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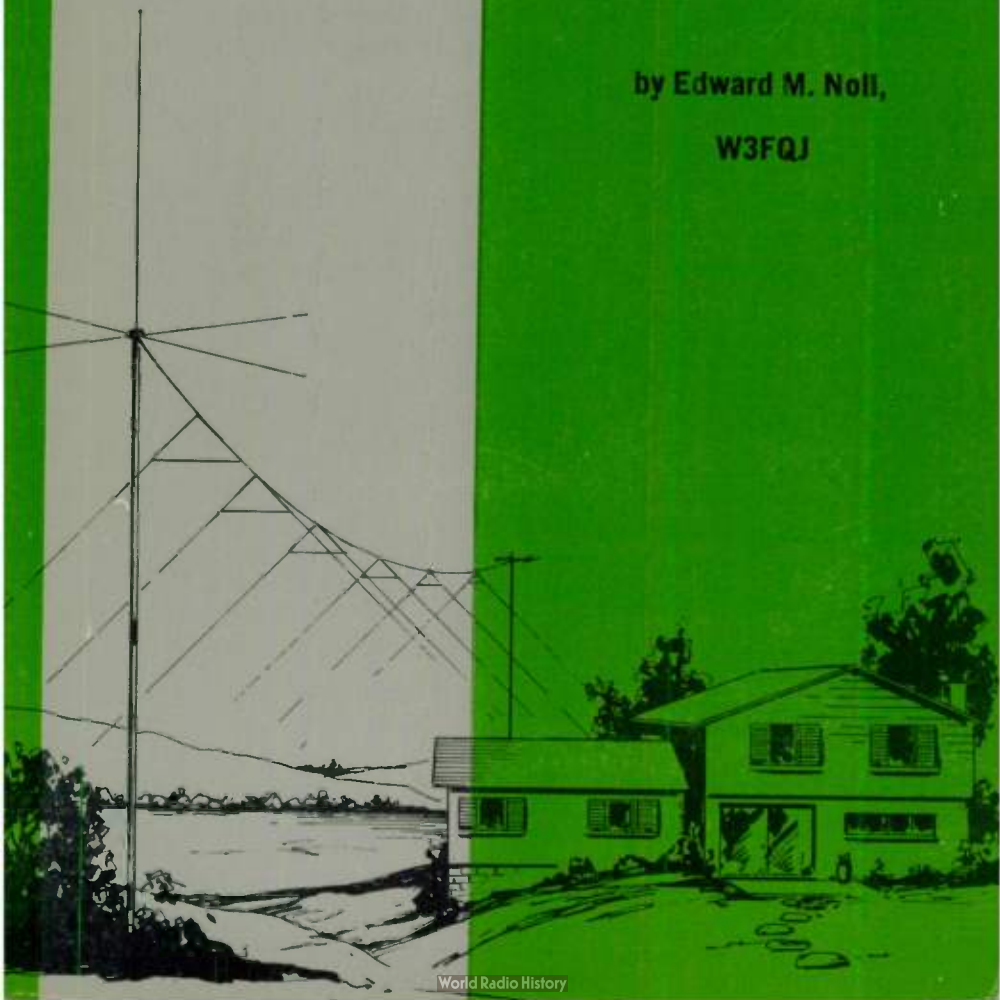
Vertical, Beam, and Triangle Antennas

by Edward M. Noll,

W3FQJ

73 Vertical, Beam, and Triangle Antennas

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Preface

An often heard comment of the present is "The day of amateurs building and operating their own equipment are things of the past." To a great extent this is true since the advent of sophisticated single-sideband equipment has convinced many that construction of their own gear is no longer practical.

The one big exception to this is in the field of amateur antennas. The amateur, at very little expense, and without the requirement of an R&D laboratory, can indulge in experimentation with antennas, sometimes with startling results.

73 Vertical, Beam and Triangle Antennas is the second of a series of books which can make the hobby of amateur radio more than an operational spectator activity. Each antenna described in this book was constructed by the author without assistance. A minimum of tools and equipment were used. You can do the same and use the world as your testing ground.

Many of the antennas described in this book compete with. and sometimes surpass, the performance of commercial beams. A number of new approaches in the construction of basic antenna types are detailed. The book is not so much a rehash of common antennas and basic theory as it is a coverage of new approaches and ideas not often used by the amateur.

There are 73 individual vertical and beam antennas included in an order that begins with simple construction and progresses in sequential manner to more complex arrangements. However, if you are interested in only one particular type, you can locate that type immediately and proceed with its erection.

73 Vertical, Beam, and Triangle Antennas is an invitation to some inexpensive education and fun. You will find it very educational and satisfying to put up an antenna that you have calculated, erected, and tuned. You have also gained a conversation peak that can bring you that much nearer to other radio amateurs all over the world. There are very few of them who are not interested in antennas.

<div align="right">Edward M. Noll. W3FQJ</div>

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Quarter-Wave Verticals

1—Half-Wavelength Dipole (Hertz)

As a starting point for the antennas discussed in this book, the half-wavelength dipole is considered basic. It serves as the basic driven element of the beam antenna and the driven elements of a phased directional array. Vertical radiators also stem from this fundamental half-wavelength dimension.

In a dipole arrangement the transmission line is attached at the center (Fig. 1) and there is a quarter-wavelength sector on each

Fig. 1. Half-wavelength dipole antenna.
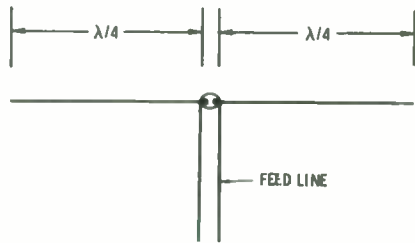
side of the feed point. In free space and for high antenna heights the feed-point impedance approximates 72 ohms. This can vary as a function of antenna height and the proximity of other conducting materials.

The physical length of a resonant dipole antenna is shorter than a half wavelength in free space. Thus the physical length of a dipole must be made shorter than that value calculated from the free-space wavelength equation.

A half wavelength in space has the following length:

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$$\lambda = \frac{492}{f\ (\text{MHz})}\ \text{feet}$$

The physical length of the dipole antenna needed to establish a resonant length for frequency (f) is shorter than this value by approximately 5 percent. A practical equation for calculating the length of a half-wavelength dipole is:

$$\lambda = \frac{468}{f\ (\text{MHz})}\ \text{feet}$$

This length is influenced some by conductor cross-sectional area, height above ground, and nearby conducting objects.

The horizontal pattern of a *horizontal* dipole is a figure eight with maximum radiation and sensitivity broadside to the wire (Fig. 2). The
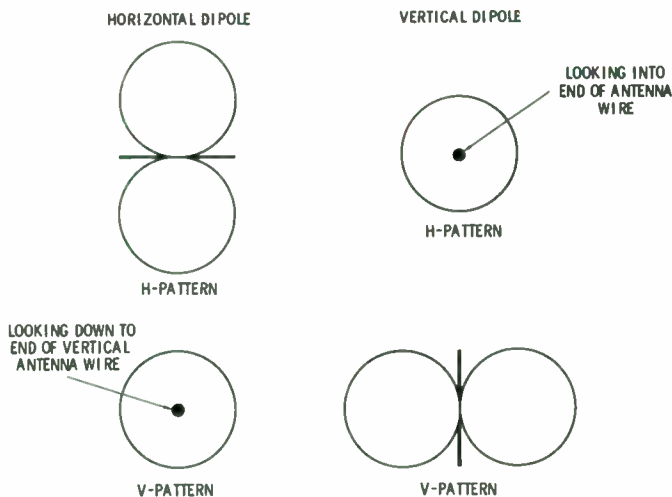
Fig. 2. Free-space dipole radiation patterns.

vertical radiation pattern is circular. For a *vertical* half-wavelength dipole, the horizontal pattern is circular, while the vertical pattern is a figure eight. In practice the vertical pattern of a vertical dipole is modified substantially by the influence of ground.

When a dipole antenna is fed with a 72-ohm line and the transmitter output load circuit can be tuned to an output impedance of 72 ohms,

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the entire system is matched, and there is peak transfer of power to the antenna. Standing waves on the transmission line are minimium, and there is minimum attenuation of the signal by the line. In this case the matching is unaffected by the overall length of the line.

Line loss does increase with line length as a function of the attenuation figures for the particular type of line. Under matched conditions for a good quality line these losses can be quite insignificant with surprisingly long lengths of transmission line.

Chart 1 presents dipole antenna dimensions for the radio amateur bands from 10 meters through 160 meters as related to the center of each band, center of the phone segment, and center of the cw segment.

Chart 1. Dipole and Half-Wavelength Line Dimensions

Band in Meters	Band Center			CW Band			Phone Band		
	Ant.	0.66 Line	0.81 Line	Ant.	0.66 Line	0.81 Line	Ant.	0.66 Line	0.81 Line
160	256'5"	178'1"	218'1"	256'5"	178'1"	218'1"	256'5"	178'1"	218'1"
80	124'10"	86'8"	106'2"	128'3"	89'	109'	120'	83'4"	104'9"
40	65'5"	45'5"	55'8"	65'11"	45'9"	56'1"	64'7"	44'10"	54'9"
20	33'	22'11"	28'1"	33'2"	23'1"	28'3"	32'9"	22'9"	27'11"
15	22'	15'4"	18'9"	22'1"	15'4"	18'10"	21'11"	15'3"	18'8"
10	16'3"	11'3"	13'10"	16'7"	11'6"	14'1"	16'1"	11'2"	13'8"

2 —Quarter-Wavelength Vertical (Marconi)

The fundamental vertical antenna is a quarter-wavelength radiator (Fig. 3). This is not a true vertical dipole because the physical length of the antenna approximates just one-half the length of a vertical dipole. In the case of the basic quarter-wave vertical, the ground acts as a mirror quarter-wave segment (Fig. 3). Ground conditions, in fact, have a great influence on the performance of the vertical antenna. The mirror segment of the quarter-wave vertical can be ground itself, or it may be a network of wires or conducting tubing that acts as a synthetic ground. If placed on the surface of the ground or a few inches below ground, such a low-resistance conducting surface can bring about a substantial improvement in antenna performance. The use of a synthetic ground (called a ground plane) is also employed when the quarter-wavelength radiator is to be positioned high above the physical ground. In effect, the ground plane brings the ground up to the level of the antenna.

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LINE

INSULATOR

GROUND LEVEL

$\lambda/4$

$\lambda/4$ MIRROR GROUND
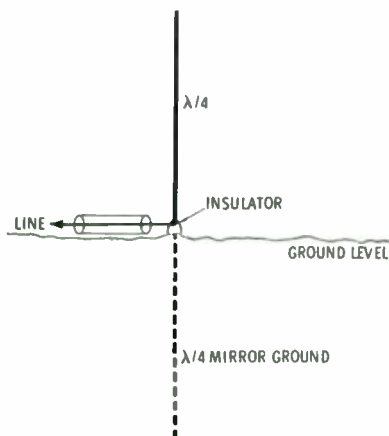
Fig. 3. Basic quarter-wave vertical antenna (Marconi).
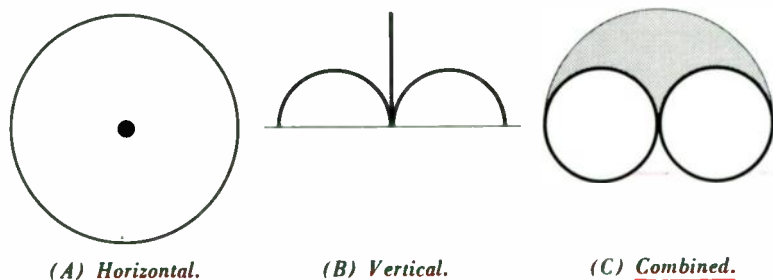
(A) Horizontal.   *(B) Vertical.*   *(C) Combined.*

Fig. 4. Patterns of a quarter-wave vertical antenna.

The radiation patterns of a quarter-wave vertical are given in Fig. 4. Note that the horizontal pattern is circular indicating the radiation of equal signals in all compass directions. The vertical radiation pattern approximates a figure eight sliced lengthwise. Note that maximum radiation is concentrated at the lower vertical angles below 45 degrees. Little energy is radiated skyward toward the zenith; in fact, the net horizontal-vertical radiation patterns is doughnut-like in appearance as shown in Fig. 4C.

The simplest quarter-wave vertical is a single rod or tube, the base of which is connected to the inner conductor of a coaxial transmission line (Fig. 5). In the least effective arrangement the outer conductor of the coaxial line is permitted to hang free at this feed point. However, if the overall length of the transmission line is made a whole multiple

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ROD OR TUBE

λ/4

COAX LINE

Fig. 5. Simple quarter-wave vertical antenna.
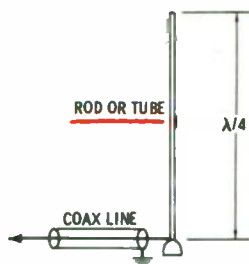
of an electrical half wavelength at the operating frequency, the antenna performs reasonably well. A better plan is to connect the outer conductor of the coaxial line to a reasonably good ground, such as a pipe (6′ or longer) driven into the ground, or a large conducting surface beneath the base of the antenna as mentioned in topic 1.

Chart 2 tabulates physical quarter-wavelength dimensions for the various segments of the radio amateur bands. The dimensions are based on an equation that takes into consideration end effect; hence, the physical lengths are somewhat shorter than the values obtained by calculating the quarter wavelength in free space. Chart lengths are based on the equation:

$$\text{Quarter wavelength} = \frac{234}{f \text{ (MHz)}} \text{ feet}$$

The theoretical value for the antenna resistance of the quarter-wave vertical is one-half that of a dipole, or 36 ohms. Actual values depend on ground conditions and other factors. Nevertheless, a good match is made to 50-ohm coaxial line. Refer to topic 1.

Chart 2. λ/4 Vertical and λ/2 Line Dimensions

	CW Bands			SSB Bands		
	Ant.	Line 0.66 VF	Line 0.81 VF	Ant.	Line 0.66 VF	Line 0.81 VF
160	128′3″	178′1″	218′1″	128′3″	178′1″	218′1″
80	64′2″	89′	109′	60′	83′4″	104′9″
40	32′9″	45′9″	56′1″	32′4″	44′10″	54′9″
20	16′7″	23′1″	28′3″	16′5″	22′9″	27′11″
15	11′1″	15′4″	18′10″	10′11″	15′3″	18′8″
10	8′4″	11′6″	14′1″	8′2″	11′4″	13′11″

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3—Quarter-Wave Vertical, Line-Tuned

A quarter-wave vertical antenna at resonance does not always present exactly 36 ohms to the transmission line because feed-point impedance is a function of type of ground and ground-plane conditions. Also the antenna impedance off the resonant frequency is other than 36 ohms. Antenna height above ground and the presence of nearby conducting surfaces also influence the antenna resistance. Even under almost ideal conditions a perfect match to 50- or 72-ohm coaxial transmission lines is not always feasible.

A rather high standing-wave ratio can develop on the line. Poor ratios should be avoided because transmitters, especially modern transceivers, are quite critical of loading. Poor standing-wave ratios are to be avoided, not so much because of added line loss, but because of improper loading of the transmitter. For short lengths of transmission line (up to 100 feet, for example), line losses with even high standing-wave ratios are quite unimportant.

A proper match at the transmitter end of the line is important for two reasons—proper loading of the transmitter and efficient operation of the antenna system. It is advisable to stay away from reactive loading of the transmitter if at all possible. This can be accomplished by cutting the length of the transmission line to an electrical half wavelength or a whole multiple of one-half wavelength (Fig. 6). In
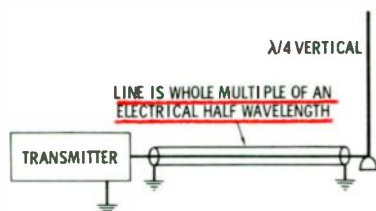
Fig. 6. Quarter-wave vertical with a trimmed and tuned line.

cutting an electrical half wavelength of line it is necessary to consider the velocity factor (VF) of the line:

$$\text{Line length} = \frac{\lambda}{2} = \frac{492 \times \text{VF}}{f \text{ (MHz)}}$$

Of course, the length of the transmission line can be any integral multiple of the above value.

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Chart 3 is based on velocity factors of 0.66 and 0.81 typical of 50-ohm and 72-ohm *regular* and *foam* type coaxial lines respectively. This information can be used to determine the line lengths which will best accommodate the separation between the transmitter and the antenna feed point. For example, if you plan to operate a quarter-wave vertical on 7.1 MHz and the approximate distance between antenna and transmitter is 100 feet, it is wise to use a length of transmission line of approximately 91 or 137 feet corresponding to either two or three electrical half wavelengths of regular RG/58U or RG/59U line:

$$\text{Line length} = \frac{650}{7.1} = 91.55 \text{ feet}$$

$$\text{Line length} = \frac{975}{7.1} = 137.3 \text{ feet}$$

Chart 1 tabulates half-wavelength lengths with 0.66 and 0.81 velocity factors for the various amateur bands.

A very precise cut cannot always be made by calculation alone because velocity factors are not always the stated values of 0.66 and 0.81 or because of discontinuities and other variables. The exact velocity factor of a given line can be obtained by measurement. or a line can be trimmed for the half-wavelength condition on some precise frequency. Techniques and procedures are given in Appendices I through V.

Chart 3. Dimensions of Half-Wavelength Line Segments for Velocity Factors of 0.66 and 0.81

Line Segments in Wavelengths	(VF = 0.66) Line Lengths in Feet Reg. RG/58U-RG/59U	(VF = 0.81) Line Lengths in Feet of Foam RG/58U-RG/59U
1/2	325/f	400/f
2/2	650/f	800/f
3/2	975/f	1200/f
4/2	1300/f	1600/f
5/2	1625/f	2000/f
6/2	1950/f	2400/f
7/2	2275/f	2800/f
8/2	2600/f	3200/f
9/2	2925/f	3600/f
10/2	3250/f	4000/f
11/2	3575/f	4400/f
12/2	3900/f	4800/f
13/2	4225/f	5200/f
14/2	4550/f	5600/f
15/2	4875/f	6000/f
16/2	5200/f	6400/f

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For multiband operation, compromise line lengths are used. In most cases a length can be found that provides a reasonable match on each band. Examples are given for many of the multiband antennas in the book.

A good compromise length for 40-, 20-, 15-, and 10-meter operation using VF-0.66 line is a whole multiple of 45 feet 6 inches. If 80-, 40-, 20-, 15-, and 10-meter operation is desired, use a whole multiple of 90 feet. When VF-0.81 line is used, a whole multiple of 56 feet provides good performance on 10 through 40. A whole multiple of 112 feet includes 80 meters.

An alternative plan is to employ a line tuner (Fig. 7). Refer to Appendix VI. Such a tuner can accommodate a random length of line
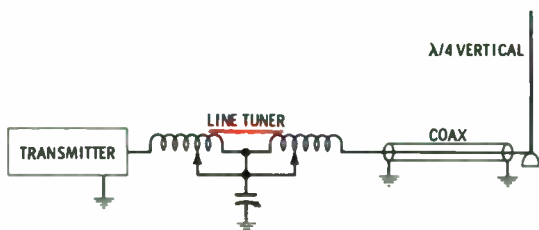
Fig. 7. Quarter-wave vertical with a line tuner.

although it is still advisable to cut near to one of the half-wavelength figures. An added advantage of the line tuner is that it can tune such a line over an entire amateur band or over a group of bands by using a tapped inductor and a variable capacitor. Such a tuner can be adjusted to present the proper resistive load to the transmitter, and it tunes out reasonable reactive components so that they are not reflected to the transmitter.

Some preferred line lengths for 10-, 15-, 20-, and 40-meter sideband and cw operation of a quarter-wave vertical are given as a part of Chart 2. Refer to topics 1 and 2.

4—Quarter-Wave Vertical With Ground System

Many quarter-wave vertical antennas have their base at or near ground level. It is the most common arrangement for 40-, 80-, and 160-meter verticals. Some 20-meter verticals are mounted in this manner and so are a few 15- and 10-meter installations.

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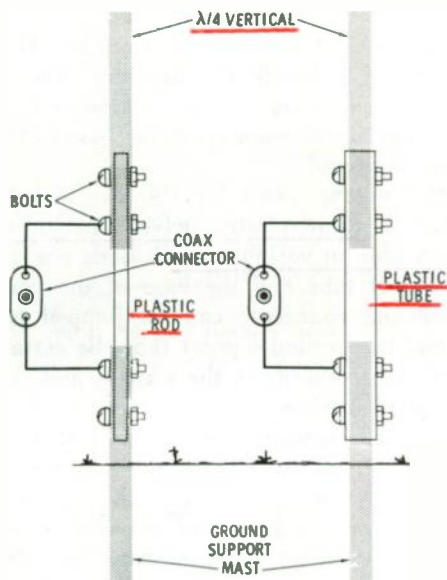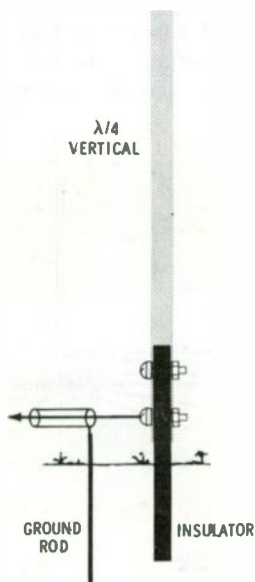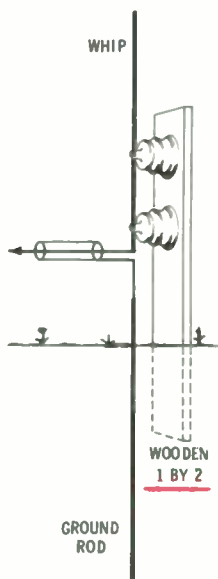
Fig. 8. Simple mounting arrangements for verticals.

The base of the vertical rests on an insulator. The ground system is installed immediately beneath the insulator. The transmission line is then attached between the base of the vertical and ground. The inner conductor of the coaxial line connects to the base of the vertical; outer braid is connected to ground.

Simple mounting arrangements for 10-, 15-, and 20-meter verticals are shown in Fig. 8. Rigid plastic, polystyrene, or composition rods and tubes are available in various sizes.* Ends are drilled and bolted to the ground-support tube and the base of the vertical antenna. A dipole-to-coax antenna connector can be jumped between the base of the antenna and the ground-support tube. Be certain that the inner conductor of the coax connects to the vertical and the braid connects to the ground-support tubing.

Short verticals can be supported by properly shaped bottles or plastic rods. The diameter of the quarter-wave vertical should then be such that it fits snugly over the insulator. The dipole-to-coax connector is then connected between the base of the vertical and a rod driven down into the ground a short distance away from the insulator. This type of support structure requires that the vertical antenna be guyed. Strong plastic clothesline with a nonmetallic core is satisfactory.

In a third arrangement the ground-level support can be wooden 2 $\times$ 4's or 1 $\times$ 2's. Standoff insulators are attached to the board, and hose or other clamps hold the mast to the spaced standoff insulators
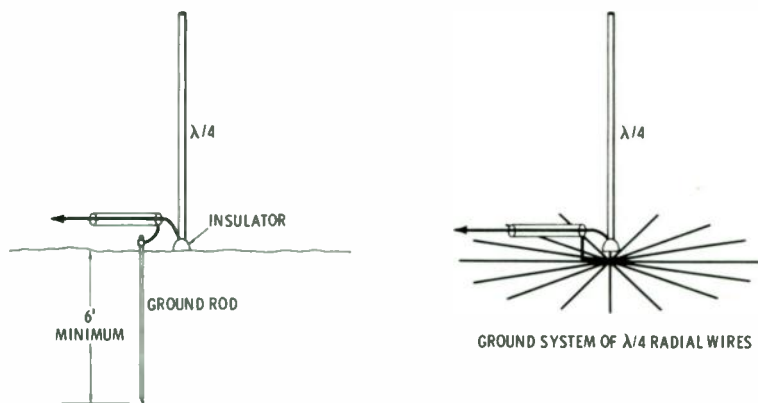
Fig. 9. Ground systems.

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*Rods, tubes and sheets are available in standard sizes and cut to order from: Plastics of Philadelphia, 12th and Arch Sts., Philadelphia, Pa. 19107.

as shown in C. Again a dipole-to-coax connector can be connected between the base of the vertical and a ground rod.

The ground system is quite important to the operation of a vertical antenna. It can be a metal rod or tube of good conductivity (6 feet or more) driven into the ground; or a better plan is to use a system of radial wires (Fig. 9). Although fewer radials are often employed, the very best performance is obtained by using at least 18 radials, each a minimum quarter wavelength long at the lowest operating frequency.

A versatile mounting arrangement for a vertical is shown in Figs. 10 and 11. Metal ground-support tubing is cemented two feet into the ground. A twelve-by-six sheet of $\frac{3}{8}$- or $\frac{1}{2}$-inch plexiglas or other strong insulation is fastened to the top of the ground-support tubing
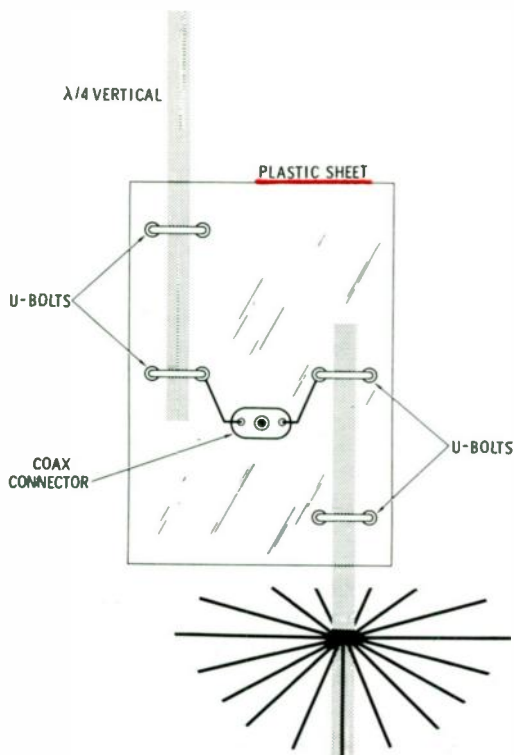
Fig. 10. Vertical mounting with plastic-sheet insulator.

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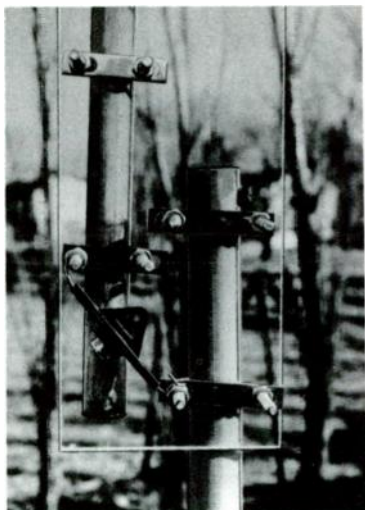
with U bolts. Another pair of U bolts fastens the bottom of the vertical to the insulator. The dipole-to-coax connector is fastened between radiator and ground-support U bolts. This manner of connection raises the radiator above physical ground (at least above the high snow mark).

Ground-level radial wires are extended out from the support mast. Minimum length from the top of the ground-support mast to the end of each radial should be at least one-quarter wavelength at the lowest operating frequency. The radials can be buried one or two inches below the surface.

An alternative plan for the radial system can be to run a system of resonant radials out from the top of the ground-support mast as shown in Fig. 12. These radials slope away from the feed point and can help in obtaining the most favorable antenna impedance. Note that there are insulators at the far ends. Overall length corresponds to a quarter wavelength at the lowest operating frequency. A minimum of four resonant radials should be employed.

The fundamental equation for the quarter-wave vertical is $234/f$. However, a number of factors affect this length, although it is reasonably correct for small diameter tubing, thin metal rods, and antenna wire. However, if larger-diameter tubing ($1\frac{1}{4}$-inch and larger) is used, the physical length is somewhat shorter than the calculated electrical quarter wavelength. In fact, the resonant length may be 2 to 10 percent shorter than the $234/f$ formula value.

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Fig. 12. Resonant quarter-wave radials for vertical antenna.

Guys also have a pronounced effect on the resonant length of a vertical antenna because they are attached near the top of the vertical. This is a high-impedance (maximum voltage and minimum current) point. Thus stray capacitances and loading influences can be significant.

If wire guys are used they must be segmented with separations preferably less than $\frac{1}{8}$ wavelength at the highest operating frequency. Insulators should be present right at the point where the guy wires attach to the guy ring. Better still, make your guy ring out of plastic or other insulating material. Guys can give you considerable trouble in setting to a particular resonant frequency and in establishing a very low standing-wave ratio. Refer to topics 1, 2, and 3.

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5—10-15-20 Quarter-Wave Vertical and Ground System

The vertical antenna pattern is omnidirectional and has a low vertical angle of radiation, sending out signals uniformly in all compass directions. Similarly it displays a uniform pick-up sensitivity to signals arriving from various directions.

The low vertical angle of radiation is an important advantage for DX contacts on the 10-, 15-, and 20-meter bands. Although the signal radiated from a vertical antenna is essentially the same at all compass angles, it is radiated at an angle which is almost horizontal to the surface of the earth. This low angle of radiation is advantageous for long-distance communications.

The dimensions of a quarter-wave vertical for operation in the sideband segments of the 10-, 15-, and 20-meter bands are as follows:

(10) $\text{Antenna length} = \dfrac{234}{f \text{ (MHz)}} = \dfrac{234}{28.6} = 8'2''$

(15) $\text{Antenna length} = \dfrac{234}{f \text{ (MHz)}} = \dfrac{234}{21.3} = 11'$

(20) $\text{Antenna length} = \dfrac{234}{f \text{ (MHz)}} = \dfrac{234}{14.2} = 16'6''$

When the vertical antenna is made an above specified length, it becomes resonant and displays a low resistive impedance at its base which is of a value that provides an efficient transfer of signal between the coaxial transmission line and the antenna. If the basic antenna is to be operated on each of the three bands it is necessary to include some means of changing the physical length. This can be accomplished by cutting individual lengths and making it possible to slip the vertical radiator into position at the mounting position according to the desired operating band. As a matter of fact, sections of telescoping tubing can be employed, and the overall length of the vertical radiators can be varied to obtain resonance on the desired band and any frequency within that band. Inexpensive telescoping masts used for television receiving antennas can be modified and used as effective vertical radiators. Such telescoping sections can be suitably scribed to permit greater ease in finding specific resonant points.

The mounting arrangement shown in Fig. 11 and discussed in topic 4 is an admirable set-up for changing vertical radiators quickly.

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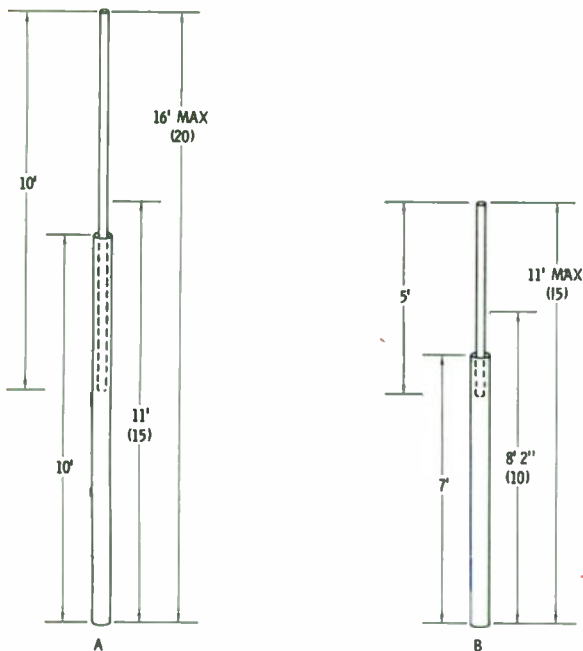
Fig. 13. Dimensions for telescoping two-band antennas.

Dimensions for the two radiators that provide three-band operation are given in Fig. 13. Operation on 10 and 15 meters was accomplished by telescoping a five-foot section of tubing into a seven-foot section. Minimum and maximum possible lengths are seven and twelve feet, and operation on any frequency within the 10- or 15-meter bands is possible. (This vertical will also accommodate the Citizen's band frequency assignment near 27 MHz.)

Twenty-meter operation is possible using a 10-foot or shorter section of tubing telescoping within another 10-foot segment. The exact sideband length of 16'6" can be telescoped or a length that resonates in any part of the 20-meter band. (It will also tune into the 15-meter band.) It is best to guy the 20-meter vertical as shown in Fig. 14. Guys can be released at ground level whenever the 20-meter vertical is to be removed from its mounting position. The 20-meter vertical was made from a 20-foot telescoping television antenna. The 10/15-meter combination was made by cutting down a similar mast to the dimensions of Fig. 13. It was not necessary to guy the 10/15-meter

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arrangement. The length of the transmission line is 45'6" (can be any whole multiple thereof).

Using the large-diameter telescoping tubing, practical lengths are shorter than equation values shown in Fig. 13. The techniques of Appendices IV and V are recommended for locating resonance and measuring SWR. Refer to topics 1, 2, 3, and 4.

6 —Elevated Quarter-Wave Vertical With Wire Ground Plane

An elevated quarter-wave vertical is very effective if a good conducting ground (ground plane) is directly beneath its base. The arrangement of Figs. 15 and 16 shows a simple plan employing inexpensive telescoping tubes. To construct such an antenna for 10 meters the top 10-foot telescoping section is cut down to 8'2". A plastic rod acts as an insulator and joins this radiator physically with the short remaining piece of the top section. The coaxial receptacle is connected between the two segments.

The ground plane consists of four resonant wire radials that are connected to the top of the next section of the telescoping mast. These

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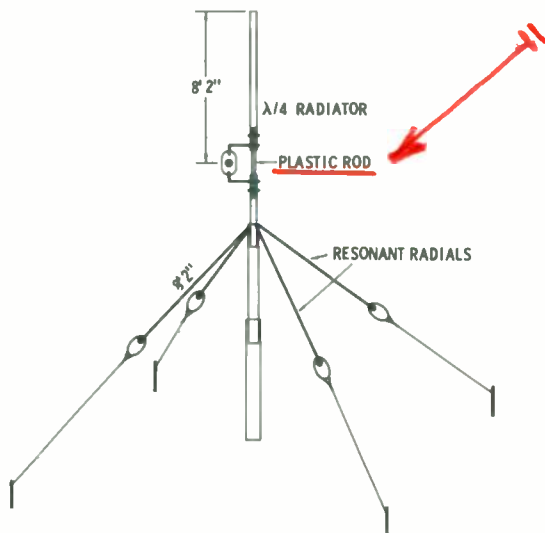
Fig. 15. Elevated quarter-wave vertical.

Fig. 16. Rod insulator and coax receptacle for elevated quarter-wave vertical.
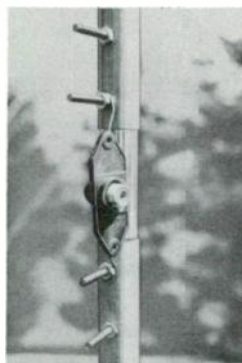
four radials also serve as guys for the mast. As a function of overall height, additional lower guying may be necessary. Refer to topics 2, 3, 4, and 5.

7 —Base-Loaded Quarter-Wave Vertical

The quarter-wave vertical is a resonant antenna with its physical length determining its resonant frequency. A vertical antenna can be

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made resonant on wavelengths substantially longer than its physical length with the addition of a coil at its base. The resonant frequency depends on the physical length of the radiator and the inductive reactance contributed by the coil. If such an antenna is mounted at or near ground level, taps on the coil can be used to change the resonant frequency of the antenna.

Only a single-tap coil of proper size is needed for one-band operation. The inner conductor of coaxial line is tapped to a point that provides an impedance match (Fig. 17A).

(A) Single-band operation.　　　(B) Multiband operation.
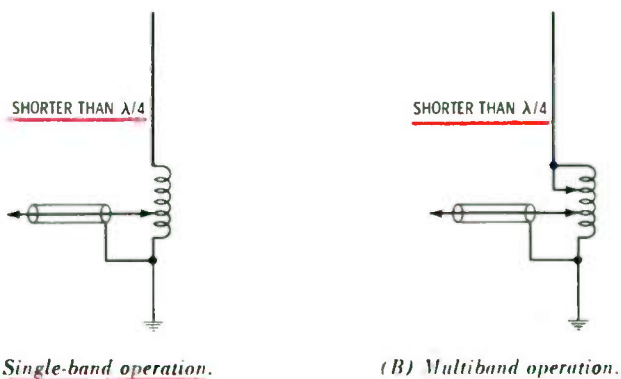
Fig. 17. Base-loaded quarter-wave verticals.

