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**Chapter 13 —
CD-ROM Content**

Supplemental Articles

- "A Four Wire Steerable V Beam for 10 through 40 Meters" by Sam Moore, NX5Z

Chapter 13

Long-Wire and Traveling-Wave Antennas

The power gain and directive characteristics of electrically long wires (that is, wires that are long in terms of wavelength) make them useful for long-distance transmission and reception on the higher frequencies. Long wires can be combined to form antennas of various shapes that increase the gain and directivity over a single wire. The term *long wire*, as used in this chapter, means any such configuration, not just a straight-wire antenna. Techniques for feeding these antennas are discussed in the chapter **Transmission Line System Techniques**. The Beverage antenna is covered in the **Receiving and Direction-Finding Antennas** chapter.

13.1 OVERVIEW

13.1.1 LONG WIRES VERSUS MULTIELEMENT ARRAYS

In general, the gain obtained with long-wire antennas is not as great, when the space available for the antenna is limited, as you can obtain from the multielement phased arrays in or from a parasitic array such as a Yagi or quad. (See the **Multielement Arrays** chapter.) However, the long-wire antenna has advantages of its own that tend to compensate for this deficiency. The construction of long-wire antennas is simple both electrically and mechanically, and there are no especially critical dimensions or adjustments. The long-wire antenna will work well and give satisfactory gain and directivity over a 2-to-1 frequency range. In addition, it will accept power and radiate well on any frequency for which its overall length is not less than about a half wavelength. Since a wire is not electrically long, even at 28 MHz, unless its physical length is equal to at least a half wavelength on 3.5 MHz, any long-wire can be used on all amateur bands that are useful for long-distance communication.

Between two directive antennas having the same theoretical gain, one a multielement array and the other a long-wire antenna, many amateurs have found that the long-wire antenna seems more effective in reception. One possible explanation is that there is a *diversity effect* with a long-wire antenna because it is spread out over a large distance, rather than being concentrated in a small space, as would be the case with a Yagi, for example. This may raise the average level of received energy for ionospheric-propagated signals. Another factor is that long-wire antennas have directive patterns that can be extremely sharp in the horizontal (azimuthal) plane. This is an advantage that other types of multielement arrays do not have, but it can be a double-edged sword too. We'll discuss this aspect in some detail in this chapter.

13.1.2 GENERAL CHARACTERISTICS OF LONG-WIRE ANTENNAS

Whether the long-wire antenna is a single wire running in one direction or is formed into a V-beam, rhombic, or some other configuration, there are certain general principles that apply and some performance features that are common to all types. The first of these is that the power gain of a long-wire antenna as compared with a half-wave dipole is not considerable until the antenna is really long (its length measured in wavelengths rather than in a specific number of feet). The

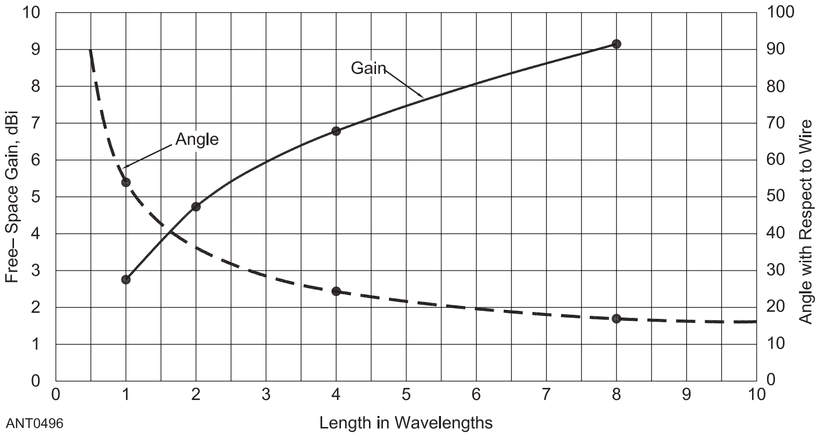
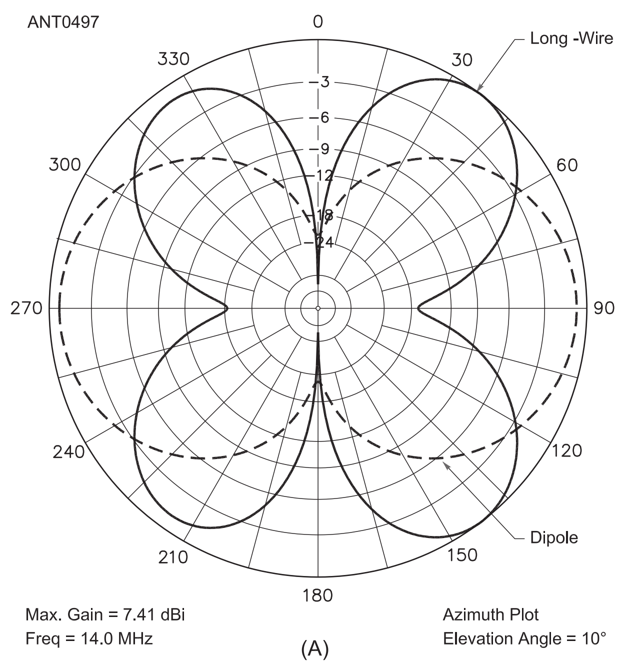


Figure 13.1 — Theoretical gain of a long-wire antenna, in dBi, as a function of wire length. The angle, with respect to the wire, at which the radiation intensity is maximum also is shown.



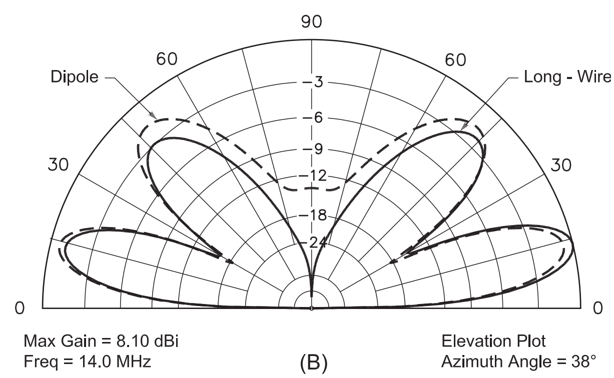


Figure 13.2 — At A, comparison of azimuthal patterns for a 1-λ long-wire antenna (solid line) and a ½-λ dipole (dashed line) at an elevation angle of 10°. Each antenna is located 1 λ (70 feet) over flat ground at 14 MHz. At B, the elevation-plane patterns at peak azimuth angles for each antenna. The long-wire has about 0.6 dB more gain than the dipole.

reason for this is that the fields radiated by elementary lengths of wire along the antenna do not combine, at a distance, in as simple a fashion as the fields from half-wave dipoles used in other types of directive arrays.

There is no point in space, for example, where the distant fields from all points along the wire are exactly in phase (as they are, in the optimum direction, in the case of two or more collinear or broadside dipoles when fed with in-phase currents). Consequently, the field strength at a distance is always less than would be obtained if the same length of wire were cut up into properly phased and separately driven dipoles. As the wire is made longer, the fields combine to form increasingly intense main lobes, but these lobes do not develop appreciably until the wire is several wavelengths long. See **Figure 13.1**.

The longer the antenna, the sharper the lobes become, and since it is really a hollow cone of radiation about the wire in free space, it becomes sharper in both planes. Also, the greater the length, the smaller the angle with the wire at which the maximum radiation lobes occur. There are four main lobes to the directive patterns of long-wire antennas; each makes the same angle with respect to the wire.

Figure 13.2A shows the azimuthal radiation pattern of a 1-λ long-wire antenna, compared with a ½-λ dipole. Both antennas are mounted at the same height of 1 λ above flat ground (70 feet high at 14 MHz, with a wire length of 70 feet) and both patterns are for an elevation angle of 10°, an angle suitable for long-distance communication on 20 meters. The long-wire in Figure 13.2A is oriented in the 270° to 90° direction, while the dipole is aligned at right angles so that its characteristic figure-8 pattern goes left-to-right. The 1-λ long-wire has about 0.6 dB more gain than the dipole, with four main lobes as compared to the two lobes from the dipole.

You can see that the two lobes on the left side of Figure 13.2A are about 1 dB down compared to the two lobes on the right side. This is because the long-wire here is fed at the left-hand end in the computer model. Energy is radiated as a wave travels down the wire and some energy is also lost to ohmic resistance in the wire and the ground. The forward-going wave then reflects from the open-circuit at the right-hand end of the wire and reverses direction, traveling toward the left end, still radiating as it travels. An antenna operating in this way has much the same characteristics as a transmission line that is terminated in an open circuit — that is, it has standing waves on it. Unterminated long-wire antennas are often referred to as standing wave antennas. As the length of a long-wire antenna is increased, a moderate front-to-back ratio results, about 3 dB for very long antennas.

Figure 13.2B shows the elevation-plane pattern for the long-wire and for the dipole. In each case the elevation pattern is at the azimuth of maximum gain — at an angle of 38° with respect to the wire-axis for the long-wire and at 90° for the dipole. The peak elevation for the long-wire is very slightly lower than that for the dipole at the same height above ground, but not by much. In other words, the height above ground is the main determining factor for the shape of the main lobe of a long-wire's elevation pattern, as it is for most horizontally polarized antennas.

The shape of the azimuth and elevation patterns in Figure 13.2 might lead you to believe that the radiation pattern is simple. **Figure 13.3** is a 3-D representation of the pattern from a 1-λ long-wire that is 1 λ high over flat ground. Besides the main low-angle lobes, there are strong lobes at higher angles. Things get even more complicated when the length of the long-wire increases.

Directivity

Because many points along a long wire are carrying currents in different phases (with different current amplitudes as well), the field pattern at a distance becomes more complex as the wire is made longer. This complexity is manifested in a series of minor lobes, the number of which increases with the wire length. The intensity of radiation from the minor lobes is frequently as great as, and sometimes greater than, the radiation from a half-wave dipole. The energy radiated in the minor lobes is not available to improve the gain in the major lobes, which is another reason why a long-wire antenna must be long to give appreciable gain in the desired directions.

Figure 13.4 shows an azimuthal-plane comparison between a 3-λ (209 feet long) long-wire and the comparison ½-λ dipole. The long-wire now has eight minor lobes besides the four main lobes. Note that the angle the main lobes make with respect to the axis of the long-wire (also left-to-right in Figure 13.4) becomes smaller as the length of the long-wire increases. For the 3-λ long-wire, the main lobes occur 28° off the axis of the wire itself.

Other types of simple driven and parasitic arrays do not have minor lobes of any great consequence. For that reason they frequently seem to have much better directivity than long-wire antennas, because their responses in undesired directions are well down from their response in the desired direction. This is the case even if a multielement array and a long-wire antenna have the same peak gain in the favored direction. **Figure 13.5** compares the same 3-λ long-wire with a 4-element Yagi and a ½-λ dipole, again both at the same height as the long-wire. Note that the Yagi has only a single rear lobe, down about 21 dB from its broad main lobe, which

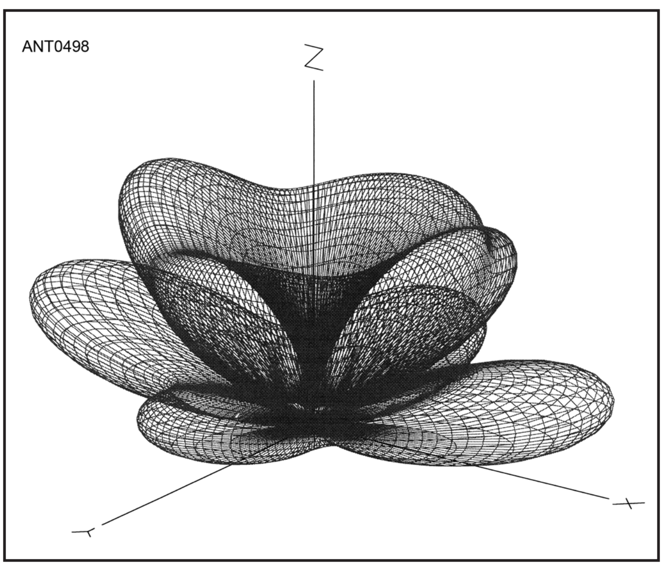


Figure 13.3 — A 3-D representation of the radiation pattern for the 1-λ long-wire shown in Figure 13.2. The pattern is obviously rather complex. It gets even more complicated for wires longer than 1 λ.

