The Quad Beam as an Amateur Satellite Antenna

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US amateur satellite operators use a variety of antennas for frequencies just below 146 MHz and in the 435.6-MHz area. Most often, if the operator desires a circularly polarized signal, he uses crossed quadrature-fed Yagis. The 3:1 frequency ratio of the two satellite sub-bands tends to create difficulties in constructing interlaced crossed Yagis. Therefore, most serious satellite operators use widely separated antenna booms. The mechanical issues associated with such a structure, especially when controlled by an elaborate AZ-EL rotator control system, are well known.

An alternative to the crossed Yagi is the quadrature-fed quad beam. The technique of feeding a quad loop to obtain circular polarization is quite simple and long known. A version of a quadrature-fed quad loop appears in the sample models in the MININEC program AO by K6STI. One simply feeds signals 90 degrees out of phase but of equal current magnitude to points on the quad loop that are also 90-degrees apart. These can be adjacent corners or adjacent side-centers.

In the following design notes, we shall look at some of the issues involved in both the electrical design and the physical implementation of concentric quads for 146 MHz and for 435.6 MHz. If we can arrange the quads concentrically, we may mount both on a single boom and relieve the greater part of the mechanical issues associated with the use of crossed Yagis.

A Dual-Band Quadrature-Fed Satellite Quad Beam

The design goals of the effort are the following.

- 1. A minimum of 10 dBi forward gain on each band with a reasonably well-shaped pattern.
- 2. Reversible circular polarization.
- 3. 50-60° -3-dB beamwidth with under 1° variation for ease and reliability of aiming.
- 4. Minimal structure using a single boom and common materials, commensurate with performance goals.
- 5. Simple quadrature feed for each quad, with a 50-Ohm main feedline impedance.

A square quad loop drivers may be fed at the center of adjacent sides or at proximate corners with a 90° current phase shift to achieve circular polarization. Parasitic elements do not require separate treatment for each component of the polarization. The result is remarkably even current magnitudes along the quad loops, with considerable latitude for physical or frequency inexactness before the resulting pattern takes on enough distortion to be unusable. The limiting factor in combining satellite arrays for 146 and 435.6 MHz is the almost precise 3:1 frequency ratio between the two satellite allocations. A wavelength at 146 MHz is about 80.84", while a wavelength at 435.6 MHz is 27.10". Combined Yagis often interact in uncontrollable ways. However, it is possible to control the interactions between concentric quads to minimize unwanted interactions. The keys to successful 435.6-MHz operation are relative element placement and compensation for gain lost by remnant interactions with the 146-MHz elements.

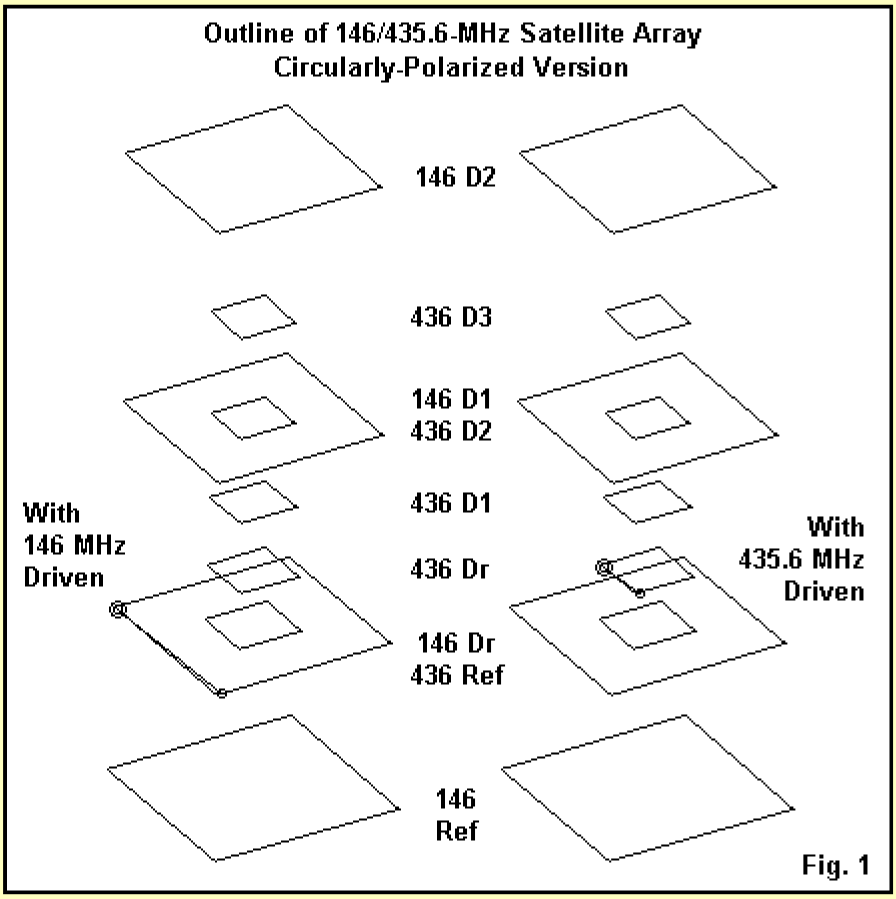

Outline of 146/435.6-MHz Satellite Array
Circularly-Polarized Version

Fig. 1

Fig. 1 shows the general outline of the dual quad array with each band active. The graphic identifies each element. On the left, the 146-MHz driver is active, with the feedpoint to the far left and a phase line providing a 90° current phase lead to the next clockwise corner--yielding right polarization. Moving the feedpoint to the lower corner reverses the polarization to left-hand polarization. On the right, the 435.6-MHz driver is active, and the same polarization rules and reversal potentials apply.

