Just Another Loop Antenna

Or Is It?

by John Sehring WB2EGQ

Just when you start to feel comfortable with an old, familiar antenna which you think you know all about, along comes a new twist. No, this is not just another antenna article. Question: *Would you like to get some directionality on 75 meters (and 160 capability, too) from a familiar antenna, without moving parts or phased arrays?* Then read on!

I've always liked loop antennas. When they're one wavelength or more in length, they can show a bit of gain over a dipole. They are broadbanded, are tolerant of their surroundings, and seem quieter for reception.

About 10 years ago, when I lived in New Jersey, up went about 275 feet of 14-gauge stranded insulated wire in the shape of an inverted delta loop. Its length was calculated from the formula for the driven element of a square (quad) loop: $L = 1005/F$, where L is the length in feet and F is the frequency, in my case 3.8 MHz. I added about 25 feet of wire "just in case."

The loop was in the shape of an isosceles triangle with the horizontal portion on top, about 45 feet high, and tied between two trees. It looked like an upside-down "delta" and lay wholly in the vertical plane. The plane of the wire ran in the northeast-southwest direction. The bottom end was almost at ground level and came right into the basement shack; so there was practically no feedline, just six feet of extra wires at the ends.

The resonant frequency of the loop turned out to be 3.8 MHz; therefore, the extra 25 feet of wire was necessary. Because my impedance bridge showed the loop's input impedance to be about 165 ohms resistive at resonance, I made up a 4:1 voltage-type balun[1]. The balun transforms the impedance of the antenna downward toward 50 ohms. It also matches the unbalanced coaxial feed to the balanced load of the antenna.

The wire's insulation, while not necessary, does serve three purposes: 1) it keeps RF off of tree branches; 2) due to a velocity factor of about 0.98, it reduces a bit the necessary size of the antenna; and 3) it prevents wire corrosion, which can increase the wire's resistance (especially to RF), thus reducing antenna efficiency[2].

On the air, the loop performed well both transmitting and receiving. Compared to a 130-foot-long, end-fed wire that ran from ground level upward at a 30° angle, it seemed quieter with respect to local QRN and QRM, such as power line noise. During the day, signals from further away were now readable, thanks to reduced noise levels—a definite improvement as the SNR was better.

Surprise!

I discovered an unsuspected facet of the antenna quite by accident. The feed points of the loop were temporarily connected to the balun with alligator clips. One day as I listened to a QSO on 75m, one of the clips popped off. This left only one of the two feed wires of the loop connected and the other dangling.

When that happened, the signal to which I was listening dropped considerably in signal strength but the noise level stayed about the same, indicating that the antenna was still "hearing." Reversing the connections by hooking up the other feed wire of the loop (leaving the first one unconnected) made the signal stronger! Further checking revealed definite directional properties of the loop when it was fed this way. The nulls were quite narrow and deep, and sometimes useful in reducing QRM and QRN. The directionality seemed evident in both azimuth and elevation.

In spite of the interesting directional properties of the loop when fed this way (end-fed with an L-network against ground, like the high impedance end of a long wire), the balanced feed produced stronger signals on both transmit and receive for the kind of casual operation (out to 1,000 miles) that I usually do on 75m. So I left the end-fed arrangement for receive-only use, where signal-to-QRM and/or signal-to-QRN ratio, not just signal strength alone, are important for hearing a desired signal.

DX

Then, during the cooler months came some excellent DX propagation conditions on 75m. Surprisingly, the end-fed configuration was often superior to the balanced feed. It usually elevated DX signals from the northeast direction (for example, Europe from New Jersey) by a few dB or so and, at the same time, suppressed stateside signals and QRN significantly. Curiously, these effects occurred most often when feeding the wire end toward the northeast; here was that directionality again.

Evidently, the end-fed loop had a high elevation angle null in its pattern, tilted away from the end that was being fed. Local signals and noise were suppressed as their high angle of arrival put them right into the null.

What I had found here was an

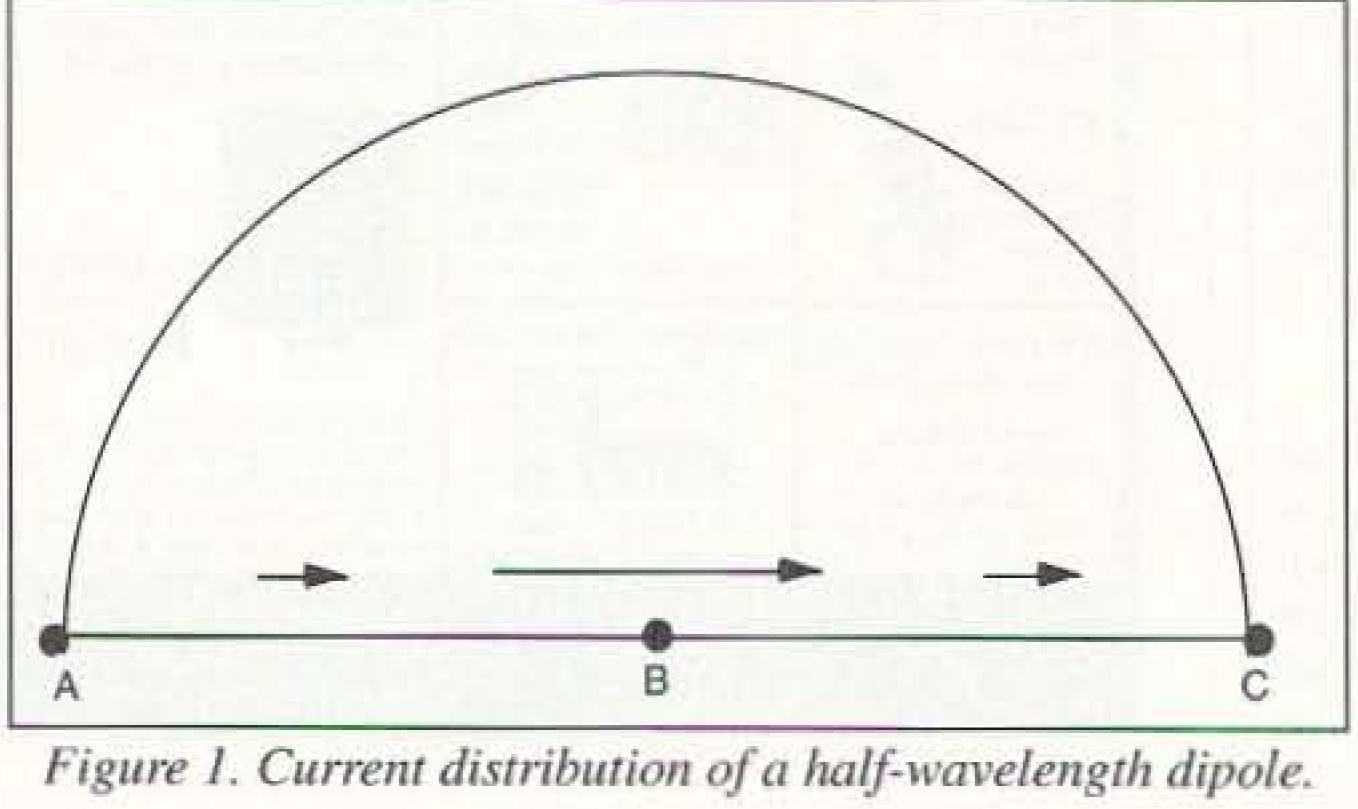

Figure 1. Current distribution of a half-wavelength dipole.

