Experimental Omni-Directional Antennas for 6-Meters

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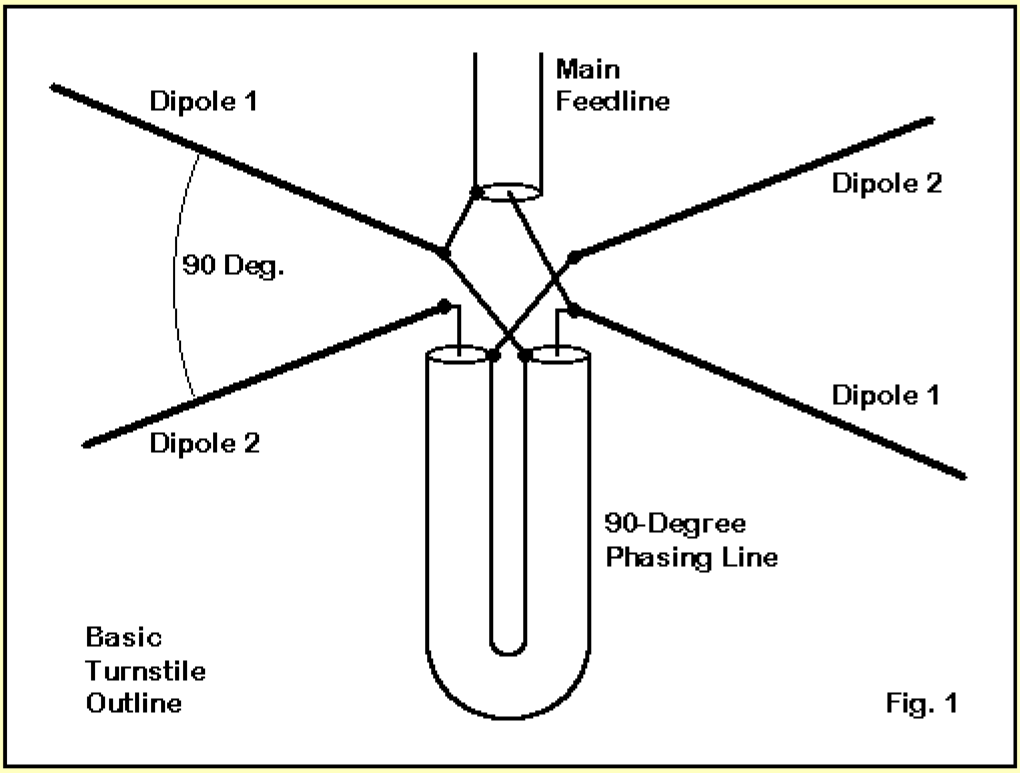
Although our subject matter refers to the 6-meter band--more specifically, 50.5 MHz as a design frequency--the ideas in the following notes are applicable to any other band on which we wish to use any of the antenna designs to obtain a horizontally polarized omni-directional pattern.

We shall do a brief review of turnstiles and their limitations, followed by the introduction of some different types of omni-directional antennas.

Turnstiles

The basic idea of a turnstile is not dependent upon any one type of antenna. Any horizontally polarized antenna is a fit subject for turnstiling. The most common type of turnstile employs two dipoles, as sketched in **Fig. 1**.



The dipoles are set at right angles to each other. We then run a 90-degree long phasing line between the two to obtain quadrature, that is 90-degree phasing. There are more complex systems of achieving the required phasing, but each is subject to the same limitations. The key requirement for the simple phasing system is that the characteristic impedance (Zo) of the phasing line must be very close to the natural resonant impedance of the individual dipoles. A 70-Ohm line is a good match for the dipole turnstile. The net feedpoint impedance will be 1/2 of the impedance of the individual dipoles, or about 35 Ohms for the antenna sketched in **Fig. 1**.

A dipole has a limited -3 dB beamwidth. Therefore, the pattern that is produces in a turnstile antenna will be less than perfectly circular. The gain variation around the rim of the pattern is a little over 1 dB for an ideally constructed turnstile. **Fig. 2**--on the left--shows the squared but usable dipole turnstile azimuth pattern.

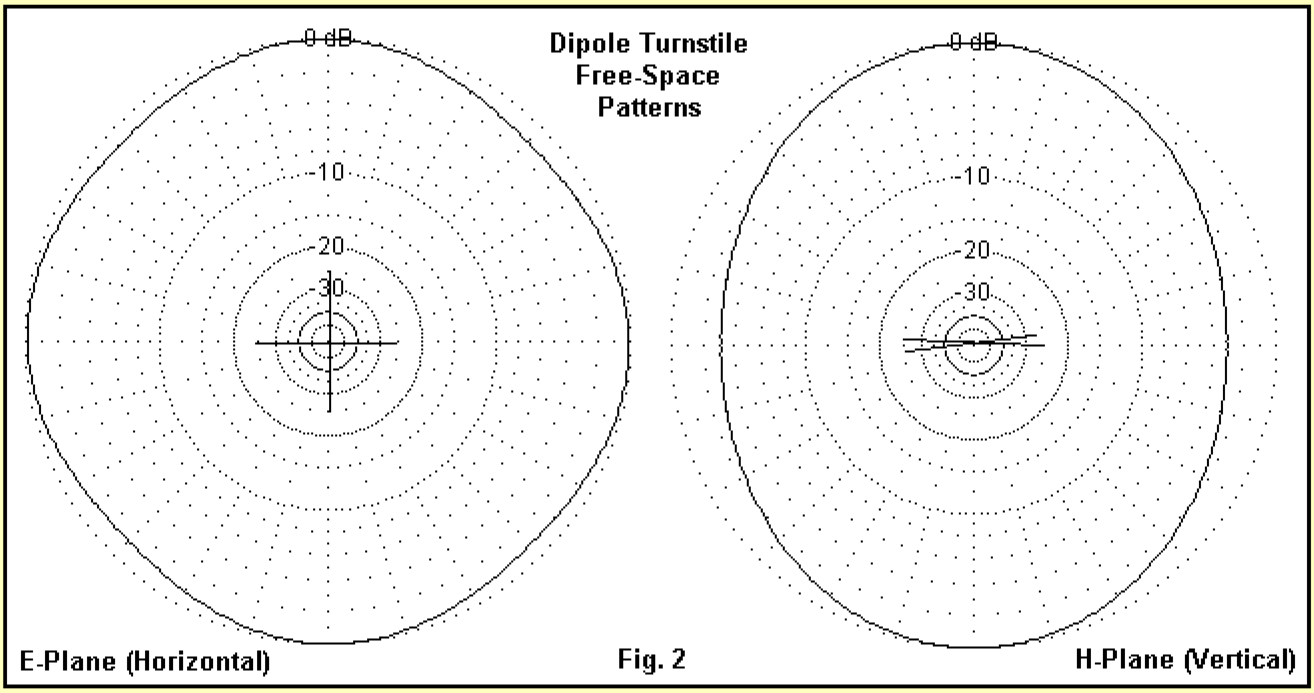
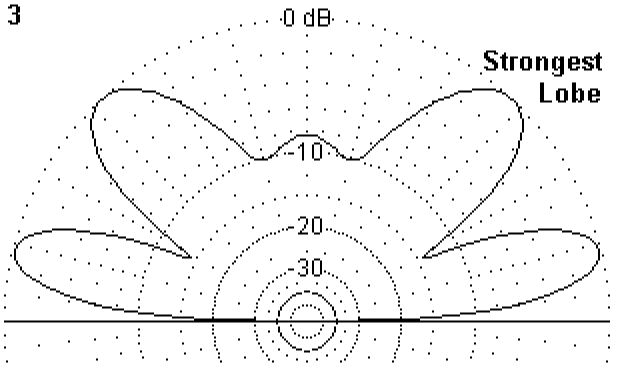


Fig. 2

The azimuth pattern--whether a free-space E-plane pattern or an azimuth pattern over real ground--does not change except for the increase in signal strength created by ground reflects and the elevation angle of maximum radiation over ground. All of the antennas that we shall discuss have take-off angles of 13 degrees when mounted 1 wavelength above ground.

The H-plane pattern in free space becomes the elevation pattern over ground. **Fig. 2**--to the right--shows the free space H-plane pattern for the dipole turnstile. From it, we should draw a clue as to one major limitation of the dipole turnstile: it radiates better broadside to the plane of the wires than off the edges--and it is the edge radiation which makes horizontally polarized communications possible from point-to-point.

Fig. 3



Elevation Pattern: Dipole Turnstile
1-Wavelength Above Average Ground (240" = 20')
50.5 MHz

Fig. 3 shows the resulting elevation pattern when we place the dipole turnstile 1 wavelength above ground. At 50.5 MHz, this is a height of about 20'. The strongest lobe is not the lowest lobe, but the second lobe. The lowest lobe of the dipole turnstile has a gain of only about 4.8 dBi. While adequate for many purposes, designers have felt that we can do somewhat better. However, we must always remember that when we create a nearly or perfectly omni-directional pattern, we should always expect lower gain than from a dipole. The dipole achieve between 7.5 and 8.0 dBi gain at the same height because it has only two lobes, with deep nulls off the ends. The dipole turnstile uses that same power evenly in all directions, so there will be lower power in each direction than in the bi-directional main lobes of the solitary dipole.