The 146-MHz Driver and the 435.6-MHz Reflector are in the same plane, requiring a single support structure for both elements. Likewise, the 146-MHz director 1 and 435.6-MHz Director are also in the same plane, and require a single support system. **Table 1** provides the specific dimensions for each element within the dual array.

Dimensions of the 146/435.6-MHz Dual Quad Satellite Array--Quadrature-Fed

Frequency MHz	**Element**	**Side Length in Inches**	**Hypotenuse in Inches**	**Circumference in Inches**	**Distance from 146-MHz Reflector**
146 MHz	**Reflector**	**21.91**	**30.98**	**87.63**	**-----**
	Driver	**20.78**	**29.38**	**83.10**	**19.40***
	Dir. 1	**19.48**	**27.54**	**77.93**	**44.06****
	Dir. 2	**19.16**	**27.09**	**76.64**	**73.57**
435.6 MHz	**Reflector**	**7.343**	**10.383**	**29.372**	**19.40***
	Driver	**7.020**	**9.926**	**28.082**	**25.91**
	Dir. 1	**6.530**	**9.233**	**26.120**	**34.03**
	Dir. 2	**6.422**	**9.081**	**25.687**	**44.06****
	Dir. 3	**6.422**	**9.081**	**25.687**	**56.06**

Table 1. Dimensions of the 146/435.6-MHz dual quad array when quadrature fed. The 146-MHz elements use AWG #14 copper wire (0.0641" diameter); the 435.6-MHz elements use AWG #22 copper wire (0.0253" diameter). * and ** indicate elements that share a single support structure.

Quad Positioning: As **Fig. 1** and **Table 1** clearly indicate, the 435.6-MHz quad begins with its reflector even with the driven element of the 144-MHz array. The positioning does permit two elements on each quad to share support structures, thus simplifying the mechanical design. However, the chief reason for the positioning arises from the design goal of minimizing interactions between the two quads. The quads are positioned relative to each other so that the 435.6-MHz quad activates as little as possible the elements of the 2-meter array surrounding it.

When elements of a multi-band array bear a harmonic relationship to each other, activating a higher frequency driver can also activate one or more lower frequency elements. When the elements have a 2:1 frequency relationship, as is often the case for 20-10-meter Yagi arrays, a 20 meter element may dominate. The 20-meter element often pushes the 10-meter passband downward in frequency. When the relationship is 3:1, as it is with a 146-432-MHz array, the dominating lower frequency element often breaks the desired single-lobe pattern into multiple lobes.

The cure is to use "control" elements. In linear-element arrays, such as Yagis, the control element for the higher frequency is located behind or toward the driver and closely spaced to the lower frequency elements--sometimes as close as 6-12 inches in HF arrays. With quads, the controlling element may be placed in line with the lower-frequency element, as is the case with the 435.6-MHz second director and the 146-MHz first director. In either case, we need a further director forward of the control element to restore array gain. Hence, the 435.6- MHz quad has one more element than the 146-MHz quad.

Quadrature Feed: The two concentric quad beams employ quadrature feed to achieve circular polarization. The simplest form of quadrature feed is a 1/4-wavelength feedline having a characteristic impedance (Zo) that equals the natural resonant impedance of the driver. Both quads are designed for a natural impedance of about 95-100 Ohms. Quadrature-feed results in a net feedpoint impedance that is half the impedance of the individual feedpoints, and the result is a good match for a 50-Ohm main feedline.

For 146-MHz, RG-62, with a 93-Ohm Zo, is a satisfactory material for the phasing line. Since the cable has a velocity factor (VF) far less than 1.0, a 1/4-wavelength line will not reach from one corner of the array to the next. As well, a direct line would likely interact with the driver wire length between the two points. Hence, the best line is likely 3/4 wavelengths electrically and routed toward and around the boom at the center of the quads. Separating the two drivers, as in the present design, minimizes interaction between the 146-MHz and the 435.6-MHz phase lines.

If we use a length of coax cable for the phasing line, we can achieve a reversible circular polarization simply by installing Tee connectors at the phase-line connection corners. Connecting the main feedline to one corner produces a signal circularly polarized left, while connecting the feedline to the other corner produces a right-hand circular polarization.

Common coax cables are 1/4" or more in diameter. Although this diameter is usable at 146 MHz, it creates problematical bulky connections at 435.6 MHz, especially with the use of #22 wire for the element. More applicable to the higher frequency is the use of a glass board as the driver support and as a field for etched phase lines. A well-balanced 100-Ohm line can be etched on the board using both sides. Since the impedance of the line requires that we divide the usual parallel line constant by the dielectric constant of the material between the lines, fabrication of such a line requires knowledge of the board material properties. As well, the board may well create a velocity factor less than 1.0, and we would need to experiment to discover the VF of the material used. The VF might also be affected by the material used to weather protect the phase-line traces on the board.

However, a glass board would also permit 2 other conveniences. First, one might construct the driver from etched copper paths on the board perimeter, creating an integrated driver loop and phase line. Second, we might also create a 50-Ohm line down to the boom and connect the main feedline at this structurally sounder position. However, this latter step requires that we know in advance that we would require only one of the two possible circular polarizations. Otherwise, we may use PC-board-mounted feedline connectors at the two relevant corners.

We may cut out portions of the board not required for structural or electrical duties to increase the wind-slippage of the board. Finally, we may also adapt these same techniques to the 2-meter driver, although the larger glass board, even with cut-outs--will undoubtedly add significant weight to the array. The added weight need not be a disadvantage, since it may help stabilize an array whose main support lies behind the 2-meter reflector. The parasitic elements require no special treatment to create a directional array when we quadrature-feed the driver.

Performance: The array achieves at least 10 dBi forward gain on each of the two bands within the segments used for satellite service. For most satellite operations, this is excess gain relative to minimums required. However, the excess is useful in situations that call for the use of a signal splitter-combiner to allow for a single feedline to the main equipment.

