Horizontally Polarized Omni-Directional Antennas: Some Compact Choices

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Obtaining omni-directional coverage with vertical polarization is simple: use a version of the many vertical antennas including the ¼-wavelength ground-plane monopole, the vertical dipole with or without a J-pole matching section, or any number of collinear variations on these antennas. However, if we wish to have omni-directional coverage with horizontal polarization, solutions are less automatic. In fact, the search for a perfect horizontally polarized omni-directional (HPOD) antenna goes back into the dim recesses of antenna history. We shall examine a number of options, their limitations, and, in some cases, ways to overcome those limitations. We shall divide the work into two parts, looking at some of the more compact choices in this episode. Next time, we shall examine a few larger omni-directional horizontal arrays and take a longer look at stacking them.

The search has two dimensions. The first is obtaining a perfect circle for an azimuth radiation pattern. How far from circular you may be willing to accept a pattern may determine how much work you will put into the antenna design and construction-or vice versa. The second dimension is field strength or the antenna gain at low angles. As we shall see, some designs with good patterns unfortunately send a goodly part of their energy in useless directions, such as straight up or down. While helpful for satellite reception, these antennas are less than ideal for some VHF point-to-point applications.

All of the antennas in these notes use 144.5 MHz as the test frequency. Patterns and performance values assume a height of 20' above average ground.

Turnstile or 90° Phase Fed Systems

Perhaps the oldest HPOD antennas employ one or another form of phase feeding, using at least 2 elements. **Figure 1** shows the most common form of feeding one element with the same current magnitude but phase-shifted 90° from the other. Both elements are identical, but are at right angles to each other. The phase line characteristic impedance is the feedpoint impedance of the directly fed element. However, with both elements connected, the net feedpoint impedance is one-half of the impedance of an isolated element. There are alternative feed systems to arrive at the same goal, but a few of them concern themselves with impedance matching rather than obtaining the correct current magnitude and phase angle at the center of each element.

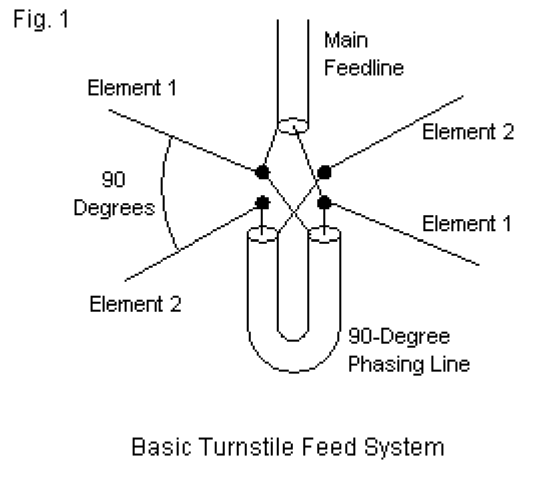


Fig. 1

Basic Turnstile Feed System

The simplest version of this antenna also gave birth to the generic names for the feed system. A pair of resonant dipoles at right angles to each other presents the appearance of a turnstile. **Figure 2** provides the general outline of the antenna. The version from which we drew the patterns uses 0.125" aluminum for the 38.96" elements. The model places the elements 0.25" apart, center-to-center. Each dipole presents a 70-Ohm impedance. With the 70-Ohm ¼-wavelength phase line in place, NEC-4 reports a net feedpoint impedance of 35 Ohms. Since the impedance does not change over a very broad frequency range, we may accept the 1.43:1 50-Ohm SWR or we might use a series matching system to match more exactly a 50-Ohm feedline.