If the antenna is to be operated on other frequencies and other bands, it is more appropriate to use two taps as shown in Fig. 17B. In this case the top tap has the more pronounced effect on the resonant frequency of the antenna while the bottom tap has more responsibility in obtaining a proper match. A convenient mounting arrangement is shown in Fig. 18. A plastic-rod insulator is employed and the coil is made to span the separation between the radiator and the ground-support tubing. The mounting arrangement of Fig. 11 is also adaptable to the use of a base-loading coil, connecting the coil between one of the U bolts supporting the radiator and one associated with the ground-support mast.

Good operation on two or three adjacent amateur bands is possible with the base-loaded vertical. An antenna that is cut as a quarter-wave vertical on 10 meters can be operated on 15 and 20. Another possible combination is a 20-meter radiator that operates on 40 and 80.

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Fig. 18. Loading coil connected between base of vertical and ground-support tubing.
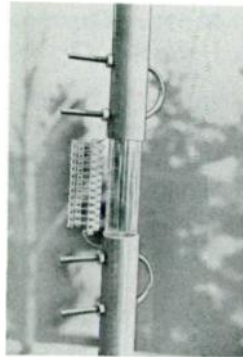
Length and coil data are given in Fig. 19. Approximate tap positions are also indicated although these may have to be adjusted according to mounting position and overall length of transmission line. Again it is helpful to use a length of transmission line that approximates an electrical half wavelength at the desired operating frequencies. Refer to topics 1, 2, 4, and 5.
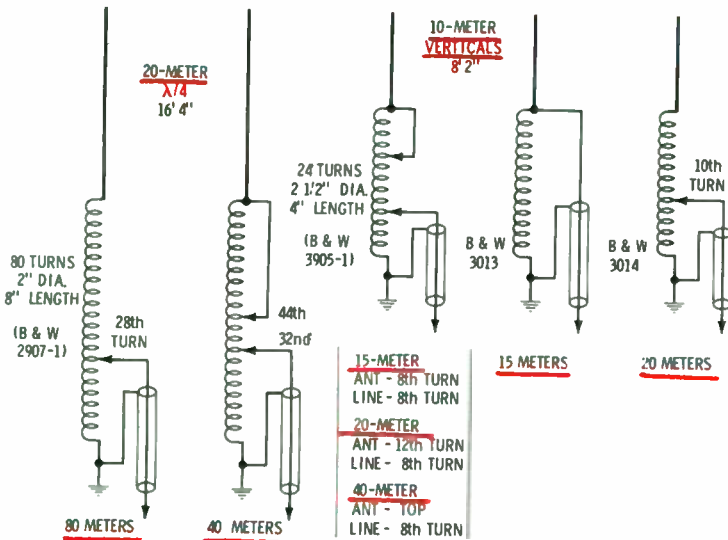
Fig. 19. Loading-coil data.

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8 —20-Meter Quarter-Wave Vertical, Multiband Operation

The length of a 20-meter quarter-wave vertical is also convenient for multiband operation in conjunction with a simple line tuner (Fig. 20). This length permits excellent performance on 10 and 15 meters using the simple line tuner detailed in Appendix VI. The antenna is approximately one-half wavelength on 10 and 15 meters and provides low vertical radiation angles.
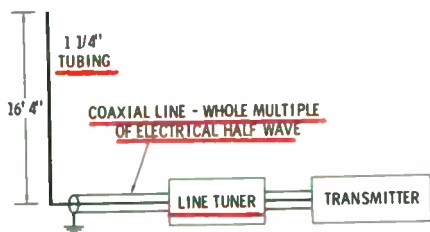
Fig. 20. Twenty-meter vertical with line tuner.

The same antenna also loads and performs satisfactorily on 40 meters and permits acceptable 80-meter operation as well.

The line tuner can be positioned at the transmitter or, if the antenna is mounted at or near ground level, at the antenna base. In the latter arrangement the SWR on the line can be held down to a lower value, which is helpful when line length exceeds 100 feet. Again the technique for using a length of transmission line corresponding to whole multiples of an electrical half wavelength improves line conditions. Refer to topics 1, 2, 3, 4, and 6.

9 —Elevated 40-Meter Ground Plane

On the low-frequency bands (40, 80, and 160), a high percentage of DX contacts are made with one or both of the stations using a vertical antenna. The vertical antenna has an inherent low angle of radiation, while horizontal antennas must be higher than a half wavelength above ground and preferably a full wavelength to obtain good low-angle emission. Such heights are seldom feasible for amateur operations on the low-frequency bands.

The characteristics of the vertical antenna are used to best advantage when operated above a high-conductance ground. When the vertical antenna has its base at ground level, a radial system buried an inch

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or two below the ground is ideal. A minimum of twelve radials should be employed. If the vertical antenna is to be elevated, a minimum of six resonant radials (ground plane) is advisable.

A typical elevated-ground-plane vertical for 40 meters is shown in Fig. 21. The mast itself can be a guyed telescoping mast or a self-
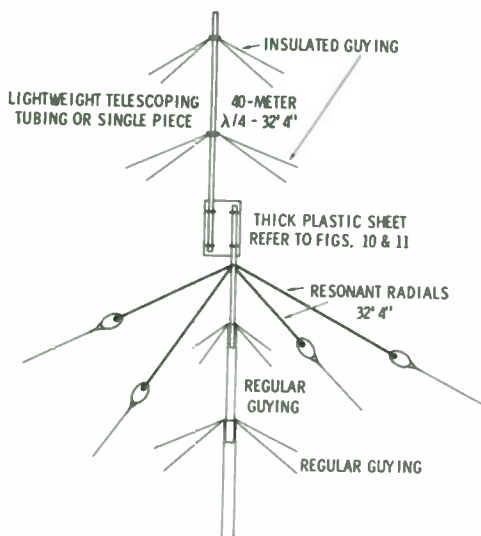
Fig. 21. Elevated ground-plane vertical for 40 meters.

supported structure. The base insulator can be a plastic sheet with a thickness of ½ inch or greater. The radial system is attached at the top of the support mast directly below the insulator.

The quarter-wave vertical can be made of telescoping aluminum tubing and suitable insulated guying using plastic clothesline. Mounted on top of a forty- or fifty-foot mast, this antenna does an excellent job. It also performs well on 10, 15, and 20 with the use of the simple line tuner of Appendix VI. It is approximately a half-wavelength vertical on 20, ¾ wavelength on 15, and something less than a full wavelength on 10.

It loads well using the tuner as a ⅛-wavelength antenna on 75. Standing-wave ratios on all bands using the tuner of Appendix VI are below 1.5 to 1. Refer to topics 2, 3, 4, 6, and 8.

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10—Vertical Radiators and Base Tuner

The electrical length of a vertical antenna can be increased by the use of a base coil, or decreased by use of a base capacitor (Fig. 22). Thus a vertical antenna can be resonated to a lower frequency with the addition of a coil and to a higher frequency with the addition of a capacitor. If one makes the base coil adjustable, a short antenna can be made resonant to frequencies substantially lower than its resonant frequency. Refer to topic 7. Capacitance can be used for resonating antennas to higher frequencies than their resonant length.

λ/4 ON 20
16' 4"
λ/4 ON 40
32' 4"
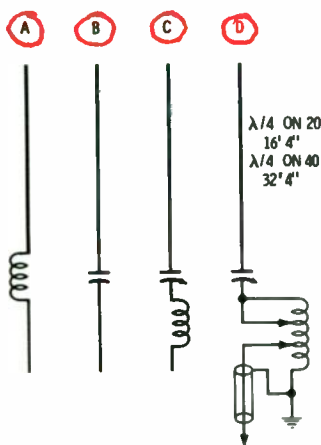
Fig. 22. Plan of base tuner for vertical radiators.

A series combination of capacitor and inductor (Fig. 22C) can tune an antenna over a substantial range of frequencies. Short jumpers can be used to remove the capacitor or the inductor according to which frequency side the antenna is to be loaded.

A versatile base tuner can be evolved by the use of a variable capacitor and an inductor with two taps (Fig. 22D). Such a base tuner for vertical radiators is detailed in Appendix VIII.

The base tuner attached to the base of a 20-meter quarter-wave vertical permits operation on bands 10 through 80. When connected to the base of a 40-meter quarter-wave vertical, operation is feasible on bands 10 through 160 meters. Standing-wave ratios are less than 1.5-to-1. Refer to topics 2, 3, 4, and 8.

1/2- and 5/8-Wavelength Verticals

11 —Half-Wavelength Verticals

Additional gain and lower vertical radiation angles can be obtained by increasing the length of a vertical antenna. This improvement is shown in Fig. 23. Compare the vertical radiation pattern for a half-

Fig. 23. Influence of length of vertical radiator on vertical pattern.
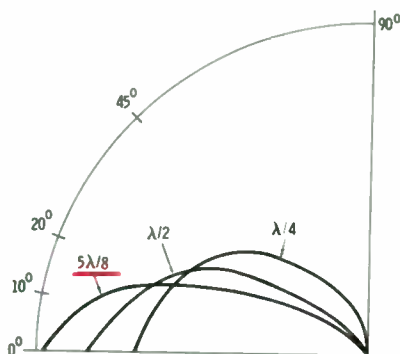
wavelength antenna with that of a quarter-wave radiator. The response extends out further at low angles (between 0° and 15°). The lower angles are a particular advantage in making DX contacts. In general, vertical radiators have the advantages of low vertical angles along with omnidirectional horizontal patterns.

Three basic constructions for the half-wavelength vertical antenna are given in Fig. 24. The plastic-rod construction is feasible for 10-, 15-, and 20-meter antennas made of small-diameter light-weight tubing.

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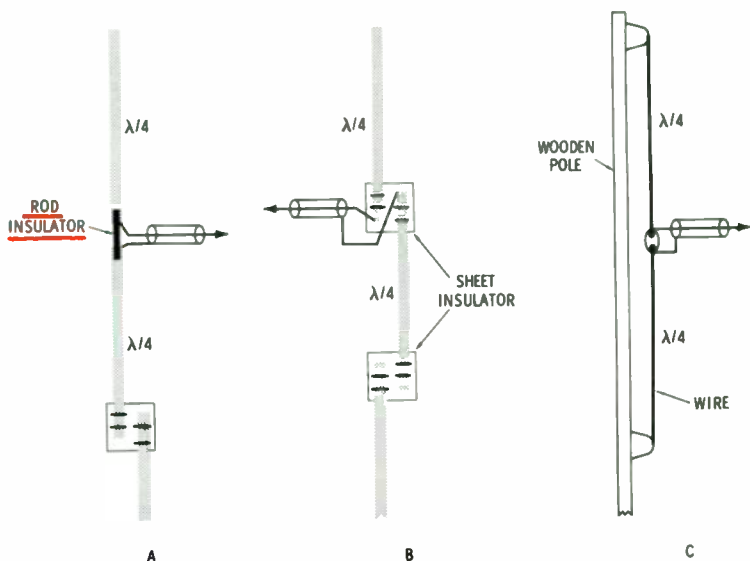
Fig. 24. Arrangements for half-wave vertical antennas.

Near-top guying is deemed advisable for the 10- and 15-meter antennas, while it is a wise practice to guy the 20-meter version at the center and the top.

When larger diameter tubing is employed, the plastic-sheet insulators permit a more substantial construction. Similar guying is also needed with the larger tubing.

Since it is easy to lift the vertical antenna from its base mount, two-band models can be constructed either for 10-15 or 15-20 operation. The arrangements covered in topic 5 are appropriate except that there must be two telescoping sections to form a complete half-wavelength antenna. Feed-point impedance is near 70 ohms and the half-wavelength antenna matches up with fewer difficulties than the quarter-wave radiator.

The vertical antenna, too, can be constructed from antenna wire (sizes 12 to 18 are popular). Such an antenna can be suspended between any insulated high point and ground, or between suitable insulators mounted on a rigid mast (Fig. 24C).

A line tuner (Fig. 25) permits acceptable operation of this antenna style on more than one band. Cut for 20-meter operation, a line tuner produces good results on both 10 and 15 meters. The antenna can

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Fig. 25. Half-wave vertical with line tuner.
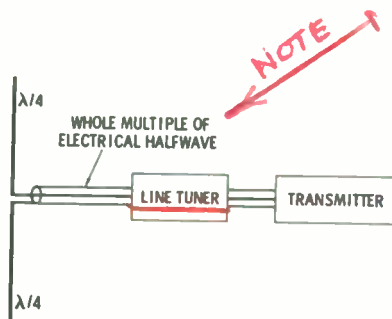
also be loaded reasonably well as a short antenna for 40 and 80 meters using the line tuner of Appendix VII. Refer to topics 1, 2, 3, 4, and 5.

12 —Half-Wave Vertical With Balanced Line

Half-wave vertical antennas like horizontal dipoles can also be fed in a balanced manner to attain more uniform radiation off of each side and minimum line radiation. One method is to use a 1-to-1 balun as shown in Fig. 26. In feeding half-wavelength antennas the transmission line should be routed directly away from the antenna if this is feasible. In a practical situation it is usually necessary to run the transmission line down alongside the lower quarter-wave segment. In this case the line should be held away from the element as far as is practical. Long stand-off insulators can even be attached to the element near the feedpoint and at about mid-position. It is advisable not to attach standoffs near the end where there is a voltage maximum.

A balanced transmission line such as good quality 300-ohm televi-
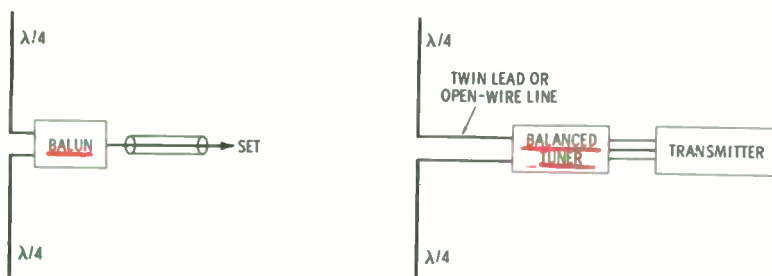
(A) Using a balun at the antenna.   *(B) Using a balanced tuner.*

Fig. 26. Balanced feed systems for half-wave vertical antennas.

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sion line can be employed. In this arrangement a tuner with a balanced input is needed (Fig. 26B). Refer to Appendix VII. In this feed method there is a mismatch at the antenna. However, losses are not serious because of the lower attenuation of good-quality 300-ohm line.

An advantage of the use of 300-ohm line along with the balanced tuner is that the antenna can also be loaded on other bands. If the antenna is cut for 20 meters, good results are obtained on both the 10- and 15-meter bands. SWR does not exceed 1.5 to 1. It is also possible to load the antenna on 40 meters. Refer to topics 2, 3, 4, and 11.

13 –Half-Wave Coaxial Vertical

The coaxial vertical construction (Fig. 27) affords a convenient means of feeding a half-wavelength vertical antenna. Note that the top quarter-wave section connects to the inner conductor of the
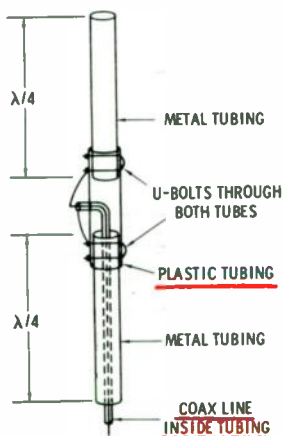
Fig. 27. Coaxial half-wave vertical.

coaxial transmission line. The braid of the coaxial line connects to the bottom quarter-wave segment at the feed point. There is no connection between the bottom of the lower section and the transmission line, the line simply feeding up through the center of the tubing.

This arrangement reduces the interaction between the transmission line and the radiating vertical antenna. In fact, the bottom quarter-wave section also acts as a transformer, changing over between the

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unbalanced coaxial transmission line and the balanced half-wavelength antenna.

It is permissible to connect the bottom section to a small-area metallic support structure. However, in practice a more favorable match results when it is kept free.

Fig. 28. Coaxial vertical showing plastic tubing and aperture for coaxial line.
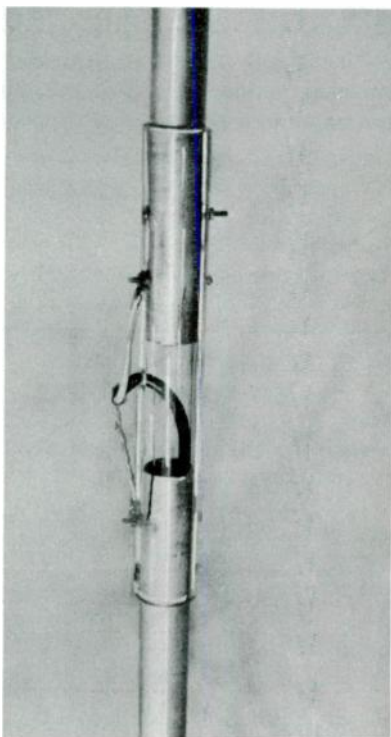
A typical 10-meter coaxial vertical is shown in Fig. 28. The insulator is made of thick-wall plastic tubing with the appropriate inner diameter to permit a snug fit over the metal tubing of the antenna elements. Straight bolts or U bolts fasten the elements to the plastic tubing.

A single hole at the center of the length of plastic tubing serves as an aperture for the coaxial transmission line. Soldering lugs and additional nuts connect the inner conductor and braid of the coaxial line to the upper and lower quarter-wave elements.

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A line tuner provides an optimum match and is usually advisable when the bottom quarter-wave section is held in place with some form of metallic support. If the antenna is mast-mounted, a plastic-sheet arrangement can be used to insulate the bottom of the lower section from the mast (Fig. 11). Refer to topics 2, 3, 4, 8, and 11.

14 — ⅝-Wavelength Vertical

The ⅝-wavelength vertical is a preferred length for the best low-angle radiation (Fig. 23). A fundamental equation for calculating the length of a ⅝-wavelength vertical is:

$$⅝\text{-wavelength vertical (feet)} = \frac{585}{f \, (\text{MHz})}$$

Typical dimensions for sideband or cw operation are:

Band	CW	SSB
10 Meters	20'10"	20'6"
15 Meters	27'9"	27'6"
20 Meters	41'6"	41'

A long vertical of this type can be used to best advantage with the use of a line tuner or base tuner (Fig. 29). When a base tuner is used the standing-wave ratio on the entire line can be held to a low value. A base tuner is recommended, especially when the length of line between the antenna and the transmitter is long (over 100 feet). The advantage of the line tuner is that it can be adjusted from the shack.
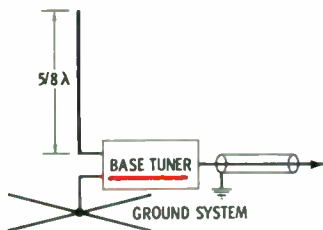
(A) Base tuner arrangement. (B) Use of a line tuner.
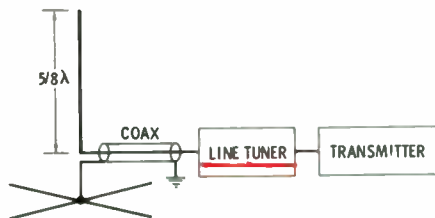
Fig. 29. Arrangements for tuning the ⅝-wavelength vertical.

The use of either type tuner also permits multiband operation. In fact, a vertical cut for ⅝ wavelength on 10 meters has an electrical length not too much shorter than this value on 15 meters, and it functions as a quarter-wave vertical on 20 meters with just a little base loading. Good low vertical radiation is feasible on all three DX bands. Refer to topics 2, 3, 4, 7, 8, and 10.

15 —Three-Quarter Wavelength Vertical

The three-quarter wavelength vertical is only ⅛-wavelength longer than the ⅝-wavelength vertical of topic 14. There is some slight deterioration of the low-angle vertical pattern but this is not serious. Furthermore, some high-angle radiation also occurs. This could be advantageous for local coverage. The advantage of the ¾-wavelength dimension is the fact that a low-impedance point exists at the base of the radiator.

Fundamental equation is:

$$\text{¾ wavelength (feet)} = \frac{702}{f\,(\text{MHz})}$$

Typical dimensions for sideband and cw operation are:

Band	CW	SSB
10 Meters	24'10"	24'6"
15 Meters	33'3"	32'11"
20 Meters	49'10"	49'3"

In conjunction with a quarter-wavelength ground support or a set of quarter-wavelength resonant radials, a good direct match is made to a coaxial line (Fig. 30A). An electrical quarter wavelength at the base can also be provided by the antenna base tuner covered in topic 9 and Appendix VIII.

The ¾-wavelength vertical cut for 15-meter operation is very attractive. Good low-angle performance is still feasible on 10 meters while the antenna is long enough to function as a quarter-wave vertical on 40 (Fig. 30B). On 20 meters it approximates half-wavelength vertical performance with its good low vertical angle. In conjunction with 40-meter resonant radials it can provide a low-impedance direct feed

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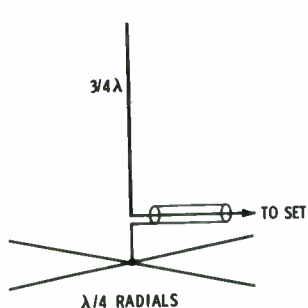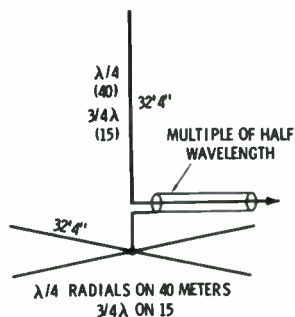
(A) ¾-wave direct match.　　　(B) Multiband operation.

Fig. 30. Three-quarter wavelength vertical.

to a coaxial transmission line on both 15 and 40 meters. Use a line or base tuner for all-band matching. Refer to topics 2, 3, 4, 8, 10, 11, and 14.

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SECTION 3

Phased Verticals

16 —Quarter-Wave End-Fire Pair, 90°

Two or more vertical antennas can be operated as a single antenna system to obtain additional gain and a directional horizontal radiation pattern. Two vertical antennas can be combined in three different ways (Fig. 31). These are known as end-fire, broadside, and collinear groupings. In the broadside arrangement the two verticals are fed in phase, and a figure-eight pattern results that is broadside to the plane of the verticals. In an end-fire configuration, the two verticals are fed out of phase and the figure-eight pattern is in line with the two antennas. A collinear arrangement stacks one vertical antenna above the other. This latter arrangement is not practical for the low-frequency amateur bands. (Occasionally half-wavelength verticals are stacked one above the other for 10- or 15-meter operation.)

An end-fire pair of verticals can be spaced and fed in such a manner that a unidirectional pattern results. To do so the antennas must be separated by a quarter wavelength and one vertical must be fed 90° behind the other (Fig. 32). The direction of maximum radiation is in line with the two verticals in the direction of the vertical receiving the lagging excitation. The 90° lag is obtained by feeding the one vertical through an additional quarter-wave section of line or an appropriate odd multiple of a quarter wavelength (Fig. 33).

A second method is to locate the junction at some point between the individual feed lines to the verticals. Connect an electrical quarter wavelength of line between the junction and one vertical and a half-wavelength section between the junction and the second vertical.

The simple feed method of Fig. 33A presents a problem because of the velocity factor of the transmission line. For example, for 15-meter sideband operation, the separation between the two verticals

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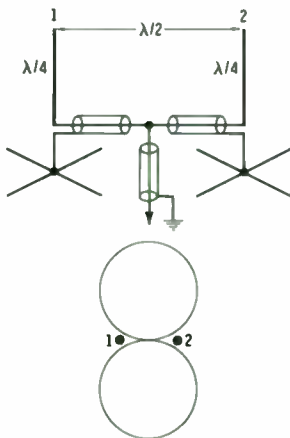
(A) Broadside.
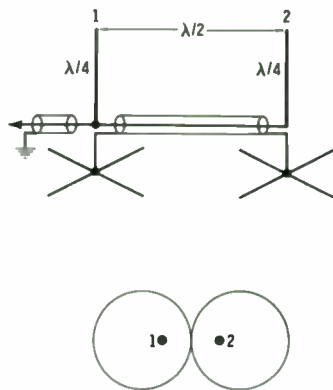
(B) End fire.
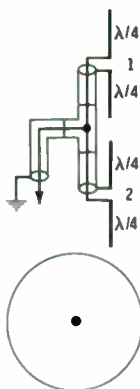
(C) Collinear.

Fig. 31. Basic two-element phased verticals.

should be approximately 11′6″ (246/21.3). However, a section of coaxial transmission line spans between the two verticals and would be longer than an electrical quarter wavelength because of its velocity factor. The calculation indicates only 7′7½″ ($\frac{246 \times 0.66}{21.3}$) as being an electrical quarter wave. This problem can be overcome by using a ¾-wavelength section of transmission line between the two verticals. In our example this would be 22′10″ ($\frac{738 \times 0.66}{21.3}$).

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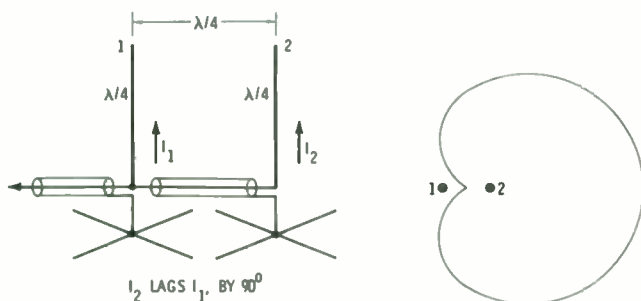
Fig. 32. End-fire 90° verticals.
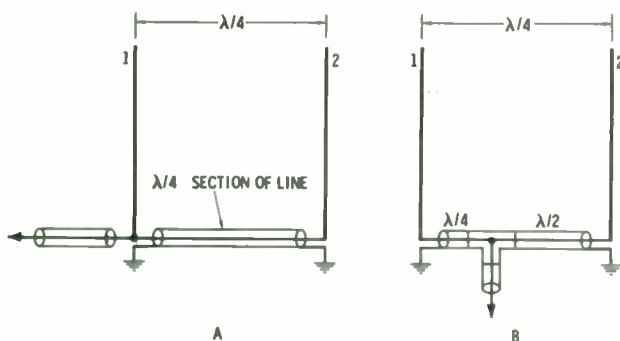
Fig. 33. End-fire 90° feed methods.
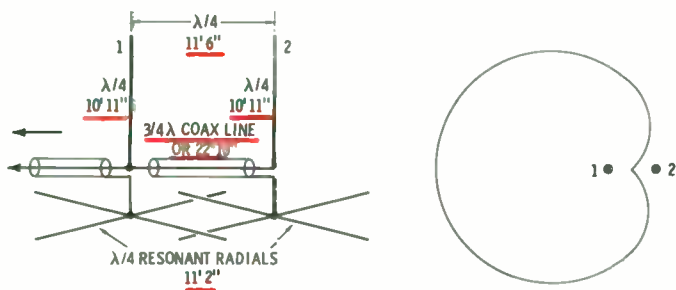
Fig. 34. Practical 15-meter end-fire vertical.

Change occurs in the horizontal directional pattern with the maximum being in the direction of the first vertical rather than away from it. This is shown in Fig. 34.

The length of the interconnecting transmission line would need to be 5/4 wavelength long to have the same pattern as that obtained with a one-quarter-wavelength line between the two verticals. An electrical 7/4-wavelength line would establish the same pattern as a 3/4-wavelength feed section, etc.

Chart 4 tabulates a considerable amount of useful information in the planning of phased verticals for use in 10-, 15-, 20-, and 40-meter operations. Quarter-wave spacing distances are given as well as coaxial cable lengths for ¼ and ¾ odd multiples of a quarter wavelength.

When the velocity factor of the transmission line is not known it can be measured using the techniques described in Appendices I, II, and III. Remember, when measuring to an *odd multiple* of a quarter wavelength, the opposite end of the line should be *open*; while measuring and cutting to an *even multiple* of a half wavelength, the far end of the line should be *shorted*.

The practical 15-meter end-fire vertical of Fig. 33 mounted at ground level ensures a low angle of vertical radiation and a directional horizontal pattern. In effect, the use of phased verticals gives horizontal directivity to the fundamental vertical antenna and its inherent low angle of radiation. These advantages are used most effectively when a good ground system is employed.

For direct feed without the use of a line tuner, either resonant radials or a pipe ground driven down 6 feet is recommended. In most phased vertical configurations tried, the lowest SWR was obtained using resonant radials elevated or, just a few inches above ground for ground-level mounting. Use at least six radials for each vertical and *do not* join them together electrically except at the base.

Chart 4. End-Fire Dimensions

	Antenna	Spacing	Phasing			
			0.66 Line		0.81 Line	
	λ/4	λ/4	λ/4	¾λ	λ/4	¾λ
Equations	**234/f**	**246/f**	**162.3/f**	**487/f**	**199.2/f**	**598/f**
10 Meters (28.6 MHz)	8'2"	8'7"	5'9"	17'1"	6'11"	20'11"
15 Meters (21.3 MHz)	10'11"	11'6"	7'8"	22'10"	9'4"	28'1"
20 Meters (14.2 MHz)	16'6"	17'4"	11'4"	34'3"	14'1"	42'1"
40 Meters (7.2 MHz)	32'6"	34'1"	22'6"	67'8"	27'8"	83'1"

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A large-area ground (1 to 2 inches below ground surface) extending out at least a quarter wavelength from each vertical also provides an acceptable match. At least 12 radials should be used. Do not join the systems electrically.

A good ground keeps the SWR below 1.5 to 1. Higher ratios are also tolerable if they are not excessive; otherwise a base or line tuner should be used. An advantage of a tuner is that it also permits loading on other bands although the resultant horizontal pattern may be quite indefinite. It will become increasingly omnidirectional as one operates on lower and lower frequency bands.
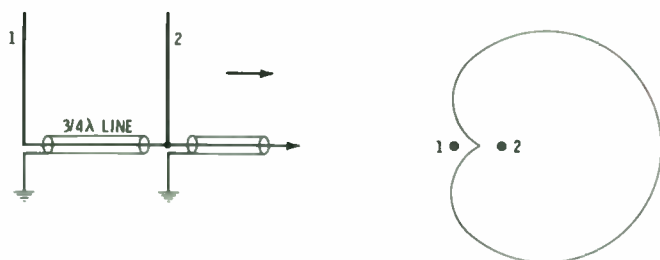
Fig. 35. Influence of feed point on pattern. Compare with Fig. 34.

Two simple means can be used to change the 90° end-fire directivity (Fig. 35). A 180° turnabout is possible by changing the transmission line feed point from one vertical to the other. Another technique is to set up several mounting positions for the one vertical. It can then be moved about from one position to another to favor a given direction. It is to be noted that the end-fire pattern is rather broad while the back-radiation is very much lower. Refer to topics 1, 2, 3, 4, and 8.

17—Quarter-Wave End-Fire Verticals, 180°

A bidirectional figure-eight pattern is obtained when verticals are separated by a half-wavelength and fed out of phase, (Fig. 36). Dimensions for 15-meter operation are given.

Two alternatives are given for the bidirectional arrangement. If the spacing is to be maintained at a half wavelength, a half-wavelength section of coaxial line does not span between the two verticals. The

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answer to the problem is to use an intervening section of transmission line that is an electrical three-halves wavelength. Figures shown are for a velocity factor of 0.66. Additional data is given in Chart 5.
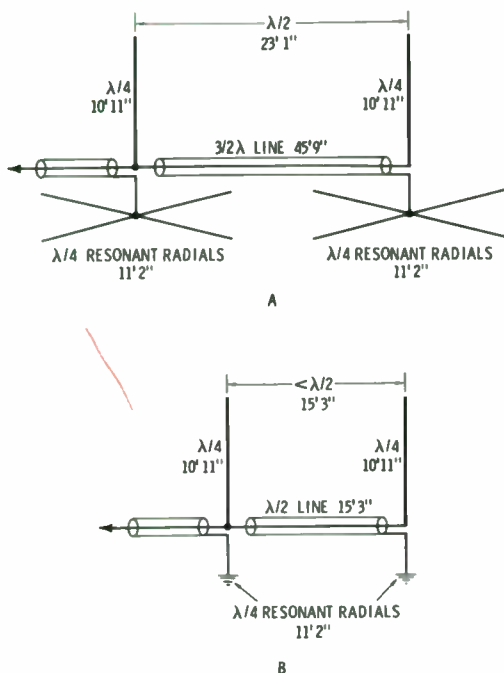
Fig. 36. Two-element end-fire 180° connections.

If a bit less bidirectional gain and a somewhat broader pattern are acceptable, the spacing between the two verticals can be reduced to accommodate the required physical length of an electrical half-wave section of coaxial line. If the foam-type coaxial line is used, the separation between the two verticals can be greater because of its higher velocity factor. Refer to topics 2, 3, 4, 8, and 16.

18 —Quarter-Wave Broadside

A figure-eight pattern that is broadside to the plane of a two-element vertical can be obtained by feeding the two verticals in phase (Fig. 37). An easy method of in-phase feeding is shown in A. The T-junction

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Chart 5. Dimensions for Phased Verticals

Equations	Antenna λ/4 234/f	Spacing λ8 123/f	λ/4 246/f	λ/2 492/f	0.66 VF Line 45° 1/8λ 81.2/f	90° 1/4λ 162.4/f	135° 3/8λ 244/f	180° 1/2λ 325/f	225° 5/8λ 406/f	270° 3/4λ 487/f	360° 1λ 650/f	540° 3/2λ 975/f
10 Meters (28.6 MHz)	8'2"	4'3½"	8'7"	17'2"	2'11"	5'9"	8'9"	11'4"	14'4"	17'1"	22'8"	34'
15 Meters (21.3 MHz)	10'11"	5'9"	11'6"	23'	3'10"	7'8"	11'6"	15'3"	19'	22'10"	30'6"	45'9"
20 Meters (14.2 MHz)	16'6"	8'8"	17'4"	34'8"	5'8"	11'4"	17'	22'10"	28'6"	34'3"	45'8"	67'8"
40 Meters (7.2 MHz)	32'6"	17'1"	34'1"	68'2"	11'3"	22'6"	33'9"	45'2"	56'4"	67'8"	90'4"	135'6"

Equations	Antenna λ/4 234/f	Spacing λ/8 123/f	λ/4 246/f	λ/2 492/f	0.81 VF Line 45° 1/8λ 99.6/f	90° 1/4λ 199.2/f	135° 3/8λ 299/f	180° 1/2λ 398/f	225° 5/8λ 498/f	270° 3/4λ 598/f	360° 1λ 796/f	540° 3/2λ 1194/f
10 Meters (28.6 MHz)	8'2"	4'3½"	8'7"	17'2"	3'6"	6'11"	10'6"	14'	17'6"	20'11"	28'	42'
15 Meters (21.3 MHz)	10'11"	5'9"	11'6"	23'	4'8"	9'4"	14'	18'8"	23'4"	28'1"	37'4"	56'
20 Meters (14.2 MHz)	16'6"	8'8"	17'4"	34'8"	7'1"	14'1"	21'3"	28'	35'2"	42'2"	56'	
(40 Meters (7.2 MHz)	32'6"	17'1"	34'1"	68'2"	13'10"	27'8"	41'6"	55'3"	69'2"	83'1"	110'6"	

is located an equal distance from each of the verticals (Fig. 37A). Hence they are excited in phase. An alternative plan uses an electrical full wavelength of coaxial line between the two verticals as shown in Fig. 37B. The velocity factor must be considered. Typical dimensions for 20-meter operation are given. Data for other bands can be gleaned from Charts 4 and 5.
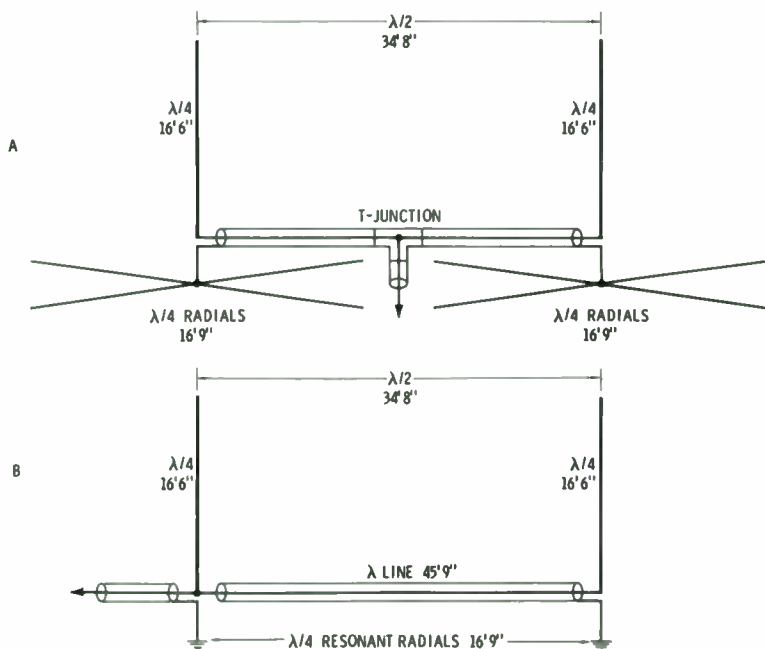
Fig. 37. Two-element broadside connections, 20 meters.