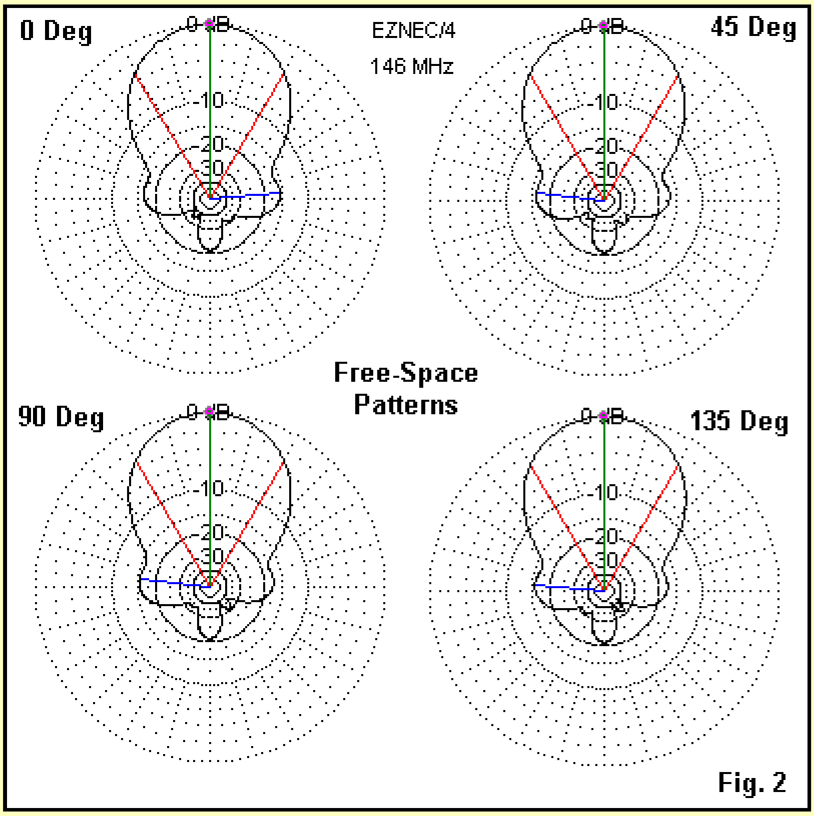


Fig. 2 shows the free-space pattern of the 146-MHz array taken at 4 cross-section angles. The modeling technique used here was to create the geometry along the Z-axis, so that all 4 patterns are "elevation" patterns taken at different azimuth angles, giving us a cross-section of the array pattern every 45 degrees. The cross section labeled 0 degrees gives us a pattern running through the main feedpoint to the opposite corner. The cross section labeled 90 degrees runs through the quadrature-fed point through its opposite corner.

There are slight asymmetries to the pattern, but they occur in the region of side and rear lobes. The half-power points are not more than 2 degrees off of perfect symmetry.

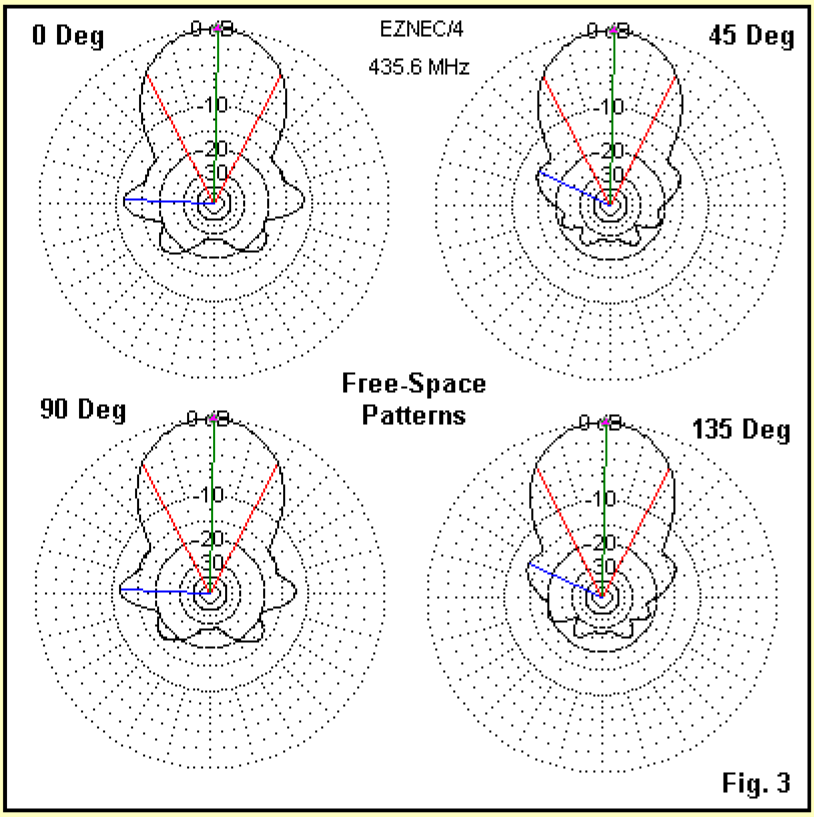


Fig. 3

In **Fig. 3**, we have the corresponding free-space patterns of the array at 435.6 MHz. The side lobes are more evident in the planes running from corner to corner than they are in the planes running through the centers of the sides of the loop structure.