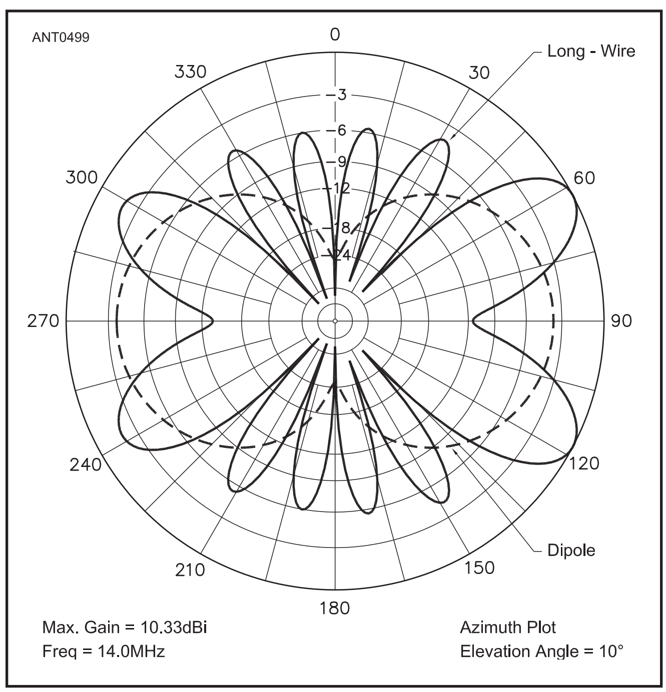


Figure 13.4 — An azimuthal-plane comparison between a 3-λ (209 feet long) long-wire (solid line) and the comparison ½-λ dipole (dashed line) at 70 feet high (1 λ) at 14 MHz.

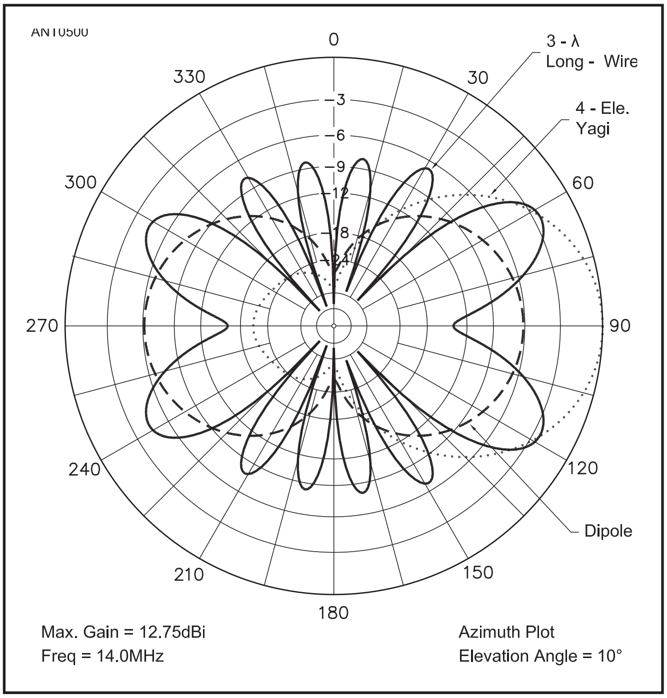


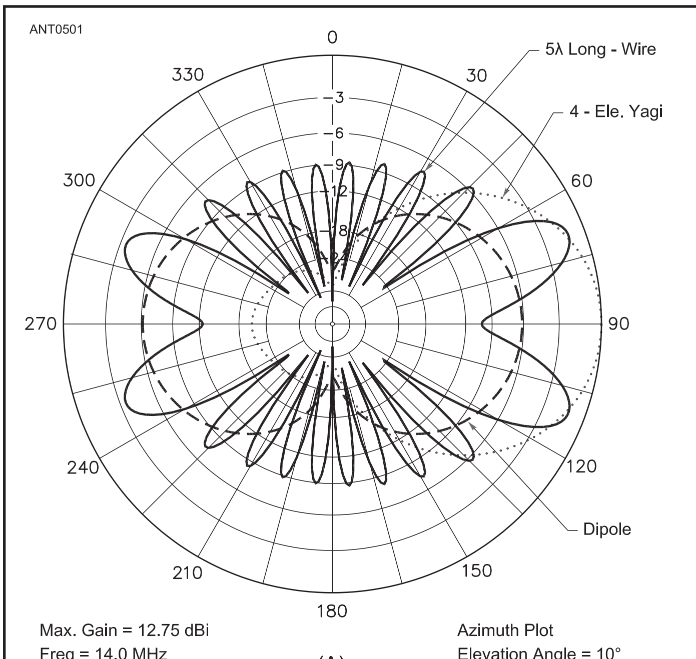
Figure 13.5 — A comparison between the 3-λ long-wire (solid line) in Figure 13.4, a 4-element 20-meter Yagi on a 26-foot boom (dotted line), and a ½-λ dipole (dashed line), again at a height of 70 feet. The main lobes of the long-wire are very narrow compared to the wide frontal lobe of the Yagi. The long-wire exhibits an azimuthal pattern that is more omnidirectional in nature than a Yagi, particularly when the narrow, deep nulls in the long-wire's pattern are filled-in due to irregularities in the terrain under its long span of wire.

has a 3-dB beamwidth of 63°. The 3-dB beamwidth of the long-wire's main lobes (at a 28° angle from the wire axis) is far more narrow, at only 23°.

For amateur work, particularly with directive antennas that cannot be rotated, the minor lobes of a long-wire antenna have some advantages. Although the nulls in the computer model in Figure 13.5 are deeper than 30 dB, they are not so dramatic in actual practice. This is due to irregularities in the terrain that inevitably occur under the span of a long wire. In most directions the long-wire antenna will be as good as a half-wave dipole, and in addition will give high gain in the most favored directions, even though that is over narrow azimuths.

Figure 13.6A compares the azimuth responses for a 5-λ long-wire (350 feet long at 14 MHz) to the same 4-element Yagi and dipole. The long-wire now exhibits 16 minor lobes in addition to its four main lobes. The peaks of these sidelobes are down about 8 dB from the main lobes and they are stronger than the dipole, making this long-wire antenna effectively omnidirectional. Figure 13.6B shows the elevation pattern of the 5-λ long-wire at its most effective azimuth compared to a dipole. Again, the shape of the main lobe is mainly determined by the long-wire's height above ground, since the peak angle is only just a bit lower than the peak angle for the dipole. The long-wire's elevation response breaks up into numerous lobes above the main lobes, just as it does in the azimuth plane.

For the really ambitious, **Figure 13.7** compares the performance for an 8-λ (571 feet) long-wire antenna with a 4-element Yagi and the ½-λ dipole. Again, in actual practice, the nulls would tend to be filled in by terrain irregularities, so a very long antenna like this would be a pretty potent performer.



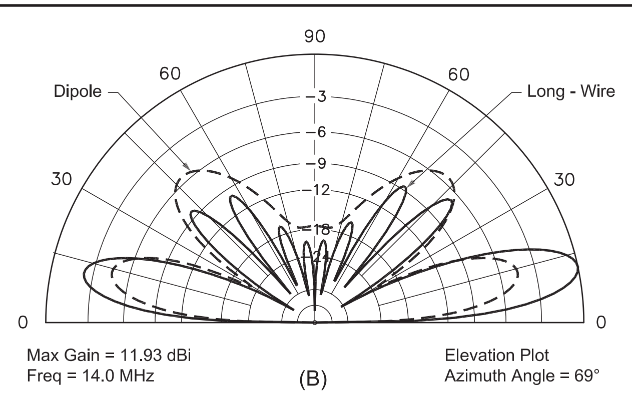


Figure 13.6 — At A, the azimuth responses for a 5-λ long-wire (350 feet long at 14 MHz — solid line) to the same 4-element Yagi (dotted line) and dipole (dashed line) as in Figure 13.5. At B, the elevation-plane responses for the long-wire (solid line) and the dipole (dashed line) by themselves. Note that the elevation angle giving peak gain for each antenna is just about the same. The long-wire achieves gain by compressing mainly the azimuthal response, squeezing the gain into narrow lobes; not so much by squeezing the elevation pattern for gain.

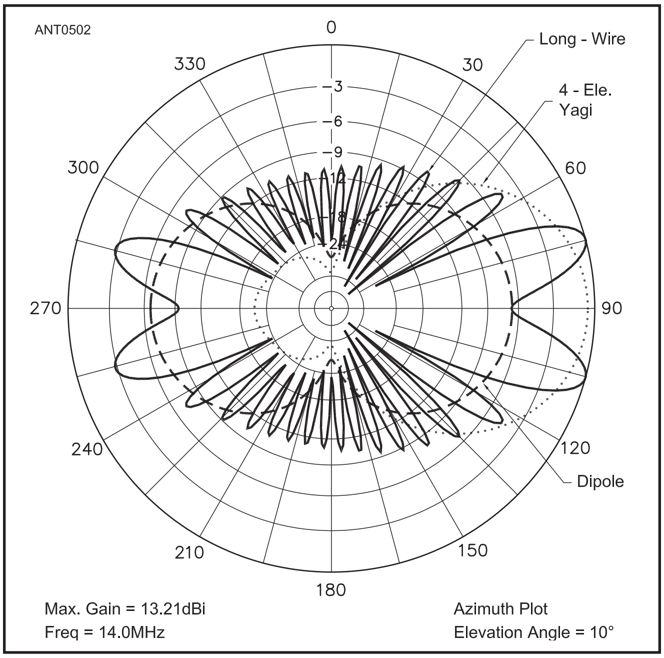


Figure 13.7 — The azimuthal-plane performance for an 8-λ (571 feet) long-wire antenna (solid line), compared with a 4-element Yagi (dotted line) and a ½-λ dipole (dashed line).

Calculating Length

In this chapter, lengths are discussed in terms of wavelengths. Throughout the preceding discussion the frequency in the models was held at 14 MHz. Remember that a long-wire that is 4 λ long at 14 MHz is 8 λ long at 28 MHz.

There is nothing very critical about wire lengths in an antenna system that will work over a frequency range including several amateur bands. The antenna characteristics change very slowly with length, except when the wires are short (around one wavelength, for instance). There is no need to try to establish exact resonance at a particular frequency for proper antenna operation.

The formula for determining the lengths for harmonic wires is:

$$\text{Length (feet)} = \frac{984\,(N - 0.025)}{f\,(\text{MHz})} \qquad \text{(Eq 1)}$$

where N is the antenna length in wavelengths. In cases where precise resonance is desired for some reason (for obtaining a resistive load for a transmission line at a particular frequency, for example) it is best established by trimming the wire length until the standing-wave ratio on the line is minimum.

Tilted Wires

In theory, it is possible to maximize gain from a long-wire antenna by tilting it to favor a desired elevation take-off angle. Unfortunately, the effect of real ground under the antenna negates the possible advantages of tilting, just as it does when a Yagi or other type of parasitic array is tilted from horizontal. You would do better keeping a long-wire antenna horizontal, but raising it higher above ground, to achieve more gain at low takeoff angles.

13.1.3 FEEDING LONG WIRES

A long-wire antenna is normally fed at the end or at a current maximum where feed point impedance is relatively low. Since a current maximum changes to a minimum when the antenna is operated at any even multiple of the frequency for which it is designed, a long-wire antenna will operate as a true long wire on all bands only when it is fed at the end where feed point impedance is always high. It is important to note that for antennas with more than one current maximum (typically 1 λ or longer), the position of the feed point will alter the current distribution on the antenna and that will affect the antenna's radiation pattern. In such cases, modeling will help determine the best place to feed the antenna.

A common method of feeding a long-wire is to use a resonant open-wire line. This system will work on all bands down to the one, if any, at which the antenna is only a half-wave long. Any convenient line length can be used if you match the transmitter to the line's input impedance using an antenna tuner. Using coaxial cable to feed long wires directly can lead to excessive losses if the SWR is high and so open-wire line is the usual choice.

Two arrangements for using nonresonant lines are given in **Figure 13.8**. The one at A is useful for one band only since the matching section must be a quarter-wave long, approximately, unless a different matching section is used for each band. In B, the λ/4 transformer (Q-section) impedance can be designed to match the antenna to the line. You can determine the value of radiation resistance using a modern modeling program or you can actually measure the feed point impedance. Although it will work as designed on only one band, the antenna can be used on other bands by treating the line and matching transformer as a resonant line. In this case, as mentioned earlier, the antenna will not radiate as a true long wire on even multiples of the frequency for which the matching system is designed.