Low gain is not the sole limitation of the dipole turnstile. As we vary the frequency, the turnstile gives us the illusion of being a simple antenna, because the SWR remains almost constant for a very wide frequency span. However, the pattern does not stand still. As we vary the frequency off the design frequency, the pattern grows increasingly less circular. **Fig. 4** shows the dipole turnstile patterns 1 MHz off the design frequency.

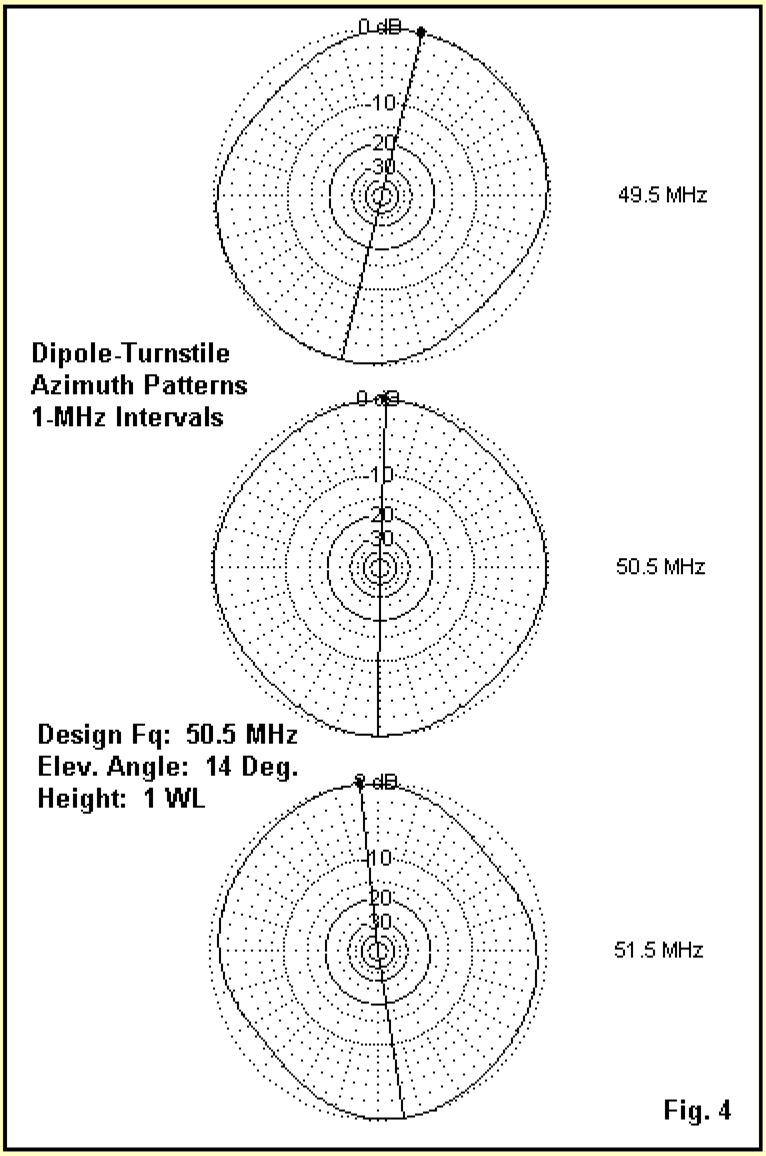


Fig. 4

The patterns in **Fig. 4** would also be good illustrations of other deviations from perfect construction. For example, if the phase line is too long or too short, we shall obtain non-circular patterns. If the line has a higher or lower Zo than the individual antennas, we shall obtain non-circular patterns. There are a number of schemes for obtaining a 50-Ohm feedpoint impedance by using differential lengths of line to each dipole. However, it is not impedance that sets the pattern. Instead, it is the current at each dipole being equal in magnitude and different in phase angle by 90 degrees that yields a circular pattern. Virtually all of the matching schemes result in distorted patterns.

The dipole turnstile, then, is a somewhat precision instrument that is not amenable to casual construction unless we can live with a non-circular azimuth pattern. If we can achieve good precision in our element measurements and in the construction of the phase line, we can make some improvements over the dipole elevation pattern and achieve a bit more gain.

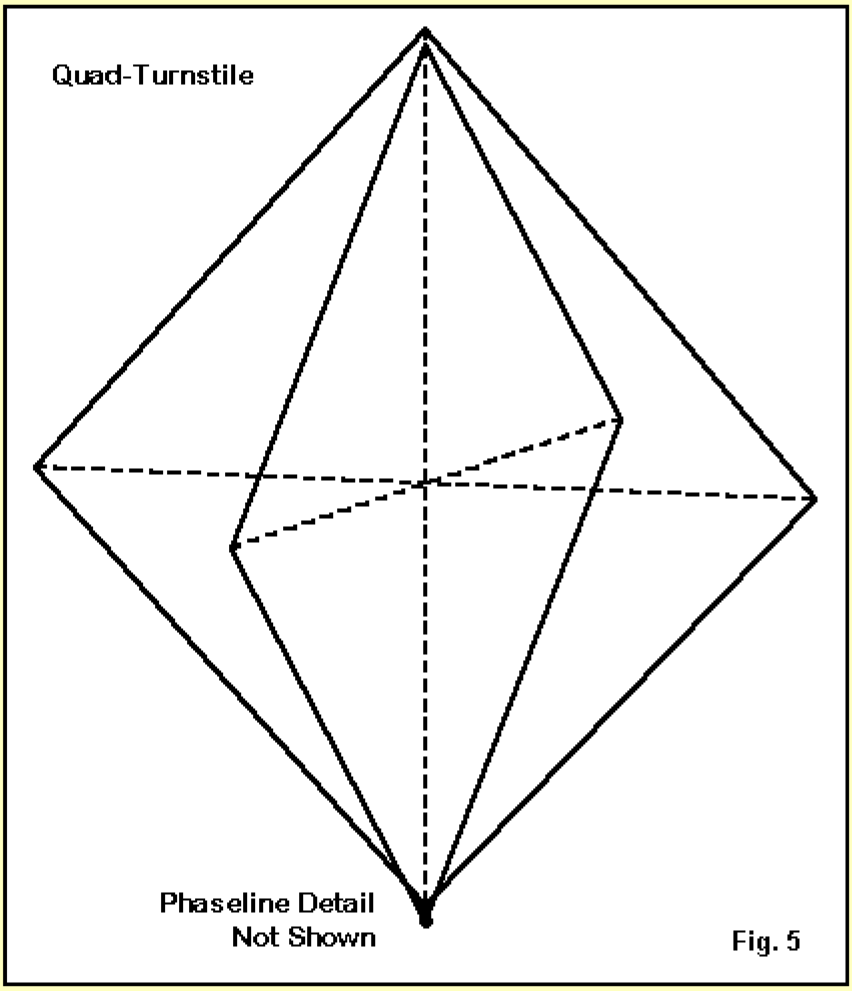
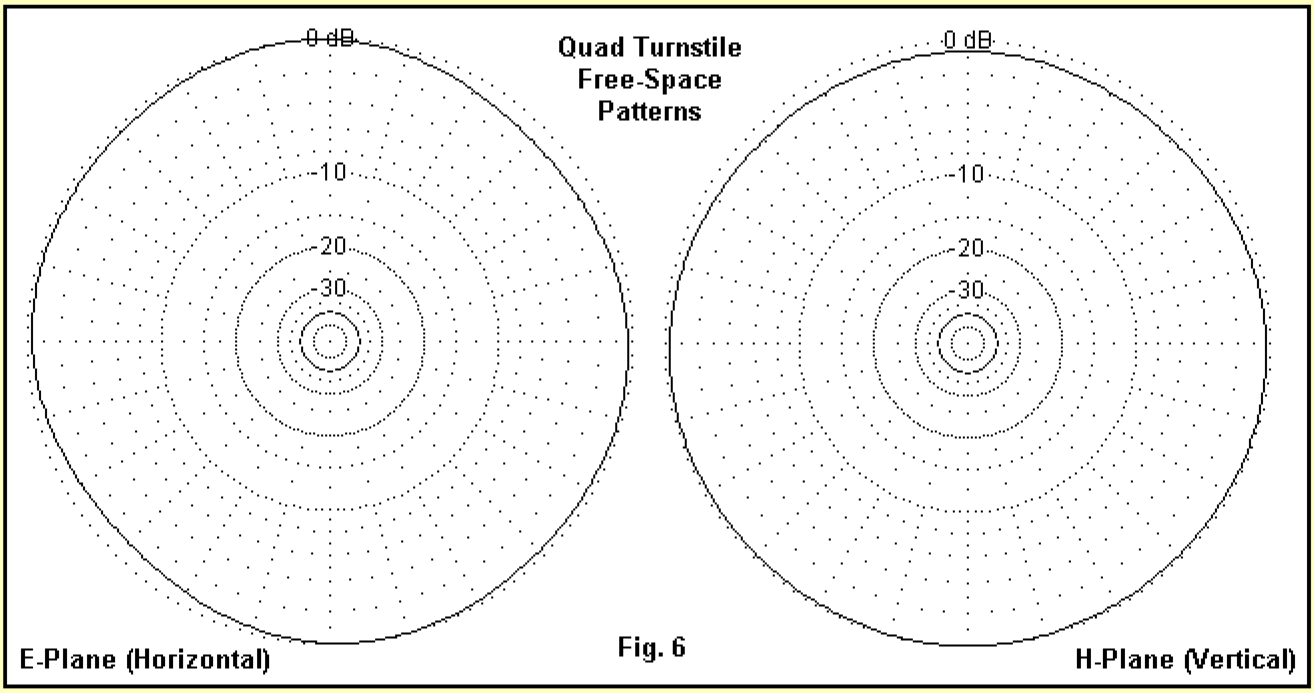


