Large Loop Antennas

The delta-loop antenna is a superb example of a high-performance compromise antenna. The single-element loop antenna is almost exclusively used on the low bands, where it can produce low-angle radiation, requiring only a single quarter-wave high support. We will see that a vertically polarized loop is really an array of two phased verticals, and that the ground requirements are the same as for any other vertically polarized antenna.

This means that with low delta loops, the horizontal wire will couple heavily to the lossy ground and induce significant losses, unless we have improved the ground by putting a ground screen under the antenna. (See Chapter 9, Section 1.3.3 and Section 2.) I have seen it stated in various places that delta loops don't require a good ground system. This is as true as saying that verticals with a single elevated radial don't require a good ground system.

Loop antennas have been popular with 80-meter DXers for more than 30 years. Resonant loop antennas have a circumference of 1 λ. The exact shape of the loop is not particularly important. In free space, the loop with the highest gain, however, is the loop with the shape that encloses the largest area for a given circumference. This is a circular loop, which is difficult to construct. Second best is the square loop (quad), and in third place comes the equilateral triangle (delta) loop (Ref 677).

The maximum gain of a 1-λ loop over a λ/2 dipole in free space is approximately 1.35 dB. Delta loops are used extensively on the low bands at apex heights of λ/4 to 3λ/8 above ground. At such heights the vertically polarized loops far outperform dipoles or inverted-V dipoles for low-angle DXing, assuming good ground conductivity.

Loops are generally erected with the plane of the loop perpendicular to the ground. Whether or not the loop produces a vertically or a horizontally polarized signal (or a combination of both) depends only on how (or on which side) the loop is being fed.

Sometimes we hear about horizontal loops. These are antennas with the plane of the loop parallel to the ground. They produce horizontal radiation with takeoff angles determined, as usual, by the height of the horizontal loop over ground.

1. QUAD LOOPS

Belcher, WA4JVE, Casper, K4HKX, (Ref 1128), and

Dietrich, WAØRDX, (Ref 677), have published studies comparing the horizontally polarized vertical quad loop with a dipole. A horizontally polarized quad loop antenna (**Fig 10-1A**) can be seen as two short, end-loaded dipoles stacked λ/4 apart, with the top antenna at λ/4 and the bottom one just above
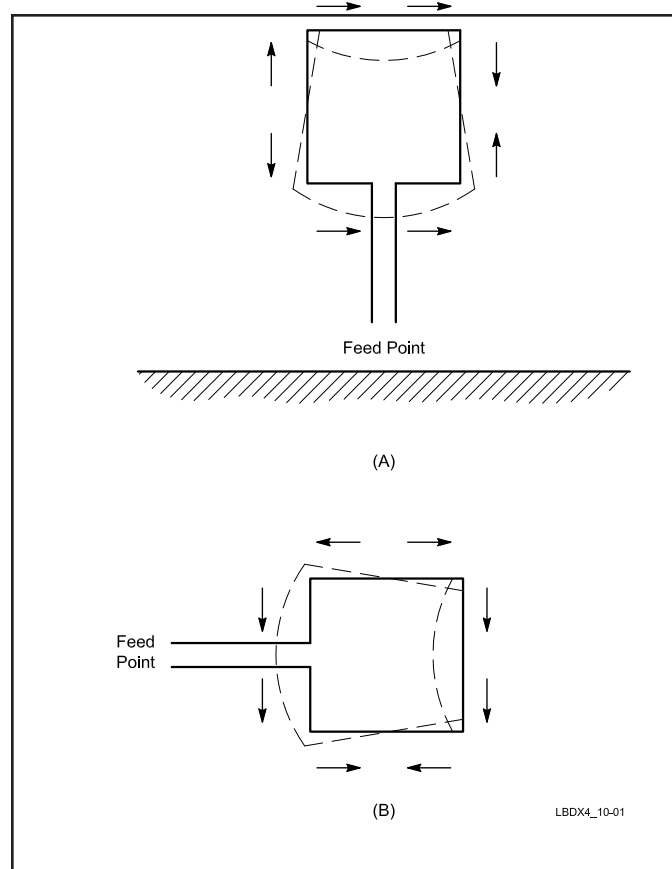
Fig 10-1—Quad loops with a 1-λ circumference. The current distribution is shown for (A) horizontal and (B) vertical polarization. Note how the opposing currents in the two legs result in cancellation of the radiation in the plane of those legs, while the currents in the other legs are in-phase and reinforce each other in the broadside direction (perpendicular to the plane of the antenna).
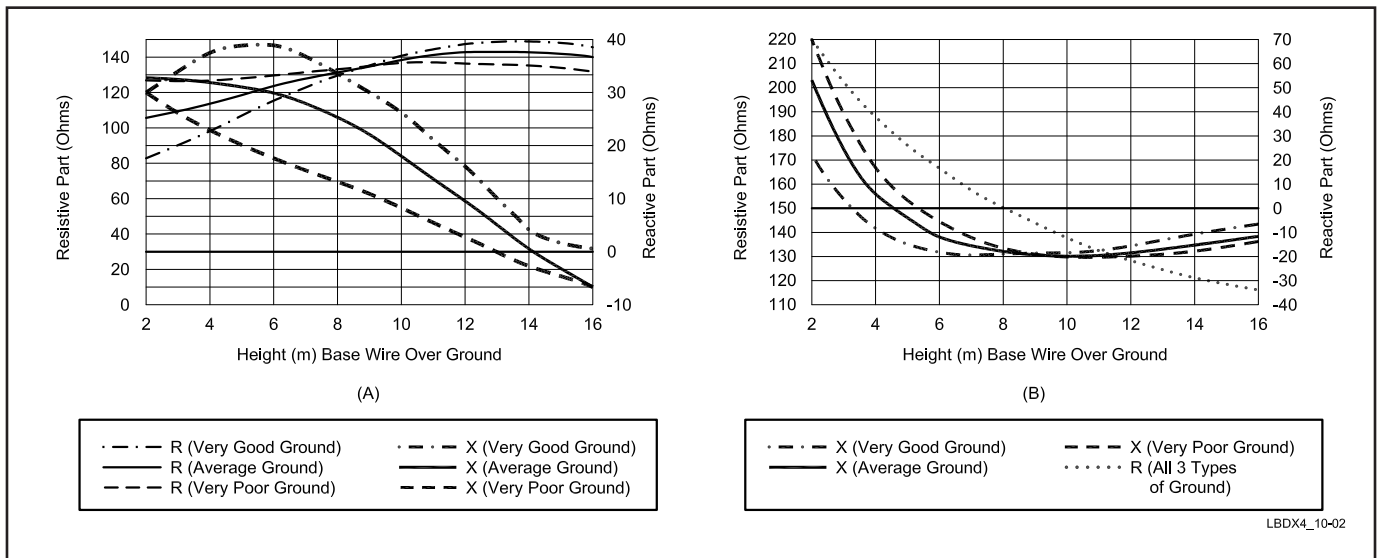
Fig 10-2—Radiation resistance and feed-point resistance for square loops at different heights above real ground. The loop was first dimensioned to be resonant in free space (reactance equal to zero), and those dimensions were used for calculating the impedance over ground. At A, for horizontal polarization, and at B, for vertical polarization. Analysis was with *NEC* at 3.75 MHz.

ground level. There is no broadside radiation from the vertical wires of the quad because of the current opposition in the vertical members. In a similar manner, the vertically polarized quad loop consists of two top-loaded, λ/4 vertical dipoles, spaced λ/4 apart. Fig 10-1B shows how the current distribution along the elements produces cancellation of radiation from certain parts of the antenna, while radiation from other parts (the horizontally or vertically stacked short dipoles) is reinforced.

The square quad can be fed for either horizontal or vertical polarization merely by placing the feed point at the center of a horizontal arm or at the center of a vertical arm. At the higher frequencies in the HF range, where the quads are typically half to several wavelengths high, quad loops are usually fed to produce horizontal polarization, although there is no specific reason for this except maybe from a mechanical standpoint. Polarization by itself is of little importance at HF (except on 160 meters! See Chapter 1), because it becomes random after ionospheric reflection.

1.1. Impedance

The radiation resistance of an equilateral quad loop in free space is approximately 120 Ω. The radiation resistance for a quad loop as a function of its height above ground is given in **Fig 10-2**. The impedance data were obtained by modeling an equilateral quad loop over three types of ground (very good, average and very poor ground) using *NEC*. *MININEC* cannot be used for calculating loop impedances at low heights (see Section 2.9).

The reactance data can assist you in evaluating the influence of the antenna height on the resonant frequency. The loop antenna was first modeled in free space to be resonant at 3.75 MHz and the reactance data was obtained with those free-space resonant-loop dimensions.

For the vertically polarized quad loop, the resistive part of the impedance changes very little with the type of ground under the antenna. The feed-point reactance is influenced by the ground quality, especially at lower heights. For the hori-

zontally polarized loop, the radiation resistance is noticeably influenced by the ground quality, especially at low heights. The same is true for the reactance.

1.2. Square Loop Patterns

1.2.1. Vertical polarization

The vertically polarized quad loop, Fig 10-1B, can be considered as two shortened top-loaded vertical dipoles, spaced λ/4 apart. Broadside radiation from the horizontal elements of the quad is canceled, because of the opposition of currents in the vertical legs. The wave angle in the broadside direction will be essentially the same as for either of the vertical members. The resulting radiation angle will depend on the quality of the ground up to several wavelengths away from the antenna, as is the case with all vertically polarized antennas.

The quality of the reflecting ground will also influence the gain of the vertically polarized loop to a great extent. The quality of the ground is as important as it is for any other vertical antenna, meaning that vertically polarized loops close to the ground will not work well over poor soil.

Fig 10-3 shows both the azimuth and elevation radiation patterns of a vertically polarized quad loop with a top height of 0.3 λ (bottom wire at approximately 0.04 λ). This is a very realistic situation, especially on 80 meters. The loop radiates an excellent low-angle wave (lobe peak at approximately 21°) when operated over average ground. Over poorer ground, the wave angle would be closer to 30°. The horizontal directivity, Fig 10-3C, is rather poor, and amounts to approximately 3.3 dB of side rejection at any wave angle.
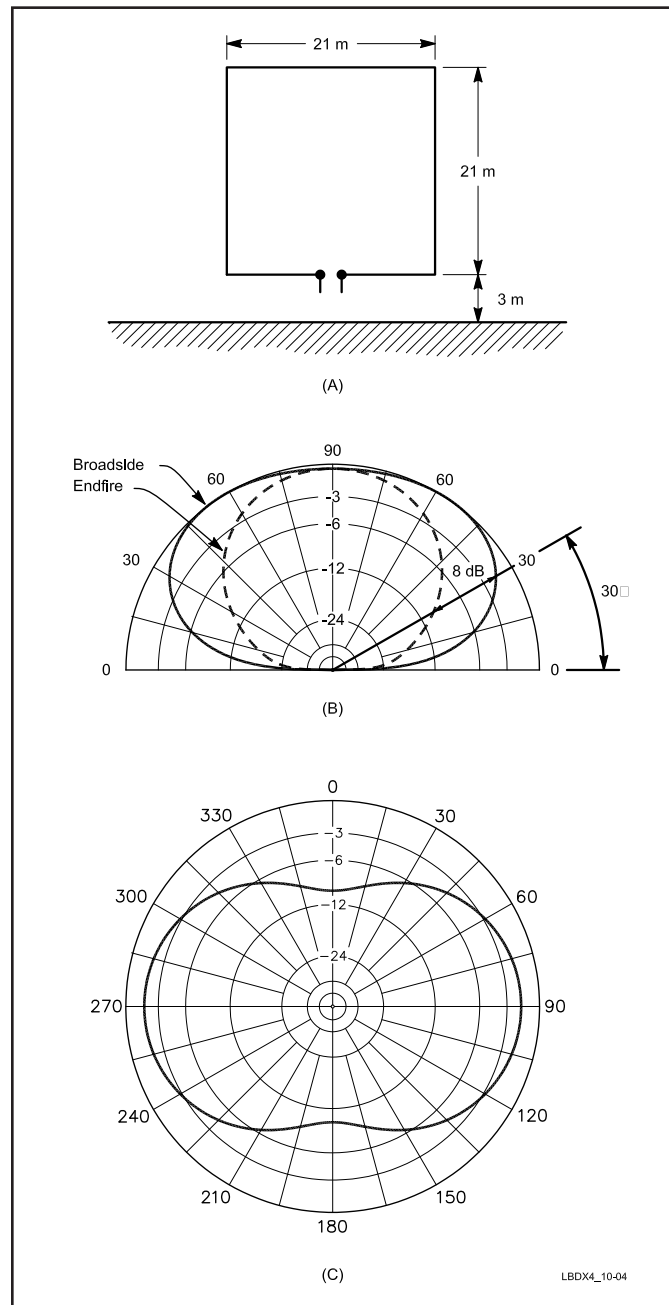
1.2.2. Horizontal polarization

A horizontally polarized quad-loop antenna (two stacked short dipoles) produces a wave angle that is dependent on the height of the loop. The low horizontally polarized quad (top at 0.3 λ) radiates most of its energy right at or near zenith angle (straight up).

