Some Notes on Long-Boom Quads

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In the course of examining existing designs for long-boom, high-gain monoband quad beams, I have been struck but the "hit or miss" nature of the designs. Although popular since the 1960s, quad design appears to have missed out on anything systematic. The absence of systematic design principles does not apply to the basic nature of loops, which are well covered in books by Haviland and Orr. However, the addition of parasitic elements to achieve gain, front-to-back, and operating bandwidth seems almost devoid of adequate study and full treatment.

As a step in the direction of such investigations, these notes offer some thoughts on modeling studies into parasitic quad beams. More precisely, they offer three (of many possible) approaches to the design of long boom quad beams. What the designs reveal may be useful to others in further work.

The baseline for each of the approaches was to produce a quad beam model that yielded 11 dBi free-space gain and about 20 dB or more of 180-degree front-to-back ratio across the operating bandwidth. The operating bandwidth itself would eventually become a consideration, but was not among initial concerns. All antennas were designed and modeled for 20 meters, with a 14.175 MHz design frequency.

I selected the gain level based on the popular notion that a quad loop can achieve about 1.8 to 1.9 dB more gain than an equivalent dipole. This notion has given rise to the presumption that a quad beam has about the same gain advantage over a Yagi with the same number of elements and a similar boom length. However, the presumption does not work out in reality, largely because quad beams are constructed using thin wire elements in contrast to the fatter tubing used by typical Yagis. Because the thin wire results in lower levels of inter-element coupling, the quad's gain advantage is seriously reduced and is often completely negated in large arrays. Some of the gain advantage can be restored by the use of fatter elements, which in models can be single fat wire elements or multi-wire simulated fat elements. The restoration of gain through the use of dual-wire elements, despite the higher material losses of the dual thin wires, tends to demonstrate the relative dominance of inter-element coupling over wire loss in establishing the gain of a large array. For this reason, the models we shall discuss use a variety of wire sizes, ranging from 1/10 to 1/2 inch.

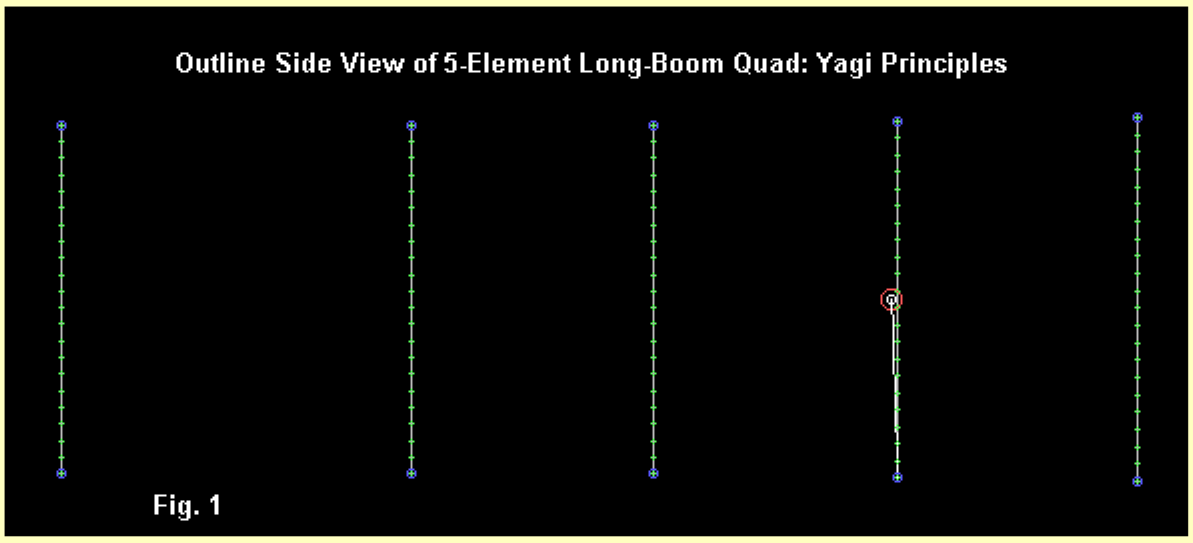
The selection of the 20-dB front-to-back criterion rests on the ability of monoband Yagis to achieve this figure routinely across the designed operating passband. Equivalent performance should be possible from a quad if it is to justify itself as a competitor for the Yagi. (This considerations is apart from operational reports that quads have an advantage at band openings and closings. Models cannot simulate the propagation conditions that would either confirm of disconfirm such reports.)

The approaches taken to designing this collection of long-boom quads are varied. The first design is a direct adaptation of parasitic element placement taken from Yagi design. The second is a wide-band variation of Yagi design sometimes called optimized wide-band arrays (OWA). The third approach uses wide-spaced principles in which elements use approximately the same spacing throughout the design.

1. The Standard Yagi Approach

The first approach to quad designs uses standard Yagi spacing as a basis for quad design, with element size and spacing optimized after initial placement. I used the approach to design a 3-element quad with excellent performance over its passband. However, several peculiarities--relative to a comparison Yagi--appeared in the results. First, the element spacing was somewhat larger than for the Yagi, despite elements of the same diameter. Second, the operating bandwidth for both the front-to-back ratio and the SWR were considerably narrower than for the Yagi. Third, instead of the traditional 50 to 100 Ohm quad feedpoint impedance, the 3-element quad showed a feedpoint impedance close to 25 Ohms. All of these conditions and limitations also showed up on a longer version of the antenna.