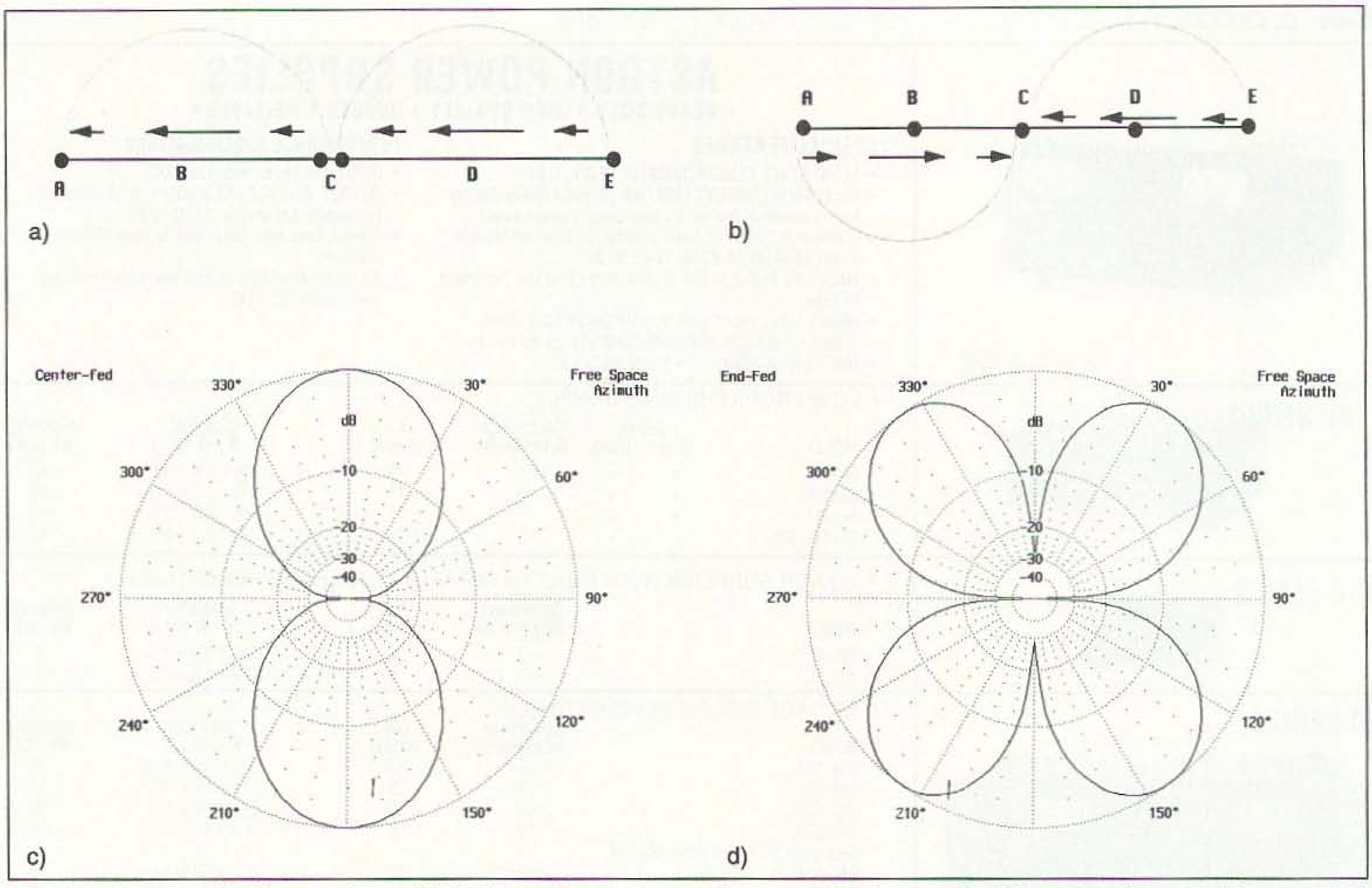

Figure 2. A) current distribution of an end fed full-wavelength antenna; B) current distribution of a full-wavelength center-fed antenna; C) radiation pattern for a center-fed one-wavelength antenna; D) radiation pattern for an end-fed one-wavelength antenna.

antenna of flexibility, capable of strong high-elevation angle performance for stateside contacts (when balanced-fed) and, at the flip of a switch, improved performance for DX with a low-angle lobe and simultaneous high-angle rejection (when end-fed). An added bonus was the 180° switchable endfire directivity.

No, it cannot compete with a dipole at 150 feet, or phased vertical or parasitic arrays, but the improvement over a typical low dipole or inverted-vee is obvious, and the complexity and cost is minimal.

Some Detective Work

The loop's unusual properties when end-fed caught my interest. To see what was happening, I compared the antenna's current distribution in free space with both balanced- and end-feed, so I could estimate what kind of radiation patterns they would produce. Yes, there are computer programs that analyze antennas, but they are most efficiently used when you have at least a qualitative understanding of how an antenna works. I'll touch on this again.

Half-Wavelength Wire

Figure 1 shows the current distribution of a half-wavelength dipole that is sinusoidal. The dotted lines show the amount of current in various parts of the antenna. The arrows show both the direction of current flow and, by their length, the amount of current flow where they are drawn, like a vector.

The relative amount of current at a point on an antenna can tell us the impedance there. Since impedance equals voltage divided by current ($Z = E/I$), high current indicates a low feed-point impedance and, conversely, low current indicates a high impedance.

The amount of current in a dipole is highest at its center (point B), giving a low impedance there. We know this to be true, as its impedance when center-fed is usually about 50 to 70 ohms.

At each end of the dipole we have current minimums. It has to be this way because it's the end of the antenna and so current cannot flow to anywhere. The impedance there, at points A and C, is therefore high.

To avoid upsetting the symmetric current distribution of a dipole when center feeding it, we need to use a balanced feed (a coaxial feedline would need a balun). A balanced feedline presents equal but opposite polarity (plus and minus) voltages, so its presence in the center of a dipole would not disturb current distribution there.

Full-Wavelength Wire

Now we'll extend our wire to one full wavelength and draw the current flow again (see Figure 2). If we feed it at the center (point C), we get the current distribution shown in Figure 2A. There are now two current maximums, at points B and D. Current in both halves is forced to run in the same direction (they are in phase) by the feedline. Current is at a minimum in the center and at both ends (points C, A, and E, respectively).

But if we feed this antenna at an end instead of the center, the current distribution will be quite different, as seen in Figure 2B. There are once again two current maximums. But current in the two halves now runs in opposite directions (they are anti-phase). It could be fed at either end, point A or E, which are, once again, high impedance points.

Since it is current flow (its strength and direction) that generates a radiation pattern from an antenna, we expect