Fig 10-4 shows directivity patterns for a horizontally
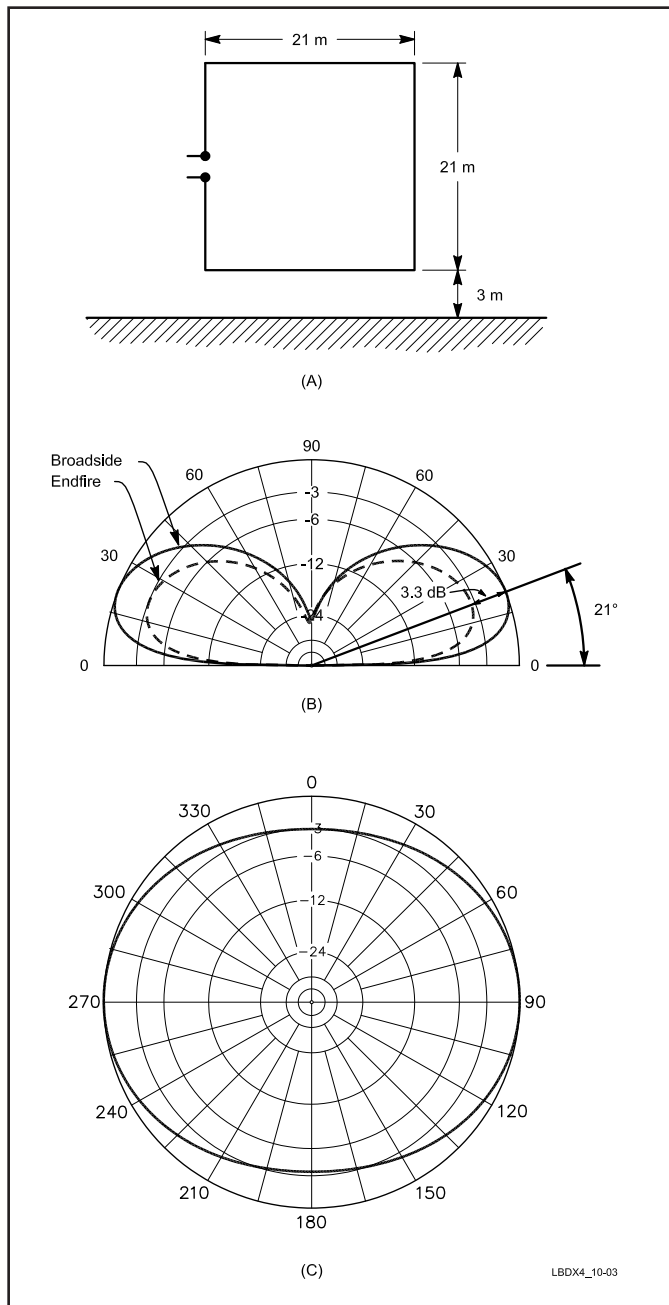
Fig 10-3—Shown at A is a square loop, with its eleva-tion-plane pattern at B and azimuth pattern at C. The patterns are generated for good ground. The bottom wire is 0.0375 λ above ground (3 meters or 10 feet on 80 meters). At C, the pattern is for a wave angle of 21°.

Fig 10-4—Azimuth and elevation patterns of the horizontally polarized quad loop at low height (bottom wire 0.0375 λ above ground). At an elevation angle of 30°, the loop has a front-to-side ratio of approximately 8 dB.

polarized loop. The horizontal pattern, Fig 10-4C, is plotted for a takeoff angle of 30°. At low wave angles (20° to 45°), the horizontally polarized loop shows more front-to-side ratio (5 to 10 dB) than the vertically polarized rectangular loop.

1.2.3. Vertical versus horizontal polarization

Vertically polarized loops should be used only where very good ground conductivity is available. From **Fig 10-5A** we see that the gain of the vertically polarized quad loop, as well as the wave angle, does not change very much as a function of the antenna height. This makes sense, since the

vertically polarized loop is in the first place two phased verticals, each with its own radial. However, the gain is drastically influenced by the quality of the ground. At low heights, the gain difference between very poor ground and very good ground is a solid 5 dB! The wave angle for the vertically polarized quad loop at a low height (bottom wire at 0.03 λ) varies from 25° over very poor ground to 17° over very good ground.

I have frequently read in Internet messages that a delta loop has certain advantages over a vertical antenna (or arrays of vertical antennas) since the loop antenna does not require
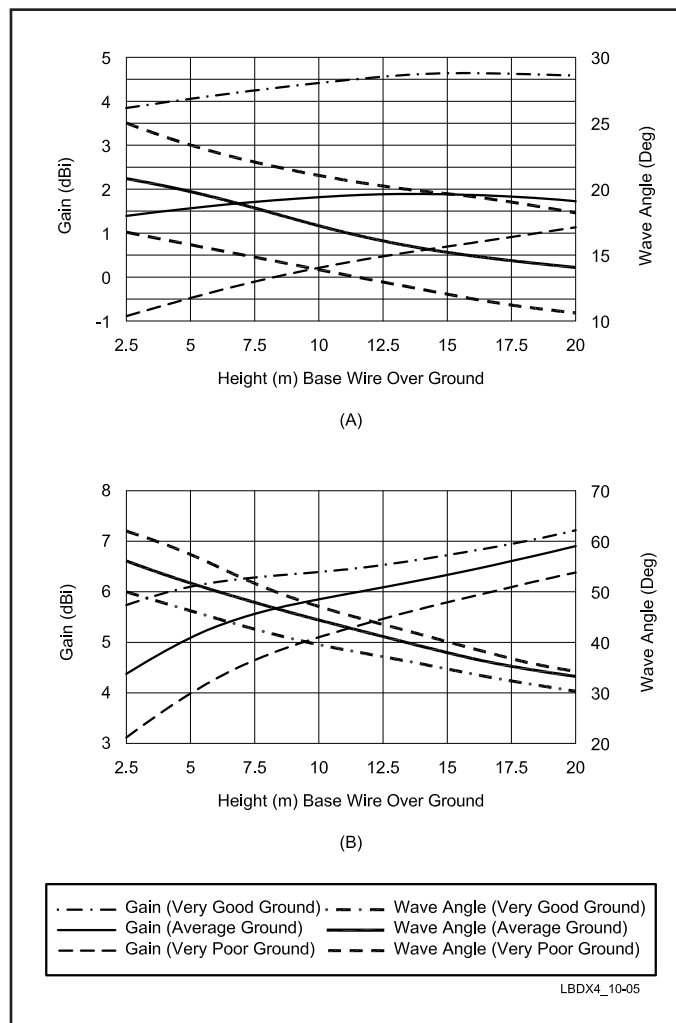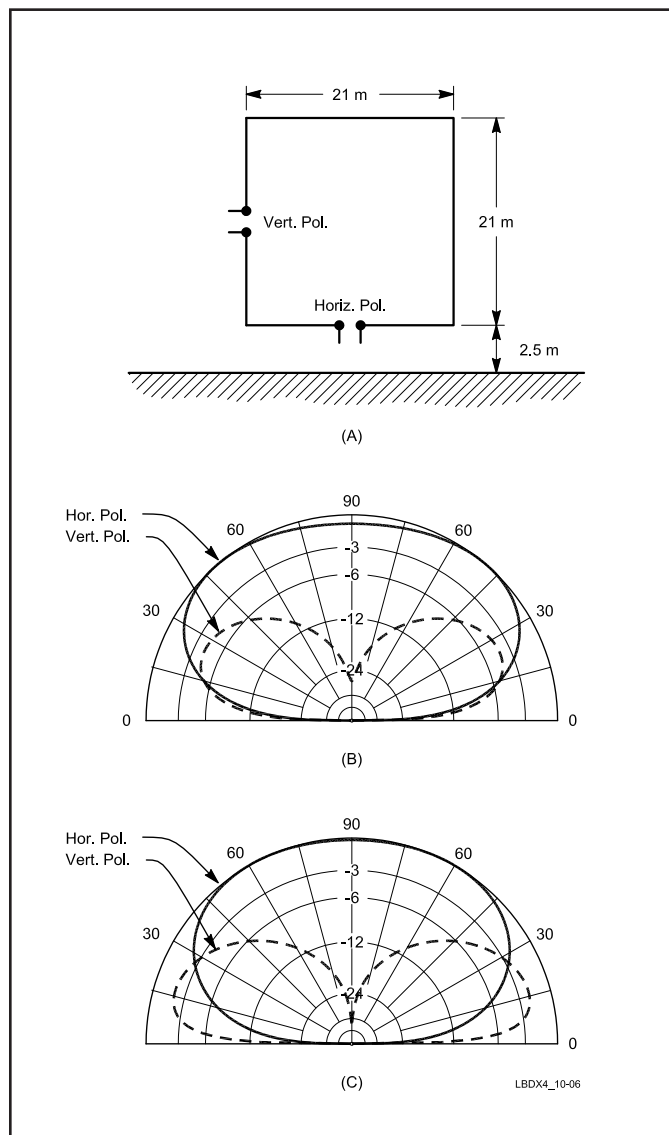
Fig 10-5—Radiation angle and gain of the horizontally and the vertically polarized square loops at different heights over good ground. At A, for vertical polarization, and at B, for horizontal polarization. Note that the gain of the vertically polarized loop never exceeds 4.6 dBi, but its wave angle is low for any height (14 to 20°). The horizontally polarized loop can exhibit a much higher gain provided the loop is very high. Modeling was done over average ground for a frequency of 3.75 MHz, using *NEC*.

Fig 10-6—Superimposed (same dB scale) patterns for horizontally and vertically polarized square quad loops (shown at A) over very poor ground (B) and very good ground (C). In the vertical polarization mode the ground quality is of utmost importance, as it is with all verticals. See also Fig 10-14.

any radials. This statement is really quite misleading—It is like saying that a vertical with elevated radials does not require any radials. Indeed, in a delta loop (and a quad loop), the "element" that takes care of the return current is part of the antenna itself just like with a dipole!

With a horizontally polarized quad loop the wave angle is very dependent on the antenna height, but not so much by the quality of the ground. At very low heights, the main wave angle varies between 50° and 60° (but is rather constant all the way up to 90°), but these are rather useless radiation angles for DX work.

As far as gain is concerned, there is a 2.5-dB gain difference between very good and very poor ground, which is only half the difference we found with the vertically polarized loop. Comparing the gain to the gain of the vertically polarized loop, we see that at very low antenna heights the gain is about 3-dB

better than for the vertically polarized loop. But this gain exists at a high wave angle (50º to 90º), while the vertically polarized loop at very low heights radiates at 17º to 25º.

Fig 10-6 shows the vertical-plane radiation patterns for both types of quad loops over very poor ground and over very good ground on the same dB scale. For more details see Section 2.3.

1.3. A Rectangular Quad Loop

A rectangular quad loop, with unequal side dimensions, can be used with very good results on the low bands. An impressive signal used to be generated by 5NØMVE from Nigeria with such a loop antenna. The single quad-loop element is strung between two 30-meter high coconut trees, some 57 meters apart in the bush of Nigeria. 5NØMVE fed the loop in the center of one of the vertical members. He first tried to

feed it for horizontal polarization but he says it did not work well. The vertical and the horizontal radiation patterns for this quad loop over good ground are shown in **Fig 10-7**. The horizontal directivity is approximately 6 dB (front-to-side ratio).

Even in free space, the impedance of the two varieties of this rectangular loop is not the same. When fed in the center of a short (27-meter) side, the radiation resistance at resonance is 44 Ω. When fed in the center of one of the long (57-meter) sides, the resistance is 215 Ω. Over real ground the feed-point impedance is different in both configurations as well; depending on the quality of the ground, the impedance varies between 40 and 90 Ω.

1.4. Loop Dimensions

The total length for a resonant loop is approximately 5 to 6% longer than the free-space wavelength.

1.5. Feeding the Quad Loop

The quad loop feed point is symmetrical, whether you feed the quad in the middle of the vertical or the horizontal wire. A balun should be used. Baluns are described in Chapter 6 on matching and feed lines.

Alternatively, you could use open-wire feeders (for example, 450-Ω line). The open-wire-feeder alternative has the advantage of being a lightweight solution. With a tuner you will be able to cover a wide frequency spectrum with no compromises.
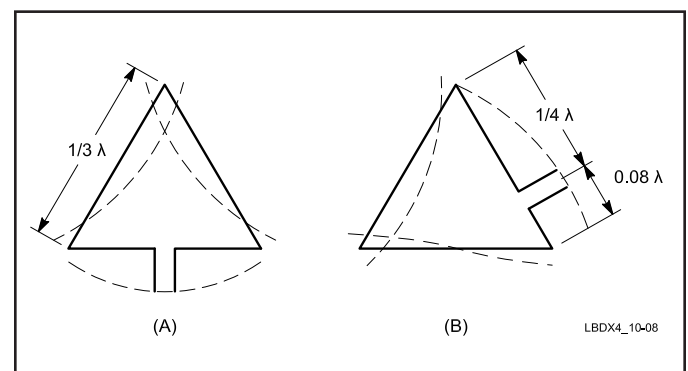
2. DELTA LOOPS

Just as the inverted-V dipole has been described as the poor man's dipole, the delta loop can be called the poor man's quad loop. Because of its shape, the delta loop with the apex on top is a very popular antenna for the low bands; it needs only one support.

In free space the equilateral triangle produces the highest gain and the highest radiation resistance for a three-sided loop configuration. As we deviate from an equilateral triangle toward a triangle with a long baseline, the effective gain and the radiation resistance of the loop will decrease for a bottom-corner-fed delta loop. In the extreme case (where the height of the triangle is reduced to zero), the loop has become a half-wavelength-long transmission line that is shorted at the end, which shows a zero-Ω input impedance (radiation resistance), and thus zero radiation (well-balanced open-wire line does not radiate).

Just as with the quad loop, we can switch from horizontal to vertical polarization by changing the position of the feed point on the loop. For horizontal polarization the loop is fed either at the center of the baseline or at the top of the loop. For vertical polarization the loop should be fed on one of the sloping sides, at $\lambda/4$ from the apex of the delta. **Fig 10-8** shows the current distribution in both cases.