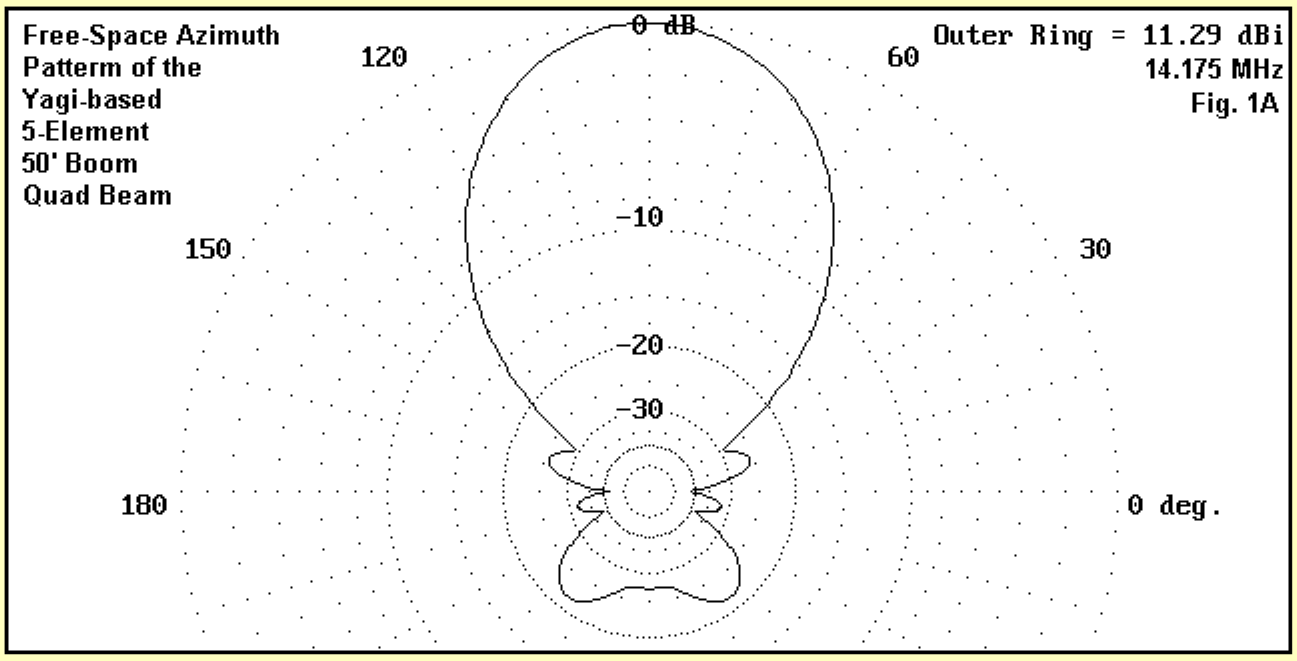
For a Yagi model, I took a 3-element 20-meter design developed by K6STI. I enlarged it to 5 elements by adding 2 directors. It is equivalent to a 48' boom length Yagi that would provide about 10.1 dBi free space gain across 20 meters with good front-to-back figures. After optimizing the 0.1" diameter elements and spacing them to achieve 11 dBi free-space gain and the requisite front-to-back ratio, the boom length increased to 50.36'. **Fig. 1** presents a side view of the antenna to show the relative element spacing.



The following table provides dimensions for the antenna (in feet).

Element	Length/Side	Circumference	Distance from Reflector
Reflector	**18.11**	**72.45**	**-----**
Driver	**17.77**	**71.06**	**11.25**
Director 1	**17.38**	**69.54**	**22.62**
Director 2	**17.38**	**69.54**	**34.00**
Director 3	**17.38**	**69.54**	**50.36**

Fig. 1A provides a free-space azimuth pattern for the antenna at the design frequency.



Despite its excellent pattern, the antenna turned out to have a narrow operating bandwidth: a little over 110 kHz on 20 meters. If we accept this restriction, then the antenna has much to recommend it, including the achievement of 11 dBi free-space gain with only 5 elements. (Wider-band designs will require 6 elements for the same achievement.)