Turnstiled Dipole Elements
General Outline and Patterns
at 20' above Average Ground

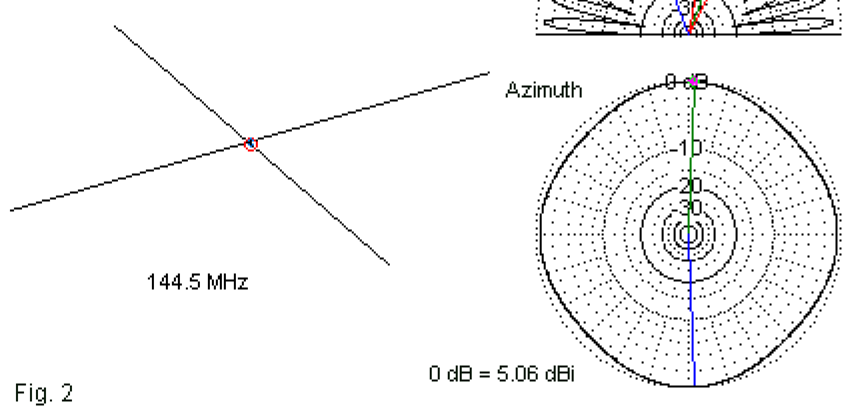
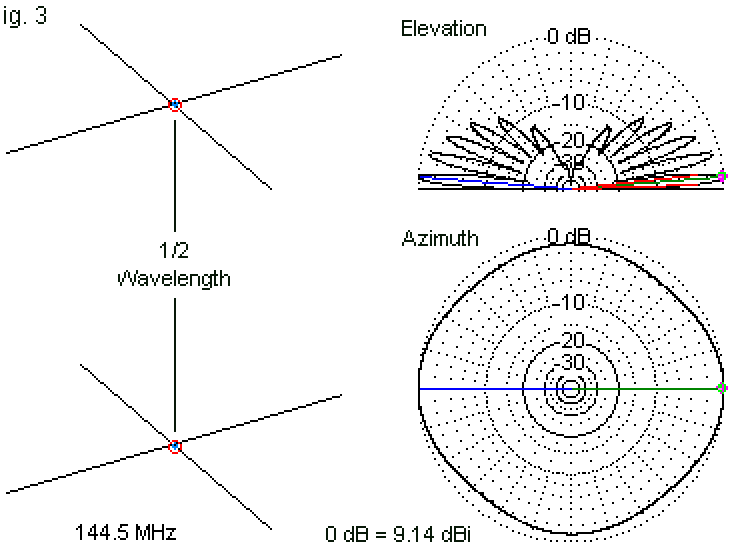


Fig. 2

The azimuth patterns show a slight squaring, but the gain range is only about 0.5 dB, less than we could detect in operation. The chief limitation of the turnstiled dipoles is revealed in the elevation pattern. We find more energy broadside to the dipole pair than off its edges. Hence, the maximum gain at 20' and a 4.8° TO (take-off) angle is only 5.06 dBi.

Ott Fiebel, W4WSR, pointed out to me an interesting variation on the standard turnstile by placing two ½-wavelength elements at a 90° angle, but using one end of each element to form the apex. A simple ¼-wavelength parallel line matching section connected in series with the ends at the apex allows a 50-Ohm match. Although the pattern is not quite as clean as the standard turnstile pattern, the construction is simple and reliable.