Ground system is again of special importance for obtaining good performance and a direct match. If preferred, a line tuner can be employed, reducing the standing wave at the transmitter to a very low value. If the SWR is high, a line tuner is essential. The line tuner can be positioned at the transmitter or just before the T-junction point. This latter arrangement is helpful in keeping the standing-wave ratio on the line at a low value and is of significance when there must be a long length of line between the antenna system and the transmitter. Refer to topics 2, 3, 4, 8, 16, and 17.

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19—Multiband Broadside With Tuner

The in-phase feeding method used with broadside antennas is attractive in terms of multiband operation. Regardless of the physical spacing of the two verticals, their fields are additive perpendicular (broadside) to the plane of the verticals.
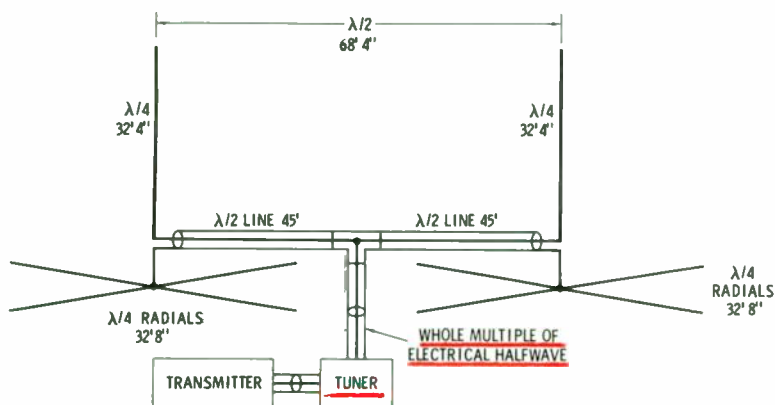
Fig. 38. Forty-meter broadside verticals with tuner for multiband operation.

The 40-meter arrangement of Fig. 38 is commendable. The antenna operates as a true broadside pair on this band. Results are good on 10, 15, and 20 meters using a line tuner. The electrical separation between verticals is two wavelengths on 10 meters and an acceptable multilobe pattern does exist. On 15 meters the antennas function as two in-phase $\frac{3}{4}$-wavelength elements. On 20 meters they are two in-phase half-wavelength verticals.

Operation on 80 meters is quite good, the electrical separation being approximately $\frac{1}{4}$ wavelength. The transmission line should be the compromise length that results in an electrical length that is a whole multiple of an electrical half wavelength. Refer to topics 2, 3, 4, 8, 16, 17, and 18.

20—End-Fire, Broadside Combination

An end-fire, broadside combination is easy to arrange as a simple pattern-changing antenna. Two ways of doing this are shown in Fig.

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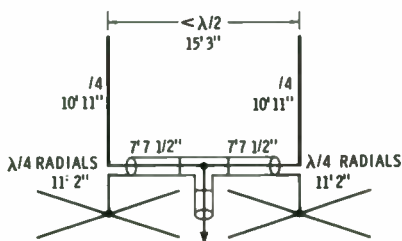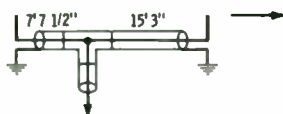
(A) Broadside.
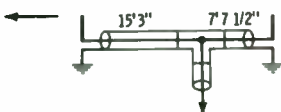
(B) End-fire 90°.

(C) End-fire 90°.
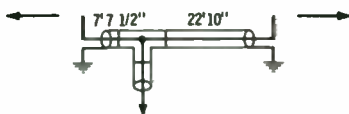
(D) End-fire 180°.

Fig. 39. End-fire broadside pair, center feed.

39. In example A the junction point is located at the center of the line between the two verticals. For 15-meter operation the separation between the two verticals is a compromise value of 15′3″ (somewhere between a quarter-wavelength and a half-wavelength separation). A satisfactory broadside pattern is possible with this spacing and the separation is not so great as to prevent the formation of an end-fire unidirectional pattern.

For broadside operation a transmission line length of 7′7½″ is used between the junction and each vertical. This generates the in-phase broadside figure-eight pattern. A unidirectional pattern results when a quarter-wave section of line is connected between the junction and one vertical (7′7½″) and a half-wave section of line between the junction and the second vertical (15′3″). Maximum radiation is toward the vertical fed with lagging current. Pattern can be turned about by switching the positions of the quarter-wave and half-wave sections of line.

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(A) Broadside.

(B) End-fire 90°.

(C) End-fire 90°.

(D) End-fire 180°.
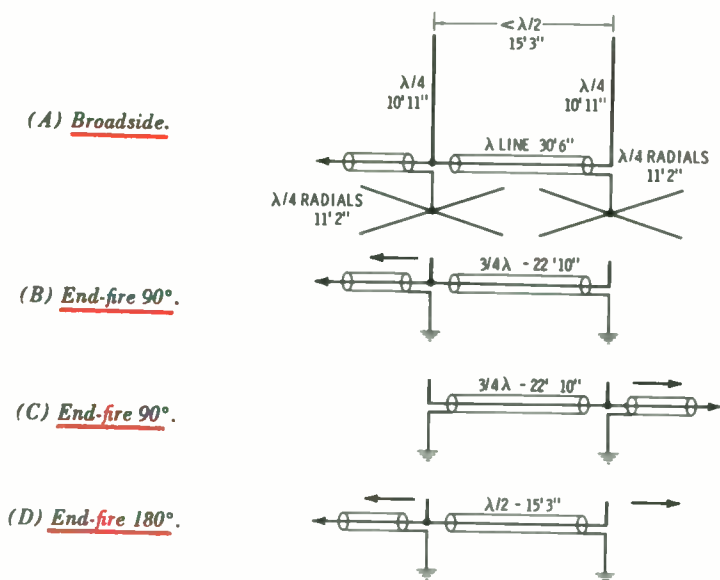
Fig. 40. End-fire broadside pair, end feed.

The final combination is attained by using a quarter-wave section of line between the junction and one vertical and a ¾-wave section (22'10″) between the junction and the second vertical. This produces the in-line figure-eight pattern of the out-of-phase end-fire connection. Dimension data for other bands can be obtained from Charts 4 and 5.

If you prefer to feed at one of the verticals rather than the center, the arrangement of Fig. 40 is feasible. The unidirectional end-fire 90° pattern can be obtained by using a ¾-wavelength section of line between the two verticals (22'10″). For end-fire bidirectional 180° feed, the 15'3″ half-wave section of line interconnects the two verticals. The broadside pattern requires a length of line that is a full wavelength so the two verticals are fed in-phase. In the 15-meter example using coaxial line with a 0.66 velocity factor this value is 30'6″. Refer to topics 2, 3, 4, 8, 16, 17, and 18.

21—Close-Spaced End-Fire Vertical

A variety of patterns can be obtained by the proper selection of spacing and the electrical phasing between two vertical antennas. Some representative examples are shown in Fig. 41. The spacings selected

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	1 ● ● 2			PHASING				
SPACING	0-1 0^0 - 360^0	1/8 45^0	1/4 90^0	3/8 135^0	1/2 180^0	5/8 225^0	3/4 270^0	7/8 315^0
$\lambda/2$								
$\lambda/4$								
$\lambda/8$								
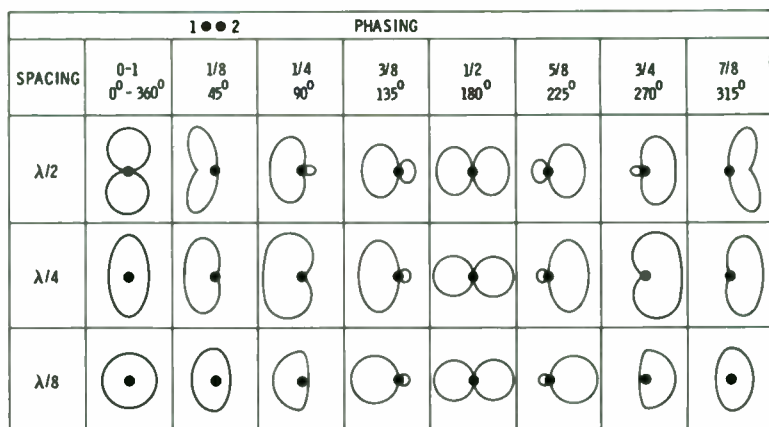
Fig. 41. Common 2-element patterns.

are ½ wavelength, ¼ wavelength, and ⅛ wavelength. Phasing values given are for each ⅛ wavelength between 0° and 360°.

In previous topics on vertical antennas we dealt with the four most common configurations. These were in-phase (0°) with ½-wavelength spacing, 180° phasing with ½-wavelength separation, 90° phasing with ¼-wavelength spacing, and 270° phasing with ¼-wavelength spacing. Locate the representative patterns in Fig. 41. When an adequate ground is employed, antenna height is right, and phasing lines are cut properly, these antennas permit direct connection to a coaxial transmission line. An acceptable SWR is obtained.

There are a number of other attractive patterns of a unidirectional nature. For example, with ½-wavelength spacing and a phasing of either 135° or 225° a unidirectional pattern in line with the verticals results. Thus it is possible to obtain a unidirectional pattern even though the two antennas are separated by a half wavelength.

The ⅛-wavelength spacing between verticals is expedient in the design of close-spaced driven beams. Note that unidirectional patterns can be obtained with a spacing of ⅛ wavelength and phasing of ⅜ or ⅝ wavelength.

An example of a close-spaced vertical combination for 15-meters is shown in Fig. 42. The spacing between the two 15-meter ¼-wave verticals is only 5′9″; ⅜-wavelength phasing is obtained with 11′6″ ($\frac{369 \times 0.66}{21.3}$) length of 0.66 VF coax line. Pattern maximum is in

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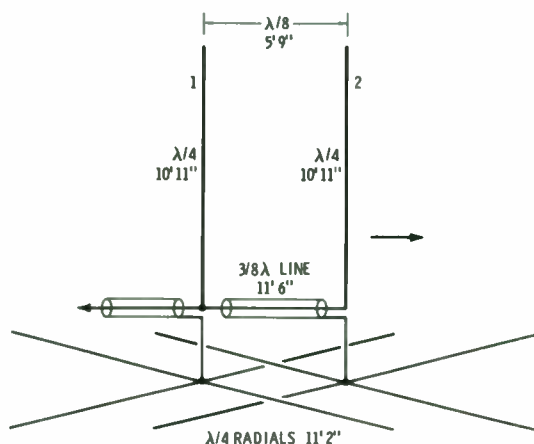
Fig. 42. Close-spaced 2-element vertical.

line with the two verticals in the direction between vertical No. 1 and vertical No. 2. The transmission line from the transmitter connects to the former. The pattern can be reversed by using a ⅝-wavelength section of line or, by feeding vertical No. 2 instead of vertical No. 1.

When other than the more favored feed methods are employed there is a tendency toward higher SWR's. A tuner can be employed at the antenna or, if the length of transmission line between the transmitter and the antenna is not too long, the line tuner can be connected at the transmitter. In practice low standing-wave ratios are more likely to be obtained when resonant radials are employed and no connection is established between the radial systems of the two verticals. Keep length of the transmission line a whole multiple of an electrical half wavelength. Refer to topics 2, 3, 4, 8, 16, 17, 18, and 19.

22 —Elevated Two-Element Phased Verticals

Vertical antennas can be elevated and phased to obtain figure-eight or unidirectional patterns. Low standing-wave ratios for direct feed can be obtained by using a length of transmission line between the base of the vertical and the junction point of the phasing system, which is a whole multiple of an electrical half-wavelength. Using this technique the actual height of the vertical is unimportant in terms of phasing. Feed lines are made long enough to reach the transmission-line junction point. Phasing can be controlled from the ground level.

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The broadside phasing is the simplest, bringing equal lengths of transmission line from the base of the verticals to the central junction point. It is possible to obtain 180° end-fire phasing simply by connecting an additional half wavelength of transmission line in one side. A unidirectional pattern is obtained by inserting an additional length of transmission line in one side with an electrical length of either 135° or 225°, depending on the desired direction for the end-fire pattern.

A 20-meter example is given in Fig. 43. The two verticals are spaced 34'8":

$$\tfrac{1}{2}\text{-wavelength spacing} = \frac{492}{14.2} = 34'8''$$
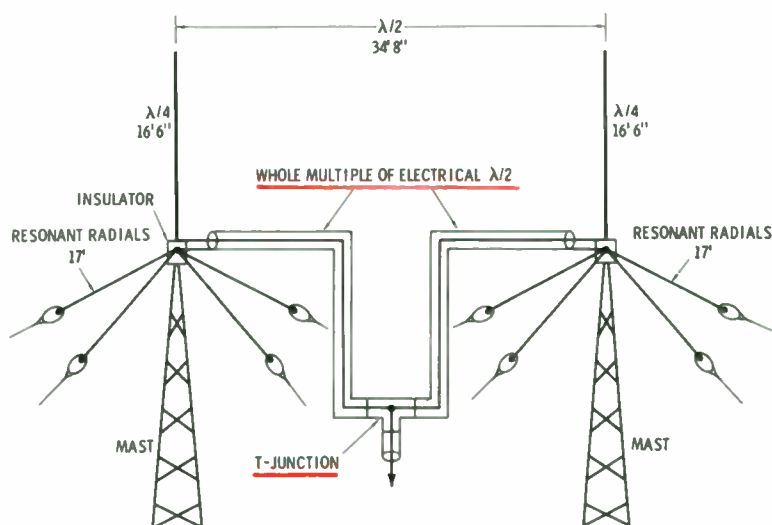
Fig. 43. Elevated and phased 20-meter verticals.

Four resonant radials were employed for each vertical. The length of the transmission line connected between each vertical base and the center junction is 45'6" (one electrical wavelength on 20 meters for 0.66 VF coax).

To obtain bidirectional end-fire phasing an additional half-wavelength segment of line was added in one side. This length was 22'10":

$$(20) \quad \tfrac{1}{2}\text{-wavelength phasing} = \frac{492 \times 0.66}{14.2} = 22'10''$$

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To obtain a unidirectional pattern an additional ⅛-wavelength segment of line is needed on the same side to obtain a total of 225° (180° + 45°). The additional length needed is 5'9":

$$(20) \quad \text{⅛-wavelength} = \frac{123 \times 0.66}{14.2} = 5'9''$$

If lines and elements have been cut properly a low-SWR direct feed is possible. The addition of a tuner at the antenna junction point or at the transmitter can bring the SWR down to an extremely low value. Furthermore, the tuner permits operation on other bands as a broadside antenna. Good results are obtained on both 10 and 15 meters. Satisfactory loading is also possible on 40. Pattern changes are to be anticipated. In general when the spacing between verticals is greater than a half wavelength there is a tendency for additional horizontal lobes to appear. On those frequencies where the spacing is less than an electrical half wavelength between verticals, the pattern becomes increasingly omnidirectional. Refer to topics 2, 3, 4, 8, 16, 17, 18, 19, and 20.

23 —Four-Element End-Fire Broadside

More than two verticals can be combined to obtain more directive patterns and higher gains. The end-fire, broadside combination is popular (Fig. 44). This arrangement of two end-fire pairs in broadside
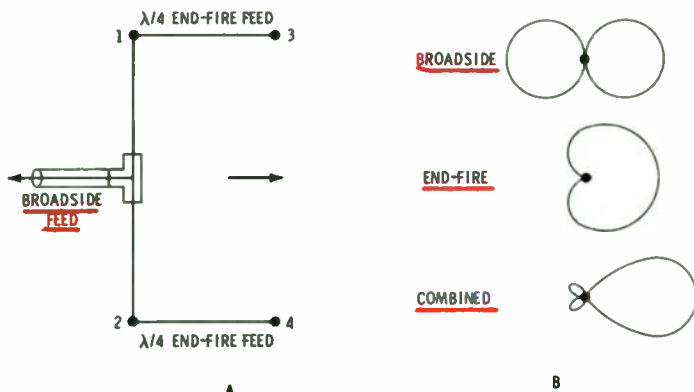
Fig. 44. Arrangement and patterns of 4-element end-fire broadside antenna.

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combines the figure-eight pattern of the broadside connection with the end-fire unidirectional pattern to obtain a narrower and higher gain unidirectional lobe.

A practical 15-meter antenna using this principle is shown in Fig. 45. The end-fire elements are spaced 90° (¼ wavelength). They are joined by ¾-wavelength sections of coaxial line of 22′10″ ($\frac{730 \times 0.66}{21.3}$). The broadside grouping is fed at the center of the system using coaxial line. There are ½-wavelength sections of coaxial line 15′3″ ($\frac{492 \times 0.66}{21.3}$) between junction and each pair.

Good gain and a fine pattern are obtained along with the low vertical angles inherent to vertical antennas. Four individual resonant ground radials were employed for each one of the verticals. A direct match for low standing-wave ratio is obtained. Refer to topics 2, 3, 4, 16, 17, 18, and 19.

24 —20-Meter End-Fire (180°), Broadside Combination

A simple and effective end-fire, broadside antenna system can be fed with 300-ohm TV line. A balanced tuner (Appendix VII) is required. The velocity factor of such line is 0.82 and it is possible then to space the verticals almost a half wavelength.

Fig. 45. Practical 15-meter end-fire, broadside 4-element array.

On 20 meters an electrical half wavelength of TV line corresponds to:

$$\lambda/4 \text{ line} = \frac{492 \times 0.82}{14.2} = 28'4''$$

The two verticals are spaced about 27 feet (Fig. 46). The 300-ohm line connected back to the transmitter is attached to the near vertical. When the 300-ohm line is not transposed, as in Fig. 46A, the two verticals operate 180° end fire. There is a figure-eight pattern in line with the two verticals. They have been fed out of phase because there is a 180° reversal in the segment of line between vertical No. 1 and vertical No. 2.

If broadside operation is desired, the 300-ohm line between the two verticals is transposed as shown in Fig. 46B. The transposition of the line adds a second 180° reversal and the two verticals are now fed in phase. As a result, a figure-eight pattern is produced broadside to the plane of the two verticals. The simple process of reversing the coupling line at the far vertical permits the 90° shift in the figure-eight pattern of the antenna.
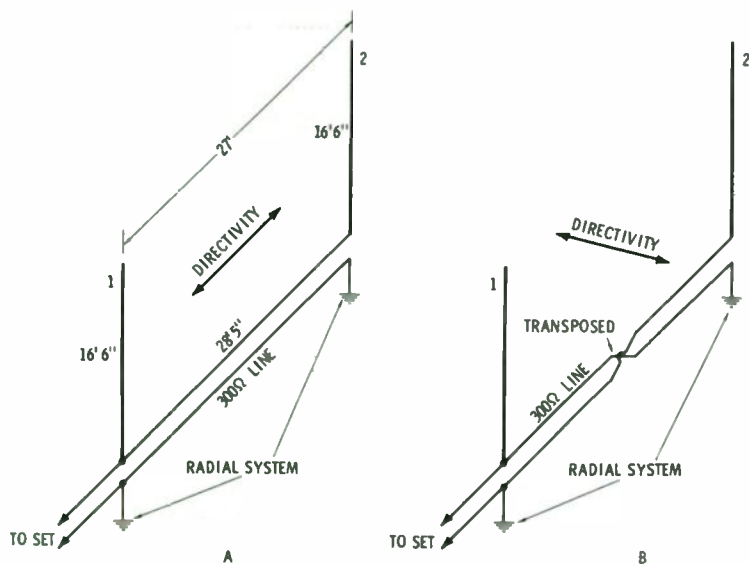
Fig. 46. End-fire, broadside combination using 300-ohm transmission line.

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The balanced tuner of Appendix VII does a fine job of matching the 300-ohm line to the lower unbalanced impedance present at the output of the transmitter. Select the coil assembly that will permit the lowest SWR reading. Refer to topics 2, 3, 4, 12, 16, 17, 18, 20, 22, and 23.

25 —Eight-Element 10-Meter Vertical

The end-fire broadside combination is easily extended to attain more gain and a more directional pattern. Two broadside pairs and four end-fire groupings are employed in the 10-meter arrangement of Fig. 47. Half-wave and full-wave sections of coaxial line are used for broadside phasing while ¾-wavelength sections of line feed the end-fire pairs. Broadside spacing is ½ wavelength; end-fire spacing, ¼ wavelength.

Appropriate spacing equations are:

$$(10) \quad \tfrac{1}{2}\lambda = \frac{492}{28.6} = 17'2''$$

$$(10) \quad \tfrac{1}{4}\lambda = \frac{246}{28.6} = 8'7''$$

Coaxial line of 0.66 velocity factor requires the following phasing line lengths:

$$(10) \quad \tfrac{1}{2}\lambda \text{ phasing line} = \frac{492 \times 0.66}{28.6} = 11'4''$$

$$(10) \quad \tfrac{3}{4}\lambda \text{ phasing line} = \frac{738 \times 0.66}{28.6} = 17'1''$$

$$(10) \quad \lambda \text{ phasing line} = \frac{984 \times 0.66}{28.6} = 22'8''$$

The end-fire, broadside combination of verticals can be a problem-solving antenna in many locations. With the use of a sufficient number of verticals it is possible to attain a high gain and a sharp directional pattern. All of this is accompanied by a low angle of vertical radiation with the antenna system mounted at ground level.

Such combinations are fine anti-QRM receiving antennas. They have a low sensitivity to high-angle signals. The front-to-back ratio is very good because of the end-fire connection. This can be a particular ad-

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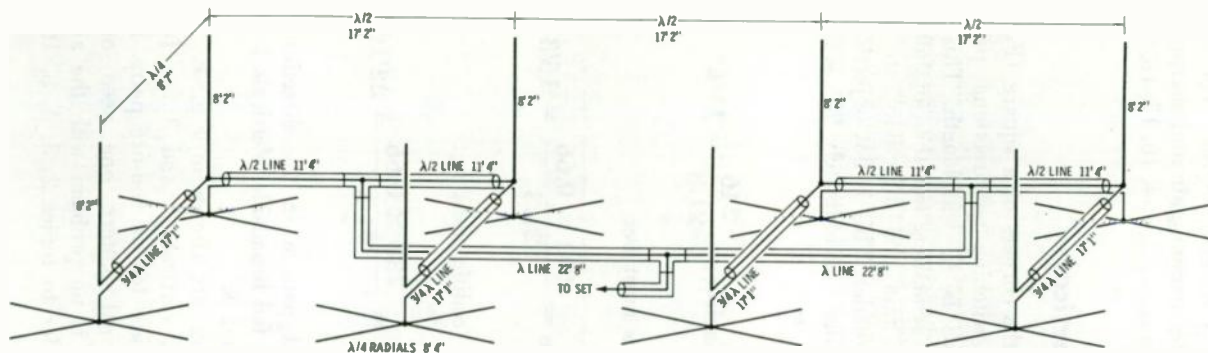
Fig. 47. Eight-vertical, broadside, end-fire antenna for 10 meters.

vantage in reducing short-skip back-side QRM. The half-wavelength broadside spacing builds up the antenna gain and sharpens the forward unidirectional pattern. Refer to topics 2, 3, 4, 16, 17, 18, 19, 20, and 23.

26 —Four-Square Verticals

Four verticals mounted at the corners of a square (Fig. 48) permit design of a simple direction-switching unidirectional pattern antenna. The spacing between verticals is $\frac{1}{4}$ wavelength. This is the ideal spacing for end-fire pairs but something less than optimum for broadside feed. Nevertheless good gain and directivity are possible. The unidirectional lobe is a bit broader. This is not objectionable because it permits 360° coverage in four approximately 90° segments.

Quarter-wavelength spacing is:

$$(15) \quad \frac{1}{4}\lambda \text{ spacing} = \frac{246}{21.3} = 11'6''$$

The broadside $\frac{1}{2}\lambda$ feedlines must be:

$$(15) \quad \frac{1}{2}\lambda \text{ line} = \frac{492 \times 0.66}{21.3} = 15'3''$$

The $\frac{3}{4}\lambda$ lines for end-fire feeding must be:

$$(15) \quad \frac{3}{4}\lambda \text{ lines} = \frac{738 \times 0.66}{21.3} = 22'10''$$

To obtain a unidirectional pattern in the direction indicated in Fig. 48, verticals 1 and 2 are fed broadside. Verticals 1 and 3 are fed end fire, as are verticals 2 and 4.

The other three possibilities are shown in Fig. 49. For example, in directing the signal west, verticals 1 and 3 are fed broadside; verticals 1 and 2, 3 and 4, are fed as end-fire pairs. It is apparent that to change the directional pattern one need only shift the phasing harness about. This is no problem with the antenna system mounted at ground level. Refer to topics 2, 3, 4, 8, 16, 17, 18, 19, 20, and 23.

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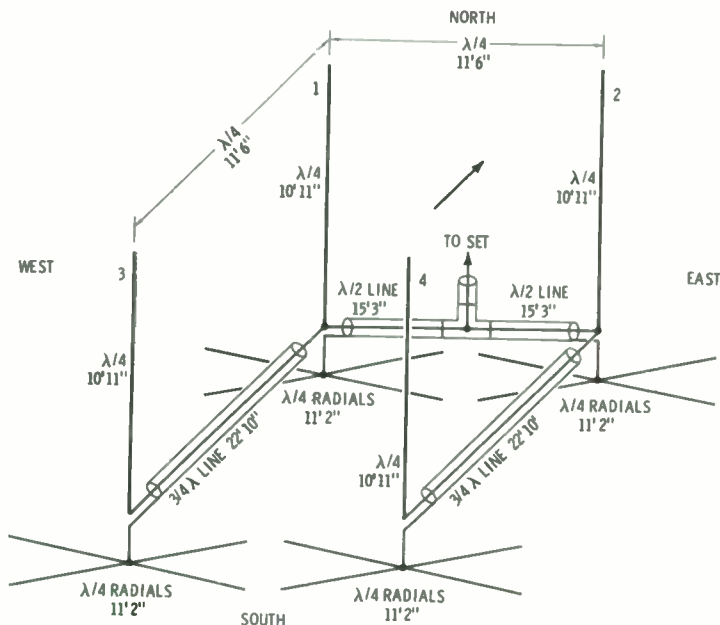
Fig. 48. Four-square vertical antennas for 15 meters.

27 –10-15-20 Four-Square Vertical

The four-square construction lends itself to a simple pattern-changing antenna for 10, 15, and 20 meters. The dimensions are such that there is a quarter-wace spacing on 20 meters. Configuration is identical to that of topic 26.

Values are determined as follows:

$$(20) \quad \tfrac{1}{4}\lambda \text{ vertical antenna} = \frac{234}{14.2} = 16'6''$$
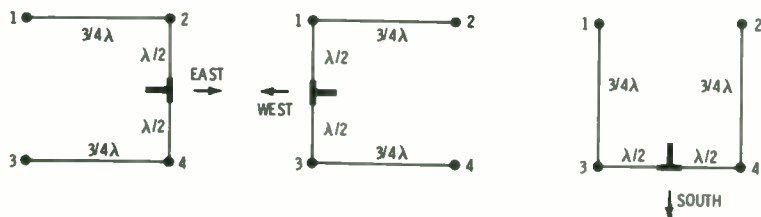
Fig. 49. Harness arrangements for shifting pattern in 90° steps.

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$$(20) \qquad \frac{1}{4}\lambda \text{ spacing} = \frac{246}{14.2} = 17'4''$$

$$(20) \quad \text{broadside } \frac{1}{2}\lambda \text{ lines} = \frac{492 \times 0.66}{14.2} = 22'10''$$

$$(20) \qquad \frac{3}{4}\lambda \text{ end-fire lines} = \frac{738 \times 0.66}{14.2} = 34'3''$$

Antenna arrangement is shown in Fig. 50.

Individual vertical construction is detailed in Fig. 51. Aluminum tubing is bolted to 2 × 3's (or 2 × 4's) with U bolts. The 2 × 3's are 10 feet long and are imbedded two feet into the ground. To accommodate three-band operation each vertical can be telescoped. The larger diameter tubing is made 8'2" long for 10-meter vertical operation. Four such verticals are necessary.

For 15-meter operation four 3½-foot lengths of thinner tubing telescope within the bottom section to obtain the 11' length needed
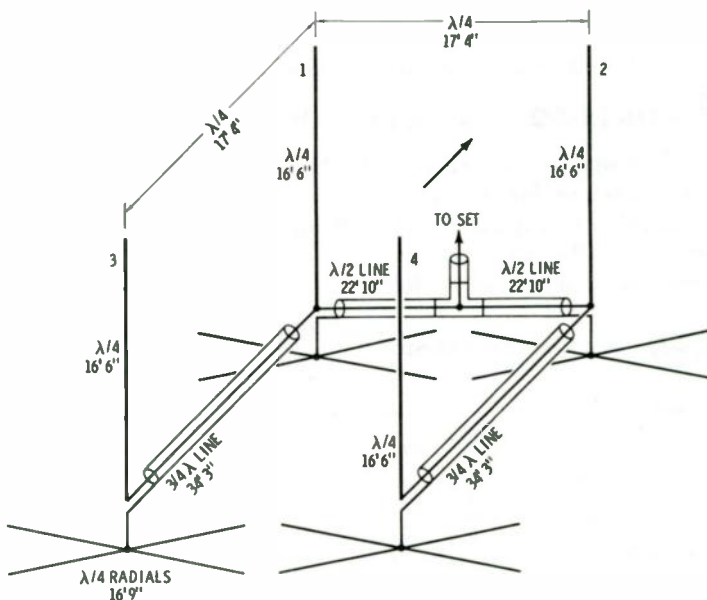
Fig. 50. Four-square 10-15-20 construction, 20-meter operation.

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Fig. 51. Base construction for each
of the four-square verticals.

for 15-meter operation. Twenty-meter operation is obtained with four
additional pieces of thinner tubing each with a length of 10 feet.
These lengths are telescoped within the larger diameter 10-meter
vertical to obtain an overall length of 16'6" for 20 meters.

On 15-meters (Fig. 52) the 17'4" spacing corresponds to an
electrical spacing of about ⅜ wavelength. This is good for broadside

(A) 15 meters—11' verticals.   (B) 10 meters—8' 2" verticals.
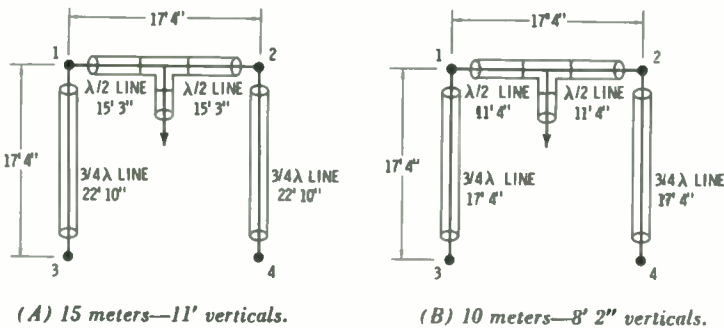
Fig. 52. Phasing lines dimensions for 15- and 10-meter operation.

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operation. At the same time a good end-fire pattern is still present. Phasing line dimensions are:

$$(15) \quad \tfrac{1}{2}\lambda \text{ broadside lines} = \frac{492 \times 0.66}{21.3} = 15'3''$$

$$(15) \quad \tfrac{3}{4}\lambda \text{ end-fire lines} = \frac{738 \times 0.66}{21.3} = 22'10''$$

The $\tfrac{3}{4}$-wavelength lines for 15-meter operation and the $\tfrac{1}{2}$-wavelength lines for 20-meter operation are the same length; they can be used interchangeably.

On 10-meters the spacing is $\tfrac{1}{2}$ wavelength, which is ideal for broadside operation. The end-fire pattern remains acceptable with the $\lambda/2$ spacing. The combined patterns again produce a good unidirectional pattern. Dimensions for the phasing lines are:

$$(10) \quad \tfrac{1}{2}\lambda \text{ broadside lines} = \frac{492 \times 0.66}{28.6} = 11'4''$$

$$(10) \quad \tfrac{3}{4}\lambda \text{ end-fire lines} = \frac{738 \times 0.66}{28.6} = 17'$$

The latter lines were lengthened slightly to accommodate the 17'4" spacing between verticals.

On each band the directional pattern can be rotated in 90° steps simply by shifting the phasing harness around as detailed in topic 26.

The ground system is quite simple. It consists of four five-foot metal fence posts. At each vertical, such a fence post is driven into the ground to a depth of slightly more than 4 feet; about six inches of the fence post is left above ground. This is done at each vertical and a dipole connector is connected between the base of each vertical antenna and its associated fence-post ground. These can be seen in Fig. 51. Radials can be run out $\lambda/4$ (on 20 meters) from each ground post, buried about 1 to 2 inches beneath the turf. Refer to topics 2, 3, 4, 16, 17, 18, 19, 23, and 26.

Low-Band Verticals and Inverted Vees

28 —TV Mast 80-Meter Vertical

The vertical is the favorite antenna for low-band (40, 80, and 160) DXing. The telescoping and guyed TV mast affords an inexpensive and simple means of erecting an 80-meter vertical. The antenna of Fig. 53 employs a 50-foot telescoping TV mast. Two thinner-diameter
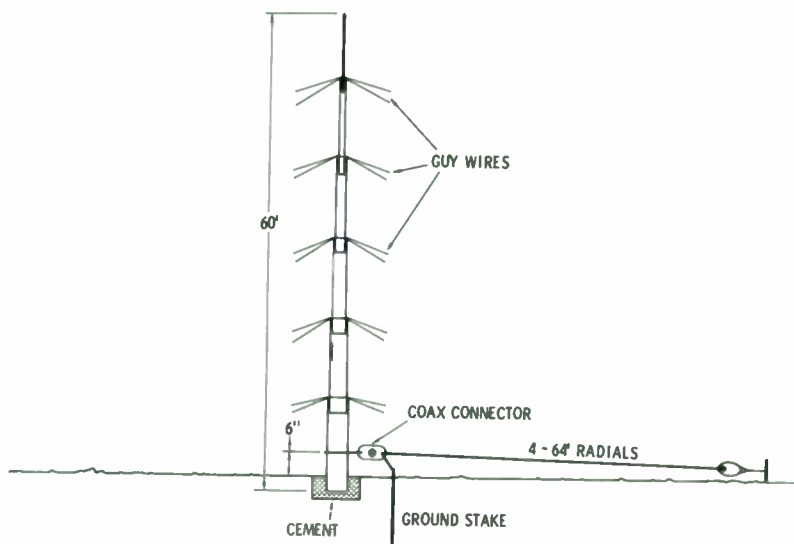
Fig. 53. TV-mast 80-meter vertical.

10-foot lengths of telescoping tubing were purchased to telescope into the top section. The TV mast is imbedded in cement $2\frac{1}{2}$ feet into the ground. Immediately beside the mast a five-foot metal fence post is driven $4\frac{1}{2}$ feet into the ground. A coaxial-to-dipole connector links a point on the TV mast 6 inches above the ground to the ground stake. With this simple arrangement and a length of transmission line that is some whole multiple of an electrical half wavelength, a standing-wave ratio of less than 1.5 to 1 is obtained over the entire 80-meter band.

It is very easy to adjust the overall length of the mast at one of the telescoping points so it can be resonated to any precise frequency in the band. A 60-foot overall length resonates the antenna very near to 3.9 MHz. Four 62-foot resonant radials are added in the interest of obtaining low-angle radiation. The antenna is guyed at each ten-foot position using plastic clothesline with nonmetallic core. Strong rope can also be used. Of course, for a long-term permanent arrangement, metal guy wires with suitable break-up insulators are possible. Usually the physical length must be adjusted downward to obtain resonance at a specific frequency when metal guying is employed. Refer to topics 2, 3, 4, and 5.

29 —Low-Band Vertical With Line or Base Tuner

A quarter-wave 80-meter vertical antenna has good length, a favorable attribute when one desires all-band operation with the use of a

(A) Tuner at transmitter.   (B) Tuner at antenna.
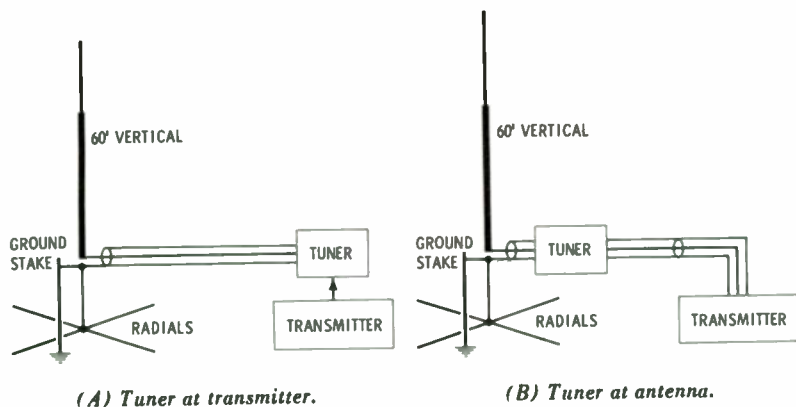
Fig. 54. Multiband vertical and tuner arrangements.

line tuner (Fig. 54). Using the large-diameter telescoping tubing along with a good ground provides reasonably good wideband characteristics. Therefore the simple line tuner of Appendix VI permits multiband operation. In fact, the SWR is 1.5 to 1, and lower on all bands 10 through 160 meters.

