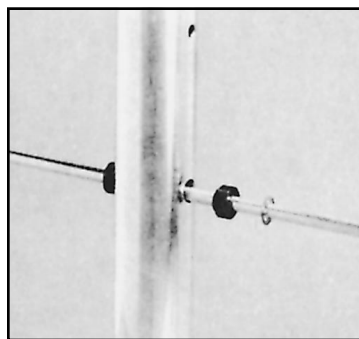
Although this Yagi design is relatively broadband, it is suggested that close attention be paid to copying the design exactly as built. Metric dimensions are used because they are convenient for a Yagi sized for 432 MHz. Element holes should be drilled within  $\pm 2$  mm. Element lengths should be kept within  $\pm 0.5$  mm. Elements can be accurately constructed if they are first rough cut with a hacksaw and then held in a vise and filed to the exact length.

The larger the array, the more attention you should pay to making all Yagis identical. Elements are mounted on shoulder insulators and run through the boom (see **Fig 34**). The element retainers are stainless steel push nuts. These are made by several companies, including Industrial Retaining Ring Co in Irvington, New Jersey, and AuVeco in Ft Mitchell, Kentucky. Local industrial hardware distributors can usually order them for you. The element insulators are not critical. Teflon or black polyethylene are probably the best materials. The Yagi in the photographs is made with black Delryn insulators, available from Rutland Arrays in New Cumberland, Pennsylvania.

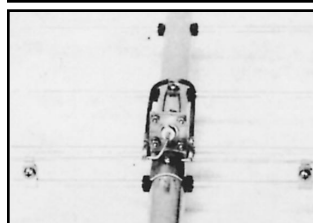
The driven element uses a UG-58A/U connector mounted on a small bracket. The UG-58A/U should be the type with the press-in center pin. UG-58s with center pins held in by "C" clips will usually leak water. Some connectors use steel retaining clips, which will rust and leave a conductive stripe across the insulator. The T-match wires are supported by the UT-141 balun. RG-303/U or RG-142/U Teflon-insulated cable could be used if UT-141 cannot be obtained. **Fig 35A** and **Fig 35B** show details of the driven-



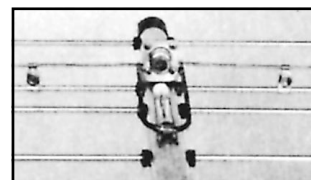
**Fig 33—SWR performance of the 22-element Yagi in dry weather.**



**Fig 34—Element-mounting detail. Elements are mounted through the boom using plastic insulators. Stainless steel push-nut retaining rings hold the element in place.**



(A)



(B)

**Fig 35—Several views of the driven element and T match.**

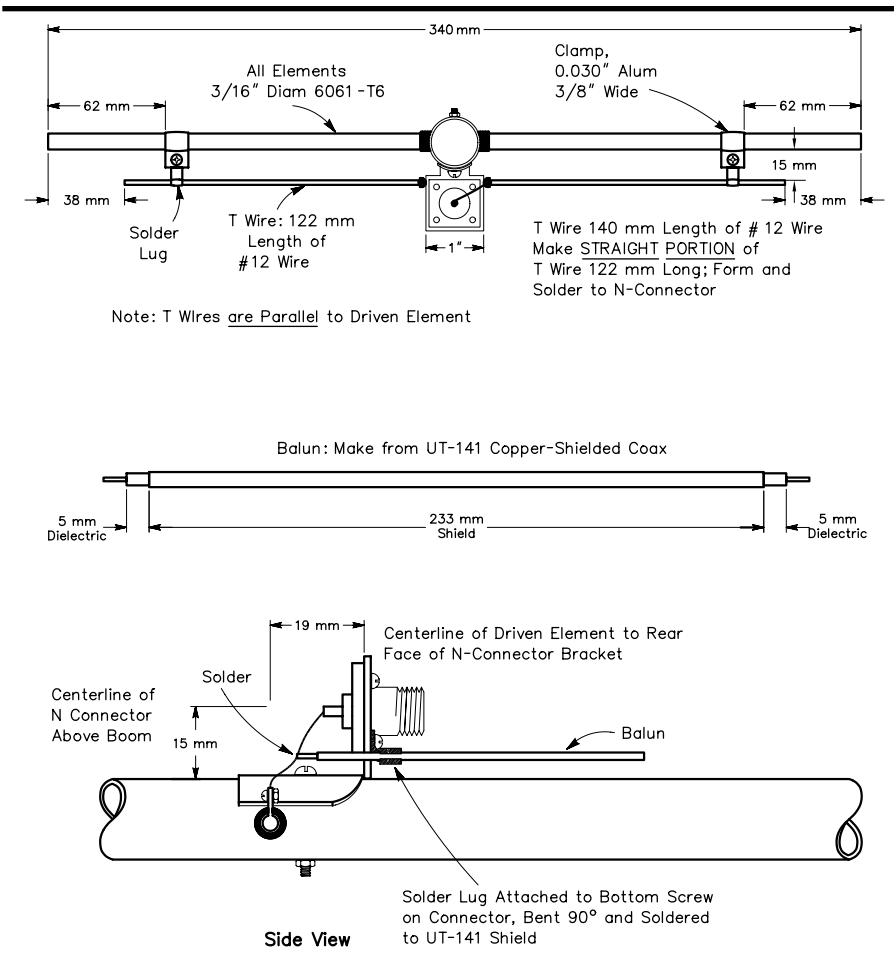
element construction. Driven element dimensions are given in **Fig 36**.

Dimensions for the 22-element Yagi are listed in **Table 9**. **Fig 37** details the Yagi's boom layout. Element material can be either <sup>3</sup>/<sub>16</sub>-inch 6061-T6 aluminum rod or hard aluminum welding rod.

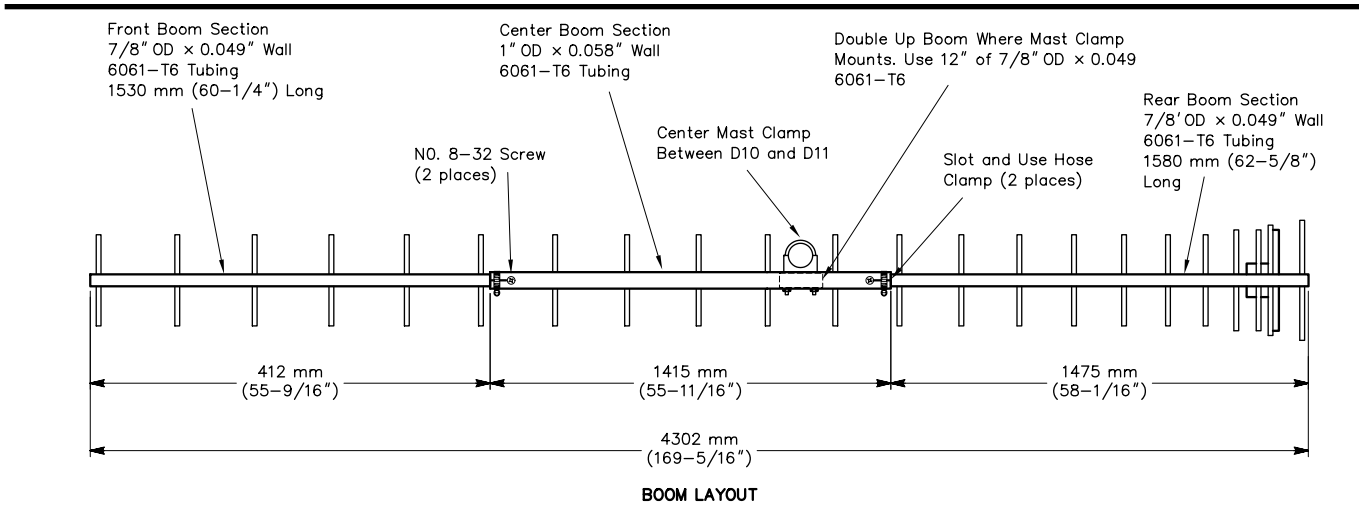
A 24-foot-long, 10.6-λ, 33-element Yagi was also built. The construction methods used were the same as the 22-element Yagi. Telescoping round boom sections of 1, 1<sup>1</sup>/<sub>8</sub>, and 1<sup>1</sup>/<sub>4</sub> inches in diameter were

**Table 9**  
**Dimensions for the 22-Element 432-MHz Yagi**

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



**Fig 36—Details of the driven element and T match for the 22-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna. See text.**



**Fig 37—Boom-construction information for the 22-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna. See text.**

used. A boom support is required to keep boom sag acceptable. At 432 MHz, if boom sag is much more than two or three inches, H-plane pattern distortion will occur. Greater amounts of boom sag will reduce the gain of a Yagi. **Table 10** lists the proper dimensions for the antenna when built with the previously given boom diameters. The boom layout is shown in **Fig 38**, and the driven element is described in **Fig 39**. The 33-element Yagi exhibits the same clean pattern traits as the 22-element Yagi (see **Fig 40**). Measured gain of the 33-element Yagi is 19.9 dBi at 432 MHz. A measured gain sweep of the 33-element Yagi gave a -1 dB gain bandwidth of 14 MHz with the -1 dB points at 424.5 MHz and 438.5 MHz.

A HIGH-PERFORMANCE 144-MHz YAGI

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

Mathematical models do not always directly translate into real working examples. Although the computer design provided a good starting point, the author, Steve Powlishen, K1FO, built several test models before the final working Yagi was obtained. This hands-on tuning in-

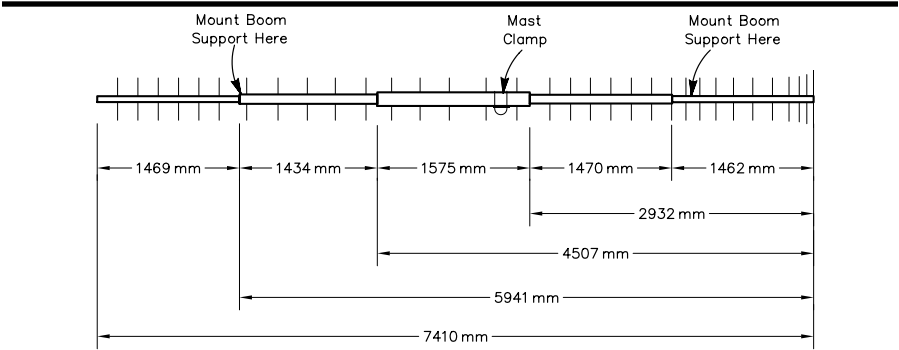


Fig 38—Boom-construction information for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

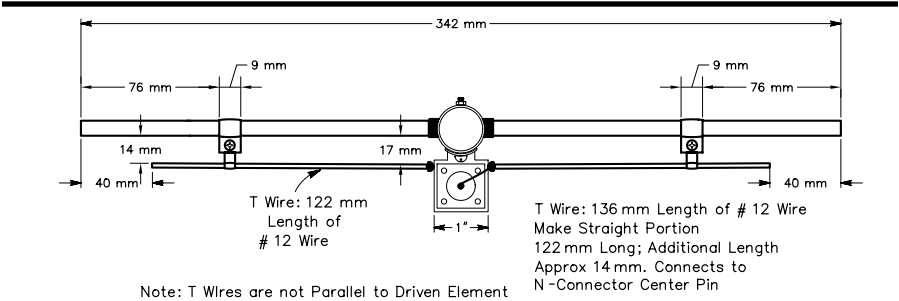


Fig 39—Details of the driven element and T match for the 33-element Yagi. Lengths are given in millimeters to allow precise duplication of the antenna.