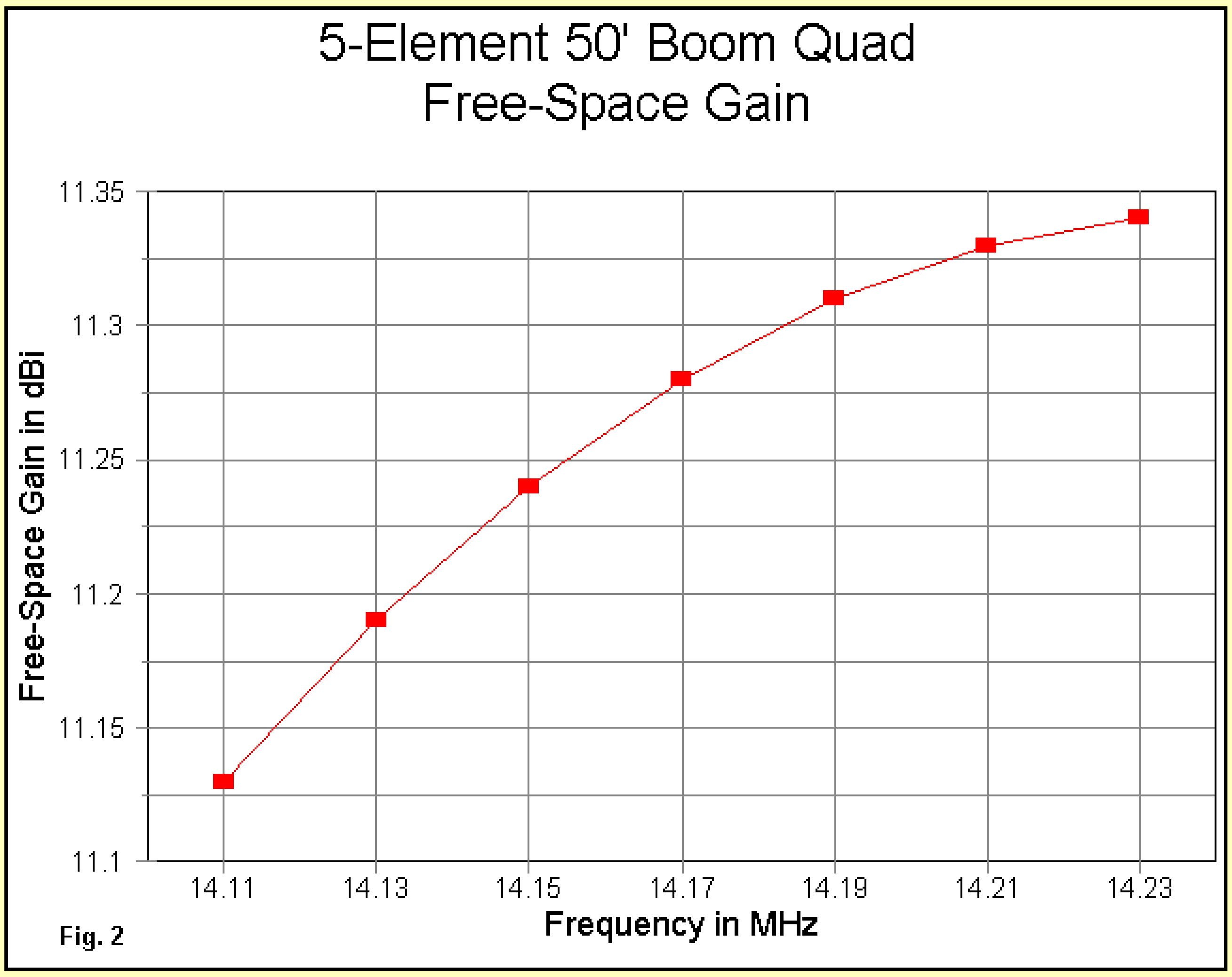


Fig. 2 presents the free-space gain of the 5-element quad over its working bandwidth. The rate of gain change--nearly 0.25 dB over 110 kHz--is quite high, a mark of a narrow-band antenna design. Nonetheless, the gain figures exceed the 11 dBi target everywhere in the passband.

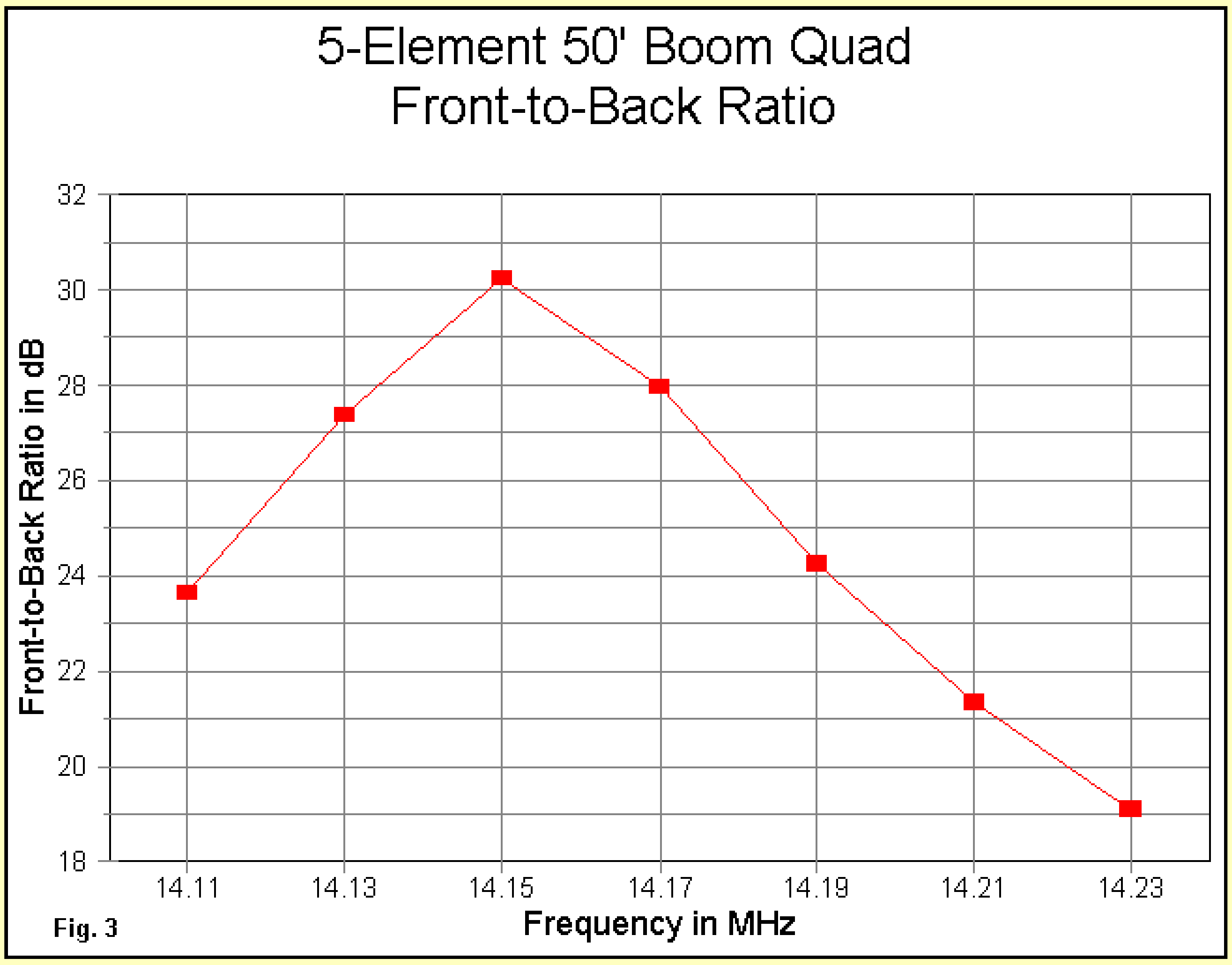


Fig. 3

Fig. 3 shows the front-to-back ratio over the same bandwidth. The peak is over 30 dB, but the rate of decrease from the peak is fairly rapid. With slightly more work, the peak front-to-back ratio might be better centered in the passband. The result would be better than 20 dB across the passband.