(A)

(B)

(C)   LBDX4_10-07
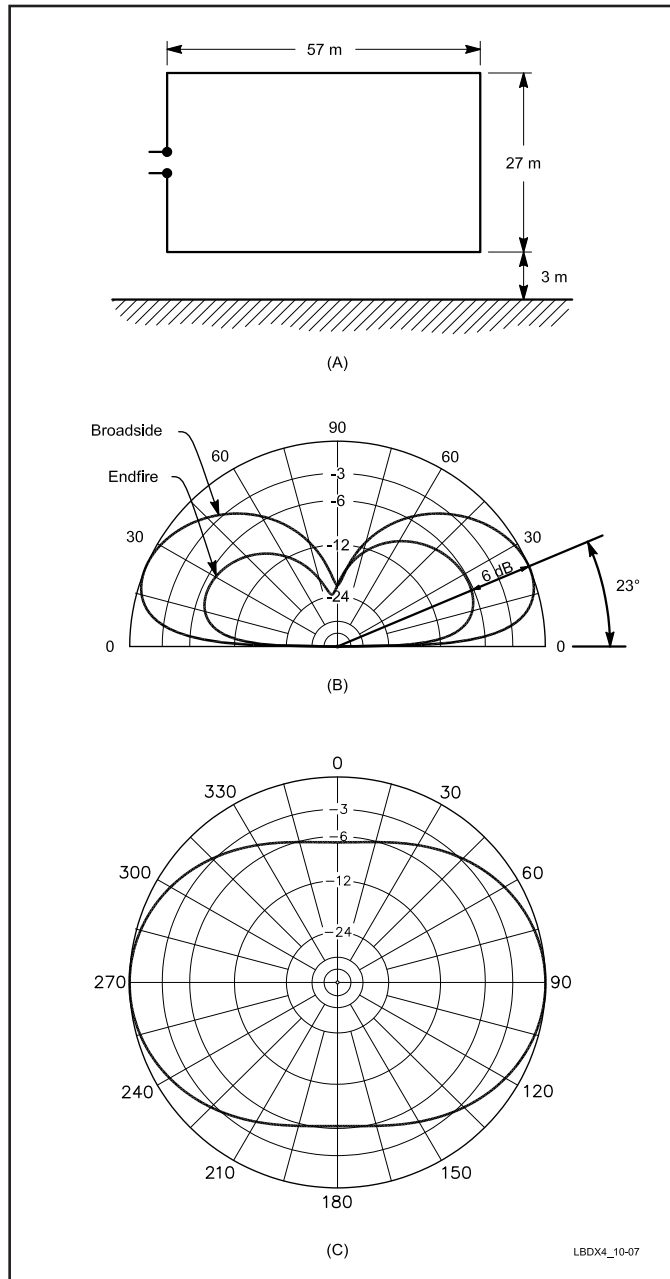
Fig 10-7—At A, a rectangular loop with its baseline approximately twice as long as the vertical height. At B and C, the vertical and horizontal radiation patters, generated over good ground. The loop was dimensioned to be resonant at 1.83 MHz. The azimuth pattern at C is taken at a 23° elevation angle.

(A)   (B)   LBDX4_10-08

Fig 10-8—Current distribution for equilateral delta loops fed for (A) horizontal and (B) vertical polarization.

2.1. Vertical Polarization

2.1.1. How it works

Refer to **Fig 10-9**. In the vertical-polarization mode the delta loop can be seen as two sloping quarter-wave verticals (their apexes touch at the top of the support), while the baseline (and the part of the sloper under the feed point) takes care of feeding the "other" sloper with the correct phase. The top connection of the sloping verticals can be left open without changing anything about the operation of the delta loop. The same is true for the baseline, where the middle of the baseline could be opened without changing anything. These two points are the high-impedance points of the antenna. Either the apex or the center of the baseline must be shorted, however, in order to provide feed voltage to the other half of the antenna. Normally, of course, we use a fully closed loop in the standard delta loop, although for single-band operation this is not strictly necessary.

Assume we construct the antenna with the center of the horizontal bottom wire open. Now we can see the two half baselines as two $\lambda/4$ radials, one of which provides the necessary low-impedance point for connecting the shield of the coax. The other radial is connected to the bottom of the second sloping vertical, which is the other sloping wire of the delta loop.

This is similar to the situation encountered with a $\lambda/4$ vertical using a single elevated radial (see Chapter 9 on vertical antennas). The current distribution in the two quarter-wave radials is such that all radiation from these radials is effectively canceled. The same situation exists with the voltage-fed T antenna, where we use a half-wave flat top (equals two $\lambda/4$ radials) to provide the necessary low-impedance point to raise the current maximum to the top of the T antenna.

The vertically polarized delta loop is really an array of two $\lambda/4$ verticals, with the high-current points spaced 0.25 λ to 0.3 λ, and operating in phase. The fact that the tops of the verticals are close together does not influence the performance to a large degree. The reason is that the current near the apex of the delta is at a minimum (it is current that takes care of radiation!).

Considering a pair of phased verticals, we know from the study on verticals that the quality of the ground will be very important as to the efficient operation of the antenna:

This does not mean that the delta loop requires radials. It has two elevated radials that are an integral part of the loop and take care of the return currents. The presence of the (lossy) ground under the antenna is responsible for near-field losses, unless we can shield it from the antenna by using a ground screen or a radial system, which should not be connected to the antenna.

As with all vertically polarized antennas the quality of the ground within a radius of several wavelengths will determine the low-angle radiation of the loop antenna.

2.1.2. Radiation patterns

2.1.2.1. The equilateral triangle

Fig 10-10 shows the configuration as well as both the broadside and the end-fire vertical radiation patterns of the vertically polarized equilateral-triangle delta loop antenna. The model was constructed for a frequency of 3.75 MHz. The baseline is 2.5 meters above ground, which puts the apex at 26.83 meters. The model was made over good ground. The delta loop shows nearly 3 dB front-to-side ratio at the main wave angle of 22°. With average ground the gain is 1.3 dBi.

2.1.2.2. The compressed delta loop

Fig 10-11 shows an 80-meter delta loop with the apex at 24 meters and the baseline at 3 meters. This delta loop has a long baseline of 30.4 meters. The feed point is again located $\lambda/4$ from the apex.

The front-to-side ratio is 3.8 dB. The gain with average ground is 1.6 dBi. In free space the equilateral triangle gives a higher gain than the "flat" delta. Over real ground and in the vertically polarized mode, the gain of the flat delta loop is 0.3 dB better than the equilateral delta, however. This must be explained by the fact that the longer baseline yields a wider separation of the two "sloping" verticals, yielding a slightly higher gain.

For a 100-kHz bandwidth (on 80 meters) the SWR rises to 1.4:1 at the edges. The 2:1-SWR bandwidth is approximately 175 kHz.

Bill, W4ZV, used what he calls a "squashed" delta loop very successfully on 160 meters. The apex is 36-meters high and Bill claims that this configuration actually has improved gain over the equilateral delta loop, which can indeed be verified by accurate modeling. The antenna was also fed a $\lambda/4$ from the apex, using a $\lambda/4$ 75-Ω matching stub. Bill says that this loop can actually be installed on a 27-meter tower by pulling the base away from the tower. By pulling the base away about 8 meters from a tower, you can actually use a full-wave delta on a 24-meter high tower, with very little trade-off.

2.1.2.3. The bottom-corner-fed delta loop

Fig 10-12 shows the layout of the delta loop being fed at one of the two bottom corners. The antenna has the same
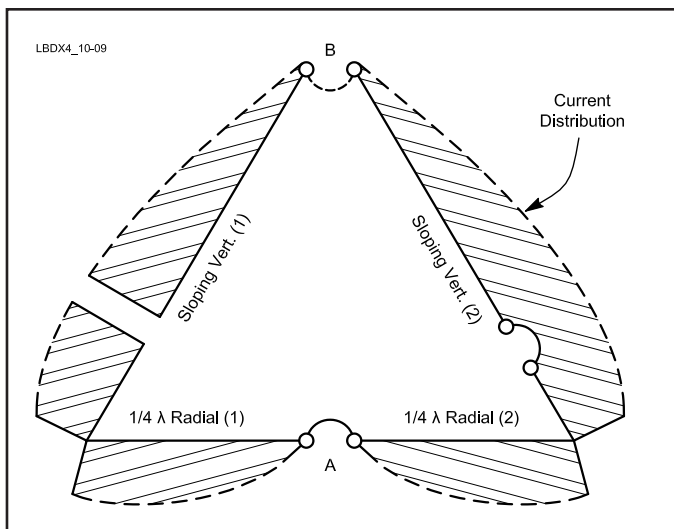
Fig 10-9—The delta loop can be seen as two $\lambda/4$ sloping verticals, each using one radial. Because of the current distribution in the radials, the radiation from the radials is effectively canceled.

apex and baseline height as the loop described in Section 2.1.2.2. Because of the "incorrect" location of the feed point, cancellation of radiation from the base wire (the two "radials") is not 100% effective, resulting in a significant horizontally polarized radiation component. The total field has a very uniform gain coverage (within 1 dB) from 25º to 90º. This may be a disadvantage for the rejection of high-angle signals when operating DX at low wave angles.

Due to the incorrect feed-point location, the end-fire radiation (radiation in line with the loop) has become asym-metrical. The horizontal radiation pattern shown in Fig 10-12D is for a wave angle of 29º. Note the deep side null (nearly 12 dB) at that wave angle. The loop actually radiates its maximum signal about 18º off the broadside direction.

All this is to explain that this feed-point configuration (in the corner of the compressed loop) is to be avoided, as it really deteriorates the performance of the antenna.
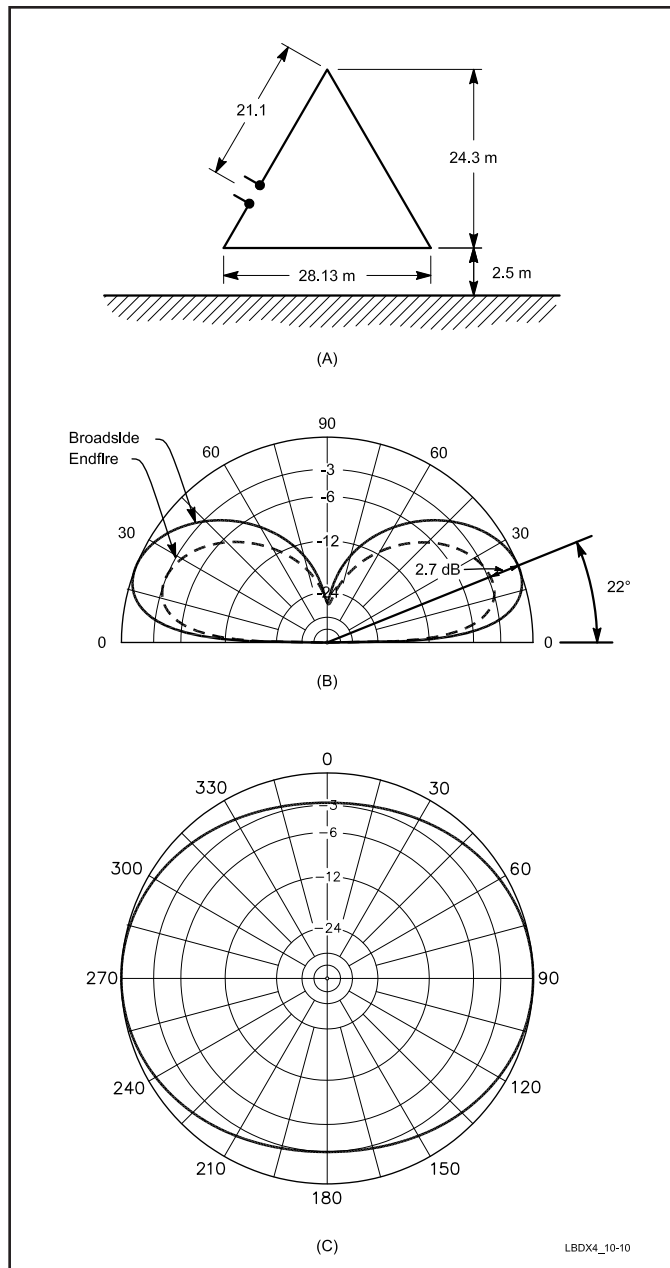
Fig 10-10—Configuration and radiation patterns for a vertically polarized equilateral delta loop antenna. The model was calculated over good ground, for a frequency of 3.8 MHz. The elevation angle for the azimuth pattern at C is 22°.
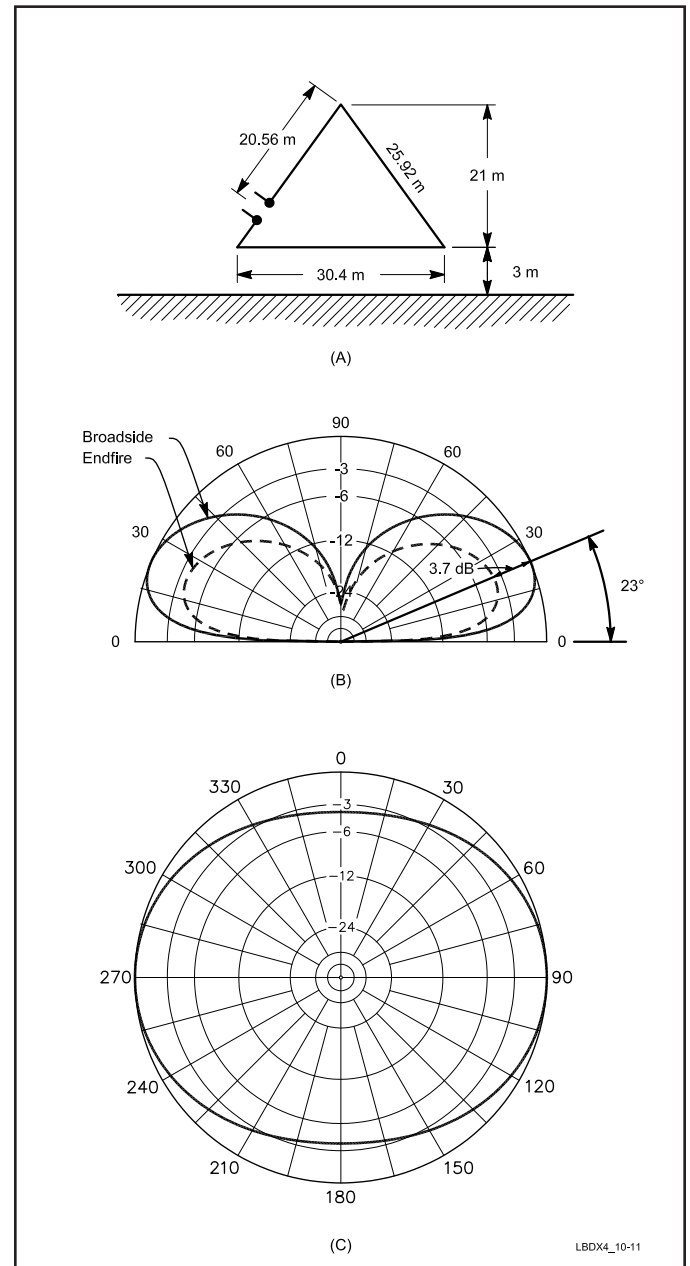
Fig 10-11—Configuration and radiation patterns for the "compressed" delta loop, which has a baseline slightly longer than the sloping wires. The model was dimensioned for 3.8 MHz to have an apex height of 24 meters and a bottom wire height of 3 meters. Calculations are done over good ground at a frequency of 3.8 MHz. The azimuth pattern at C is for an elevation angle of 23°. Note that the correct feed point remains at λ/4 from the apex of the loop.