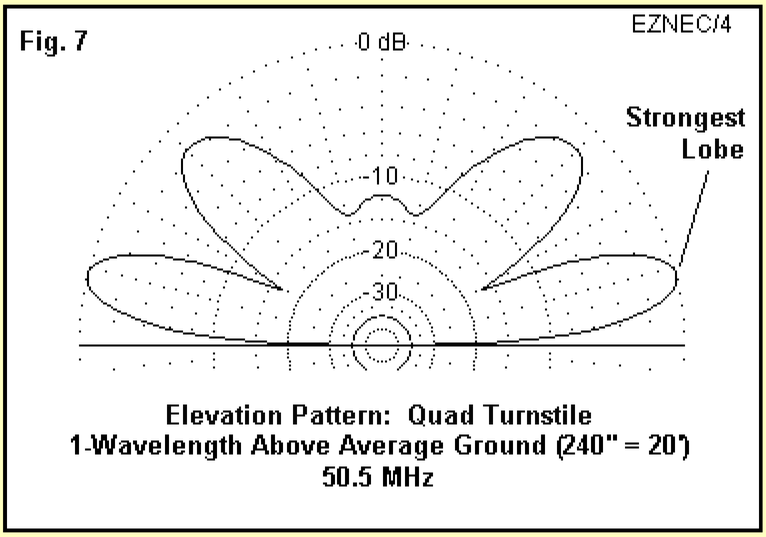
Fig. 5

Fig. 5 shows one direction that we might go: the quad turnstile. Essentially, the quad turnstile is two quad loops--shown in diamond configuration--fed at the base just as we would feed two dipoles. However, the impedance of the resonant quad loop at 6 meters composed of #14 copper wire is about 125 Ohms. Hence, we must make our phasing line out of RG-63, about the only available 125-Ohm coax. The net impedance will be about 62 Ohms, which yields an adequate coax match, especially since the quad SWR curve will be as flat as the dipole curve. Indeed, SWR tells us almost nothing about the performance of a turnstile, with two exceptions. It may tell us that we have an open circuit or a short circuit somewhere along the line. As well, it may reveal the need for some means of suppressing common mode currents.

Because the lobes of an individual quad loop are somewhat wider than those of a dipole, the E-plane or azimuth pattern will be somewhat more rounded. **Fig. 6** shows the free space azimuth pattern (on the left) for the quad turnstile. The maximum-to-minimum gain variation is somewhat under 1 dB for the quad turnstile.



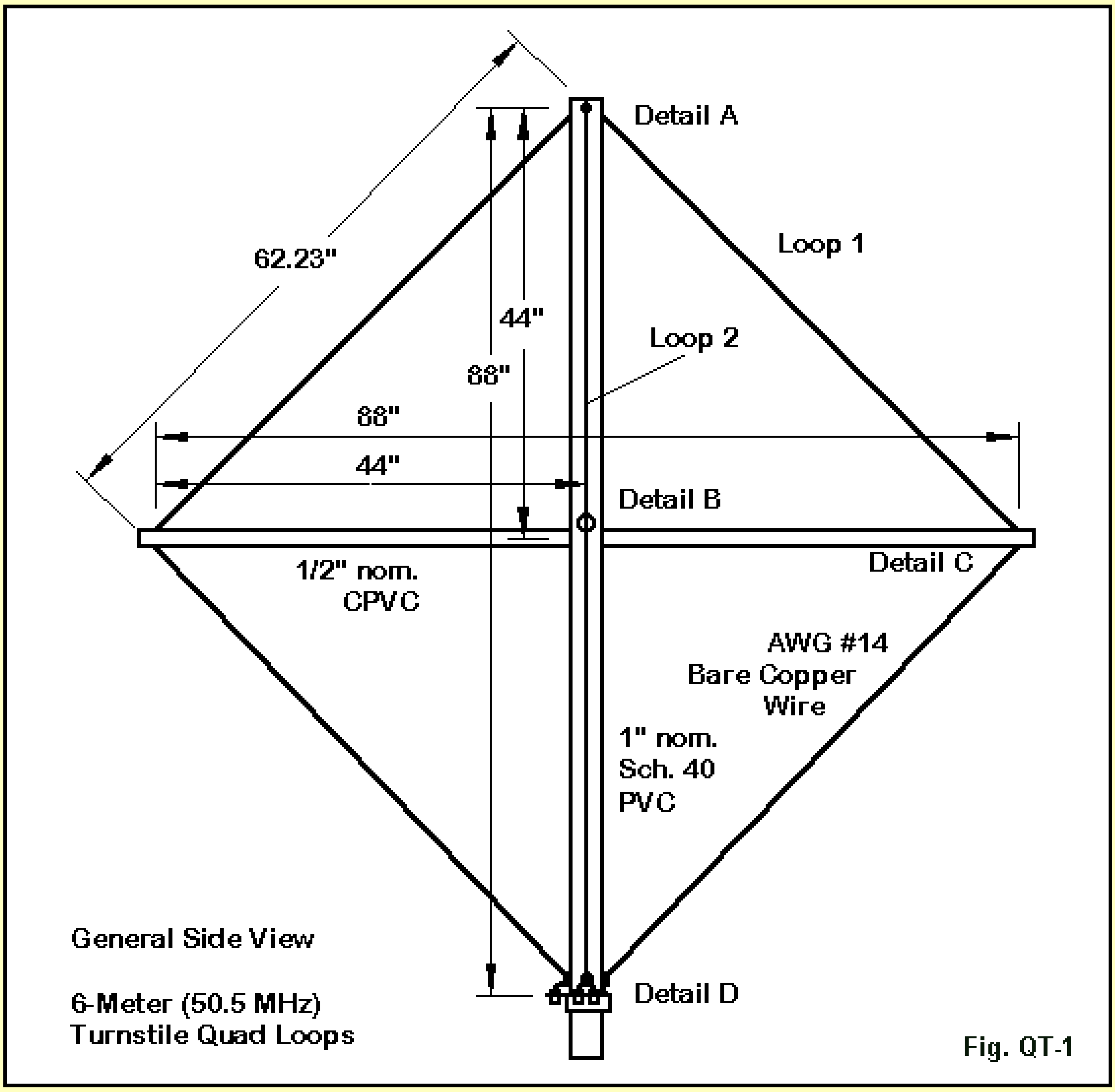
The H-plane pattern on the right reveals the advantage of the quad over the dipole as an antenna to put into turnstile operation. The gain in the vertical direction does not exceed the gain in the horizontal direction. As a result, the elevation pattern of a quad turnstile with the center hub 1 wavelength above ground will exhibit a main lobe that is significantly stronger than the second lobe upward. As well, the radiation directly upward drops by about 5 dB. **Fig. 7** provides a sample elevation pattern.



The quad turnstile shows a gain (over ground at 13-degrees elevation) of about 5.7 dB, almost a full dB stronger than the dipole turnstile. However, the quad turnstile is subject to all of the same sensitivities to imprecise construction and design as the dipole turnstile. *QEX* ran an article in Mar/Apr, 2002, covering those sensitivities in detail.

Updating a Practical 6-Meter Turnstile Quad

In May, 2002, I published in *QST* some notes on a practical 6-meter turnstiled quad for omni-directional horizontally polarized communications ("A 6-Meter Quad Turnstile," pp. 42-46). The general outline and dimensions of the antenna appear in **Fig. QT-1**. You will find details and background in the article.



The key elements for these update notes are the particular construction methods that I used, with crossed CPVC arms to spread the wires. **Fig. QT-2** shows some of the details. Note especially the use of holes in the main mast and bolts to secure the cross arms.