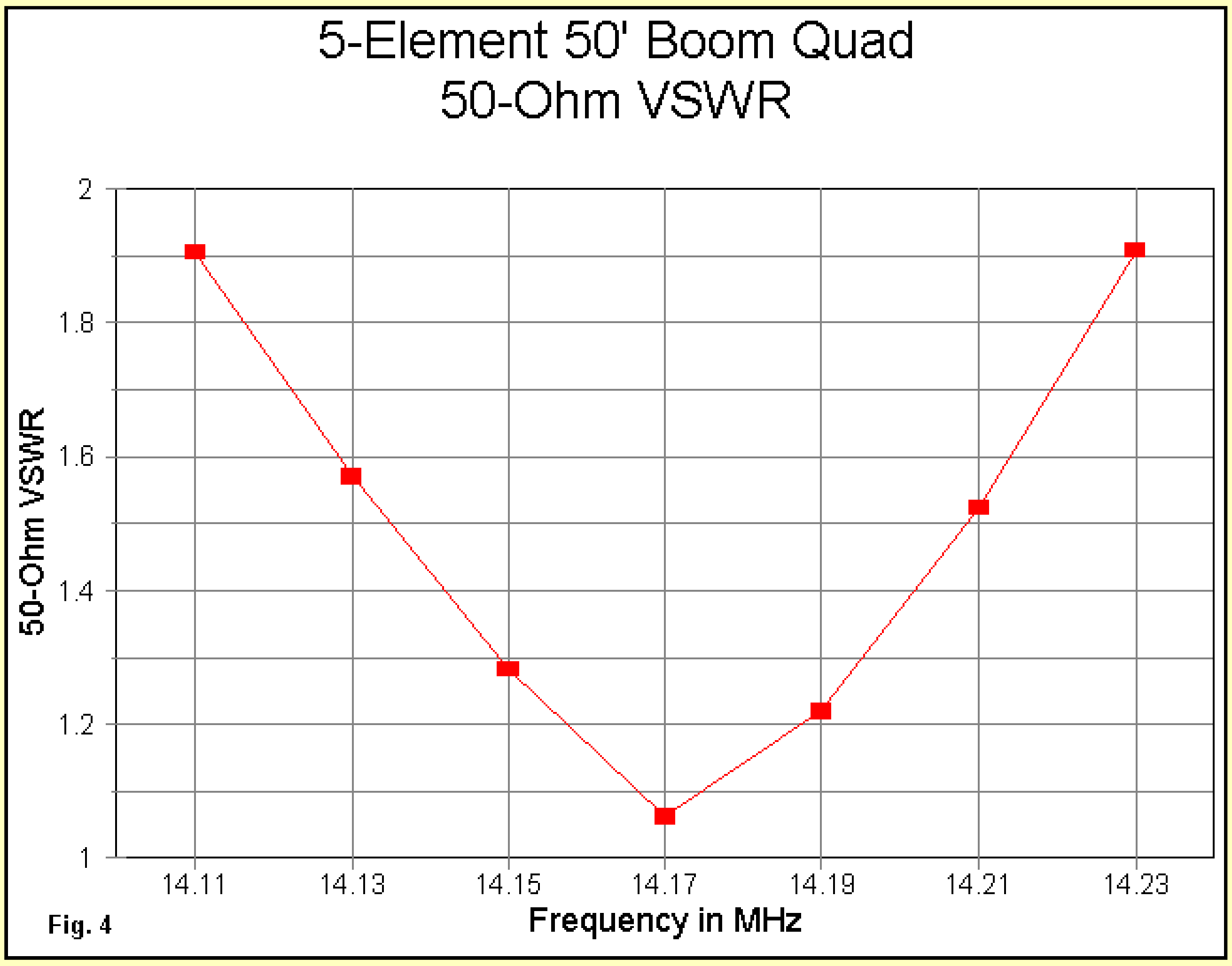


Fig. 4

The VSWR curve (**Fig. 4**) is the 50-Ohm SWR resulting from matching the feedpoint of the model. The resonant 25-Ohm feed impedance was transformed via a 1/4-wl section of 37.5-Ohm coax (presumptively made from parallel sections of 75-Ohm cable). The limits of the graph show values just above 1.9:1 at each end. However, the SWR curve continues to steepen at both ends of the passband so that only about another 10-15 kHz are available before the SWR reaches 2:1.

The 5-element quad design would be inappropriate for use on 20 meters except for certain operators who use only small portions of the band. However, scaled to 17 or 12 meters, the antenna would provide the same performance and cover the entire 100 kHz band. Indeed, if this design has a home at all, it would be on the WARC bands.

Of all the quad designs that we shall consider, the 5-element Yagi-based design is the most compact. However, most quad builders shy away from antennas with odd numbers of elements. Performance is not so much the worry as is mounting the antenna. With an odd number of elements, the center-most elements comes quite lose to the tower unless one uses a long mast above the tower-top. One can overcome the problem to some degree by weighting the mast to one side or the other. Still, balancing weight loads and wind loads makes this move uncertain for all but those with considerable mechanical engineering experience.

The following table is the EZNEC model description for anyone who wishes to experiment further with the design.