The end-fed arrangement, although the most convenient

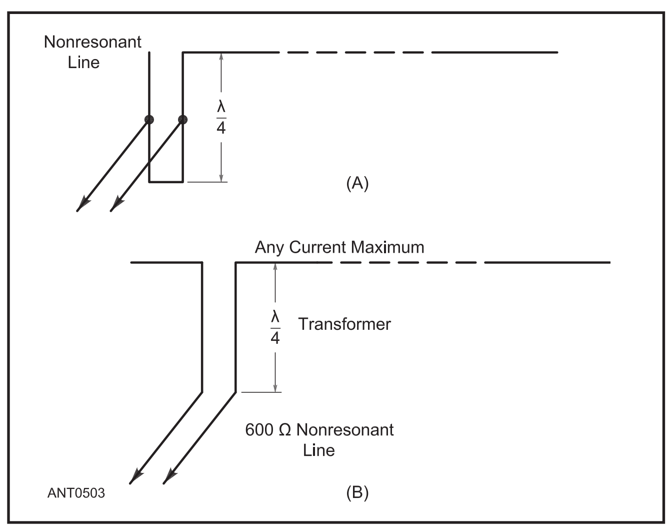


Figure 13.8 — Methods for feeding long single-wire antennas.

when tuned feeders are used, has the disadvantage that there is likely to be a considerable antenna current on the line. In addition, the antenna reactance changes rapidly with frequency. Consequently, when the wire is several wavelengths long, a relatively small change in frequency — a fraction of the width of a band — may require major changes in the adjustment of the antenna tuner. Also, the line becomes unbalanced at all frequencies between those at which the antenna is resonant. This leads to a considerable amount of radiation from the line. The unbalance can be overcome by using multiple long wires in a V or rhombic shape, as described below.

13.2 COMBINATIONS OF LONG WIRES

The directivity and gain of long wires may be increased by using two wires placed in relation to each other such that the fields from both combine to produce the greatest possible field strength at a distant point. The principle is similar to that used in designing multielement arrays.

13.2.1 PARALLEL WIRES

One possible method of using two (or more) long wires is to place them in parallel, with a spacing of ½ λ or so, and feed the two in phase. In the direction of the wires the fields will add in phase. However, the takeoff angle is high directly in the orientation of the wire, and this method will result in rather high-angle radiation even if the wires are several wavelengths long. With a parallel arrangement of this sort the gain should be about 3 dB over a single wire of the same length, at spacings in the vicinity of ½ wavelength.

13.2.2 THE V-BEAM ANTENNA

Instead of using two long wires parallel to each other, they may be placed in the form of a horizontal V, with the included angle between the wires equal to twice the angle made by the main lobes referenced to the wire axis for a single wire of the same physical length. For example, for a leg length of 5 λ, the angle between the legs of a V should be about 42°, twice the angle of 21° of the main lobe referenced to the long-wire's axis. See Figure 13.6A.

The plane directive patterns of the individual wires combine along a line in the plane of the antenna and bisecting the V, where the fields from the individual wires reinforce each other. The sidelobes in the azimuthal pattern are suppressed by about 10 dB, so the pattern becomes essentially bidirectional. See **Figure 13.9**.

The included angle between the legs is not particularly critical. This is fortunate, especially if the same antenna is used on multiple bands, where the electrical length varies directly with frequency. This would normally require different included angles for each band. For multiband V-antennas, a compromise angle is usually chosen to equalize performance. **Figure 13.10** shows the azimuthal pattern for a

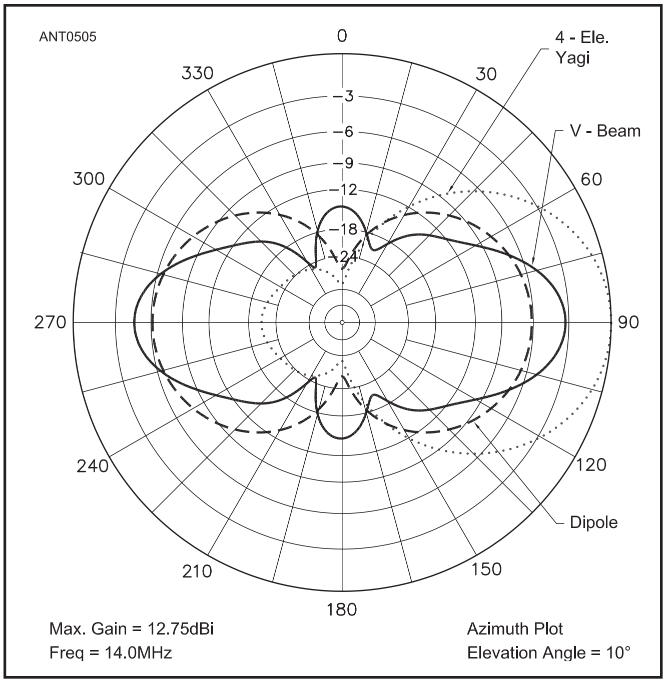
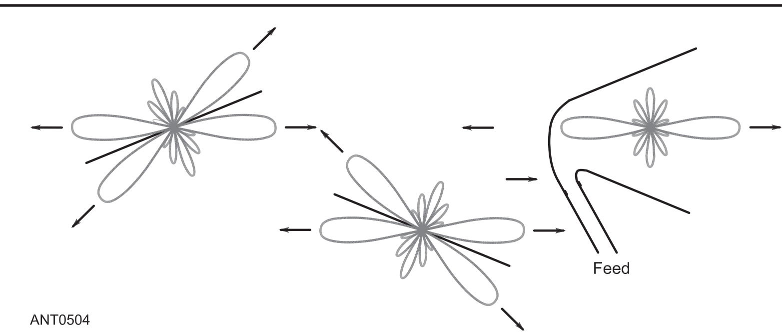


Figure 13.10 — Azimuthal-plane pattern at 10° elevation angle for a 14-MHz V-beam (solid line) with 1-λ legs (68.5 feet long), using an included angle of 75° between the legs. The V-beam is mounted 1 λ above flat ground, and is compared with a ½-λ dipole (dashed line) and a 4-element 20-meter

Figure 13.9 — Two long wires and their respective patterns are shown at the left. If these two wires are combined to form a V with an angle that is twice that of the major lobes of the wires and with the wires excited out of phase, the radiation along the bisector of the V adds and the radiation in the other directions tends to cancel.



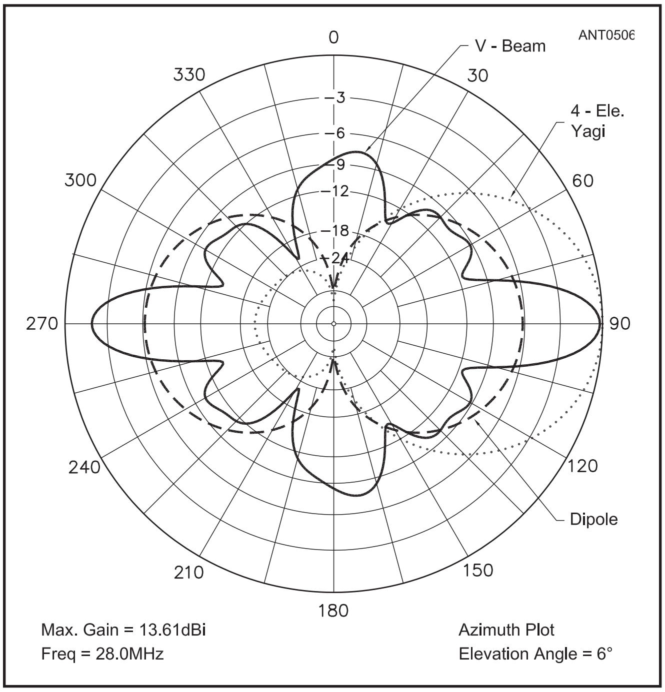


Figure 13.11 — The same V-beam as in Figure 13.10 at 28 MHz (solid line), at an elevation angle of 6°, compared to a 4-element Yagi (dotted line) and a dipole (dashed line). The V-beam's pattern is very narrow, at 18.8° at the 3-dB points, requiring accurate placement of the supports poles to aim the antenna at the desired geographic target.

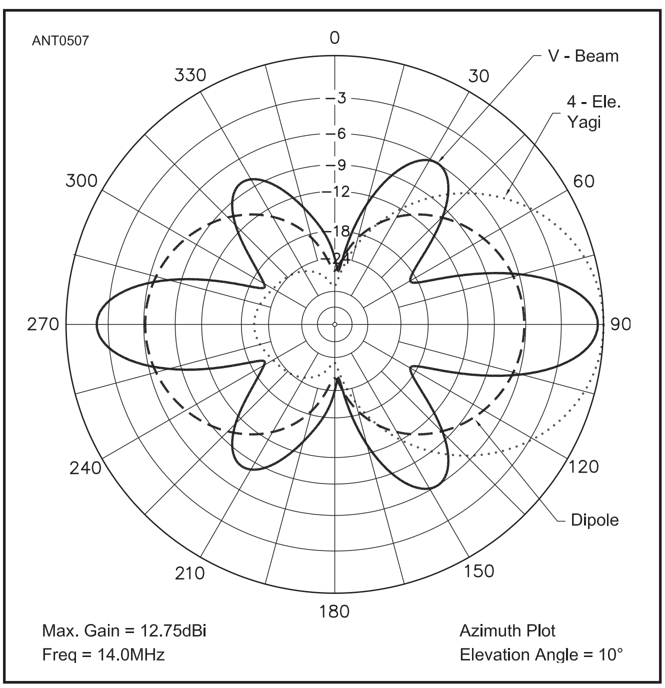


Figure 13.12 — Azimuthal pattern for a V-beam (solid line) with 2-λ legs (137 feet at 14 MHz), with an included angle of 60° between them. The height is 70 feet, or 1 λ, over flat ground. For comparison, the response for a 4-element Yagi (dotted line) and a dipole (dashed line) are shown. The 3-dB beamwidth has decreased to 23.0° .

V-beam with 1-λ legs, with an included angle of 75° between the legs, mounted 1 λ above flat ground. This is for a 10° elevation angle. At 14 MHz the antenna has two 70-foot high, 68.5-foot long legs, separated at their far ends by 83.4 feet. For comparison, the azimuthal patterns for the same 4-element Yagi and ½-λ dipole used previously for the long-wires are overlaid on the same plot. The V has about 2 dB more gain than the dipole but is down some 4 dB compared to the Yagi, as expected for relatively short legs.

Figure 13.11 shows the azimuthal pattern for the same antenna in Figure 13.10, but at 28 MHz and at an elevation angle of 6°. Because the legs are twice as long electrically at 28 MHz, the V-beam has compressed the main lobe into a narrow beam that now has a peak gain equal to the Yagi, but with a 3-dB beamwidth of only 18.8°. Note that you could obtain about 0.7 dB more gain at 14 MHz, with a 1.7-dB degradation of gain at 28 MHz, if you increase the included angle to 90° rather than 75°.

Figure 13.12 shows the azimuthal pattern for a V-beam with 2-λ legs (137 feet at 14 MHz), with an included angle of 60° between them. As usual, the assumed height is 70 feet, or 1 λ at 14 MHz. The peak gain for the V-beam is just about equal to that of the 4-element Yagi, although the 3-dB nose beamwidth is narrow, at 23°. This makes setting up the geometry critical if you want to maximize gain into a particular geographic area. While you might be able to get away with using convenient trees to support such an antenna, it's far more likely that you'll have to use carefully located towers to make sure the beam is aimed where you expect it to be pointed.

For example, in order to cover all of Europe from San Francisco, an antenna must cover from about 11° (to Moscow) to about 46° (to Portugal). This is a range of 35° and signals from the V-beam in Figure 13.12 would be down some 7 dB over this range of angles, assuming the center of the beam is pointed exactly at a heading of 28.5°. The 4-element Yagi on the other hand would cover this range of azimuths more consistently, since its 3-dB beamwidth is 63°.

Figure 13.13 shows the same V-beam as in Figure 13.12, but this time at 28 MHz. The peak gain of the main lobe is now about 1 dB stronger than the 4-element Yagi used as a reference, and the main lobe has two nearby sidelobes that tend to broaden out the azimuthal response. At this frequency the V-beam would cover all of Europe better from San Francisco.