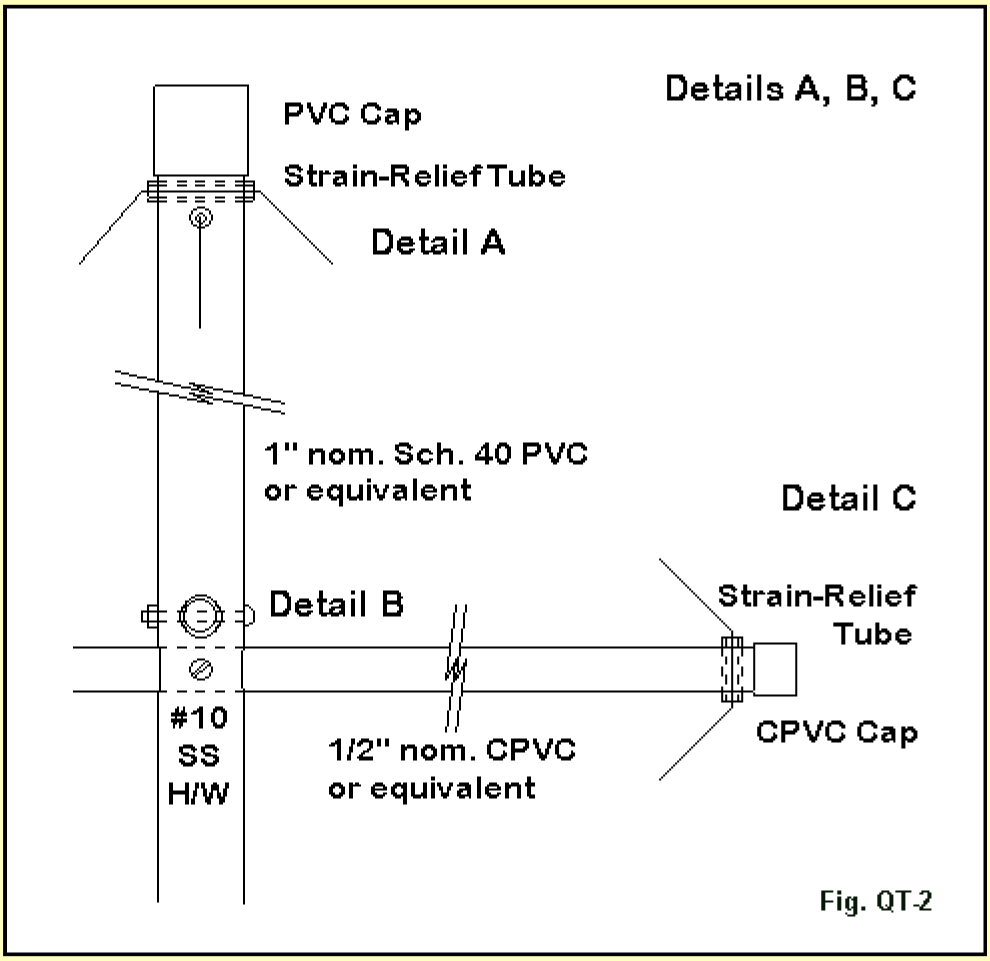


Fig. QT-3 shows the method that I used to join the phase-line and main feedline, with a plate that surrounds the mast at the bottom of the loops. The oriogindl article provides explanations for all of the abbreviations in the sketch.

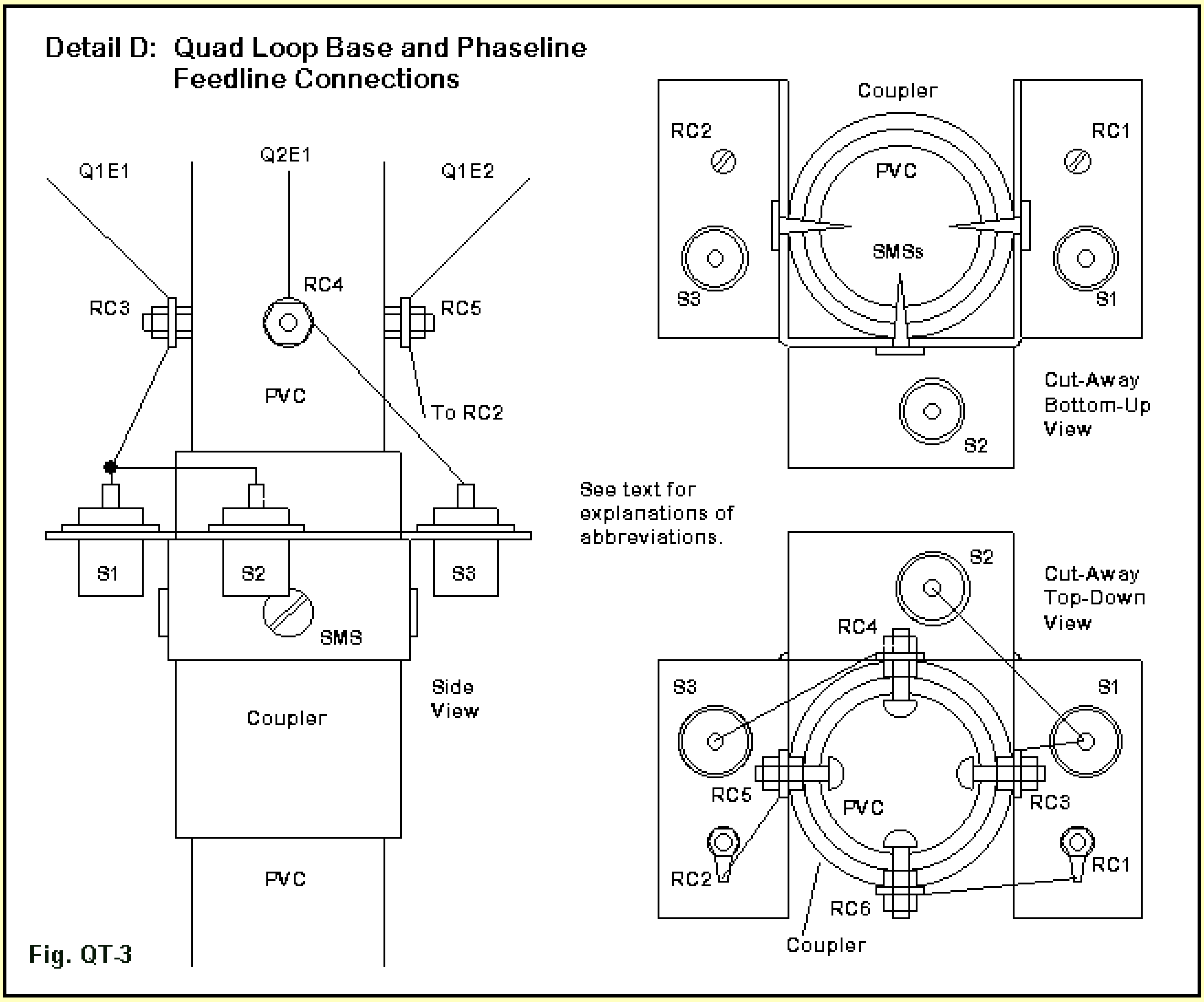


Fig. QT-3

Ivan Cook, K4SRB, has built an interesting variation on the turnstile quad for 6. His version uses some ingenious twists on PVC--literally. **Fig. QT-4** shows Ivan explaining his antenna to a local club. In terms of construction, perhaps the most notable feature is the absence of nuts and bolts at the center junction of the support arms with the mast. Instead, Ivan uses a set of elbows and short PVC links to put the arms at the same level. He cements most joints, but leaves a few using only a friction fit.

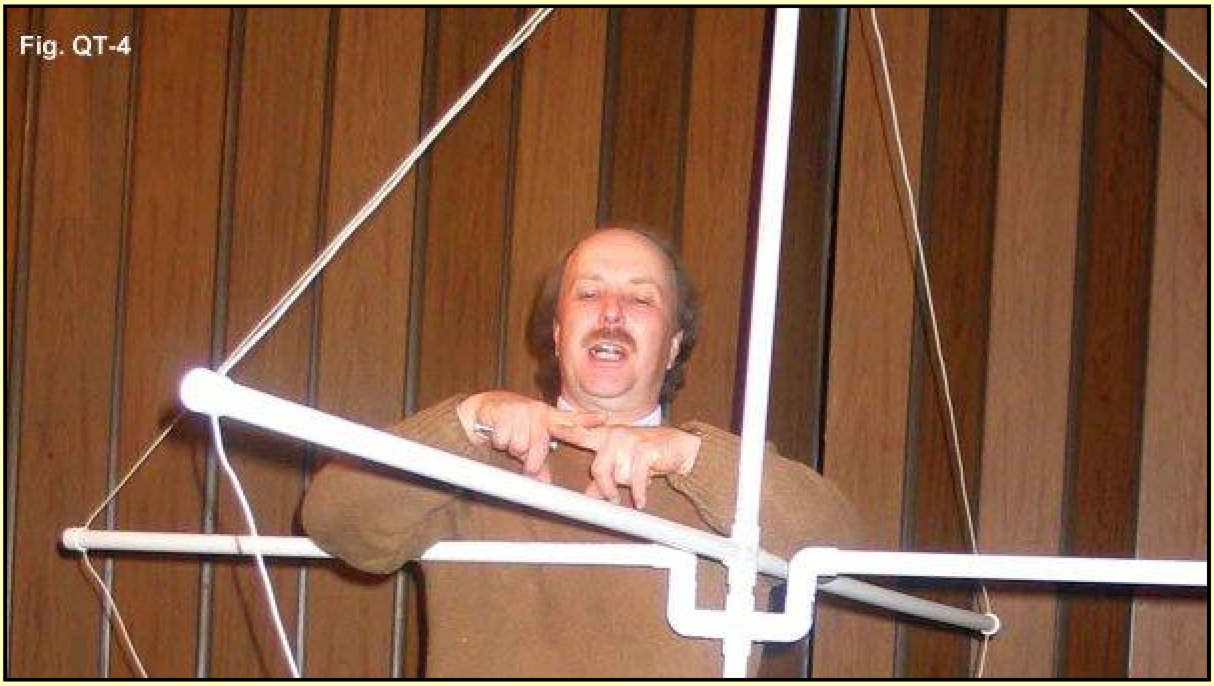


Fig. QT-4

The reason for the friction fit is that Ivan uses his turnstile quad in the field. To transport it, he can twist the elements into a flat plane. In addition, he has used soldered connections--covered by the PVC--for the phase-line and the main feedline connections. These moves effectively eliminate the need for a mast extending from the ground to the base of the antenna. In lieu of a mast, Ivan has put a hook at the top of the central arm and hangs the antenna from a tree limb. **Fig. qt-5** provides a general idea of the antenna in use.