(A)

(B)

(C)

(D)

LBDX4_10-12
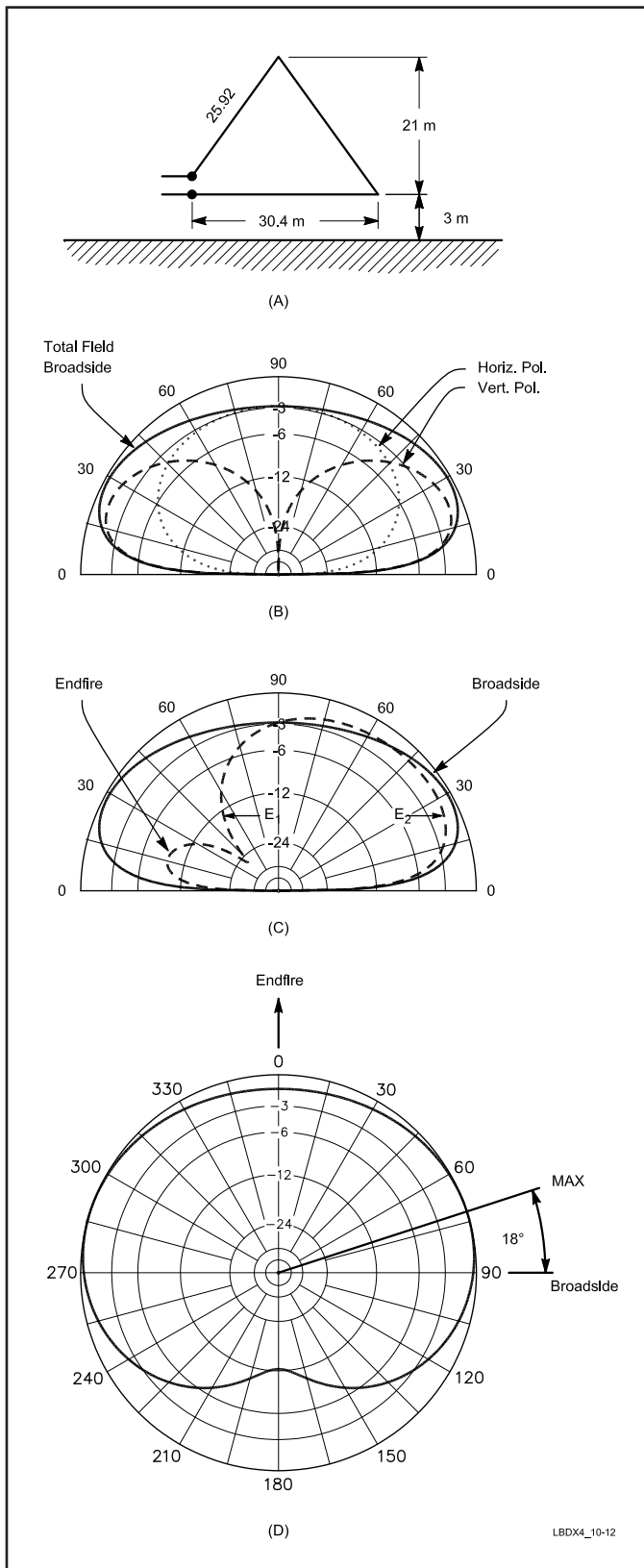
Fig 10-12—Configuration and radiation patterns for the compressed delta loop of Fig 10-11 when fed in one of the bottom corners at a frequency of 3.75 MHz. Improper cancellation of radiation from the horizontal wire produces a strong high-angle horizontally polarized component. The delta loop now also shows a strange horizontal directivity pattern (at D), the shape of which is very sensitive to slight frequency deviations. This pattern is for an elevation angle of 29°.
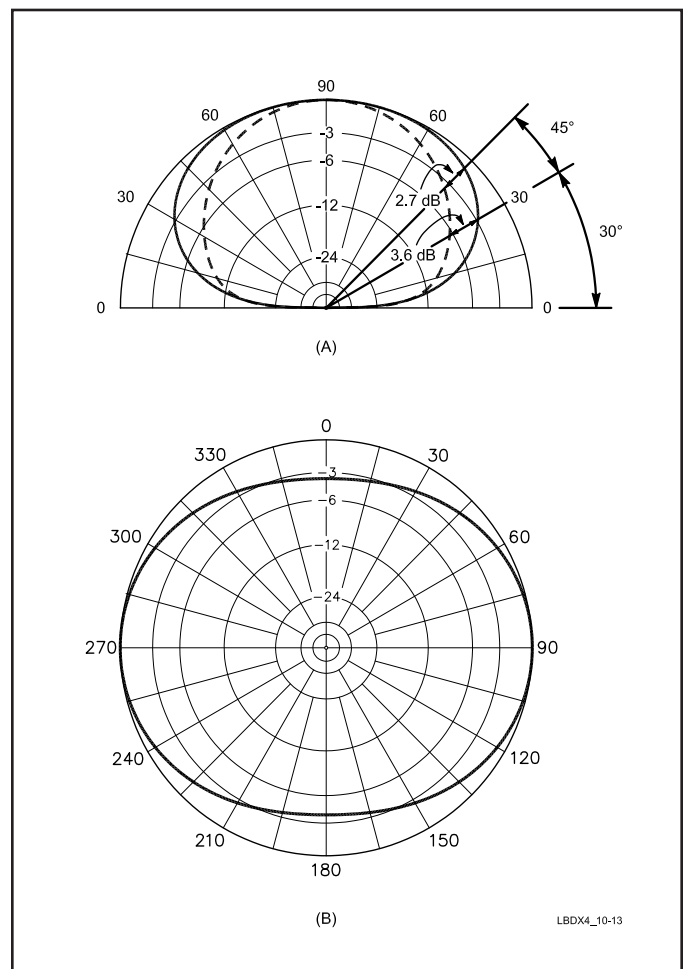
2.2. Horizontal Polarization

2.2.1. How it works

In the horizontal polarization mode, the delta loop can be seen as an inverted-V dipole on top of a very low dipole with its ends bent upward to connect to the tips of the inverted V. The loop will act as any horizontally polarized antenna over real ground; its wave angle will depend on the height of the antenna over the ground.

2.2.2. Radiation patterns

Fig 10-13 shows the vertical and the horizontal radiation patterns for an equilateral-triangle delta loop, fed at the center of the bottom wire. As anticipated, the radiation is maximum at zenith. The front-to-side ratio is around 3 dB for a 15 to 45° wave angle. Over average ground the gain is 2.5 dBi.

Looking at the pattern shape, one would be tempted to say that this antenna is no good for DX. So far we have only spoken about relative patterns. What about real gain figures from the vertically and the horizontally polarized delta loops?

(A)

(B)

LBDX4_10-13

Fig 10-13—Vertical and horizontal radiation patterns for an 80-meter equilateral delta loop fed for horizontal polarization, with the bottom wire at 3 meters. The radiation is essentially at very high angles, comparable to what can be obtained from a dipole or inverted-V dipole at the same (apex) height.

2.3. Vertical Versus Horizontal Polarization

Fig 10-14 shows the superimposed elevation patterns for vertically and horizontally polarized low-height equilateral-triangle delta loops over two different types of ground (same dB scale). *MININEC*-based modeling programs cannot be used to compute the gain figures of these loops, since impedance and gain figures are incorrect for very low antenna heights.

2.3.1. Over very poor ground

The horizontally polarized delta loop is better than the vertically polarized loop for all wave angles above 35º. Below 35º the vertically polarized loop takes over, but quite marginally. The maximum gain of the vertically and the horizontally polarized loops differs by only 2 dB, but the big difference is that for the horizontally polarized loop, the gain occurs at almost 90º, while for the vertically polarized loop it occurs at 25º.

One might argue that for a 30º elevation angle, the horizontally polarized loop is as good as the vertically polarized loop. It is clear, however, that the vertically polarized antenna gives good high-angle rejection (rejection against local signals), while the horizontally polarized loop will not.
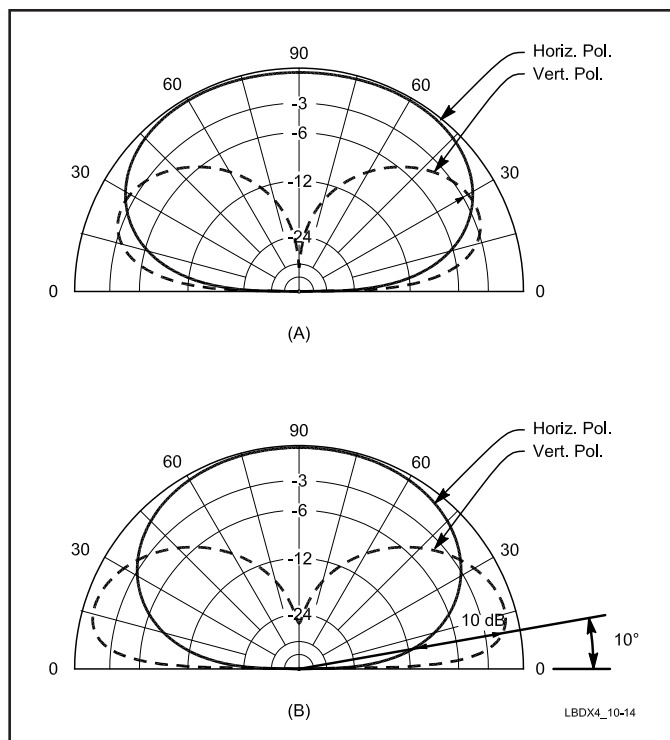
Fig 10-14—Radiation patterns of vertically and horizontally polarized delta loops on the same dB scale. At A, over very poor ground, and at B, over very good ground. These patterns illustrate the tremendous importance of ground conductivity with vertically polarized antennas. Over better ground, the vertically polarized loop performs much better at low radiation angles, while over both good and poor ground the vertically polarized loop gives good discrimination against high-angle radiation. This is not the case for the horizontally polarized loop.

2.3.2. Over very good ground

The same thing that happens with any vertical happens with our vertically polarized delta: The performance at low angles is greatly improved with good ground. The vertically polarized loop is still better at any wave angle under 30º than when horizontally polarized. At a 10º radiation angle, the difference is as high as 10 dB. We have learned, in Chapter 5, that on the low bands very low angles (down to just a few degrees) are often involved, and in that respect the vertically polarized delta over good ground is far superior.

2.3.3. Conclusion

Over very poor ground, the vertically polarized loops do not provide much better low-angle radiation when compared to the horizontally polarized loops. They have the advantage of giving substantial rejection at high angles, however.

Over good ground, the vertically polarized loop will give up to 10-dB and more gain at low radiation angles as compared to the horizontally polarized loop, in addition to its high-angle rejection. See Fig 10-14B.

2.4. Dimensions

The length of the resonant delta loop is approximately 1.05 to 1.06 λ. When putting up a loop, cut the wire at 1.06 λ, check the frequency of minimum SWR (it is always the resonant frequency), and trim the length. The wavelength is given by

$$\lambda = \frac{299.8}{f \, (MHz)} \qquad \text{(Eq 1)}$$

2.5. Feeding The Delta Loop

The feed point of the delta loop in free space is symmetrical. At high heights above ground the loop feed point is to be considered as symmetrical, especially when we feed the loop in the center of the bottom line (or at the apex), because of its full symmetry with respect to the ground.

Fig 10-15 shows the radiation resistance and reactance for both the horizontally and the vertically polarized equilateral delta loops as a function of height above ground. At low heights, when fed for vertical polarization, the feed point is to be considered as asymmetric, whereby the "cold" point is the point to which the "radials" are connected. The center conductor of a coax feed line goes to the sloping vertical section. Many users have, however, used (symmetric) open-wire line to feed the vertically polarized loop (eg, 450-Ω line).