Figure 13.14 shows a V-beam with 3-λ (209 feet at 14 MHz) legs with an included angle of 50° between them. The peak gain is now greater than that of a 4-element Yagi, but the 3-dB beamwidth has been reduced to 17.8°, making aiming the antenna even more critical. **Figure 13.15** shows the same V-beam at 28 MHz. Here again, the main lobe has nearby sidelobes that broaden the effective azimuth to cover a wider area.

Figure 13.16 shows the elevation-plane response for the same 209-foot leg V-beam at 28 MHz (3-λ at 14 MHz), compared to a dipole at the same height of 70 feet. The higher-gain V-beam suppresses higher-angle lobes, essentially

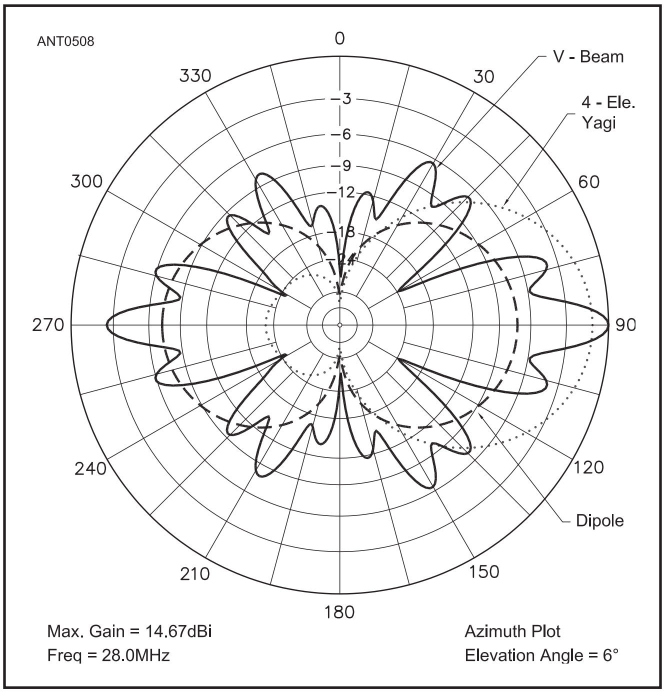


Figure 13.13 — The same 2-λ-per-leg V-beam (solid line) as in Figure 13.12, but at 28 MHz and at a 6° takeoff elevation angle. Two sidelobes have appeared flanking the main lobe, making the effective azimuthal pattern wider at this frequency.

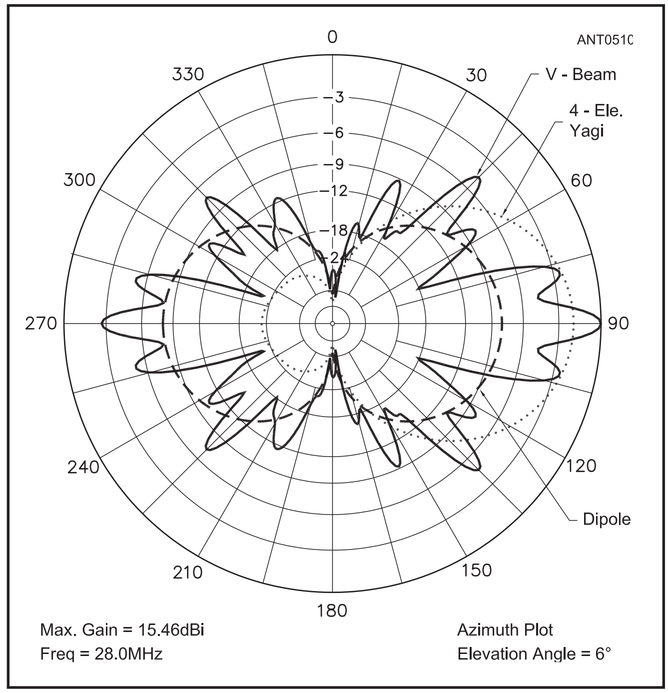


Figure 13.15 — The same 209-foot-per-leg V-beam as Figure 13.14, but at 28 MHz. Again, the two close-in sidelobes tend to spread out the azimuthal response some at 28 MHz.

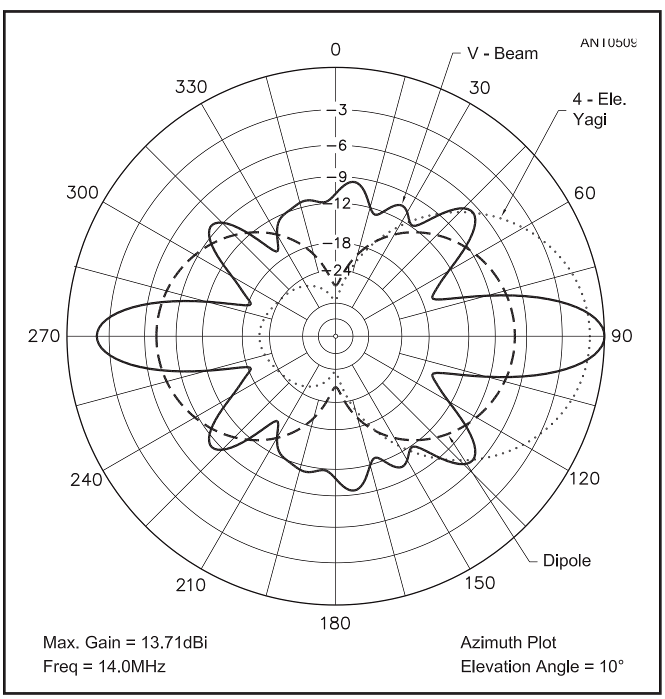


Figure 13.14 — A V-beam (solid line) with 3-λ (209 feet at 14 MHz) legs using an included angle of 50° between them, compared to a 4-element Yagi (dotted line) and a dipole (dashed line). The 3-dB beamwidth has now decreased to 17.8°.

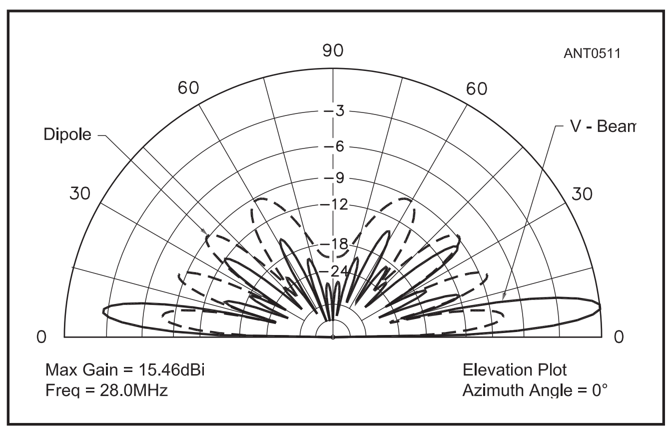


Figure 13.16 — The elevation-plane of the 209-foot-per-leg V-beam (solid line) compared to the dipole (dashed line). Again, the elevation angle for peak gain corresponds well to that of the simple dipole at the same height.

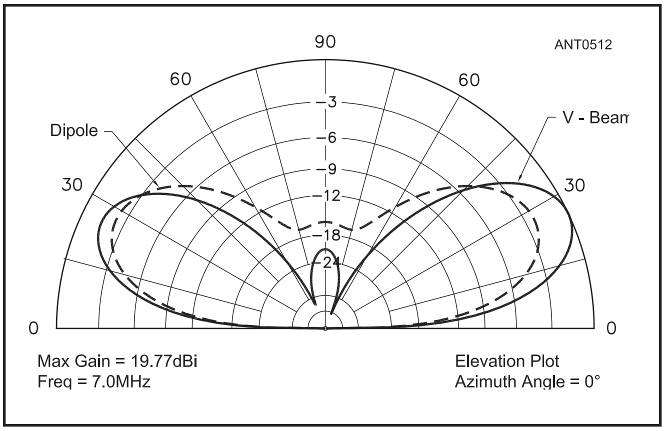


Figure 13.17 — Elevation pattern for the same 209-foot-per-leg V-beam (solid line), at 7 MHz, compared to a 40-meter dipole (dashed line) at the same height of 70 feet.

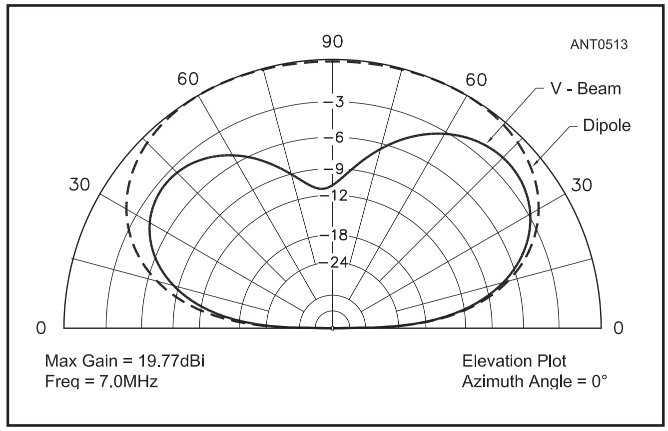


Figure 13.18 — Elevation pattern for the same 209-foot-per-leg V-beam (solid line), at 3.5 MHz, compared to an 80-meter dipole at 70 feet (dashed line).

stealing energy from them and concentrating it in the main beam at 6° elevation.

The same antenna can be used at 3.5 and 7 MHz. The gain will not be large, however, because the legs are not very long at these frequencies. **Figure 13.17** compares the V-beam versus a horizontal ½-λ 40-meter dipole at 70 feet. At low elevation angles there is about 2 dB of advantage on 40 meters. **Figure 13.18** shows the same type of comparison for 80 meters, where the 80 meter dipole is superior at all angles.

Other V Combinations

A gain increase of about 3 dB can be had by stacking two V-beams one above the other, a half wavelength apart, and feeding them with in-phase currents. This will result in a lowered angle of radiation. The bottom V should be at least a quarter wavelength above the ground, and preferably a half wavelength. This arrangement will narrow the elevation pattern and it will also have a narrow azimuthal pattern.

The V antenna can be made unidirectional by using a second V placed an odd multiple of a quarter wavelength in back of the first and exciting the two with a phase difference of 90°. The system will be unidirectional in the direction of the antenna with the lagging current. However, the V reflector is not normally employed by amateurs at low frequencies because it restricts the use to one band and requires a fairly elaborate supporting structure. Stacked Vs with driven reflectors could, however, be built for the 200- to 500-MHz region without much difficulty.

Feeding the V Beam

The V-beam antenna is most conveniently fed with tuned open-wire feeders with an antenna tuner, since this permits multiband operation. Although the length of the wires in a V-beam is not at all critical, it is important that both wires be the same electrical length. If a single band matching solution is desired, probably the most appropriate matching system is that using a stub or quarter-wave matching section.

13.3 THE RESONANT RHOMBIC ANTENNA

The diamond-shaped or rhombic antenna shown in **Figure 13.19** can be looked upon as two acute-angle V-beams placed end-to-end. This arrangement is called a resonant rhombic. The leg lengths of the resonant rhombic must be an integral number of half wavelengths to avoid reactance at its feed point.

The resonant rhombic has two advantages over the simple V-beam. For the same total wire length it gives somewhat greater gain than the V-beam. A rhombic with 3 λ on a leg, for example, has about 1 dB gain over a V antenna with 6 wavelengths on a leg. **Figure 13.20** compares the azimuthal pattern at a 10° elevation for a resonant rhombic with 3 λ legs on 14 MHz, compared to a V-beam with 6 λ legs at the same height of 70 feet. The 3-dB nose beamwidth of the resonant rhombic is only 12.4° wide, but the gain is very high at 16.26 dBi.

The directional pattern of the rhombic is less frequency sensitive than the V when the antenna is used over a wide frequency range. This is because a change in frequency causes the major lobe from one leg to shift in one direction while the lobe from the opposite leg shifts the other way. This automatic compensation keeps the direction the same over a considerable frequency range. The disadvantage of the rhombic as compared with the V-beam is that an additional support is required. Some authors also report success with "half-rhombics" oriented vertically over ground with and without a counterpoise. (See Bibliography entry for Orr.)

The same factors that govern the design of the V-beam apply in the case of the resonant rhombic. The optimal apex angle A in Figure 13.19 is the same as that for a V having an

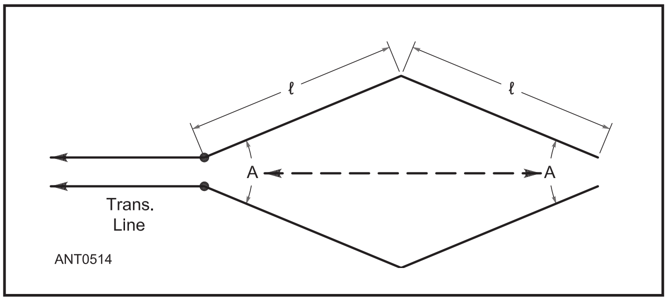


Figure 13.19 — The resonant rhombic or diamond-shaped antenna. All legs are the same length, and opposite angles of the diamond are equal. Length ℓ is an integral number of half wavelengths for resonance.