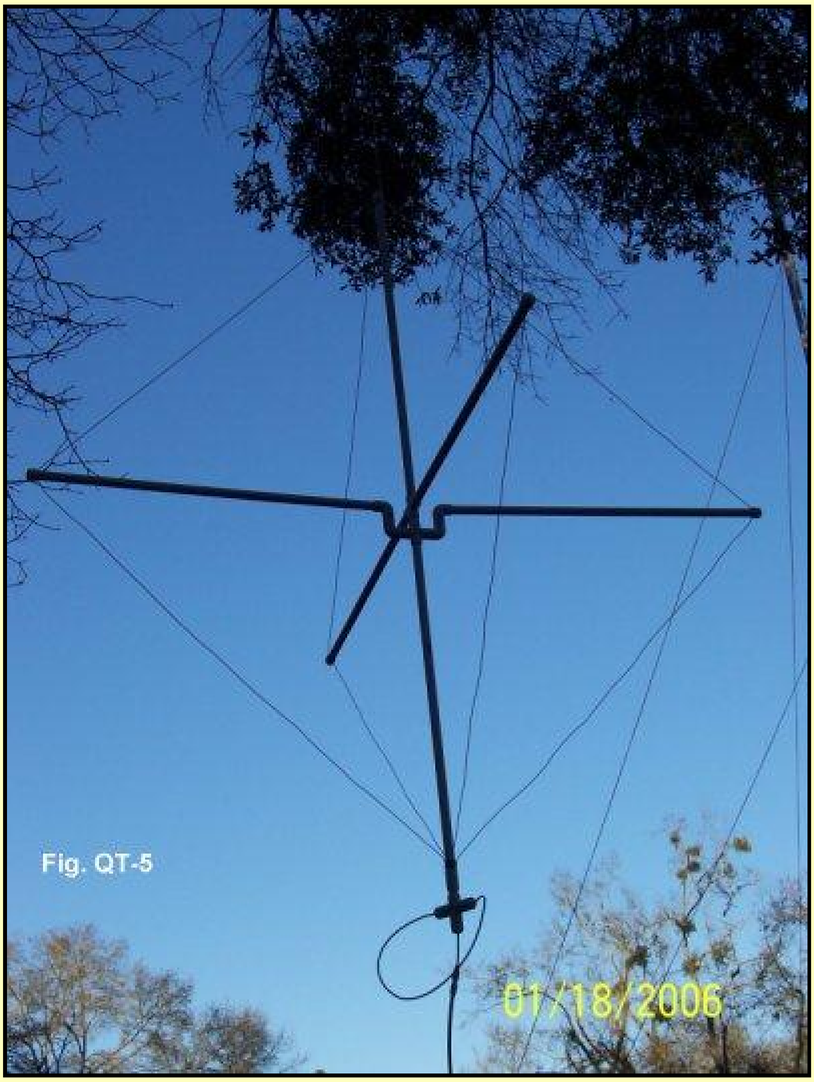
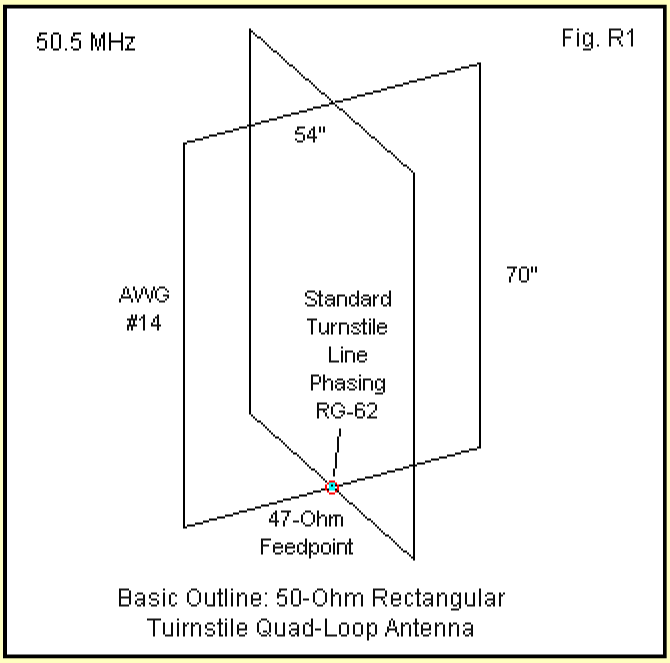


Fig. QT-5

Ivan's variations show two things of importance to antenna experimenters. The first item is the versatility of PVC as a general support structure that is RF invisible at least through 2 meters and for many purposes through 70 cm. The second item is the ingenuity of the individual experimenter in adapting an antenna design to a specific set of needs and goals. Ivan has converted a somewhat ungainly structure into one that is field-friendly both in use and in transport.

The quad turnstile is not necessarily an ideal antenna. It does have a disadvantage. Its loop construction essentially places two dipoles an average distance apart of 1/4 wavelength. It is the double or phased dipoles that account for the stronger lower elevation lobe of the antenna, relative to the dipole turnstile. However, it is not usually practical to place two quad turnstiles in a vertical stack. The practice is common with dipole turnstiles, but with a degree of usual carelessness that results in relatively poor performance. The pair of dipole turnstiles will interact with each other. If the stack is to have a nearly ideal circular pattern, the individual dipoles must be re-resonated in the stack. Only under this condition will they provide a circular pattern.

For better control of the feedpoint impedance, some quad-turnstile builders have turned to the vertical rectangle as the base antenna. If we increase the verical dimension of a square and decrease the horizontal dimension, we can change the feedpoint impedance from the square's 125-Ohm value to something closer to what we need. In fact, we can arrive at 50 Ohms, but that is not our goal here. Instead, we want an impedance of between 95 and 100 Ohms so that the turnstile phaseline will give us a direct 50-Ohm feedpoint impedance. **Fig. R1** provides an outline of such a turnstile using AWG #14 copper wire and set for 50.5 MHz.



Basic Outline: 50-Ohm Rectangular Tuirnstile Quad-Loop Antenna

The vertical sides are about 1.3 times the length of the horizontal wires. The phaseline is 49" of RG-62, which has a velocity factor of 0.84 (for a 58.33" electrical length). The feedpoiont impedance is so close to 50 Ohms that the SWR does not rise above 1.1:1 across the first MHz of 6 meters. However, SWR is never a problem with turnstiled elements. The SWR remain nearly constant over a bandwidth that is much wider than the bandwidth over which the pattern holds its omni-directional shape.

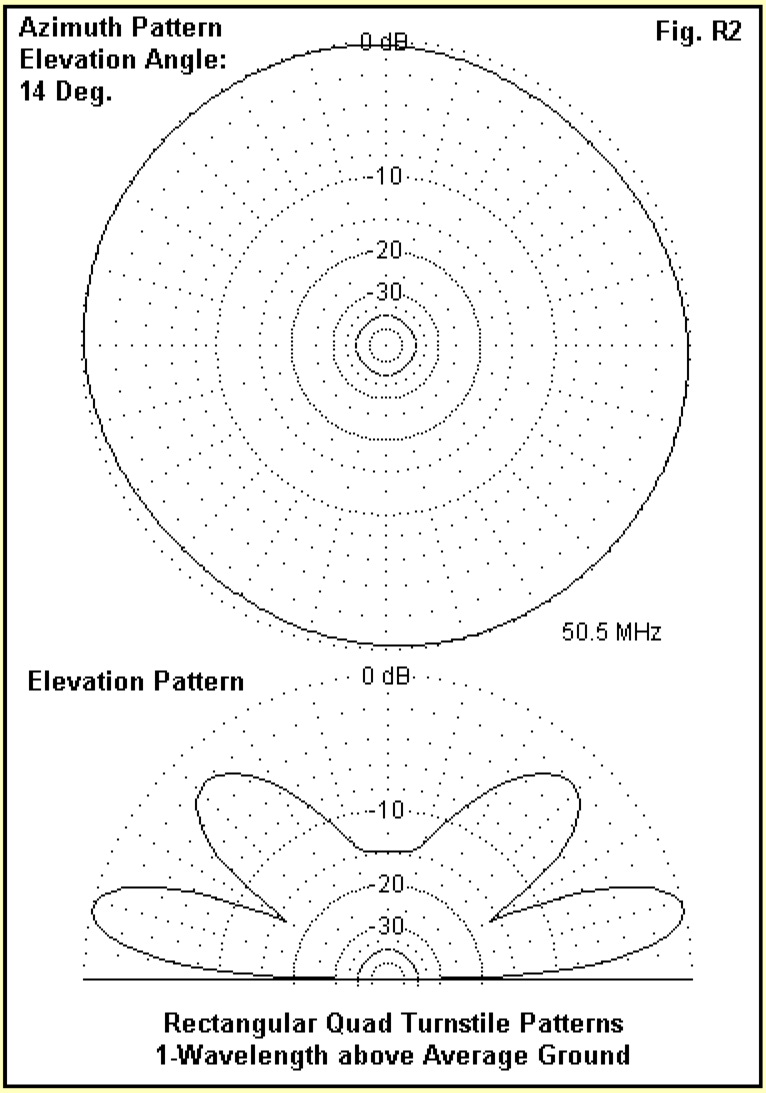


Fig. R2 shows the elevation and azimuth patterns of the rectangular quad turnstile. The pattern is virtually identical to the pattern for the diamond quad-turnstile version. Because the rectangles are so little out of square to arrive at individual loop impedances near 100 Ohms, the gain does not increase sgnificantly. In this case, the average gain is about 5.5 dBi with a 1-dB variation between maximum and minimum points.

The finickiness of turnstile antennas--as well as their relatively large size at 6 meters and below--has led designers to look for other options in producing a horizontally polarized omni-directional antenna.