Table 10  
Dimensions for the  
33-Element 432-MHz Yagi

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

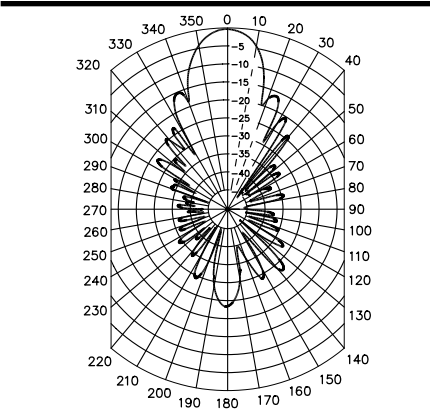


Fig 40—E-plane pattern for the 33-element Yagi. This pattern is drawn on a linear dB grid scale, rather than the standard ARRL log-periodic grid, to emphasize low sidelobes.

cluded changing the element-taper rate in order to obtain the flexibility that allows the Yagi to be built with different boom lengths.

The design is suitable for use from  $1.8 \lambda$  (10 elements) to  $5.1 \lambda$  (19 elements). When elements are added to a Yagi, the center frequency, feed impedance and front-to-back ratio will range up and down. A modern tapered design will minimize this effect and allow the builder to select any desired boom length. This Yagi's design capabilities per boom length are listed in **Table 11**.

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

**Table 12** gives free-space element lengths for  $1/4$ -inch-diameter elements. The use of metric notation allows for much easier dimensional changes during the design stage. Once you become familiar with the metric system, you'll probably find that construction is easier without the burden of cumbersome English fractional units. For  $3/16$ -inch-diameter elements, lengthen all parasitic elements by 3 mm. If  $3/8$ -inch-diameter elements are used, shorten all of the directors and the reflector by 6 mm. The driven element will have to be adjusted for the individual Yagi if the 12-element design is not adhered to.

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

Longer versions could be made by telescoping smaller-size boom sections into the last section. Some sort of boom support will be required on versions longer than 22 feet. The elements are mounted on shoulder insulators and mounted through the boom. However, elements may be mounted, insulated or uninsulated, above or through the boom, as long as appropriate element length corrections are made. Proper tuning can be verified by checking the depth of the nulls between the main lobe and first side lobes. The nulls should be 5 to 10 dB below the first side-lobe level at the primary operating frequency. The boom layout

**Table 11**  
**Specifications for the 144-MHz Family**

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

**Table 12**  
**Free-Space Dimensions for  
the 144-MHz Yagi Family**

Element diameter is  $1/4$  inch.

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

for the 12-element model is shown in **Fig 41**. The actual corrected element dimensions for the 12-element 2.5- $\lambda$  Yagi are shown in **Table 13**.

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

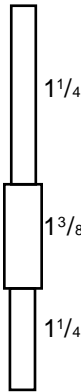
The driven-element size ( $\frac{1}{2}$ -inch diameter) was chosen to allow easy impedance matching. Any reasonably sized driven element could be used, as long as appropriate length and T-match adjustments are made. Different driven-element dimensions are required if you change the boom length. The calculated natural driven-element impedance is given as a guideline. A balanced T-match was chosen because it's easy to adjust for best SWR and provides a balanced radiation pattern. A 4:1 half-wave coaxial balun is used, although impedance-transforming quarter-wave sleeve baluns could also be used. The calculated natural impedance will be useful in determining what impedance transformation will be required at the 200- $\Omega$  balanced feed point. *The ARRL Antenna Book* contains information on **calculating folded-dipole and T-match** driven-element parameters. A balanced feed is important for best operation on this antenna. Gamma matches can severely distort the pattern balance. Other useful driven-element arrangements are the Delta match and the folded dipole, if you're willing to sacrifice some flexibility. **Fig 42** details the driven-element dimensions.

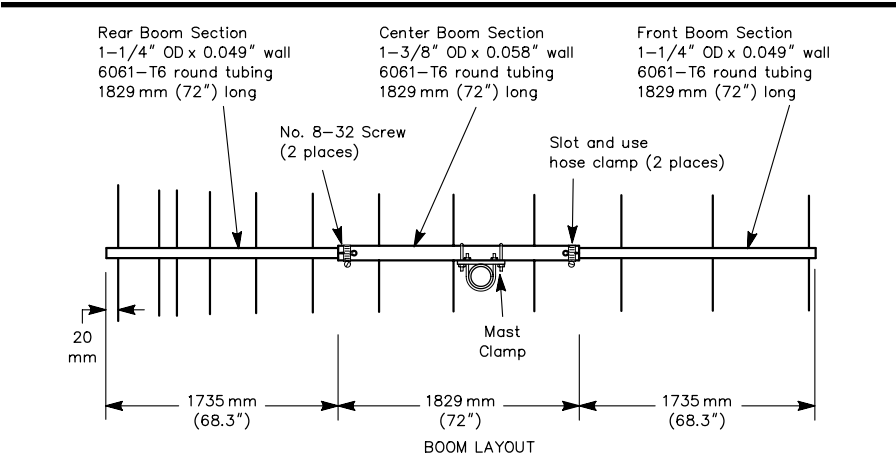
A noninsulated driven element was chosen for mounting convenience. An insulated driven element may also be used. A grounded driven element may be less affected by static build-up. On the other hand, an insulated driven element allows the operator to easily check his feed lines for water or other contamination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

**Fig 43** shows computer-predicted E and H-plane radiation patterns for the 12-element Yagi. The patterns are plotted on a 1-dB-per-division linear scale instead of the usual ARRL polar-plot graph. This expanded scale plot is used to show greater pattern detail. The pattern for the 12-element Yagi is so clean that a plot done in the standard ARRL format would be almost featureless, except for the main lobe and first sidelobes.

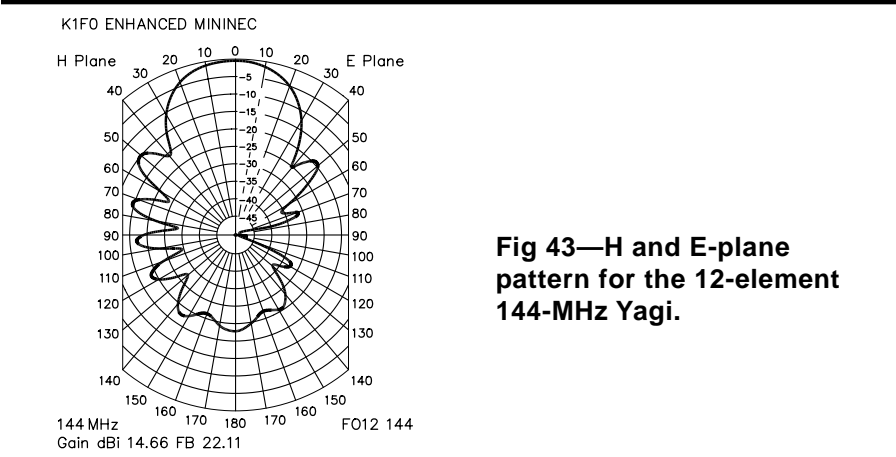
**Table 13**  
**Dimensions for the 12-Element 2.5- $\lambda$  Yagi**

Element Number	Element Position (mm from rear of boom)	Element Length (mm)	Boom Diam (in)
----------------	---	---------------------	----------------

REF	0	1044	
DE	312	955	
D1	447	962	
D2	699	938	
D3	1050	922	
D4	1482	912	
D5	1986	904	
D6	2553	898	
D7	3168	894	
D8	3831	889	
D9	4527	885	
D10	5259	882	



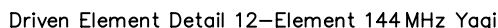
**Fig 41—Boom layout for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication.**



**Fig 43—H and E-plane pattern for the 12-element 144-MHz Yagi.**



**Fig 42—Driven-element detail for the 12-element 144-MHz Yagi. Lengths are given in millimeters to allow precise duplication.**



**(A) Driven Element Side View**

Front of Yagi

22 m

Balun

Balun Shield is Grounded

Balun Center Conductors Attach to T Bars

3/4" Long  $\times$  3/8" Dia Delryn Insulator

Material 0.062" Aluminum Connector Bracket

**(B) Hole Pattern for UG-58A/U**

No. 19 Hole (2 places)

32mm

21mm

42mm

64mm

22mm

7mm

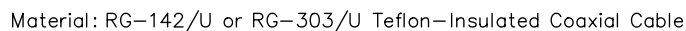
44mm

50mm

64mm

7mm

No. 21 Hole for T Bar Insulators (2 places)



(C)

## A HIGH-PERFORMANCE 222-MHz YAGI

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

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

### Construction

Large-diameter ( $1\frac{1}{4}$  and  $1\frac{3}{8}$ -inch diameter) boom construction is used, eliminating the need for boom supports. The Yagi can also be used vertically polarized. Three-sixteenths-inch-diameter aluminum elements are used. The exact alloy is not critical; 6061-T6 was used, but hard aluminum welding rod is also suitable. Quarter-inch-diameter elements could also be used if all elements are shortened by 3 mm. Three-eighths-inch-diameter elements would require 10 mm shorter lengths. Elements smaller than  $\frac{3}{16}$ -inch-diameter are not recommended. The elements are insulated and run through the boom. Plastic shoulder washers and stainless steel retainers are used to hold the elements in place. The various pieces needed to build the Yagi may be obtained from Rutland Arrays in New Cumberland, Pennsylvania. **Fig 44**

**Table 14**

#### Free-Space Dimensions for the 222-MHz Yagi Family

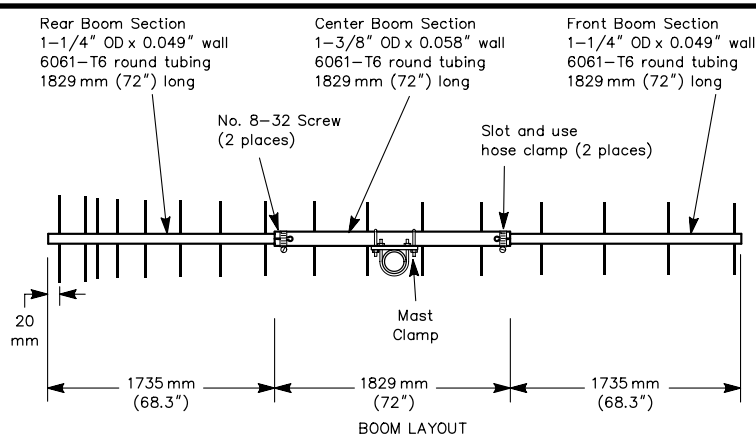
Element diameter is  $\frac{3}{16}$  inch.