Most practical delta loops show a feed-point impedance between 50 and 100 Ω, depending on the exact geometry and coupling to other antennas. In most cases the feed point can be reached, so it is quite easy to measure the feed-point impedance using, for example, a good-quality noise bridge connected directly to the antenna terminals. If the impedance is much higher than 100 Ω (equilateral triangle), feeding via a 450-Ω open-wire feeder may be warranted. Alternatively, you could use an unun (unbalanced-to-unbalanced) transformer, which can be made to cover a very wide range of impedance ratios (see Chapter 6 on feed lines and matching). With somewhat compressed delta loops, the feed-point impedance is usually between 50 and 100 Ω. Feeding can be done directly with a 50 or 70-Ω coaxial cable, or with a 50-Ω cable via a 70-Ω quarter-wave transformer (Zant = 100 Ω).
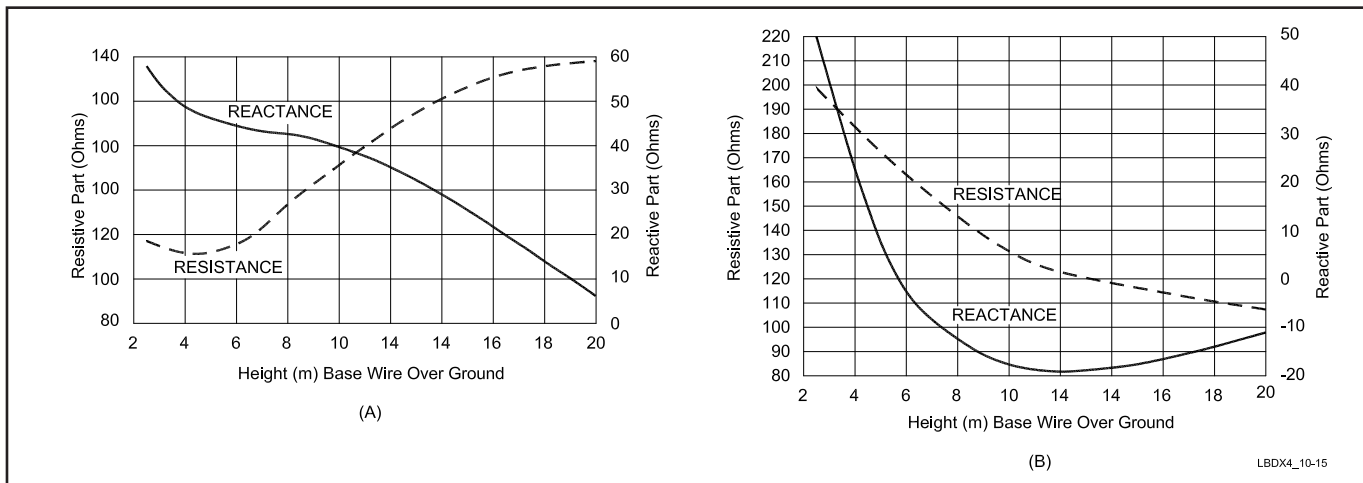
Fig 10-15—Radiation resistance of (A) horizontally and (B) vertically polarized equilateral delta loops as a function of height above average ground. The delta loop was first dimensioned to be resonant in free space (reactance equals zero). Those dimensions were then used for calculating the impedance over real ground. Modeling was done at 3.75 MHz over good ground, using *NEC*.

To keep RF off the feed line it is best to use a balun, although the feed point of the vertically polarized delta loop is not strictly symmetrical. In this case, however, we want to keep any RF current from flowing on the outside of the coaxial feed line, as these parasitic currents could upset the radiation pattern of the delta loop. A stack of toroidal cores on the feed line near the feed point, or a coiled-up length of transmission line (making an RF choke with an impedance of approximately 1000 Ω) will also be useful. For more details refer to Section 7 of Chapter 6 on feed lines and matching.

2.6. Gain and Radiation Angle

Fig 10-16 shows the gain and the main-lobe radiation angle for the equilateral delta loop at different heights. The values were obtained by modeling a 3.8-MHz loop over average ground using *NEC*.

Earl Cunningham, K6SE, investigated different configurations of single element loops for 160 meters, and came up with the results listed in **Table 10-1** (modeling done with *EZNEC* over good ground). These data correspond surprisingly well with those shown in Fig 10-16 (where the ground was average), which explains the slight difference in gain.

2.7. Two Delta Loops at Right Angles

If the 4 to 5 dB front-to-side ratio bothers you, and if you have sufficient space, you can put up two delta loops at right angles on the same tower. You must, however, make provisions to open up the feed point of the antenna not in use, as well as its apex. This results in two non-resonant wires that do not influence the loop in use. If you would leave the unused delta loop in its connected configuration, the two loops would influence one another to a very high degree, and the results would be very disappointing.

2.8. Loop Supports

Vertically polarized loop antennas are really an array of
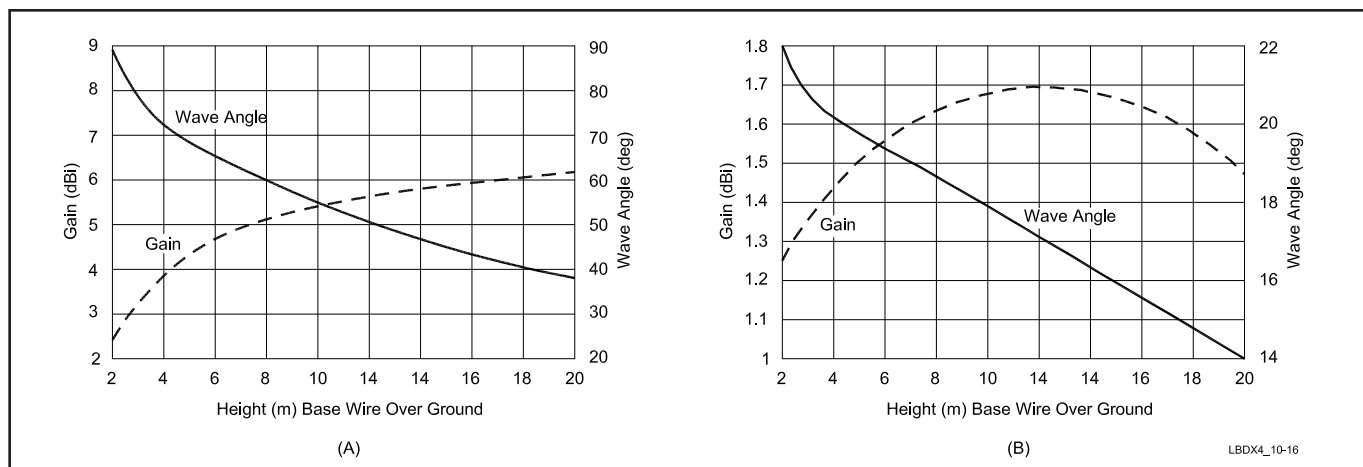
Fig 10-16—Gain and radiation angle of (A) horizontally and (B) vertically polarized equilateral delta loops as a function of the height above ground. Modeling was done at 3.75 MHz over average ground, using *NEC*.

Table 10-1
Loop Antennas for 160 Meters

| Description	Feeding Method	Gain dBi	Elevation Angle
Diamond loop, bottom 2.5 m high	In side corner	2.15 dBi	18.0°
Square loop, bottom 2.5 m high	In center of one vertical wire	2.06 dBi	20.5°
Inverted equilateral delta loop (flat wire on top)	Fed λ/4 from bottom	1.91 dBi	20.9°
Regular equilateral delta loop	Fed λ/4 from top	1.90 dBi	18.1°

two (sloping) verticals, each with an elevated radial. This means that if you support the delta loop from a metal tower, this tower may well influence the radiation pattern of the loop if it resonated anywhere in the vicinity of the loop. You can investigate this by modeling, but when the tower is loaded with Yagis, it is often difficult to exactly model the Yagis and their influence on the electrical length of the tower.

(A)

(B)

(C)   LBDX4_10-17

The safest thing you can do is to detune the tower to make sure the smallest possible current flows in the structure. The easiest way I found to do this is to drop a wire from the top of the tower, parallel with the tower (at 0.5 to 1.0 meter distance) and terminate this wire via a 2000 pF variable capacitor to ground. Next use a current probe (such as is shown in Fig 11-17 in the chapter on Vertical Arrays) and adjust the variable capacitor for *maximum* current while transmitting on the delta loop. The capacitor can be replaced with a fixed one (using a parallel combination of several values, if necessary) having the same value. This procedure will guarantee minimum mutual coupling between the loop and the supporting tower.

2.9. Modeling Loops

Loops can be modeled with *MININEC* or *NEC-2* when it comes to radiation patterns. Because of the acute angles at the corners of the delta loop, special attention must be paid to the length of the wire segments near the corners. Wire segments that are too long near wire junctions with acute angles will cause pulse overlap (the total conductor will look shorter than it actually is). The wire segments need to be short enough in order to obtain reliable impedance results. Wire segments of 20 cm length are in order for an 80-meter delta loop if accurate results are required. To limit the total number of pulses, the segment-length tapering technique can be used: The segments are shortest near the wire junction, and get gradually longer away from the junction. *ELNEC* as well as *EZNEC* have a special provision that automatically generates tapered wire segments (Ref 678).

At low heights (bottom of the antenna below approx. 0.2 λ), the gain and impedance figures obtained with a *MININEC*-based program are incorrect. The gain is too high, and the impedance too low. This is because *MININEC* calculates using a perfect ground under the antenna. Correct gain and impedance calculations at such low heights require modeling with a *NEC*-based program, such as *EZNEC*. All gain and impedance data listed in this chapter were obtained by using such a *NEC*-based modeling program.
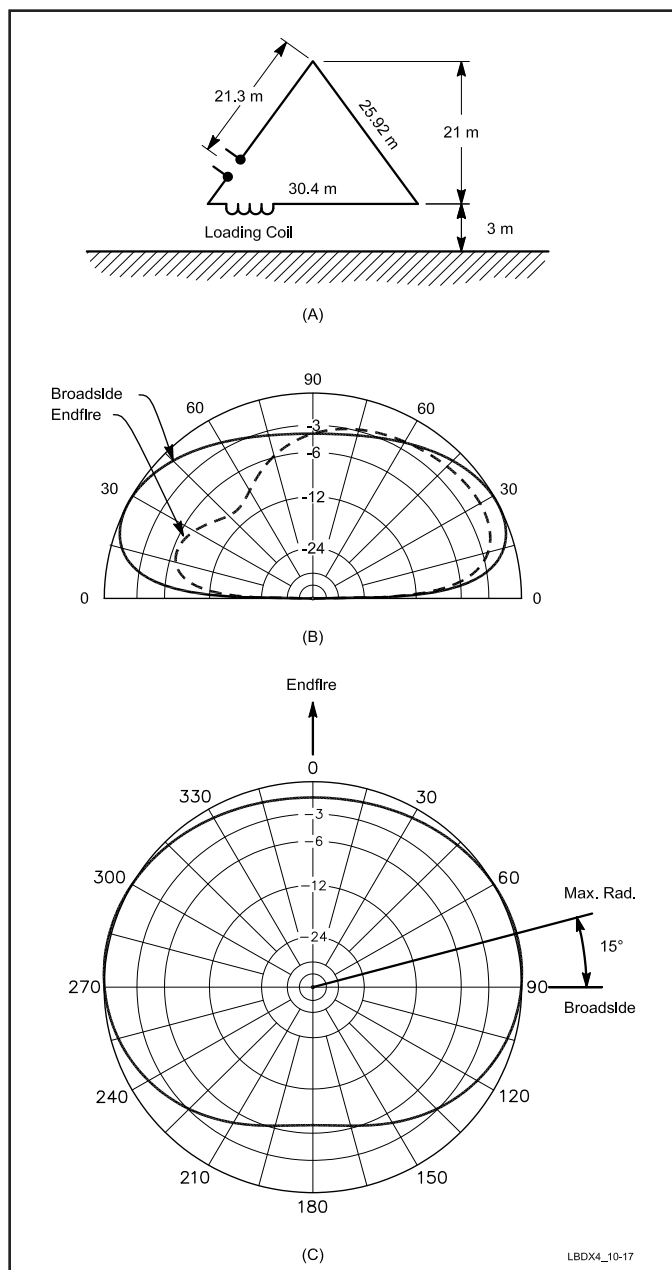
Fig 10-17—To shift the resonant frequency of the delta loop from 3.75 MHz to 3.55 MHz, a loading coil (or stub) is inserted in one bottom corner of the loop, near the feed point (A). This has eliminated the reactive component, but has also upset the symmetrical current distribution in the bottom wire. Vertical patterns are shown at B, and the horizontal pattern is shown at C for a 27° elevation angle. As with the loop shown in Fig 10-12, high-angle radiation (horizontal component) has appeared, and the horizontal pattern exhibits a notch in the endfire direction. Maximum radiation is again slightly off from the broadside direction.

3. LOADED LOOPS

3.1. CW and SSB 80-Meter Coverage

An 80-meter delta loop or quad loop will not cover 3.5 through 3.8 MHz with an SWR below 2:1. There are two ways to achieve a wide-band coverage:

1) Feed the loop with an open-wire line (450 Ω to a matching network).
2) Use inductive or capacitive loading on the loop to lower its resonant frequency.

3.1.1. Inductive loading

For more information about inductive loading, you can refer to the detailed treatment of short verticals in Chapter 9 on vertical antennas. There are three principles:

- The required inductance of the loading devices (coils or stubs) to achieve a given downward shift of the resonant frequency will be minimum if the devices are inserted at the maximum current point (similar to base loading with a vertical). At the minimum current point the inductive loading devices will not have any influence. This means that for a vertically polarized delta loop, the loading coil (or stub) cannot be inserted at the apex of the loop, nor in the middle of the bottom wire.
- Do not insert the loading devices in the radiating parts of the loop. Insert them in the part where the radiation is canceled. For example, in a vertically polarized delta loop, the loading devices should be inserted in the bottom (horizontal) wire near the corners.
- Always keep the symmetry of the loop intact, including after having added a loading device.

From a practical (mechanical) point of view it is convenient to insert the loading coil (stub) in one of the bottom corners. **Fig 10-17A** shows the loaded, compressed delta loop (with the same physical dimensions as the loop shown in Fig 10-11), where we have inserted a loading inductance in the bottom corner near the feed point.

A coil with a reactance of 240 Ω (on 3.5 MHz) or an inductance of 10.9 µH will resonate the delta on 3.5 MHz. The 100-kHz SWR bandwidth is 1.5:1. Note again the high-angle fill in the broadside pattern (no longer symmetrical baseline configuration), as well as the asymmetrical front-to-side ratio of the loop.