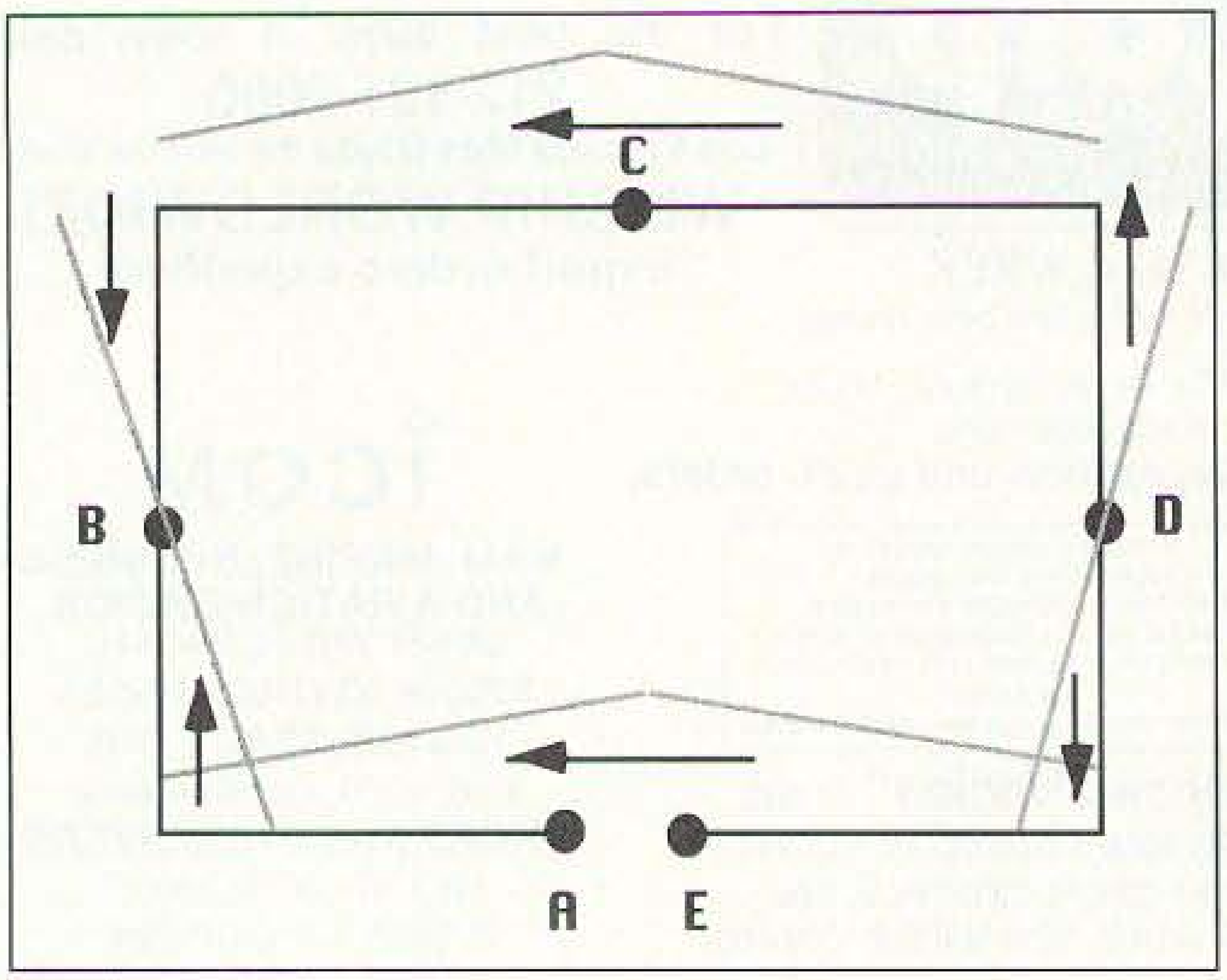

Figure 3. Current distribution of a quad loop.

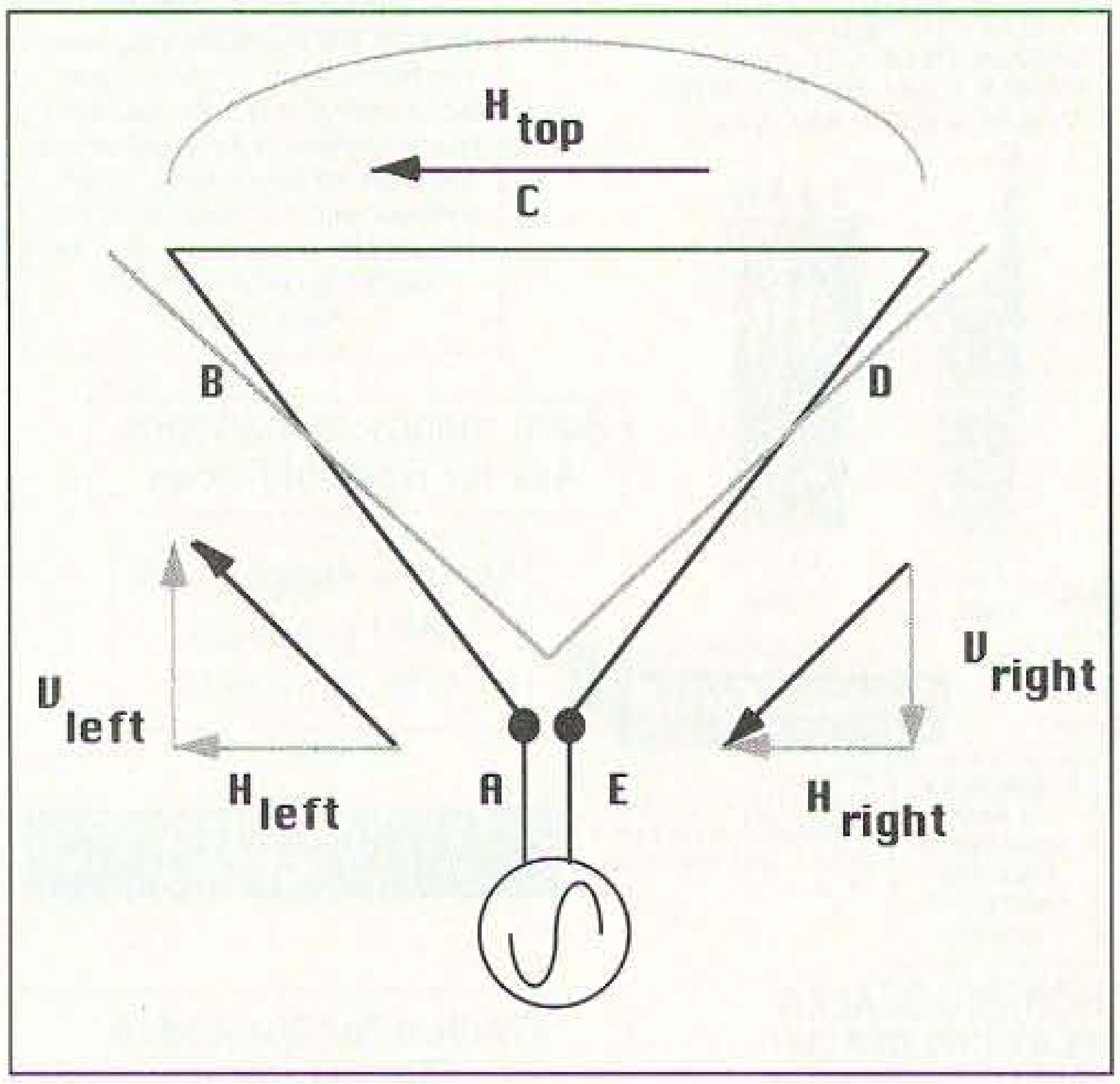

Figure 4. Current distribution of an inverted delta loop, balanced fed.

