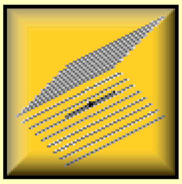


The 3-D Corner Reflector

L. B. Cebik, W4RNL (SK)

Back in 1999 (seems like a century ago), I examined some properties of the corner reflector (See "Corner Reflectors Revisited".) Since that time, a number of scattered ideas for improved performance have come my way. Among them was a 3-dimensional corner array that first appeared in the *IEEE Transactions on Antennas and Propagation*, July, 1974. The article was "Three-Dimensional Corner Reflector Array" by Naoki Inagaki (pp. 580-582). I am indebted to Gene Wood, WA4PGI, for supplying me with both the article and his experiences in building a version of the antenna for the mid-UHF region.

The 3-D corner is calculated by the authors to have considerably more gain than a conventional corner array. I wondered how the claim might appear in NEC-4 models, so I built up a couple to see the results. Let's review the state of the corner array and then explore further the 3-D corner.

The Conventional Corner Array

The conventional corner array consists of two flat planes forming a triangle. The most commonly used angle is 45 degrees, although others are usable. The apex of the angle may be sharp or somewhat rounded. As well, the forward edges of the plane may continue linearly or be slightly folded toward the line formed by the apex of the triangle through the dipole that usually serves as the fed element.

Modeling the conventional corner array generally follows construction practices, as shown in **Fig. 1**.

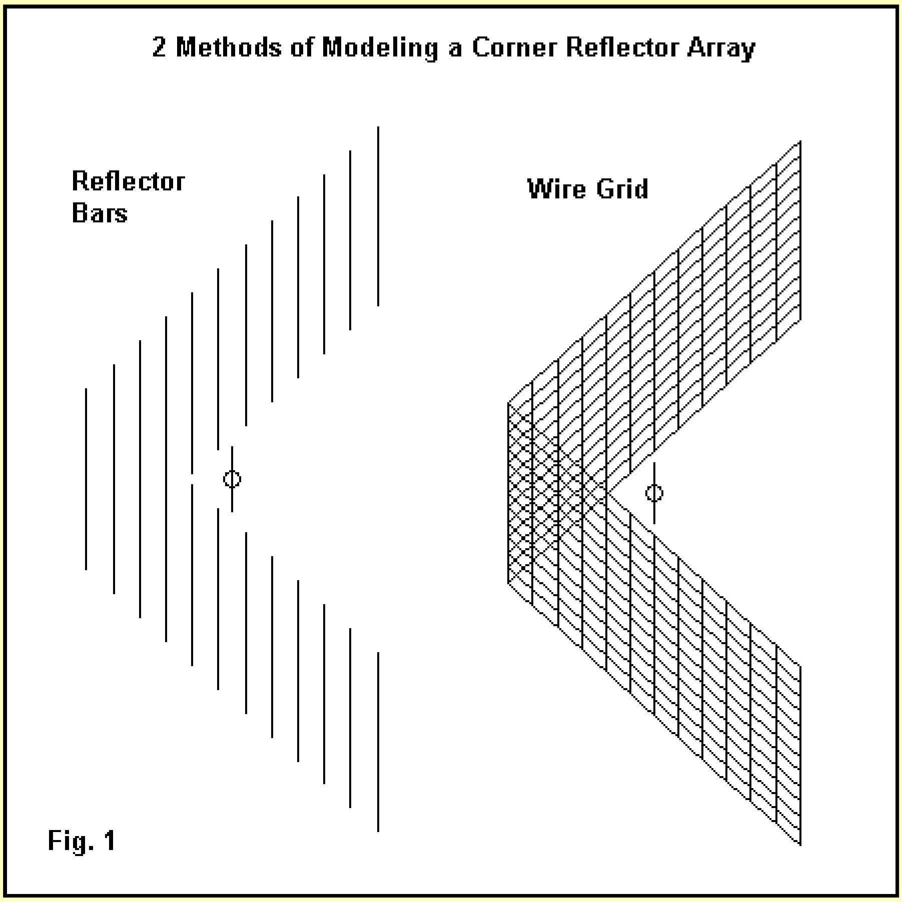

2 Methods of Modeling a Corner Reflector Array

Fig. 1

For consistency, let's call the length of the wire at the apex in either version of the model the width. The distance between the forward edges of the two planes is the aperture. The distance from the apex through the driving element to the forward edge of the reflector planes will be the depth.

Many corner reflectors use bars or rods to form the plane of the reflector. The rods are parallel to the fed dipole element. Models following this technique tend to be smaller in terms of the total number of wires and segments than models simulating solid or screen wire reflector planes. The required wire-grid structure is a highly effective simulation of solid planes, but requires far more wires and segments.

The need for many more segments arises from the recommended maximum spacing between wires in a grid: 0.1 wavelength. Using a maximum wire diameter that is the segment length divided by PI results in wires thick enough to simulate a solid surface without violating NEC recommendations for segment length to radius ratios. However, the spacing between wires results in segment lengths that are in excess of conservative recommendations. However, tests using shorter segment lengths in corner reflector planes (0.05 wavelength) yield no significant differences in performance data, despite the 4-fold increase in the total number of segments in the model.

The use of corner reflectors in amateur radio service has tended to produce skimpy reflector planes, well under 1.5 wavelength per side. However, corner reflectors perform partially as a function of the size of the reflector planes. Let's consider a reflector with a width of about 1.5 wavelengths, an aperture of 3 wavelengths and a depth of about 1.5 wavelengths.