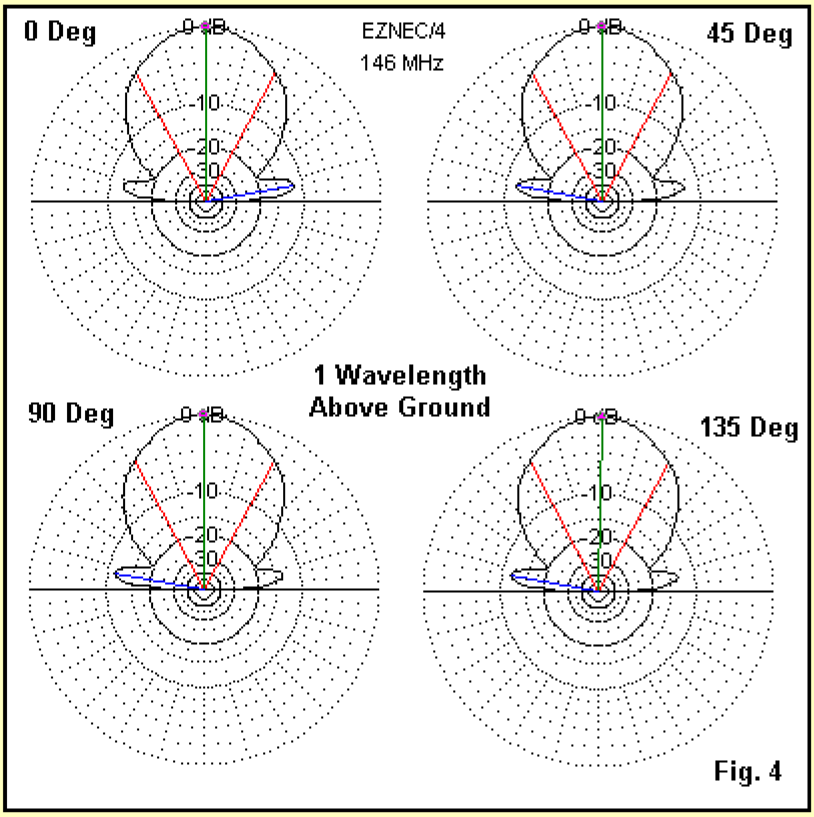


Fig. 4

Perhaps more significant than the free-space patterns are the patterns over ordinary ground. The array was set 80" above ground at its lowest point. This distance is about 1 wavelength at 146 MHz and about 3 wavelengths at 435.6 MHz. **Fig. 4** shows the patterns at 2 meters. The lowest side lobe is inevitable due to ground reflections at the 1-wavelength height.

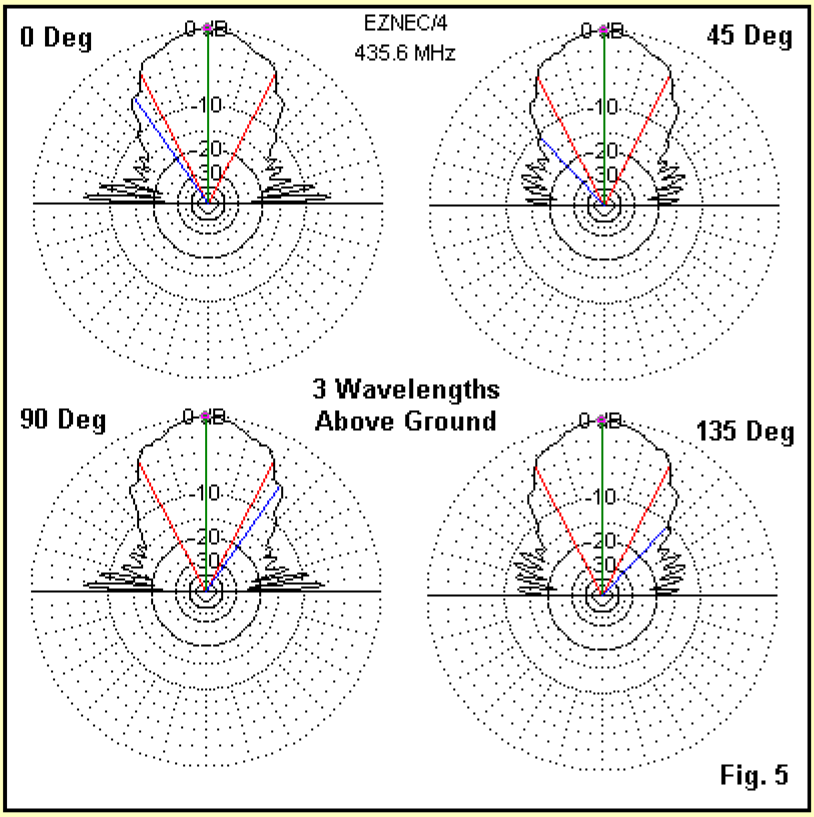


Fig. 5

When we examine the 435.6-MHz patterns in **Fig. 5**, we see the more complex lower lobe structure that goes along with the increase in height. The stronger free-space side lobes at 0 and 90 degrees yield stronger low angle lobes for the array.

Nonetheless, the arrays maintain good gain, relatively good forward lobe structure, and a good beamwidth. The gain of an array pointed straight upward is normally the sum of the forward gain and the rearward gain, minus any ground losses. Hence, the 2-meter array shows a gain of about 10.4 dBi, while the 435.6-MHz quad yields nearly 10.8 dBi gain. The -3-dB beamwidth is about 57 degrees at 146 MHz and 54 degrees at 435.6 MHz. In both cases, we achieve a good match between the quads--one of the goals of the exercise.

A Dual-Band Single-Feed Satellite Quad Beam

Some satellite operators prefer the simplicity of a linear or single feedpoint, preferring to use gain as a substitute for the advantages of circular polarization. Since the array gains exceed minimums needed for satisfactory satellite operation, I redesigned them for single feed to each band driver. One technique of doing this, especially apt if the drivers use glass-board supports, would be to use the array as is and to construct a tapering Zo line from the fed corner to the boom, at which point we might connect the main feedline.

The alternative is to redesign the individual quads to achieve a 50-Ohm feed impedance. This redesign requires that we close up the spacing between the driver and the reflector and re-size each loops to restore performance. Table 2 shows the dimensions that resulted from the redesign work.