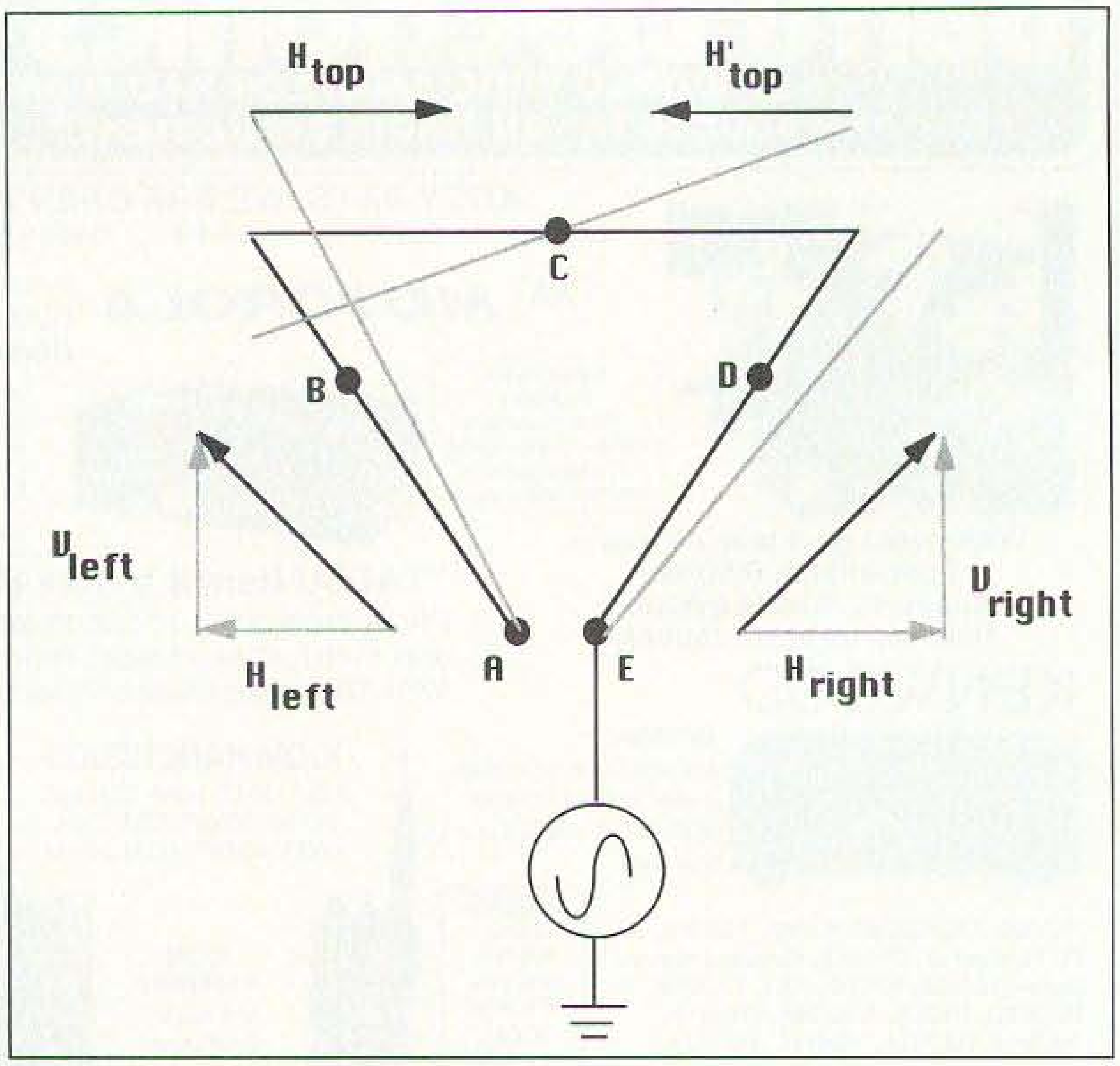

Figure 5. Current distribution of an end-fed full-wavelength loop.

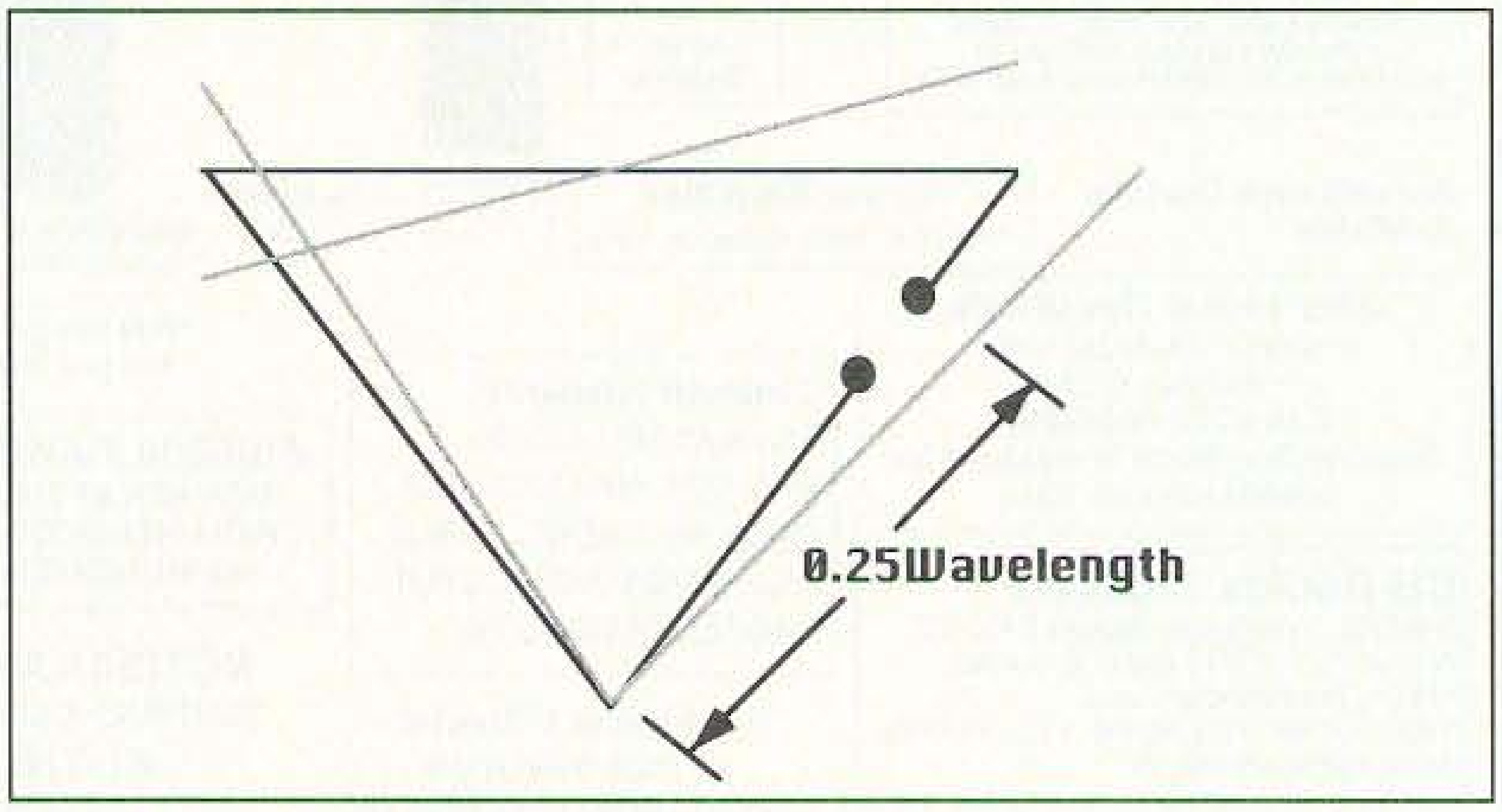

Figure 6. Current distribution of an inverted delta loop, side-fed.

(correctly so) that the directivity will be different when it is fed in these two different ways.

Looking at the end-fed antenna plot from a direction perpendicular to the wire's axis, radiation from the two equal but opposing currents cancels. On the other hand, the center-fed antenna's in-phase currents add up to produce maximum radiation in this same direction. Figures 2C and 2D show this (the plots are for free space patterns; the wire axis runs side to side in both plots).

So, by simply moving the feed point, we can get very different radiation patterns from the same piece of wire.

Balanced-Fed Loop

Let's now draw the current distribution for a balanced-fed inverted delta loop by starting with a quad (square) loop. You can think of a quad loop as two half-wavelength dipoles stacked a quarter wavelength apart, with their ends bent up (and down) to touch each other. See Figure 3.

We know from our experience that the quad loop has a low input impedance, so current must be at a maximum at the center feed point, point A-E (and also at point C opposite the feed point). The quad's upper and lower halves' current distribution does in fact correspond to a pair of dipoles. Compare the current distribution of the top and bottom halves of the quad with the dipole shown in Figure 1: They are the same.

We can now reshape the quad loop, along with its current distribution, into an inverted delta loop shape, shown in Figure 4. To see what's happening, we break the side leg currents into their horizontal and vertical components, H and V. These are shown as Hleft and Vleft for the *horizontal* and *vertical* components on the left leg of the loop, and as Hright and Vright for those on the right leg. The current in the top section, Htop, flows strictly in the horizontal direction (to the left).

The horizontal side currents Hleft and Hright both run in the same direction as the horizontal current Htop in the top portion of the antenna (to the left), so all three add up. Hence we have horizontally polarized broadside radiation from this antenna.

We see that Vleft and Vright go in opposite directions (up and down, respectively). Therefore, these vertical current components cancel each other in a direction broadside to the loop—that is, in and out of the plane of the page—and there is no broadside vertically polarized radiation. (Due to the side leg spacing, there will be some vertically polarized radiation in the endfire directions.)