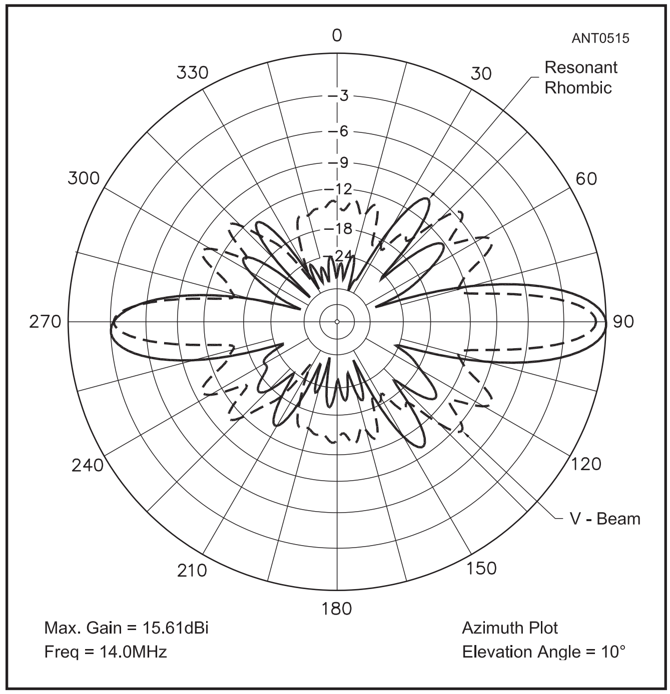


Figure 13.20 — Azimuthal-plane pattern of resonant (unterminated) rhombic (solid line) with 3-λ legs on 14 MHz, at a height of 70 feet above flat ground, compared with a 6-λ per leg V-beam (dashed line) at the same height. Both azimuthal patterns are at a takeoff angle of 10° . The sidelobes for the resonant rhombic are suppressed to a greater degree than those for the V-beam.

equal leg length. The diamond-shaped antenna also can be operated as a terminated antenna, as described later in this chapter, and much of the discussion in that section applies to the resonant rhombic as well.

The resonant rhombic has a bidirectional pattern, with minor lobes in other directions, their number and intensity depending on the leg length. In general, these sidelobes are suppressed better with a resonant rhombic than with a V-beam. When used at frequencies below the VHF region, the rhombic antenna is always mounted with the plane containing the wires horizontal. The polarization in this plane, and also in the perpendicular plane that bisects the rhombic, is horizontal. At 144 MHz and above, the dimensions are such that the antenna can be mounted with the plane containing the wires vertical if vertical polarization is desired.

When the rhombic antenna is to be used on several HF amateur bands, it is advisable to choose the apex angle, A, on the basis of the leg length in wavelengths at 14 MHz. Although the gain on higher frequency bands will not be quite as favorable as if the antenna had been designed for the higher frequencies, the system will still work well at the low angles that are necessary at such frequencies.

The resonant rhombic has lots of gain, but you must not forget that this gain comes from a radiation pattern that is very narrow. This requires careful placement of the supports for the resonant rhombic to cover desired geographic areas. This is definitely not an antenna that allows you to use just any convenient trees as supports!

Even if you cannot place its corners exactly, the rhombic can still give good performance. (See the Bibliography entry for Hallas.) The main lobe broadens and peak gain is lower but the author found it to be a very effective antenna.

The resonant rhombic antenna can be fed in the same way as the V-beam. Resonant feeders are necessary if the antenna is to be used in several amateur bands.

13.4 TERMINATED LONG-WIRE ANTENNAS

All the antenna systems considered so far in this chapter have been based on operation with standing waves of current and voltage along the wire. Although most hams use antenna designs based on using resonant wires, resonance is by no means a necessary condition for the wire to radiate and intercept electromagnetic waves efficiently, as discussed in the **Antenna Fundamentals** chapter. The result of using nonresonant wires is reactance at the feed point, unless the antenna is terminated with a resistive load.

In **Figure 13.21**, suppose that the wire is parallel with the ground (horizontal) and is terminated by a load Z equal to its characteristic impedance, Z_{ANT}. The wire and its image in the ground create a transmission line. The load Z can represent a receiver matched to the line. The *terminating resistor* R is also equal to the Z_{ANT} of the wire. A wave coming from direction X will strike the wire first at its far end and sweep across the wire at some angle until it reaches the end at which Z is connected. In so doing, it will induce voltages in the antenna, and currents will flow as a result. The current flowing toward Z is the useful output of the antenna, while the current flowing backwards toward R will be absorbed in R. The same thing is true of a wave coming from the direction X'. In such an antenna there are no standing waves, because all received power is absorbed at either end.

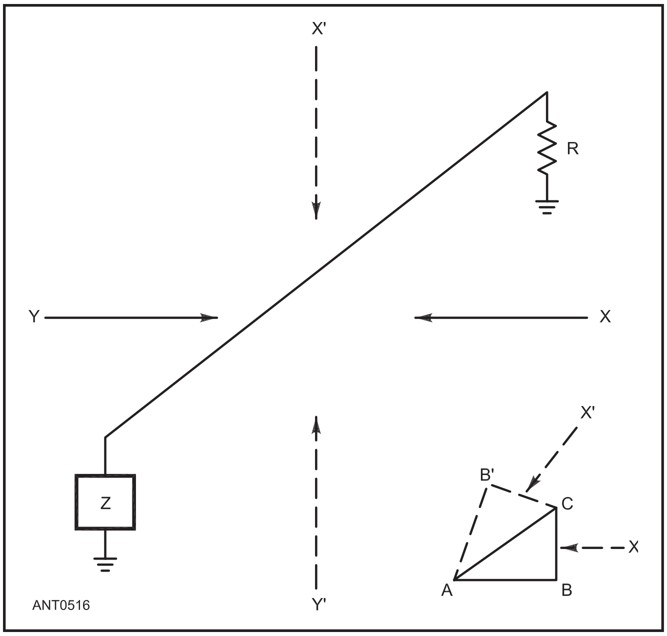


Figure 13.21 — Layout for a terminated long-wire antenna.

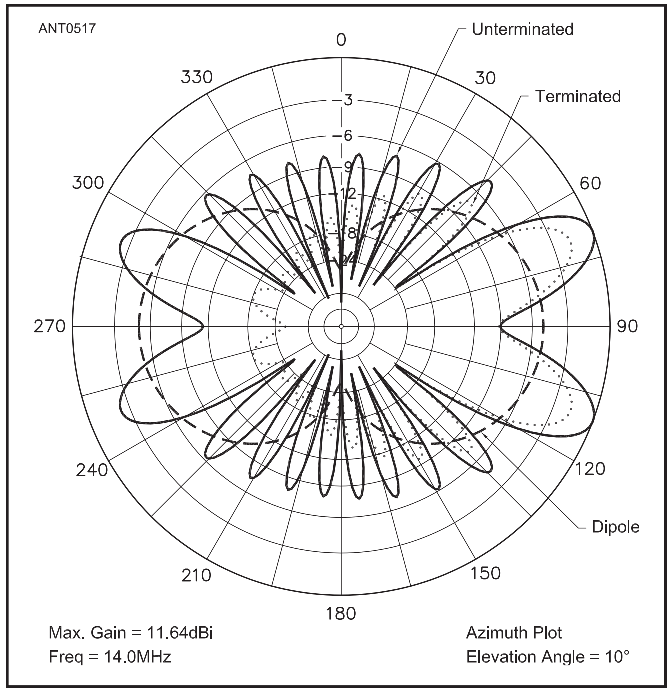


Figure 13.22 — Azimuthal-plane pattern for 5-λ long-wire antenna at 14 MHz and 70 feet above flat ground. The solid line shows the long-wire terminated with 600-Ω to ground, while the dashed line is for the same antenna unterminated. For comparison, the response for a ½-λ dipole is overlaid with the two other patterns. You can see that the terminated long-wire has a good front-to-back pattern, but it loses about 2 dB in forward gain compared to the unterminated long-wire.

The greatest possible power will be delivered to the load Z when the individual currents induced as the wave sweeps across the wire all combine properly on reaching the load. The currents will reach Z in optimum phase when the time required for a current to flow from the far end of the antenna to Z is exactly one-half cycle longer than the time taken by the wave to sweep over the antenna. A half cycle is equivalent to a half wavelength greater than the distance traversed by the wave from the instant it strikes the far end of the antenna to the instant that it reaches the near end. This is shown by the small drawing, where AC represents the antenna, BC is a line perpendicular to the wave direction, and AB is the distance traveled by the wave in sweeping past AC. AB must be one-half wavelength shorter than AC. Similarly, AB' must be the same length as AB for a wave arriving from X'.

A wave arriving at the antenna from the opposite direction Y (or Y'), will similarly result in the largest possible current at the far end. However, since the far end is terminated in R, which is equal to Z, all the power delivered to R by the wave arriving from Y will be absorbed in R. The current traveling to Z will produce a signal in Z in proportion to its amplitude. If the antenna length is such that all the individual currents arrive at Z in such phase as to add up to zero, there will be no current through Z. At other lengths the resultant current may reach appreciable values. The lengths that give zero amplitude are those which are odd multiples of ¼ λ, beginning at ¾ λ. The response from the Y direction is greatest when the antenna is any even multiple of ½ λ long; the higher the multiple, the smaller the response.

Directional Characteristics

Figure 13.22 compares the azimuthal pattern for a 5-λ long 14-MHz long-wire antenna, 70 feet high over flat ground, when it is terminated and when it is unterminated. The rearward pattern when the wire is terminated with a 600 Ω resistor is reduced about 15 dB, with a reduction in gain in the forward direction of about 2 dB.

For a shorter leg length in a terminated long-wire antenna, the reduction in forward gain is larger — more energy is radiated by a longer wire before the forward wave is absorbed in the terminating resistor. The azimuthal patterns for terminated and unterminated V-beams with 2-λ legs are overlaid for comparison in **Figure 13.23**. With these relatively short legs the reduction in forward gain is about 3.5 dB due to the terminations, although the front-to-rear ratio approaches 20 dB for the terminated V-beam. Each leg of this terminated V-beam use a 600-Ω non-inductive resistor to ground. Each resistor would have to dissipate about one-quarter of the transmitter power. For average conductor diameters and heights above ground, the Z_{ANT} of the antenna is of the order of 500 to 600 Ω.

13.4.1 THE TERMINATED RHOMBIC ANTENNA

The highest development of the long-wire antenna is the *terminated rhombic*, shown schematically in **Figure 13.24**. It consists of four conductors joined to form a diamond, or *rhombus*. All sides of the antenna have the same length and the opposite corner angles are equal. The antenna can be

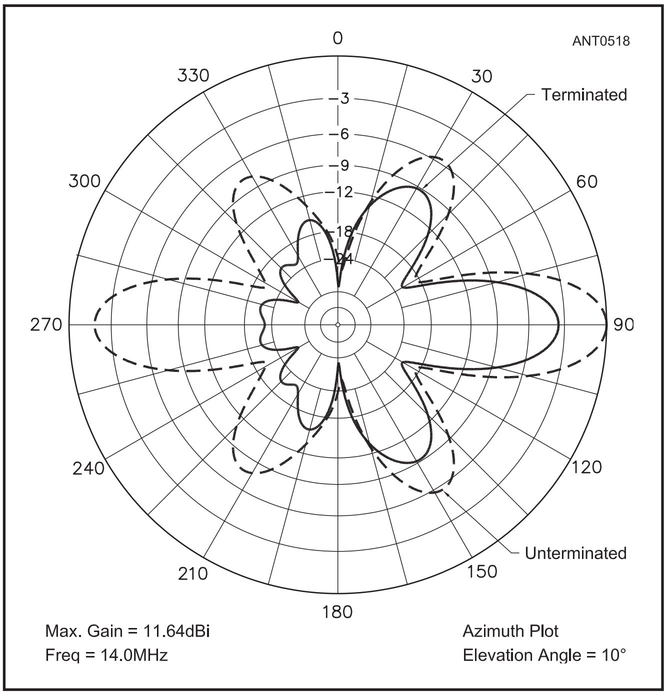


Figure 13.23 — The azimuthal patterns for a shorter-leg V-beam (2-λ legs) when it is terminated (solid line) and unterminated (dashed line). With shorter legs, the terminated V-beam loses about 3.5 dB in forward gain compared to the unterminated version, while suppressing the rearward lobes as much as 20 dB.