Although a well-designed and well made loading coil (see Chapter 9, Section 3.3) can have a much higher Q than a linear loading stub, it sometimes is easier to quickly tune the loop with a stub. The 10.9-µH coil can be replaced with a shorted stub. The inductive reactance of the closed stub is given by:

$$X_L = Z \tan \ell \qquad \text{(Eq 2)}$$

where

    Z = characteristic impedance of stub (transmission line)
    ℓ = length of line, degrees
    X_L = inductive reactance
    From this,

$$\ell = \arctan\left(\frac{X_L}{Z}\right) \qquad \text{(Eq 3)}$$

In our example:
X_L = 240 Ω
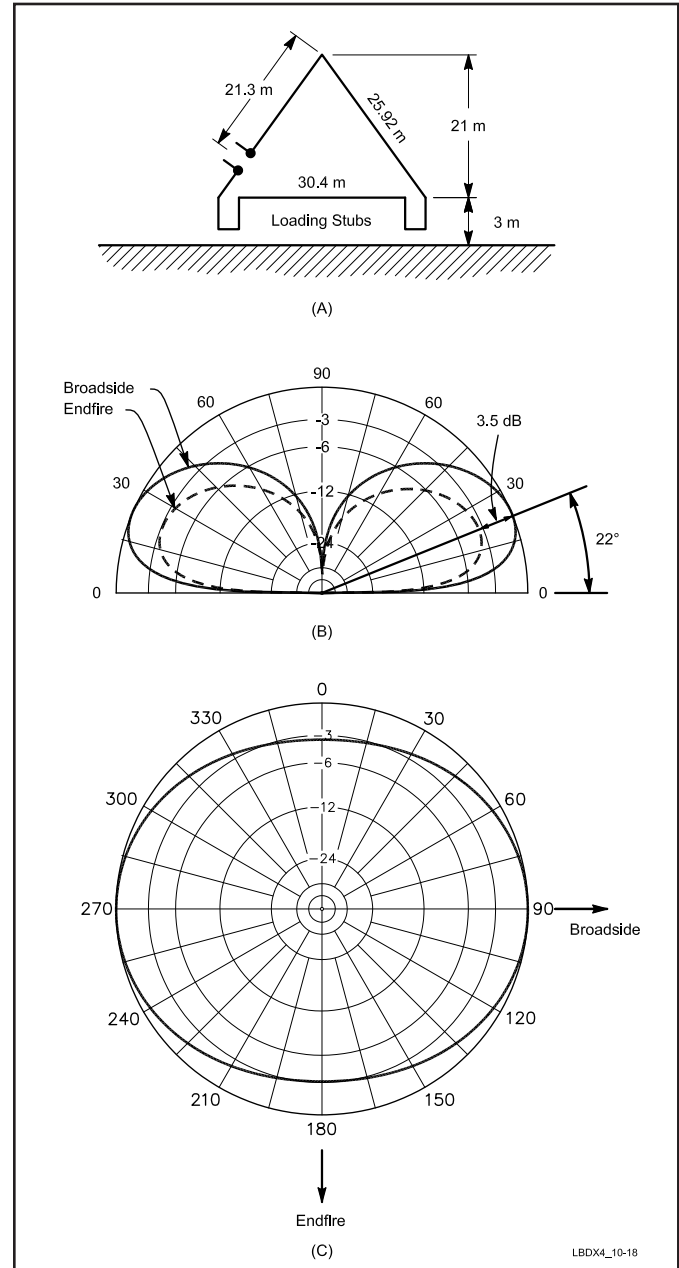Z = 450 Ω
ℓ = arctan (240/450) = 28°

Assuming a 95% velocity factor for the transmission line, we can calculate the physical length of the stub as follows:

$$\text{Wavelength} = \frac{299.8}{3.5} = 85.66 \text{ meters (for 360°)}$$

$$\text{Physical Length} = 85.66 \text{ meters} \times 0.95 \times \frac{28°}{360°} = 6.33 \text{ meters}$$

Fig 10-18—The correct way of loading the delta loop is to insert two loading coils (or stubs), one in each bottom corner. This keeps the current distribution in the baseline symmetrical, and preserves a "clean" radiation pattern in the horizontal as well as the vertical plane. The horizontal pattern at C is for an elevation angle of 22°.

Parts B and C of Fig 10-17 show the radiation patterns resulting from the insertion of a single stub (or coil) in one of the bottom corners of the delta loop. The insertion of the single loading device has broken the symmetry in the loop, and the bottom wire now radiates as well, upsetting the pattern of the loop.

This can be avoided by using two loading coils or stubs, located symmetrically about the center of the baseline. The example in **Fig 10-18A** shows two stubs, one located in each bottom corner of the loop. Each loading device has an inductive reactance of 142 Ω. For 3.5 MHz this is:

$$\frac{142}{2\pi \times 3.5} = 6.46\,\mu H$$

A 450-Ω short circuited line is 3.96 meters long (see calculation method above). The corresponding radiation patterns in Fig 10-18 are now fully symmetrical, and the annoying high-angle radiation is totally gone. The 100-kHz SWR bandwidth is 1.45:1. The 2:1 SWR bandwidth is 170 kHz.

Fig 10-19 shows the practical arrangement that can be used for installing the switchable stubs at the two delta-loop bottom corners. A small plastic box is mounted on a piece of epoxy printed-circuit-board material that is also part of the guying system. In the high-frequency position the stub should be completely isolated from the loop. Use a good-quality open-wire line and DPDT relay with ceramic insulation. The stub can be attached to the guy lines, which must be made of insulating material. If at all possible, make a high-Q coil, and replace the loading stub with the coil!
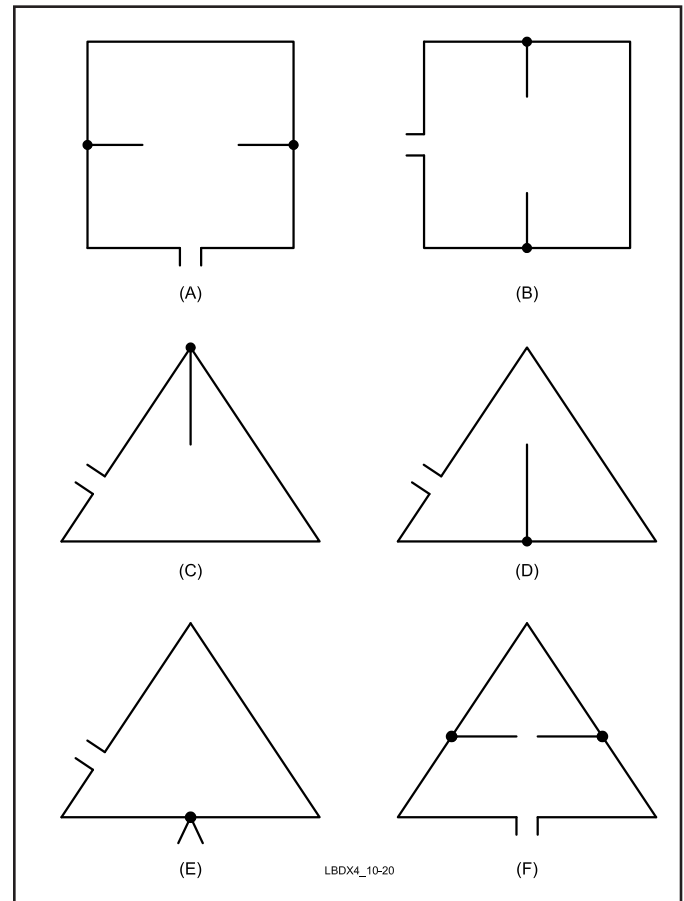
3.1.2. Capacitive loading

You can also use capacitive loading in the same way that we employ capacitive loading on a vertical. Capacitive loading is to be preferred over inductive loading because it is essentially lossless. Capacitive loading has the most effect when applied at a voltage antinode (also called a voltage point).

This capacitive loading is much easier to install than the inductive loading, and requires only a single-pole (high-voltage!) relay to switch the capacitance wires in or out of the circuit. *Keep the ends of the wires out of reach of people and animals, as extremely high voltage is present.*

Fig 10-20 shows different possibilities for capacitive
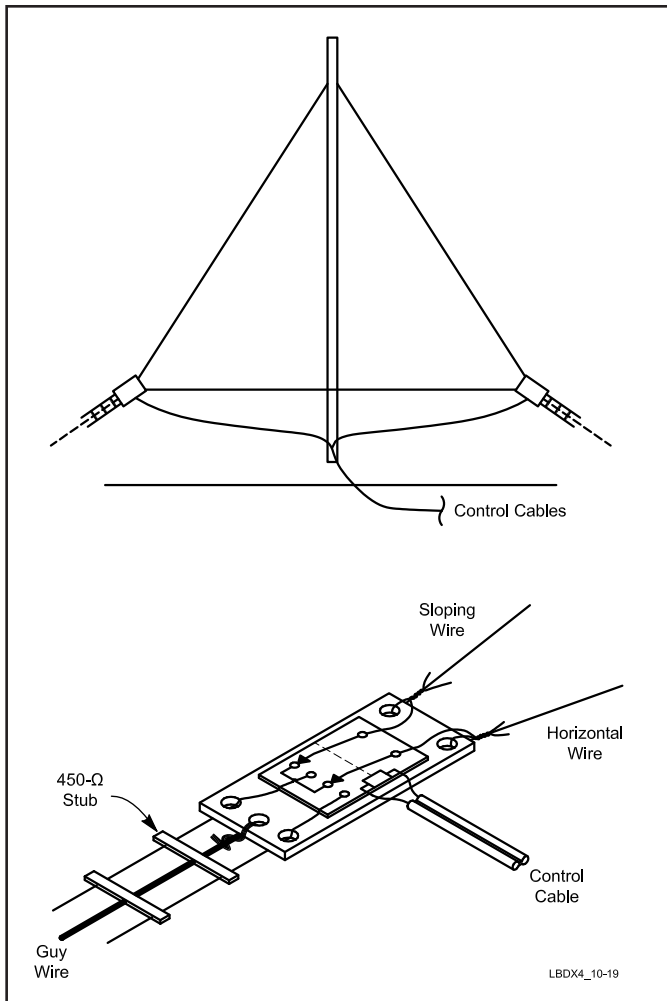
Fig 10-19—Small plastic boxes, mounted on a piece of glass-epoxy board, are mounted at both bottom corners of the loop, and house DPDT relays for switching the stubs in and out of the circuit. The stubs can be routed along the guy lines (guy lines must be made of insulating material). The control-voltage lines for the relays can be run to a post at the center of the baseline and from there to the shack. Do not install the control lines parallel to the stubs.

Fig 10-20—Various loop configurations and possible capacitive loading alternatives. Capacitive loading must be applied at the voltage maximum points of the loops to have maximum effectiveness. The loading wires carry very high voltages, and good insulators should be used in their insulation.

loading on both horizontally and vertically polarized loops. If installed at the top of the delta loop as in Fig 10-20C, a 9-meter long wire inside the loop will shift the 3.8-MHz loop (from Fig 10-11) to resonance at 3.5 MHz. For installation at the center of the baseline, you can use a single wire (Fig 10-20D), or two wires in the configuration of an inverted V (Fig 10-20E). Several wires can be connected in parallel to increase the capacitance. *(Watch out, since there is very high voltage on those wires while transmitting!)*

The same symmetry guidelines should be applied as explained in Section 3.1 to preserve symmetrical current distribution.

3.1.3. Adjustment

Once the loop has been trimmed for resonance at the high-frequency end of the band, just attach a length of wire with a clip at the voltage point and check the SWR to see how much the resonant frequency has been lowered. It should not take you more than a few iterations to determine the correct wire length. If a single wire turns out to require too much length, connect two or more wires in parallel, and fan out the wire ends to create a higher capacitance.

3.1.4. Bandwidth

By using one of the above-mentioned loading methods and a switching arrangement, a loop can be made that covers the entire 80-meter band with an SWR below 2:1.

3.2. Reduced-Size Loops

Reduced-size loops have been described in amateur literature (Refs 1115, 1116, 1121, 1129). **Fig 10-21** shows some of the possibilities of applying capacitive loading to loops, whereby a substantial shift in frequency can be obtained. G3FPQ uses a reduced-size 2-element 80-meter quad that makes use of capacitive-loaded square elements as shown in Fig 10-21A. The fiberglass spreaders of the quad support the loading wires.

It is possible to lower the frequency by a factor of 1.5 with this method, without lowering the radiation resistance to an unacceptable value (a loop dimensioned for 5.7 MHz can be loaded down to 3.8 MHz). The triangular loop can also be loaded in the same way, although the mechanical construction
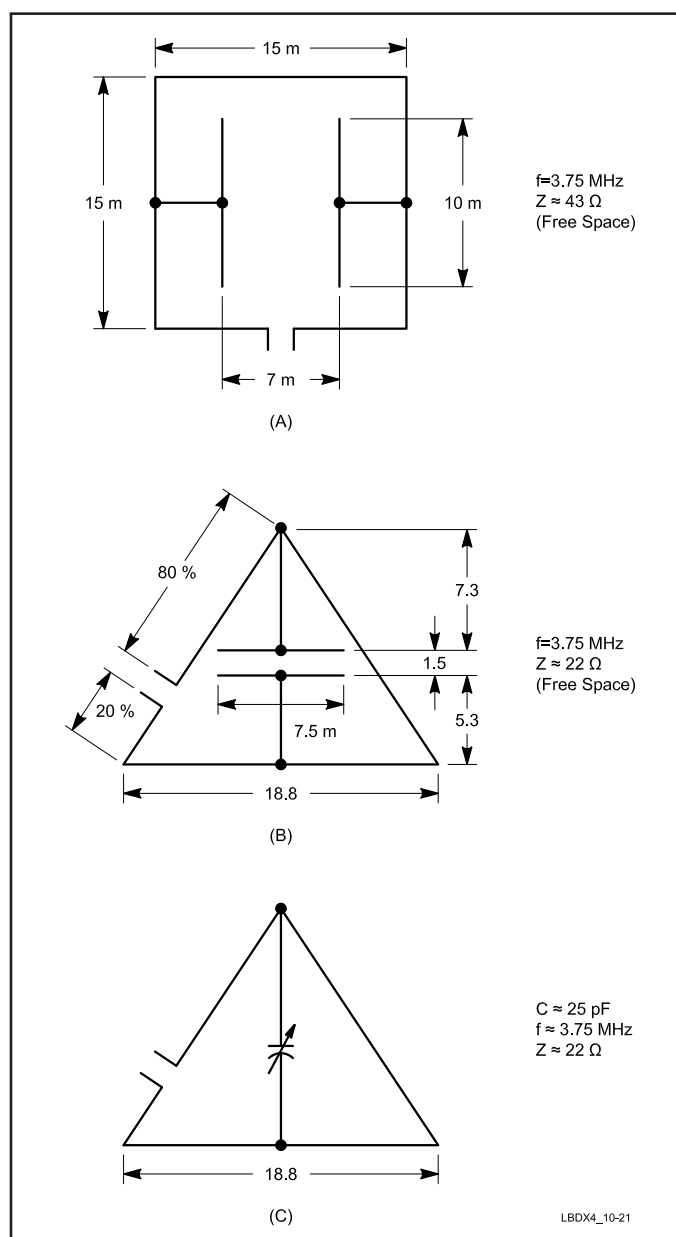