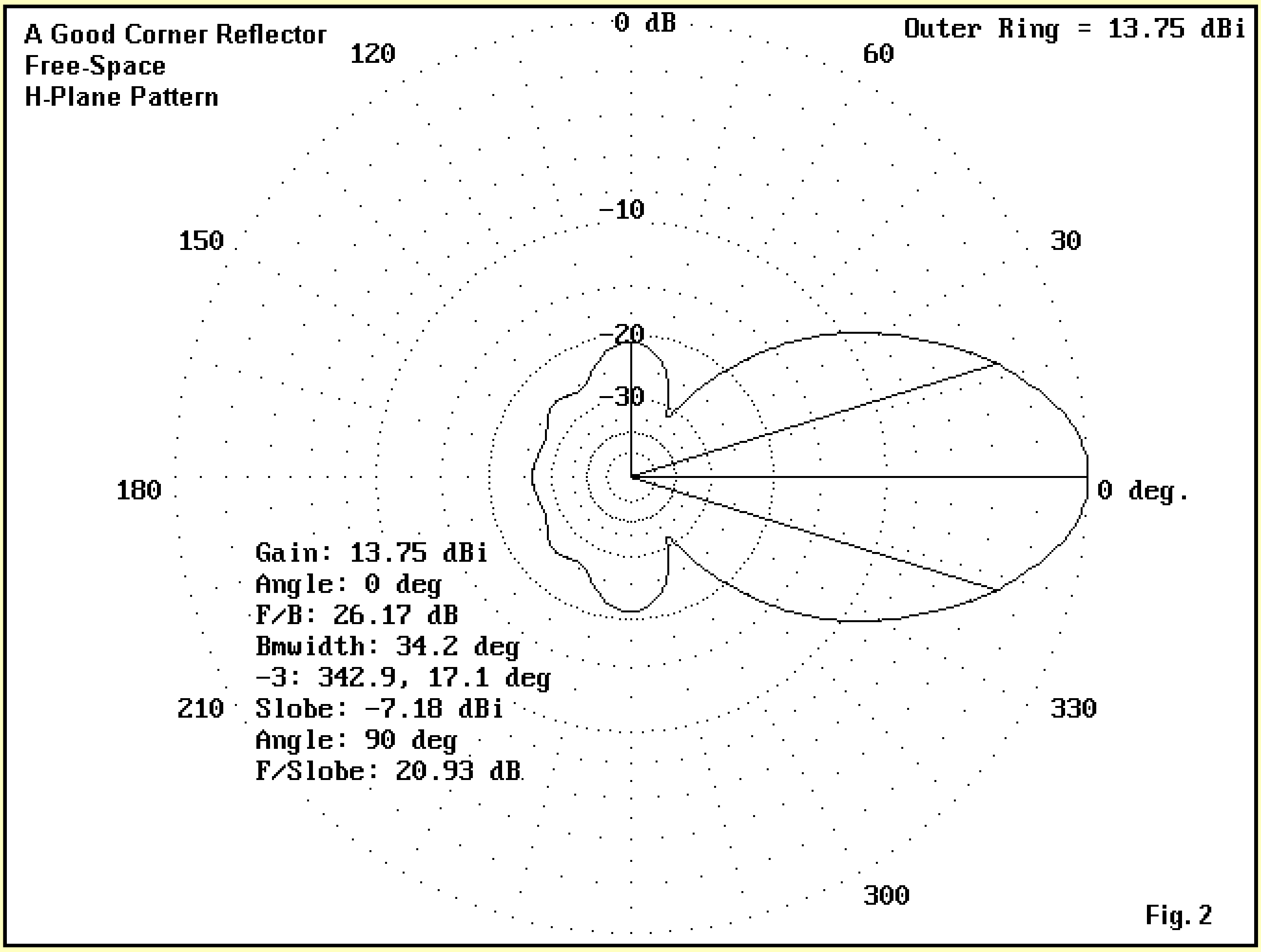


Fig. 2

Fig. 2 shows the H-plane polar plot of a good design using these proportions. The 13.75 dBi gain figure is for free space. Note that this pattern would be equivalent to setting up the reflector in the form of a Vee with the aperture toward the right. As we shall see from the E-plane pattern in **Fig. 3**, the planes of the reflector are less able to suppress side lobes than the edges of the rods in the reflector of this model and the tips of the dipole. However, the general level of H-plane sidelobes is less than from most conventional large Yagi designs with equivalent gain.

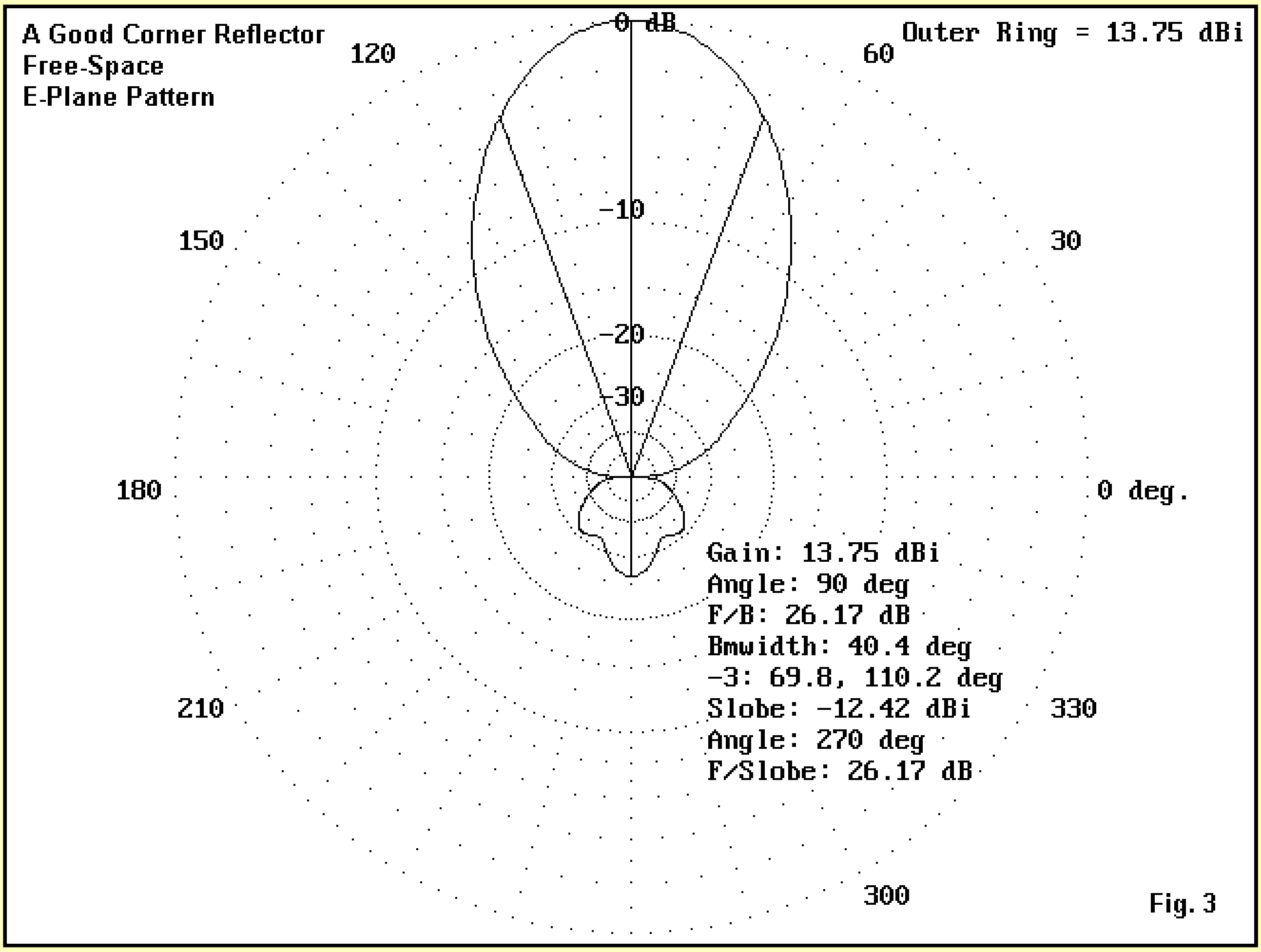
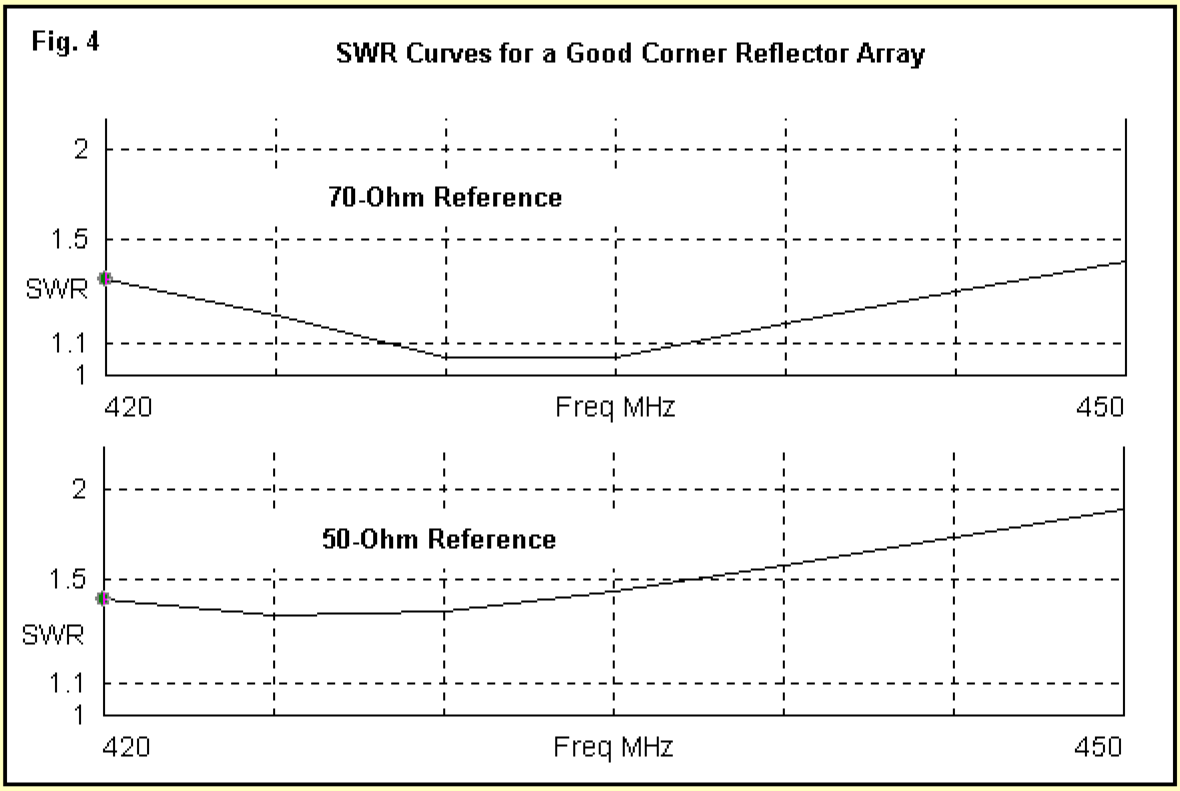