Dimensions of the 146/435.6-MHz Dual Quad Satellite Array--Single-Feed

Frequency MHz	Element	Side Length in Inches	Hypotenuse in Inches	Circumference in Inches	Distance from 146-MHz Reflector
146 MHz	Reflector	21.50	30.41	86.00	-----
	Driver	20.70	29.27	82.80	13.18
	Dir. 1	19.48	27.54	77.93	37.84
	Dir. 2	19.16	27.09	76.64	67.35
435.6 MHz	Reflector	7.240	10.240	28.960	23.98
	Driver	6.940	9.810	27.760	27.69

Dir. 1	**6.530**	**9.233**	**26.120**	**35.81**
Dir. 2	**6.422**	**9.081**	**25.687**	**45.84**
Dir. 3	**6.422**	**9.081**	**25.687**	**57.84**

Table 2. Dimensions of the 146/435.6-MHz dual quad array using a single feedpoint per band. The 146-MHz elements use AWG #14 copper wire (0.0641" diameter); the 435.6-MHz elements use AWG #22 copper wire (0.0253" diameter).

Quad Positioning: The redesign eliminated the possibility of aligning the 435.6-MHz reflector with the 146-MHz driver. (Remember that each quad is now fed at only one corner position.) In fact, the entire 435.6-MHz array required repositioning to restore its operation. See **Fig. 6**.

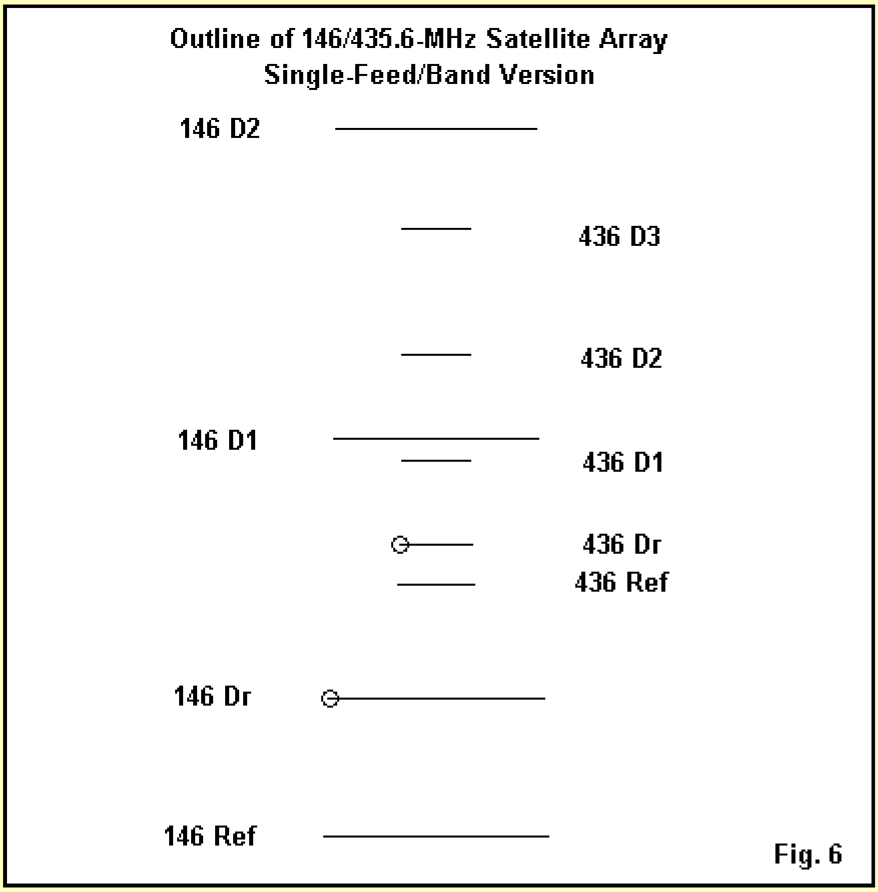


Fig. 6

The higher-frequency quad is moved forward within the 2-meter quad. The first director serves as a control element that lies slightly behind the 2-meter first director. However, both quads retain their 10+ dBi free-space gain values. As well, both quads show a near-resonant feedpoint impedance of 53-55 Ohms.

Performance: The relatively small variations in pattern shape that we saw as we took various cross sections of the quadrature-fed version of the array turn into much more significant variations using a single feedpoint for each band. In the following figures, 0 degrees represents a free-space H-plane pattern for the array, and 90 degrees gives us the E-plane pattern.