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5 el quad 20 m **Frequency = 14.175 MHz.**

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Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in) Segs

1     W4E2  -9.056,  0.000, -9.056  W2E1   9.056,  0.000, -9.056 1.03E-01  21
2     W1E2   9.056,  0.000, -9.056  W3E1   9.056,  0.000,  9.056 1.03E-01  21
3     W2E2   9.056,  0.000,  9.056  W4E1  -9.056,  0.000,  9.056 1.03E-01  21
4     W3E2  -9.056,  0.000,  9.056  W1E1  -9.056,  0.000, -9.056 1.03E-01  21
5     W8E2  -8.883, 11.248, -8.883  W6E1   8.883, 11.248, -8.883 1.03E-01  21
6     W5E2   8.883, 11.248, -8.883  W7E1   8.883, 11.248,  8.883 1.03E-01  21
7     W6E2   8.883, 11.248,  8.883  W8E1  -8.883, 11.248,  8.883 1.03E-01  21
8     W7E2  -8.883, 11.248,  8.883  W5E1  -8.883, 11.248, -8.883 1.03E-01  21
9    W12E2  -8.692, 22.623, -8.692 W10E1   8.692, 22.623, -8.692 1.03E-01  21
10    W9E2   8.692, 22.623, -8.692 W11E1   8.692, 22.623,  8.692 1.03E-01  21
11   W10E2   8.692, 22.623,  8.692 W12E1  -8.692, 22.623,  8.692 1.03E-01  21
12   W11E2  -8.692, 22.623,  8.692  W9E1  -8.692, 22.623, -8.692 1.03E-01  21
13   W16E2  -8.692, 33.999, -8.692 W14E1   8.692, 33.999, -8.692 1.03E-01  21
14   W13E2   8.692, 33.999, -8.692 W15E1   8.692, 33.999,  8.692 1.03E-01  21
15   W14E2   8.692, 33.999,  8.692 W16E1  -8.692, 33.999,  8.692 1.03E-01  21
16   W15E2  -8.692, 33.999,  8.692 W13E1  -8.692, 33.999, -8.692 1.03E-01  21
17   W20E2  -8.692, 50.360, -8.692 W18E1   8.692, 50.360, -8.692 1.03E-01  21
18   W17E2   8.692, 50.360, -8.692 W19E1   8.692, 50.360,  8.692 1.03E-01  21
19   W18E2   8.692, 50.360,  8.692 W20E1  -8.692, 50.360,  8.692 1.03E-01  21
20   W19E2  -8.692, 50.360,  8.692 W17E1  -8.692, 50.360, -8.692 1.03E-01  21
21          -0.128, 11.503,  0.000         0.128, 11.503,  0.000 1.03E-01   1

              -------------- SOURCES --------------

Source    Wire     Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1          1    21 / 50.00   ( 21 / 50.00)     1.000       0.000       V

No loads specified

                -------- TRANSMISSION LINES ---------

Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)              Ohms Fact Norm

1      5/50.0  (  5/50.0)   21/50.0  ( 21/50.0)   11.619 ft    37.5  0.67  N

Ground type is Free Space
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2. The OWA-Yagi Approach

The second and third design approaches attempt to see what might be required to achieve a quad beam with full 20-meter coverage. Ideally, this coverage would include the following criteria:

- 1. Less than 2:1 SWR across the band;
- 2. Greater than 11 dBi free-space gain across the band;
- 3. Greater than 20 dB 180-degree front-to-back ratio across the band.

In the end, I settled for some reasonable compromises. Still, the resulting designs have some aspects that make them less fit for direct construction.

The second approach also uses Yagi parasitic element principles, but of a special type. In Yagi design, the originator, NW3Z, refers to them as optimized wide-band arrays. He has developed 20 meter Yagis for 48' booms with about 10.1 dBi average gain and greater than 20 dB front-to-back ratio across 20 meters. These initial specifications sound very much like those of other 5-element Yagis on similar booms. However, the NW3Z design adds one more element, a director. By judicious spacing of the reflector and the added director from the driven element, the Yagi achieves a direct match top to a 50-Ohm feedline with low SWR (under 1.3:1) across the entire band.

Adapting the OWA principle to quad design proves to be feasible, although not without certain costs. First, the spacing of the reflector and the first director differ substantially from the Yagi version. As well, the entire array must by longer (61.2') than its Yagi counterpart to achieve the design goal of 11 dBi free-space gain.