El No.	Element Position (mm from rear of boom)	Element Length (mm)
REF	0	676
DE	204	647
D1	292	623
D2	450	608
D3	668	594
D4	938	597
D5	1251	581
D6	1602	576
D7	1985	573
D8	2395	569
D9	2829	565
D10	3283	562
D11	3755	558
D12	4243	556
D13	4745	554
D14	5259	553
D15	5783	552
D16	6315	551
D17	6853	550
D18	7395	549
D19	7939	548
D20	8483	547

**Table 15**

#### Specifications for the 222-MHz Family

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



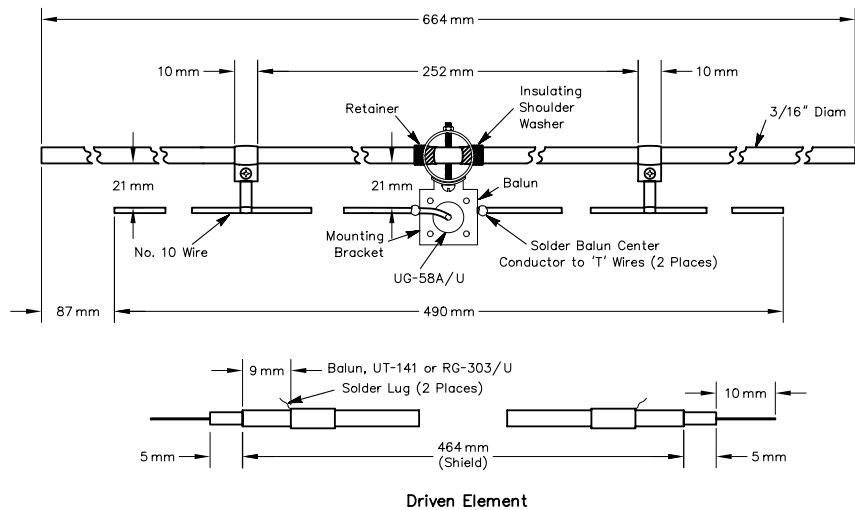
**Fig 44—Boom layout for the 16-element 222-MHz Yagi. Lengths are given in millimeters to allow precise duplication.**

**Table 16**

**Dimensions for 16-Element  
3.9- $\lambda$  222-MHz Yagi**

Element Element Element Boom  
Number Position Length Diam  
(mm from (mm) (in)  
rear of  
boom)

REF		683	
DE	204	664	
D1	292	630	
D2	450	615	
D3	668	601	1 $\frac{1}{4}$
D4	938	594	
D5	1251	588	
D6	1602	583	
D7	1985	580	
D8	2395	576	1 $\frac{3}{8}$
D9	2829	572	
D10	3283	569	
D11	3755	565	
D12	4243	563	1 $\frac{1}{4}$
D13	4745	561	
D14	5259	560	



**Fig 45—Driven-element detail for the 16-element 222-MHz Yagi. Lengths are given in millimeters to allow precise duplication.**

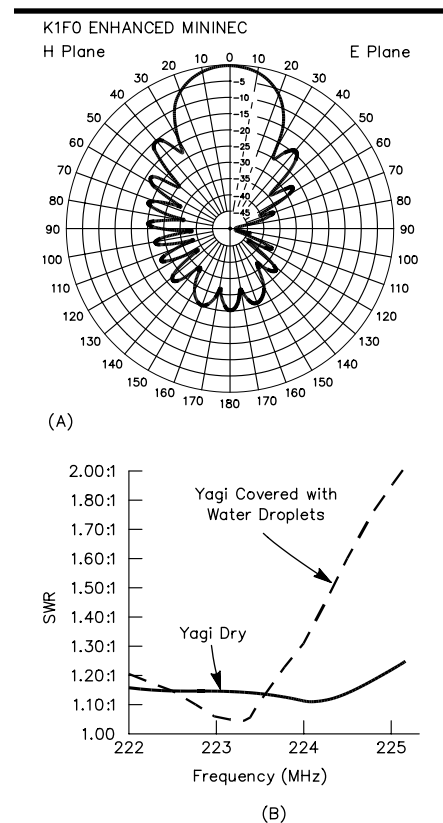
details the boom layout for the 16-element Yagi. **Table 16** gives the dimensions for the 16-element Yagi as built. The driven element is fed with a T match and a 4:1 balun. See **Fig 45** for construction details. See the 432-MHz Yagi

project elsewhere in this chapter for additional photographs and construction diagrams.

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

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

The pattern of the 16-element Yagi is shown in **Fig 46**. Like the 144-MHz Yagi, a 1-dB-per-division plot is used to detail the pattern accurately. This 16-element design makes a good building block for EME or tropo DX arrays. Old-style narrow-band Yagis often perform unpredictably when used in arrays. The theoretical 3.0-dB stack-



**Fig 46—H and E-plane patterns for the 16-element 222-MHz Yagi at A. The driven-element T-match dimensions were chosen for the best SWR compromise between wet and dry weather conditions. The SWR vs frequency curve shown at B demonstrates the broad frequency response of the Yagi design.**

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

## A 144-MHz 2-Element Quad

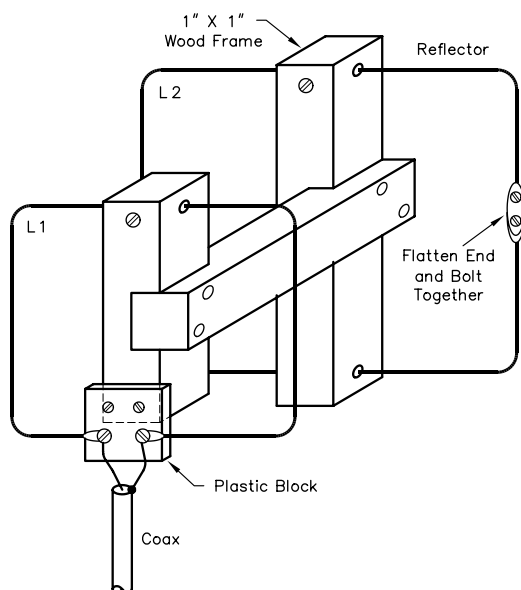
The basic 2-element quad array for 144 MHz is shown in Fig 47. The supporting frame is 1 × 1-inch wood, of any kind suitable for outdoor use. Elements are #8 aluminum wire. The driven element is 1  $\lambda$  (83 inches) long, and the reflector 5% longer (87 inches). Dimensions are not critical, as the quad is relatively broad in frequency response.

The driven element is open at the bottom, its ends fastened to a plastic block. The block is mounted at the bottom of the forward vertical support. The top portion of the element runs through the support and is held firmly by a screw running into the wood and then bearing on the aluminum wire. Feed is by means of 50- $\Omega$  coax, connected to the driven-element loop.

The reflector is a closed loop, its top and bottom portions running through the rear vertical support. It is held in position with screws at the top and bottom. The loop can be closed by fitting a length of tubing over the element ends, or by hammering them flat and bolting them together as shown in the sketch.

The elements in this model are not adjustable, though this can easily be done by the use of stubs. It would then be desirable to make the loops slightly smaller to compensate for the wire in the adjusting stubs. The driven element stub would be trimmed for length and the point of connection for the coax would be adjustable for best match. The reflector stub can be adjusted for maximum gain or maximum F/B ratio, depending on the builder's requirements.

In the model shown only the spacing is adjusted, and this is not particularly critical. If the wooden supports are made as shown, the spacing between the elements can be adjusted for best match, as indicated by an SWR meter connected in the coaxial line. The spacing has little effect on the gain (from 0.15 to 0.25  $\lambda$ ), so the variation in impedance with spacing can be used for matching. This also permits use of either 50 or 75- $\Omega$  coax for the transmission line.



**Fig 47—Mechanical details of a 2-element quad for 144 MHz. The driven element, L1, is one wavelength long; reflector L2 is 5% longer. With the transmission line connected as shown here, the resulting radiation is horizontally polarized. Sets of elements of this type can be stacked horizontally and vertically for high gain with broad frequency response. Recommended bay spacing is  $\frac{1}{2} \lambda$  between adjacent element sides. The example shown may be fed directly with 50- $\Omega$  coax.**

# A Portable 144-MHz 4-Element Quad

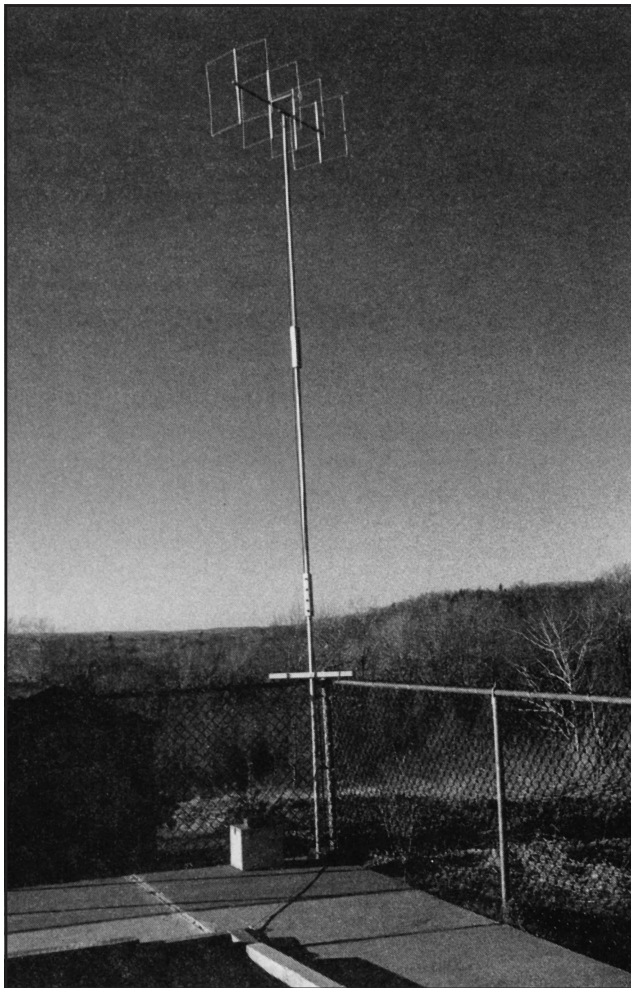
Element spacing for quad antennas found in the literature ranges from  $0.14 \lambda$  to  $0.25 \lambda$ . Factors such as the number of elements in the array and the parameters to be optimized (F/B ratio, forward gain, bandwidth, etc), determine the optimum element spacing within this range. The 4-element quad antenna described here was designed for portable use, so a compromise between these factors was chosen. This antenna, pictured in **Fig 48**, 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.