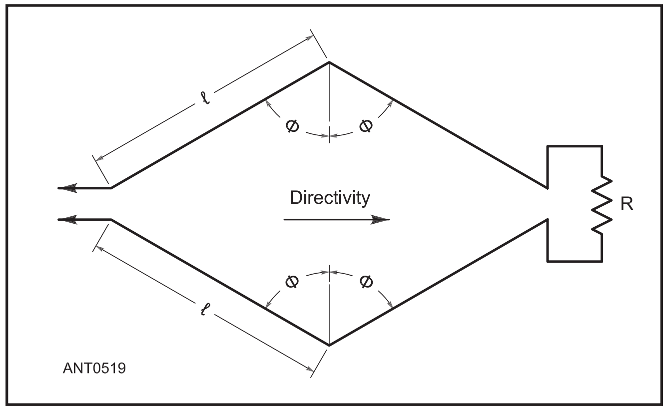
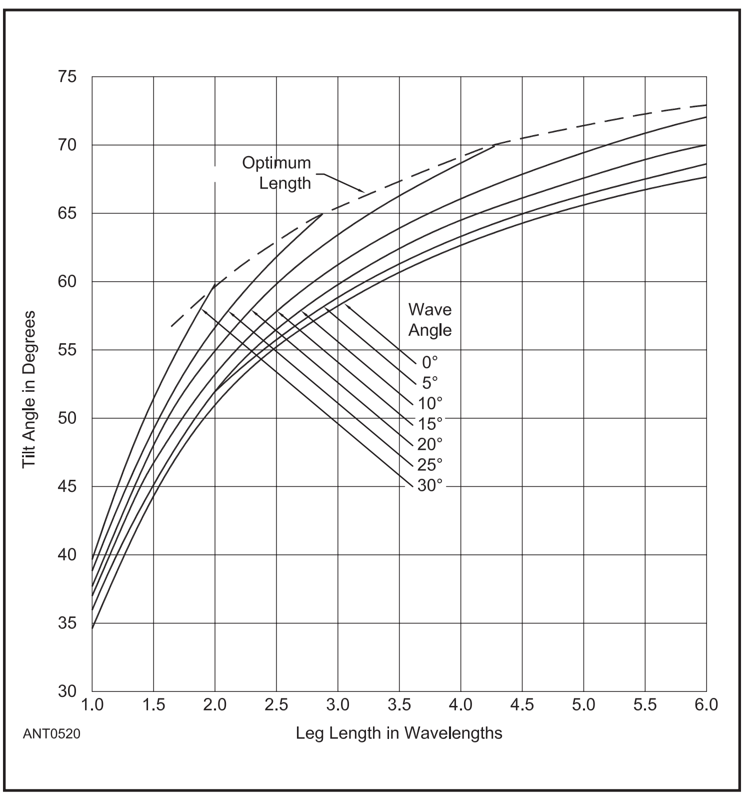


Figure 13.24 — The layout for a terminated rhombic antenna.

considered as being made up of two V antennas placed end to end and terminated by a noninductive resistor to produce a unidirectional pattern. The terminating resistor is connected between the far ends of the two sides, and is made approximately equal to the characteristic impedance of the antenna as a unit. The rhombic may be constructed either horizontally or vertically, but is practically always constructed horizontally at frequencies below 54 MHz, since the pole height required is considerably less. Also, horizontal polarization is equally, if not more, satisfactory at these frequencies over most types of soil.

The basic principle of combining lobes of maximum radiation from the four individual wires constituting the rhombus or diamond is the same in either the terminated type or the resonant type described earlier in this chapter.



Tilt Angle

In dealing with the terminated rhombic, it is a matter of custom to talk about the tilt angle (ϕ in Figure 13.24), rather than the angle of maximum radiation with respect to an individual wire. **Figure 13.25** shows the tilt angle as a function of the antenna leg length. The curve marked "0°" is used for a takeoff elevation angle of 0°; that is, maximum radiation in the plane of the antenna. The other curves show the proper tilt angles to use when aligning the major lobe with a desired takeoff angle. For a 5° takeoff angle, the difference in tilt angle is less than 1° for the range of lengths shown.

The broken curve marked "optimum length"

Figure 13.25 — Rhombic-antenna design chart. For any given leg length, the curves show the proper tilt angle to give maximum radiation at the selected takeoff angle. The broken curve marked "optimum length" shows the leg length that gives the maximum possible output at the selected takeoff angle. The optimum length as given by the curves should be multiplied by 0.74 to obtain the leg length for which the takeoff angle and main lobe are aligned.

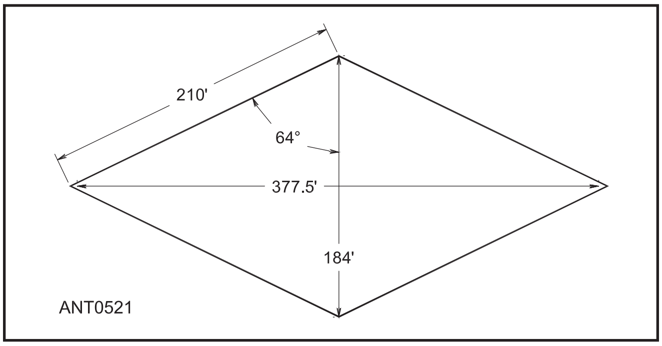


Figure 13.26 — Rhombic antenna dimensions for a compromise design between 14- and 28-MHz requirements, as discussed in the text. The leg length is 6 λ at 28 MHz, 3 λ at 14 MHz.

shows the leg length at which maximum gain is obtained at any given takeoff angle. Increasing the leg length beyond the optimum will result in less gain, and for that reason the curves do not extend beyond the optimum length. Note that the optimum length becomes greater as the desired takeoff angle decreases. Leg lengths over 6 λ are not recommended because the directive pattern becomes so sharp that the antenna performance is highly variable with small changes in the angle, both horizontal and vertical, at which an incoming wave reaches the antenna. Since these angles vary to some extent in ionospheric propagation, it does not pay to attempt to try for too great a degree of directivity.

Multiband Design

When a rhombic antenna is to be used over a considerable frequency range, a compromise must be made in the tilt angle. **Figure 13.26** gives the design dimensions of a suitable compromise for a rhombic that covers the 14 to 30 MHz range well. **Figure 13.27** shows the azimuth and elevation patterns for this antenna at 14 MHz, at a height of 70 feet over flat ground. The comparison antenna in this case is a 4-element Yagi on a 26-foot boom, also 70 feet above flat ground. The rhombic has about 2.2 dB more gain, but its azimuthal pattern is 17.2° wide at the 3 dB points, and only 26° at the –20 dB points! On the other hand, the Yagi has a 3-dB beamwidth of 63°, making it far easier to aim at a distant geographic location. Figure 13.27B shows the elevation-plane patterns for the same antennas above. As usual, the peak angle for either horizontally polarized antenna is determined mainly by the height above ground.

The peak gain of a terminated rhombic is less than that of an unterminated resonant rhombic. For the rhombic of Figure 13.26, the reduction in peak gain is about 1.5 dB. **Figure 13.28** compares the azimuthal patterns for this rhombic with and without an 800-Ω termination.

Figure 13.29 shows the azimuth and elevation patterns for the terminated rhombic of Figure 13.26 when it is operated at 28 MHz. The main lobe becomes very narrow, at 6.9° at the 3-dB points. However, this is partially compensated for by the appearance of two sidelobes each side of the main beam. These tend to spread out the main pattern some. Again, a 4-element Yagi at the same height is used for comparison.

Termination

Although the difference in the gain is relatively small with terminated or unterminated rhombics of comparable design, the terminated antenna has the advantage that over a wide frequency range it presents an essentially resistive and constant load to the transmitter. In a sense, the power

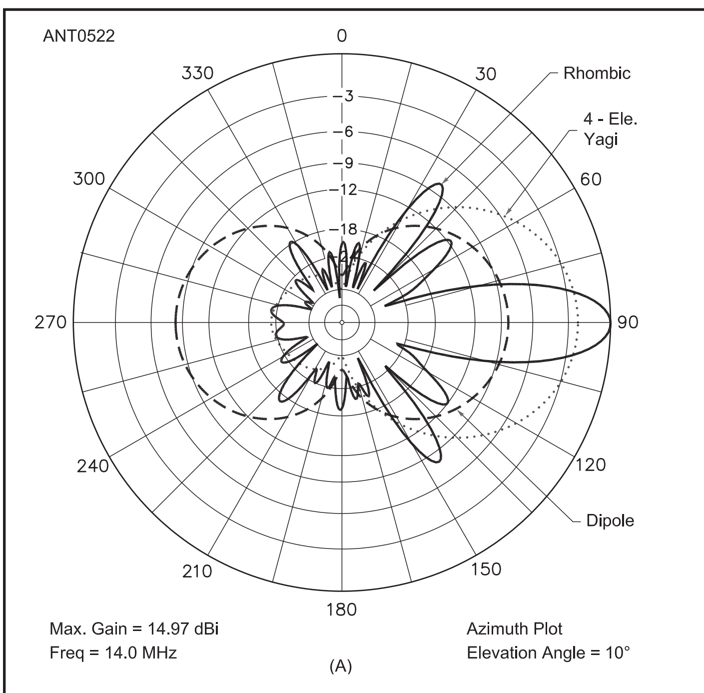


Figure 13.27 — At left, azimuthal pattern for 3-λ (at 14 MHz) terminated rhombic (solid line) shown in Figure 13.26, compared with 4-element 20-meter Yagi (dotted line) on a 26-foot boom and a 20-meter dipole (dashed line). All antennas are mounted 70 feet (1 λ) above flat ground. The rearward pattern of the terminated rhombic is good and the forward gain exceeds that of the Yagi, but the frontal lobe is very narrow. Above, elevation-plane pattern of terminated rhombic compared to that of a simple dipole at the same height.

dissipated in the terminating resistor can be considered power that would have been radiated in the other direction had the resistor not been there. Therefore, the fact that some of the power (about one-third) is used up in heating the resistor does not mean that much actual loss in the desired direction.

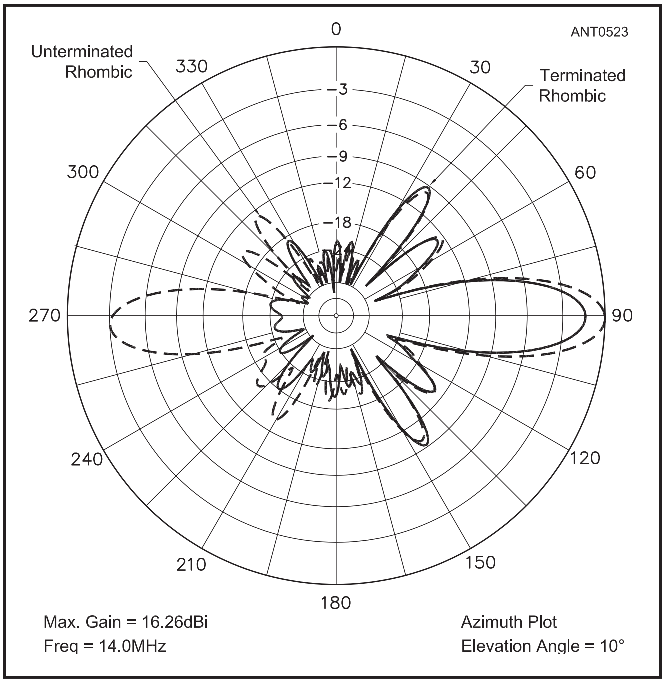


Figure 13.28 — Comparison of azimuthal patterns for terminated (solid line) and unterminated (dashed line) rhombic antennas, using same dimensions as Figure 13.26 at a frequency of 14 MHz. The gain tradeoff is about 1.5 dB in return for the superior rearward pattern of the terminated antenna.

The characteristic impedance of an ordinary rhombic antenna, looking into the input end, is in the order of 700 to 800 Ω when properly terminated in a resistance at the far end. The terminating resistance required to bring about the matching condition usually is slightly higher than the input impedance because of the loss of energy through radiation by the time the far end is reached. The correct value usually will be found to be of the order of 800 Ω, and should be determined experimentally if the flattest possible antenna is desired. However, for average work a noninductive resistance of 800 Ω can be used with the assurance that the operation will not be far from optimum.