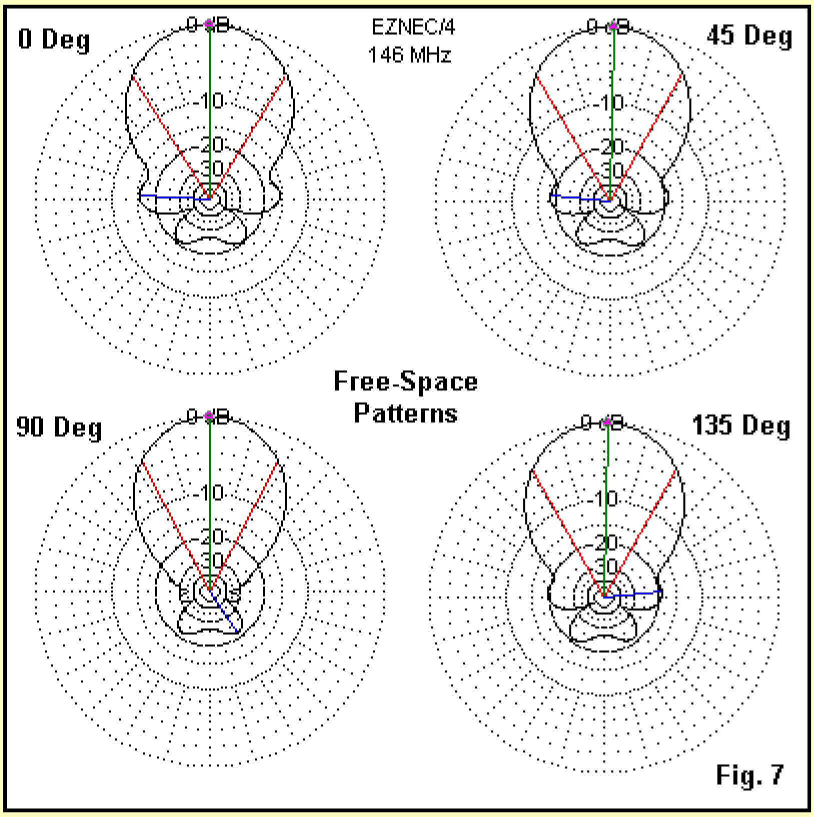
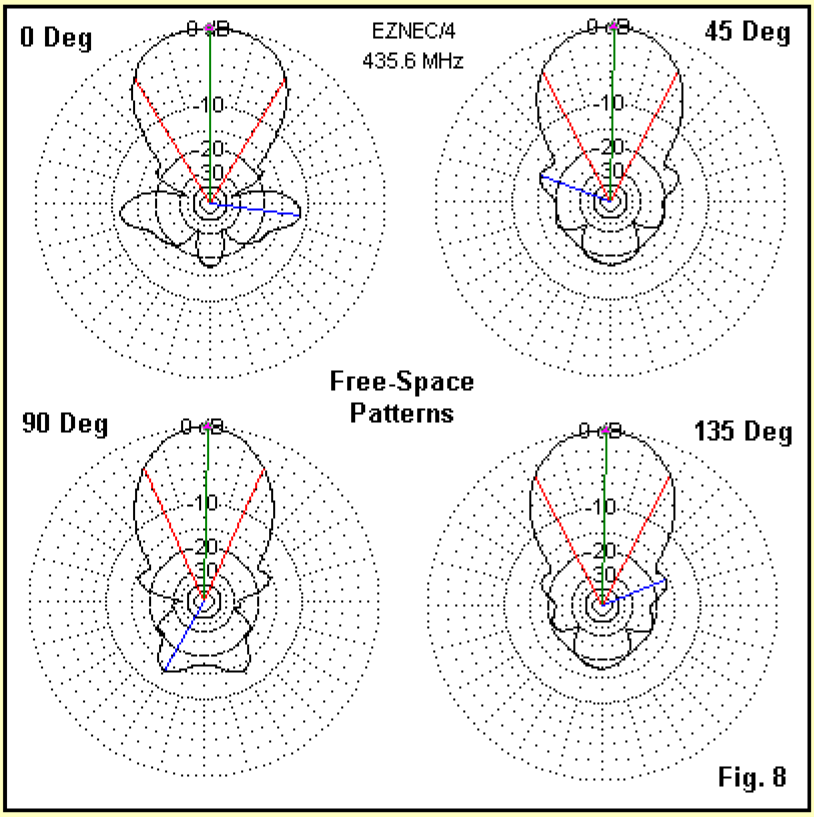


Fig. 7 provides us with the free-space patterns at 146 MHz. The E-plane and H-plane pattern differences are readily apparent. The tiny side lobe in the E-plane becomes a much larger lobe in the H-plane, a phenomenon perfectly normal for both Yagis and quads using linear feed.



The patterns at 435.6 MHz, **Fig. 8**, show much more radical differences between the E-plane and the H-plane patterns. The energy in the H-plane side lobes becomes energy in the E-plane rear lobes. The 45-degree and 135-degree patterns show how this energy is averaged at these intermediate positions.

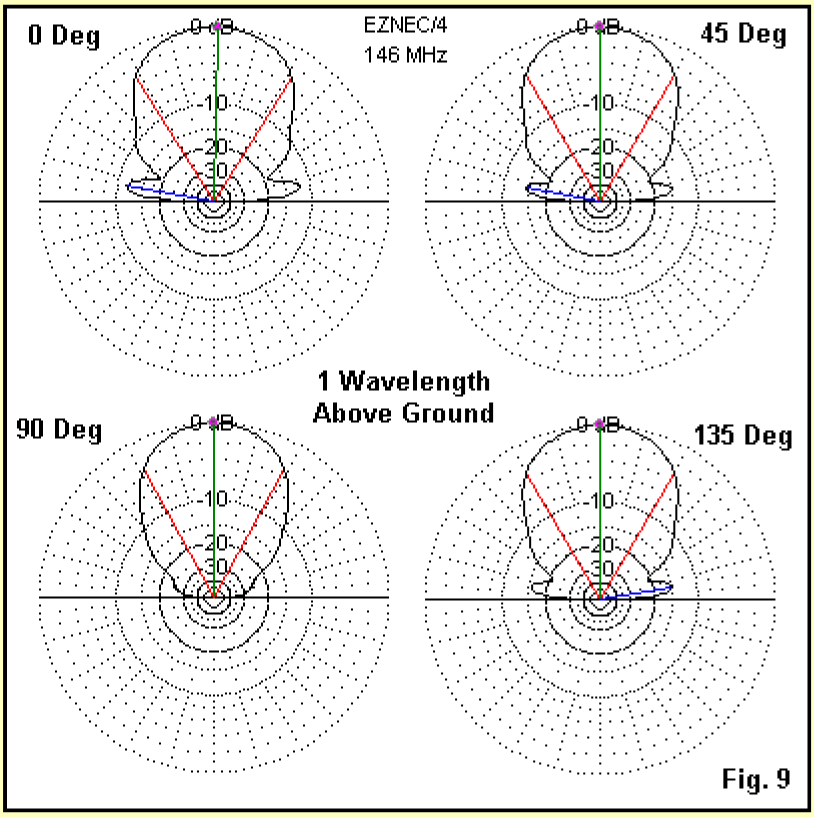


Fig. 9

At 146 MHz, the array patterns are well-behaved when the base of the array is 80" above ground, as shown in **Fig. 9**. The E-plane smaller side lobes result in an absence of low-angle radiation, although the lowest lobe grows as we move to angle closer to the H-plane. The forward gain at 146 MHz is about 10.4 dBi when we set the array about 1 wavelength above ground, pointed straight up.