Unclosed Loops

It is possible to create an omni-directional horizontally polarized antenna by employing a interrupted loop less than 1 wavelength in total wire length. There are two sorts of these loops--which resemble triangles or rectangles: larger loops with a total wire length that is about 3/4 wavelength and smaller loops with a wire length in the vicinity of 1/2 wavelength. There are interesting differences between the larger and smaller loops, so we shall look at them separately.

Larger Loops

In any of the open-loop designs, one key to success is to find the right shape so that the radiation from the center-portion and the radiation from the legs balances into a circular pattern overall. For this reason, only certain relationships between the center portion and the end pieces will work. The current on the center and end portions is not equal. Therefore, in general, the shaping of the larger loops will be triangular. Bending the end portions towards each other is one way to fine tune the balance of currents and the resulting pattern.

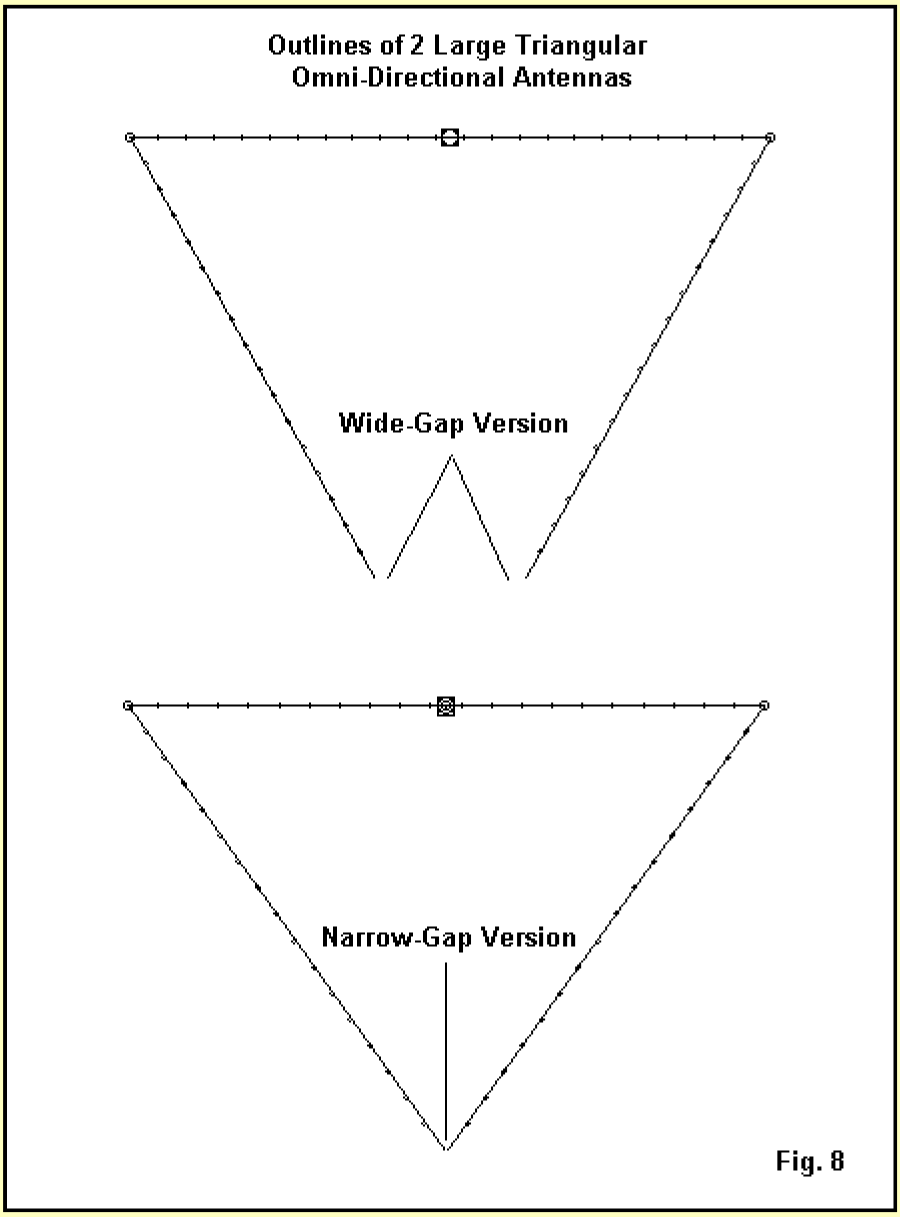
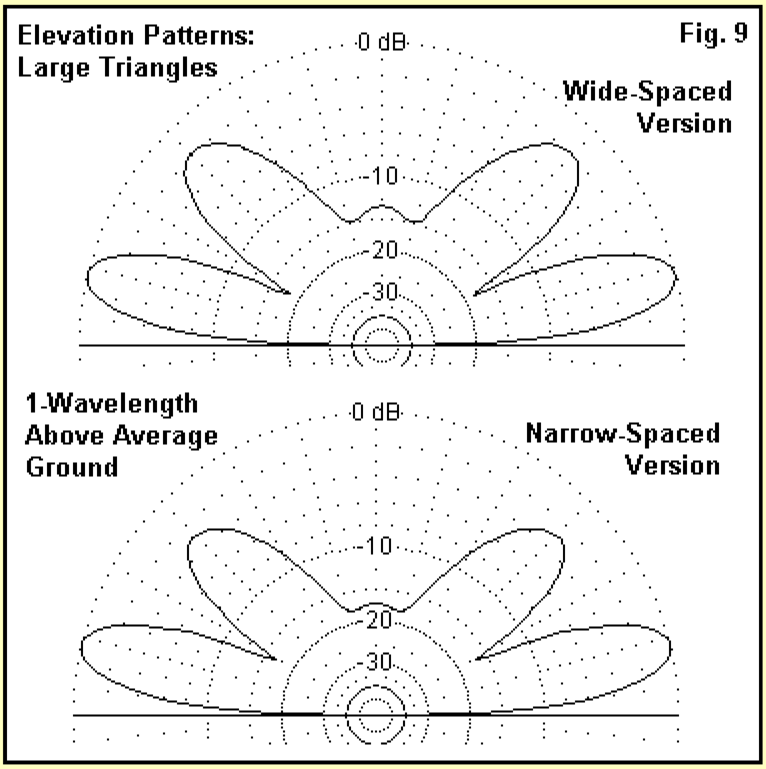


Fig. 8

Fig. 8 shows two examples of larger loops: the wide-gap and the narrow gap versions. The versions result from giving precedence to one of the other goals of the exercise in addition to pattern shape. The other two goals are the feedpoint impedance and the distance between the tips of the loop ends. In general, with larger loops, the two goals are not compatible.

The top wide-gap triangle in **Fig. 8** sacrifices the convenience of closely spaced tips for a 50-Ohm feedpoint impedance. In fact, like all of the loops that we shall examine, there is a high inductive reactance at the feedpoint. However, we may compensate for this with series capacitance at the feedpoint, using methods that we shall describe further on. The wide-gap model shows a 50-Ohm impedance after compensation, with a 1 MHz 2:1 SWR bandwidth.

The antenna material for the initial design is 1/4" aluminum. Dimensions will vary with the diameter of the element. The center portion is 68" long, with 53.7" ends. The bending of the ends to make a near triangle results in a 47" dimension from the center section to the element tips. The tips are 16" apart. The pattern shows a maximum azimuth pattern gain variation of well under 0.1 dB. With the antenna 1 wavelength up, the gain over average ground at a 13-degree take-off angle is 6.0 dBi, about 0.3 dB higher than the quad turnstile.



The top of **Fig. 9** shows the elevation pattern of the antenna at the 1-wavelength height. The vertical radiation (straight up) is several dB lower than for the quad loop.

Let's return to **Fig. 8** an examine the lower loop. Here the gap is narrowed to 0.5" so that aligning the ends becomes a much simpler mechanical process. To sustain a circular pattern, the 1/4" diameter element is 62" long in the center portion. The ends are 52.9" long, resulting in a 43" distance between the center element section and the tips.

The azimuth pattern for this version of the interrupted loop is circular within 0.6 dB around the horizon. As the lower half of **Fig. 9** shows, the secondary lobes are further reduced, with vertical radiation running nearly 18 dB below the strength of the main lobes. The gain--again at a 13-degree take-off angle with the antenna 1 wavelength up--averages about 6.3 dBi, a further increase over the wide-space loop.

Like the wide-spaced loop, the feedpoint of the narrow-gap version of the antenna has a high inductive reactance, calling for compensation. The resistive component of the impedance is about 23.3 Ohms. Therefore, we require a further method of matching this antenna--even with the reactance compensated--to a 50-Ohm coaxial cable. The simplest method is to use a 35-Ohm 1/4 wavelength section of cable. We can construct the section from 38.5" of RG-83 (with a velocity factor of 0.66, for an electrical length of 58.4") or from parallel sections of 70-Ohm cables (which come in various velocity factors, depending upon the use of solid or foam dielectrics).

The result at the design frequency is a very close match to 50-Ohm coax. However, the 2:1 SWR bandwidth is only about 540 kHz at the antenna terminals. Due to cable losses, SWR measured at the transmitter end of the line would likely show a wider bandwidth.

Both loops require that we place series capacitors in the line at the feedpoint terminals. The total capacitance for the wide-gap version is 4.98 pF, while the total for the narrow-gap version is 5.48 pF. These numbers are unduly precise, because construction variables will create considerable differences in the feedpoint inductive reactance.