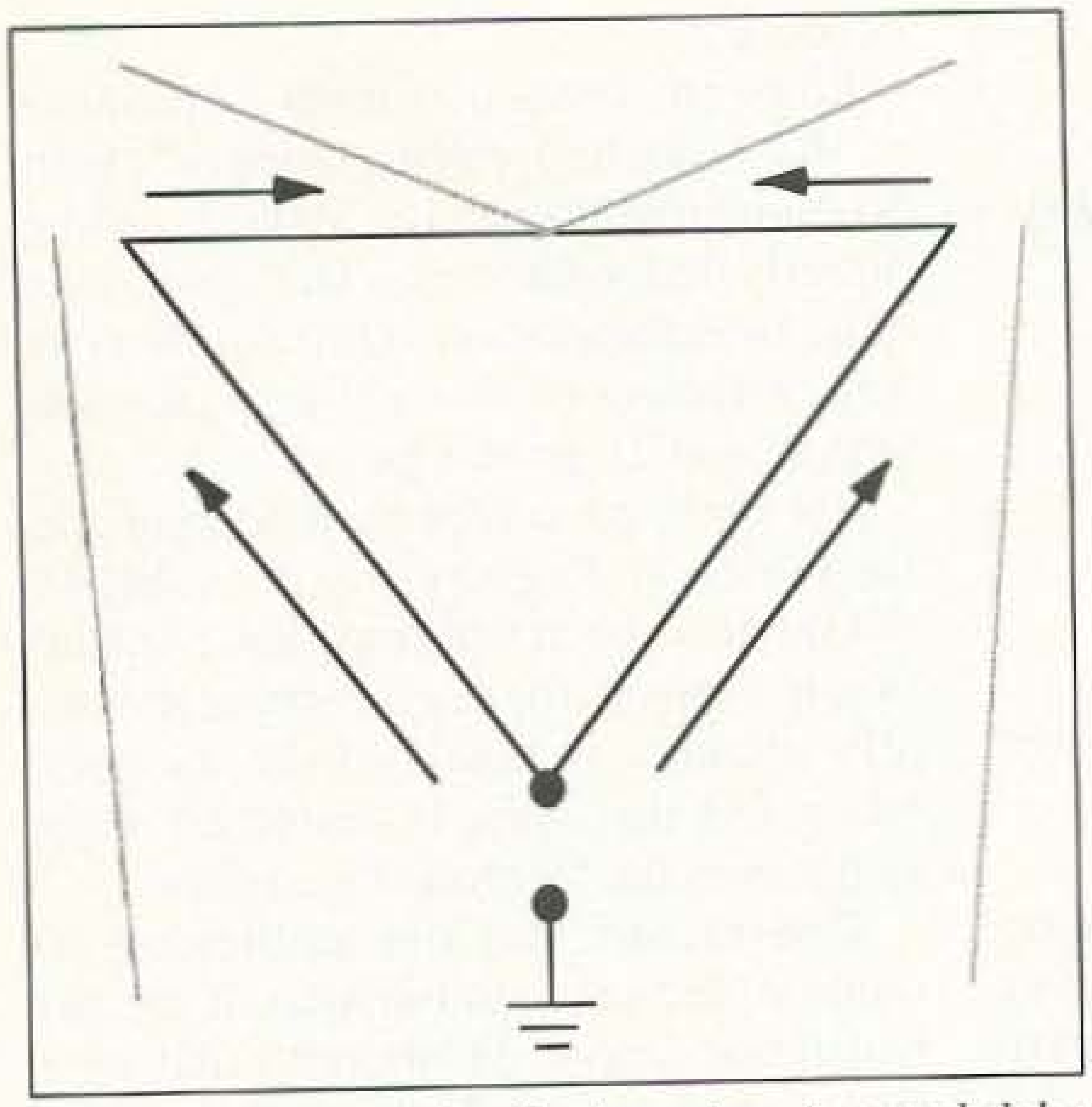

Figure 7. Current distribution of an inverted delta loop, F = 1.9 MHz. fed as a vertical element.

End-Fed Loop

Now what about feeding only one of the wires, leaving the other unconnected? Let's fold the one-wavelength, end-fed wire of Figure 2B into an inverted delta shape along with its current distribution (see Figure 5).

We now have high impedance at our feed point as the current maximums have moved to points B and D of Figure 5. This altered current distribution in the loop changes its pattern, just as we saw with the straight wires in Figures 2C and 2D.

In this case, there are two horizontal currents (Htop and H'top) in the top portion that are equal in strength but run in opposite directions and so cancel. The side leg currents, broken again into horizontal and vertical components, show that Hleft and Hright also run in opposite directions and they too cancel. The result is no horizontally polarized radiation.

But the vertical components Vleft and Vright now run in the same direction (up) and so aid each other. Thus, we have vertically polarized broadside radiation from the antenna when it is fed this way.

And depending on the spacing of, and relative phasing of current in, the two side legs, we also have the potential for endfire vertically polarized radiation. But we haven't yet explained the two different endfire directivities noted on the air.

Endfire Directivity

The end-fed loop currents in the side legs should be in phase with each other since the distance from the feed point to the end of the antenna is exactly one wavelength; 360° of phase shift brings you around to 0°, in phase again. If this were actually so, the end-fed loop would have exactly the same pattern in both endfire directions.

But this is not so. We have observed endfire pattern changes when switching feeds from one end to the other. This could occur only if there were an extra amount of phase shift in the currents as they moved along the wire. What can the source of this phase shift be?

Traveling Waves

It is caused by "traveling waves" on the antenna. Non-center-fed antennas display a traveling wave effect. This shows up as an increasing phase shift in the current as we move away from the feed point. It is mostly the result of RF energy being radiated from the antenna. The effect of the traveling wave is to skew the pattern of an antenna, pulling it in the direction of the wire axis away from the end feed point[3, 4, 5].

In the case of our end-fed loop (which, you recall, is a bent, end-fed antenna), it makes the pattern nonsymmetric in the two endfire directions. This shows up as different low-angle gain and a high-elevation angle null that is tilted away from the end being fed.

Side Feed

Another possible feed arrangement for the inverted delta loop is to break it at an upper corner to feed. This is reported to be a good configuration for DX with a strong, low-elevation angle, a vertically polarized lobe, and only a weak high-angle lobe[6].

A further refinement is to feed it below the upper corner, on one side leg, at a distance of a quarter wavelength up from the wire axis at the bottom (see Figure 6)[7]. This side feed location forces the currents in the two bottom legs to reverse direction exactly at the bottom junction and exactly in the middle of the top section, when the loop is operated at resonance.

This gives perfect current symmetry: The vertical components add up and the horizontal components cancel, to the greatest possible extent. This maximizes the strength of the low-elevation angle lobe, while producing the deepest high-angle null.

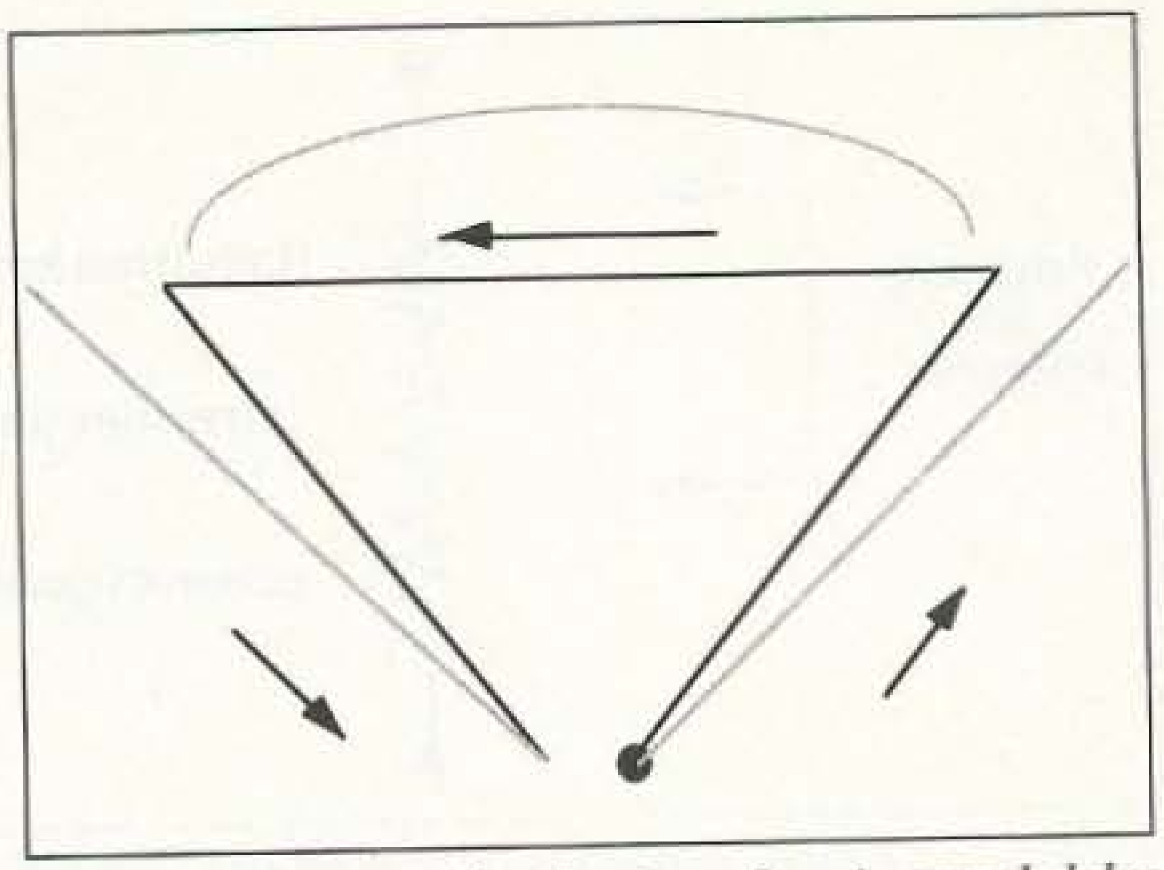

Figure 8. Current distribution of an inverted delta loop, F = 1.8 MHz. end-fed.