$$\text{Reflector length (ft)} = \frac{1046.8}{f_{\text{MHz}}} \quad (\text{Eq } 8)$$

$$\text{Driven element (ft)} = \frac{985.5}{f_{\text{MHz}}} \quad (\text{Eq } 9)$$

$$\text{Directors (ft)} = \frac{973.3}{f_{\text{MHz}}} \quad (\text{Eq } 10)$$



**Fig 48**—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. (Photo by Adwin Rusczech, W1MPO)

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 **Fig 49**. 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



**Fig 49**—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)

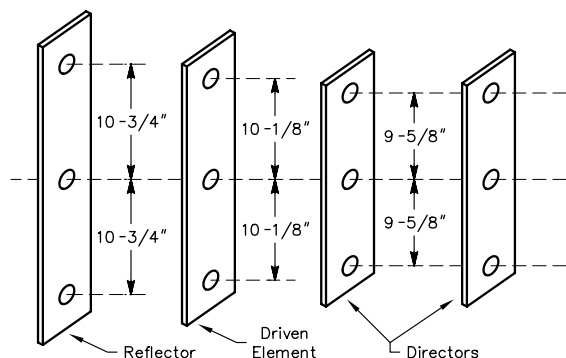
of heavier pine trim. Elements are made of #8 aluminum wire. Plexiglas is used to support the feed point. **Table 17** lists the hardware and other parts needed to duplicate the quad.

### Construction

The elements of the quad are assembled first. The mounting holes in the boom should be drilled to accommodate 1½ inch no. 8 hardware. Measure and mark the locations where the holes are to be drilled in the element spreaders, **Fig 50**. Drill the holes in the spreaders just large enough to accept the #8 wire elements. It is important to drill all the holes straight so the elements line up when the antenna is assembled.

Construction of the wire elements is easiest if the directors are made first. A handy jig for bending the elements can be made from a piece of 2 × 3-inch wood cut to the side length of the directors. It is best to start with about 82 inches of wire for each director. The excess can be cut off when the elements are completed. (The total length of each director is 77 inches.) Two bends should initially be made so the directors can be slipped into the spreaders before the remaining corners are bent. See **Fig 51**. 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

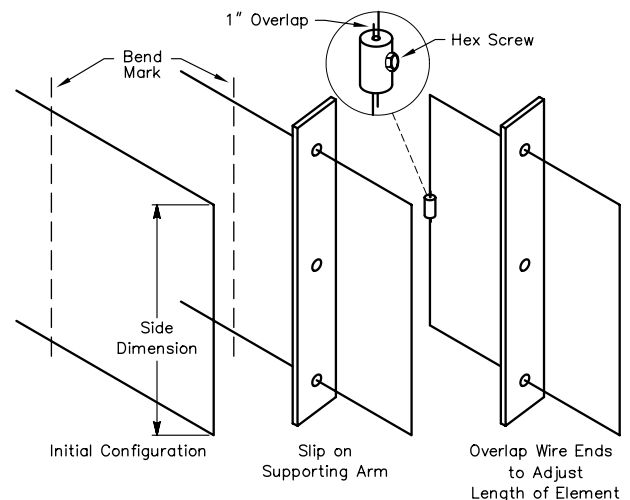


**Fig 50—Dimensions for the pine element spreaders for the 144-MHz 4-element quad.**

**Table 17**

### Parts List for the 144-MHz 4-element Quad

Boom: ¾ × ¾ 48-in. pine  
 Driven element support (spreader): ½ × ¾ × 21¼ in. pine  
 Driven element feed-point strut: ½ × ¾ × 7½ in. pine  
 Reflector support (spreader): ½ × ¾ × 22½ in. pine  
 Director supports (spreaders): ½ × ¾ × 20¼ in. pine, 2 req'd  
 Mast brackets: ¾ × 1½ × 12 in. heavy pine trim, 4 req'd  
 Boom to mast bracket: ½ × 1⅝ × 5 in. pine  
 Element wire: Aluminum ground wire (Radio Shack no. 15-035)  
 Wire clamps: ¼-in. electrician's copper or zinc plated steel clamps, 3 req'd  
 Boom hardware:  
   6 no. 8-32 × 1½ in. 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 in.  
   8 hex nuts, ¼-20  
   16 flat washers  
 Mast material: 1⅝ in. × 6 ft wood clothes-closet poles, 3 req'd  
 Feed-point support plate: 3½ × 2½ in. Plexiglas sheet  
 Wood preparation materials: Sandpaper, clear polyurethane, wax  
 Feed line: 52Ω 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



**Fig 51—Illustration showing how the aluminum element wires are bent. The adjustment clamp and its location are also shown.**



support the feed-point strut, as shown in **Fig 52**. 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 Fig 52. 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 Fig 52. (The elements of Fig 52 should be rotated 90° for vertical polarization.)

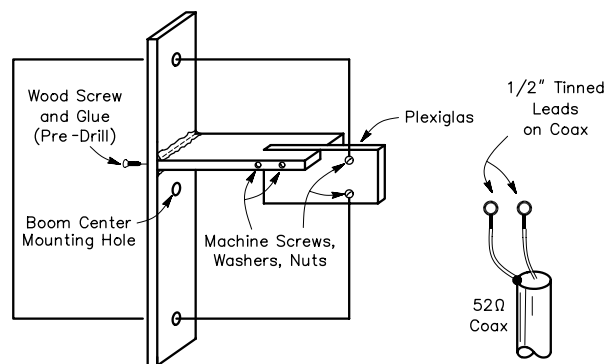
Orient the driven element spreader so that it mounts properly on the boom when the antenna is assembled. Bend the driven element the same way as the reflector and directors, but do not leave any overlap at the feed point. The ends of the wires should be  $\frac{3}{4}$  inch apart where they mount on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

Drill the boom as shown in **Fig 53**. 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.

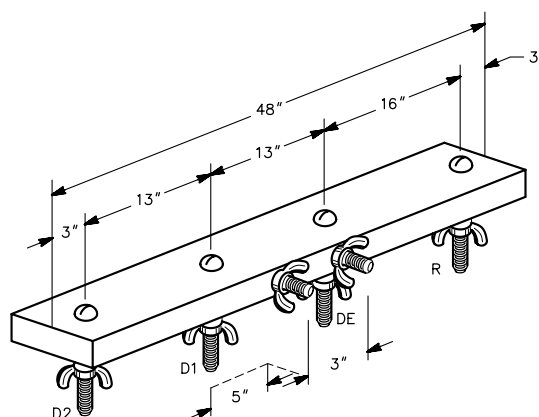
The boom to mast attachment is made next. Square the ends of a 6-foot section of clothes closet pole (a miter box is useful for this). Drill the center holes in both the boom attachment piece and one end of the mast section (**Fig 54**). Make certain that the mast hole is smaller than the flat-head screw to be used to ensure a snug fit. Accurately drill the holes for attachment to the boom as shown in Fig 54.

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.

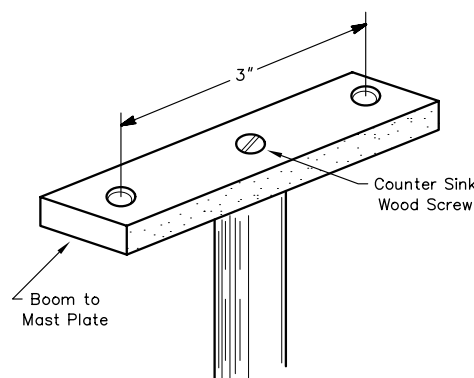
Two additional 6-foot mast sections are pre-



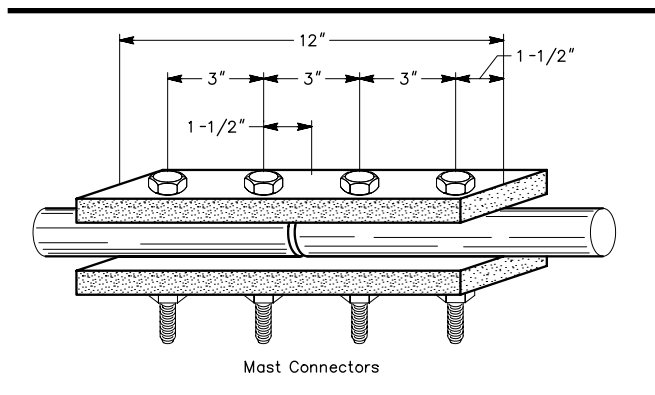
**Fig 52—Layout of the driven element of the 144-MHz quad. The leads of the coaxial cable should be stripped to  $\frac{1}{2}$  inch and solder lugs attached for easy connection and disconnection. See text regarding impedance at loop support points.**



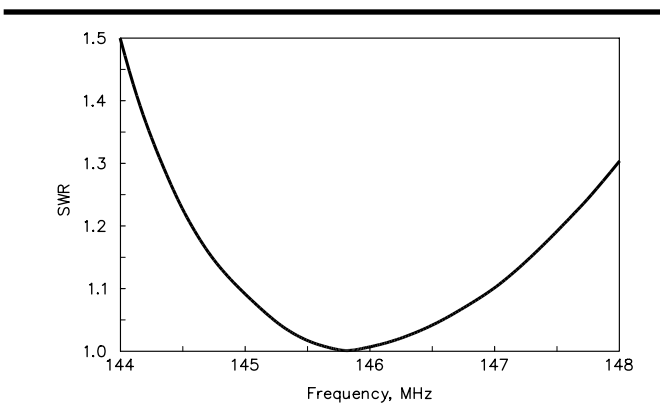
**Fig 53—Detail of the boom showing hole center locations and boom-to-mast connection points.**



**Fig 54—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.**



**Fig 55—Mast coupling connector details for the portable quad. The plates should be drilled two at a time to ensure the holes line up.**



**Fig 56—Typical SWR curve for the 144-MHz portable quad. The large wire diameter and the quad design provide excellent bandwidth.**

pared 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 **Fig 55**. Using  $3\frac{1}{2} \times \frac{1}{4}$ -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 pre-drilled 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 (**Fig 56**).