Fig. 3

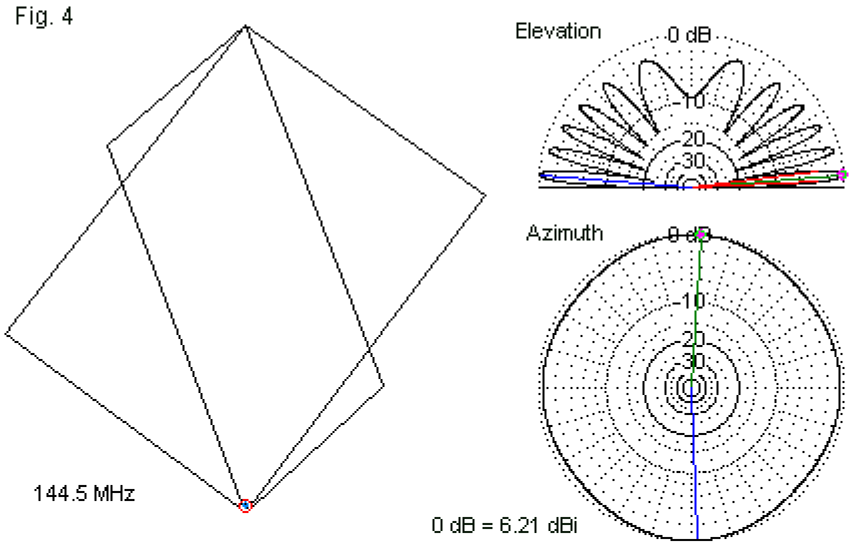


Dipole Turnstile 2-Stack: General Outline and Patterns
with Lower Antenna 20' above Average Ground

Figure 3 shows one way to overcome the broadside radiation of turnstiled dipoles: create a stack with ½-wavelength separation. In the model, the lower antenna is at 20', with the upper antenna about 80" above it. The elevation pattern shows a radical reduction in high-angle radiation. The maximum gain of the antenna pair is 9.14 dBi, with a 0.9-dB range of gain around the perimeter of the azimuth pattern. However, we cannot use the same dipoles that we used in the single turnstile. Mutual coupling between the bays requires that we lengthen the dipoles to 40.2". Without this adjustment, the pattern becomes very distorted. We would not notice the distortion from the SWR. For all turnstiles, the SWR bandwidth is very much wider than the operating bandwidth measured in terms of an acceptable pattern. For further information on the performance behavior of turnstiled antennas, see "Some Notes on Turnstile Antenna Properties," *QEX*, March/April, 2002, pp. 35-36.

We may also turnstile 1-wavelength quad loops at right angles to each other. A single quad loop has an impedance of about 125 Ohms, for a net feedpoint impedance of 62.5 Ohms for the turnstiled pair. RG-63 (125-Ohm) coax is suitable as a phase line. **Figure 4** shows the outline and patterns for one version of the antenna using a diamond configuration for simplified construction. (See "A 6-Meter Quad Turnstile," *QST*, May, 2002, pp. 42-46, for one version of this antenna.) The elements are AWG #12 copper wire, with each loop having a circumference of 87.7". Alternatively, one might equally use quad loops in a square configuration, the so-called eggbeater. In either configuration, we may leave a gap between the top wires at the crossing point or connect them together. Performance does not change.

Fig. 4



Turnstiled Quad Loop Elements: General Outline
and Patterns 20' above Average Ground

The elevation pattern shows a significant improvement in the direction of radiation from the antenna, with the lowest lobe as the strongest. The maximum gain of the modeled turnstiled quad is 6.21 dBi, with a gain range of about 0.5 dB, as shown by the not-quite-perfect circle of the azimuth pattern. The TO angle is 4.8°. All of the patterns in these notes will use the maximum gain at the TO angle as a measure of performance. It serves as a stand-in for our real concern with HPOD antennas: the signal strength for point-to-point communications over some fixed distance and a fixed observation or reception height.