If 160-meter operation is desired it is advisable to extend the four resonant ground radials to 130 feet. A satisfactory beneath-ground radial system would consist of four quarter-wave radials each on 40, 80, and 160 (Fig. 55).
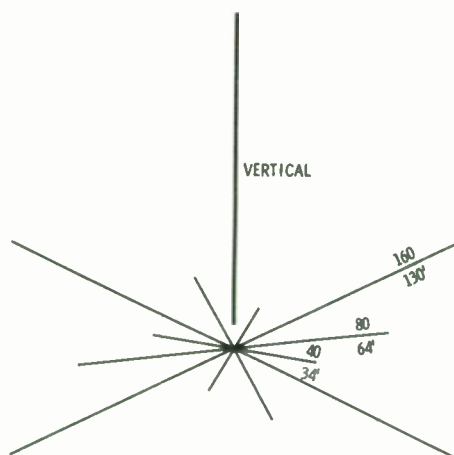
Fig. 55. Beneath-ground radial system for 40, 80, and 160 meters.

If the length of transmission line between the vertical and the transmitter is very long and/or a minimum SWR is desired on the line, the tuner of Appendix VI or the base tuner of Appendix VIII is recommended. In this case the SWR on the entire length of line can be brought down below 1.5 to 1 on all bands 10 through 160 meters. Refer to topics 2, 3, 4, 8, 10, and 28.

30 —80-160 Vertical

An 80-meter quarter-wave vertical antenna along with a gamma matching arrangement can also be loaded well on 160 meters. As shown in Fig. 56, the gamma section is attached at a point 12.5 feet above ground. A piece of 1-inch flat aluminum one foot in length

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joins this point to the top of the vertical section of the gamma. In fact, the vertical section can be a 20-foot telescoping TV mast, the top section of which is extended 2½ feet to obtain a total of 12½ feet.
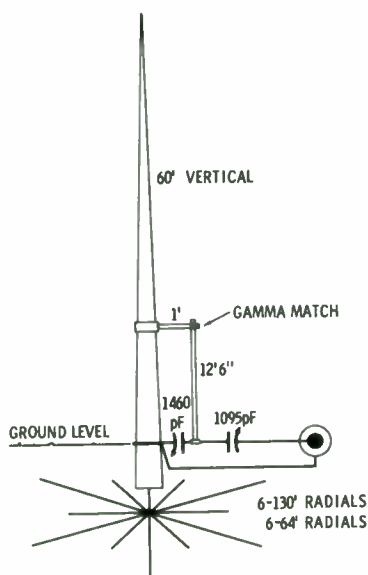
Fig. 56. Plan for 80-160 vertical.

Excellent two-band matching is obtained by the use of a two-capacitor impedance divider at the base of the gamma section.

The low-angle performance is very much the function of the radial system employed. A satisfactory radial system would consist of six 160-meter quarter-wave radials interspaced with six 80-meter quarter-wavelength radials, above ground or buried approximately 2 inches under ground.

To obtain an exact match with the usual gamma section there must be considerable jockeying of the physical length and spacing along with the gamma capacitor. Furthermore, these settings are only appropriate for a single band or a portion of a single band. The use of a capacitive divider at the base permits a convenient way of tuning the gamma section and also permits operation on more than one band. One need only attach an SWR meter at the base of the vertical and jockey the capacitors back and forth to obtain a minimum SWR.

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The capacitor values given permit almost ideal matching on 80 and 160 meters. Refer to topics 2, 3, 4, 28, and 29.

31—40-80 Vertical

A 50-foot telescoping TV mast along with a gamma section can provide good performance on 40 and 80 meters. The gamma arrangement is the same as that described in topic 30. Vertical antenna height has been shortened, permitting good matching at the base for 40-meter operation.
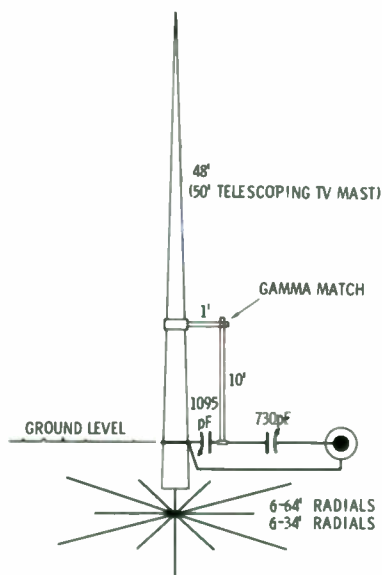
Fig. 57. Plan for 40-80 vertical.

48'
(50' TELESCOPING TV MAST)

GAMMA MATCH

1'

10'

1095 pF

730 pF

GROUND LEVEL

6-64' RADIALS
6-34' RADIALS

The gamma attaches at a point only 10 feet from the base, and smaller capacitors are used in the divider (Fig. 57). Refer to topics 2, 3, 4, 28, 29, and 30.

32—Low-Band Vertical With Gamma- and T-Matching

If the length of transmission line is a good compromise value of a whole multiple of an electrical half wavelength for the desired

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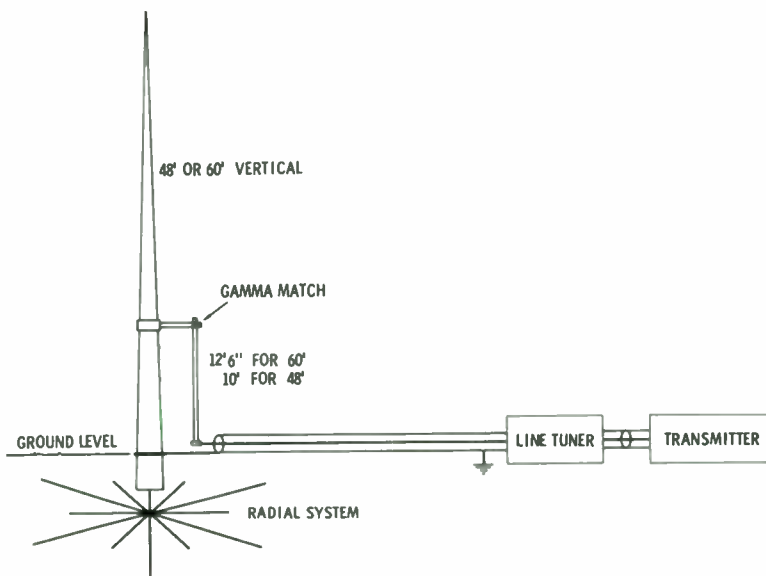
Fig. 58. Multiband vertical using line tuner.

low-frequency bands, a line tuner can be employed at the transmitter (Fig. 58). In this arrangement the inner conductor of the coax line attaches to the bottom of the vertical member of the gamma section. The outer braid of the coaxial line connects to the bottom of the vertical radiator. The simple T-matching line tuner of Appendix VI provides multiband matching for either the 48-foot or 60-foot verticals shown in Figs. 56 and 57. In this arrangement no capacitive divider is employed at the base of the antenna.

This plan is a convenient one because it permits 20-, 40-, 80-, and 160-meter band-changing and tuning from the transmitter. However, there are some performance compromises in the form of additional transmission-line loss because of a higher SWR on the line and some decline in 160-meter performance. Refer to topics 2, 3, 4, 8, 28, 29, 30, and 31.

33 —Short 160-Meter Vertical

A quarter wavelength on 160 meters is 130 feet (234/1.8). At most locations an antenna of this height is unwise, impractical, or too

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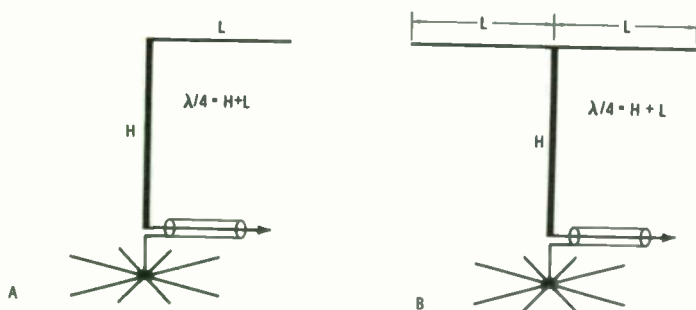
Fig. 59. Inverted-L and T 160-meter configurations.

costly. In fact, most 160-meter verticals have heights that fall between 50 and about 80 feet. Additional length can be added to a 160-meter vertical with top loading or, more simply, by extending the antenna horizontally from the top of the mast. Two popular arrangements are the
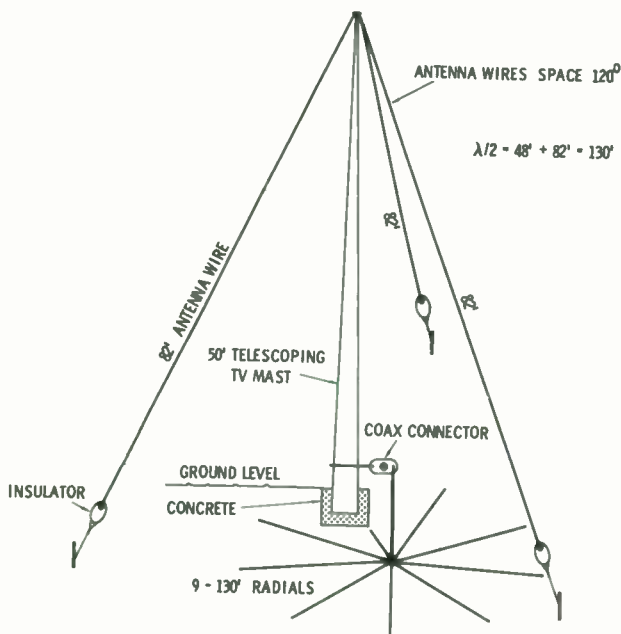
Fig. 60. Umbrella vertical for 160 meters.

inverted—L or T plans of Fig. 59. To ensure direct match to a coaxial line or by way of a simple matching arrangement, the overall length of the antenna should approximate an electrical quarter wavelength. This is to state that the sum of H and L should be about 130 feet. Usually a bit of trimming is necessary to obtain exact resonance. A radial system is essential to good low-angle performance. A minimum of nine 130' radials is recommended.

The antenna of Fig. 60 has as its vertical segment a 50-foot telescoping TV mast. The top-loaded segment consists of three 82-foot lengths of antenna wire spaced 120° around the top. These are brought down to ground level in umbrella-like fashion as shown in Fig. 60. The fact that they are brought near to ground means that they can be trimmed conveniently to obtain a direct match to a coaxial transmission line. Refer to topics 2, 3, 4, 28, 29, 30, 31, and 32.

34—Low-Band Inverted Dipoles

The inverted dipole or inverted-vee dipole has been and is a popular low-band antenna because of its fine results, ease of erection, durability, low cost, and limited space requirement. The inverted dipole is in effect a conventional half-wavelength horizontal dipole with its ends tilted down toward the ground (Fig. 61). The angle between
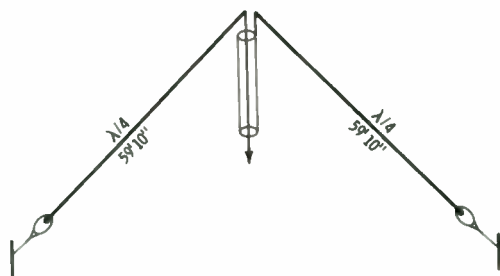
Fig. 61. Inverted dipole antenna.

the two dipole legs is usually between 90° and 150°, depending on the apex height and leg length.

The leg length for a given resonant frequency approximates that of a straight horizontal dipole. In general, the standard dipole equation (234/f) can be used. As a function of the apex angle and nearness of the leg ends to ground, it may be necessary to shorten leg length

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slightly. However, tuning such an antenna and bringing it to resonance on an exact frequency is quite easy because the dipole leg ends are very near ground level. An antenna noise bridge or SWR meter is helpful in resonating the antenna. Refer to Appendices I through IV.

Antenna resistance changes from that of a horizontal dipole, becoming lower as the angle between the two wires is decreased. Again, the most favorable conditions exist when the transmission line is a multiple of an electrical half wavelength at the operating frequency.

The performance of the inverted dipole is in general more uniform than a straight dipole. The horizontal pattern is less directive. Gain is somewhat less by comparison to the broadside gain of a horizontal dipole of similar mid-point height because the height of the inverted dipole has its leg ends near to ground level. However, the performance of the inverted dipole, relative to other horizontal angles, equals or betters the straight dipole. Another advantage of the inverted dipole is its somewhat lower angle of radiation and the presence of some vertically polarized components. Thus for long-distance communications, especially on 80 meters and lower, surprising results are often obtained.

Only a single erection mast or high mounting position for the antenna apex is needed. The inverted dipole ends can be brought very
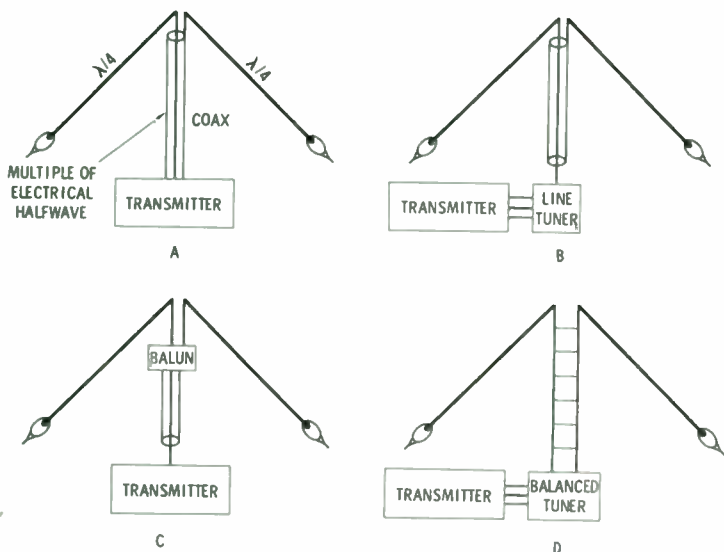
Fig. 62. Inverted dipole and vee feed methods

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near to the ground and can be tied down to metal fence posts, the side of a garage, shed, etc.

The practical dimensions given in Fig. 61 are for an 80-meter inverted dipole cut for operation in the phone band. This antenna resonates at 3.9 MHz.

Four common methods of feeding an inverted dipole are given in Fig. 62. A coaxial line can be attached directly, and a low SWR is obtained if the antenna has been resonated correctly. This arrangement in conjunction with a line tuner, as in Fig. 62B, permits multiband operation of the basic 80-meter inverted dipole. The antenna can be loaded on every band 10 through 160 meters using the T-network tuner of Appendix VI. Keep in mind that the use of such a tuner does not ensure optimum performance on each band but loading is possible and acceptable performance is obtained.

Example C demonstrates the use of a 1-to-1 balun. Such a balun makes a conversion from the unbalanced coaxial transmission line to a balanced antenna. Consequently, there is balanced radiation from the two legs of the inverted dipole and a better pattern is obtained.

Another balanced feed arrangement is shown in D. This is a very popular method of feeding inverted dipole antennas. The open-wire transmission line permits balanced feed and equal radiation from each leg at the same time the line loss itself is minimum. A balanced open-wire feed system requires the use of a balanced tuner at the transmitter. Such a tuner is described in Appendix VII. Standing-wave ratio at the transmitter can be brought down to a very low value using this method of feed. Furthermore improved multiband operation is possible. Again, 10- through 160-meter operation is feasible. Refer to topics 1, 2, 3, 8, and 12.

35—Inverted-Vee Antennas

All antennas require a support structure and transmission line. This expense is a part of each antenna system. To this must be added the cost of the antenna proper. If the antenna is made of antenna wire and end insulators, it amounts to a very low-cost system. Such is the case for the inverted-vee construction. Another economy is that only a single mast or high point of erection is needed (Fig. 63).

The inverted dipole is a one-half wavelength antenna. The smallest inverted vee antenna is one that has 3/2 wavelength total length or ¾ wavelength per leg. Matching problems are reduced by leg lengths that correspond to odd multiples of ¼ wavelength at the operating

70
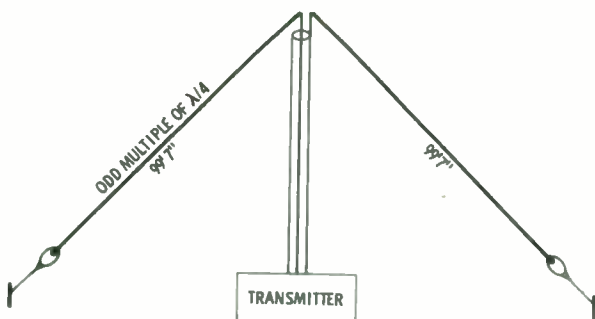
Fig. 63. Forty-meter inverted vee, ¾-wavelength legs.

frequency and transmission-line lengths that correspond to whole multiples of an electrical half wavelength at the operating frequency. Lengths are selected according to available space and apex height using Chart 6. The dimensions of Chart 6 are somewhat longer than that which produces resonance at a given frequency. Inasmuch as the antenna ends are near ground level, they can now be cut back to set the antenna resonance on a specific frequency. Next the separation between the feed point and the transmitter is estimated. Chart 3 is then used to determine the preferred length of line.

A practical 40-meter design is given in Fig. 63. Leg length for ¾λ operation is:

$$\text{Leg length} = \frac{738}{7.2} = 102'6''$$

The antenna is erected with this length of line and is then cut back to attain resonance at the desired frequency.
This length is given in Fig. 63 for a typical installation.

An estimate indicates that separation between feed point and location of the transmitter is at least 75 feet. The constants of Chart 2 indicate that a favorable transmission line length would be:

$$\text{Line length} = \frac{650}{7.2} = 90'$$

The inverted-vee antenna is a sturdy construction. The mast itself does not support the antenna. Rather, the antenna wires contribute additional guying for the mast. If multiband operation is desired, a

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Chart 6. Leg Lengths in Quarter Wavelengths and Feet

Leg Length in Wavelengths	Leg Length in Feet (f in MHz)
1/4	234/f
3/4	738/f
5/4	1230/f
7/4	1722/f
9/4	2214/f
11/4	2706/f
13/4	3198/f
15/4	3690/f
17/4	4182/f
19/4	4674/f
21/4	5166/f
23/4	5658/f.
25/4	6150/f
27/4	6642/f
29/4	7134/f
31/4	7626/f
33/4	8118/f
35/4	8610/f
37/4	9102/f
39/4	9594/f
41/4	10086/f

line tuner or open-wire transmission line and a balanced line tuner can be employed. When direct coaxial feed is used, the use of a balun can ensure equal radiation from both legs of the inverted vee. Refer to topics 1, 2, 3, 8, 12, and 34.

36—40-80-160 Inverted-Vee Antenna

The inverted-vee and inverted-dipole construction is ideal for trimming an antenna to a precise resonant frequency from near ground level. Furthermore, a simple arrangement of insulators that break up the two legs can normally permit multiband operation with the use of a single directly connected coaxial transmission line. The inverted construction of Fig. 64 permits three-band operation with the use of three pairs of insulators and two pairs of jumpers. Practical dimensions are given for 40-, 80-, and 160-meter operation. Of course, if you desire only 40-, and 80-meter operation, the added section of antenna wire used for 160-meter resonance is not necessary.

When operating on 80 meters the jumpers are kept open at the first pair of insulators down from the antenna feed point. The antenna operates as an inverted dipole on 80 meters. For 40-meter operation
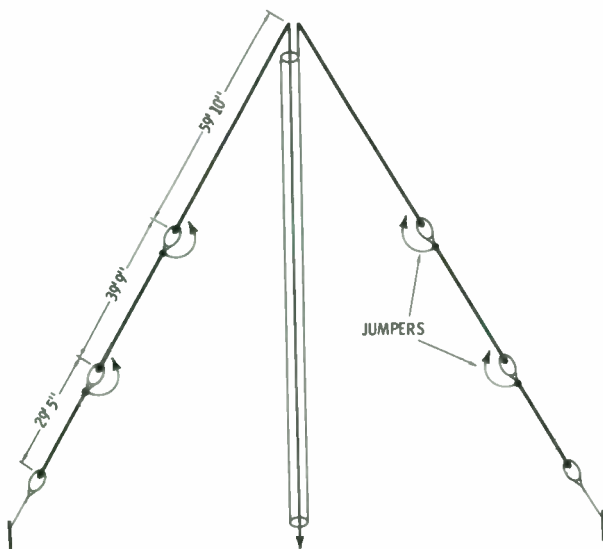
Fig. 64. Inverted vee antenna for 40, 80, and 160.
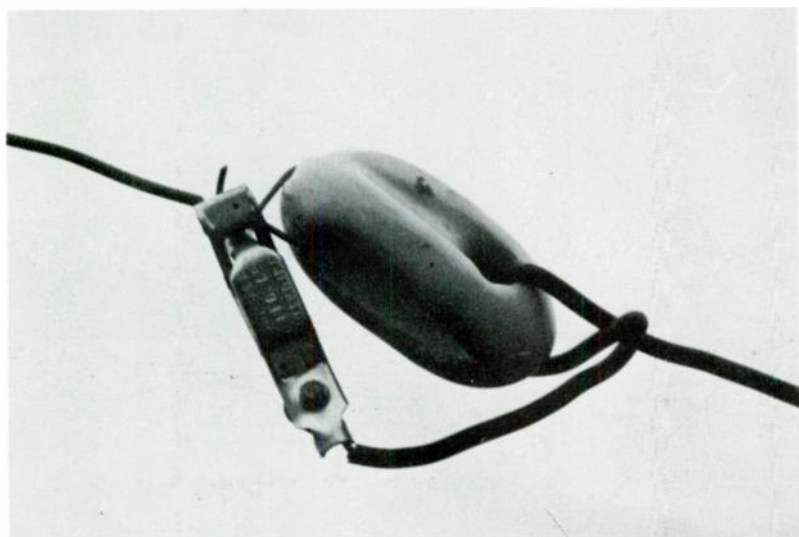
Fig. 65. Alligator clips can be used to add length to an inverted vee.

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the antenna functions as an inverted vee with $\frac{3}{4}$-wavelength legs. In this case the first pair of jumpers are closed while the second pair are kept open. Note that the 40-meter dimension is the same as that used previously for the antenna shown in Fig. 63. For 160-meter operation all of the jumpers are closed and the antenna legs are of maximum length.

A very simple jumper arrangement is shown in Fig. 65. Many versatile antennas can be constructed using the basic inverted-dipole and inverted-vee configuration. Many such antennas are covered in *73 Dipoles and Long-Wire Antennas*, published by Editors and Engineers, Ltd., New Augusta, Indiana. Refer to topics 1, 2, 3, 34, and 35.
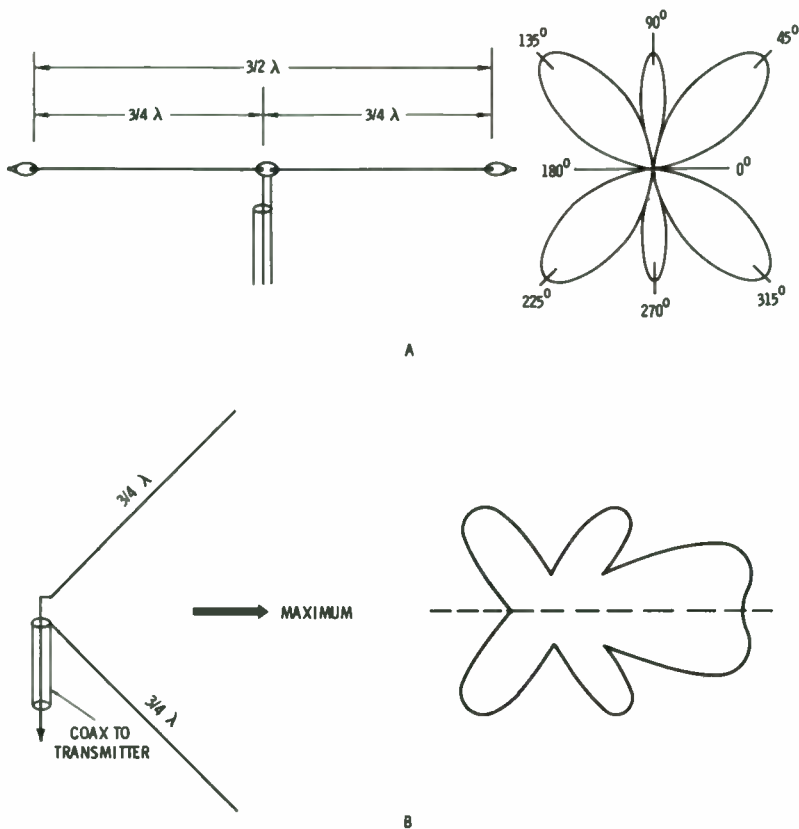
Fig. 66. Vee-beam antenna and patterns.

37—Three-Quarter Wavelength Tilted Inverted Vee

An antenna with legs that are ¾-wavelength long or longer can be made unidirectional to a degree by tilting the legs forward as shown in Fig. 66. When this is done the antenna is usually referred to as a vee beam.

In the case of a horizontal three-halves wavelength antenna the characteristic six-lobe pattern (Fig. 66B) is changed over to the more unidirectional pattern with a major forward lobe. Typically the included angle falls somewhere between 90° and 120°. The same technique can be used for a ¾λ inverted-vee antenna as described pre-

Fig. 67. Inverted-vee beam.
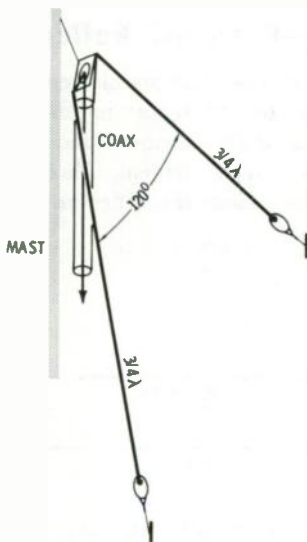
viously in topic 35. Thus, instead of having the two legs of the inverted vee 180° related they are tilted forward in a desired direction to set up an included angle of about 120°. A practical antenna of this type is shown in Fig. 67. Dimensions are for 40-meter operation. An appropriate line tuner permits this antenna to load on higher-frequency bands where it will display a similar directivity. Refer to topics 1, 2, 3, 8, 34, and 35.

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Two-Element
Parasitic Antennas

38—Parasitic Reflector, Wide Spaced

A parasitic antenna element has no direct connection with the driven element or the transmission line. A parasitic *reflector* is cut longer than the driven element and resonates on a frequency lower than that of the driven element. Maximum directivity is broadside in a line extending from the reflector through the driven element (Fig. 68). A

MAXIMUM   MAXIMUM

λ/2 DRIVEN ELEMENT
468/f   0.15λ-0.25λ   0.1λ-0.25λ

DIRECTOR
468/f -4%

REFLECTOR
468/f + 5%

λ/2 DRIVEN ELEMENT
468/f

(A) Parasitic reflector.   *(B) Parasitic director.*
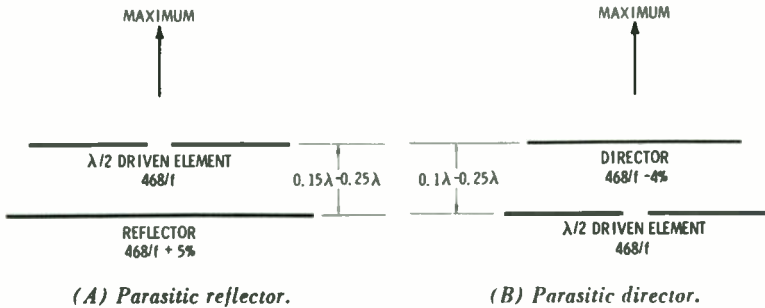
Fig. 68. Basic 2-element parasitic antennas.

parasitic *director* is cut shorter than the driven element. In this case the maximum directivity is in a broadside direction from the driven element through the director (Fig. 68B).

The spacing between the driven and parasitic elements falls between 0.1 and 0.25 wavelength. A bit more gain is obtained with close spacing. However, there is a greater reduction in the antenna resistance as compared to the resistance of a dipole. *Close spacings* extend between

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0.1 and 0.15 wavelength. With a spacing of 0.25 wavelength there is no great reduction in antenna impedance. *Wide spacings* extend between 0.2 and 0.25 wavelength.

The standard equations are used to determine the length of the dipole.

$$\frac{1}{2}\lambda \text{ dipole} = \frac{468}{f}$$

$$\frac{1}{4}\lambda \text{ dipole leg} = \frac{234}{f}$$

The reflector must be made 5 percent longer than the driven dipole element. However, in calculating the length of the reflector use the lowest operating frequency or:

$$\textbf{Reflector length} = \frac{468 \times 1.05}{f_L} = \frac{492}{f_L}$$

Calculations for 40-meter dipole (Fig. 69) would be:
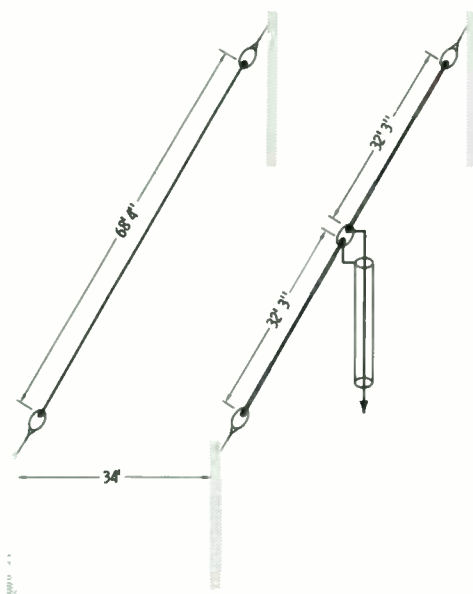
Fig. 69. Forty-meter dipole and reflector.

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$$\text{Dipole leg length} = \frac{234}{7.25} = 32'3''$$

The parasitic reflector length based on the lowest phone operating frequency of 7.2 MHz is:

$$\text{Reflector length} = \frac{492}{7.2} = 68'4''$$

The spacing between driven element and reflector for 40-meter operation is:

$$\frac{1}{4}\lambda \text{ spacing} = \frac{246}{7.25} = 34'$$

Driven element, reflector, and spacing dimensions for operation 10 through 160 meters are as follows:

SIDEBAND PORTION OF:	λ/4 DRIVEN 234/f	REFLECTOR 492/f_L	λ/4 SPACING 246/f
10 meters	8'2"	17'3"	8'7"
15 meters	10'11"	23'2"	11'6"
20 meters	16'5"	34'8"	17'3"
40 meters	32'3"	68'4"	33'11"
80 meters	60'	130'	63'1"
160 meters	128'	273'	134'9"

When the antenna is trimmed properly the antenna resistance is such that a direct connection can be made to a coaxial transmission line. Standing-wave ratio is lower than 1.5 to 1. A line tuner can be employed if the very lowest SWR is desired at the transmitter. A 1-to-1 balun can also be employed to obtain balanced radiation from the dipole legs. A final method of feed is to use open-wire transmission line and a balanced tuner. Refer to topics 1, 2, 3, 8, and 12.

39—Parasitic Director, Wide Spaced

A director is cut shorter than the driven element and resonates to a higher frequency. Again, with wide spacing (0.2 to 0.25λ) there is minimum influence on the dipole antenna resistance. The resistance is such that a direct connection to a coaxial transmission line is feasible. A director must be cut 4 percent shorter than the driven element. Practical equations are:

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$$\tfrac{1}{4}\lambda \text{ dipole length } = \frac{234}{f}$$

$$\text{Parasitic director length } = \frac{468 \times 0.96}{f_H} = \frac{450}{f_H}$$

$$\tfrac{1}{4}\lambda \text{ spacing } = \frac{246}{f}$$

Dipole, director, and spacing lengths for sideband operation on bands 10 through 160 meters are as follows:

SIDEBAND PORTION OF:	λ/4 DRIVEN 234/f	DIRECTOR 450/f_H	λ/4 SPACING 246/f
10 meters	8'2"	15'8"	8'7"
15 meters	10'11"	21'	11'6"
20 meters	16'5"	31'4"	17'3"
40 meters	32'3"	61'8"	33'11"
80 meters	60'	112'6"	63'1"
160 meters	128'	249'	134'9"

Typical dimensions are given in Fig. 70 for 40-meter operation. Equations are as follows:
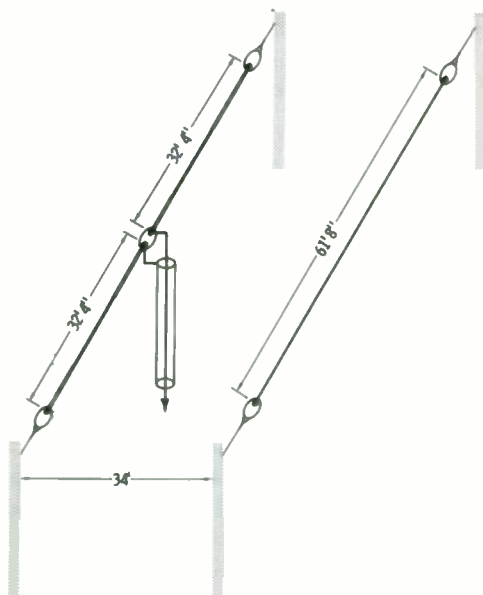
Fig. 70. Forty-meter dipole and director.

$$\frac{1}{4}\lambda \text{ dipole length} = \frac{234}{7.25} = 32'4''$$

$$\text{Parasitic director length} = \frac{450}{7.3} = 61'8''$$

$$\frac{1}{4}\lambda \text{ spacing} = \frac{246}{7.25} = 34'$$

Possible feed methods are: direct connection to coaxial line, coaxial line with a line tuner, 1-to-1 balun, or open-wire line with a balanced tuner. Refer to topics 1, 2, 3, 8, 12, and 38.

40—Two-Element Parasitic Antenna, Close Spaced

When close spacing is used for a two-element beam, less space is needed in which to erect a 40-, 80-, or 160-meter antenna and a shorter boom suffices for the construction of a 10-, 15-, 20-, or 40-meter beam. Bandwidth and antenna resistance are less than that obtained with $\frac{1}{4}$-wave spacing but the possible gain is higher. The equation and dimensions given in topics 38 and 39 are appropriate; however, the spacing differs. Usually a spacing of 0.15 wavelength is used for reflector operation and 0.1 wavelength for director spacing. Values for 10- through 160-meter bands are as follows:

SIDEBAND PORTION OF:	$\lambda/4$ DRIVEN 234/f	REFLECTOR 492/f_L	DIRECTOR 450/f_H	0.1λ SPACING 98.4/f	0.15λ SPACING 148/f
10 meters	8'2"	17'3"	15'8"	3'6"	5'2"
15 meters	10'11"	23'2"	21'	4'8"	6'11"
20 meters	16'5"	34'8"	31'4"	6'11"	10'4"
40 meters	32'3"	68'4"	61'8"	13'6"	20'5"
80 meters	60'	130'	112'6"	25'3"	38'
160 meters	128'	273'	249'	53'10"	81'

Parasitic element length can be adjusted in accord with the desired bandwidth. Cutting the parasitic element nearer to the frequency of the driven element narrows the bandwidth and also increases the gain at the dipole resonant frequency. However, the antenna resistance decreases, and more careful consideration must be given to matching.

Cuts that are 4 percent less for the director and 5 percent more for the reflector provide good front-to-back ratio and gain. If the ulti-mate in gain is desired, one can experiment with decreasing the length

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TOP VIEW

17' 3"

8' 2"

8' 2"

0.15 λ
5' 2"

A

1 by 2

22' 3"

13' 6"

61' 8"

22' 3"

B
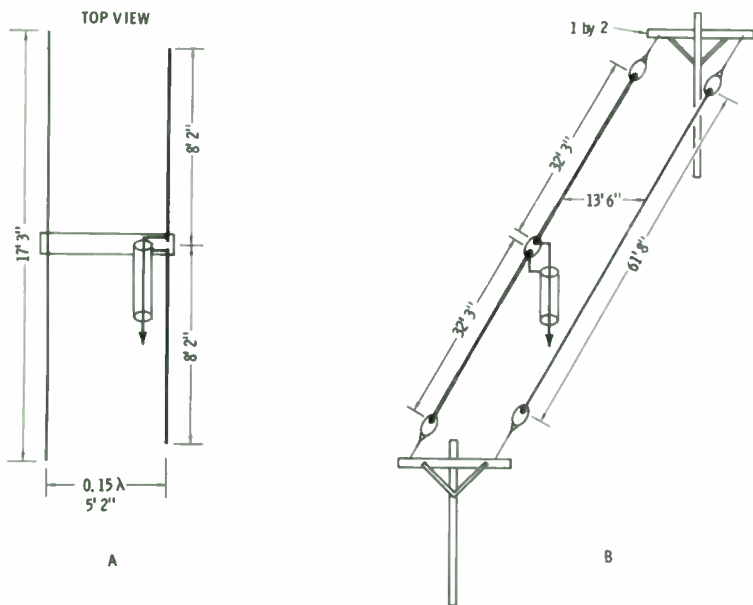
Fig. 71. Close-spaced 2-element parasitic antennas.

of the reflector or increasing the length of the director. There is some-
what less forward gain when maximum front-to-back ratio is obtained.
Usually this is not more than 1 dB.