**Table 18**  
**Dimensions, 8-Element Quagi**

Element	Frequency				
Lengths	144.5 MHz	147 MHz	222 MHz	432 MHz	446 MHz
Reflector <sup>1</sup>	86 <sup>5</sup> / <sub>8</sub> "	85"	56 <sup>3</sup> / <sub>8</sub> "	28"	27 <sup>1</sup> / <sub>8</sub> "
Driven <sup>2</sup>	82"	80"	53 <sup>1</sup> / <sub>2</sub> "	26 <sup>5</sup> / <sub>8</sub> "	25 <sup>7</sup> / <sub>8</sub> "
Directors	35 <sup>15</sup> / <sub>16</sub> " to 35" in 3/16" steps	35 <sup>5</sup> / <sub>16</sub> " to 34 <sup>3</sup> / <sub>8</sub> " in 3/16" steps	23 <sup>3</sup> / <sub>8</sub> " to 22 <sup>3</sup> / <sub>4</sub> " in 1/8" steps	11 <sup>3</sup> / <sub>4</sub> " to 11 <sup>7</sup> / <sub>16</sub> " in 1/16" steps	11 <sup>3</sup> / <sub>8</sub> " to 11 <sup>1</sup> / <sub>16</sub> " in 1/16" steps
Spacing					
R-DE	21"	20 <sup>1</sup> / <sub>2</sub> "	13 <sup>5</sup> / <sub>8</sub> "	7"	6.8"
DE-D1	15 <sup>3</sup> / <sub>4</sub> "	15 <sup>3</sup> / <sub>8</sub> "	10 <sup>1</sup> / <sub>4</sub> "	5 <sup>1</sup> / <sub>4</sub> "	5.1"
D1-D2	33"	32 <sup>1</sup> / <sub>2</sub> "	21 <sup>1</sup> / <sub>2</sub> "	11"	10.7"
D2-D3	17 <sup>1</sup> / <sub>2</sub> "	17 <sup>1</sup> / <sub>8</sub> "	11 <sup>3</sup> / <sub>8</sub> "	5.85"	5.68"
D3-D4	26.1"	25 <sup>5</sup> / <sub>8</sub> "	17"	8.73"	8.46"
D4-D5	26.1"	25 <sup>5</sup> / <sub>8</sub> "	17"	8.73"	8.46"
D5-D6	26.1"	25 <sup>5</sup> / <sub>8</sub> "	17"	8.73"	8.46"
Stacking Distance Between Bays					
	11"	10'10"	7'1 <sup>1</sup> / <sub>2</sub> "	3'7"	3'5 <sup>5</sup> / <sub>8</sub> "

<sup>1</sup> All #12 TW (electrical) wire, closed loops.

<sup>2</sup> All #12 TW wire loops, fed at bottom.

## Building Quagi Antennas

The Quagi antenna was designed by Wayne Overbeck, N6NB. He first published information on this antenna in 1977 (see [Bibliography](#)). There are a few tricks to Quagi building, but nothing very difficult or complicated is involved. In fact, Overbeck mass produced as many as 16 in one day. **Tables 18** and **19** give the dimensions for Quagis for various frequencies up to 446 MHz.

For the designs of Tables 18 and

19, the boom is *wood* or any other nonconductor (such as, fiberglass or Plexiglas). If a metal boom is used, a new design and new element lengths will be required. Many VHF antenna builders go wrong by failing to follow this rule: If the original uses a metal boom, use the same size and shape metal boom when you duplicate it. If it calls for a wood boom, use a nonconductor. Many amateurs dislike wood booms, but in a salt air environment they outlast aluminum (and surely cost less). Varnish the boom for added protection.

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

The quad elements are supported at the current maxima (the top and bottom, the latter beside the feed point) with Plexiglas or small strips of wood. See **Fig 57**. The quad elements are made of #12 copper wire, commonly used in house wiring. Some builders may elect to use #10 wire on 144 MHz and #14 on 432 MHz, although this changes the resonant frequency slightly. Solder a type N connector (an SO-239 is often used at 144 MHz) at the midpoint of the driven element bottom side, and close the reflector loop.

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

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

**Table 19**

**432-MHz, 15-Element, Long Boom Quagi Construction Data**

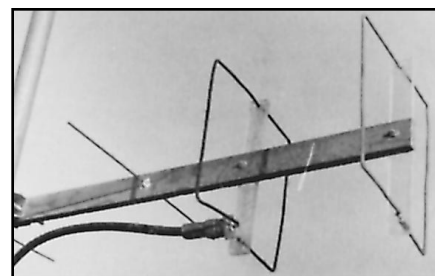
<i>Element Lengths, Inches</i>	<i>Interelement Spacing, Inches</i>
R—28	R-DE7
DE—26 $\frac{5}{8}$	DE-D1—5 $\frac{1}{4}$
D1—11 $\frac{3}{4}$	D1-D2—11
D211—11 $\frac{1}{16}$	D2-D3—5 $\frac{7}{8}$
D3—11 $\frac{5}{8}$	D3-D4—8 $\frac{3}{4}$
D4—11 $\frac{9}{16}$	D4-D5—8 $\frac{3}{4}$
D5—11 $\frac{1}{2}$	D5-D6—8 $\frac{3}{4}$
D6—11 $\frac{7}{16}$	D6-D7—12
D7—11 $\frac{3}{8}$	D7-D8—12
D8—11 $\frac{5}{16}$	D8-D9—11 $\frac{3}{4}$
D9—11 $\frac{5}{16}$	D9-D10—11 $\frac{1}{2}$
D10—11 $\frac{3}{4}$	D10-D11—9 $\frac{3}{16}$
D11—11 $\frac{3}{16}$	D11-D12—12 $\frac{3}{8}$
D12—11 $\frac{1}{8}$	D12-D13—13 $\frac{3}{4}$
D13—11 $\frac{1}{16}$	

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

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

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

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



**Fig 57—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-foot 10-inch boom! The same basic arrangement is used on lower frequencies, but wood may be substituted for the Plexiglas spreaders. The boom is  $\frac{1}{2}$ -inch exterior plywood.**

### Construction Reminders

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

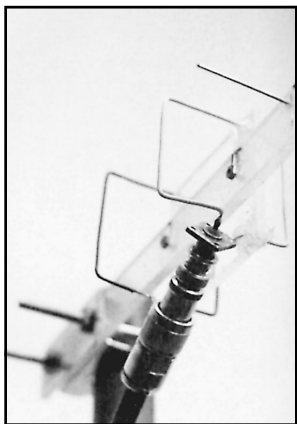
Finally, remember that a balanced antenna is being fed with an unbalanced line. Every balun the designer tried introduced more trouble in terms of losses than the feed imbalance caused. Some builders have tightly coiled several turns of the feed line near the feed point to limit line radiation. In any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

## QUAGIS FOR 1296 MHz

The Quagi principle has recently been extended to the **1296-MHz band**, where good performance is extremely difficult to obtain from homemade conventional Yagis. **Fig 58** shows the construction and **Table 20** 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.

The Quagis (and the cubical quad) are built on  $\frac{1}{4}$ -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



**Fig 58—A view of the 10-element version of the 1296-MHz Quagi. It is mounted on a 30-inch Plexiglas boom with a  $3 \times 3$ -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.**

**Table 20**

### 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  $\frac{1}{16}$ -in. brass brazing rod. See text for a discussion of director taper.

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

**Boom:**  $\frac{1}{4}$ -in. thick Plexiglas, 30 in. long for 10-element quad or Quagi and 48 in. long for 15-element Quagi; 84 in. for 25-element Quagi.

#### 10-Element Quagi for 1296 MHz

Element	Length, Inches	Construction	Interelement Element Spacing, In.
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 in.; D7 to D8 is also 4.0 in.

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

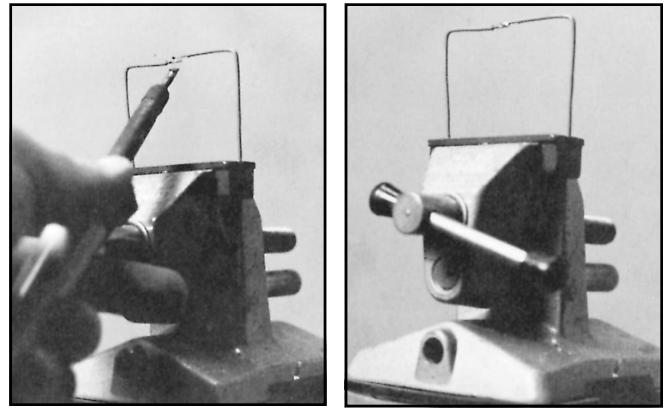
#### 25-Element Quagi for 1296 MHz

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-in. intervals and taper in length successively by 0.02 in. per element. Thus, D23 is 3.39 in.

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 (**Fig 59**), although the shape is relatively noncritical. The element lengths, however, *are* critical. At 1296 MHz, variations of  $\frac{1}{16}$  inch alter the performance measurably, and a  $\frac{1}{8}$ -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  $\frac{1}{8}$ -inch overlap where the two ends of the reflector (and director) loops are joined, as shown in Fig 59.

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



**Fig 59—These photos show the construction method used for the 1296-MHz quad type parasitic elements. The two ends of the #18 bell wire are brought together with an overlap of  $\frac{1}{8}$  inch and soldered.**

## Loop Yagis for 1296 MHz

Described here are loop Yagis for the 1296-MHz band. The loop Yagi fits into the quad family of antennas, as each element is a closed loop with a length of approximately  $1\lambda$ . 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. Since then, many versions have been developed with different loop and boom dimensions. Chip Angle, N6CA, developed the antennas shown here.

Three sets of dimensions are given. Good performance can be expected if the dimensions are carefully followed. Check all dimensions before cutting or drilling anything. The 1296-MHz version is intended for weak-signal operation, while the 1270-MHz version is optimized for FM and mode L satellite work. 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  $\pm 30$  MHz from the design frequency. The SWR, however, deteriorates within a few megahertz on the low side of the design center frequency.