The terminating resistor must be practically a pure resistance at the operating frequencies; that is, its inductance and capacitance should be negligible. Ordinary wire-wound resistors are not suitable because they have far too much inductance and distributed capacitance. Small carbon resistors have satisfactory electrical characteristics but will not dissipate more than a few watts and so cannot be used, except when the transmitter power does not exceed 10 or 20 watts or when the antenna is to be used for reception only. The special resistors designed either for use as dummy antennas or for terminating rhombic antennas should be used in other cases. To allow a factor of safety, the total rated power dissipation of the resistor or resistors should be equal to half the power output of the transmitter.

To reduce the effects of stray capacitance it is desirable to use several units, say three, in series even when one alone will safely dissipate the power. The two end units should be identical and each should have one fourth to one third the total resistance, with the center unit making up the difference. The units should be installed in a weatherproof housing at the end of the antenna to protect them and to permit mounting

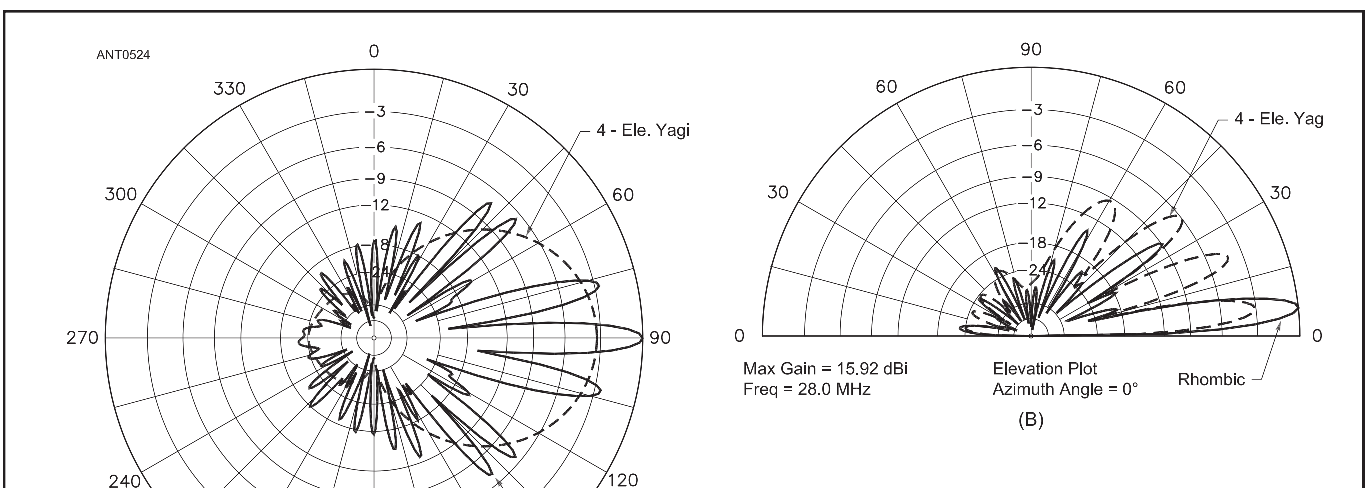


Figure 13.29 — At A, the azimuthal pattern for the same terminated antenna in Figure 13.26, but now at 28 MHz compared to a 4-element 10-meter Yagi. At B, the elevation-plane pattern comparison for these antennas.

without mechanical strain. The connecting leads should be short so that little extraneous inductance is introduced.

Alternatively, the terminating resistance may be placed at the end of an 800-Ω line connected to the end of the antenna. This will permit placing the resistors and their housing at a point convenient for adjustment rather than at the top of the pole. Resistance wire may be used for this line, so that a portion of the power will be dissipated before it reaches the resistive termination, thus permitting the use of lower wattage lumped resistors.

If the rhombic is to be used on a single-band, Hallas (see the Bibliography) presents an interesting method of using an antenna tuner and a more common 50-Ω dummy load to create a "tunable load" that can be adjusted for the best performance.

Multi-Wire Rhombics

The input impedance of a rhombic antenna constructed as in Figure 13.26 is not quite constant as the frequency is varied. This is because the varying separation between the wires causes the characteristic impedance of the antenna to vary along its length. The variation in Z_{ANT} can be minimized by a conductor arrangement that increases the capacitance per unit length in proportion to the separation between the wires.

The method of accomplishing this is shown in **Figure 13.30**. Three conductors are used, joined together at the ends but with increasing separation as the junction between legs is approached. For HF work the spacing between the wires at the center is 3 to 4 feet, which is similar to that used in commercial installations using legs several wavelengths long. Since all three wires should have the same length, the top and bottom wires should be slightly farther from the support than the middle wire. Using three wires in this way reduces the Z_{ANT} of the antenna to approximately 600 Ω, thus providing a better match for practical open-wire line, in addition to smoothing out the impedance variation over the frequency range.

A similar effect (although not quite as favorable) is obtained by using two wires instead of three. The 3-wire system has been found to increase the gain of the antenna by about 1 dB over that of a single-conductor version.

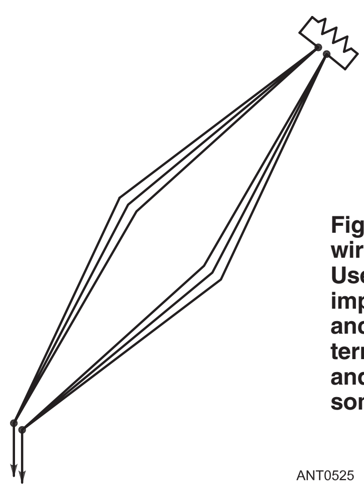


Figure 13.30 — Three-wire rhombic antenna. Use of multiple wires improves the impedance characteristic of a terminated rhombic and increases the gain somewhat.

Front-to-Back Ratio

It is theoretically possible to obtain an infinite front-to-back ratio with a terminated rhombic antenna, and in practice very large values can be had. However, when the antenna is terminated in its characteristic impedance, the infinite front-to-back ratio can be obtained only at frequencies for which the leg length is an odd multiple of a quarter wavelength. The front-to-back ratio is smallest at frequencies for which the leg length is a multiple of a half wavelength.

When the leg length is not an odd multiple of a quarter-wave at the frequency under consideration, the front-to-back ratio can be made very high by decreasing the value of terminating resistance slightly. This permits a small reflection from the far end of the antenna, which cancels out the residual response at the input end. With large antennas, the front-to-back ratio may be made very large over the whole frequency range by experimental adjustment of the terminating resistance. Modification of the terminating resistance can result in a splitting of the back null into two nulls, one on either side of a small lobe in the back direction. Changes in the value of terminating resistance thus permit steering the back null over a small horizontal range so that signals coming from a particular spot not exactly to the rear of the antenna may be minimized.

Methods of Feed

If the broad frequency characteristic of the terminated rhombic antenna is to be utilized fully, the feeder system must be similarly broadbanded. Open-wire transmission line of the same characteristic impedance as that shown at the antenna input terminals (approximately 700 to 800 Ω) may be used. Data for the construction of such lines is given in the chapter on **Transmission Lines**. While the usual matching stub can be used to provide an impedance transformation to more satisfactory line impedances, this limits the operation of the antenna to a comparatively narrow range of frequencies centering about that for which the stub is adjusted. Probably a more satisfactory arrangement would be to use a coaxial transmission line and a broadband transformer balun at the antenna feed point.

13.5 PROJECT: FOUR-WIRE STEERABLE V BEAM FOR 10 THROUGH 40 METERS

A simple arrangement of four wires can be used to work multiple bands and have antenna gain in different directions without using a rotator. A version of this antenna was described in *QST* (see Bibliography entry for Colvin) and is included in ARRL's *Wire Antenna Classics*. That version had wires 584 feet long. In this version, built by Sam Moore, NX5Z, each wire is only 106 feet long. Many DX stations have had great success with this type of antenna.

Antenna Characteristics

An unterminated V beam gain pattern is bidirectional with two main gain lobes 180° apart if the leg lengths are at least a wavelength long. In **Figure 13.31**, a long wire antenna at the left is shown to have a gain pattern of four major lobes. Another long wire antenna positioned 45° from the first is also shown. If these are combined to form a V, it has the gain pattern as shown to the right in Figure 13.31.

In this design, four 106 foot wires are spaced at 45°. The length of the wire is not as important as that they all be the same length. The author installed his V beam with the apex and relay control box at a height of 40 feet with the wire ends 10 feet off the ground in a sloping V configuration. This V beam's gain approximates that of a three element Yagi on 10, 12, 15 and 17 meters and is within a few dB on 20 meters. The antenna provides useful operation on 30 and 40 meters, with essentially an omnidirectional pattern on 40. The beam direction is controlled by simply switching two switches in the station.

This antenna may also be built with wire lengths as short as 60 feet to more easily fit on a city lot. There will be a small decrease in gain. The V beam gain increases with the length of the wires. The longer the wires, the greater the gain. As the wire lengthens, however, the beamwidth narrows. The gains and beamwidths of 106 and 60 foot versions are shown in **Table 13.1**, based on *EZNEC* analysis. (*EZNEC* modeling software is discussed in the **Antenna Modeling** chapter.) As a reference, the typical two element Yagi has 6 to 7 dBi gain while a three element Yagi can be expected to have a 7.5 to 8.1 dBi gain, depending on design, especially boom length.

The azimuth pattern looking down on a V beam is shown in **Figure 13.32**. If the height of the V beam is less than ½ wavelength, the gain pattern will distort and make the antenna more omnidirectional.

To reduce the gain lobe to the rear of the V beam you can terminate the wire ends with a resistor. An unterminated version has gain in both directions. If terminated, the antenna would need eight wires instead of four to have gain in all directions.

Since this antenna may be used for multiband operation, the gain waveform changes somewhat depending on the frequency of operation. The higher the frequency, the greater the gain, since the frequency to wire length ratio changes. For example, if your V beam is 1 wavelength long at 20 meters, it is 2 wavelengths long at 10 meters, thus causing greater gain and narrower beamwidth as shown in Table 13.1. While essentially bidirectional on the upper bands, there is a 1 to 2 dB front to back ratio, with the maximum signal to the open end of the V. The beamwidth shown in Table 13.1 is of the front beam, with the rear beam

Table 13.1
Gain and Beamwidth of the V Beam on Each Band

Frequency (MHz)	*Gain at 106' (dBi)*	*3 dB Beamwidth at 106' (°)*	*Gain at 60' (dBi)*	*3 dB Beamwidth at 60' (°)*
7.15	1.9*	Omnidirectional	2.4*	Omnidirectional
10.12	3.6	133	3.7*	Omnidirectional
14.15	6.7	71	4.1	137
18.11	8.5	42	4.1	136
21.2	9.1	33	6.0	63
24.93	9.7	28	6.1	61
28.3	10.7	23	7.3	40

*Essentially omnidirectional with maximum gain nearly perpendicular to the wire bisector.

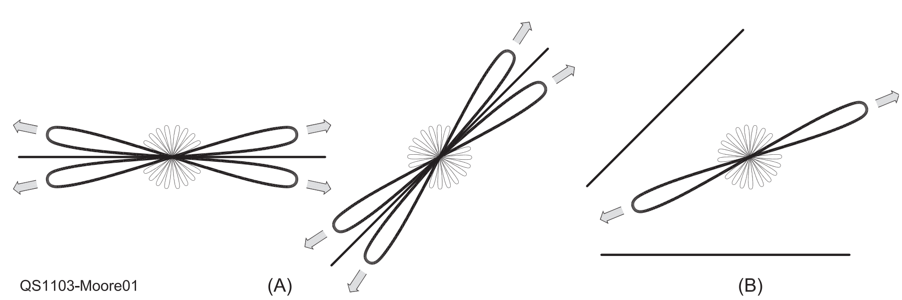


Figure 13.31 — The azimuth patterns of two long wire antennas are shown at (A). If the two are combined in phase to form a V, the resulting pattern is shown at (B).