Dimensions for a close-spaced 10-meter driven element and reflector
combination and a 40-meter driven element and director combination
are given in Fig. 71. The 40-meter antenna requires but two masts,
antenna elements are made of wire, while 14-foot wooden 1 × 2's
establish the spacing between driven element and director. Refer to
topics 1, 2, 3, 8, 12, 38, and 39.

41—Close-Spaced Two-Element, Stub Matched

Stub matching affords a positive means of matching an antenna and
reducing the SWR on the transmission line to a low value (Fig. 72A).
In the first quarter-wavelength section of transmission line beginning
at the antenna terminals, the impedance rises from minimum to maxi-
mum. It is assumed that the antenna is fed at a maximum-current
point and $Z_A < Z_0$. Somewhere along this span there is a point of the

81
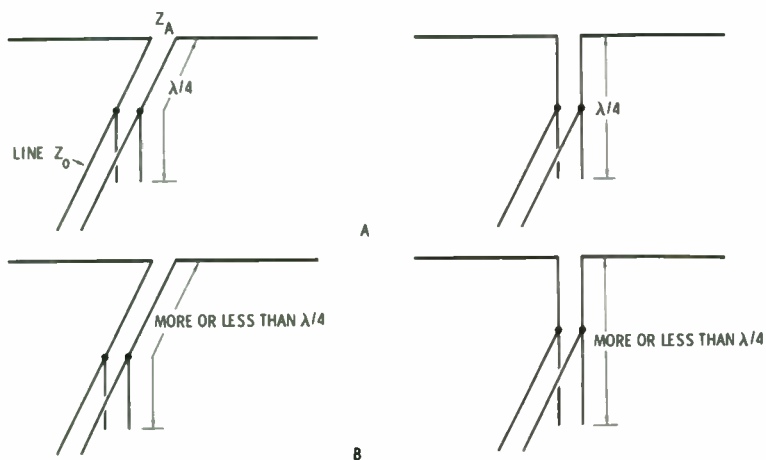
Fig. 72. Stub-matching arrangements, low-impedance antenna $Z_A < Z_O$.

same impedance as the transmission line. The two arrangements of A are identical. The lower is the antenna resistance or the higher is the transmission-line impedance, the greater is the separation between the antenna terminal and the point at which the transmission line is attached for matching.

The above arrangement assumes that the antenna impedance is entirely resistive and does not have a reactive component. (The above condition is met at the resonant frequency of the antenna.)

If the antenna has a reactive component the stub of Fig. 72B is appropriate. The basic plan is identical except that the stub is more or less than $\frac{1}{4}$ wavelength in electrical length as a function of whether the reactive component of the antenna is inductive or capacitive. In this case, by the use of proper stub length and correct positioning of the transmission-line tap-off point, the reactance of the antenna can be cancelled out and a proper resistive match made.

When the antenna is a high impedance one (fed at a voltage maximum and current minimum point), a similar system of matching can be employed (Fig. 73). In moving a $\frac{1}{4}$ wavelength away from the antenna terminal the impedance declines toward a minimum value at the short-circuit point of the stub. Therefore, as the transmission-line tap point is moved away from the antenna terminal, the impedance falls. Consequently, an antenna of a high impedance is matched to a transmission line of a lower impedance. Again, if the antenna also displays a reactive component it can be cancelled out by regulating the

82
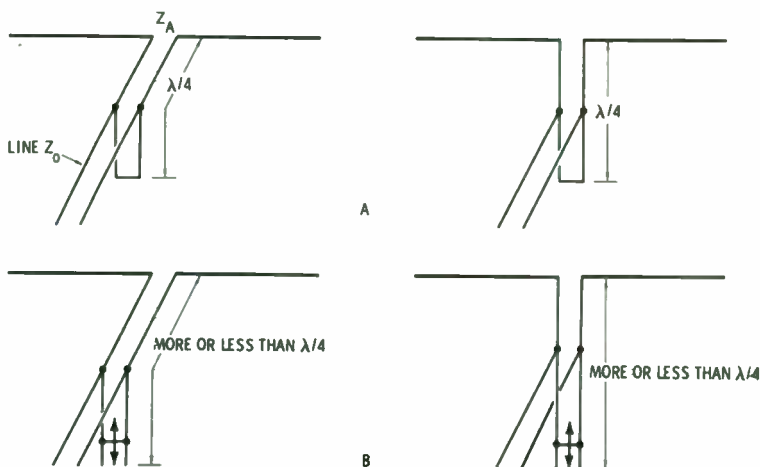
Fig. 73. Stub-matching arrangements, high impedance $Z_A > Z_O$.

length of the stub. It is again longer or shorter than a ¼-wavelength as a function of whether the antenna reactance is capacitive or inductive.

Chart 6 is of help in the practical location of the tap point. As a function of standing-wave-ratio, it indicates the required electrical length T between the antenna terminals and the tap point and the electrical length of the stub L that must be attached at the tap. For example, when matching a ratio of 2.5-to-1 the tap position must be 0.09 wavelength (T) away from the antenna terminal while the length of the stub must be 0.11 wavelength (L) approximately.

In using the table, first measure the standing-wave ratio at the antenna (no stub attached) or at a point exactly an electrical half wavelength away from the antenna terminal. When this value is known the electrical length of T and L can be determined from Chart 6. This information then can be converted to physical length for cutting your stub. Be certain to consider the velocity factor of the line used in the stub. It is advisable to use the same type of line for stub and trans-mission line.

The values given in Chart 6 provide an ideal match to an antenna that is displaying a resistive impedance. Dimensions are only ap-proximate when considerable reactance is present. However, the idea is still workable and can be used to load an antenna, the resonant frequency of which is considerably above or below the signal value.

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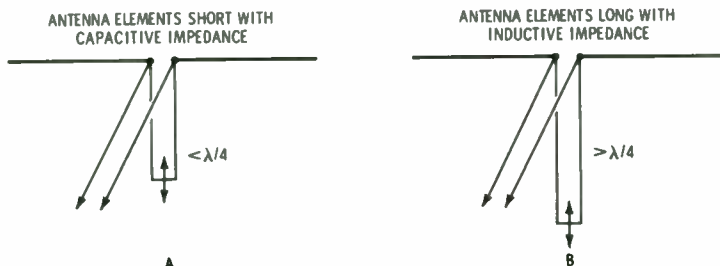
Fig. 74. Alternative matching plan when Z_A and Z_0 are not too different.

When a current-fed antenna is too long, it displays an inductive reactance which must be cancelled by a capacitive reactance from the stub. To make a shorted stub capacitive, it is necessary to make it longer than an electrical quarter wavelength $(T + L > \lambda/4)$. Use chart values plus an extra length for T and L corresponding to how much overlength the dipole might be or:

$$T' \cong T + (\text{actual } \lambda/4 \text{ length} - \text{resonant } \lambda/4 \text{ length})$$

$$L' \cong L + (\text{actual } \lambda/4 \text{ length} - \text{resonant } \lambda/4 \text{ length})$$

This is a starting point and you can trim back from here.

The same technique is used to resonate a short antenna. A short antenna is capacitive and its reactance can be tuned out with an *open stub* that is longer than an electrical quarter wavelength (Fig. 74). Such a stub is inductive. Again, chart values must be modified and a starting point can be based on just how much the dipole lengths are undersize or:

$$T' \cong T + (\text{resonant } \lambda/4 \text{ length} - \text{actual } \lambda/4 \text{ length})$$

$$L' \cong L - (\text{resonant } \lambda/4 \text{ length} - \text{actual } \lambda/4 \text{ length})$$

Trim for minimum SWR.

A special version of the stub-matching plan connects both the stub and the transmission line to the antenna terminals (Fig. 75). In this case the electrical length of the antenna itself is shortened so that it displays a capacitive reactance at the resonant frequency. The shorted stub provides just enough inductive reactance to cancel the capacitive

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SWR RATIO	$Z_A < Z_0$		$Z_A > Z_0$	
	$T\lambda$	$L\lambda$(open)	$T\lambda$	$L\lambda$(shorted)
10-1	0.05	0.195	0.2	0.057
8-1	0.055	0.188	0.195	0.06
7-1	0.058	0.182	0.19	0.068
6-1	0.062	0.176	0.187	0.075
5.5-1	0.065	0.172	0.184	0.078
5-1	0.068	0.168	0.182	0.084
4.5-1	0.071	0.162	0.18	0.09
4-1	0.074	0.156	0.177	0.097
3.5-1	0.078	0.148	0.174	0.105
3-1	0.083	0.138	0.168	0.114
2.5-1	0.09	0.11	0.162	0.132
2-1	0.097	0.096	0.152	0.15
1.5-1	0.105	0.06	0.14	0.185
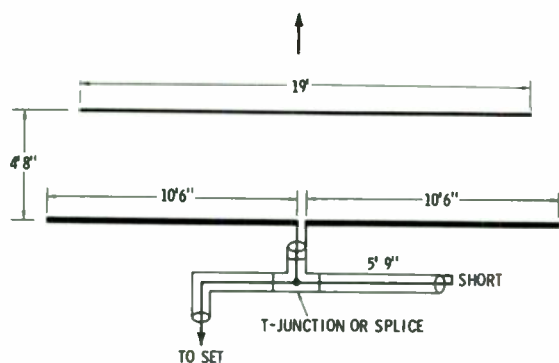
Fig. 75. Fifteen-meter 2-element parasitic antenna, stub-matched.

reactance of the antenna. At the same time a resistive impedance match is obtained.

A practical two-element 15-meter beam using this matching technique is shown. It is a close-spaced arrangement with director 0.1 wavelength in front of the driven element. The driven element is shortened until it is just slightly longer than the parasitic director. A T-junction connector is employed at the dipole antenna terminals with the transmission line connected to one side of the T and the *shorted* coaxial stub to the other. With no stub connected, the SWR on the line was 3 to 1. A $\lambda/4$ stub (0.66 VF) at 21.3 MHz has a length of 7'8". This length stub

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was connected and attached at the T connector. It was cut back while observing the SWR. A final standing-wave ratio on the line was 1.05 to 1 (21.3 MHz) and no higher than 1.13 to 1 at band ends. A compact, well-matched, and high front-to-back ratio beam results. Refer to topics 1, 2, 3, 38, 39, and 40.

42 —Parasitic Reflector-Director Combination

A parasitic element can perk up your antenna results in a given direction on the 40-, 80-, or 160-meter low-frequency bands. Gain step-up is 3 to 5 dB. At the same time the omnidirectional performance is satisfactory.

On the east coast such an antenna directed west provides improved transcontinental coverage. Similarly, such an antenna on the west

DRIVEN   234/f (7.05MHz)
DIRECTOR 450/f_H (7.1MHz)
REFLECTOR 492/f_L (7.0MHz)
SPACING   148/f (7.05MHz)

0.15λ
20' 10"

70'
63'4"
33'3"
33'3"

Fig. 76. Forty-meter cw parasitic reflector-director combination.

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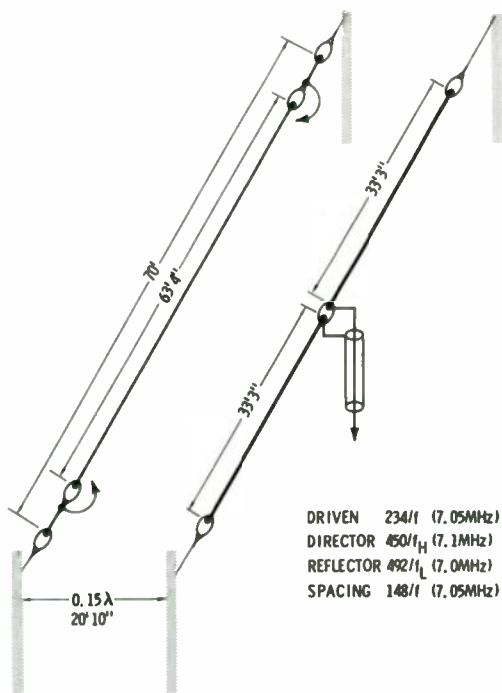coast improves eastward signals. For midwest locations it is possible to set up a single parasitic element that can be used either as a director or reflector which can be preset according to the preferred direction of transmission. A practical antenna of this type for 40-meter cw operation is given in Fig. 76. Four masts instead of two are needed; the second pair are separated from the first by 0.15 wavelength.

Note that the parasitic element contains two pairs of insulators. When the inner pair of insulators are jumped the parasitic element acts as a reflector. If an open is established at the inner pair of insulators, the parasitic element acts as a director. A simple halyard arrangement at one of the masts can be used to lower the parasitic wire to make the necessary changeover between director and reflector use. In one direction the antenna functions as a driven element and parasitic director; in the other, as a driven element and reflector.

Dimensions for the cw end of the 40-meter band are given in Fig. 76. A reasonable direct match is made to a coaxial line which is made a whole multiple of an electrical half wavelength. Of course, a line tuner can be used, or, if open-wire transmission line is preferred, a balanced line tuner is employed. The stub-matching system of topic 41 is excellent when an exact match is desired. Refer to topics 1, 2, 3, 8, 12, 38, 39, 40, and 41.

43 —Inverted-Vee Parasitic

The inverted dipole antenna is a single-mast configuration. A parasitic reflector or director can be added with a second mast. Spacings can be 0.25, 0.15, or 0.1 wavelength. The influence of spacing on antenna resistance and other characteristics are like those of straight horizontal construction.

Leg length of an inverted dipole may have to be adjusted to obtain the proper resonant frequency. Usually there may be some adjustment needed as a function of the apex height and the nearness of the leg ends to ground. For operation with parasitic element, it is best to keep the apex angle 120° or greater. In general, the nearer the leg ends are brought to ground, the shorter is the antenna for a given frequency. However, this is counterbalanced by the fact that the more acute (smaller) the apex angle, the longer must be the leg length for a given frequency. Thus, a cut-and-try procedure is used. An antenna noise bridge or SWR meter can be employed. Refer to Appendices I through V.
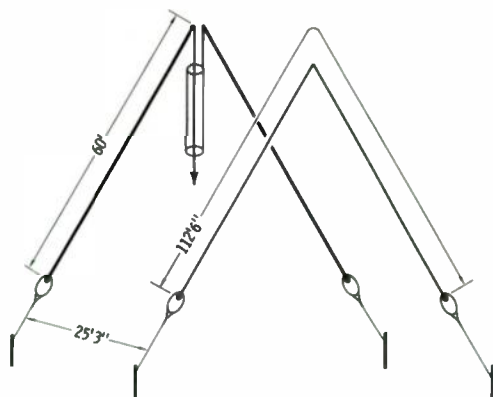
Fig. 77. Inverted-vee driven element and parasitic director for 80 meters.

Antenna resistance is also lower with the presence of the inverted parasitic. The nearer the parasitic is to the driven element, the lower is this resistance.

Practical dimensions for an 80-meter driven element and director combination are given in Fig. 77. Note that the masts can be mounted
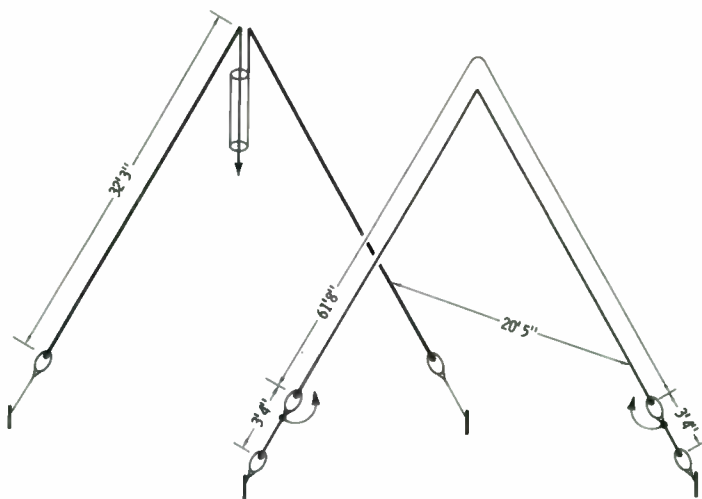
Fig. 78. Inverted-vee parasitic reflector-director combination for 40 meters.

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quite near to each other because of the 0.1 wavelength spacing which amounts to only 25 feet for 80-meter sideband operation.

The inverted-vee parasitic construction is ideal for any combination director and reflector operation because the parasitic ends are near ground level. A 40-meter inverted-vee with a combination director-reflector parasitic is shown in Fig. 78. A variety of feed arrangements can be employed including direct connection to coaxial line, stub, 1-to-1 balun, line tuner, and last, open-wire along with a balanced tuner. Refer to topics 1, 2, 3, 8, 35, 38, 39, 40, and 42.

44 —Multiband Inverted-Vee and Parasitic-Element Combinations

The inverted dipole is an attractive antenna because band changes can be made conveniently from ground level. Likewise, an inverted parasitic element can be changed over conveniently at ground level for multiband operation. The technique is covered in topics 34 and 36. Such a bandswitching parasitic-element antenna can be constructed conveniently for 40 and 80 meters or for 40-, 80-, and 160-meter operations.
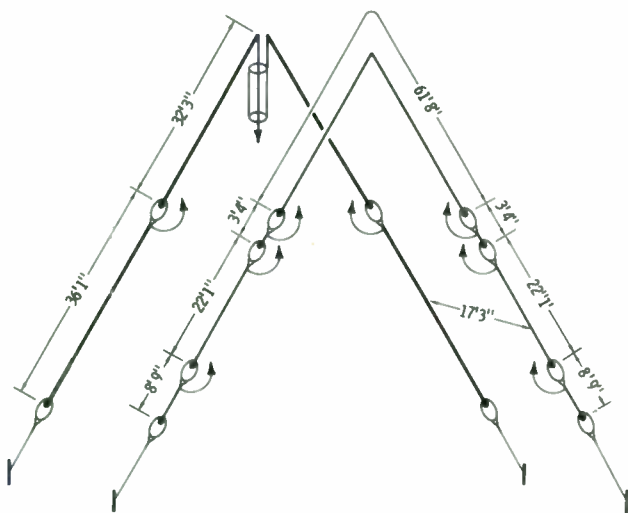

Fig. 79. Inverted-vee parasitic reflector-director combination for 40 and 80 meters.

Practical dimensions for 40- and 80-meter operation are given in Fig. 79. Keep the apex angle 120° or greater. The driven element uses a single pair of jumpers. These are opened for 40-meter operation and closed on 80. Note that the parasitic element contains four pairs of insulators. They permit bidirectional operation of the antenna. On 40 and 80 meters the parasitic operates either as a director or reflector. With the innermost pair of jumpers open, the parasitic functions as a director on 40 meters. When all jumpers are closed, it operates as an 80-meter reflector.

The spacing is λ/4 on 40 meters. This amounts to approximately 0.125 wavelength on 80 meters.

If space is available, the three-band version can be constructed to include 160 meters. Considerably more erection space is needed because of the long length of the 160-meter legs. Ideal spacing is not so readily obtainable as for the two-band version. However, a spacing of 0.1λ on 160 meters is used. This corresponds to a spacing of approximately 0.2λ on 80 meters and 0.4λ on 40. A sacrifice in 40-meter gain is made. Refer to topics 1, 2, 3, 8, 12, 34, 36, 38, 39, 40, 42, and 43.

45—Single-Mast Inverted Vee With Parasitic Element

A director or reflector can be added to an inverted dipole antenna in the manner shown in Fig. 80. The legs of the inverted dipole extend out in opposite directions or can be tilted forward slightly (no more than 120°). The parasitic-element reflector or director is continuous and also spans outward from the center mounting position. However, the parasitic elements have a greater tilt so that the separation of the dipole and parasitic ends falls somewhere between 0.1 and 0.25 wavelength.

Dimensions for 40-meter operation are given in Fig. 80. The parasitic element serves either as a director or reflector depending upon whether the jumpers of the innermost insulators are opened or closed. The length of the reflector must be made somewhat longer when it tilts back away from the driven element. Its ends should extend beyond the ends of the driven element as shown in the small insert of Fig. 80. A value of 540/f is usually long enough. Final trimming to a specific frequency can be accomplished at ground level.

In addition to the bidirectional switching of the parasitic element this arrangement can be oriented readily from ground level. The

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REFLECTOR ENDS MUST
EXTEND BEYOND DIPOLE ENDS
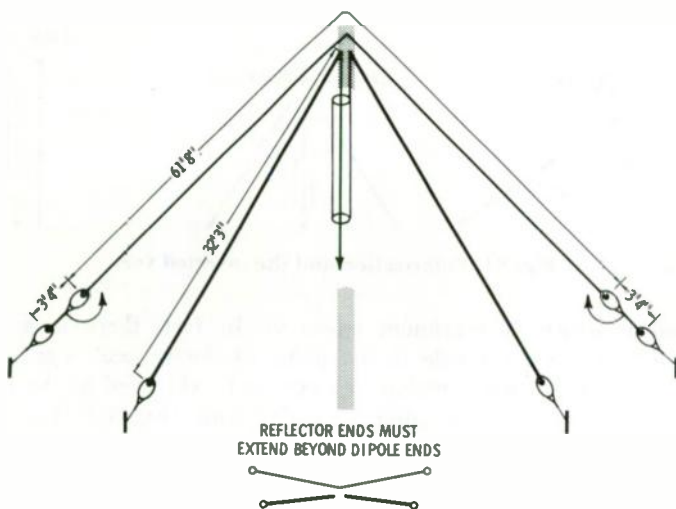
Fig. 80. Single-mast inverted vee with parasitic element.

elements can be moved about to favor a given direction. The sharpness of the directivity of this type of antenna is not as good as when the antenna elements are horizontal. However, there is an improvement in a given single direction, and, at the same time, the omnidirection characteristic is good. It is possible to construct two- and three-band versions of the same antenna using appropriate jumpers for the driven and parasitic elements. Refer to topics 1, 2, 3, 8, 12, 34, 35, 36, 38, 39, 40, 42, 43, and 44.

46—Acute-Angle Vee With Parasitic Element

The angle between the two legs of an inverted dipole has much to do with the dominant polarization of the emitted wave. When the angle approaches the horizontal (Fig. 81), the dominant polarization is horizontal and maximum radiation is broadside to the antenna legs. There is some vertically polarized radiation off the ends. However, as the apex angle is made more and more acute, the magnitude of the vertically polarized component coming off the ends increases while the horizontally polarized broadside radiation decreases. The extreme case as shown in Fig. 81 occurs when the apex angle has been decreased to the extent that the two legs are parallel to each other. In this case the bulk of the energy is radiated as a vertically polarized

120° PLUS —
HORIZONTAL DOMINATES

90° MINUS —
VERTICAL DOMINATES

VERTICAL –
VERTICAL DOMINATES
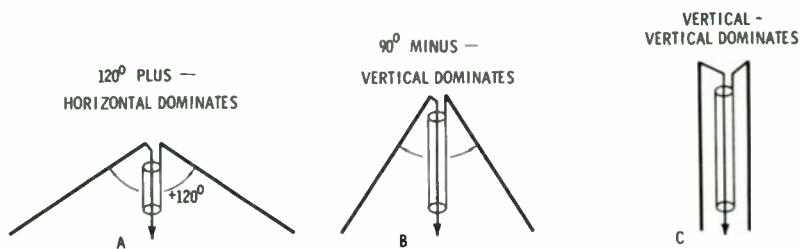
Fig. 81. Polarization and the inverted vee.

component which is maximum edgewise. In fact, there is a rather deep null exactly broadside to the plane of the vertical legs.

The very simple construction of example C when fed at the bottom and attached to a rotator using a wooden mast (Fig. 82) has a good directional characteristic. Although this cannot be considered a big transmitting beam antenna it can be loaded simply with a stub. The very sharp receiving null broadside to the frame is a definite aid in minimizing received QRM.
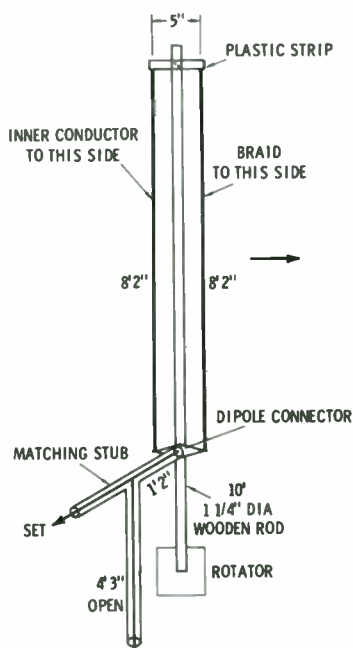
Fig. 82. Simple directional vertical for 10 meters.

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When a coaxial feedline is used the unbalance can be used to advantage to obtain a unidirectional pattern. Maximum radiation and sensitivity are in a line between the side of the frame fed by the center conductor of the coaxial line toward the side attached to the coaxial braid (Fig. 82). It is a simple vertically polarized beam construction.

More transmit gain and higher receive sensitivity can be obtained by opening up the angle as shown in Fig. 83. Of course, the angle may not be increased too much because of the resultant increase in horizontally polarized components that are radiated broadside to the plane of the inverted dipole legs. In practice an angle of 90° or less ensures strong vertically polarized radiation and only a relatively low level broadside horizontal radiation. A unidirectional pattern is obtained by adding a parasitic director or reflector (Fig. 83B).

It is easy to suspend this type of beam between two masts which make it readily adaptable to both high- and low-band operation. The
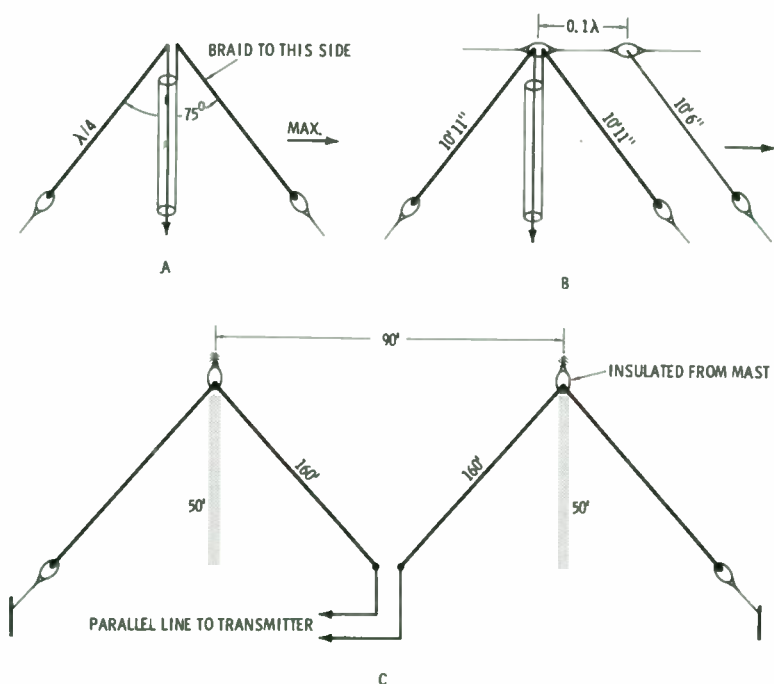
Fig. 83. Acute-angle inverted vee's.

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suspension span can be made of wire, hanging the vee and parasitic elements from insulators, or from plastic clothesline (nonmetallic core). This antenna does a fine job with the antenna ends near ground level. With the antenna ends about 4 or 5 feet above ground level they are accessible for tuning, bandswitching, and pattern changing.

The practical antenna shown in Fig. 83B was cut for 15-meter operation. A single jumper permits the parasitic element to be used either as a director or reflector. Tuners and open-wire transmission line can also be used with the antenna type. This antenna plan can be applied to long wires also. The antenna of Fig. 83C, with open-wire line and balanced tuner, performed very well on all bands 10 through 160. High gain and sharp bidirectivity off the ends were obtained 10 through 40 meters. Gain on 10 meters surpassed a three-element beam. Patterns were more omnidirectional on 80 and 160 meters. Refer to topics 1, 2, 3, 8, 12, 34, 35, 36, 38, 39, 40, 42, 43, 44, and 45.

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SECTION 6

Horizontal Phased Arrays

47—Horizontal End-Fire, 90° and 180°

In a 180-degree end-fire configuration two horizontal dipoles are fed out of phase (Fig. 84A). Maximum radiation is broadside to the

Fig. 84. Basic end-fire configurations.

Fig. 85. Feed methods for end-fire (180°) two elements.

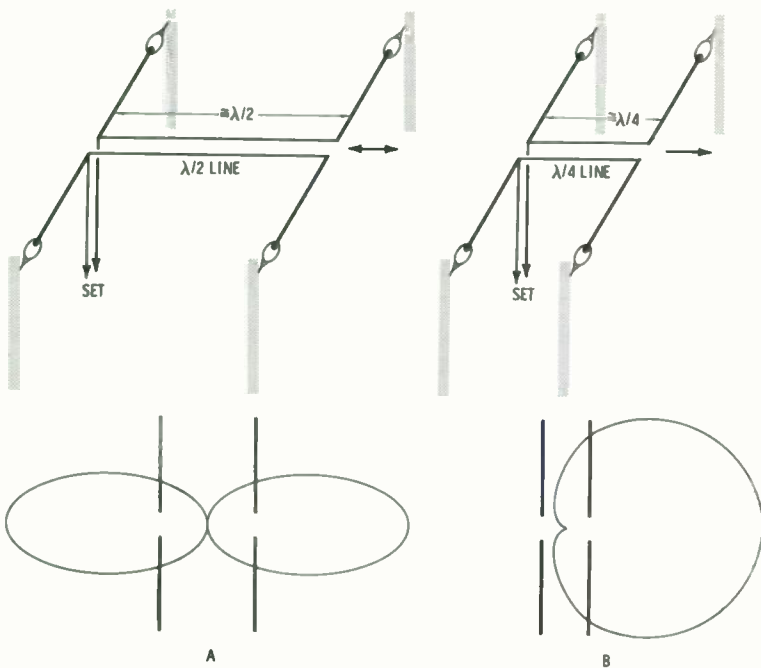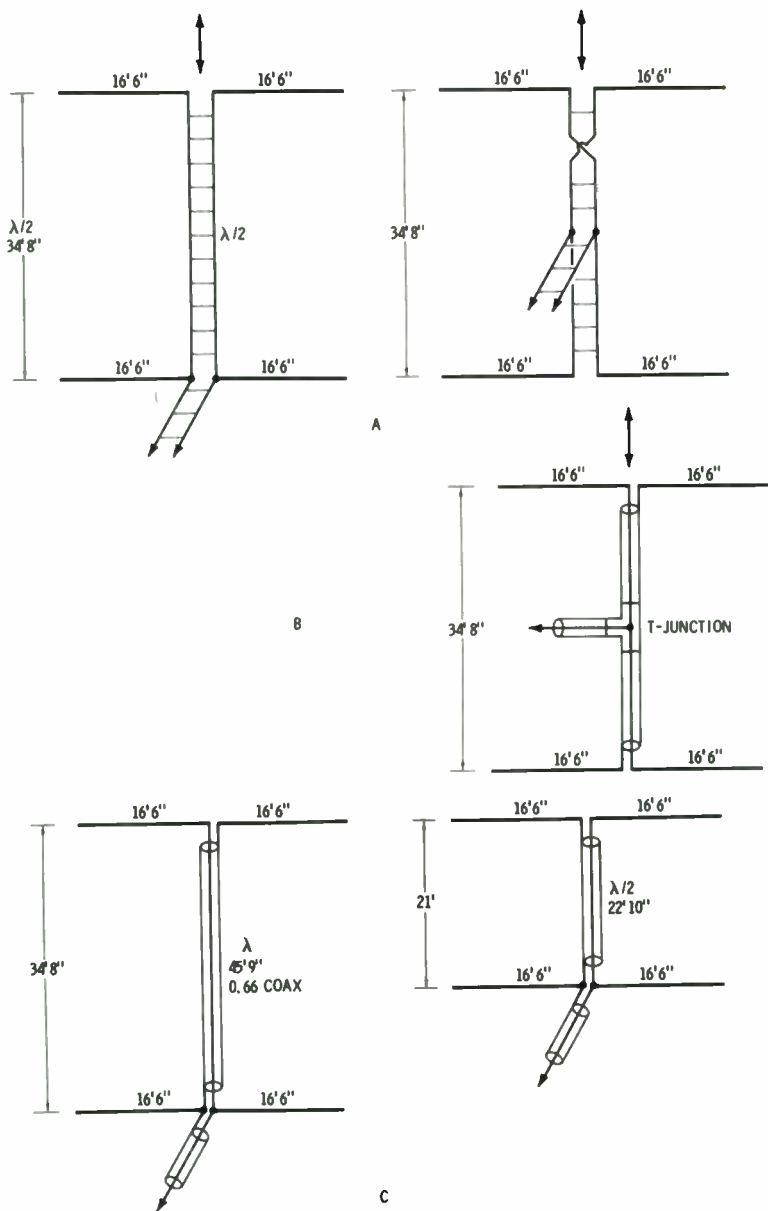antenna wire just as in the case of a horizontal dipole. However, the figure eight is a narrower one and the gain in the maximum directions is approximately 4 dB.

Practical dimensions for 20-meter operation are given with the antenna of Fig. 85. Various feed methods are permissible. Open-wire line is ideal for this type of configuration because its velocity factor is near unity. Therefore, the two half-wavelength antennas can be separated by exactly a half wavelength. The interconnecting half-wave section of open-wire line produces the phase reversal needed to feed the two antennas out of phase. The alternative arrangement of A is to feed at the center through quarter-wavelength segments of open-wire line. However, the line on one side is transposed so as to obtain out-of-phase feed of the two dipoles. A balanced tuner, either at the antenna or at the transmitter, is required. When a tuner is used, the antenna can also be loaded on other bands.

When coaxial transmission line feeds the two dipoles, use a T-junction at the center. One coaxial feed line is transposed. This involves connecting the inner conductor of one feed line to the left leg of No. 1 dipole and the outer braid of the other section of coaxial feed line to the same side of the second dipole. This is shown in Fig. 85B.

When the interconnecting line is to be run from one dipole to the other, the velocity factor of the coaxial line must be considered. To obtain out-of-phase feed with one-half wavelength spacing, it is necessary that the coaxial line between the two be an electrical full wavelength and transposed in its feed, as shown in C.

An alternative method that provides somewhat less gain is shown in C. In this case the two dipoles are spaced less than a half wavelength so that a coaxial transmission line of an electrical half wavelength can be strung between them. If the coaxial line has a velocity factor of 0.66, the spacing between the two dipoles should be somewhat less than $(0.66 \times 0.5\lambda)$. If the velocity factor is 0.81, the spacing should be less than $(0.81 \times 0.5\lambda)$.

When using coaxial feed systems a line tuner can be employed at the transmitter to lower the SWR. An alternative approach is to use the stub-matching scheme detailed in topic 41.

An end-fire pair of verticals can be spaced and fed in such a manner that a unidirectional pattern results. To do so the antennas must be separated by $\lambda/4$ and one vertical must be fed 90° behind the other (Fig. 84B). The direction of maximum radiation is in line with the two verticals in the direction of the vertical receiving the lagging excitation. The 90° lag is obtained by feeding the one vertical through

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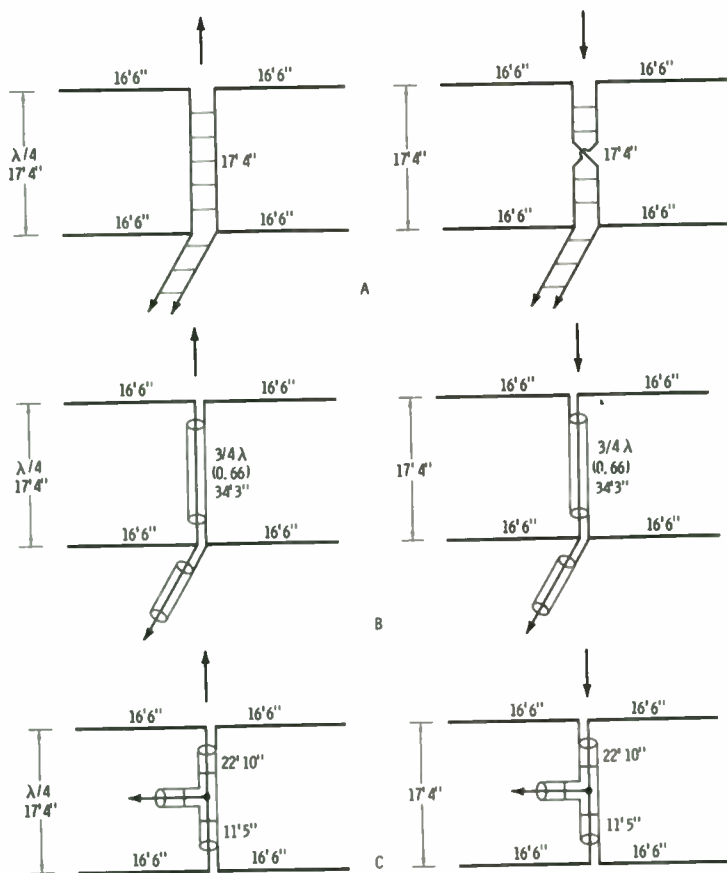
Fig. 86. Ninety-degree end-fire feed methods.

an additional λ/4-section of line or an appropriate odd multiple of an electrical quarter wavelength. The 90° feed method produces a broad unidirectional forward load. At the same time, the back response dips down to a minimum. This is an ideal situation in locations troubled by severe QRM pickup from the rear.