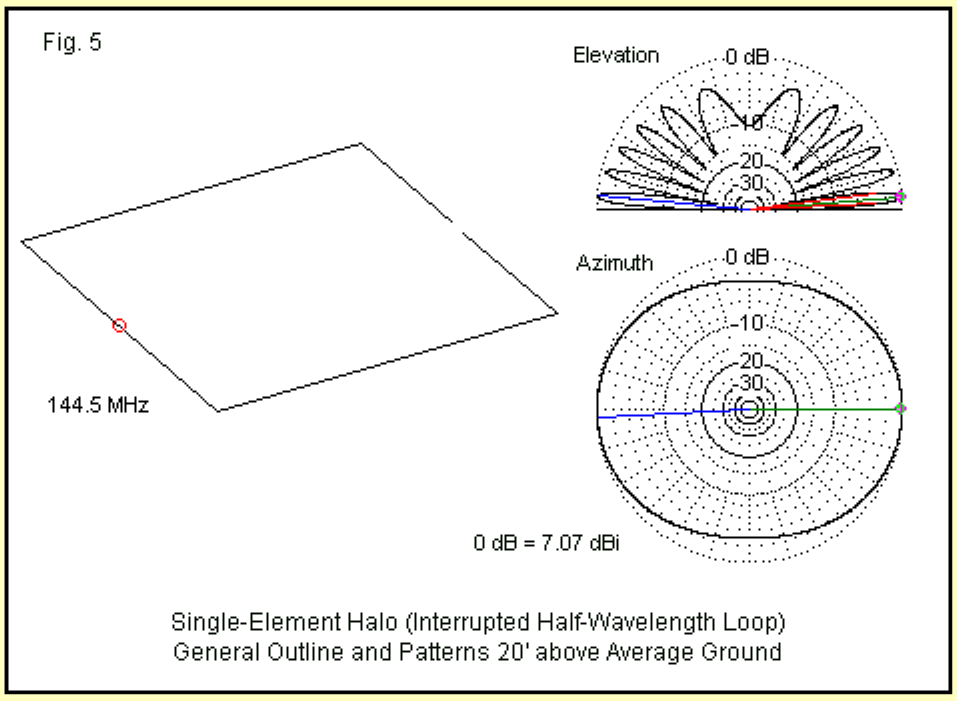
Once we overcome the basic turnstile's broadside radiation that robs energy from the desired edgewise signal path, matching becomes the most obvious construction hurdle. However, the turnstile antenna has a hidden limitation. The pattern shape is highly dependent upon the magnitude and phase relationship between the two feedpoints. Most common feed systems provide a correct relationship at only one frequency, and the values change as we move away from that frequency. Small inequalities in the current magnitude and departures from the required 90° phase-angle result in considerable distortion to the nearly circular pattern at the design frequency.

We might easily turnstile or phase-feed a number of other antennas. However, most of them would serve better for satellite communications than for horizontally polarized direct communications. Therefore, we may let the dipole and quad loop turnstile pairs serve as examples of our initial technique for obtaining omni-directional patterns.

Halos

The second common category of antenna for obtaining at least a semblance of a circular azimuth pattern is one or another version of the halo. More correctly, this class of antenna rests on a ½-wavelength dipole bent so that the ends almost meet. The most tempting form for the halo is either a circle or a square. However, as **Figure 5** shows, a symmetrical halo with a single element yields a highly non-circular pattern. The model uses 0.5" aluminum for the element that is 10" on a side with a 0.52" gap. The azimuth pattern gain varies by nearly 3 db. To boot, the impedance is only about 8.3 Ohms.