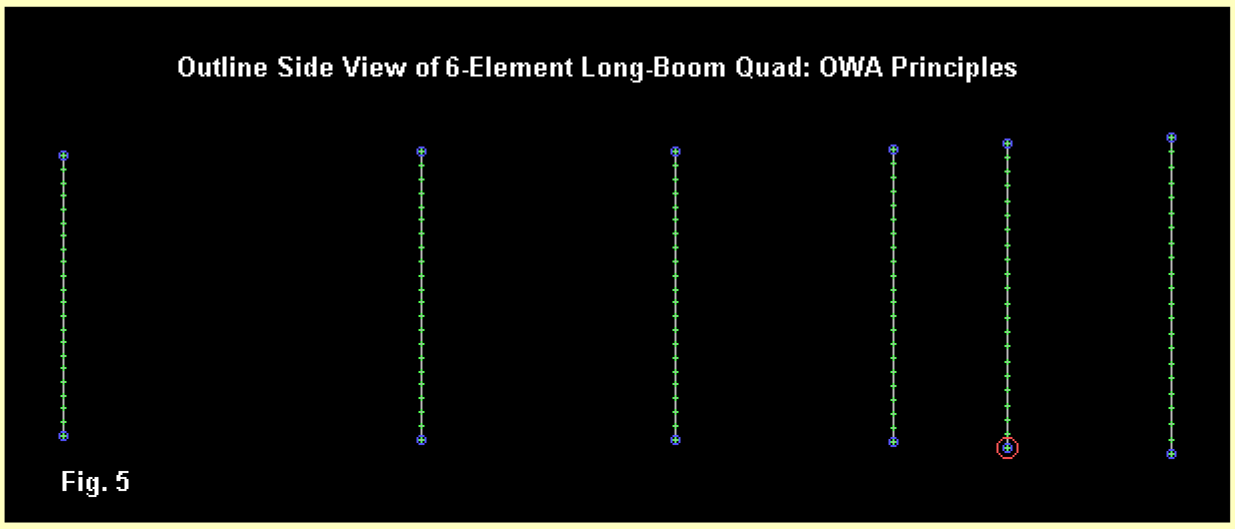
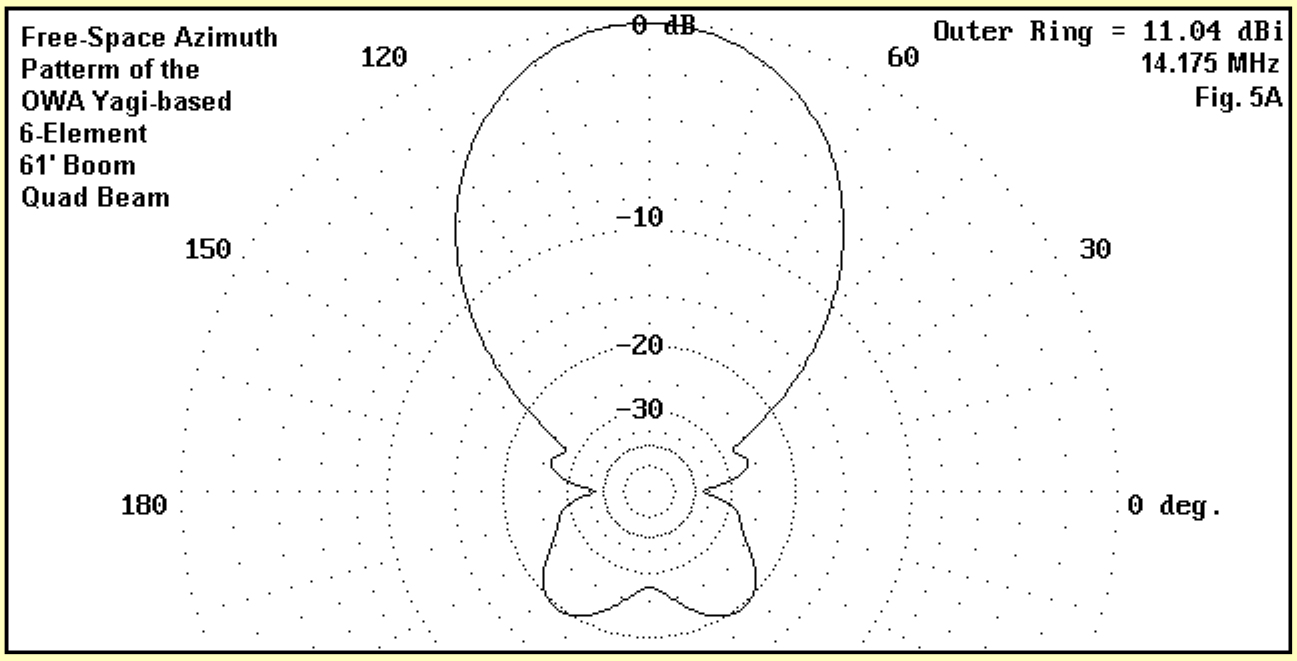


Fig. 5

Fig. 5 shows the side view of the final design to provide a perspective on the required element spacing. Note especially the reflector and first director positions. **Fig. 5A** is a free-space azimuth pattern for the design at its design frequency, 14.175 MHz.


Free-Space Azimuth
Pattern of the
OWA Yagi-based
6-Element
61' Boom
Quad Beam

Outer Ring = 11.04 dBi
14.175 MHz
Fig. 5A

An added cost to achieve the design goals was the use of 0.5" diameter elements in all of the elements. Hence, the design is unlikely to be directly implemented, although alternative element construction is possible. The following table provides the array dimensions for 20 meters. Once more, all dimensions are in feet.

Element	Length/Side	Circumference	Distance from Reflector
Reflector	**18.54**	**74.16**	**-----**
Driver	**18.52**	**74.08**	**9.06**
Director 1	**17.06**	**68.24**	**15.32**
Director 2	**16.84**	**67.36**	**27.39**
Director 3	**16.82**	**67.28**	**41.38**
Director 4	**16.30**	**65.20**	**61.20**

If you compare the element dimensions with those for the 5-element narrow-band quad, you will discover some interesting differences other than spacing. First, the OWA reflector and driver have dimensions that are quite close to each other, with both being somewhat longer than the corresponding elements in the 5-element array. Second, the directors tend to be shorter than those in the smaller beam.

For the performance curves, we shall use the entire 20 meter band from 14.0 to 14.35 MHz.