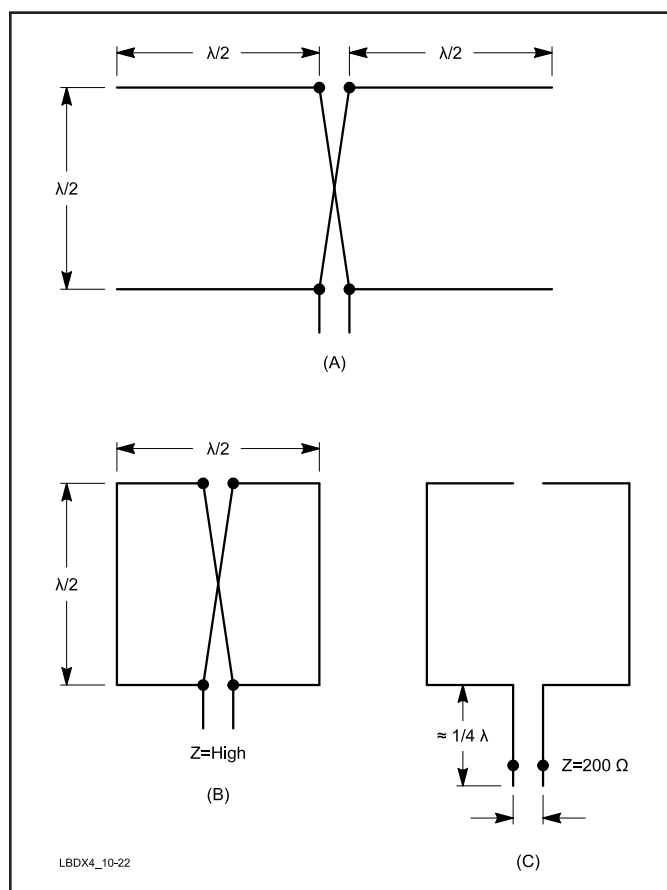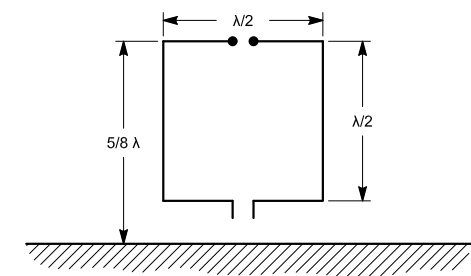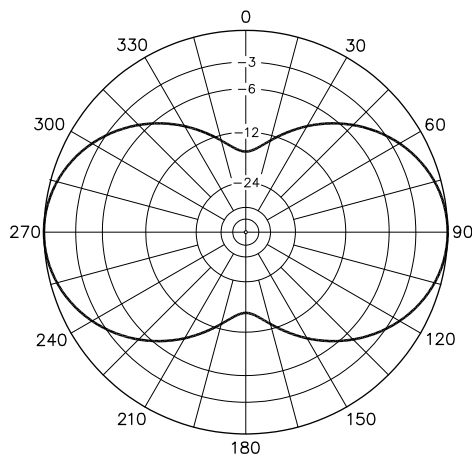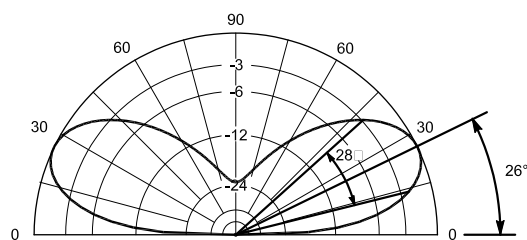Fig 10-21—Capacitive loading can be used on loops of approximately ⅔ full size. See text for details.

Fig 10-22—The bi-square antenna is a lazy-H antenna (two λ/2 collinear dipoles, stacked λ/2 apart and fed in phase), with the ends of the dipoles bent down (or up) and connected. The feed-point impedance is high and the array can best be fed via a λ/4 stub arrangement.
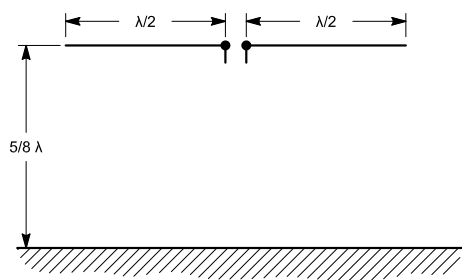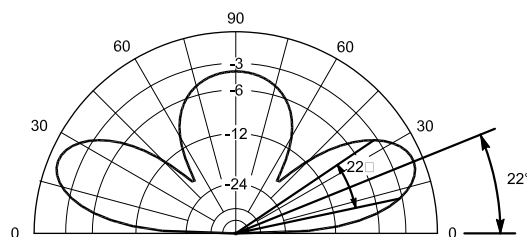
may be more complicated than with the square loop. See Fig 10-21B.

In principle, we can replace the parallel wires with a (variable) capacitor. This would allow us to tune the loop. The example in Fig 10-21C requires approximately 30 pF to shift the antenna from 5.7 to 3.8 MHz. Beware, however, that extremely high voltages exist across the capacitor. It would certainly not be over-engineering to use a 50-kV or higher capacitor for the application.

4. BI-SQUARE

The bi-square antenna has a circumference of 2 λ and is opened at a point opposite the feed point. A quad antenna can be considered as a pair of shortened dipoles with λ/4 spacing. In a similar way, the bi-square can be considered as a lazy-H antenna with the ends folded vertically, as shown in **Fig 10-22**. Not many people are able to erect a bi-square antenna, as the dimensions involved on the low bands are quite large.

In free space the bi-square has 3-dB gain over two λ/2 dipoles in phase (collinear), and almost 5 dB over a single λ/2 dipole. Over real ground, with the bottom wire λ/8 above ground (10 meters for an 80-meter bi-square), the gain of the bi-square is the same as for the two λ/2 dipoles in phase. The bottom two λ/2 sections do not contribute to low-angle radiation of the antenna.

The bi-square has the advantage over two half-waves in phase that the antenna does not exhibit the major high-angle sidelobe that is present with the collinear antenna when the height is over λ/2. **Fig 10-23** shows the radiation patterns of the bi-square and the collinear with the top of the antenna 5λ/8 high. Notice the cleaner low-angle pattern of the bi-square. Of course you could obtain almost the same result by lowering the collinear from 5λ/8 to λ/2 high!

The bi-square can be raised even higher in order to further reduce the wave angle without introducing high-angle lobes, up to a top height of 2 λ. At that height the wave angle is 14°, without any secondary high-angle lobe. With the top at 5λ/8, the takeoff angle is 26°.

To exploit the advantages of the bi-square antenna, you need quite impressive heights on the low bands. N7UA is one of the few stations using such an antenna, and he produces a most impressive signal on the long path into Europe on 80 meters. With a proper switching arrangement, the antenna can be made to operate as a full-wave loop on half the frequency (eg, 160 meters for an 80-meter bi-square).

The feed-point impedance is high (a few thousand ohms), and the recommended feed system consists of 600-Ω line with a stub to obtain a 200-Ω feed point. By using a 4:1 balun, a coaxial cable can be run from that point to the shack. Another alternative is to run the 600-Ω line all the way to the shack into an open-wire antenna tuner.

Fig 10-23—The bi-square antenna (A) and its radiation patterns (B and C). The azimuth pattern at B is for an elevation angle of 25°. At D, two half waves in phase and at E, its radiation pattern. Note that for a top-wire height of 5λ/8, the bi-square does not exhibit the annoying high-angle lobe of the collinear antenna.

5. THE HALF LOOP

The *half loop* was first described by Belrose, VE2CV (Ref 1120 and 1130). This antenna, unlike the half sloper, cannot be mounted on a tall tower supporting a quad or Yagi. If this was done, the half loop would shunt-feed RF to the tower and the radiation pattern would be upset. This can be avoided by decoupling the tower using a λ/4 stub (Ref 1130).

The half loop as shown in **Fig 10-24** can be fed in different ways.

5.1. The Low-Angle Half Loop

For low-angle radiation, the feed point can be at the end of the sloping wire (with the tower grounded), or else at the base of the tower (with the end of the sloping wire grounded).
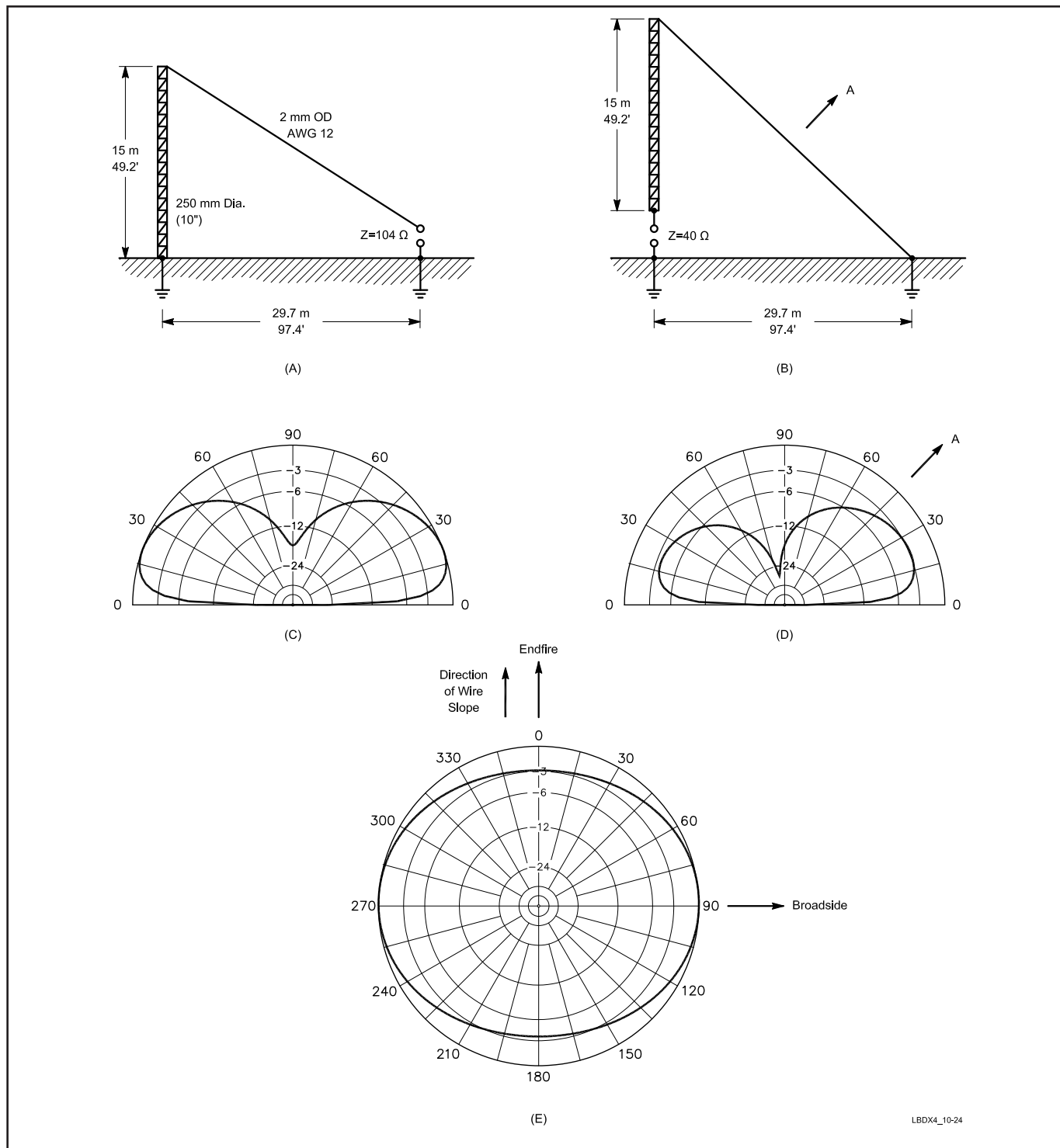