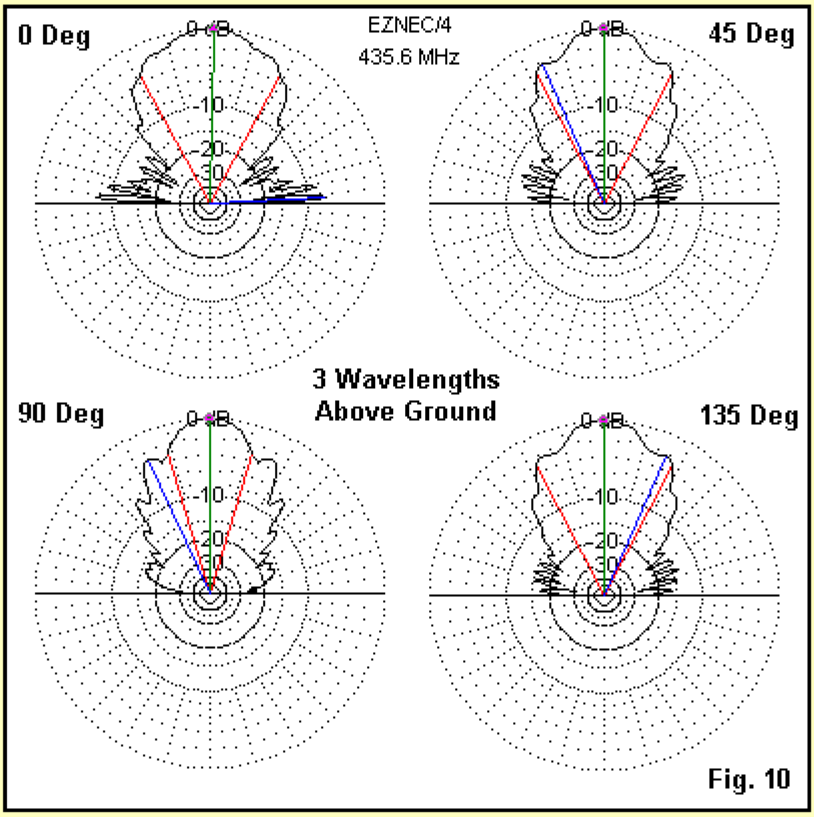


Fig. 10

The single-feed version of the array shows much less "good behavior" with its base 80" above ground, as revealed by **Fig. 10**. The beamwidth varies considerably as we change angles from the H-plane to the E-plane. As well, the forward lobe shows some influence from the 2-meter elements in the development of irregularities in the shape. The lower free-space front-to-back ratio results in a higher forward gain vertically, about 11.3 dBi, up from the 10.7 dBi free-space figure.

Ultimately, then, the single-feed version of the two-band array would provide satisfactory performance for those who use linearly polarized feed system--within the limits imposed by not using circular polarization. The individual quads provide a good match to a 50-Ohm feedline, and the single-feed version retains the one-boom structural advantage offered by quads in this service.

The Two Arrays at an Angle

The use of a vertical orientation for the arrays in assessing their performance provides usable expectations for the two versions of the quad beams for most high angle uses. However, satellites have the disturbing habit of changing their elevation angles continuously as they make their orbital passes. Therefore, a fuller assessment requires that we do something to take this into account.

To make the assessment, I used NEC-Win Plus' geometry rotation feature to tilt the models 45 degrees. (This procedure involved saving the EZNEC Pro/4 models as .NEC files, processing then in NEC-Win Plus as .NWP files, and then resaving them as .NEC files for re-importation into EZNEC to produce pattern graphics that coincided with the original vertical models. The process is almost as fast to perform as it is to describe.)

The arrays for this exercise have one loop side parallel to the ground. Therefore, the feedpoint(s) are at the corner, corresponding to the 45-degree and 135-degree patterns in earlier figures.

Quadrature Feed: At an elevation angle of 45 degrees, the quadrature-fed version of the array shows the patterns given in **Fig. 11**.