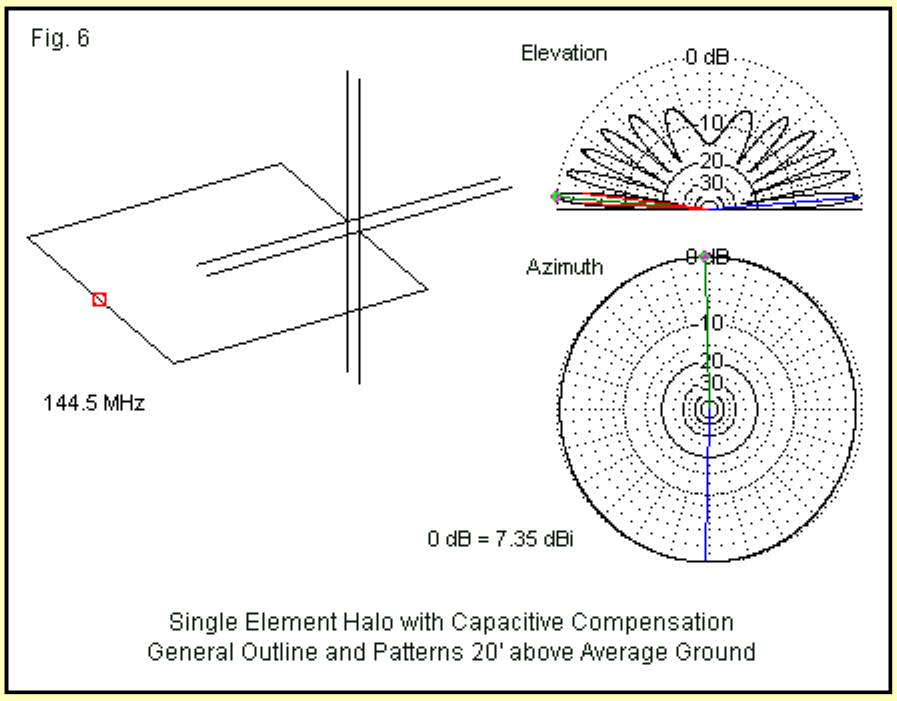
Fig. 5



Single-Element Halo (Interrupted Half-Wavelength Loop)
General Outline and Patterns 20' above Average Ground

One way to circularize the pattern is to add a surface on each element end to increase the capacitance between ends. The model outlined in **Figure 6** simulates plates be using 4 facing 6" wires on each side of the gap. A normal halo would employ a disk. We see an obvious improvement in the pattern shapes, with a maximum gain of 7.35 dBi and a gain variation of less than 0.4 dB. As well, the feedpoint resistance is about 49 Ohms. However, the plates have added an inductive reactance of j1000 Ohms. Hence, we need a series capacitance at the feedpoint of 1.1 pF. This requirement creates a considerable matching difficulty, since very small changes in the capacitance will create large changes in the feedpoint impedance.

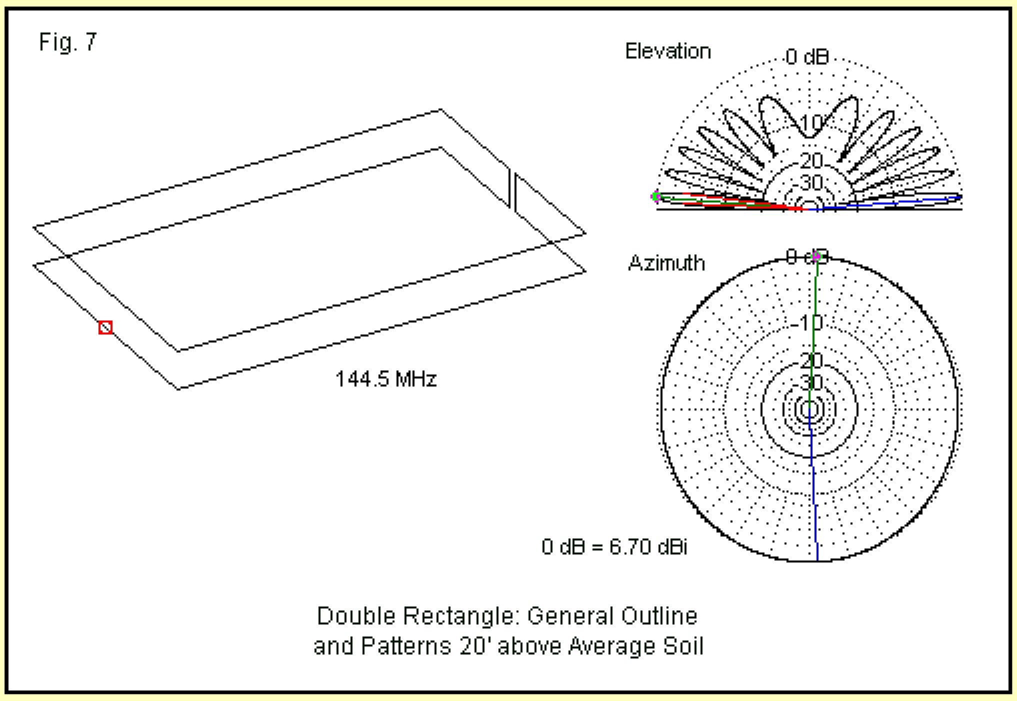
Fig. 6



Single Element Halo with Capacitive Compensation
General Outline and Patterns 20' above Average Ground