Surprise Number Two

Drawing the currents of the side-fed loop shown in Figure 6 reveals a startling fact: The current distribution is exactly the same as for our end-fed loop! Compare it with Figure 5.

I had long wanted to try the side feed arrangement, but was daunted by the fact that this configuration would not be optimum for non-DX contacts and that the upper corners of my loop were located in high trees. So there would be no easy, quick way of changing the feed point from bottom to side, and vice versa, to switch modes. End feeding the loop solved these problems and gave switchable endfire directivity, too.

You Mean There's More?

Yes, 160m can also be had with this piece of wire Here's how: If you could grab the middle of the top of the loop and stretch it all the way up, you'd have a quarter-wavelength long, 160m vertical antenna consisting of two parallel wires connected at the top.

So I thought to feed the wire as a "squashed" or wide cage quarter-wavelength long vertical antenna. I did this by tying both bottom ends together and feeding them against ground. The input impedance was about 50 ohms.

Once more we can plot the currents (see Figure 7), remembering that on 160m the wavelength is twice as long as on 80m. Based on an analysis of the current as before, the horizontal components of the current in the sides and top run in opposite directions and so cancel. This leaves only the vertical components of current in the sides running in the same direction (up) and so add together, and we have vertically polarized radiation.

Another ham suggested that I ground one end of the loop and feed the other against ground. This turns it into a conical, vertical, folded unipole (half of a

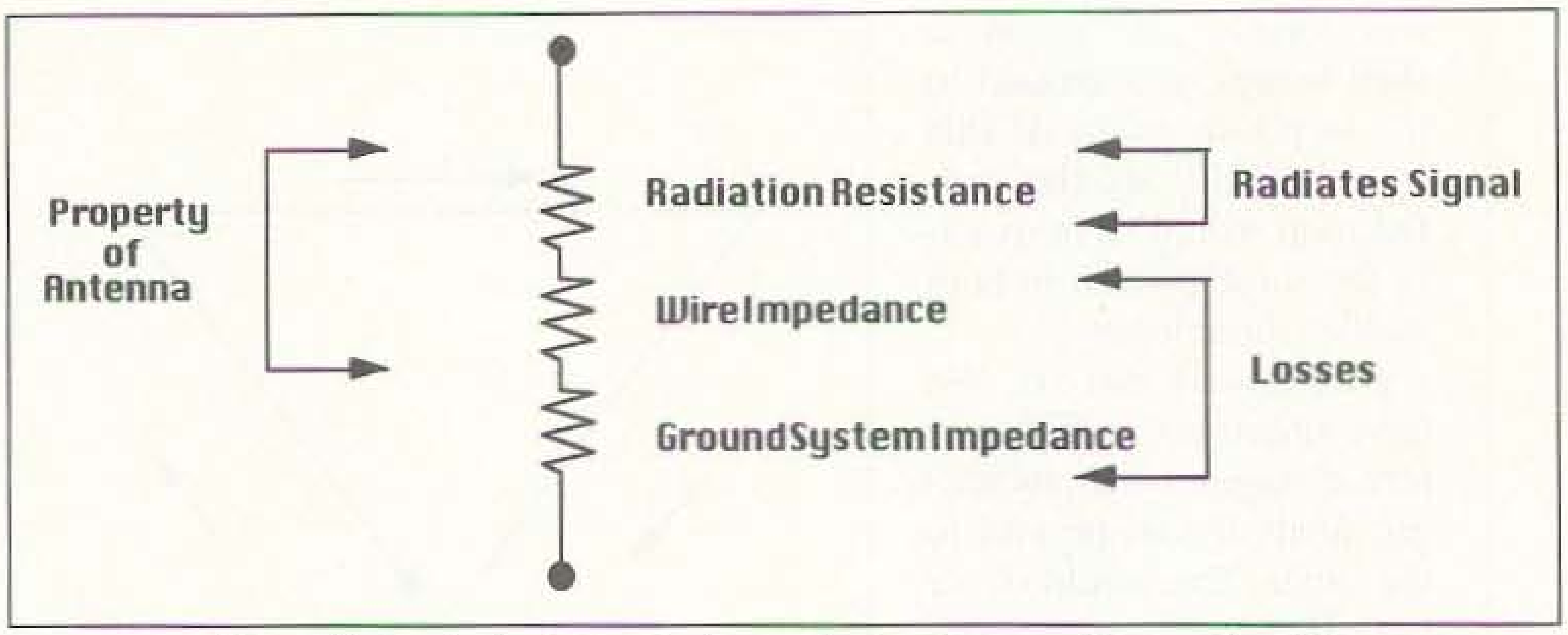

Figure 9. Equivalent circuit of a vertical antenna and ground system.

folded dipole). The feed point impedance is about 75 ohms, which still allows direct coax feed. This configuration works about as well as the squashed vertical feed arrangement above but is sometimes noisier on receive.

Don't kid yourself about improved efficiency here, though. It's just the input impedance of the antenna that's been stepped up by the folded dipole action. Series losses due to ground resistance are still there to the same extent[8].

Let's give that end-fed trick a try on 160 too, again using the L-network and fed against ground. We could be surprised some more; it sometimes worked better than the squashed vertical configuration and occasionally displayed some mild directivity when I swapped feed ends. Looking at the currents (Figure 8) shows that it's a mostly straight-up, horizontally polarized broadside radiator with vertically polarized endfire radiation. This should give a decent combined polarization, omnidirectional pattern.

Ground System

In general, you need a good ground system to get the most out of antennas that produce vertically polarized radiation, as our end-fed and squashed vertical fed loop does.

With a base-fed quarter-wavelength vertical antenna, current flow is maximum at its bottom end, right next to the ground. The amount of ground current that is caused to flow depends on the amount of antenna current flow closest to the ground.

As a result, a large amount of current will flow in the nearby ground around the base of a quarter-wavelength antenna. This leads to highest I2RGROUND losses as the ground currents fight their way, in a radial pattern, back to the base of the antenna through lossy soil, heating up the dirt.

For this kind of antenna to work most efficiently, the ground system must intercept as much of the surrounding ground current as possible and convey it, with the least amount of loss, back to the base of the antenna.

As the ground resistance appears in series with the impedance of the antenna, power applied to the antenna will divide between them depending on the relative impedances. The ground system is therefore very important for good performance in this situation. A good radial or counterpoise (elevated radial) system, plumbing connections, ground rods, and so forth are needed to get the most performance from such antennas.

This shows why we need to think of the combination of antenna and its ground as a system.

160m Ground

On 160m, we're running the squashed vertically fed loop just like a quarter-wavelength vertical antenna (maximum current at the bottom end of the antenna), and so a good ground system is necessary.

Since the measured input impedance of our squashed vertical loop is about 50 ohms resistive at 1.9 MHz, it can be directly fed with coax. The antenna is quite broadbanded on 160m due to 1) its large effective diameter (like a cage antenna), and 2) ground losses.