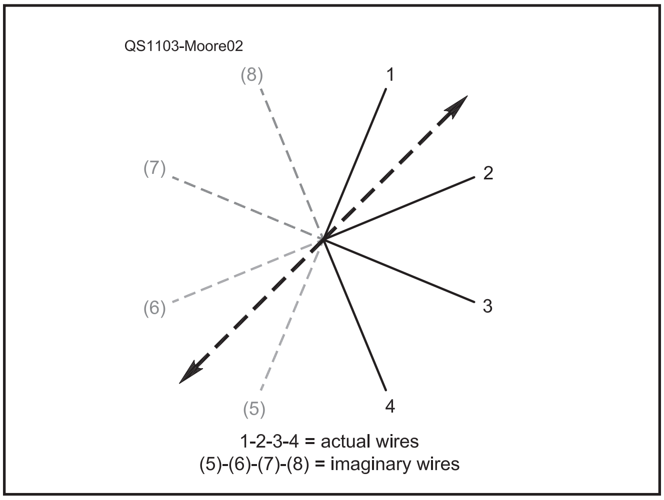


Figure 13.32 — The selectable azimuth looking down on the V beam. The arrow shows directions of maximum radiation with wires 1 and 2 connected.

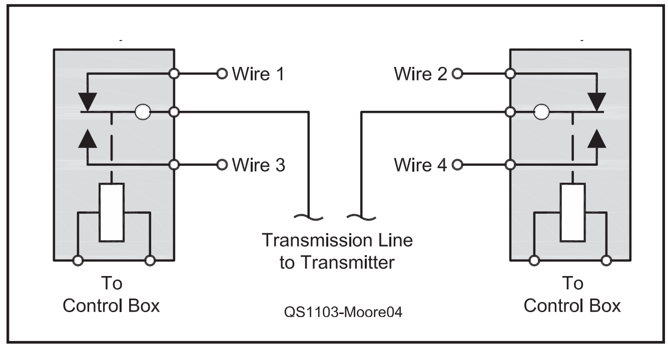


Figure 13.34 — Schematic diagram of the relay box used to remotely select the V beam wires.

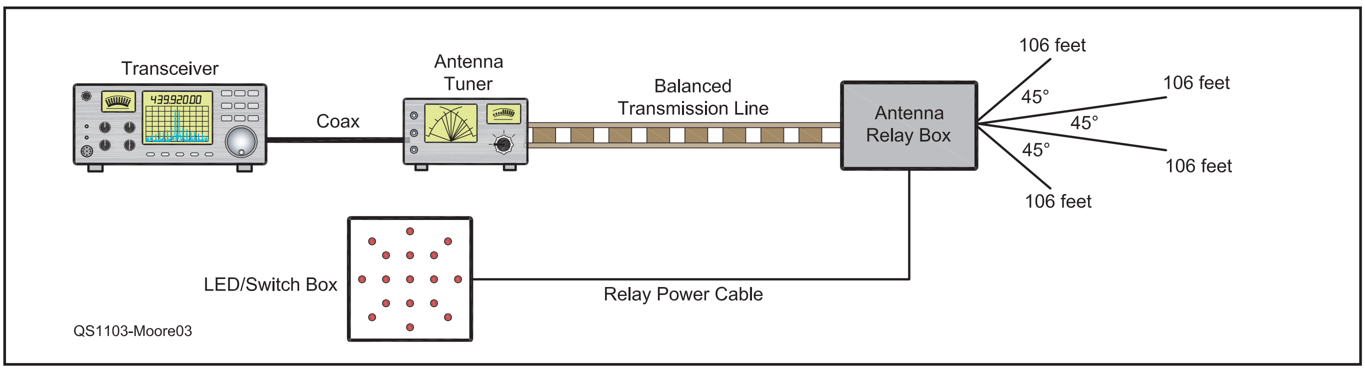


Figure 13.33 — The block diagram of the V beam system. The antenna tuner must be able to accept balanced transmission line and a built-in or external 4:1 balun is necessary.

generally somewhat narrower. A horizontal, rather than sloping, V beam will be more symmetrical.

The block diagram of the V beam system is shown in **Figure 13.33**. The antenna tuner must be able to accept balanced transmission line and a built in or external 4:1 balun is necessary. The author made a homebrew air core external 4:1 balun using 1 inch PVC pipe and used a small automatic antenna tuner.

Controls and Indicators

The LED switch box supplies power to the relays in the antenna relay box at the center of the V beam via a three wire cable such as three wire electrical zip cord. Smaller wires would work.

The relay box schematic is shown in **Figure 13.34**. Only two switches are needed to power relays 1 and 2. Relay 1 switches between wire 1 and 3 and relay 2 switches between wire 2 and 4. Note that wire 4 is used in combination with wire 1 instead of (imaginary) wire 5. This obtuse angle yields

Figure 13.35 — Relay box assembled in a power entry PVC cover.

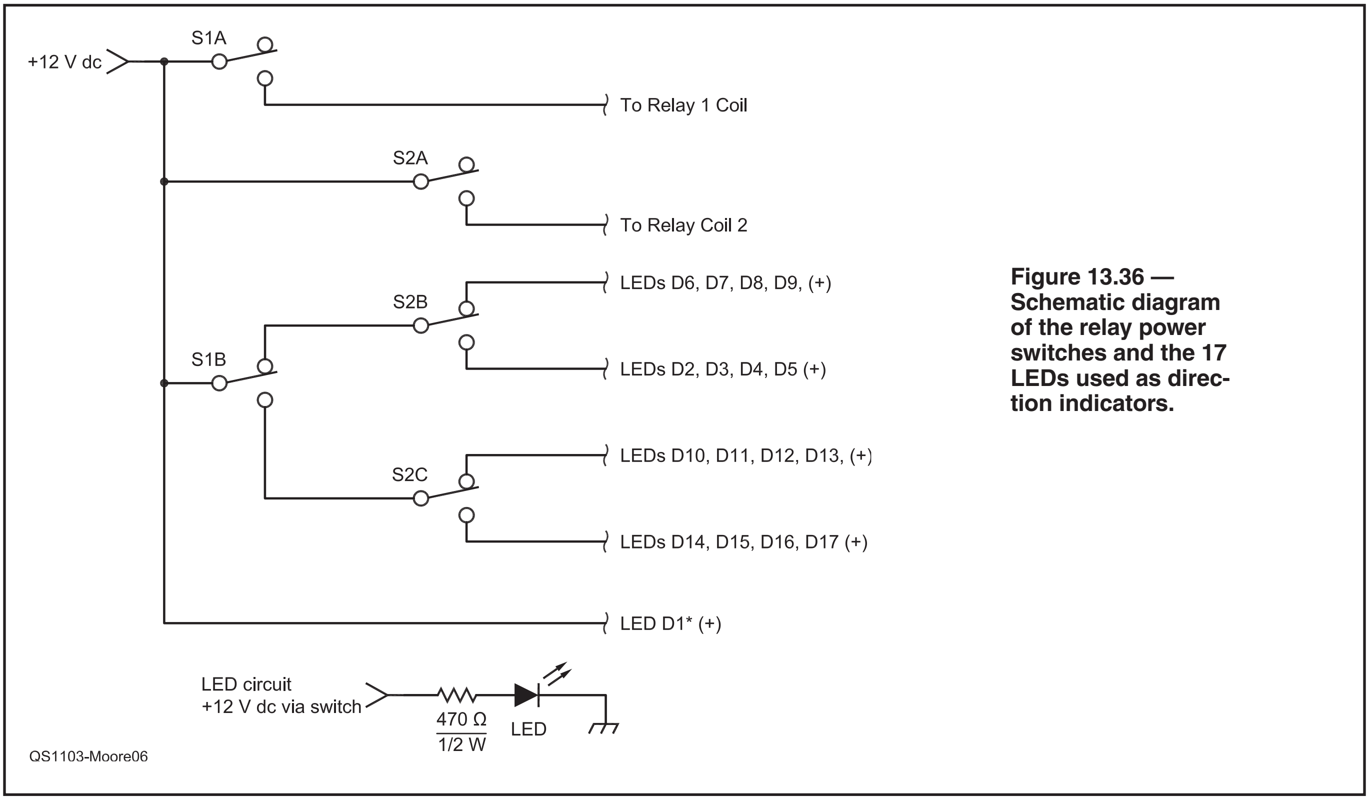


Figure 13.36 — Schematic diagram of the relay power switches and the 17 LEDs used as direction indicators.

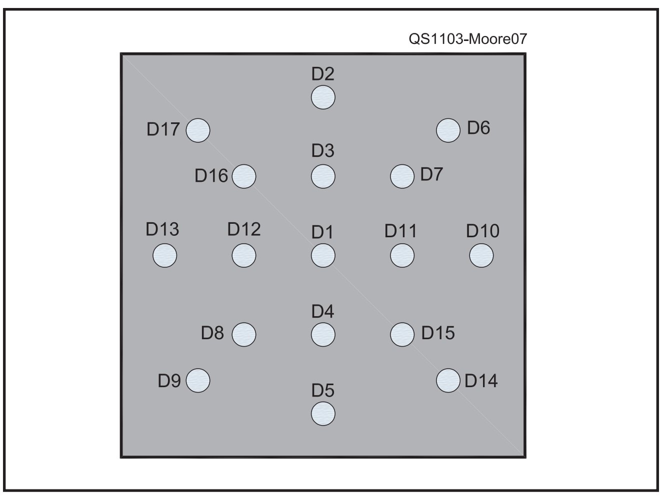


Figure 13.37 — Top view of the indicator panel showing LED placement.

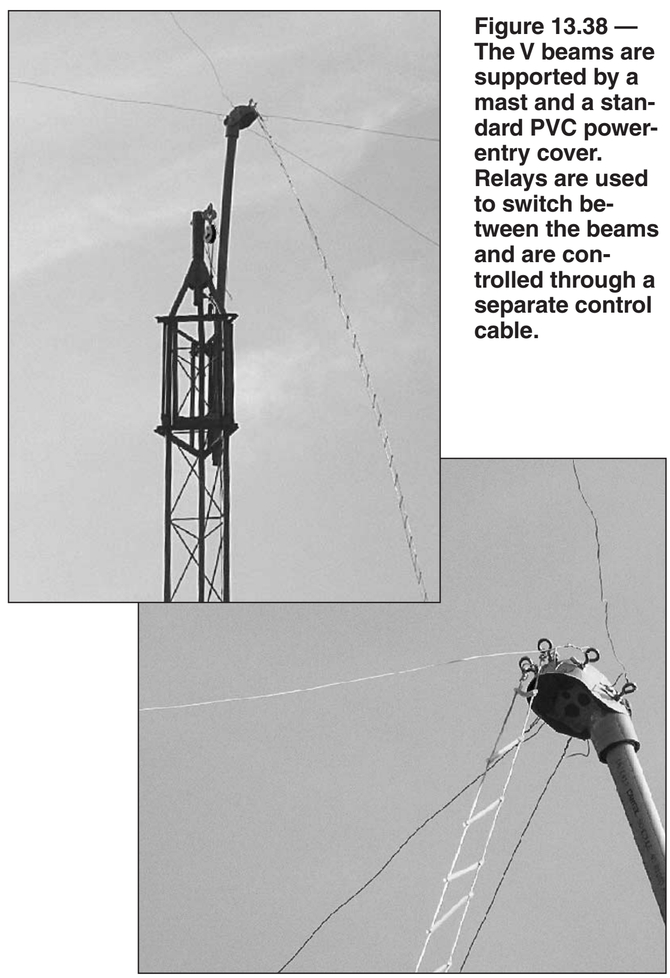


Figure 13.38 — The V beams are supported by a mast and a standard PVC power-entry cover. Relays are used to switch between the beams and are controlled through a separate control cable.

the about same gain and waveform as wire 4 to 5 would have offered, without having to string another wire. **Figure 13.35** shows an assembled relay box in a power entry PVC cover.

The schematic in **Figure 13.36** shows the relay power switches and the 17 LED connections. LED and relay common connections go to a 12 V return. A top view of the LEDs is shown in **Figure 13.37**. The LED switch box illuminated LEDs indicate the direction of greatest gain. Note LED 1 is always on, since it's used in all directions. The other 4 LEDs in a particular row, in a bingo board pattern, are connected and supplied with +12 V dc via switch 1 or 2, depending on wires chosen. Use a 3-pole switch for S2, or use two closely spaced DPDT switches and switch them at the same time.

The assembled control head is mounted as shown in **Figure 13.38**. Total cost is around $50, not counting the balun and balanced transmission line. For the four wires, the author used electric fence wire, which accepted solder surprisingly well. You can buy a ¼ mile roll of electric fence wire inexpensively at agricultural supply stores. You may also have a few necessary parts in your junk box.

13.6 BIBLIOGRAPHY

Source material and more extended discussion of topics covered in this chapter can be found in the references given below.

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