To overcome this difficulty-at least to some extent-we may use a double loop, as shown in **Figure 7**. The double loop is essentially a halo version of a folded dipole, which raises the feedpoint impedance. At the same time, the design uses a rectangular form to circularize the azimuth pattern without the need for a large capacitive structure. The sample model uses AWG #12 copper wire. Across the feedpoint, the side is 8.8", while the long sides are 14.3". The gap between ends is 0.35", and the spacing between wires is 1.34".

Fig. 7

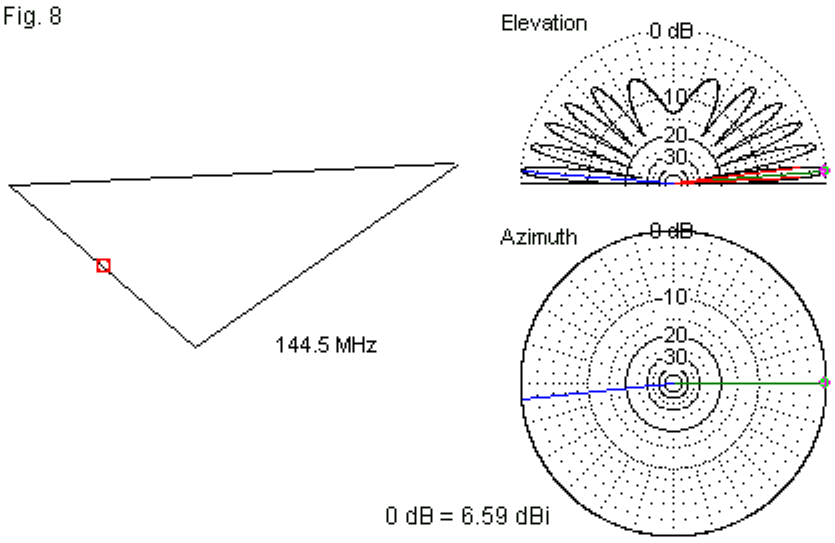


Double Rectangle: General Outline
and Patterns 20' above Average Soil

The double rectangle shows a maximum gain of 6.7 dBi (at 20' above average ground), with a variation of only about 0.5 dB around the azimuth pattern. The feedpoint resistance is 64 Ohms, but there remains a considerable inductive reactance. To compensate for the 721-Ohm reactance, we require a series capacitor at the feedpoint (1.53 pF), which complicates effective and efficient matching. Alternatively, we may adjust the capacitance across the gap by reshaping the wires that face each other.

The halo need not be either circular or rectangular to form an interrupted half-wavelength loop. One interesting alternative shape is a triangle with a gap at the apex, across from the feedpoint. With the correct ratio of leg-length to feedpoint-side leg and the correct gap, we can obtain a very circular azimuth pattern. In general, we find two versions of the triangle, a smaller version with a circumference that is less than 0.6-wavelength and a larger version with a circumference greater than 0.75-wavelength.