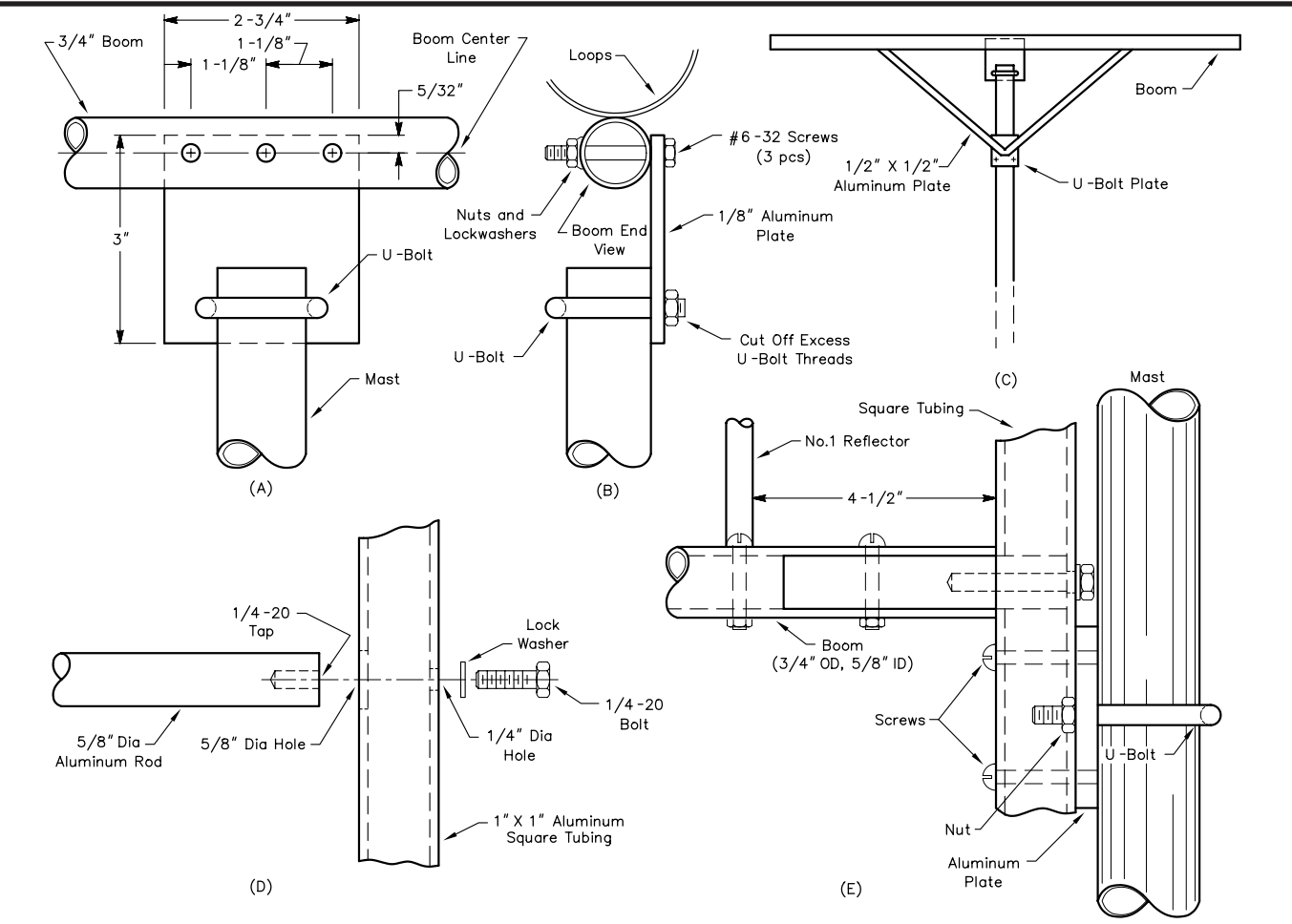
### The Boom

The dimensions given here apply only to a  $\frac{3}{4}$ -inch OD boom. If a different boom size is used, the dimensions must be scaled accordingly. Many hardware stores carry aluminum tubing in 6 and 8-foot lengths, and that tubing is suitable for a short Yagi. If a 12-foot antenna is planned, find a piece of more rugged boom material, such as 6061-T6 grade aluminum. Do not use anodized tubing. The 12-foot antenna must have additional boom support to minimize boom sag. The 6-foot version can be rear mounted. For rear mounting, allow  $4\frac{1}{2}$  inches of boom behind the last reflector to eliminate SWR effects from the support.

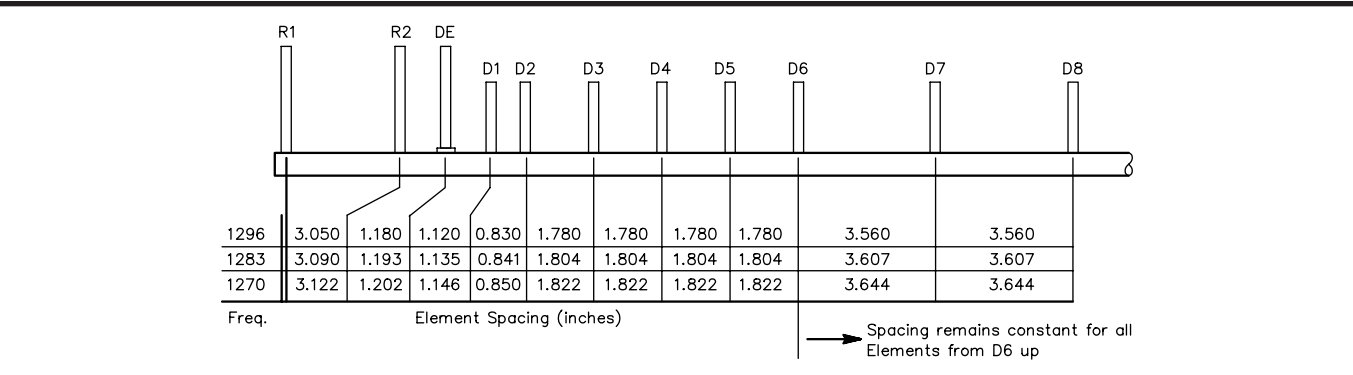
The antenna is attached to the mast with a gusset plate. This plate mounts at the boom center. See

**Fig 60.** 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 #4-40 machine screws, so a series of #33 (0.113-inch) holes must be drilled along the center of the boom to accommodate this hardware. **Fig 61** shows the element spacings for different parts of the band. Dimensions should be followed as closely as possible.



**Fig 60—**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 feet long.



**Fig 61—**Boom drilling dimensions. These dimensions must be carefully followed and the same materials used if performance is to be optimum. Element spacings are the same for all directors after D6—use as many as necessary to fill the boom.



## Parasitic Elements

The reflectors and directors are cut from 0.032-inch thick aluminum sheet and are  $\frac{1}{4}$  inch wide. **Fig 62** 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 **Fig 62** 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.)

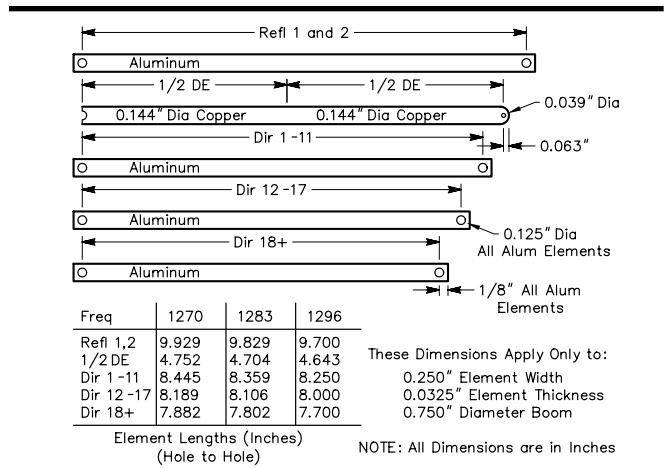
Mount the loops to the boom with #4-40  $\times$  1-inch machine screws, lock washers and nuts. See **Fig 63**. It is best to use only stainless steel or plated brass hardware. Although the initial cost is higher than for ordinary plated steel hardware, stainless or brass hardware will not rust and need replacement after a few years. Unless the antenna is painted, the hardware will definitely deteriorate.

## Driven Element

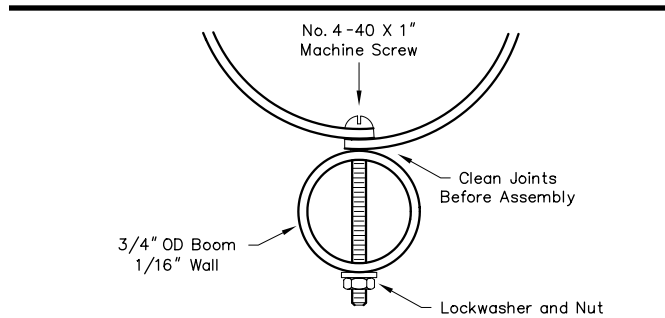
The driven element is cut from 0.032-inch copper sheet and is  $\frac{1}{4}$  inch wide. Drill three holes in the strap as detailed in **Fig 62**. Trim the ends as shown and form the strap into a loop similar to the other elements. This antenna is like a quad; if the loop is fed at the top or bottom, it is horizontally polarized.

Driven element mounting details are shown in **Fig 64**. A mounting fixture is made from a  $\frac{1}{4}$ -20  $\times$   $\frac{1}{4}$ -inch brass bolt. File the bolt head to a thickness of  $\frac{1}{8}$  inch. Bore a 0.144-inch (#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.

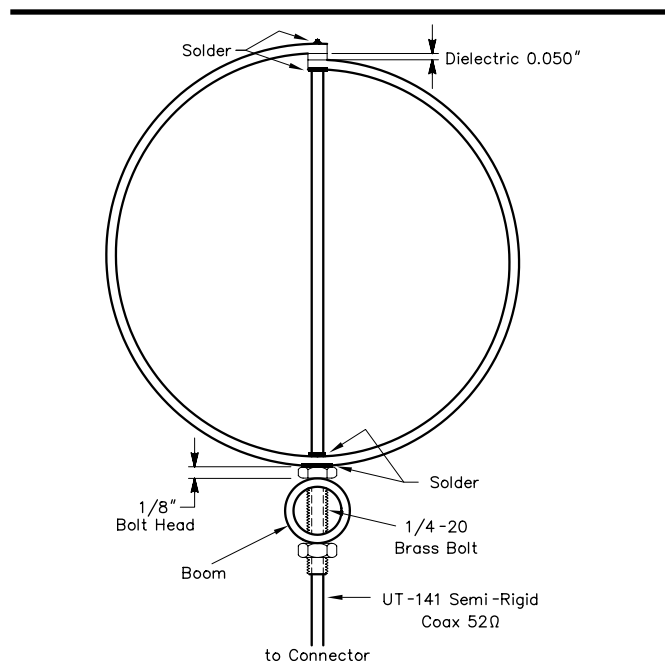
The UT-141 can be any convenient length. Attach the connector of your choice (preferably type N). Use a short piece of low-loss RG-8 size cable (or  $\frac{1}{2}$ -inch Hardline) for the run down the boom and mast to the main feed line. For best results, the main feed line should be the lowest loss 50- $\Omega$  cable obtainable. Good  $\frac{7}{8}$ -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.