Fig. 3

The E-plane pattern is a paragon of good pattern behavior. The beamwidth to the half-power points is just over 40 degrees. The oval pattern is the dream of Yagi designers. The array shows consistent characteristics over a very wide bandwidth, as illustrated by the SWR curves shown in **Fig. 4**. Unlike long-boom Yagis of conventional design, corner reflector arrays lack strong forward sidelobes. Hence, they exhibit less off-axis sensitivity. I have used the 420-450 MHz amateur band as a modeling convenience. For many purposes, the physical structures required by the corner reflector might be too large to permit home workshop construction. However, the results are easily transportable to higher frequency ranges by simple scaling.

Fig. 4



The natural impedance of the dipole in the array is about 70 Ohms. We may control this value to some extent by the position of the dipole relative to the apex of the triangle. Still, there will be some change in performance with a repositioning of the dipole, and the design goal is always the best compromise between performance and feedline matching. Nonetheless, for this design example, a feedline composed of low loss 75-Ohm TV hard-line would be close to ideal.

To some extent, the operating bandwidth of the array is a function of the diameter of the dipole. Some designers have used solid-surface fan dipoles to achieve very wide bandwidths. Others have used phase-fed dipoles and similar structures to achieve more gain from the array.

Perhaps the most interesting direction of corner reflector studies has been taken by John Regnault (G4SWX) and John Sager, who have constructed some interesting models based on the fact that a corner reflector--especially of bar construction--acts somewhat like an optical reflector and somewhat like a parasitic reflector array. Using a reflector about 1.44 wavelengths wide with a 2 wavelength depth and an aperture of about 2.6 wavelengths, they obtain nearly 15.8 dBi free-space gain. The most fascinating aspect of their design work is the variable lengths used for reflector rods, with some being in the vicinity of 1/2 wavelength.

These notes provide some background into what we can expect of and achieve with corner reflectors designed in the conventional manner, along with variations on that theme. However, their function in the context of this small study is to provide a setting for considering the potentials of the 3-dimensional corner array.

The 3-D Corner Reflector Array

The 3-dimensional corner reflector array makes two key changes in the conventional corner array. First, it uses 3 planes as reflector surfaces, as shown in **Fig. 5**. Second, it places a monopole on one of the surfaces. The length of the monopole is variable, but something close to 3/4 wavelength yields a good match for common feedlines.