Again, open-wire line affords a good feed method. With the two dipoles spaced λ/4, the quarter-wave section of line between the two dipoles provides the 90° feed (Fig. 86A). Furthermore, by transposing the feedline it is possible to obtain 270° feed which will reverse the pattern direction.

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Coaxial feed methods are shown in Fig. 86B. In the first arrangement the two dipoles are separated by a quarter wavelength with the second dipole being fed from the first dipole through a section of coaxial line which is an electrical ¾-wavelength long. The maximum is in the direction from the second dipole toward the transmission-line-fed dipole. Pattern reversal can be obtained by transferring the feed line over to the second dipole or by transposing the ¾-wavelength line between the two dipoles.

An alternative feed method involves a center junction and a length of transmission line on one side that is an electrical quarter wavelength longer than on the other. Pattern reversal can be obtained simply by transposing either one of the feed lines at the point where they connect to the dipole. Refer to topics 1, 2, 3, 8, 12, 16, and 17.

48 —Broadside and Collinear Two-Element Horizontals

Two dipole antennas, one stacked a half wavelength above the other and fed in phase, result in a figure-eight horizontal pattern and a figure-eight vertical pattern (Fig. 87). The horizontal pattern is the same as that obtained with a single horizontal dipole. The vertical pattern sharpens and produces low-angle radiation, a favorable condition for DX operation. Open-wire line feed is again attractive because its velocity factor is near unity and the transmission line can be attached to the bottom dipole, transposed and then continued on to the top dipole. Center feed is also feasible but the transmission line must be routed up to a midpoint between the top and bottom dipoles.

If there are space limitations the two dipoles need only be separated a quarter wavelength with some sacrifice in gain. Center feed provides in-phase operation of the two dipoles (Fig. 87B). Maximum gain is obtained when the two dipoles are separated by ⅝ wavelength. Center feed is used.

Coaxial feed methods are shown in Fig. 88. The center-tap feed method is most often used for coaxial line using a T-junction. Spacing can be anywhere between ¼ and ⅝ wavelength, according to mounting requirements.

The coaxial feed method (Fig. 88B) uses a full-wavelength section of coaxial line between the bottom and top dipoles. If the velocity factor is 0.66 wavelength, this corresponds to a section of coaxial line of 45′9″ (0.66 × 984/14.2) on 20 meters. A spacing of ⅝ wavelength in free space corresponds to approximately 43′3″ (⅝ × 984/14.2) on

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20 meters. Therefore, with a separation corresponding to the length of the full-wave section of transmission line there can be in-phase feed, and, at the same time, the separation between the two broadside
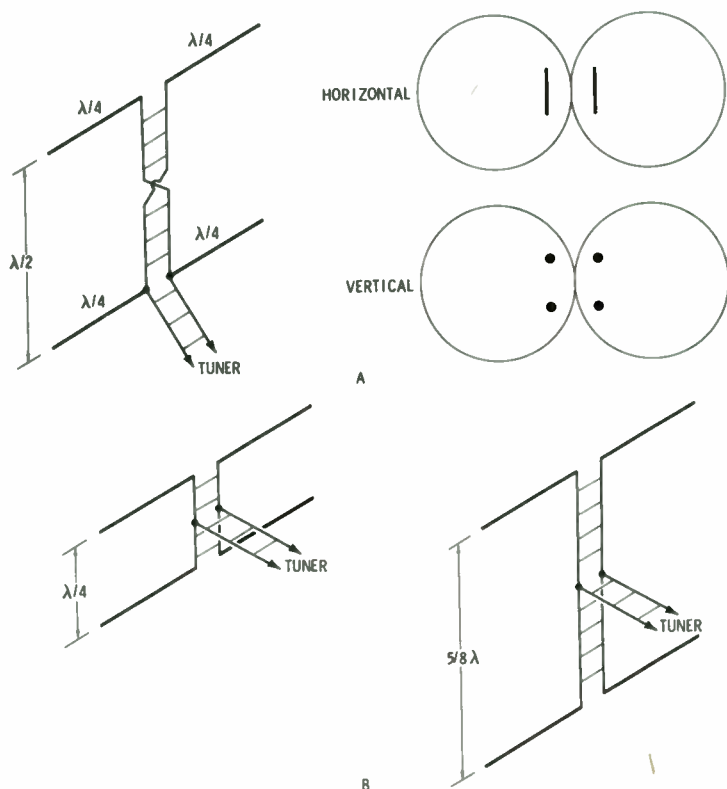
Fig. 87. Two-element horizontal broadside antenna.

dipoles provides maximum gain. Dimensions for this antenna for 20-meter operation are given in Fig. 88B. However, a similar relationship exists for other bands.

The collinear antenna (Fig. 89) is not used too frequently on the low-frequency bands because of space requirements. In a collinear configuration the two antennas must be placed end to end. However, for good performance it is necessary that the two ends be well separated. The collinear pattern is a sharpened figure eight broadside to the collinear elements.

100
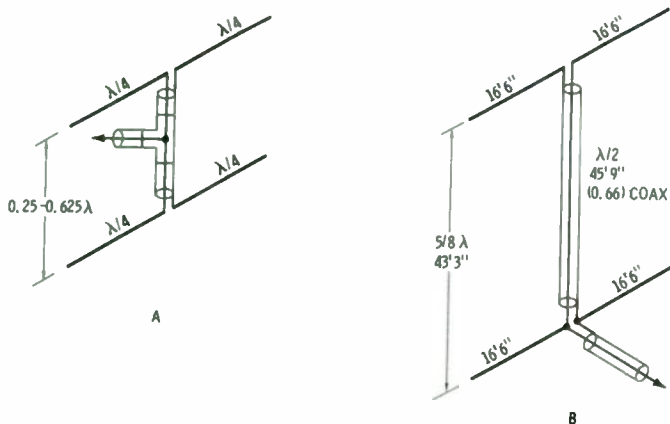
Fig. 88. Coaxial feed methods for 2-element broadside.
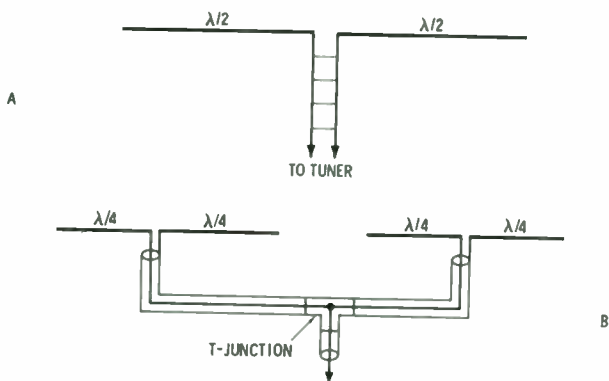
Fig. 89. Collinear feed methods.

The two most common feed methods are shown in Fig. 89. In A, each antenna leg is a half wavelength long. These two antenna legs are end-fed, which is a maximum voltage and minimum current point. Therefore, it presents a high impedance to the transmission line, and open-wire line with balanced tuner represents the preferred feed method.

The low-impedance feed method is shown in B. This method of feed can employ coaxial transmission line. A T-junction is located at the center between the two collinears. An equal length of line goes out to each of the dipoles and provides in-phase excitation. Preferred

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separation between the ends of the dipoles is at least $\lambda/4$. More gain is obtained with $\lambda/2$ separation between ends.

All of the common methods of feeding can be employed with the phased horizontal antennas—direct coaxial connection with a line tuner, open-wire line with a balanced tuner, stub matching, etc. Refer to topics 1, 2, 3, 8, 12, 16, 18 19, 41, and 47.

49—Collinear, End-Fire (180°)

The simple full-wavelength collinear antenna can be combined with more than one collinear element in an end-fire or broadside combination. The antenna of Fig. 90 is an end-fire collinear combination with
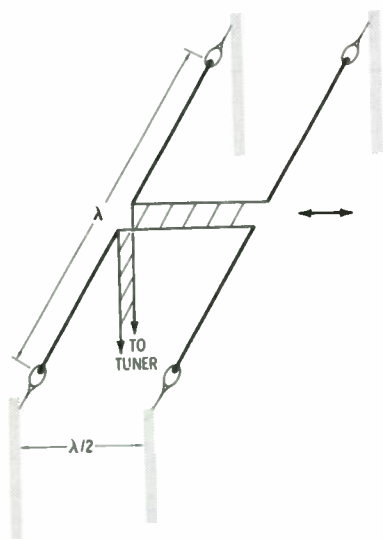
Fig. 90. Collinear, end-fire, 180° phased horizontals.

the end-fire pair being fed 180^c related. The horizontal radiation pattern is an elongated figure eight. The end-fire connection also provides a favorable low-angle vertical radiation.

This antenna is a high-impedance one because of the collinear connection, and open-wire transmission line is preferred. An alternative is to use stub matching. Refer to topics 1, 2, 3, 8, 12, 16, 18, 19, 41, 47, and 48.

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50—End-Fire (90°), Broadside

The 90° end-fire connection provides a unidirectional pattern that can be combined with the low vertical-angle characteristics of a broadside connection. This antenna has good gain and a single-direction pattern. Such an antenna also has a minimum of back pickup and a consequent reduction in the QRM pickup from the rear.
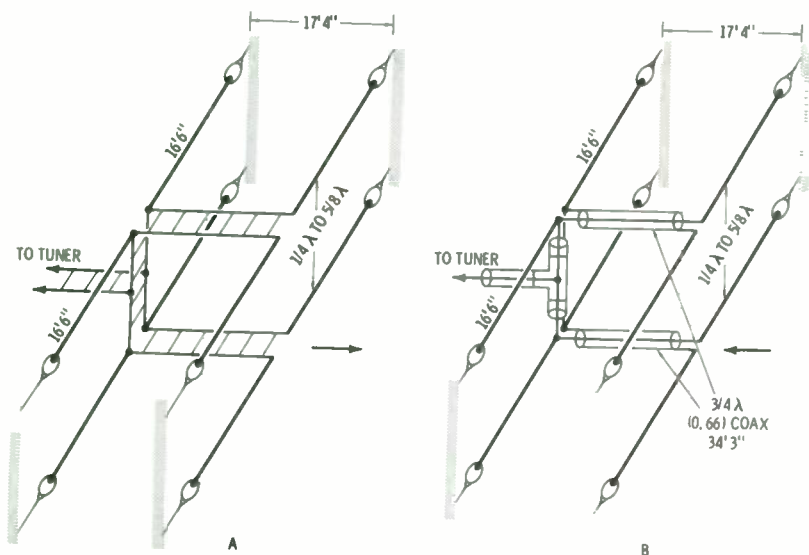
Fig. 91. End-fire (90°) broadside antenna.

The antenna of Fig. 91 is dimensioned for 20-meter sideband operation. Quarter-wave open-wire line or ¾-wavelength coaxial line links the end-fire pairs. Note that the ¾-wavelength line must be transposed if the same pattern direction is to be obtained for open-wire and coaxial feed. The pattern can be reversed simply by reversing connections at the outside end-fire dipoles. The broadside grouping is fed correctly by attaching the transmission line at the center between the upper and lower dipoles.

A variety of feed methods can be employed as with most of the phased antennas. Feed methods can be direct connection of coaxial transmission line and a line tuner, open-wire line with a balanced tuner or a stub-matching arrangement. Refer to topics 1, 2, 3, 8, 12, 16, 18, 19, 20, 41, 48, and 49.

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51 –End-Fire Beam

The end-fire configuration, because of the close spacing of its elements, also lends itself to the construction of small beams for 10 and 15 meters. It can be noted from Fig. 41 that with $\lambda/8$ spacing and phasing angle between 90° and 135° that a reasonably good unidirectional pattern can be obtained. A 15-meter antenna using this principle is shown in Fig. 92. The $\lambda/8$ spacing is:

$$\text{Spacing} = \frac{123}{21.3} = 5'9''$$
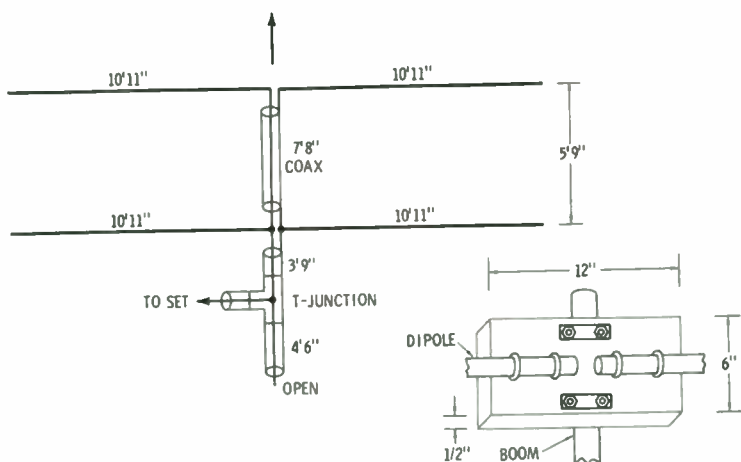
Fig. 92. Close-spaced end-fire beam.

A $\lambda/4$ section of coaxial line with a velocity factor of 0.66 is:

$$\text{Phasing line} = \frac{246 \times 0.66}{21.3} = 7'8''$$

Stub matching reduces the SWR to a very low value. This antenna has a broad forward lobe and when attached to a rotator it is possible to maneuver the antenna for a minimum rear pickup of QRM at the same time the desired signal is not changed too much in magnitude as the antenna is rotated over a reasonable range. Stub

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matching is a trial and error process. Measure SWR and start out with stub values about one foot longer than Chart 6 calculations. Lengths given in Fig. 92 should be satisfactory in most situations.

A very short boom is required and the antenna assembly can be made quite simple. Insulators are cut from plastic sheet according to the dimensions of Fig. 92. U-bolts hold the insulators to the boom. Smaller U-bolts hold the antenna elements to the insulators. Refer to topics 1, 2, 3, 8, 16, 21, 41, 47, 50, and 51.

52 —10-15 End-Fire Beam, Open-Wire Line

The use of open-wire line and the balanced tuner of Appendix VII lend themselves well to the construction of a phased two-band beam. Good results are obtained on both bands although the antenna itself is dimensioned for 15 meters (Fig. 93). Two 15-meter dipoles are spaced $\lambda/4$ on a 12-foot boom. The spacing between the end-fire dipoles is:

$$\lambda/4 \text{ spacing} = \frac{236}{21.3} = 11'6''$$

The $\lambda/4$ phasing line is of the same physical length. Adjust line length and spacing appropriately. The spacing of the dipoles is made slightly less than $\lambda/4$, just enough to permit the open-wire line to be interconnected and insulated away from the boom with standoffs. If the antenna is used with a rotator it is of course necessary to provide enough slack in the 450-ohm open-wire line to permit a complete rotation.

Good performance is obtained on 10 meters although the element lengths are somewhat greater than that needed for dipole resonance. Likewise the spacing and phasing is somewhat greater than 90°. A good unidirectional pattern is obtainable. The balanced tuner permits ideal loading on both 10 and 15 meters using the single 10- and 15-meter coil assembly of Appendix VII. Refer to topics 1, 2, 3, 12, 16, 21, 47, 50, and 51.

53 —Stacked 10-15 End-Fire Beam

A phased beam antenna can be stacked (fed broadside) to obtain higher gain and improved low-angle vertical radiation. In fact, the antenna of Fig. 93 lends itself well to two-band operation. The two
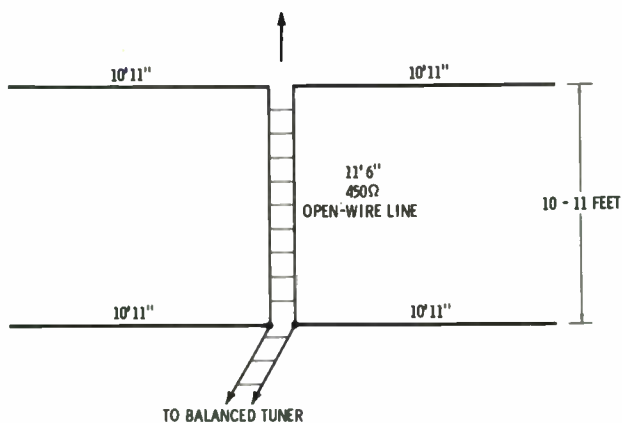
105

Fig. 93. Ten- and fifteen-meter open-wire end-fire beam.
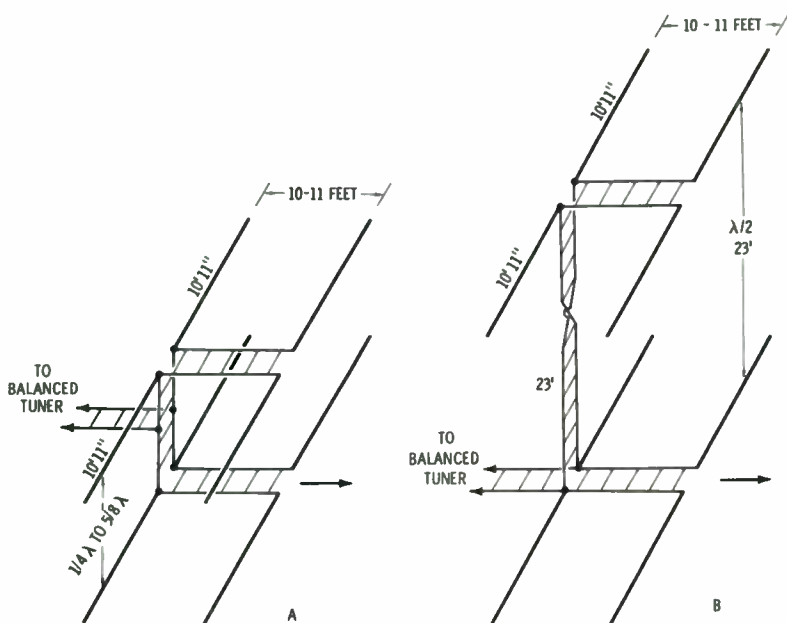
Fig. 94. Stacking end-fire antennas.

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sections (Fig. 94A) can be stacked anywhere from a $\frac{1}{4}$ to $\frac{5}{8}$ wavelength apart, depending on mounting facilities. The greater the separation up to the $\frac{5}{8}$ maximum is, the higher is the possible gain. However, this gain can only be obtained if the bottom end-fire pair can be kept at least $\lambda/2$ above ground. Regardless of the spacing this expedient helps to improve the low-angle radiation.

For $\lambda/4$ stacking the separation must be 11'6". This can also be the length of the broadside phasing line. The transmission line that runs back to the transmitter is connected to the midpoint of the broadside phasing line.

If 23-foot half-wavelength broadside spacing is possible, the antenna can be fed at the bottom and the broadside phasing line transposed to obtain in-phase feeding of the two end-fire pairs (Fig. 94B). With this latter arrangement the antenna provides proper broadside phasing only on 15 meters.

If one desires an optimum end-fire pattern on each band it is possible to use telescoping elements that can be pushed in for 10-meter operation and extended full length for 15-meter operation. With the telescoping sections extended for 15-meter operation, the use of the balanced tuner detailed in Appendix VII ensures proper loading of the transmitter when 10-meter operation is desired. Separation between the end-fire pairs should again fall between $\lambda/4$ and $\frac{5}{8}\lambda$, keeping the bottom pair at least $\lambda/2$ above ground. Refer to topics 1, 2, 3, 8, 12, 16, 17, 18, 19, 20, 21, 47, 48, 50, and 52.

Yagis, Quads, and Triangles

54—Three-Element Yagi, Stub-Matched

The most popular yagi antenna in "hamdom" is the three-element type (Fig. 95). The reflector is cut longer than the driven element and resonates lower in frequency; the director is cut shorter
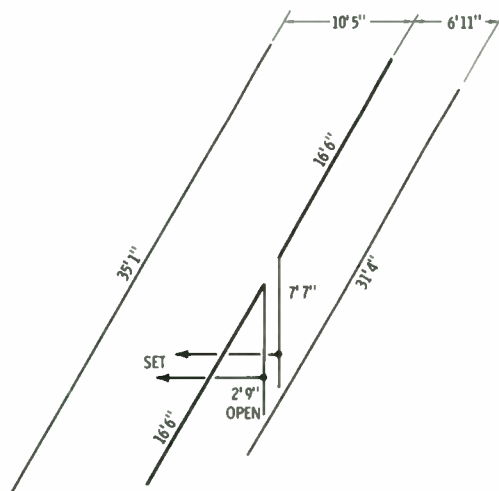
Fig. 95. Three-element 20-meter beam, stub-matched.

and resonates higher in frequency than the driven element. Rule-of-thumb figures indicate that the reflector must be cut at least 5 percent longer than the driven element and the director 4 percent shorter. However, bandwidth is a factor in selecting the most appropriate

length. A good practice is to cut the reflector for the lowest frequency and the director for the highest frequency of the desired bandwidth. Dimensions for all-band operation on the various amateur bands are as follows:

BAND	λ/4 Driven Element 234/f	Reflector 492/f_L	Director 450/f_H	Spacings λ			
				0.1	0.15	0.2	0.25
10	8'2"	17'6"	15'3"	3'5"	5'2"	6'10"	8'6"
15	11'	23'5"	20'11"	4'8"	6'11"	9'3"	11'6"
20	16'6"	35'1"	31'4"	6'11"	10'5"	13'9"	17'4"
40	32'9"	70'	61'8"	13'8"	20'6"	27'4"	34'2"

The most popular matching methods are the closed types of connection such as gamma, T, and delta. There are mechanical advantages because the driven element is continuous and not broken. Some hams favor the more open type of matching using a split dipole driven element. There is evidence that more beam-like characteristics result, especially with regard to receiving. However, this apparent improvement in receive performance may be more directly related to receiver input characteristics rather than the beam characteristics of the yagi.
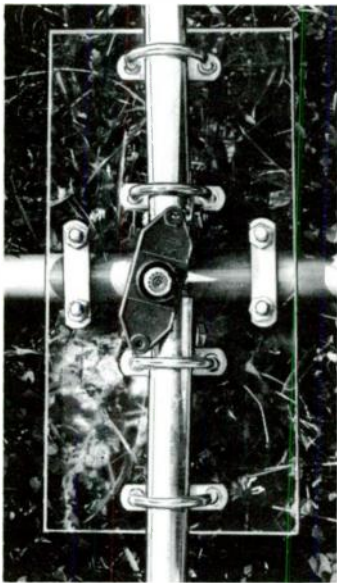
Fig. 96. Plastic insulator for split dipole.

Yagi-style antennas covered in this book emphasize the split dipole with stub matching and the use of open-wire transmission line. The dimensions of Fig. 95 are for a 20-meter sideband beam with driven element cut for 14.25, reflector for 14.2 and director for 14.35 MHz. The stub-matching plan of topic 41 is employed. The stub was adjusted at step-ladder height with the total length of transmission line in the circuit made a whole multiple of an electrical half wavelength at 14.25 MHz. The SWR meter was connected between the yagi coaxial connector and the end of the transmission line. The reading obtained was then used with the chart of topic 41 to determine approximate L and T lengths. Cut each section one foot longer and trim back for lowest SWR. Driven elements can be shortened and the techniques of topic 41 (Fig. 75) used for matching.

The mechanical construction of the driven element is shown in Fig. 96. The insulator is made of 12″ × 6″ × ⅝″ plastic sheet.

A wire-type yagi for 40 meters is shown in Fig. 97. Four poles are needed for this antenna. The wire-driven element can be suspended across the center. Using a $\lambda/4$ spacing between driven element and reflector and driven element and director, the four poles can be mounted in a square of approximately 70 feet. If a pair of jumpers

Fig. 97. Forty-meter fixed wire yagi.

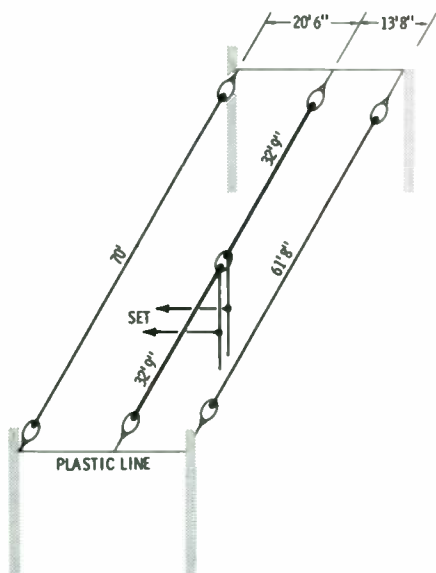are included with each parasitic element and a halyard for letting them down easy, the pattern can be reversed conveniently. Refer to topics 1, 2, 3, 8, 12, 38, 39, 40, 41, and 42.

55 —Three-Element Yagi, Open-Wire Line

Open-wire line represents a low-loss method of feeding a beam. When a long length of line must be employed the comparison between a beam that is coax fed and another one that is open-wire fed is quite surprising, and especially so from the standpoint of reception. The disadvantage is that a balanced tuner (Appendix VII) or a commercial balanced matchbox is needed.

In addition to the low standing-wave ratio seen by the transmitter, the use of a tuner has other advantages. The antenna system is

DIRECTOR ON 20   DIRECTOR ON 15   DIRECTOR ON 10

DIPOLE ON 20   DIPOLE ON 20   DIPOLE ON 20

OPEN-WIRE LINE   TO BALANCED TUNER

REFLECTOR ON 20   REFLECTOR ON 20   REFLECTOR ON 20

(A) 20 meters.   *(B) 15 and 20 meters.*   *(C) 10, 15, and 20 meters.*
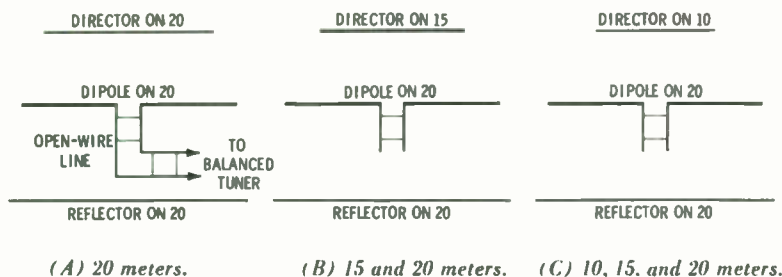
Fig. 98. Three-element yagi, open-wire feed line.

peaked for reception on a given frequency. Spurious and harmonic radiations are reduced. Furthermore, it permits a monoband beam to be loaded on other bands as well, particularly those on its high-frequency side. For example, the 20-meter beam of Fig. 98A does load on both 10 and 15 meters and has an acceptable pattern on these bands. On 10 and 15 meters (and particularly on 10 meters) the driven element acts as two collinear half waves. The reflector is effective on both 10 and 15 meters.

If good two-band operation (15 and 20) is desired with some decrease in 20-meter gain, cut the director for 15 (21 feet). A director cut for 10 (15 feet 6 inches) provides three-band operation with a decrease in 20-meter gain. Refer to topics 1, 2, 3, 12, 38, 39, 40, 41, 42, and 54.

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Fig. 99. Suspended 15-meter yagi.

56—Multielement Yagis

More than two parasitic elements can be added to the basic three-element yagi configuration. Four and five element monoband yagis are quite common. They use three and four parasitic directors, respectively. Wide spacing (0.2λ) between directors is typical. Performance measurements and experimentation over the years have indicated that wide spacing of multielement yagis provides more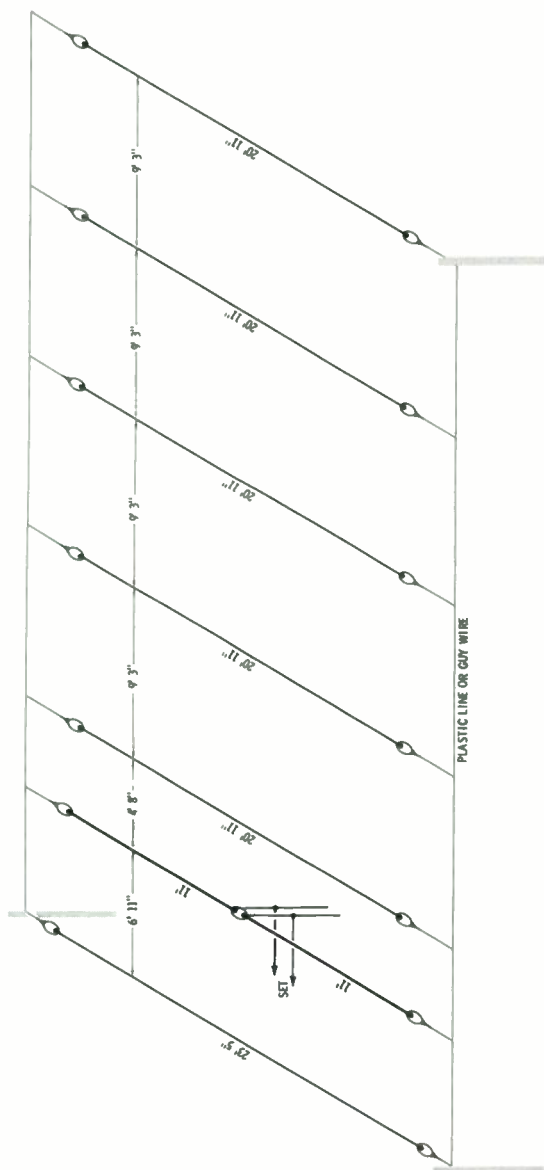 gain, better pattern, and fewer impedance-matching problems as compared to close-spaced types when more than two parasitic elements are used. In some models the first director is close spaced (0.1λ) to the driven element while all succeeding directors are spaced 0.2λ.

A suspended wire yagi for 15-meter operation is illustrated in Fig. 99. Four poles are erected at the corners of a 30' by 60' rectangle. This area can accommodate a seven-element yagi with wide-spaced directors.

Dimensions are as shown. Stub matching can be used with coaxial line. For a very long length of transmission line between antenna and transmitter, the open-wire line and balanced tuner provide optimum results. Refer to topics 1, 2, 3, 8, 12, 38, 39, 40, 41, 54, and 55.

57—Stacked Yagis

The broadside stacking of yagi antennas has produced rewarding performance. The theoretical gain increase, particularly with spacing of only λ/4, is not encouraging. However, for long-distance work there appears to be an ample improvement in low-angle vertical radiation.

Recommended spacings fall between a λ/4 and 0.625λ. Higher gains are obtained with wider spacing. However, the good characteristics of stacking are best obtained when the low member (bay) of the stack is at least a half wavelength above ground.

Stacked yagis must be fed in phase. Of course, the easiest way to do this is to feed at the center between bays. A coaxial T-junction can be used for this purpose (Fig. 100A). A stub can be used for matching on the transmission line side of the T junction or a line tuner (Appendix VI).

Open-wire transmission line can be used in a similar fashion as shown in B. With a center-point feed arrangement the bay separation can be set in accordance with the physical needs of the mounted positions.

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(A) Coaxial feed system.   (B) Open-wire feed system.
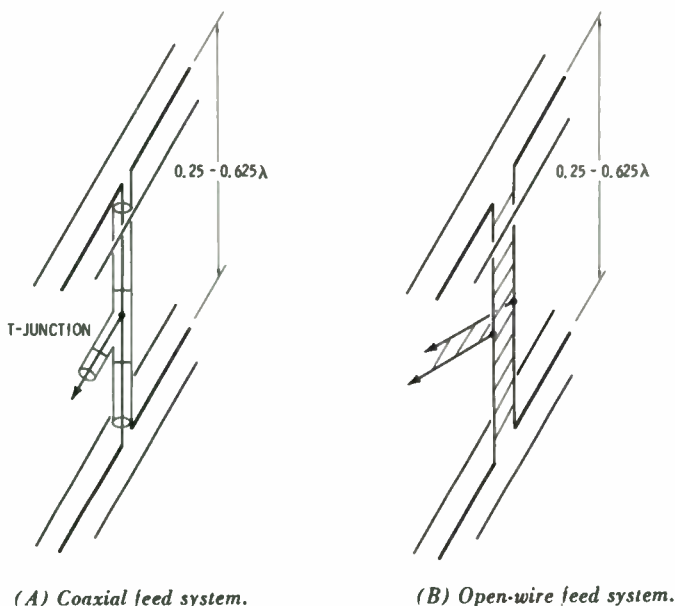
Fig. 100. Stacking of yagis, midpoint feed.

When the transmission line is to be attached to the bottom bay, the interconnecting feed line must be made an *even multiple of an electrical half wavelength* when not transposed. The two cases are shown in Fig. 101. In example A there is no transposition. Consequently, the length of the line must be a full wavelength. If the velocity factor of the coaxial line is 0.66λ, the physical length of the line must be:

$$\text{Electrical } \lambda = \frac{0.66 \times 984}{f}$$

This indicates that the spacing between bays must be approximately 0.66 wavelength, which is nearly maximum-gain optimum.

If the coaxial line is transposed, a half wavelength segment will suffice. Again, with a velocity factor of 0.66 the length of the transmission line must be:

$$\text{Electrical } \lambda/2 = \frac{0.66 \times 492}{f}$$

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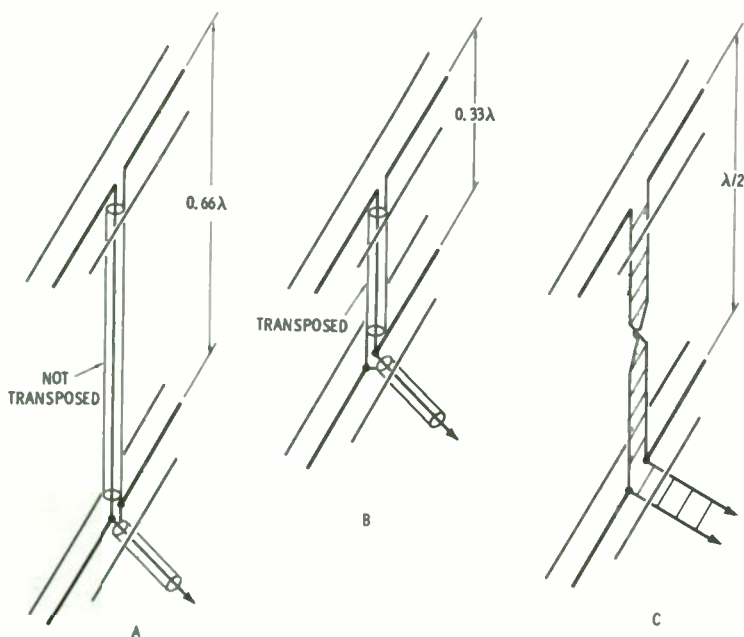
Fig. 101. Stacking of yagis, bottom feed.

To accommodate this requirement it is necessary that the bays be separated by approximately 0.33 (0.66/2) wavelength. Thus with some loss in gain it is now possible to mount the two bays near to each other.

If open-wire transmission line with its velocity factor near unity is used, the separation between bays must be $\lambda/2$, provided the interbay coaxial feed line is transposed as shown in Fig. 101C.

Where coaxial line with a velocity factor of 0.81 is used, an electrical half wavelength transposed feed for 10 meters would have a physical length of:

$$\text{Electrical } \lambda/2 = \frac{0.81 \times 492}{28.6} = 13'11''$$

The separation between bays for 10 meters would be approximately the same, corresponding to about 0.4λ. Refer to topics 1, 2, 3, 8, 12, 28, 39, 40, 41, 54, 55, and 56.

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58 —Two-Band Inverted-Vee Yagi for Low Bands

The inverted-vee construction lends itself well to the construction of low-band antennas with yagi-like characteristics. With a 30-to-40-

(A) Single band.

(B) Two-band, fold back.

(C) Two-band, stretched out.

Fig. 102. Single and 2-band inverted-vee yagis, 40 and 80 meters.