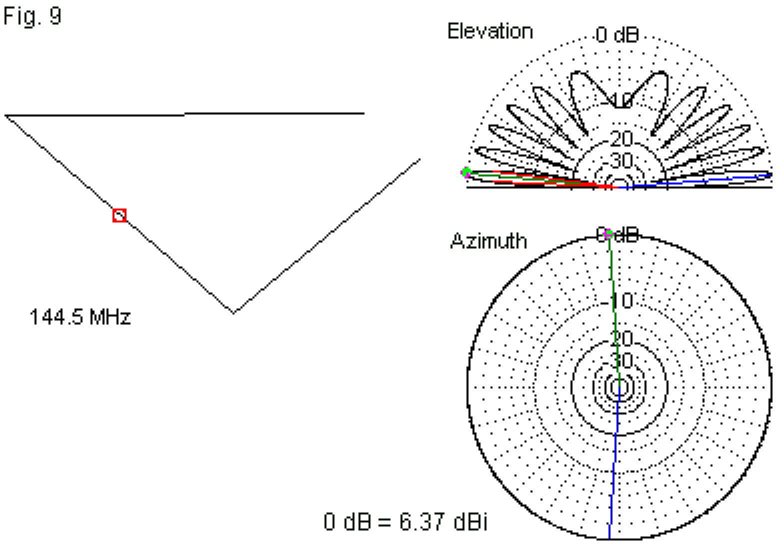
Fig. 8



Small Triangle: General Outline
and Patterns 20' above Average Ground

Figure 8 shows the outline of a small triangle that uses a 0.125" diameter aluminum element. The feedpoint side is about 14" long, while the angled legs are each 16.8". The circumference is 47.5". The apex gap is quite small in the model: 0.12". At 144.5 MHz, the maximum gain is 6.59 dBi, with less than 0.1-dB variation in the gain. However, the resonant feedpoint impedance is only 8.4 Ohms. Hence, we require an impedance transformer to use the antenna effectively.

Fig. 9



Large Triangle: General Outline
and Patterns 20' above Average Ground

The large triangle is an alternative to the smaller one. The modeled sample in **Figure 9** has a circumference of 64.3", with a 23.8" feedpoint side and 20.3" angled legs. The large triangle achieves about 6.37-dBi gain at the test height. Like the small triangle, the gain variation around the azimuth pattern is under 0.1 dB. The ostensible advantage of the large triangle is the feedpoint resistance: 58 Ohms. However, the feedpoint impedance also shows a remnant inductive reactance of 525 Ohms. Hence, we require once more a series capacitance (1.85 pF) or other treatment to arrive at resonance.

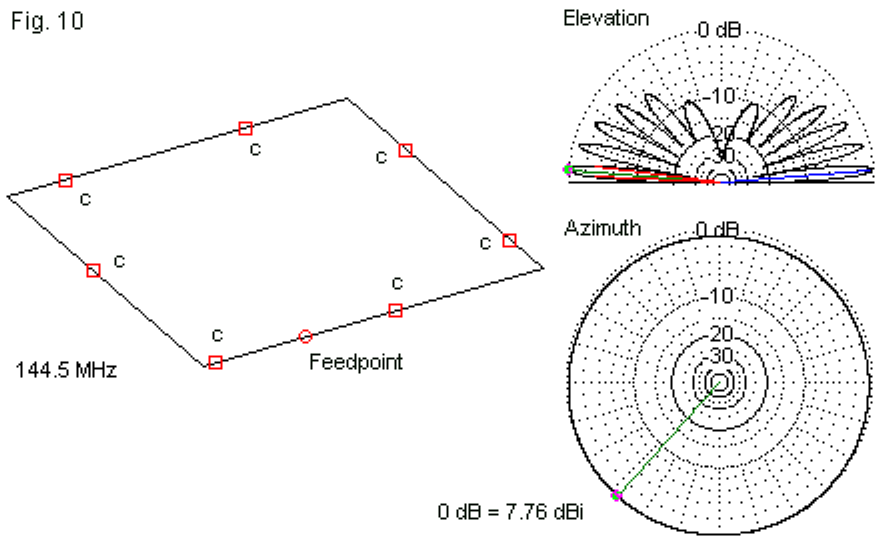
In general, accurately constructed halos exhibit very circular azimuth patterns. Unlike the turnstiles, the pattern shape is quite stable over frequency spreads within the SWR bandwidth of the antenna. Nevertheless, halos have their own limitations for the home builder. Prototypes that I have built of various halos-both rectangles and triangles-in my modest shop suggest that the antenna type presents us with two significant hurdles. The elimination of remnant reactance is the more obvious of the challenges. The second difficulty lies in the susceptibility of these antennas to changing resonant frequency with only minor flexing of the elements. The interrupted-loop construction adds the size and alignment of the gap to the list of dimensional concerns. An effective halo must freeze both the size of the gap and the alignment of the element at the gap. As well, the remaining lengths of element material should not be susceptible to flexing that would change the design shape.