Fig 10-24—Half-loop antenna for 3.75 MHz, fed for low-angle radiation. The antenna can be fed at either end against ground (A and B). The grounded end must be connected to a good ground system, as must the ground-return conductor of the feeder. Radials are essential for proper operation. Note that while the feed-point locations are different, the radiation patterns do not change. C shows the broadside vertical pattern, E is the end-fire vertical pattern, and E is the azimuth pattern for an elevation angle of 20°.
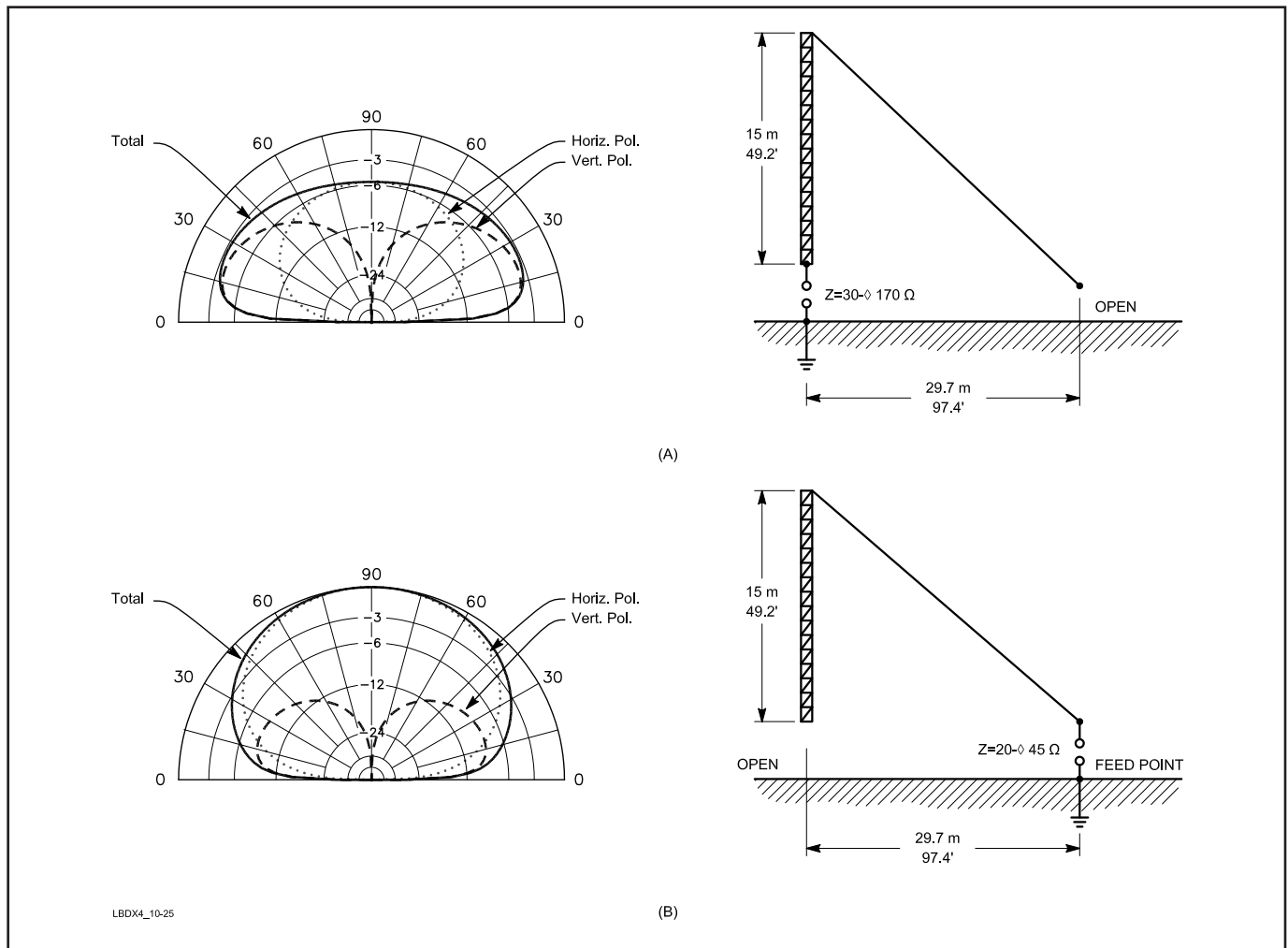
Fig 10-25—High-angle versions of the half delta loop antenna for 3.75 MHz. As with the low-angle version, the antenna can be fed at either end (against ground). The other end, however, must be left floating. The two different feed points produce different high-angle patterns as well as different feed-point impedances.

The radiation pattern in both cases is identical. The front-to-side ratio is approximately 3 dB, and the antenna radiates best in the broadside direction (the direction perpendicular to the plane containing the vertical and the sloping wire).

There is some pattern distortion in the end-fire direction, but the horizontal radiation pattern is fairly omnidirectional. Most of the radiation is vertically polarized, so the antenna requires a good ground and radial system, as for any vertical antenna. As such, the half loop does not really belong to the family of large loop antennas, but as it is derived from the full-size loop, it is treated in this chapter rather than as a top-loaded short vertical.

The exact resonant frequency depends to a great extent on the ratio of the diameter of the vertical mast to the slant wire. The dimensions shown in Fig 10-24 are only indicative. Fine-tuning the dimensions will have to be done in the field.

5.2. The High-Angle Half Loop

The half delta loop antenna can also be used as a high-angle antenna. In that case you must isolate the tower section from the ground (use a good insulator because it now will be at a high-impedance point) and feed the end of the sloping wire. Alternatively, you can feed the antenna between the end of the sloping wire and ground, while insulating the bottom of the tower from ground. Using the same dimensions that made the low-angle version resonant no longer produces resonance in these configurations.

Fig 10-25 shows the low-angle configurations with the radiation patterns. Note that the alternative where the end of the slant wire is fed against ground produces much more high-angle radiation than the alternative where the bottom end of the tower is fed. In both cases, the other end of the aerial is left floating (not connected to ground).

Dimensional configurations other than those shown in the relevant figures can be used as well, such as with a higher tower section and a shorter slant wire. If you move the end of the sloping wire farther away from the tower, you will need to decrease the height of the tower to keep resonance, and the radiation resistance will decrease. This will, of course, adversely influence the efficiency of the antenna. If the bottom of the sloping wire is moved toward the tower, the length of the vertical will have to be increased to preserve resonance. When the end of the sloping wire has been moved all the way to the base of the tower we have a λ/4 vertical with a folded feed system. The feed-point impedance will depend on the spacing and the ratio of the tower diameter to the feed-wire diameter.

Compared to a loaded vertical, this antenna has the advantage of giving the added possibility for switching to a high-angle configuration. For a given height, the radiation resistance is slightly higher than for the top-loaded vertical, whereby there is no radiation from the top load. The sloping wire in this half-loop configuration adds somewhat to the vertical radiation, hence the increase (10% to 15%) in R_{rad}.

Being able to feed the antenna at the end of the sloping wire may also be an advantage: This point may be located at the transmitter location, so the sloping wire can be directly connected to an antenna tuner. This would enable wide-band coverage by simply retuning the antenna tuner. Switching from a high to a low-angle antenna in that case consists of shorting the base of the tower to ground (for low-angle radiation).

6. THE HALF SLOPER

Although the so-called half sloper of **Fig 10-26A** may look like a half delta, it really does not belong with the loop antennas. As we will see, it is rather a loaded vertical with a specific matching system and current distribution.

Quarter-wave slopers are the typical result of ham ingenuity and inventiveness. Many DXers, short of space for putting up large, proven low-angle radiators, have found their half slopers to be good performers. Of course they don't know how much better other antennas might be, as they have no room to try them. Others have reported that they could not get their half sloper to resonate on the desired frequency (that's because they gave up trying before having found the proverbial needle in the haystack). Of course resonating and radiating are two completely different things. It's not because you cannot make the antenna resonant that it will not radiate well. Maybe they need a matching network?

To make a long story short, half slopers seem to be very unpredictable. There are a large number of parameters (different tower heights, different tower loading, different slope angles, and so forth) that determine the resonant frequency and the feed-point impedance of the sloper.

Unlike the half delta loop, the half sloper is a very difficult antenna to analyze from a generic point of view, as each half sloper is different from any other. Belrose, VE2CV, thoroughly analyzed the half sloper using scale models on a professional test range (Ref 647). His findings were confirmed by DeMaw, W1FB (Ref 650). Earlier, Atchley, W1CF, reported outstanding performance from his half sloper on 160 meters (Ref 645).

I have modeled an 80-meter half sloper using *MININEC*. After many hours of studying the influence of varying the many parameters (tower height, size of the top load, height of the attachment point, length of the sloper, angle of the sloper, ground characteristics, etc), I came to the following conclusions:

Fig 10-26—At A, a half-sloper mounted on an 18-meter tower that supports a 3-element full-size 20-meter Yagi. See text for details. At B, the azimuth pattern for a 45°elevation angle with vertically and horizontally polarized components, and at C and D, elevation patterns. The antenna shows a modest F/B ratio in the end-fire direction at a 45° elevation angle.
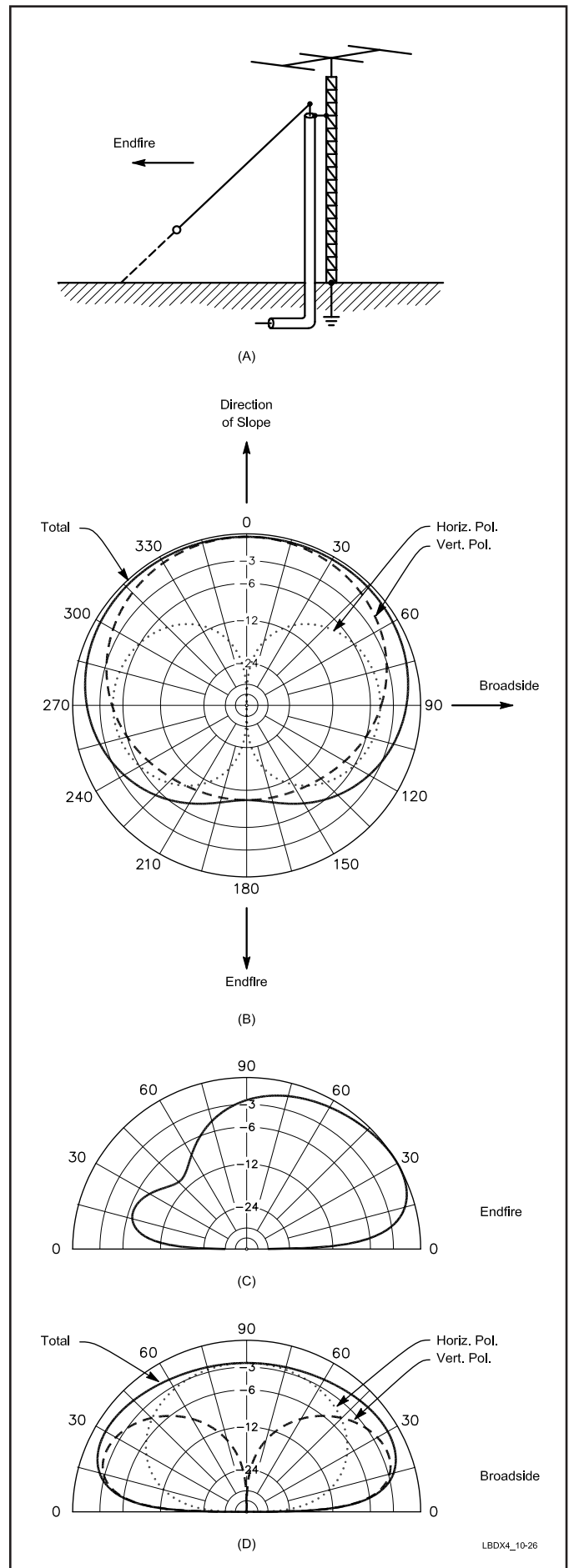
- The so-called half sloper is made up of a vertical and a slant wire. Both contribute to the radiation pattern. The radiation pattern is essentially omnidirectional. The low-angle radiation comes from the loaded tower, the high-angle radiation from the horizontal component of the slant wire. The antenna radiates a lot of high-angle signal (coming from the slant wire).
- Over poor ground the antenna has some front-to-back advantage in the direction of the slope, ranging from 10 to 15 dB at certain wave angles. Over good and excellent ground the F/B ratio is not more than a few dB.

An interesting testimony was sent on Internet by Rys, SP5EWY, who wrote "*Well, I had previously used my tower without radials and the half sloper favored the South, with the wire sloping in that direction, by at least 1 S-unit. Later I added 20 radials and since then it seems to radiate equally well in all directions.*"

In essence the half sloper is a top-loaded vertical, which is fed at a point along the tower where the combination of the tower impedance and the impedance presented by the sloping wire combine to a 50-Ω impedance (at least that's what we want). The sloping wire also acts as a sort of *radial* to which the *other* conductor of the feed line is connected (like radials on a vertical to push against). In other words, the sloping wire is only a minor part of the antenna, a part that helps to create resonance as well as to match the feed line. Belrose (Ref 647) also recognized that the half sloper is effectively a top-loaded vertical. Fig 10-26 (B through D) shows the typical radiation patterns obtained with a half-sloper antenna.

While modeling the antenna, it was very critical to find a point on the tower and a sloper length and angle that give a good match to a 50-Ω line. The attachment point on the tower need not be at the top. It is not important how high it is, as you are not really interested in the radiation from the slant wire.

Changing the attachment point and the sloper length does not appreciably change the radiation pattern. This indicates that it is the tower (capacitively loaded with the Yagi) that does the bulk of the radiating. As the antenna mainly produces a vertically polarized wave, it requires a good ground system, at least as far as its performance as a low-angle radiator is concerned.

From my experience in spending a few nights modeling half slopers, I would highly recommend any prospective user to first model the antenna using *EZNEC*, which is great for such a purpose and which has the most user-friendly interfaces for multiple iterations.

There is an interesting analysis by D. DeMaw (Ref 650). DeMaw correctly points out that the antenna requires a metal support, and that a tree or a wooden mast will not do. But he does not emphasize anywhere in his study that it is the metal support that is responsible for most of the desirable low-angle radiation. DeMaw, however, recognizes the necessity of a good ground system on the tower, which implicitly admits that the tower does the radiating. DeMaw also says, "*The antenna is not resonant at the operating frequency,*" by which he means that the slant wire is not a quarter-wave long. This is again very confusing, as it seems to indicate that the slant wire is the antenna, which it is not. Describing his on-the-air results, DeMaw confirms what we have modeled: Due to the presence of high-angle radiation, it outperforms the vertical for short and medium-range contacts, while the vertical takes over at low angles for real DX contacts.

To summarize the performance of half slopers, it is worthwhile to note Belrose's comment, "*If I had a single quarter-wave tower, I'd employ a full-wave delta loop, apex up, lower-corner fed, the best DX-type antenna I have modeled.*"

Of course, a delta loop still has a baseline of approximately 100 feet (on the 80-meter band), which is not the case with the half sloper. But the half sloper, like any vertical, requires radials in order to work well. It may look like the half sloper has a space advantage over many other low-band antennas, but this is only as true as for any vertical.