But both my computer modeling and the *Antenna Engineering Handbook*[9] tell me that the actual impedance (radiation resistance, the useful part that actually radiates a signal) of the antenna, when fed this way, is about 20 ohms rather than the 50 ohms I measured.

This means that the additional 30 ohms is due to a combination of ground resistance (about 28 ohms[10]) and wire impedance (about 2 ohms; this is not DC resistance but the RF impedance of the wire that is higher due to the skin effect—see Reference 1) that show up in series with the radiation resistance of the antenna. Figure 9 shows the equivalent circuit of the system.

This causes inefficiency, about 8 dB worth, which means I'm throwing about 60% of the power away with my particular ground system! A better ground system would reduce this loss and thereby increase antenna efficiency.

Your tip-off here to better performance is that the antenna's measured input impedance will drop toward, but won't quite ever reach, about 20 ohms as the ground system is improved.

75m Ground

When our loop is end-fed on 75m, its current maximums (points B and D in

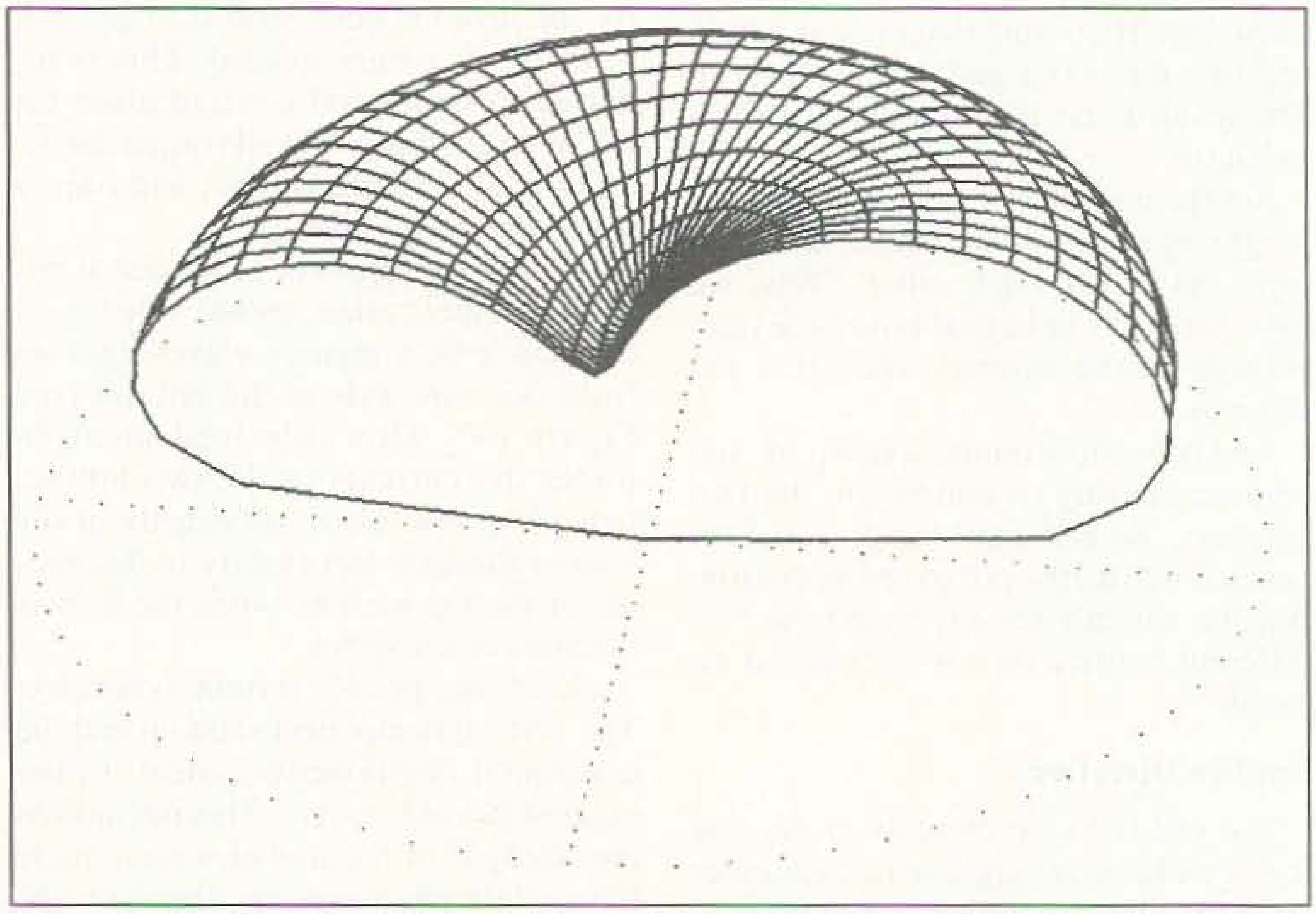

Figure 10. The 3-D plot of the end-fed loop (75 meters), showing the high-angle null in the pattern which is tilted away from the end being fed, and the low-angle lobe all around.

Figure 5) are raised up off the ground, to a height approaching a quarter wavelength. Recall that it produces vertical polarization when end-fed. Its current distribution is like a half-wavelength vertical antenna, with the current maximum now raised up a quarter wavelength in the air. Rotate the dipole of Figure 1 by 90° and put one end touching the ground to see this.

Because antenna current at the bottom end of the antenna, near the ground, is now minimum, less (lossy) ground current is induced. Also, the feed point impedance is now higher so that relatively less voltage gets developed across the ground system impedance, as in Figure 9. This means that ground system requirements are less stringent for our end-fed loop on 75m than they are on 160 m[11].

Because those parts of the antenna radiating the most (the current maximums) are now raised off the ground, the end-fed loop on 75m shares some of the other advantages of a half-wavelength vertical antenna: 1) A slight lowering the elevation angle of radiation; and 2) Better clearance of nearby obstacles. Overall, there is a reduction of ground, environment, and feed losses, relative to a base-fed quarter-wavelength vertical.

My loop worked satisfactorily with four insulated-wire, quarter-wavelength radials that just lie on the ground. Two radials are cut for 75m and two for 160m. They lie in the plane of (directly beneath) the antenna in both directions. This arrangement of radials gives me maximum measured RF ground current.

Broadcast Band

Since the upper edge of the standard AM broadcast band lies just below 160m, I thought to try the antenna and its feed variations there. I noted different reception effects when changing among the feed types, down to about 1100 kHz though they are strongest toward 1600 kHz.

For example, feeding the antenna as a squashed vertical brought one vertically-polarized 50 kW BC station on 1560 kHz located within ground-wave range well up in signal strength. Switching to end feed suppresses it so greatly (20 to 30 dB) that co-channel skywave-propagated stations never before heard become audible.

On one occasion, switching among balanced, end, and squashed vertical feed allowed three different co-channel stations to be logged. This is an admittedly rare occurrence but illustrates how useful selectable directivity and polarization can be.

SWLing

As the loop shows numerous HF resonances, it's not surprising that it's useful all the way up to the top of the HF spectrum and beyond. Once again, the various feed arrangements are useful in optimizing HF reception. As before, some feeds optimize SNR and some optimize signal strength; they are not always the same!

Since the antenna is so broad and flexible, I believe that construction of the largest loop within the limits of available real estate and supports, regardless of its size (and therefore resonant frequency), would provide an excellent SWL antenna. The L-network could probably be dispensed with for reception, but you'd definitely want to be able to switch easily among various feed arrangements.