**Fig 62—Parasitic elements for the loop Yagi are made from aluminum sheet, the driven element from copper sheet. The dimensions given are for  $\frac{1}{4}$ -inch wide by 0.0325-inch thick elements only. Lengths specified are hole to hole distances; the holes are located  $\frac{1}{8}$  inch from each element end.**



**Fig 63—Element-to-boom mounting details.**



**Fig 64—Driven element details. See Fig 62 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.

## Tips for 1296-MHz Antenna Installations

Construction practices that are common on lower frequencies cannot be used on 1296 MHz. This is the most important reason why all who venture to these frequencies are not equally successful. First, when a proven design is used, copy it exactly—don’t change *anything*. This is especially true for antennas.

Use the best feed line you can get. Here are some realistic measurements of common coaxial cables at 1296 MHz (loss per 100 feet).

RG-8, 213, 214: 11 dB  $\frac{1}{2}$ -inch foam/copper Hardline: 4 dB

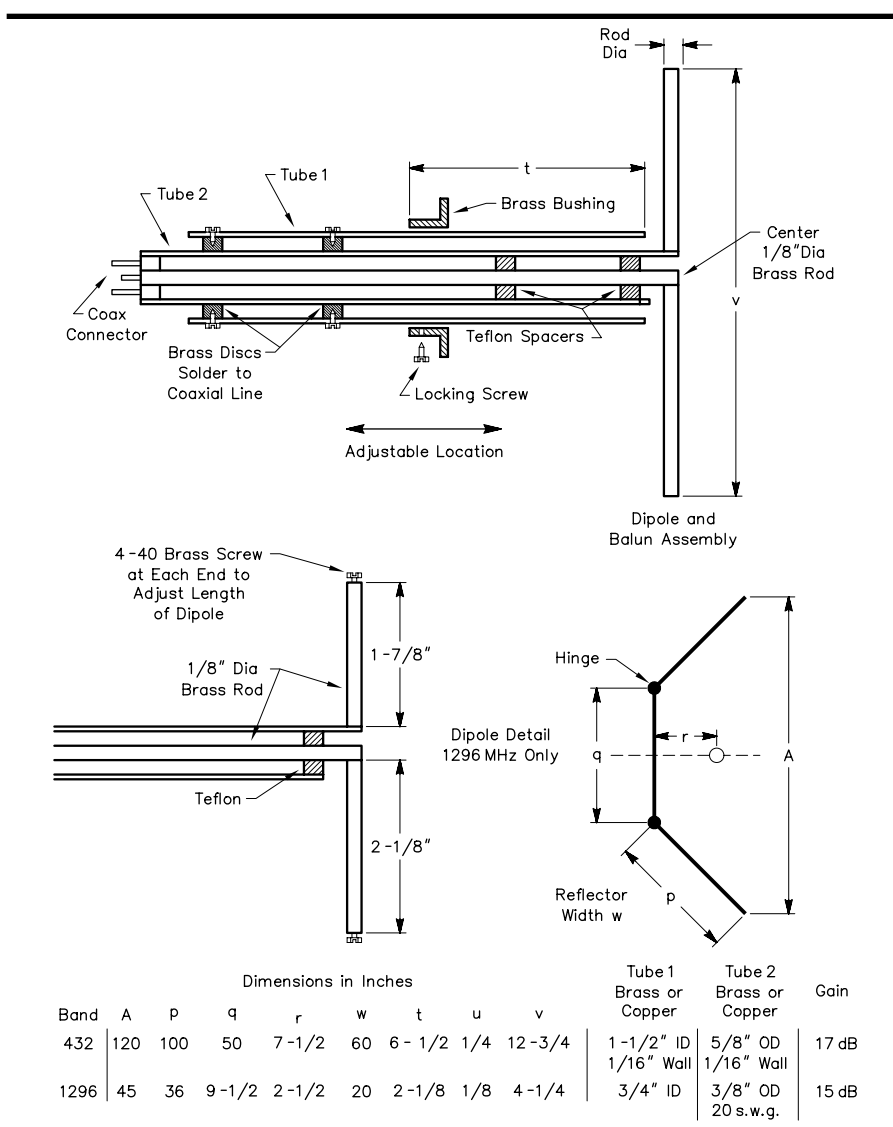
$\frac{7}{8}$ -inch foam/copper Hardline: 1.5 dB

Mount the antennas to keep feed-line losses to an absolute minimum. Antenna height is less important than keeping the line losses low. *Do not* allow the mast to pass through the elements, as is common on antennas for lower frequencies. Cut all U bolts to the minimum length needed;  $\frac{1}{4} \lambda$  at 1296 MHz is only a little over 2 inches. Avoid any unnecessary metal around the antenna.

## Trough Reflectors for 432 and 1296 MHz

Dimensions are given in Fig 65 for 432 and 1296-MHz trough reflectors. The gain to be expected is 15 dB and 17 dB, respectively. A very convenient arrangement, especially for portable work, 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 en-



**Fig 65—Practical construction information for trough reflector antennas for 432 and 1296 MHz.**

try 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.

## A Horn Antenna for 10 GHz

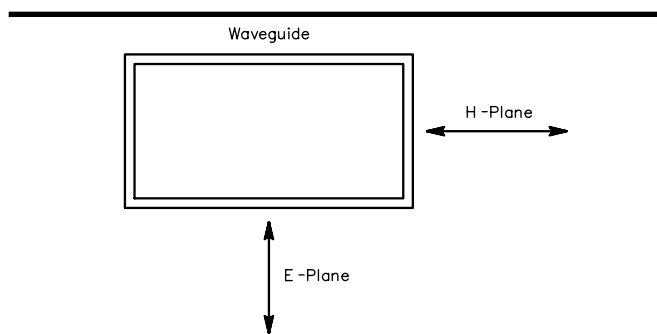
The horn antenna is the easiest antenna for the beginner on 10 GHz to construct. It can be made out of readily available flat sheet brass. Because it is inherently a broadband structure, minor constructional errors can be tolerated. The one drawback is that horn antennas become physically cumbersome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

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 **Fig 66**.

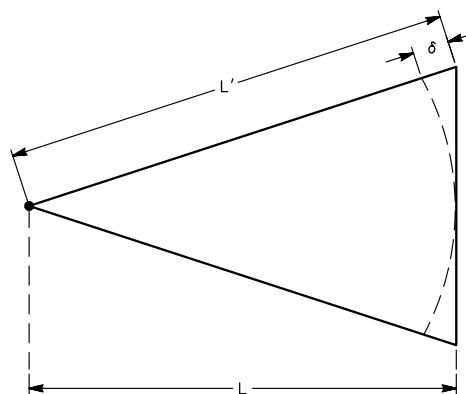
There are many varieties of horn antennas. If the waveguide is flared out only in the H-plane, the horn is called an H-plane sectoral horn. Similarly, if the flare is only in the E-plane, an E-plane sectoral horn results. If the flare is in both planes, the antenna is called a pyramidal horn.

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, side lobes 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.

**Fig 67** illustrates this problem. For a given flare 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 side lobes, 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,



**Fig 66—10-GHz antennas are usually fed with waveguide. See text for a discussion of waveguide propagation characteristics.**



**Fig 67—The path-length (phase) difference between the center and edge of a horn antenna is  $\Delta$ .**

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 side lobes become excessive and axial gain markedly decreases.

The magnitude of this permissible phase difference is different for E 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  $90^\circ$  ( $1/4 \lambda$ ). In an H-plane horn, the allowable phase difference is  $144^\circ$  ( $0.4 \lambda$ ). If the aperture of a pyramidal horn exceeds one wavelength in both planes, the E 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 beam-width. 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 side lobe intensity.

### Building the Antenna

A 10-GHz pyramidal horn with 18.5 dBi gain is shown in **Fig 68**. The first design parameter is usually the required gain, or the maximum antenna size. These are of course related, and the relationships can be approximated by the following:

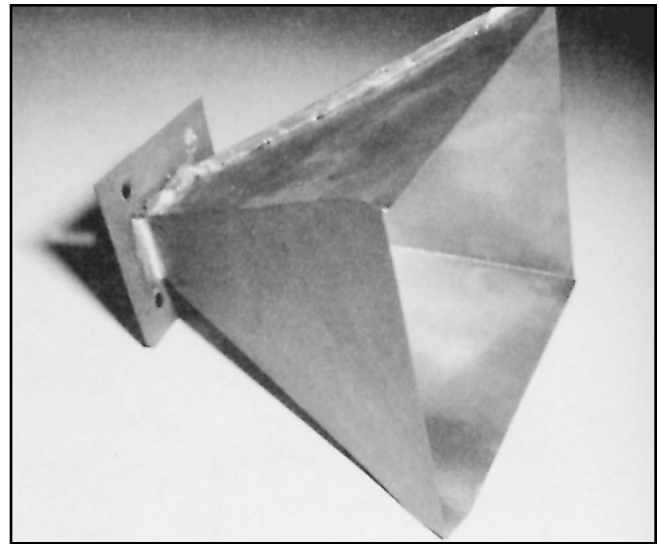
$$L = \text{H-plane length } (\lambda) = 0.0654 \times \text{gain} \quad (\text{Eq 1})$$

$$A = \text{H-plane aperture } (\lambda) = 0.0443 \times \text{gain} \quad (\text{Eq 2})$$