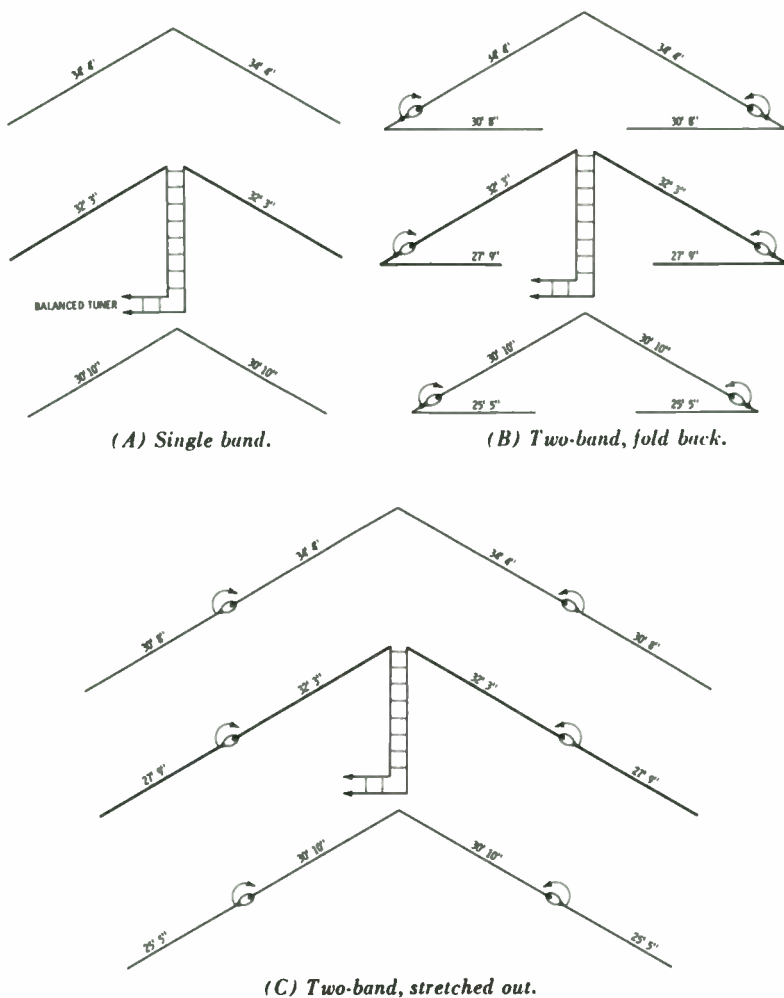foot apex height a combination 40- and 80-meter yagi takes up only limited space (Fig. 102A). For 40-meter operation, it can be confined to an area somewhat less than 60 feet square. Parasitic elements are close spaced. The use of wide spacing $(\lambda/4)$ requires about a 70- by 50-foot area. Keep the apex angle greater than 120°.

The addition of jumpers permits two-band 40- and 80-meter operation in approximately the same area. In this arrangement the driven elements and parasitics are folded around toward the center (Fig. 102B). Using wide spacing on 40 meters this becomes a close-spaced beam arrangement on 80. In an area of approximately twice the dimensions (140 feet square), one can erect an 80- and 160-meter combination using three 35- to 50-foot masts.

If space is available, the low-band elements can be stretched out to full horizontal length for both the 40-80 or 80-160 combinations (Fig. 102C). This arrangement is attractive for use with open-wire transmission line. In this case no jumpers are needed and the driven element on the higher-frequency band acts as two half wavelengths fed in a collinear manner. Refer to topics 1. 2. 3, 8, 12, 38, 39, 40, 41, 42, 43, 48. 54, and 55.

59 –10-15 Three-Element Yagi

The 10- and 15-meter bands are unique in that they are spaced rather closely in frequency. A parasitic reflector cut for 15 meters performs well as a reflector on 10 meters. Conversely, a parasitic director cut for the 10-meter band also has directive effects on 15 meters.

When this approach is used to establish dimensions for a reflector and director, and the driven element is suitably matched with a
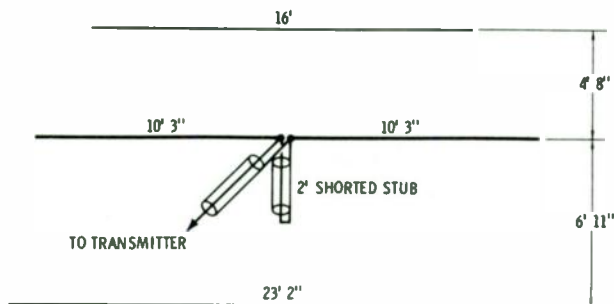

Fig. 103. Ten- and fifteen-meter 3-element yagi.

stub or line tuner, a satisfactory two-band three-element beam of simple construction is possible. Such an antenna is shown in Fig. 103.

The driven element is cut short on 15 and matched directly with a shorted stub. Note that the length of each $\lambda/4$ side is 10'3" (about 5 percent shorter than the formula value for a $\lambda/4$ dipole segment on 15 meters). A shorted two-foot stub provides a low SWR. Trim carefully for minimum SWR. It should drop below 1.5 to 1.

The reflector was made 23'2" (a favorable length for 15-meter sideband operation) while the director was made 16' long (suitable length for 10-meter sideband operation). Transmission-line length is made a whole multiple of an electrical half wavelength. Dipole insulator is a plastic sheet. Refer to topic 54.

When the antenna is stub-matched on 15 meters, no line tuner is necessary at the transmitter. However, the line tuner (Appendix VI) is needed for 10-meter operation. This antenna provides excellent performance on 15 and good results on 10. Refer to topics 1, 2, 3, 8, 41, and 54.

60 —Two-Element Quad

The two-element quad has been a popular DX antenna. It consists of a full-wavelength driven element in a perfect square and a longer but similarly shaped reflector (Fig. 104). Optimum gain spacing between driven element and reflector is approximately $\lambda/8$ (0.125
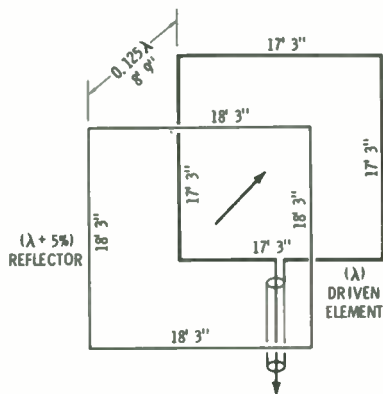

Fig. 104. Twenty-meter 2-element quad.

wavelength). On 20 meters this would be 8 to 10 feet. Quad frames are constructed variously with bamboo, aluminum cross pieces with end insulators, and *fiberglas*.

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The overall wire length for the driven element can be determined as follows:

$$\text{Wire length} = 1\lambda = \frac{984}{f(\text{MHz})} \text{ feet}$$

In the construction of multielement and/or multiband quads, it is wise to lengthen the quad driven element and the equation is modified to:

$$\text{Driven element wire length} = \frac{1000}{f(\text{MHz})}$$

The driven wire can then be cut back to the desired resonant frequency, if necessary.

Wire length for the quad reflector is made 5 percent longer than the driven element. Dimensions for the 20-meter, two-element quad are given in Fig. 104. The added reflector is handled by using a larger frame. Dimensions for other bands are as follows:

BAND (METERS)	DRIVEN 984/f	REFLECTOR 1030/f_L	SPACING 123/f
10	34'5"	36'5"	4'4"
15	46'3"	48'10"	5'9"
20	69'3"	73'1"	8'9"
40	136'8"	147'	17'6"

Various procedures can be used to resonate the driven element of a quad to a specific frequency. A dip meter along with a calibrated receiver affords a convenient and accurate combination for checking resonance. A single-turn loop connected from one side of the quad insulator to the other and around the dip-meter coil is all the coupling that is required (Fig. 105). The dip point is located on the meter. Next the dip-oscillator signal is picked up on the receiver to obtain an accurate frequency measurement.

Two other methods of checking resonance are also given. An SWR meter can be located right at the feed point of the driven element (Fig. 105B). Resonance is that frequency at which the SWR reading is minimum. The SWR meter can also be located at the transmitter to make this arrangement, provided the overall length of the transmission line is a multiple of an electrical half wavelength.
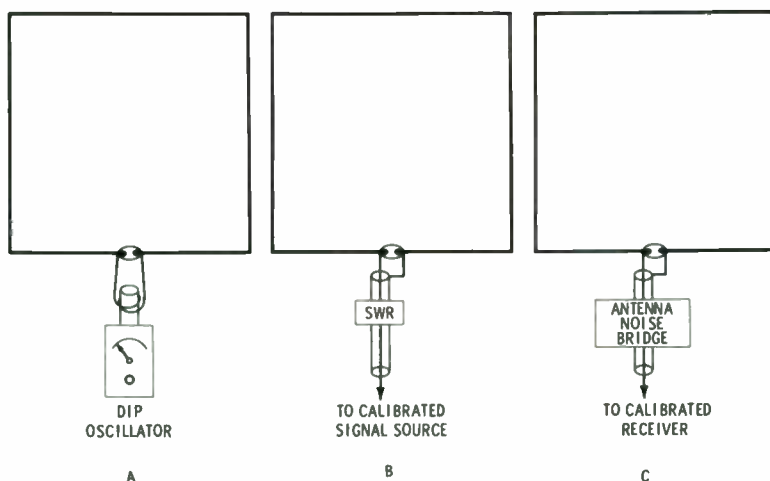
119

Fig. 105. Resonating a quad antenna.

The third method is to position an antenna noise bridge right at the feed point. This signal is delivered to the receiver at the other end of the line. There is a minimum reading when the receiver is tuned through the resonant frequency of the driven quad.

Either the dip method or the antenna noise bridge can also be used to tune the reflector. To do so, provide some means of opening the reflector loop at a position comparable to the feed point of the driven element. Customarily the reflector wire length is 5 percent longer than that of the driven element. Consequently, reflector resonant frequency will be on a frequency 5 percent lower than the resonant frequency of the driven element:

$$f_{refl} = f_{res} - 0.05 f_{res}$$

When this approach is used, it is possible to counteract the influence that one frame has on the other in terms of the resonant frequency. This approach is particularly useful for multiband quads for tuning out the interaction between frames and among the multiband wires on each frame.

The dip oscillator and noise-bridge approach can be used to find the resonant frequency. However, the SWR technique is not feasible

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because the resonant points usually fall outside the radio amateur bands. Refer to topics 1, 2, and 3 plus Appendices I, IV, and V.

61—Two-Element Quad, Tuned Reflector

The two-element quad of topic 60 incorporates a reflector with a larger-area frame than the driven element. It is possible and popular to use the same length of reflector wire as driven wire. Frames are the same dimensions. In this case the reflector is resonated to a proper frequency by using a shorted stub or an inductor as shown in Fig. 106.

In example A the shorted stub provides the additional electrical length that resonates the reflector wire to a lower frequency than the driven wire. Again, reflector resonance can be measured using a dip oscillator or a noise bridge.
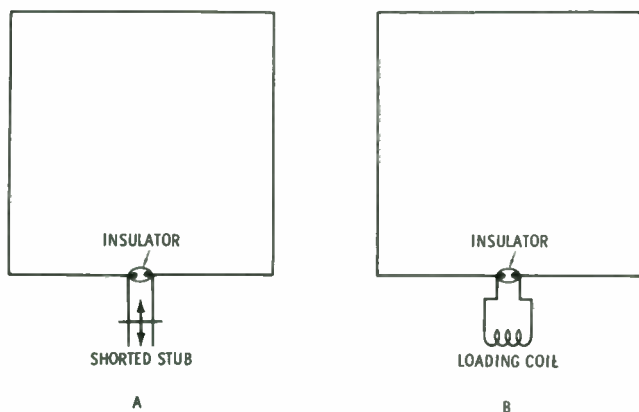
Fig. 106. Tuned reflector.

Small coils can be fashioned and used to join the two ends of the reflector wire. A dip oscillator held near the coil can be used to adjust coil turns and spacing for the desired reflector resonant frequency.

It must be stressed that there is interaction between frames, between other-band wires for the multipurpose type, and between other metallic surfaces such as spreaders and spiders. Therefore, the cut-and-try method is recommended for obtaining reflector resonance on a desired frequency.

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The advantage of the tuned-reflector method is that identical frames and wire lengths can be used for reflector and driven element. Refer to topics 1, 2, 3, and 60.

62 —Two-Element Quad, Straight Reflector

A common on-the-air complaint about quad antennas is their substantial side and back pickup. In fact, to obtain optimum performance from a two-element quad it is necessary to adjust reflector length and frame spacing quite carefully. Furthermore, one must compromise between forward gain and front-to-back ratio.
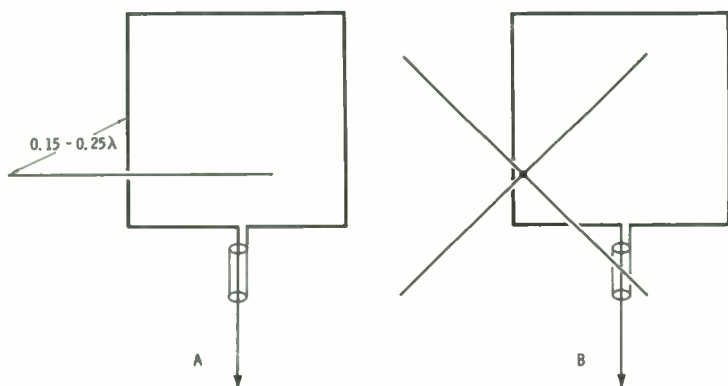
Fig. 107. Quad driven element with straight or X reflector.

The good characteristics of a quad seem to be pretty much vested in the quad driven element. In fact, the use of a straight reflector or the X-type reflector of Fig. 107 makes very little difference in the forward gain and may even increase it if dimensioned carefully. There is some pattern improvement with the X-type in particular in the form of less rear pickup and radiation. Most of all, the use of a conventional reflector circumvents the tedious process of adjusting the reflector frame.

$$\text{Reflector length} = \frac{492}{f(\text{MHz})} \text{ feet}$$

Refer to topics 1, 2, 3, 60, and 61.

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Fig. 108. Quad driven element and director.
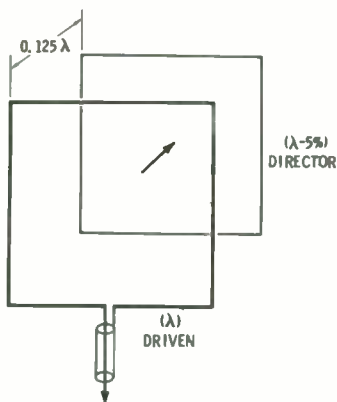
63 —Two-Element Quad, Director

It has been the author's experience that a parasitic quad director tunes easier and results in a higher gain and a better pattern than a quad driven element and reflector combination. Of course, stub tuning or the use of a series coil are not appropriate for a director. The director effect is obtained by making the length 5 percent less than that of the driven element (Fig. 108). Dimensions for various amateur bands are:

BAND	DRIVEN 984/f	DIRECTOR 935/f$_H$	SPACING 123/f
10	34'5"	32'4"	4'4"
15	46'3"	43'7"	5'9"
20	69'3"	65'2"	8'9"
40	136'8"	128'	17'6"

Spacing between director and driven element is $\lambda/8$ (0.125λ). The match to a 70-ohm coaxial line is almost ideal. Refer to topics 1, 2, 3, 60, 61, and 62.

64 —Three-Element Quad

Additional gain can be obtained with a reflector and a director. A typical 20-meter three-element arrangement is shown in Fig. 109. Reflector and director frames are spaced $\lambda/8$ from the driven-element frame. The director wire length is made approximately 5 percent
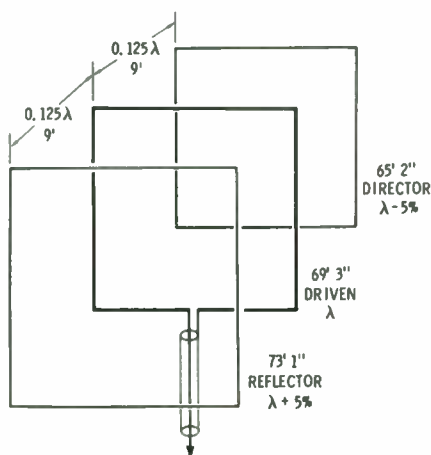
123

Fig. 109. Three-element quad.

shorter than that of the driven wire. However, dip oscillator or noise bridge can be used to trim to an exact frequency 5 percent higher than that of the driven element. The reflector can be either a tuned type, a longer frame wire, or a straight X. Refer to topics 1, 2, 3, 60, and 61.

65—Two- or Three-Element Quad, TV-Line Feed

The quad is a balanced antenna. Therefore, it is adaptable to any sort of balanced feed system. When there is a long length of transmission line (over 100′) between antenna and transmitter, the use of a good quality 300-ohm TV line instead of coaxial line results in a significant improvement in output and sensitivity. The improvement can be comparable to that obtained with the addition of another director to the antenna.

The disadvantage of the plan is that a balanced tuner such as that covered in Appendix VII is required. However, the use of such a tuner ensures that an optimum load is placed on the transmitter, so it can deliver the maximum power of which it is capable.

The balanced feed permits the driven element to operate in a more balanced manner and a definite drop in the side radiation can be noted. Also, a general improvement in the overall pattern results. Refer to topics 1, 2, 3, 12, 60, 61, 62, 63, and 64.

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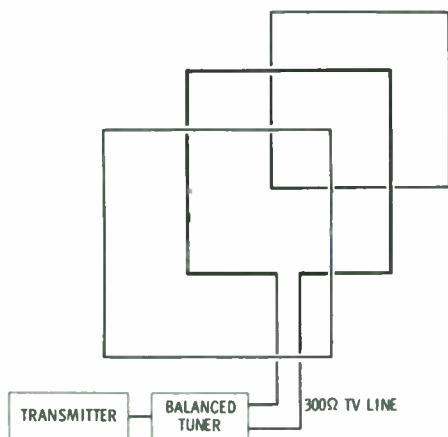
Fig. 110. Two- or three-element quads fed with TV line.

66 —Multiband Quad

A multiband 10-15-20 meter quad consists of a group of three quad wires mounted on a single frame. The frame is made large enough to accommodate the 20-meter wire and then the 15- and 10-meter wires are placed within the frame according to their required full-wavelength wire lengths (Fig. 111). Driven element, reflector, and director frames are constructed in the same manner. Spacing between frames corresponds to 0.125λ on 20 meters. Wavelength spacings are greater and are not optimum values for the 15- and 10-meter bands. Also the antenna resistance rises and matching arrangements are mandatory when using coaxial transmission line.

Fig. 111. Three-band quad, TV line fed.

Optimum results are obtained when the quad is fed with three separate transmission lines. However, it is common to use single-line feed with some sacrifice in performance. Wire-length dimensions are the same as those given in topics 60, 61, and 63. The antenna must be adjusted on each band using a dip oscillator, noise bridge, or SWR meter.
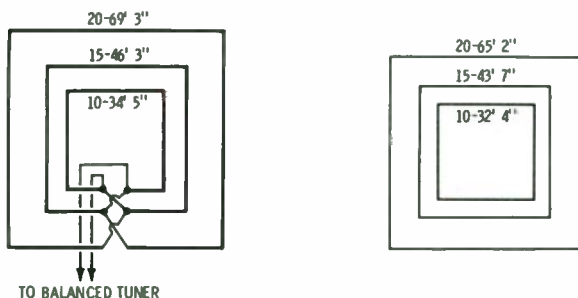
The quad arrangement of Fig. 111 uses a single good-quality 300-ohm TV line to feed all three driven elements. The TV line transposes between driven elements, the feedpoint being at the 10-meter terminals. The parasitic element is a director and is dimensioned as shown. It is positioned 8 feet in front of the driven element.

The balanced tuner of Appendix VII is used at the transmitter. It brings the SWR down to less than 1.05 to 1. Excellent results are obtained on all three bands. Refer to topics 1, 2, 3, 12, 60, 61, 62, 63, 64, and 65.

67—Low-Band Triangle

On low frequencies the quad becomes large, clumsy, and almost impossible to construct. However, most of the favorable characteristics of a quad can be obtained from a triangular driven element. The triangular construction is simple, strong, and easy to erect (Fig. 112). The quad equation can be used to calculate the overall length of the triangle wire:
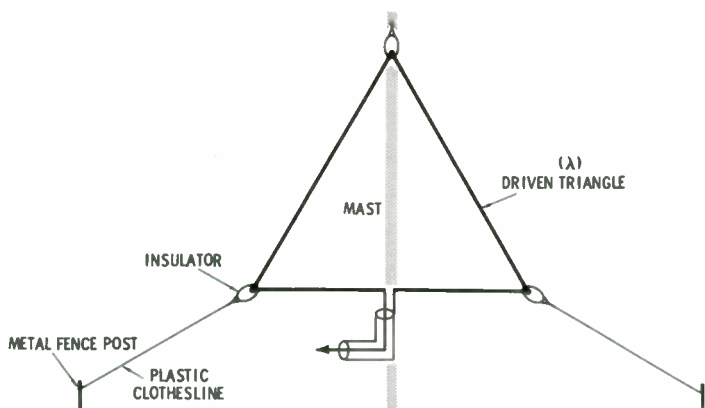

Fig. 112. Low-band triangle.

$$\text{Total wire length} = \frac{984}{f(\text{MHz})} \text{ feet}$$

The proximity of ground and the support mast may require that the triangle be shortened somewhat below this value after it is erected. This can be accomplished quite readily from step-ladder height.

The very center of the full-wavelength wire is attached at the top of the support mast with an insulator. The two legs then fan out and fold back on themselves. The ends are returned to the mast to a dipole connector or other form of insulator. The triangle can then be stretched out on each side using plastic clothesline (nonmetallic core) and two metal fence posts. You will find it is a very rigid assembly, acting also as partial guying for the mast. Furthermore, its directivity can be changed from ground level by shifting the side supports to other fence posts. A single triangle, driven element functions as a very good low-frequency antenna. Omnidirectional performance is quite good.

Antenna impedance is quite low because the base of the triangle is so near ground. A rather good direct match to coaxial line is possible. The triangle is also adaptable to stub matching, line tuner, or balanced transmission line and tuner. A balun is a fine matching aid. In fact, if a ground radial system is employed for low-band DXing, the ground point of the balun secondary can be connected electrically to the radial system via the mast or a piece of large-diameter wire.

An important advantage is the almost perfect direct match that can be obtained when using a triangle driven element with a triangle reflector and/or director frames. Refer to topics 1, 2, 3, 8, 12, 41, 60, 61, 62, 63, 64, 65, and 66.

68—Triangle and Parasitic

Reflector and director triangles can be added to increase the gain and sensitivity in a preferred direction (Fig 113A). Wire lengths for low-band triangle directors and reflectors are given in the chart:

BAND	DRIVEN 984/f	REFLECTOR 1030/f_L	DIRECTOR 935/f_H	SPACING 123/f
40	136'8"	147'	128'	17'6"
80	252'3"	278'3"	234'	31'6"
160	540'	572'3"	505'5"	67'4"

The parasitic element can be made to act either as a director or reflector if it is dimensioned first for director operation. When reflector
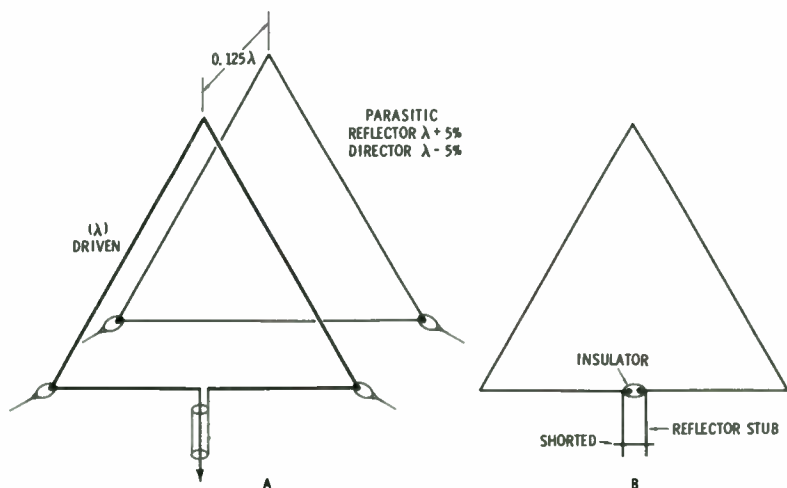
127

Fig. 113. Driven triangle and parasitic element.

operation is desired a shorted stub can be clipped on as shown in Fig. 113B. The triangular driven element and parasitics can be adjusted and measured in the same manner as the quad antenna elements using SWR meter, dip oscillator, or noise generator. A reflector should be
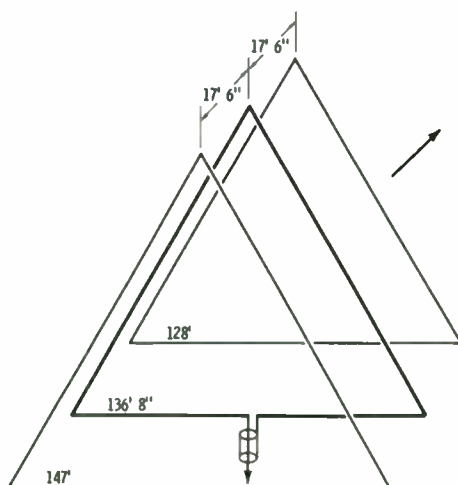

Fig. 114. Triangle beam.

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tuned 5 percent lower than the resonant frequency of the triangle; a director, 5 percent higher in frequency.

Dimensions for a three-element 40-meter triangle are given in Fig. 114. A triangle reflector, driven element, and director are arranged in yagi-like fashion on separate masts. Spacing between elements is $\lambda/8$ (0.125λ). This is only about 17 feet on 40 meters. In fact, the 40-meter antenna occupies an area no greater than 60' $\times$ 40'. Oriented for 45° on the east coast, European contacts became routine.

The apex height of the driven element was approximately 40' while the reflector apex was 4' higher and the director apex about 4' lower. Similar type displacements were made for the triangle bases with the reflector being the lower and placed about 8 feet above ground.

For minimum loss, when there is a long transmission line span between transmitter and triangle driven element, a good quality 300-ohm TV line and balanced tuner (Appendix VII) can be employed. Refer to topics 1, 2, 3, 8, 12, 60, 61, 62, 63, 64, 65, 66, and 67.
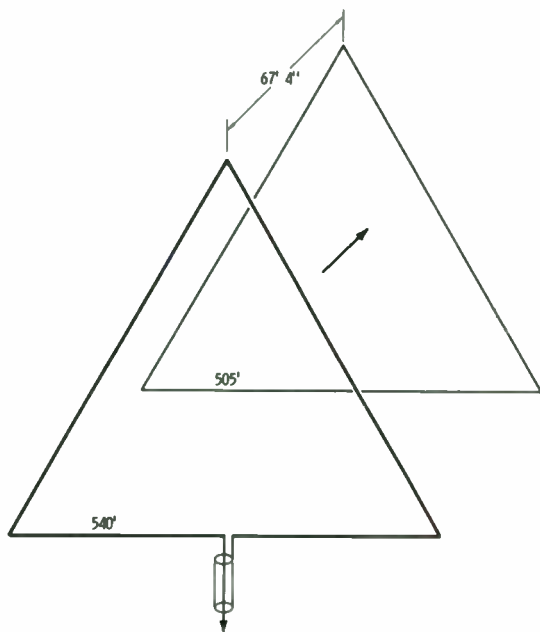

Fig. 115. Driven triangle and director for 160 meters.

69 —160-Meter Two-Element Triangle

It is on the 160-meter band that it is difficult to obtain beam-like characteristics without requiring a lot of space and some costly high masts. The triangle is able to give you a beam-like characteristic in a relatively small area. At the same time a good low wave angle is maintained and only two supporting masts are needed (Fig. 115).

In a practical installation 60-foot telescoping masts were used. The apex of the director was dropped down five feet below that of the driven triangle. This well-performing 160-meter antenna is erected in an area 240' × 70'. The antenna can be fed directly with coaxial transmission line or, for very long spans of transmission line, open-wire or good-quality TV line with a balanced tuner provides minimum line loss. Refer to topics 1, 2, 3, 8, 12, 67, and 68.

70 —40-80 Three-Element Double Triangle

Like a quad antenna, double or triple driven and parasitic elements can be constructed to obtain multiband capability. Reflector, driven element, and director dimensions are shown in Fig. 116. The spacing between elements on the 75-meter band is made 0.1λ. This corresponds to a spacing of approximately 0.2λ on 40 meters.

A good dip meter can be used to tune the driven element as well as parasitic reflectors and directors. Of course, the parasitic elements must be open at the center of the base when making resonance measurements. In the practical antenna, insulators were used at the center of the base for both the director and the reflector to aid in making measurements. In normal operation a jumper is then connected across the director and reflector base insulators. Coaxial or balanced
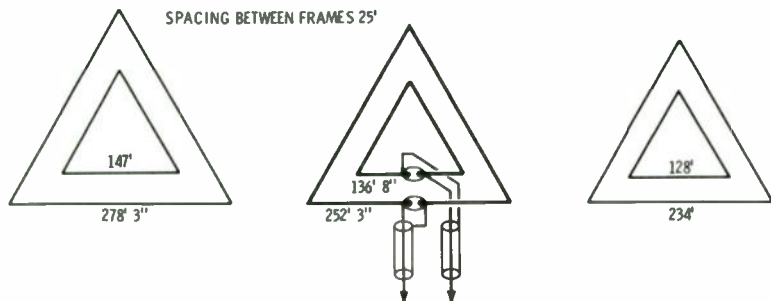

Fig. 116. Forty-and eighty-meter 3-element triangle.
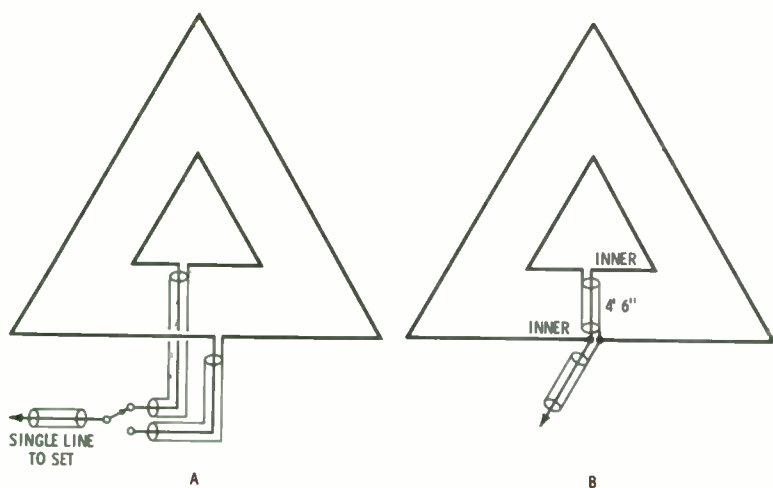
A   B

Fig. 117. Separate- and joint-feed arrangements.

parallel line can be used to feed the two driven elements separately.

Separate lines can be dropped down to reach-level as shown in Fig. 117. With a suitable connector, the transmission line from the transmitter can be attached to either one of the driven elements. Single-transmission-line feed can also be employed.

For joint operation the least influence on the performance of either antenna was obtained by connecting the transmission line to the 80-meter driven element and using a 4.5-foot segment of 70-ohm line between the 40-meter and 80-meter antenna feed points. Use transposed feed between elements by transposing the line or coaxial connector (as in Fig. 116). Refer to topics 1, 2, 3, 8, 12, 67, 68, and 69.

71 —Single-Mast Triangle and Parasitic

The triangle configuration is quite versatile and permits the construction of a rather directive low-frequency beam on a single support mast. This is accomplished, as shown in Fig. 118, by pulling the plane of the triangle away from the vertical. This pull out is such that the separation between the base of the driven element and the mast and the separation between the parasitic element and the mast is $\lambda/16$. By so doing, the separation between the bases of the two triangles is $\lambda/8$.

The apex of each triangle is attached to, but insulated from, the

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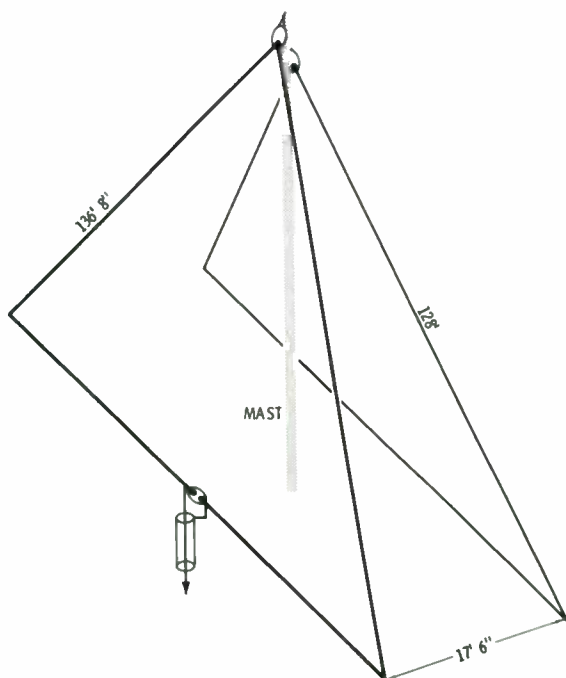
Fig. 118. Single-mast driven triangle and director.

mast. The apex of the driven triangle is at the very top of the mast with the director triangle apex approximately 4 feet below.

Dimensions are given for 40-meter operation. It is to be noted that the triangle bases separate from the mast by approximately 8.5 feet. Thus the departure from the vertical is really not great.

A parasitic-reflector, driven-element combination is also feasible. One mast can support the driven triangle and reflector. In fact, a second mast spaced $\lambda/4$ in front of the first one can support two director triangles in a similar manner. The apex of the reflector triangle is at the very top of mast 1, while the apex of the driven triangle is placed four feet lower. The two directors have their apex at the very top of the second mast. However, the top of this mast is approximately 8 feet lower than mast 1. There is a 30-foot separation between the two masts establishing the required $\lambda/8$ separations between all adjacent elements. Refer to topics 1, 2, 3, 8, 12, 67, 68, 69, and 70.

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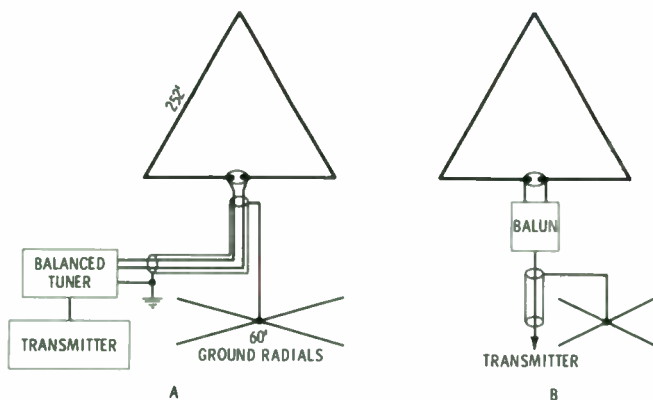Fig. 119. Triangle antenna with radial ground system.

72 —80-Meter Triangle With Ground Radial System

A triangle is a balanced driven element and operates well with the use of a balanced line and tuner. A rather unique feed system can be employed by using balanced TV line which includes an outer braid. In this arrangement (Fig. 119) the two balanced leads are connected to the triangle while the outer braid of the transmission line connects to the underground radial ground system. At the balanced tuner, the braid is connected to ground. This creates an attractive possibility for low-frequency antenna systems, the performance of which depends on a good low-resistance ground system.

An alternative method uses a 2-to-1 or 4-to-1 balun (whichever is needed) and the balun ground connection (outer braid of coaxial line) is connected to the ground radial system.

The dimensions shown in Fig. 119 are for 80 meters. Six $\lambda/4$ ground radials are employed. Results are gratifying, not reaching the peak of the three-element triangle of topic 70, but providing good low wave-angle performance in an omnidirectional manner. All the low-band triangle antennas are adaptable to grounded radials and balanced-line system. Refer to topics 1, 2, 3, 8, 12, 67, 70, and 71.

73 —Triangle Turnstile

A triangle antenna with a more omnidirectional pattern and a lower antenna resistance than a single triangle can be erected by

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using two triangles mounted at right angles (Fig. 120). All four ends are returned to the mast. The ends from opposite pairs are joined and connected to the center insulator or coaxial connector. A similar arrangement can be used for 80 or 160 meters.