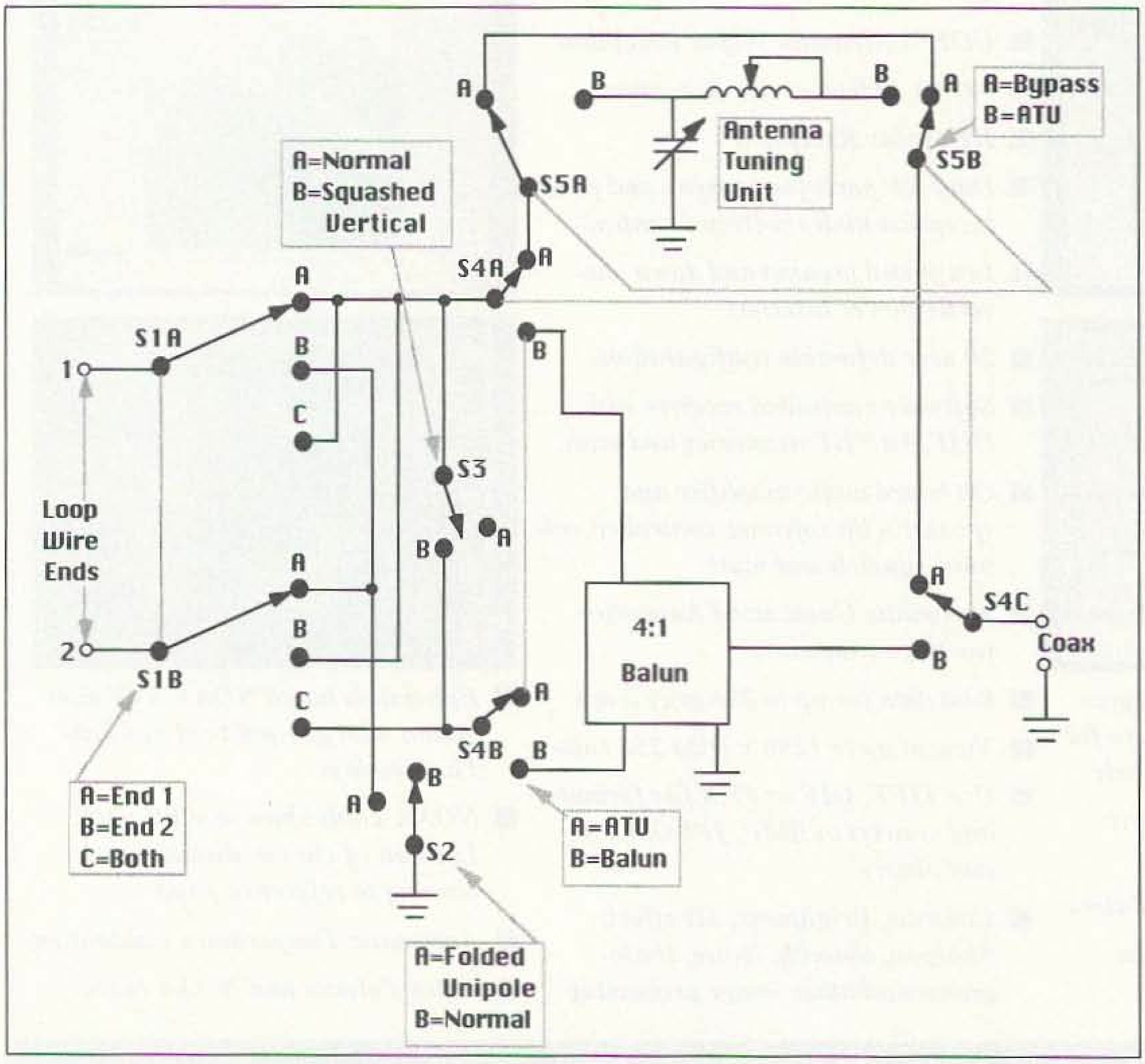

Figure 11. Loop switching and feeding arrangement for convenient selection of all the different feed arrangements described.

Other Bands

The loop also works fine on 40, 20, 15, and 10 meters using the various feed and matching arrangements. I haven't tried it on 30, 17, or 12 meters yet but I'd expect good results there too.

Other Loop Shapes

I think it's worth trying these various feed arrangements with any other loop shape (quad, delta, circular, and so forth) as well, no matter what their height above ground, or length and type of feedline, or whether they are oriented in the vertical or horizontal plane, or anywhere between.

Computer Modeling

After using the antenna for several years, I was able to model it using the MININEC antenna analysis program. MININEC has certain limitations when modeling antennas with horizontal wires, or horizontally flowing currents, less than 0.2 wavelengths off the ground: For example, gain predictions will be too high, but pattern shapes will be reasonably correct[12].

The analysis clearly revealed what I had noticed on the air when end feeding the antenna on 75m. The 3-D plot shown in Figure 10 shows the high-angle null in the pattern that is tilted away from the end being fed, and the low-angle lobe all around.

Summary

This article has described four different ways of feeding an inverted delta loop antenna: 1) balanced feed at bottom; 2) end-fed at bottom (one wire fed and the other wire left floating); interchanging the fed end swaps the endfire directional patterns; 3) one wire-fed and the other wire-grounded, a folded unipole; 4) both bottom end wires tied together, fed against ground, as a squashed vertical.

Figure 11 shows a switching arrangement for convenient selection of all the different feed arrangements. This could also be done with patch cords and alligator clips.

I would enjoy hearing about your experiences with this kind of antenna (Box 373, Baker, MT 59313). Please include an SASE if you'd like a reply.

Epilogue

Since moving to Montana, I have put the antenna up again. Unfortunately, I have just one row of relatively short trees to use for supports, so the loop now lies in a plane tilted about 20° from horizontal. The top of the loop still runs horizontally for about 95 feet, but is only 30 feet high.

The side legs are quite unequal in length. One leg is partly draped over the roof. The lower end of the loop (the feed point) slopes downward. The feed point is about 10 feet above ground. The feedline consists of a parallel run of extra wire that runs into the shack (again in the basement!).

In spite of these handicaps, the loop still shows some directivity effects and can be used in all the ways previously described. When end-fed on 75m, it does not have the low-elevation angle capability of the original arrangement, though. When balanced-fed, it's more of a "cloud warmer" but is still quite satisfactory. It seems to have better performance on 40m than before.

On 160, it's now electrically too long for resonance at 1.9 MHz, so I use a three-gang AM broadcast receiver-type variable capacitor in series with it to tune out the inductive reactance. When fed against a decent ground, its input impedance approaches 50 ohms resistive.

It works surprisingly well on 160 meters for such a low antenna; its top is only about 0.12 wavelength off the ground on 160m. However, soil conductivity is quite high here due to a large amount of dissolved alkaline minerals. This would enhance the performance of the antenna considerably. 73

References

1. The ARRL Handbook, *American Radio Relay League, 1983, p. 19.7. Plans for a balun can be found in almost any amateur radio handbook. Orr, W. I.*

2. Radio Handbook *(21st Ed.), Editors and Engineers Div. of Howard W. Sams, Indianapolis, 1978, p. 3.18. As frequency is raised, more and more of the current is forced to flow in the outer layers of a conductor toward its surface. This means that corrosion of antenna wires or elements, which occurs on the surface, can have a stronger effect on antenna losses because more of the RF current flows there. Insulated or coated, wire and elements can prevent corrosion.*

3. Rautio, J.C., "The Effect of Real Ground on Antennas—Part 5," QST, *November 1984, Figures 4H-4L, 5.*

4. The ARRL Antenna Book, *American Radio Relay League, 1974, p. 58, Figures 2-70.*

5. Balanis, C.A., Antenna Theory, *Harper-Row, New York, 1982, pp. 372-374. Additional traveling wave effects are caused by wire impedance and ground effects.*

6. Mayhead, L. V., "Loop Aerials Close to the Ground," Radio Communications, *May 1974, Figures 9, 15. Gives experimental results from measuring scale-model, variously shaped and fed, one-wavelength loops over a metallic ground.*

7. Devoldere, J., Low-Band DXing, *ARRL, 1987, p. II-49, Figure 2.55(C). I adapted his feed idea for a delta loop for use with an inverted delta loop.*

8. Devoldere, p. II-25, par. 2.4.4.

9. Jasik, H., ed., Antenna Engineering Handbook *(1st edition), McGraw-Hill, New York, 1961, Figures 3-13.*

10. Devoldere, op. cit., p. II-24, Table 12, "Equivalent Series Resistance of Radial Systems in Ohms." See entry for two quarter-wavelength radials.

11. Belrose, J. S., "160-meter Antennas," Technical Correspondence, QST, *July 1991, p. 49-50.*

12. Lewallen, R., "MININEC: The Other Edge of The Sword," QST, *February 1991, pp. 18-22. There is also a well-known frequency offset error in this program for which I have accounted in my analysis. This article gives a good overview of the program.*