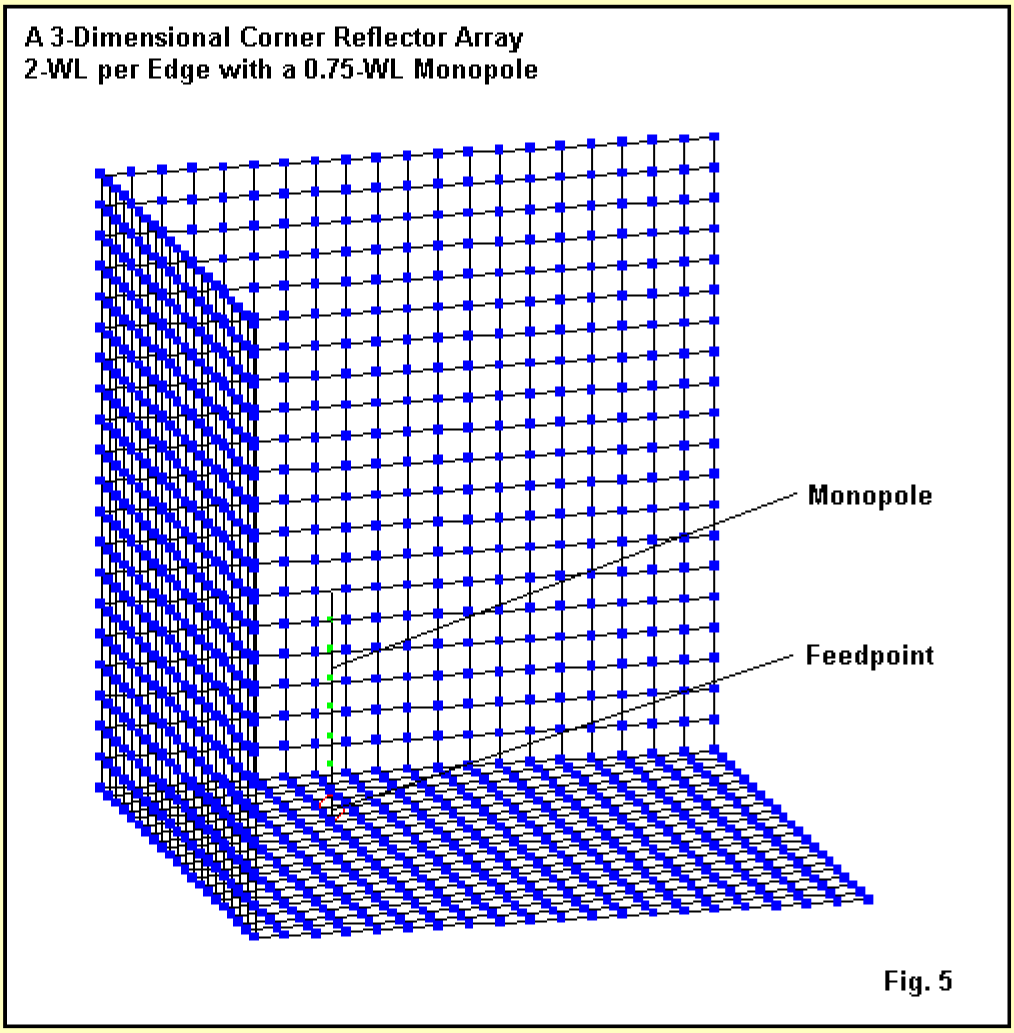


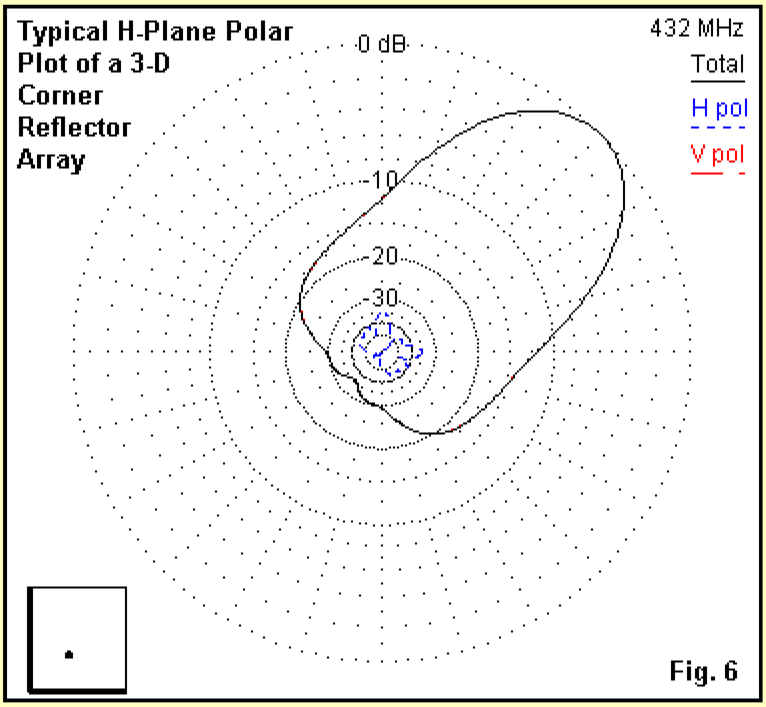
Fig. 5

Fig. 5 shows the plane of the array used as the ground plane for the monopole in a horizontal position. The other two planes are vertical. I should note in advance that this arrangement will not be the operating position of the array. However, the arrangement did simplify the construction of wire grids for the reflector surfaces.

Modeling the 3-D corner reflector requires wire grid techniques. There is simply no effective way to use rods and still make all of the required wire junctions along the joined edges of the 3 planes. Hence, the models for this array tend to be fairly large: 1403 segments for the smaller of the two models that we shall study and 2468 segments for the larger.

The model sizes result from using 0.1-wavelength spacing between wire centers-lines. Although this spacing is satisfactory for simulating solid or screen structures for the reflector planes, it limits the placement of the monopole to X and Y values in steps of 0.1-wavelength per step. As measured from the deep corner of the reflector planes, these steps increase to 0.1414 wavelength each. Fortunately, the step-size permits a close approximation of the monopole position to what is required for both maximum performance and for a good match to common feedlines. The result is that positioning the monopole becomes a matter of care, but not one of critical finickiness.

The patterns yielded by the 3-D corner reflector array are themselves worthy of study. The simpler of the two patterns is the H-plane pattern, a sample of which appears in **Fig. 6**.



All free-space H-plane patterns tend to have the same general features as the sample. The area immediate to the rear will tend to be depressed or show a bulge, depending upon the 180-degree front-to-back ratio of a given design. However, the broad shoulders and general "bullet" shape are common to most design variations. Despite this feature, we should not assume that the array will shows the same H-plane pattern shape when used over real ground. Note the very small horizontal component in the "butterfly" at the center of the polar plot. The line for the vertical component is hidden beneath the heavier line used to track the total pattern of the antenna.

Of special note is the fact that the 3-D corner reflector array--as modeled--is a vertically polarized antenna relative to the bottom plane of the reflector assembly. The conventional corner array is usable to good effect when either vertically or horizontally polarized--a matter of tilting the reflector. The 3-D corner reflector may also be tilted for horizontal polarization, so long as the monopole is parallel to the ground surface.

The reference sketch in the lower left corner of **Fig. 6** shows the orientation of the antenna and reflector relative to the pattern produced. As expected from right-angle vertical planes, the pattern center-line points to a bearing of 45 degrees. However, the elevation angle for the plot does not appear. If you initially think that it is the standard zero-degrees of free-space azimuth patterns, you would have failed to account for the effect of the third plane upon the antenna pattern.