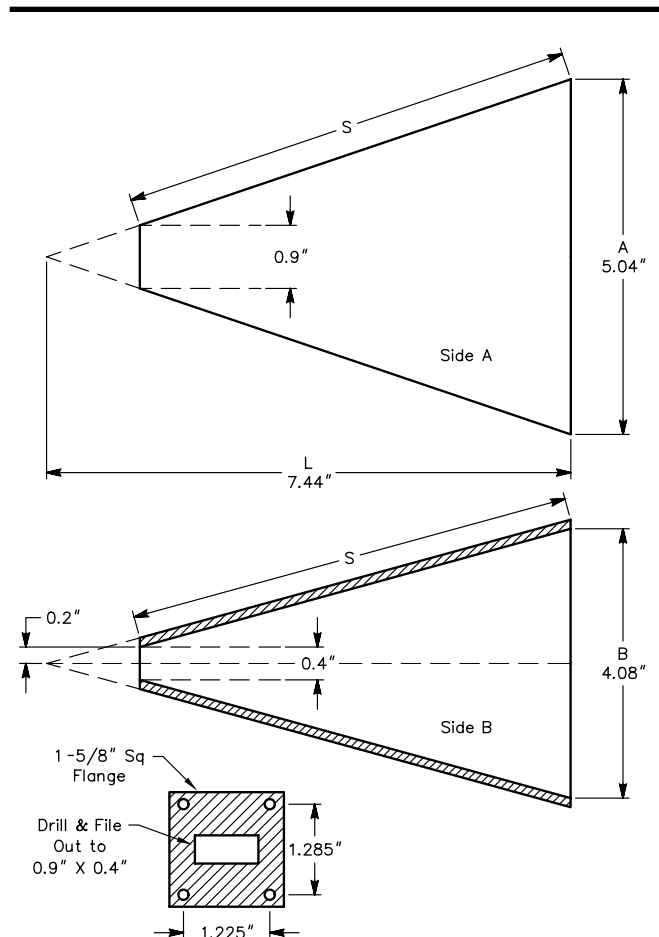
$$B = \text{E-plane aperture } (\lambda) = 0.81 A \quad (\text{Eq 3})$$

where

gain is expressed as a *ratio*; 20 dB gain = 100  
L, A and B are dimensions shown in **Fig 69**



**Fig 68—This pyramidal horn has 18.5 dBi gain at 10 GHz. Construction details are given in the text.**



**Fig 69—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).**

From these equations, the dimensions for a 20-dB gain horn for 10.368 GHz can be determined. One wavelength at 10.368 GHz is 1.138 inches. The length ( $L$ ) of such a horn is  $0.0654 \times 100 = 6.54 \lambda$ . At 10.368 GHz, this is 7.44 inches. The corresponding H-plane aperture ( $A$ ) is  $4.43 \lambda$  (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. Fig 69 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 ( $0.9 \times 0.4$  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 Fig 69. 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 Fig 69. (This procedure is much more easily followed than described.) These smaller pieces are made slightly oversize (shaded area in Fig 69) 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  $0.9 \times 0.4$  inch and the aperture at the other end should measure  $5.04 \times 4.08$  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 Fig 70. When the horn is completed, it can be soldered to a standard waveguide flange, or one cut out of sheet metal as shown in Fig 69. The transition between the flange and the horn must be smooth. This antenna provides an excellent performance-to-cost ratio (about 20 dB gain for about \$5 in parts).

## 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

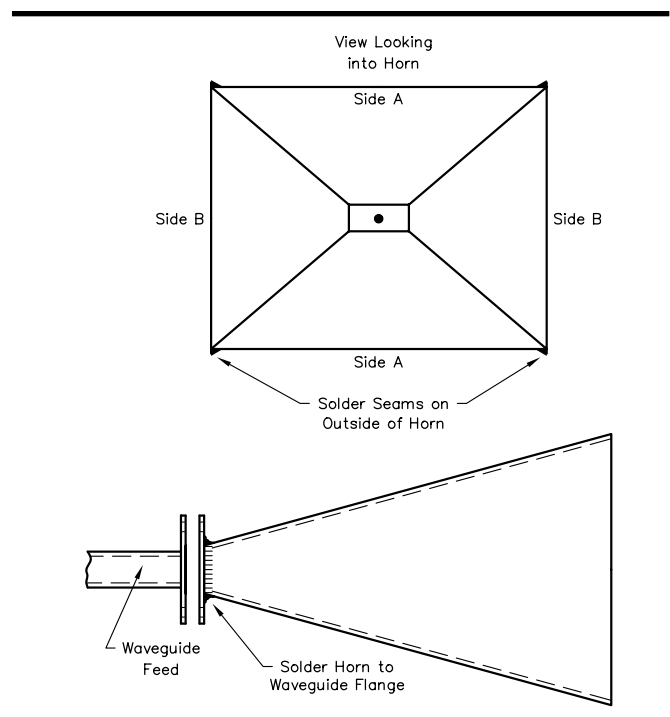


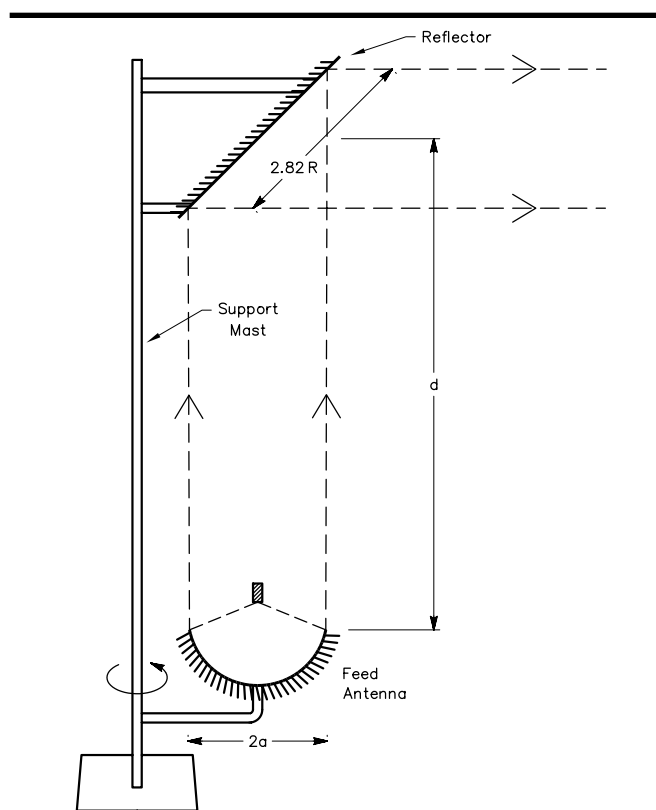
Fig 70—Assembly of the 10-GHz horn antenna.

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 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 “flyswatter antenna”).

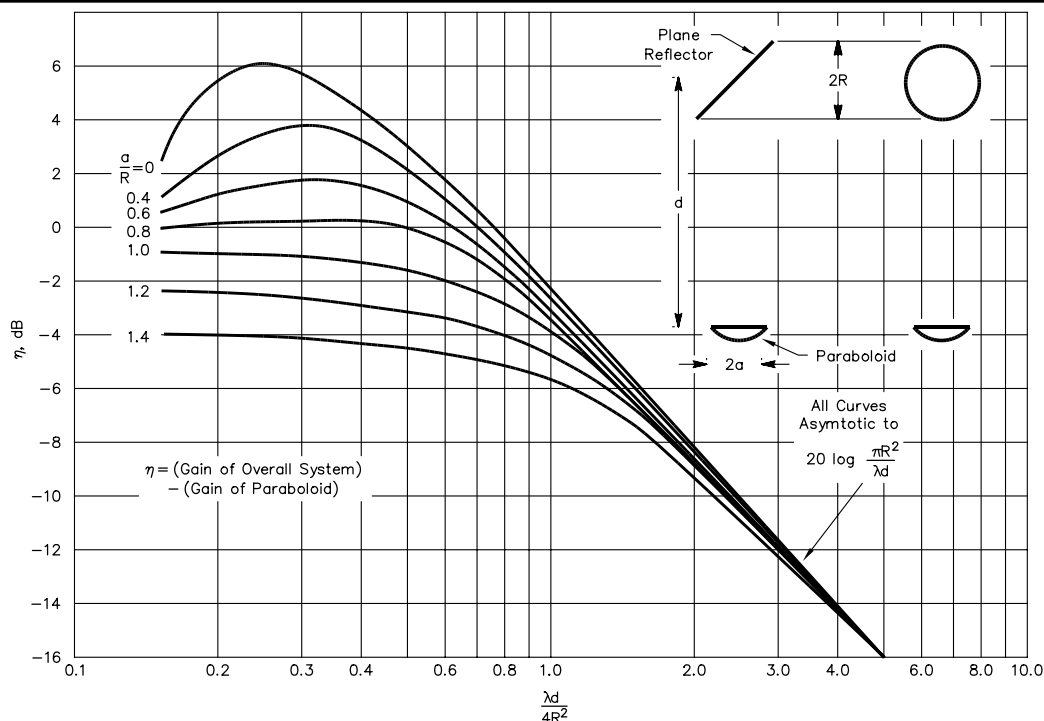
The material in this section was prepared by Bob Atkins, KA1GT, and appeared in *QST* for January and February 1984. **Fig 71** shows a schematic representation of a periscope antenna system. A plane reflector is mounted at the top of a rotating tower at an angle of  $45^\circ$ . This reflector can be 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

**Fig 72** shows the relationship between the effective gain of the antenna system and the distance



**Fig 71—The basic periscope antenna. This design makes it easy to adjust the feed antenna.**



**Fig 72—Gain of a periscope antenna using a plane elliptical reflector (after Jasik—see Bibliography).**



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, the far field (Fraunhofer) 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 Fig 72 with a rectangular reflector,  $R^2$  may be replaced by  $A/\pi$ , 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 21** gives an approximation of what to expect.  $R$  is the radius of the projected circular area of the elliptical reflector (equal to the minor axis radius), and  $b$  is the length of the side of the projected square area of the rectangular reflector (equal to the length of the short side of the rectangle).

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

### Mechanical Considerations

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

The reflector itself should be flat to better than  $1/10 \lambda$  for the frequency in use. It may be made of mesh, provided that the holes in the mesh are also less than  $1/10 \lambda$  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 **Fig 73**.

**Table 21**  
**Radiation Patterns of Periscope Antenna Systems**

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



**Fig 73—**  
**Commercial periscope antennas, such as this one, are often used for point-to-point communication.**

Circular polarization is not often used for terrestrial work, 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  $1/10 \lambda$ .

## 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 Chapter 2.

- B. Atkins, "Periscope Antenna Systems," *The New Frontier, QST*, Jan and Feb 1984.
- B. Atkins, "Horn Antennas for 10 GHz," *The New Frontier, QST*, Apr and May 1987.
- 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.
- 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.
- D. L. Hilliard, "A 902-MHz Loop Yagi Antenna," *QST*, Nov 1985, pp 30-32.
- 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*, 1st ed. (New York: McGraw-Hill, 1961).
- R. T. Knadle, "UHF Antenna Ratiometry," *QST*, Feb 1976, pp 22-25.
- T. Moreno, *Microwave Transmission Design Data* (New York: McGraw-Hill, 1948).
- 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.
- G. Southworth, *Principles and Applications of Waveguide Transmission* (New York: D. Van Nostrand Co, 1950).
- P. P. Vezbicke, "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.
- D. Vilardi, "Simple and Efficient Feed for Parabolic Antennas," *QST*, Mar 1973.
- Radio Communication Handbook*, 5th ed. (London: RSGB, 1976).