Perhaps the best way to arrive at the required capacitance with maximum trimming control is to install capacitors in each side of the line, using double the required total capacitance for this series set-up. We can experiment with small fixed capacitors or trim the antenna with variables and replace them with fixed values when tune-up is complete. However, for maximum control, we might consider running insulated wire or thin tubing snugly against the split fed element on each side of the line. The capacitance of the wire and the element depend upon several variables: the facing areas of conductor, the distance between conductors, and the dielectric constant of the insulation on the wire or thin tube. Since a builder will likely use materials on hand, it is impossible to provide detailed guidance. It likely pays to start with wire lengths that are too long and to prune them--evenly on each side--until the reactance disappears at the design frequency.

Smaller Loops

The larger loops just described will have a center-section length between 5 and 6 feet. This size is a considerable saving over a dipole or quad turnstile antenna. However, it is still considerable for many installations. Therefore, one may wish to explore interrupted loops in the 1/2-wavelength total wire region.

There are on the commercial market single element broken loops of the smaller sort. They measure about 41" at the center, with 49" legs--approximately and use a narrow gap between ends. I do not have all of the physical specifications of these antennas--made by Par Electronics in North Carolina. Therefore, the following notes do not necessarily apply to these antennas.

Most intermediate-size interrupted loops using single elements tend to have very low resistive components to the feedpoint impedance, while sustaining considerable inductive reactance. By compensating for the reactance first, one can use a balun or a broad-band toroidal transformer to raise the impedance to coaxial cable levels. However, at the feedpoint itself, the low impedance raises the potential of resistive losses for the home builder without a well equipped shop. Every fraction of an Ohm in a connection converts a higher percentage of supplied power into heat than with a higher impedance at the feedpoint. Therefore, one might leave such assemblies to the pros and for home construction take a cheaper and easier-to-build approach.

In 1997, I introduced as a limited-space 40-meter antenna the IL-ZX, the intermediate or interrupted loop impedance transforming antenna. This link will lead you to that item for background. We can apply the same approach to a 6-meter version of the IL-ZX.

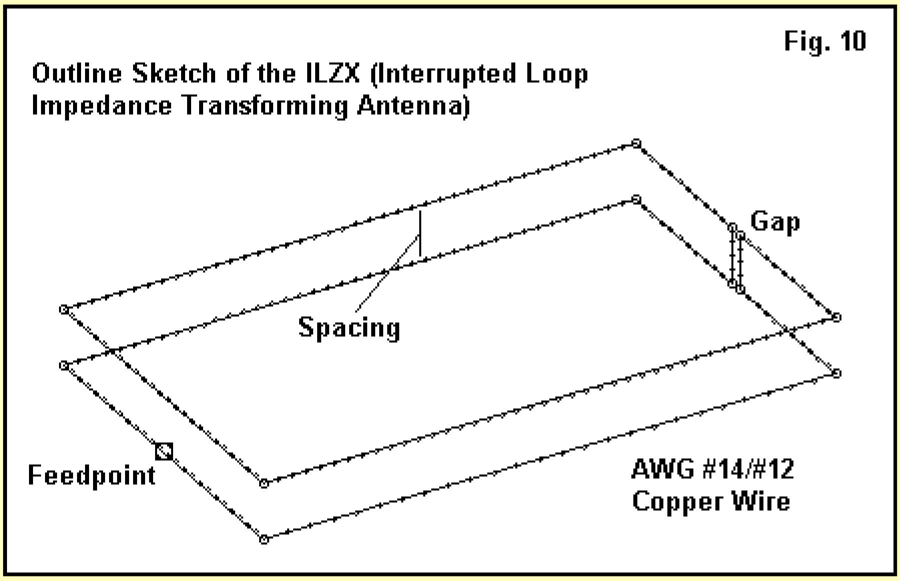
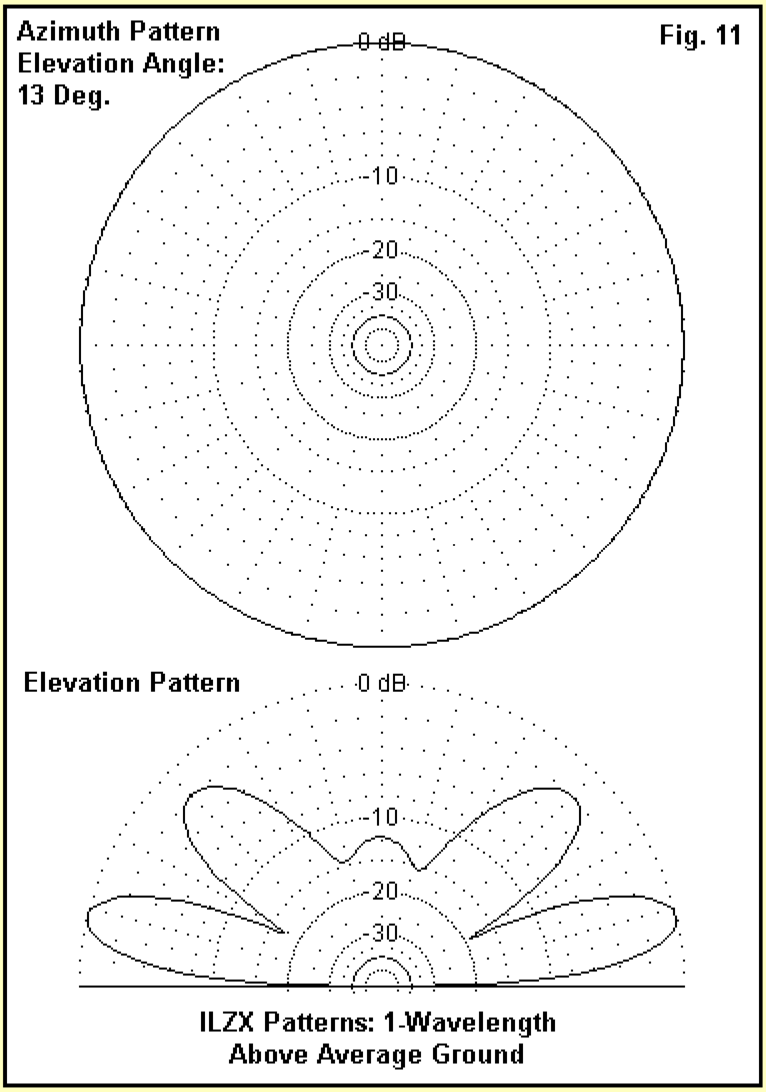


Fig. 10 shows the general outline of the rectangle forming the IL-ZX. The short portions are 25" long per side, while the longer sections are 41". There is a gap, which is set at 1". Note that the loop resembles a mutilated folded dipole. Only one wire of the over-under pair is fed. The gap consists of parallel wires, each 4" long, the spacing between the upper and lower wires.

In several design models, the spacing between wires was varied from 1" to 4" with only minor changes in the remnant inductive reactance at the feedpoint. As well, changing the wire from AWG #14 to AWG #12 resulted in similar minor variations in feedpoint reactance. In fact, one might well control the reactance by making the wires at the gap into arrow points, thus reducing the rate of change of capacitance between ends as the gap spacing is changed. However, changing the gap spacing with the present arrangement also creates only slow changes in feedpoint reactance.

The key to the design--and the reason why it is a rectangle rather than a square--lies in the need to have a circular azimuth pattern and a feedpoint impedance with a resistive component near 50 Ohms. The dimensions noted above result in a pattern with about 0.1 dB variation. The top portion of **Fig. 11** shows how nearly circular the pattern is with the antenna 1 wavelength over average ground. The elevation pattern is equally well-controlled.



Since the antenna is smaller than the larger loops that we discussed, the average gain of 5.8 dBi may seem surprising. The resistive portion of the feedpoint impedance is about 58 Ohms, and the 2:1 SWR bandwidth is about 500 kHz. Thus, the operating bandwidth matches the narrow-gap large loop, but not the wide-gap larger loop. The gain levels of all three are comparable.

The IL-ZX loop has a considerable inductive reactance, and required about 4.32 pF of total capacitance--or 8.64 pF per feedpoint terminal. The notes given earlier on methods of providing the required series capacitance for the larger loops are equally applicable for the IL-ZX.

One of the advantages of the loops that we have been discussing is the ease with which we may stack them. Unfortunately, many folks still labor under the mistaken rule of thumb that a stack nets the user 3 dB of gain. In fact, the gain advantage that we get from a stack depends on the spacing between antennas. For dipoles, 5/8 wavelength yields about the highest gain advantage over a single antenna, and with practical materials, this amounts to a little over 2.5 dB.

The goal in stacking a pair of IL-ZX antennas might initially be to further suppress vertical radiation, since that is the most useless part of the elevation radiation pattern. A spacing of 1/2 wavelength yields maximum vertical radiation suppression, but the gain advantage over a single array drops to under 2.4 dB. Although this is highly usable gain, it is simply not the theoretical 3.0 dB bandied about by so many.

Equally important is the fact that a stack will lower the overall take-off angle of the array. If the lower antenna is at 1 wavelength height and the upper is at 1.5 wavelengths, then the take off angle will drop from 13 degrees to 10 degrees. For a stack of 2 IL-ZXs, the gain will be about 8.2 dBi.