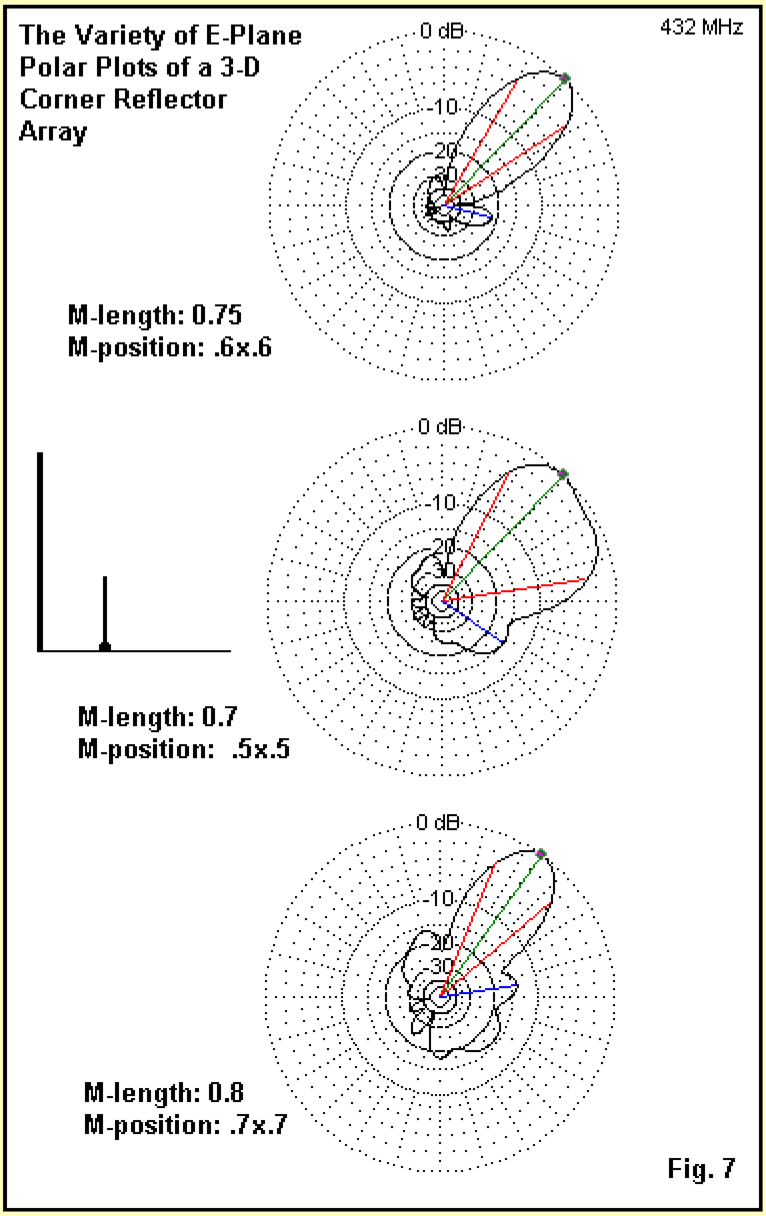


Fig. 7

If we take E-plane patterns along the center-line of the radiation field, we end up with what modeling conventionally refers to as elevation patterns--even if that term seems usually to be out of place in free space. **Fig. 7** shows three design variations and their resulting H-plane patterns. Although the H-plane pattern at the elevation angle of maximum radiation is consistent, the structure of the E-plane patterns is subject to considerable variation, both in the shape of the main lobe and in the size and shape of the side lobes. Hence, for minimal problems from potential side lobes structures, the design should be set for minimal strength in all but the main forward lobe. Not all combinations of monopole length and placement favor a clean E-plane pattern.

We shall address later the question of orienting the antenna in practice. For the moment, the key matter for design concerns the placement of the monopole on the bottom plane and the length of the monopole. In all cases, the monopole is fed on the lowest segment, the one that joins the junction of wires in the wire-grid plane.

As a test of potential performance, I tracked these variables using two different reflector plane dimension sets. The smaller set used planes that are 1.5 wavelength on each edge. The larger set uses 2.0-wavelength plane edges. The difference is sufficient to see if the plane size makes a significant performance difference.

The data for these modeling tests appears in the table below. The coordinates for the monopole position are given as X and Y values in wavelengths from the axis. However, these coordinates result in distances from the deep corner that are 1.414 times either of the coordinates. The test frequency is 432 MHz (the same as used with the corner reflector models).

Model 3c1r5: 1.5 wavelength per reflector-plane edge

Monopole length: 0.7 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	12.36	46	25.47	55	85 - j 27
.6x.6	14.06	49	23.83	53	56 - j 38
.7x.7	12.40	53	18.64	55	47 - j 26

Monopole length: 0.75 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	14.15	40	31.47	45	99 + j 13
.6x.6	14.39	47	25.76	50	73 + j 5
.7x.7	13.03	53	19.49	55	59 + j 21

Monopole length: 0.8 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	14.70	37	34.81	42	125 + j 32
.6x.6	14.44	46	27.15	48	93 + j 40
.7x.7	13.20	54	20.03	57	79 + j 67

Model 3c2r0: 2.0 wavelength per reflector-plane edge

Monopole length: 0.7 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	14.55	46	40.26	43	83 - j 26
.6x.6	15.89	48	33.64	41	54 - j 36
.7x.7	14.91	55	27.46	48	44 - j 23

Monopole length: 0.75 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	15.70	40	46.02	37	98 + j 12
.6x.6	16.19	46	35.67	39	71 + j 7
.7x.7	15.59	53	27.72	45	57 + j 27

Monopole length: 0.8 wavelength

Position (wl)	Gain (dbi)	TO angle (deg)	Front-Back Ratio (dB)	Beamwidth (deg)	Feedpoint Z (R+/-jX Ohms)
.5x.5	16.14	37	43.78	34	123 + j 32
.6x.6	16.37	45	37.48	38	91 + j 42
.7x.7	15.77	52	27.90	43	78 + j 77

These sample modeling figures reveal some interesting trends in the performance of the 3-D corner reflector array.

1. As we increase the size of the reflector--at least in the 2 steps shown here--gain and front-to-back improve, but the source impedance of the monopole does not significantly change for any given position or length.

2. As we increase the length of the monopole for a given position and reflector size, the gain increases and the signal elevation angle relative to the bottom plane increases.

3. As we move the monopole outward from the reflector deep corner, the gain peaks in all but one case at a coordinate set of 0.6x0.6, a distance from the deep corner of about 0.85 wavelength.

4. The lowest reactance for either size reflector set occurs with a monopole about 0.75 wavelength long and placed at coordinates 0.6x0.6 or 0.85 wavelength from the deep reflector corner. The impedance is close to 70 Ohms for use with either 50 or 70 Ohm cables.

5. The monopole position and length most apt to yield an elevation angle at or very close to 45 degrees is the 0.75-wavelength version spaced 0.85 wavelength from the reflector deep corner. As shown in **Fig. 7**, this combination also offers the cleanest E-plane pattern structure at close to maximum obtainable gain.

6. As we move the monopole further from the deep reflector corner, the front-to-back ratio decreases. As we increase the reflector size, the front-to-back ratio increases.