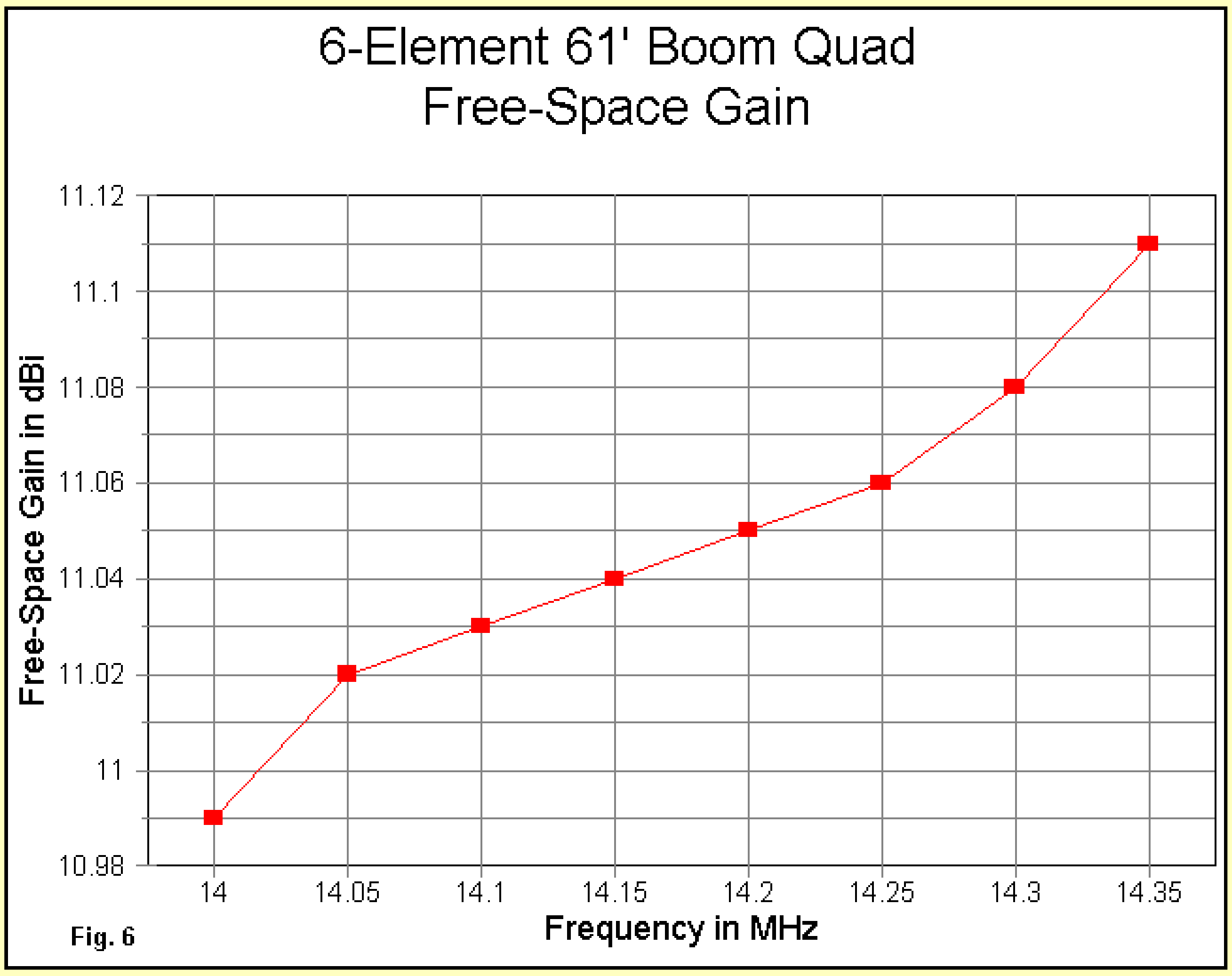

6-Element 61' Boom Quad
Free-Space Gain

Fig. 6

The gain of the OWA 6-element quad is quite stable, as shown in **Fig. 6**. It ranges from 10.99 to 11.11 across the band. This is about 1/3 the variation of the smaller array despite the 3-fold increase in operating bandwidth. The shape of the gain curve, however, suggests that the gain stability limits of the array are not very much wider than the 20 meter band itself. Note the increasing rates of change near the band edges.