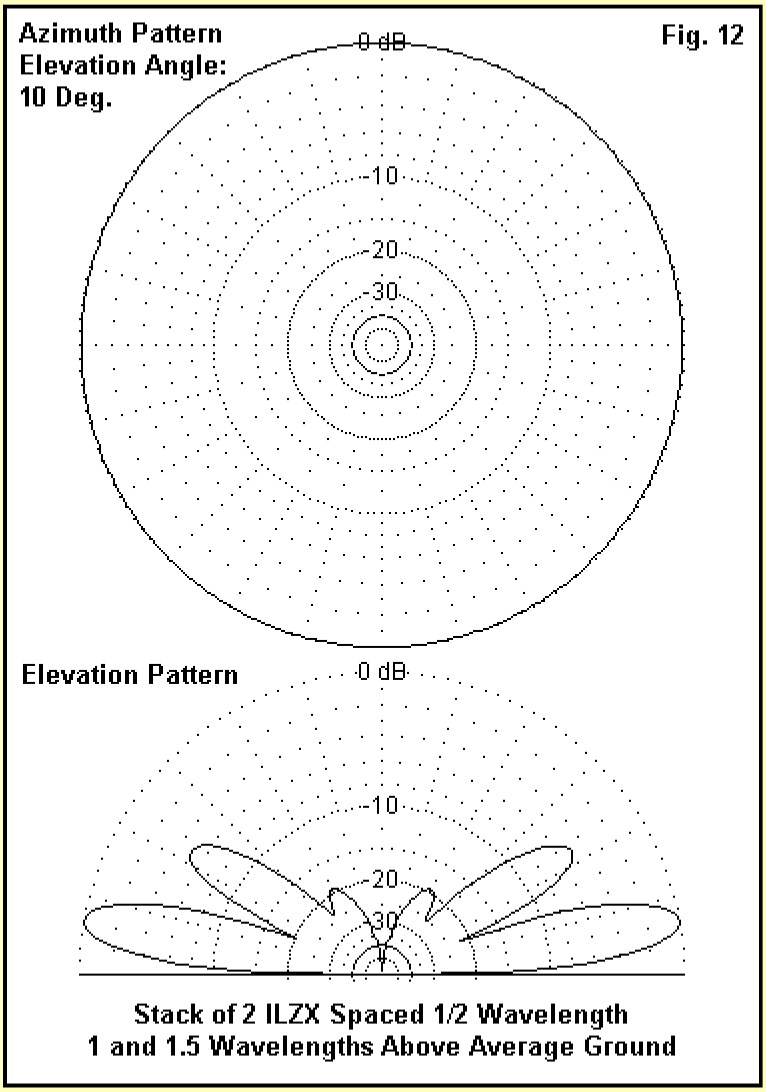


Fig. 12 shows the azimuth and elevation patterns for a stack of two IL-ZX antennas. The circular azimuth pattern appears solely to confirm that we may stack these types of loops without redesign, as is required by stacked dipole turnstiles.

The elevation pattern shows the results of using the 1/2-wavelength spacing between antennas. All lobes except the lowest have reduced strength, a desirable effect for omni-directional horizontally polarized local and regional communications.

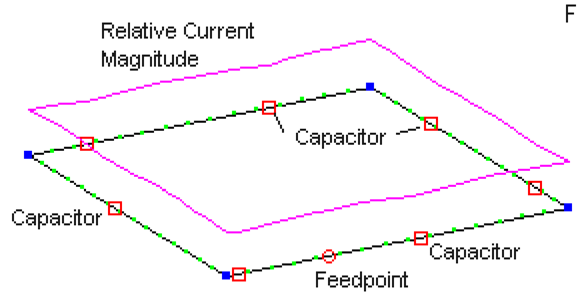
The stacking harness requires careful construction. Two lengths of 70-75-Ohm coax, each electrically 3/4 wavelength long (because 1/4-wavelength sections would not meet) will transform each pre-compensated 50-Ohm impedance to 100 Ohms. A Tee fitting parallels the two impedances to result in a 50-Ohm match to the main feedline.

Uniform-Current Loops

An overlooked design emerged in 1944 (Donald Foster, "Loop Antennas with Uniform Current, *IRE*, Oct, 1944). Recently, Robert Zimmerman resurrected the idea in "Uniform Current Dipoles and Loops," in *antenneX* for April, 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 wil be 0.12-wavelength 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 #14 calls for 9.63-pF units, whereas AWG #10 needs 10.31 pF capacitors. The design comes closest to an even 10 pF with AWG #12 wire.

In real terms for 50.4 MHz, each AWG #12 wire section is 28.1" long. The square is 49.2" on a side for a circumference of 196.7". Note that the sections (7) do not correspond to the sides (4), which is no hindrance to effective antenna operation. One model of the antenna looks like the outline in **Fig. 13**.

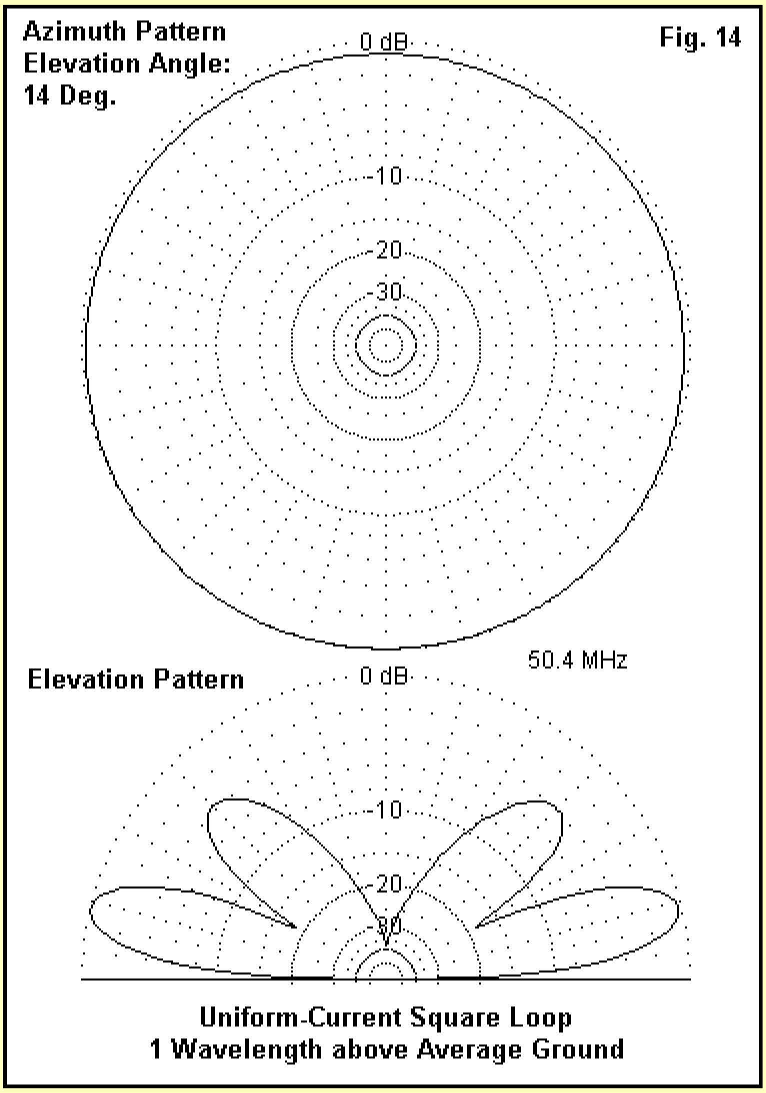
Fig. 13



General Outline and Relative Current Magnitude
Uniform-Current Square Loop for 50.4 MHz

Note that it does not matter if the feedpoint is placed mid-side or offset, so long as the feedpoint is in the middle of a wire section. The figure also shows the relative current magnitude along the circumference of the loop. The level changes by under 4% all along the perimiter. (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-dfirectionality and superior in gain. At 1 wavelength above average ground, the antenna gain averages about 6.8 dBi, with a total variation in gain of about 0.6 dB. The gain is almost a dB better than the best triangle. **Fig. 14** shows the elevation and azimuth patterns and also reveals one significant reason for the improved gain from the loop.



If you compare the elevation patterns with the one shown for the triangle, 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. As shown in **Fig. 15**, the 2:1 50-Ohm SWR range is 50 to 50.85 MHz. Once you arrive at a usable wire section length and employ the most precise and well-matched set of capacitors that will handle the anticipated power level, you can change the exact center frequency by altering the wire length, since the same capacitance within about 0.1 pF will hold good for nearly a 400-kHz change in center frequency.

Among the experimental designs shown, the uniform-current square loop is perhaps the "best in show."

Conclusion

The interrupted-loop and the uniform-current square-loop designs shown here are experimental. Any builder should expect to spend considerable time adapting local materials to the needs of the design of choice. As well, field adjustment will also require considerable care and effort. In the end, the goal is to produce a truly circular horizontally polarized pattern with a feedpoint impedance compatible with the main feedline. Hence, much work will be devoted to proportioning the antenna for pattern shape, and an equal amount of work will go into compensating for the reactance and arriving at a usable resistive impedance.

In the end, it is doubtful whether the loop designs are any less finicky than the turnstiles. Instead, they simply change the places in construction and design that require close attention to detail. Producing a circular pattern that is horizontally polarized is no mean feat, whatever the design direction we take.

For frequencies above 400 MHz, the design concepts can be applied to circuit-board construction techniques, since the elements and capacitors are easily fabricated with these methods. The antenna would be only a few inches per side. However, detailed design would require FDTD or comparable techniques that are not at my disposal.

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