With either size reflector planes, the 3-D corner array is a wide-band antenna. The following tables shows performance values at 420, 435, and 450 MHz to sample the rates of change across this amateur band. All monopoles use coordinates 0.6x0.6 (wavelength) and are 0.75 wavelength tall at 432 MHz.

Model 3c1r5: 1.5 wavelength per reflector-plane edge at 432 MHz

Frequency MHz	Gain (dBi)	TO angle (deg)	Front-Back Ratio (dB)	Feed Z (R+/-jX Ohms)
420	14.17	48	23.72	69 - j 11
435	14.44	47	26.17	73 + j 9
450	14.66	47	27.49	76 + j 30

The performance values increase (along with the feedpoint impedance) because the reflector and monopole have a constant set of physical dimensions, enlarging them slightly with increasing frequency. **Fig. 8** shows both the 75-Ohm and the 50-Ohm SWR curves for the smaller reflector array across the entire band at 5 MHz intervals.

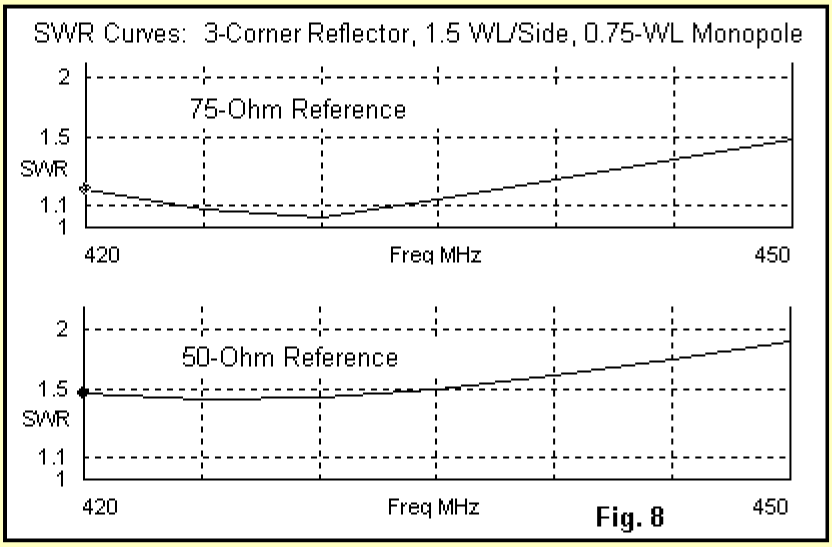


Fig. 8

Model 3c2r0: 2.0 wavelength per reflector-plane edge at 432 MHz

Frequency MHz	Gain (dBi)	TO angle (deg)	Front-Back Ratio (dB)	Feed Z (R+/-jX Ohms)
420	15.93	46	34.73	66 - j 10
435	16.26	46	35.82	72 + j 11
450	16.61	47	36.52	76 + j 33

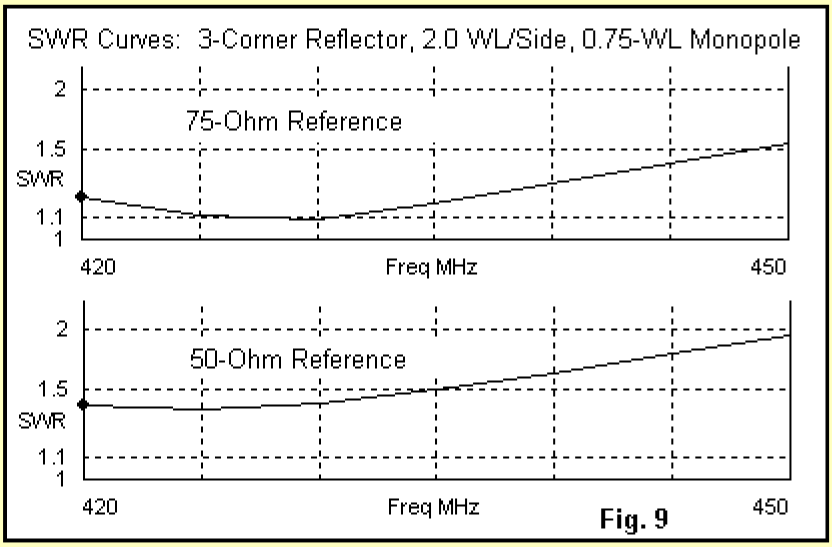


Fig. 9

Fig. 9 shows the 75-Ohm and 50-Ohm SWR curves from 420 to 450 MHz in 5 MHz intervals. In general, the performance values for the array change by well under 5% while the impedance remains well within appropriate ranges for matching to standard coaxial cables.

The performance values and operating bandwidth of the array are to some extent a function of the monopole diameter. In this design exercise, I used a 0.03-wavelength diameter, which translates into 20.8 mm or 0.82". A standard piece of copper tubing in the vicinity of these values would easily replicate the performance.

With respect to raw performance, the 2-wavelength reflector assembly yields the best values. A 0.75-wavelength monopole spaced about 0.85 wavelength from the deep reflector corner or at coordinates 0.6 x 0.6 wavelength from the bottom reflector edges offers the best compromise between gain and feedpoint impedance. The monopole length at 432 MHz will be about 20.5" or 520.5 mm.

At 432 MHz, the 2 wavelength reflector will have edge lengths of 51.9" or 1318.5 mm. These lengths may be ungainly for practical installations. The 1.5 wavelength reflector assembly has edge lengths of 38.25" or 971.5 mm, which may be more feasible. Since the source impedance does not change significantly with increases in the size of the reflector, the best reflector is the largest one that will endure local weather conditions. This suggestion applies up to the 2-wavelength version, since I have not modeled larger reflector assemblies.

With a 2-wavelength reflector assembly, the 3-D corner reflector array offers superior performance to the standard corner reflector occupying a similar volume. How much superior depends to some degree on the techniques applied to the conventional corner reflector. Nonetheless, for vertically polarized signals, the 3-D corner array offers a degree of simplicity along with its performance that may appeal to many backyard antenna builders.

Some Practical Considerations

There are two major categories of practical concerns that any potential 3-D corner array builder must address: construction and orientation.

Construction can employ any set of proven UHF techniques. For frequencies above 900 MHz, it is feasible to form the reflector from a single sheet of copper flashing. Two edges can be simple bends, with the final joint formed from an overlap that one solders securely. Raw edges can use fold-over lips with solder to stiffen and secure the junction of the lip with the flashing surface.