The Uniform or Constant Current Loop

An overlooked design emerged in 1944 in Donald Foster, "Loop Antennas with Uniform Current, *IRE*, Oct, 1944. Recently, Robert Zimmerman, NP4B, resurrected the idea in "Uniform Current Dipoles and Loops," in *antenneX* for April and May, 2006. The principle is to divide the circumference of a loop into sections such that the inductance of each wire length is offset by a periodic capacitor and so that the loop exhibits a 50-Ohm impedance--without need for any form of matching. Let's divide a square of wire into 7 sections. Each section will be 0.12-wacelength long, for a total circumference of 0.84 wavelength. At each wire junction, we shall insert a capacitor. The capacitor size will vary with the wire diameter. AWG #12 calls for 4.11-pF units.

In physical terms for 144.5 MHz, each AWG #12 wire section is 9.8" long. The square is 17.15" on a side for a circumference of 68.6". The number of sections (7) does not correspond to the number of sides (4), which is no hindrance to effective antenna operation. Although the component arrangement yields omni-directional patterns, the appearance of the antenna, as shown in **Figure 10**, may seem initially strange.

Fig. 10



Constant-Current Loop: General Outline
and Patterns 20' above Average Ground

It does not matter if the feedpoint is placed mid-side or near a corner, so long as the feedpoint is in the middle of a wire section. The relative current magnitude along the circumference of the loop changes by less than 4% all along the perimeter. (Initially, this phenomenon appears to have been the goal of the open-ended CCD long doublet, but the open ends preclude obtaining that result.).

The uniform current square loop provides horizontally polarized radiation. Although only a little larger than the triangles, the results are equal in omni-directionality and superior in gain. At 20' above average ground (close to 3 l), the maximum antenna gain is 7.76 dBi, with a total variation in gain of about 0.8 dB. The gain is about a dB better than the best triangle. The elevation pattern reveals one significant reason for the improved gain from the loop. If you compare the elevation pattern with the one's shown for the triangles, you will see that the loop produces virtually no radiation straight upward, leaving more energy for the lower lobes.

Since the antenna does not need to compensate for rapidly changing reactance values, it shows a reasonable SWR bandwidth. However, the design is sensitive to the capacitor value within very close tolerances. The resonant impedance (50.7 Ohms) of the model using 4.11-pF capacitors changed to an impedance of 45.4 - j39.1 Ohms simply by using a 4.0-pF capacitor value. However, Zimmerman uses an interesting technique involving parallel transmission line for his loops. See "Uniform Current Loop Radiators," *QEX*, May/June, 2006, pp. 45-48. By cutting alternative positions on the wire length, he allows the facing wires to form the capacitors. Field adjustment consists of slowly widening the gaps until you achieve the desired capacitance.

If you prefer a more symmetrical arrangement, you might increase the number of capacitors to 8, placing them at corners and at the center of each side. Without altering the loop size, the capacitor size increases slowly as you add capacitors. For 8 capacitors, models suggest a value of 4.7 pF for each one. The feedpoint remains centered between two capacitors. In addition, the radiation performance does not change. The chief hurdle in constructing a constant-current loop is still obtaining the correct capacitance value, a matter for careful construction.

Conclusion

We have looked as some of the basic options for horizontally polarized omni-directional antennas, including turnstiled elements, halos of various shapes, and the constant-current loop. Our concern has been less to look at specific construction ideas than to see the basic principles, as well as the limitations and challenges, presented by each class of antenna. Which one you may decide to build will likely rest as much on local shop skills as upon basic needs for the antenna. Commercial versions exist for some of the antennas discussed, with halos especially popular. For the inveterate antenna builder, there are many additional options. Next time, we shall examine a few larger arrays and the stacking question.

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