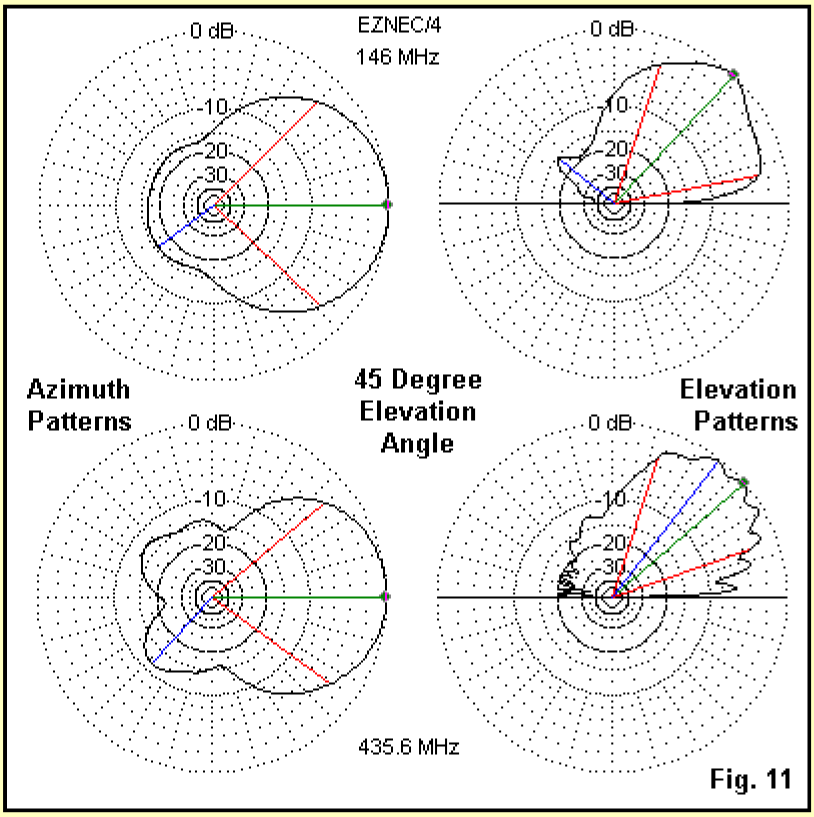


Fig. 11

At 146 MHz, the gain is about 10.7 dBi, not much different from the value with the antenna vertically oriented. The gain continues to increase as the elevation angle decreases until the ground reflections play a full role in the pattern formation. The horizontal beamwidth grows to about 88 degrees between -3 dB points. The vertical beamwidth is about 60 degrees. However, note that the point of maximum gain is about 2 degrees higher than the aiming point for the array, a function of ground reflections.

At 435.6 MHz, the gain is about 10.3 dBi. However, maximum gain occurs in two lobes evident on the elevation plot, one at about 41 degrees, the other at about 52 degrees. At these angles, the forward gain exceeds 11 dBi. The vertical beamwidth is about 52 degrees.

Single Feed:

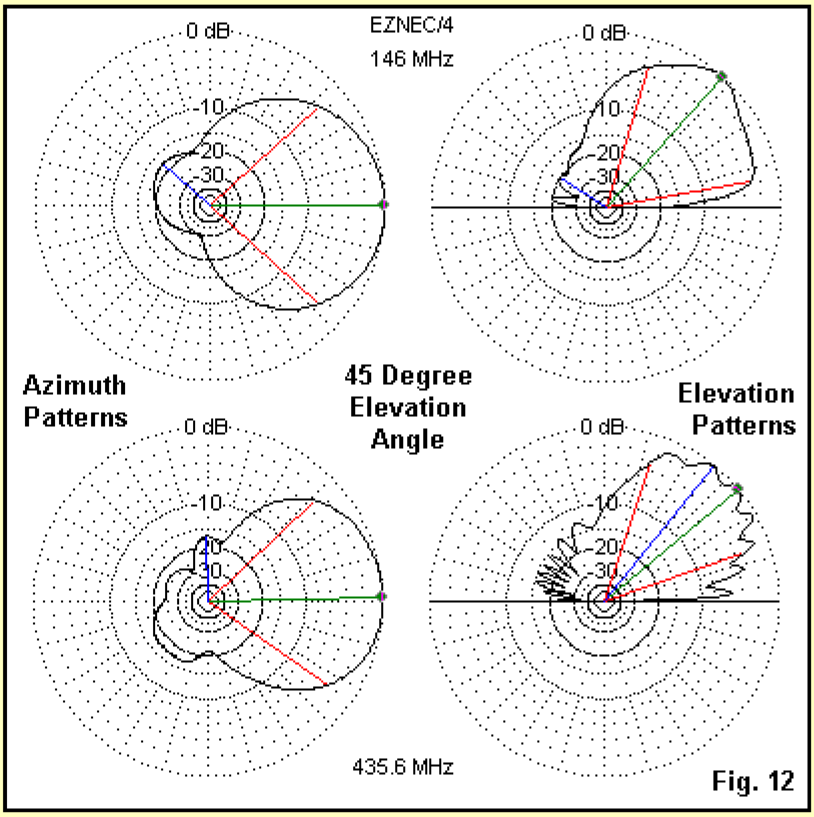


Fig. 12

Fig. 12 shows the corresponding patterns for the single-feed version of the 2-band quad array. Except for rear lobe performance, the performance is strikingly similar. At 146 MHz, the gain is 10.8 dBi with an 85-degree beamwidth horizontally. The peak gain occurs at about 3 degrees higher than the aiming point, with a 63-degree vertical beamwidth.

At 435.6 MHz, the 45-degree-angle gain is about 10.3 dBi, but climbs to about 11.1 dBi at 40 and 51 degrees. The horizontal beamwidth is 78 degrees, and the vertical beamwidth is about 53 degrees.

In terms of the shape of the total radiation pattern, then, there seems to be little to choose between the quadrature-fed and the single-feed versions of the array. However, although the pattern figures are useful, they do not tell the complete story. One has to examine the model radiation tables to read out the polarization of the two different array types. To the degree that circular polarization offers a higher potential for reduced signal fading during a satellite pass (and an equal fading of one's transmitted signal), the quadrature-fed array has some distinct advantages. Whether or not they justify the more complex construction related to such feed systems is a decision that only the builder can make.

Conclusion

We have examined the possibility of reducing the common dual-boom structures used by crossed Yagis into a single boom by the use of concentric quads. Careful design can overcome most of the interaction problems created by the 3:1 frequency ratio between 146 MHz and 435.6 MHz quads. Hence, it is possible to design a potentially successful single boom quad for satellite use that also has greater gain reserves than the 2-3 element quads currently available for this service.

The problems inherent in successfully implementing a simple quadrature feed may also be overcome through careful fabrication of glass board etched lines. The final quadrature-fed array is capable of reversed circular polarization. Of course, one may opt for the simple single-feed version.

These design notes only scratch the surface of possibilities. However, I hope they have stirred your creative juices so that any implementation will be even more successful than the these ideas presently promise.

Go to Main Index