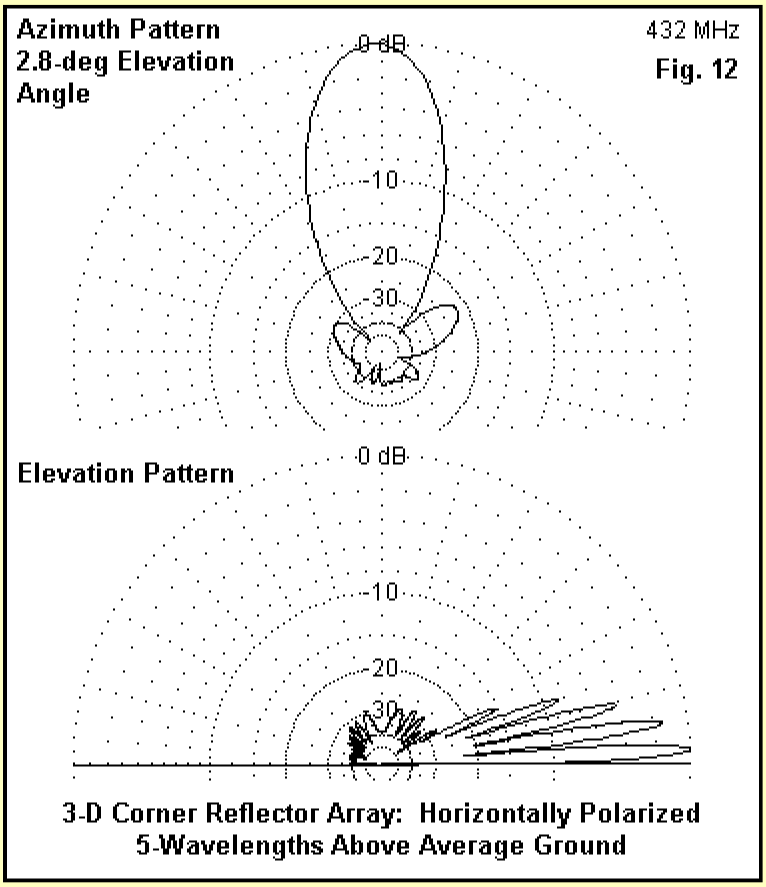
One advantage of a solid reflector surface is that anything done to the "backside" usually has no effect upon performance. Hence, the bottom plane can be stiffened to the degree necessary for the installation of both the monopole (with its cable connector) and a mounting system.

Fig. 10

An alternative construction method to the use of solid reflectors surfaces appears in **Fig. 10**. The antenna belongs to WA4PGI and is designed for 1296 MHz. It employs 1/4" aluminum hardware cloth supported at the edge-junctions by L-stock. Each diagonal along the reflector planes receives further support from a length of U-channel. The pieces are riveted together. Hardware cloth has the advantage of slipping the wind more effectively than a solid plane.

Fig. 11 provides a closer view of the monopole and its mounting. Essentially, a plate backs up the hardware cloth and permits the mounting of a coax connector to which one might solder or braze the monopole. The plate system does not disturb the overall reflector operation since it lies behind the plane. However, it also serves as a mount for attachment of the array to a mast with U-bolts. In these photographs, the array is horizontally polarized and has been used to good effect by WA4PGI for weak signal work.

Because the main beam takes off at an angle of about 45 degrees to the bottom plate, the bore sight bisects the angle formed by each of the pairs of planes in the reflector assembly. Hence, the entire array must be tipped downward about 45 degrees in vertically polarized service along a line formed from the deep corner of the reflector through the monopole to the front far corner of the bottom plane. For horizontally polarized service, rotate the tilted assembly 90 degrees around the apex of the corner (the deep reflector corner) until the monopole is parallel to the ground surface.



In **Fig. 12**, we can get a sense of the performance potential of the WA4PGI array, even though the patterns are for 432 MHz with the antenna only 5 wavelengths (about 3.5 m or 11.5') above ground. Both the model and the 1296-MHz array use 2-wavelength reflector planes. The sidelobe imbalance that we saw in the E-plane patterns in **Fig. 7** reappears, although the strongest sidelobe is nearly 22 dB below the main forward lobe. The gain at 2.8 degrees elevation is 21.95 dBi, with a 180-degree front-to-back ratio of nearly 39 dB.