TRIANGLES ARE INSULATED
FROM EACH OTHER

136' 8'

136' 8'
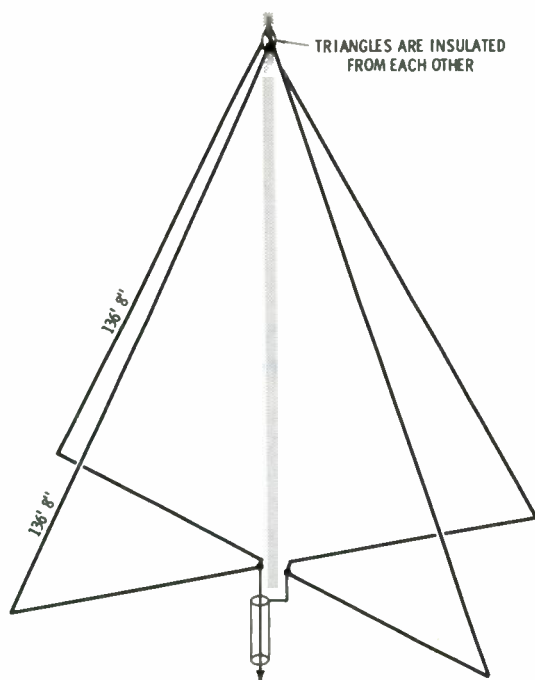
Fig. 120. Triangle turnstile.

A variety of feed arrangements is feasible. Direct connection to a coaxial line provides a fine match. If a 1-to-1 balun is employed, it is also possible to use a ground system that connects to the ground side of the balun input as shown in Fig. 119B. Shielded balanced line and balanced tuner provide an ideal feed system that operates in conjunction with a beneath-ground radial system. Refer to topic 72.

The turnstile idea also has two-band capability. A 40-meter triangle turnstile can be made to load on 80 meters, and an 80-meter turnstile can be made to load on 160 meters, using appropriate insulators and jumpers. On the higher-frequency band the antenna operates as the simple triangle turnstile discussed previously.

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A different connection is used for operation on the lower-frequency band as shown in Fig. 121. The transmission line is connected to any two adjacent half-triangle ends. The remaining two ends are joined together, effectively doubling the total length of antenna wire connected

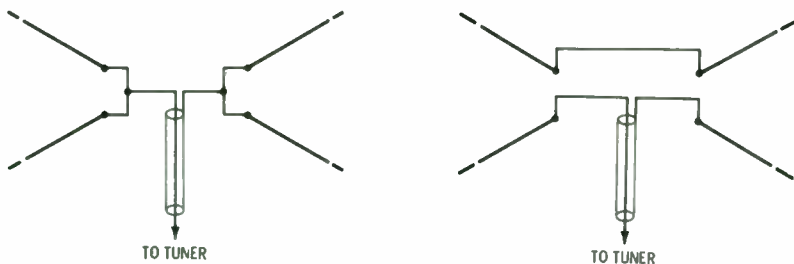TO TUNER   TO TUNER

Fig. 121. Two-band operation of turnstile.

on each side of the point at which the transmission line is connected. This total length may be somewhat shorter or longer than that needed to establish resonance on the lower-frequency band. Consequently, it is advisable to use a tuner in the line. Either a balanced or unbalanced combination can be employed. Refer to topics 1, 2, 3, 8, 12, 67, 68, 69, 70, 71, and 72.

74 —15-, 40-, and 80-Meter Triangles

Two different-frequency triangles can be attached to the same mast and connected to the same transmission line. If mounted in right-angle planes, there is a minimum of interaction. Also, triangles radiate well on odd multiples of a whole wavelength. Thus, a 40-meter triangle performs well on 15 meters, the triangle being *three* wavelengths long on this frequency.

A typical two-section triangle is shown in Fig. 122. There is a 40-meter triangle and at right angles to it an 80-meter triangle. They are insulated from each other at the apex but join at the point of transmission-line attachment. A low SWR is obtained on both bands. The antenna also loads on 15 meters with a satisfactory SWR. Refer to topics 1, 2, 3, 67, 68, 69, 70, 72, and 73.

75 —High-Band Triangles

Like the quad or the dipole, the triangle can be used as an elevated high-band antenna. For 10-15-20 meter operation the high-

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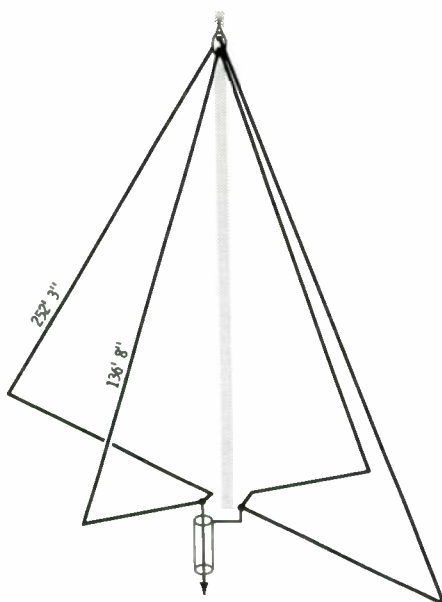
Fig. 122. Forty- and eighty-meter triangles at right
angles to each other.
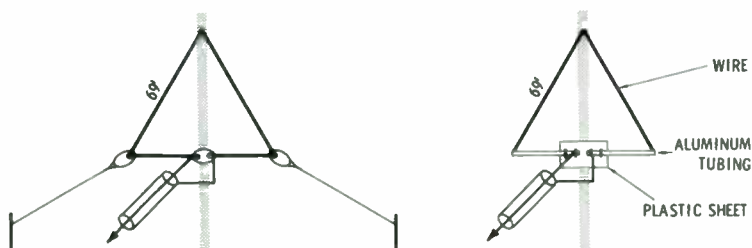
Fig. 123. High-band triangles.

frequency triangle can be constructed in two basic ways as shown in
Fig. 123. A wire triangle can be constructed similar to the low-band
type. Insulators and plastic clotheslines are attached to the base angles.
These corner angles are pulled out and supported from ground level.
The alternative approach is to use self-supporting tubing for the base
of the triangle. A plastic sheet holds the base elements to the mast.

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The ends of the tubing are then linked to the apex of the triangle with wire or additional tubing. Dimensions are given for 20-meter operation.

High-band triangles are mounted a considerable electrical distance above ground and display an impedance several times higher than that of coaxial line. Stub matching works very well. A line tuner can be used for matching. A low-loss arrangement would be balanced TV line and a balanced tuner at the transmitter. A 4-to-1 balun often does a fine matching job for high erection. Omnidirectional pattern
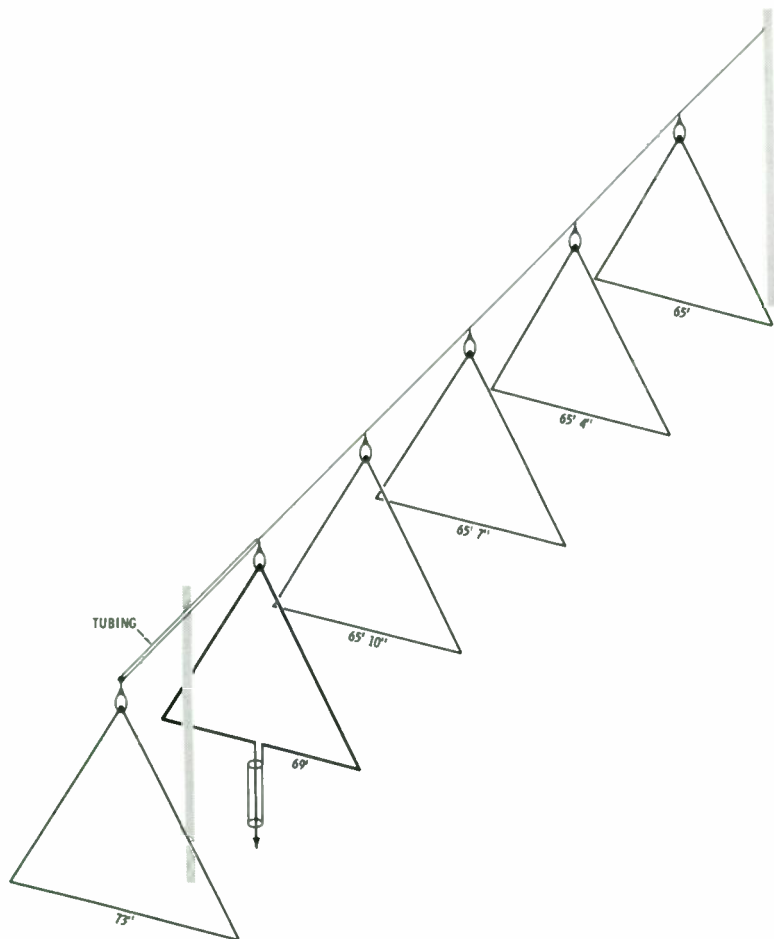
Fig. 124. High-band triangle beam suspended between 2 masts.

and lower antenna resistance are possible with a turnstile arrangement.

The triangle configuration can be used in the construction of high-band beams. The triangle is adaptable to the construction of fixed-mounted multielement high-band beams. Such an arrangement is shown in Fig. 124. The 20-meter triangle beam is suspended between two high masts. At the top of mast No. 1 there is a 10-foot cross piece which suspends the apex of the driven triangle and the reflector. A support wire runs from the driven end of the support piece to the second mast. Along this support wire there are suspended any number of directors, providing an easy method of building a triangular *Long-John* antenna. Plastic clotheslines are again used to pull out each of the triangles and support it from ground level. The match made to coaxial transmission line is good despite the multidirector arrangement. Of course, for a great separation between antenna and transmitter, use a balanced transmission line and tuner. Refer to topics 1, 2, 3, 8, 12, 41, 67, 68, 69, 70, 71, 72, 73, and 74.

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APPENDIX I

Antenna Noise Bridge

The antenna noise bridge* is an especially useful device in cutting antennas to resonance and transmission lines to specific electrical lengths. It can also be used to measure antenna resistance. The unit consists of a signal source, the bridge circuit, and a detector (Fig. A-I-1). A diode noise generator and amplifier are built into the compact device along with the bridge. Your ham receiver serves as the detector. In fact, the noise generator is a broadband type and your ham receiver serves as a calibrated frequency-selective detector.
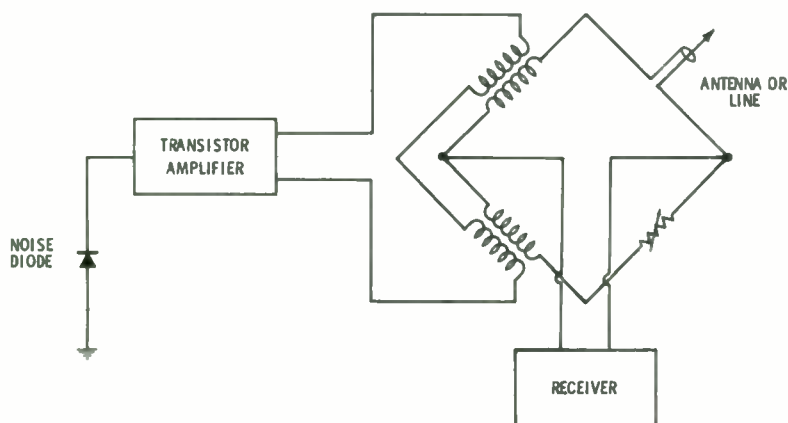

Fig. A-I-1. Omega-T antenna noise bridge.

Two balanced legs of the bridge are the secondary of a bifilar transformer which is wound on a toroid core. The broadband noise signal is applied across the primary. A third leg of the bridge is a calibrated variable resistor which is the only control of the unit.

*Omega-T Inc., Richardson, Texas 75080

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The dial is calibrated in ohms of antenna resistance between 0 and 100 ohms.

The antenna or line to be measured is connected as the fourth leg of the bridge. The receiver is, of course, connected between the junctions of the two leg pairs. When the bridge is balanced, there is minimum signal applied to the receiver. This happens when the antenna resistance is of the same value as the setting of the bridge resistor. If reactive components are present, the bridge does not balance. Any such reactance is balanced out by tuning the receiver. In doing this you also determine the resonant frequency of the antenna system.

The general operating procedure is:

1. Set the bridge control to the appropriate antenna resistance that is to be expected; for many ham antenna systems that is 50 ohms.

2. Tune the receiver over the frequency band to which the antenna is to be resonated. Find the minimum noise frequency (minimum audio output from the speaker and minimum S-meter reading).

3. Adjust the bridge resistance for the best minimum (null). Jockey the receiver tuning and bridge controls slightly for the best minimum. The resonant frequency of the antenna system is read from the receiver dial, while the antenna radiation resistance is indicated on the noise-bridge dial.

The antenna noise bridge is a small test unit, is easy to hook up, and makes antenna system checking a lot easier.

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APPENDIX II

How to Measure the Velocity Factor of Transmission Line With a Noise Bridge

The noise bridge described in Appendix I can also be used to make transmission-line checks and measurements. Velocity factor is an important line characteristic in cutting lines to specific electrical wavelengths. Sometimes the information is not available from the manufacturer, or it is necessary to know the velocity factor very exactly. If such is the case, the hookup of Fig. A-II-1 can do the job.

The near end of the transmission line is connected to the antenna terminal of the noise bridge. The far end of the line is shorted. At some frequency the total length of the line will be an electrical half
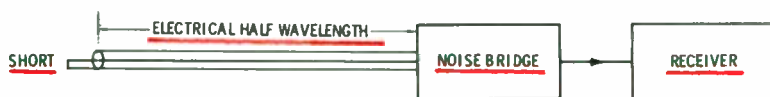
Fig. A-II-1. Determination of velocity factor of transmission line.

wavelength or a multiple of a half wavelength. At this frequency a short is reflected to the near end of the line, and there is no reactive component. The electrical length of the line is determined as follows:

1. Set the noise bridge dial just a hair away from zero corresponding to the few ohms of resistance of the transmission line. Tune the receiver for a noise null. It is customary to check a section of line that is approximately one-half wavelength long although multiples can be used for making the measurement.
2. Now measure the physical length of the transmission line. The velocity factor is obtained by dividing the physical length of the line by the calculated free-space half wavelength of the frequency indicated by the receiver dial.

$$\text{Velocity factor} = \frac{\text{physical length of line}}{492/\text{receiver freq. reading in MHz}}$$

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The length of a quarter-wave segment of line or an odd multiple of a quarter wavelength can be determined in the same way with the exception that the far end of the line is opened rather than shorted.

APPENDIX III

Cutting Half-Wave Sections of Transmission Line Using the Antenna Noise Bridge

When the velocity factor of a transmission line is known, it is possible to cut that line to some whole multiple of a half-wavelength using the following relationships:

$$\text{Line length in feet} = VF \times \frac{492}{f\text{MHz}} \times \text{whole multiple of } \lambda/2$$

If the velocity factor of a specific line is unknown it can be determined using the procedure of Appendix II.
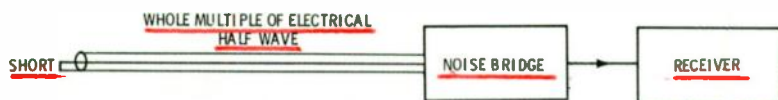
Fig. A-III-1. Method for cutting a transmission line to whole multiple of a half wavelength.

Once a section of line is cut, its exact electrical wavelength can be determined with the arrangement of Fig. A-III-1. Again, the far end of the line is shorted, while the near end is connected to the antenna terminal of the antenna bridge. This procedure is as follows:

1. Set the bridge control slightly above zero. Set the receiver to the desired frequency band.
2. Tune the receiver over the band to obtain a good null. For some receivers a more pronounced null can be obtained by deactivating the avc circuit and/or reducing the receiver r-f gain.
3. If the frequency indication is too low, the length of the transmission line can be trimmed slightly to make the electrical length of the line correspond to a specific operating frequency within the band.

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The velocity factor of some foam-type lines tends to be less than 0.81. Thus, resonance will appear at the low end of the band, or even off the low end of the band. Trim the line patiently to bring it into the band. When the overall length of your line is a *number* of whole multiples of a half wavelength long, a larger section of line must be trimmed off to obtain a given change in overall electrical length than if the line were only *one* half wavelength long.

APPENDIX IV

Measuring the Resonant Frequency and Resistance of an Antenna With the Antenna Noise Bridge

The antenna noise bridge is battery operated and can often be placed at the antenna feed point, Fig. A-IV-1. It is of small size and no external signal source is needed. A noise generator source is a part of the device.
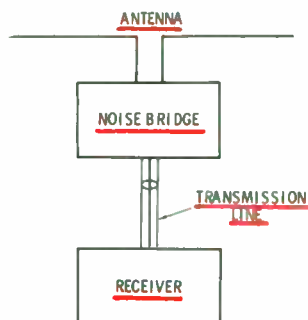
(A) Bridge at feed point of antenna.
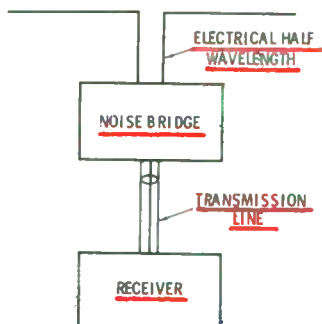
(B) Bridge at half wave from antenna terminals.

(C) Bridge at the receiver.
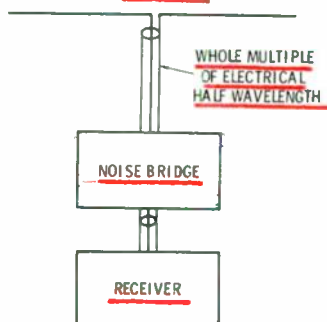
Fig. A-IV-1. Arrangements for measuring antenna resonance and antenna resistance.

The bridge can also be inserted into the line an exact electrical half wavelength away from the antenna terminals. A third alternative is to locate the noise bridge at the receiver, making certain that the overall length of the transmission line between the antenna and the bridge is a whole multiple of an electrical half wavelength for which the antenna is to be cut and measured. The transmission-line cutting procedures were covered in Appendices II and III.

The recommended operating procedure is as follows:

1. Set the noise bridge dial to the anticipated resistance of the antenna (usually 50 or 70 ohms).
2. Tune the receiver over the frequency band and locate the noise null (minimum speaker noise or minimum S-meter reading).
3. Adjust the antenna-noise-bridge dial for the best noise null.
4. The resonant frequency of the antenna can be read from the calibrated receiver dial while the antenna radiation resistance is indicated on the calibrated noise-bridge dial.
5. The two controls can be adjusted slightly for the very best null and the most accurate reading.

The most accurate readings are obtained when the transmission line is a whole multiple of an electrical half wavelength.

In the measurement and cutting of both lines and antennas, Charts 1 through 6 are employed. The physical lengths of lines and antennas indicated by the charts are invariably somewhat longer than the necessary cut for the desired resonant frequency. (Even the cut for a half-wavelength antenna using the end correction factor is usually a bit longer than necessary.) This is the favorable situation because the antenna or line can then be trimmed back to the desired higher resonant frequency.

Therefore, in using the antenna noise bridge, the null point is usually found lower than the desired operating frequency and may sometimes be even lower than the low-frequency end of the desired frequency band. You can then trim very carefully and observe the noise null rising higher toward the desired frequency.

As you well know, cutting a length that falls on the high side of the desired frequency presents the added problem of having to add on rather than trim off to reach the optimum frequency. This is certainly not the desired situation when using coaxial transmission line. Thus, the chart and formula information in this book tends to give you a long dimension rather than a short one. This can be checked throughout the text by comparing the formula dimensions with those practical

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situation dimensions shown on the various antenna illustrations. If you have no means for checking and trimming antennas and lines, use dimensions given in the illustrations and duplicate the antenna arrangement shown.

APPENDIX V

Cutting an Antenna to Resonance Using an SWR Meter

The SWR meter and/or reflectometer arrangement has been used for years in checking out and monitoring ham antenna systems. Resonant antenna cuts can be made with the proper insertion of an SWR meter designed for the specific impedance of the transmission line. (For the usual SWR meter, optimum performance is obtained with 50- or 70-ohm coaxial lines.)

Two preferred arrangements are shown in Fig. A-V-1. True SWR measurements can be made by inserting the meter right at the antenna. Usually this is not a convenient arrangement. An alternative is to insert the meter one electrical half wavelength away from the antenna terminals or at some part of the line that is a whole multiple of an electrical half wavelength. The latter plan permits the SWR meter to be located near the transmitter. However, the very best accuracy in terms of the SWR reading and in determining the resonant length
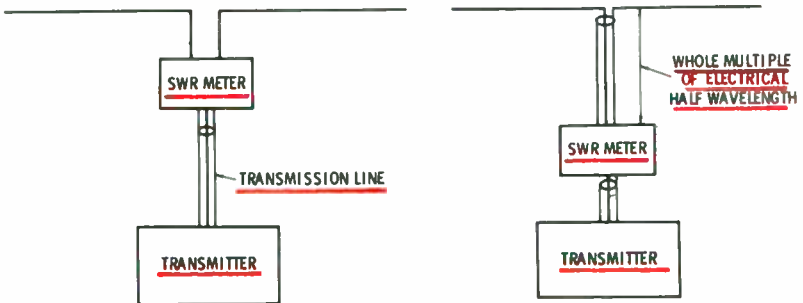

Fig. A-V-1. Measurement of SWR and antenna resonance.

of the antenna is feasible only when the exact length of line between the antenna and meter is a whole multiple of electrical half wavelengths. Under this condition the antenna terminal conditions are reflected to

the meter, and the reactive effects of the transmission line are reduced. The equation for determining the physical length of an electrical half-wavelength line for a given frequency is as follows:

$$\text{Line length} = VF \times \frac{492}{f\text{MHz}} \times \text{whole multiple of } \lambda/2$$

The SWR measurement technique requires the use of a signal source (transmitter operated at low power level or a signal generator with an output capable of supplying adequate signal level to the SWR device). Because of transmitter designs, it is sometimes necessary to operate the transmitter at normal output power level, so that its operating conditions are favorable for matching into 50 ohms.

The usual procedure for operating your SWR meter is employed. In most cases when using the formula dimensions given in Charts 1 through 6 the antenna will be cut long and to a resonant frequency lower than that which is desired. Therefore, if you tune your transmitter to the desired frequency and make an SWR measurement it will be higher than that which can be ultimately obtained. As you tune the transmitter lower in frequency the SWR reading drops. The actual minimum may be found considerably lower than desired.

The antenna may now be trimmed as you watch the SWR minimum move up toward the desired operating frequency. The resonant frequency indication and the SWR readings using this technique are reasonably accurate, and are more indicative of operating conditions than is indicated by random insertion of an SWR meter into a transmission line. In fact, with this method readings were quite comparable to those obtained using the antenna noise bridge.

APPENDIX VI

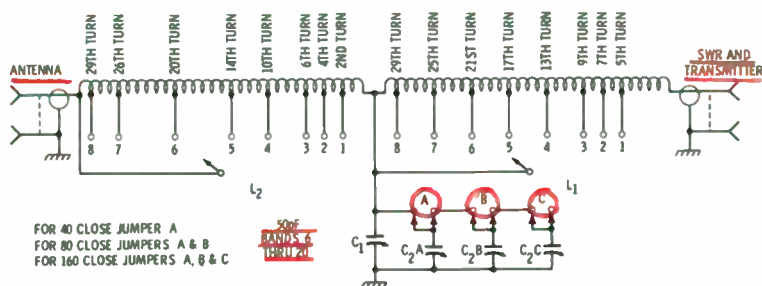## The Construction and Tuning of a Line Tuner

Fig. A-VI-1. Antenna line tuner.

2   *binding posts*
2   *coaxial receptacles*
1   *case 10″ × 5″ × 4 ″*
1   *50-pF variable capacitor*
1   *3-gang 365-pF variable capacitor*
2   *29 turns #14 wire, 1 ¾″ dia. and 2 ⅝″ length (AIR DUX 1411)*
2   *r-f switches, 1 pole and 8 positions*

The purpose of a line tuner is to provide the most favorable loading of a transmitter, although the impedance looking into the transmitter end of the transmission line is not optimum. Such a line tuner permits a given antenna to be used at a frequency removed from the limited frequency range for which it presents optimum loading conditions for the transmitter. It also permits the loading of a random length of antenna wire or permits a given antenna type to be operated on more than one amateur band. Such facility adds convenience and versatility to a station.

It must be emphasized that a line tuner does not improve the operation of an antenna and does not improve standing-wave conditions

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on the transmission line. It cannot duplicate the performance of an antenna made resonant at a specific frequency and matched precisely to the transmission-line system at that frequency. Even when using a tuner, the very best antenna-system performance is obtained by establishing favorable resonant conditions at the antenna and using optimum lengths of transmission line that correspond reasonably close to whole multiples of a half-wavelength.

A line tuner does permit you to design an antenna system for peak performance over a certain desirable band of frequencies, and, with a tuner, you can at least operate your transmitter off of these frequencies and obtain results that are superior to those obtained without using a tuner. At the same time, your transmitter operates under no burden because it sees a proper load impedance.

The tuner of Fig. A-VI-1 has been designed for optimum operation on the 10-, 15-, and 20-meter bands. It will also function on the 40-, 80-, and 160-meter bands by connecting variable capacitors (C2, A, B, and C) of appropriate value across the variable capacitor (C1).

The matching network is basically a T-section low-pass filter. Although there is some interaction between the two sections of the filter, inductor L_2 at the transmission-line (antenna) end of the tuner matches the antenna system impedance to the tuner, while the taps on inductor L_1 provide matching adjustment between the tuner and the transmitter and tune out reactive components reflected from the antenna system. Theoretically, the ohmic value of the reactance of capacitor C_1 must be:

$$X_{C1} = \sqrt{Z_{in}R_T}$$

where,
Z_{in} equals input impedance of line,
R_T equals the output impedance of transmitter.

In practice, the proper operating conditions are established by using a variable capacitor and two tapped inductors in accordance with the parts list. It has been customary in most designs to place the taps on the coils in some regular manner and let the tuner operating conditions fall where they may. However, if the very lowest standing-wave ratios are to be established, it is helpful to experiment with tap positions for the very best performance. You may wish to start out with uniform positioning of the taps to determine what the operating conditions are on each band. For most bands it is likely

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that optimum performance can be obtained. However, if you have difficulty bringing the SWR reading down on certain bands, you can experiment with the tap positions. This is particularly the case for the 10- and 15-meter bands.

For the tuner constructed by the author, the tap positions shown in Fig. A-VI-1 were found to be optimum. Coils L_1 and L_2 must be mounted at right angles to each other.
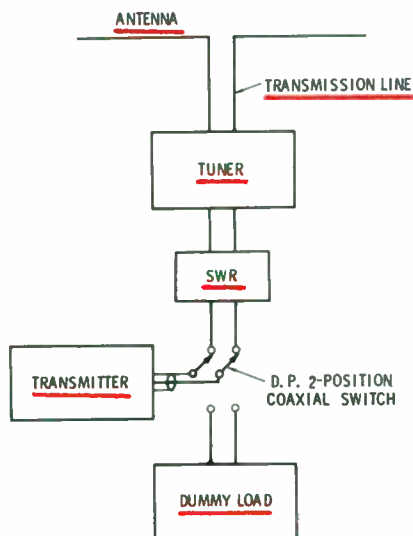

Fig. A-VI-2. Connection plan for adjusting a tuner.

Proper tuning is important if you are to derive the most benefit from your line tuner. The setup of Fig. A-VI-2 is a good one. The transmitter is first worked into a 50-ohm dummy load. Transmitter output-circuit settings (tuning and load) are set down in a notebook for specific frequencies. (You may wish to use the center frequencies of the 10-, 15-, and 20-meter phone bands.) This information helps you set the transmitter reasonably close to optimum, and then the line tuner can be adjusted in such a manner that the best performance is obtained with the transmitter preset. Some manufacturers provide tables for a match to specific impedances. If such is the case, preset the dials for 50-ohm operation.

Operate the transmitter at low power and switch off the power whenever you change tuner switch positions. Capacitor C_1 acts in a

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resonant way. If you are using the correct tap of inductor L_1 there is a dip in the SWR reading as you tune through the minimum position. The switch positions of inductor L_2 determine just how low an SWR reading can be obtained as the capacitor is tuned through its minimum. Thus various L_2 positions should be tried to determine the best minimum. If your minimum on any one band cannot be made to fall below 1.5, experiment with the appropriate tap positions of L_2. Likewise, if your minimum seems to be indicated at the minimum or maximum capacitor settings, a change in the L_1 inductor tap is indicated.

One unusual condition arises when employing a line tuner of this type with a dipole, inverted-vee, or horizontal vee beam. A false matching position can show up for which the inner conductor of the transmission line and one side of the antenna acts as the load (Fig. A-VI-3). In this case there is little or no r-f energy present at the far end of the second leg of the antenna. Thus, if at all possible, you should check for the presence of r-f energy at the ends of both legs of the antenna. This is quite easy to do, for the inverted-vee antennas or the vee-beam types with sloping ends. False loading should be avoided when you wish no changes in the pattern characteristics of your antenna.

When the center-fed dipole or vee antenna approximates an odd number of quarter wavelengths on a leg, the tuner loads both legs. However, if the leg length approaches an even number of quarter
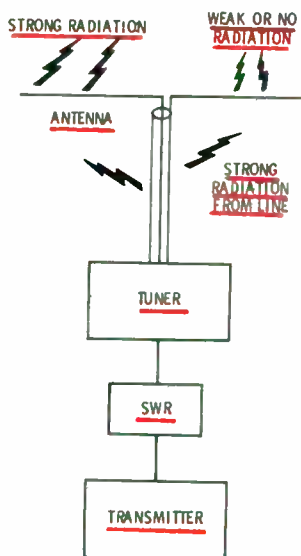
Fig. A-VI-3. Result of a tuner tuning the line and one antenna leg as random length of wire.

wavelengths the tuner tends to load one leg and the line. For example, when the antenna of topic 31 with 59-foot legs is loaded on 80 meters, it will tune in dipole fashion on 80 meters. However, the 40-meter dimension is so far off the quarter wavelength on a leg value that the tuner will simply load as a random wire with one leg more active than the other.

APPENDIX VII

Antenna Tuner for Long-Wire Vees and Rhombics

The purpose of an antenna tuner is to match and obtain the maximum transfer of r-f energy between the antenna end of a transmission line and the antenna. In the process, the SWR on the transmission line that links the tuner to the transmitter is brought down to a low value for suitable matching to the transmitter, and to ensure minimum transmission-line loss.
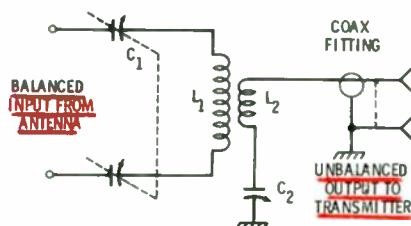

Fig. A-VII-1. Antenna tuner for vee, center-fed, long-wire, and rhombic antennas.

C_1 **2 140-pF variables, ganged with insulated shaft connector**
C_2 **200-pF variable**
L_1-L_2 **Plug-in coils (L_2 centered within L_1). L_1 AIR DUX 2006T except AIR DUX 2010T for 80 meters. L_2 AIR DUX 1610T on all bands**

BANDS	L_1 TURNS	L_2 TURNS
6-10	4	1
10-15	6	2
15-20	10	3
20-40	14	4
40-80	32 (2010T)	8
80	44 (2010T)	10
160	64 CLOSEWOUND #14 ENAMELED 2½" DIAMETER	16

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Resonant long-wire vees and rhombics usually have a low antenna resistance, and the step-up ratio between the transmission line and the antenna is not great. Hence, the rather simple tuner arrangement that matches a low-impedance unbalanced transmission line to a balanced antenna feed point of somewhat higher resistance is appropriate (Fig. A-VII-1). Both primary and secondary are series-tuned for minimum loss and lowest standing-wave ratio. Two sizes are given for most bands. Coil and component data are given in Fig. A-VII-1. If the very lowest SWR's for a variety of antennas are to be obtained, you may find one of these is better suited for a given situation.

The tuner adjusts very quickly and there is no need for making coil taps. An SWR meter is connected between the transmission line and the input of the tuner. Adjust the two tuner controls for a minimum SWR. Jockey back and forth between the two controls to obtain the very lowest minimum. The tuner must be readjusted, of course, when changing bands, or when changing from one end of the band to the other.

If you wish to construct a very versatile tuner that can meet almost any antenna situation around the amateur station, the author recommends highly the one described by Lew G. McCoy on page 58 of *QST*, July 1965. This tuner includes a standing-wave meter and has the flexibility needed to match both high and low antenna resistances.

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APPENDIX VIII

Base Tuner for Vertical Antennas

It is convenient to use an antenna tuner for a vertical antenna because its base can be positioned near ground level. Such a tuner can be mounted in a weather-proof container and mounted permanently. The advantage of such a base tuner is that a vertical antenna of almost any practical length can be tuned and loaded on any band. The antenna can be loaded properly and there will be a minimum standing wave ratio and minimum loss on the transmission line that extends between the base tuner and the transmitter.

Again, it must be emphasized that a tuner ensures proper loading and efficient feeding of the antenna. However it does not overcome the limitations in the radiation characteristics of a given antenna. For example, if a vertical antenna is a wavelength or longer on a given operating frequency there is good high-angle radiation and a decline in low-angle radiation. Likewise, an antenna that is very short (less than an eighth wavelength) does not radiate as effectively as one which is at least a quarter wavelength. However, an antenna does perform well for any length that is somewhat less than a quarter wavelength on up to three quarter wavelength when good low-angle radiation is desired. An antenna can be much longer in terms of wavelength, if it is the high-angle radiation that is preferred.

A vertical antenna that is shorter than an electrical quarter wavelength displays an impedance that contains a capacitive component. An antenna that is longer than an electrical quarter wavelength but less than a half wavelength displays an impedance that contains an inductive component. Such antennas can be resonated by including the opposite reactance at the base. That is, inductance can be added to resonate a short antenna and capacitance can be added to resonate a long antenna. This can be done more effectively if the added inductance and capacitance is variable.

The base tuner of Fig. A-VIII-1 contains inductance and capacitance which can be inserted between the base of the vertical and the ground system. By using suitable inductive taps and a proper setting of the
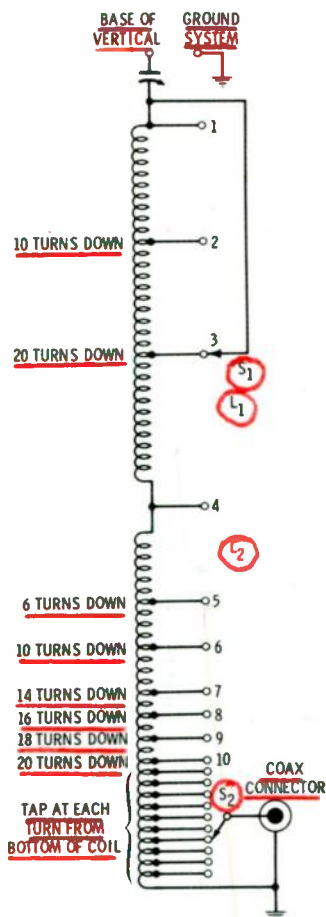
Fig. A-VIII-1. Base tuner for vertical antennas.

PARTS LIST

2   10-position, single-pole switches
2   30 turns No. 14 wire, 1 ¾" dia. and 2 ⅝" length (AIR DUX 1411)
1   400-pF variable capacitor
1   Coaxial connector

variable capacitance, a vertical antenna of random length can be resonated and loaded on a specific frequency. Proper tap position for antenna tuning is handled by switch S_1.

There are two sets of taps on the bottom inductor. The taps associated with switch S_2 connect to the coaxial transmission line that feeds back to the transmitter. The relative settings of switches S_1 and S_2 set up a transform ratio which provide a proper match between the tuned antenna system and the transmission line.

A base tuner of this type can reduce the standing-wave ratio on the transmission line to an exceedingly low value. It operates 10 through 80 meters and can be inserted in series between base and ground system of practically all of the vertical antennas covered in this book.

Schematic and parts list are given in Fig. A-VIII-1. Adjustments are made by connecting an SWR meter between the output of the tuner and the transmission line. Taps and variable capacitor are adjusted for a minimum standing-wave reading.

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VERTICAL, BEAM, and TRIANGLE ANTENNAS

by Edward M. Noll, W3FQJ

Antenna experimentation offers a unique opportunity to make amateur radio more than an "appliance operator" hobby. All you need are telescoping masts, wires, insulators, tubing, ingenuity, and a desire to experiment.

Antenna types from simple dipoles, through verticals and yagis, to quad and triangle beams are covered in this book, and the topics are arranged in a sequential manner. However, if the reader is interested in one particular type of antenna, he can go directly to that type.

The necessary mathematics are included, but no extensive knowledge is required to build the antennas described. Simple test instruments are shown which will enable the reader to optimize the designs and obtain maximum performance from his antenna.

Many of these antennas compete with, and some surpass the performance of commercial beams. The serious experimenter will find in **73 VERTICAL, BEAM, and TRIANGLE ANTENNAS** exactly what he needs.

ABOUT THE AUTHOR

In addition to being an accomplished author of technical books, lessons, articles, and instruction manuals, Ed Noll is also a consulting engineer and lecturer. His other books include:

73 Dipole and Long-Wire Antennas

First-Class Radiotelephone License Handbook

Second-Class Radiotelephone License Handbook

Radar License Endorsement Handbook

Radio Operators License Handbook

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