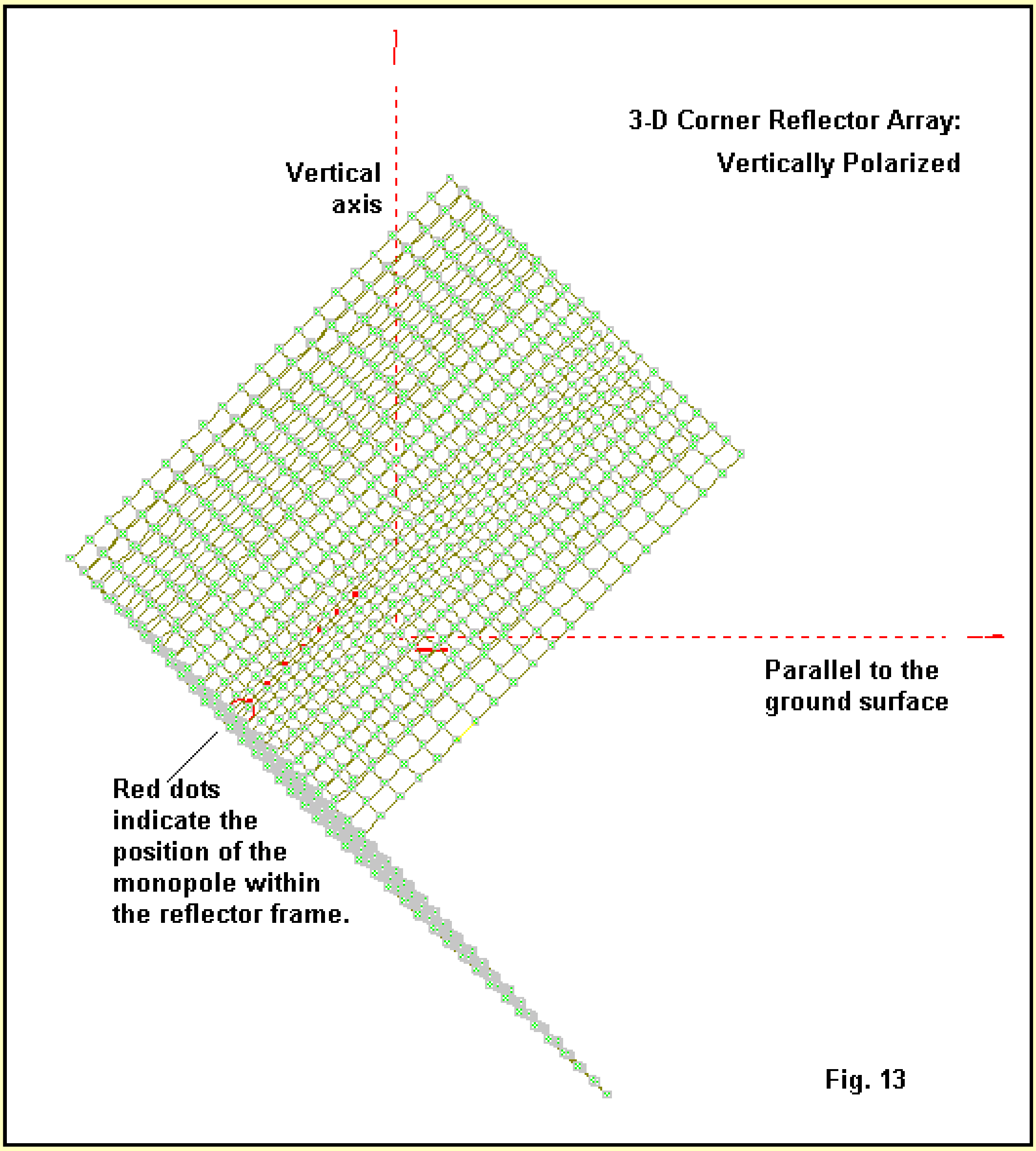
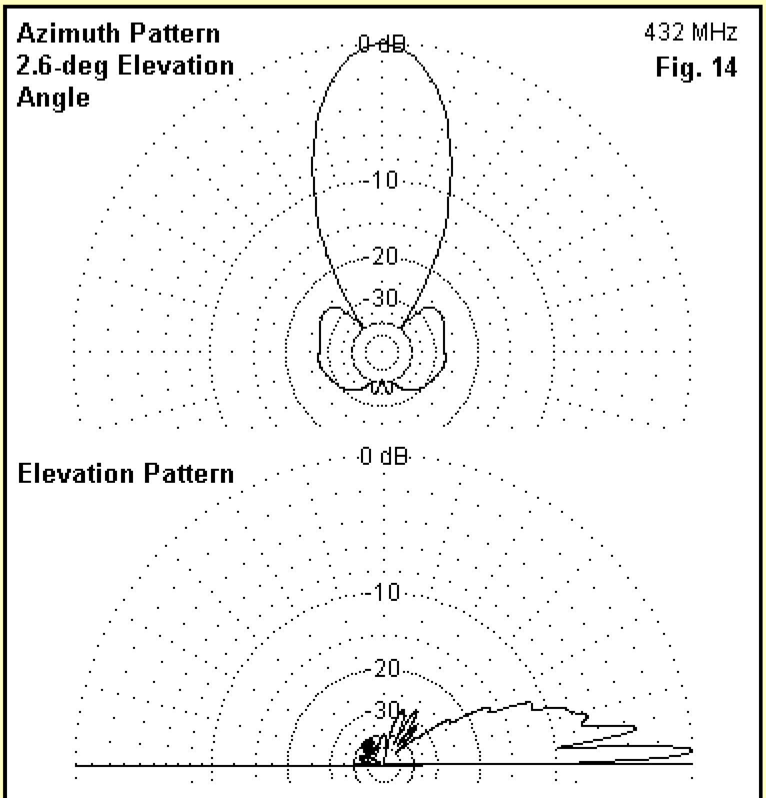


Fig. 13 is a representation of the array in vertically polarized service. The line of red dots mark the position of the monopole within the reflector planes. (The technique I used to obtain the tilted arrays was to save the EZNEC/4 file in .NEC format and then to import it into NEC-Win Plus. There, I blocked all of the wires and performed successive rotation steps. I rotated around the Z-axis by 45 degrees to place the bore sight along the Y-axis. I then rotated the array around the X-axis to obtain the tilt required for the vertically polarized model. Rotating the result by 90 degrees around the Y-axis yielded the horizontally polarized version. I saved the results as .NEC files and opened them from within EZNEC for the pattern runs (for consistency with earlier patterns).



3-D Corner Reflector Array: Vertically Polarized
5-Wavelengths Above Average Ground

In **Fig. 14**, we see the patterns of the array in vertically polarized service. The gain at an elevation angle of 2.6 degrees is 20.64 dBi. The differential between the horizontal and vertical orientation gains is a function of the relatively low height above ground. As the height increases, the two gain values gradually merge. As the free-space patterns suggested, the array has slightly better side lobe performance when vertical, with the strongest sidelobe down about 25.5 dB relative to the main forward lobe. Note that the free-space bullet-shaped pattern has given way to a more conventional pattern shape. It is not always safe to assume that free-space patterns will replicate themselves in azimuth patterns over ground. The sidelobe "ears" are a function of using a 3/4-wavelength monopole. (Similar ears show up on extended double Zepp arrays, although the ears for the corner reflector array are exceptionally modest.) The current along the monopole shows two peaks, rather than the single peak to which we are accustomed when using 1/4-wavelength monopoles.

From the patterns above ground, it is clear that the 3-D corner reflector array is capable of very high performance, whichever way we orient the array. It features a very narrow beamwidth, relatively low side-lobe levels, and high gain to go along with the relatively simple construction, wide operating bandwidth, and easily-matched feedpoint impedance.

I would recommend a gimbal or other adjustable mounting system that permits final adjustment of the angle to occur at the installation height. Select several distant targets at various headings and align the array with each. Then adjust the tilt and rotation angles for maximum signal strength. Tighten the assembly at either the average of the angles required or by reference to the most important of the sources/targets. Since the exact angle may depend upon the antenna height, the local terrain features, and the specific operating needs of the station, no single recommendation would cover all possible cases. However, an error of 1 or 2 degrees will reduce gain at the target only in the hundredths column of the gain figures.

For upper UHF service, the 3-D corner reflector offers the possibility of arranging several arrays, each pointed toward a specific target. Nothing in the performance figures suggests that one cannot arrange several reflectors in close rearward proximity to each other. Indeed, the use of this antenna design in commercial service might find them surrounded by RF-transparent housings. A cubical housing would encase the antenna well and place a point into potential winds, allowing the wind to by-pass the reflector and monopole. Other aerodynamic shapes are also possible. The small size of the array at frequencies over 900 MHz gives the 3-D corner array excellent potential for high gain, point-to-point, wide-bandwidth communications, as might be required in spread spectrum wireless applications.

As an emergency reflector system, the 3-D corner reflector also has possibilities. you may line 3 sides of a cardboard box with aluminum foil and poke the antenna of a hand-held unit through one plane. Although this procedure ignores all of the conditions for optimal service, you may still experience an increase in signal strength to your target. At a more formal level, you can preplan the reflector for your intended frequency range and then construct 3 panels that will assemble and interlock at the field site. You may even design the individual panels so that they fold up into a compact mass for transport.

My thanks once more go to Gene Wood for bringing the 3-D corner reflector antenna design to my attention. I recommend that anyone who holds an interest in the 3-D corner reflector system consult the original IEEE article by Naoki Inagaki for reference to the design equations and general theory underlying a most promising array.

Return to Main Index