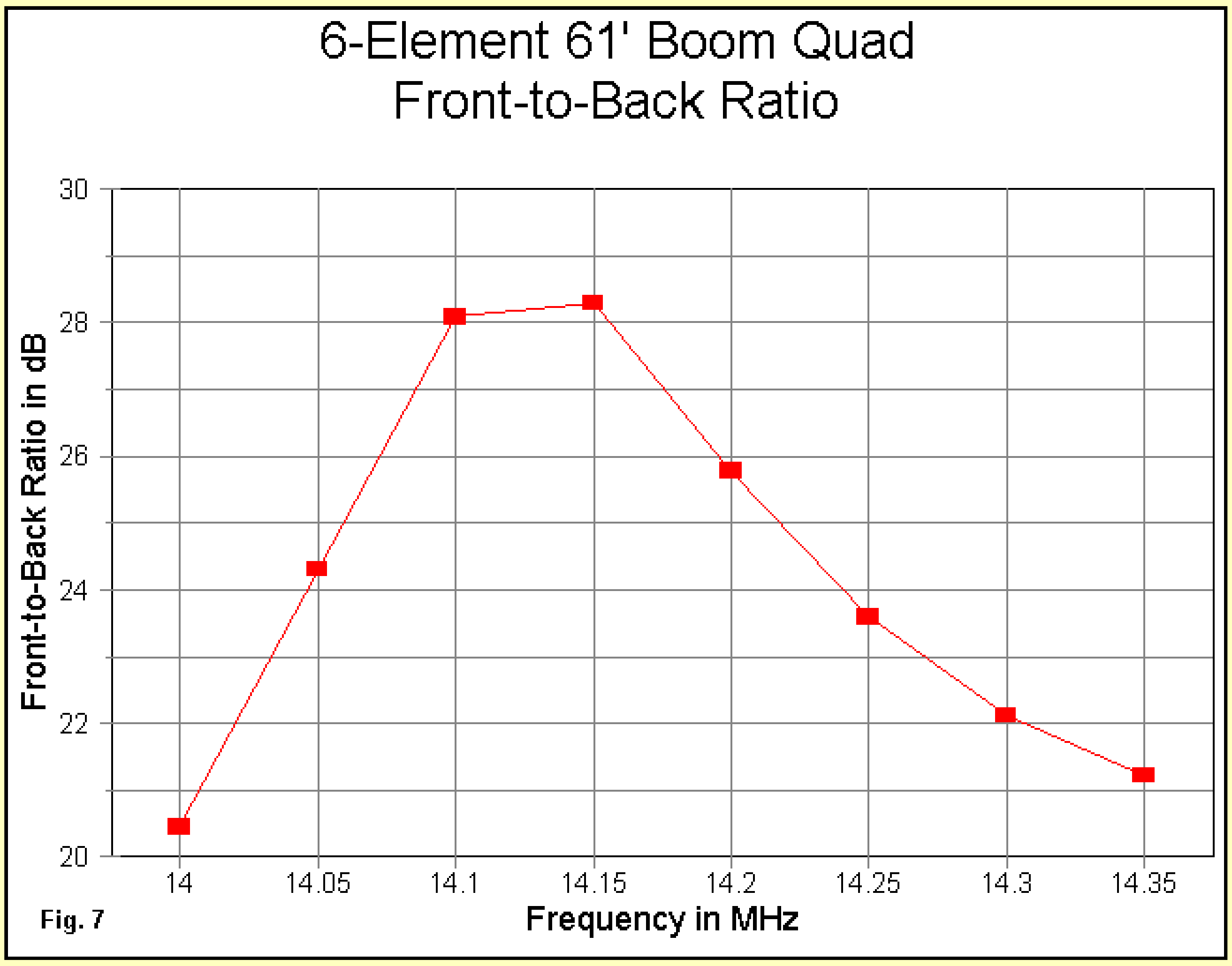


Fig. 7

The front-to-back ratio across 20 meters appears in **Fig. 7**. Of all the array approaches tested in this exercise, the OWA design is the only one to achieve greater than 20 dB front-to-back ratio for the full passband. Part of the reason for this result stems from the use of very large diameter elements. Single-wire elements of the usual #12/#14 AWG material will not yield the front-to-back operating bandwidth.

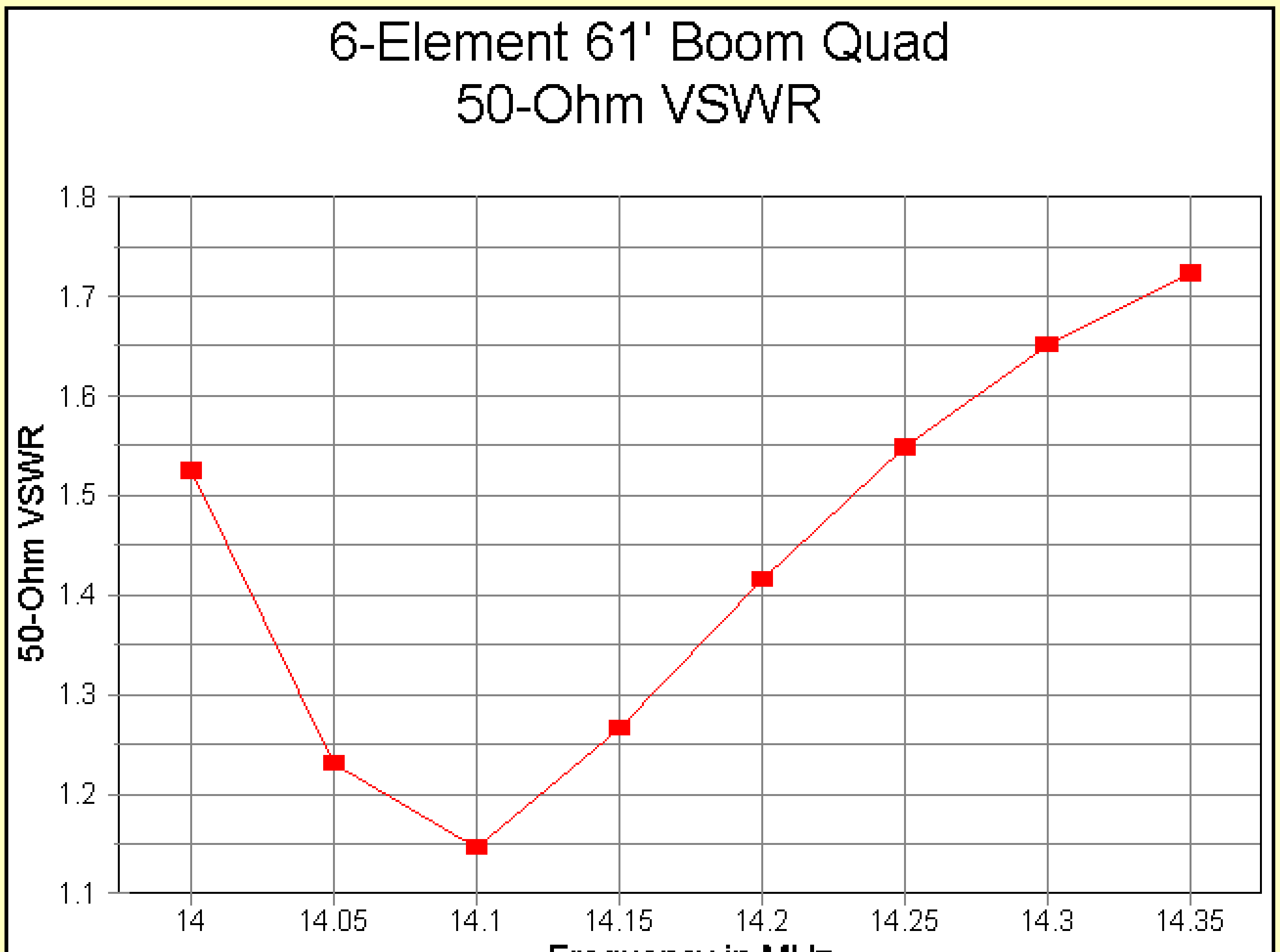


Fig. 8

The OWA 6-element quad provides a direct 50-Ohm match with no matching network components, as shown in **Fig. 8**. Interestingly, the shape of the pattern resembles that for the corresponding OWA 6-element Yagi, but with higher band-edge values. Despite the ability of the design to cover 20 meters fully, the quad shows itself to be inherently more narrow-banded than counterpart Yagis.

The OWA quad is quite possibly a usable design for a high performance, full band coverage array, with one exception. The 0.5" diameter elements are not feasible using standard quad construction techniques that employ relatively lightweight fiberglass or similar element support arms. Significant reductions in the effective element diameter reduce inter-element coupling and result in gain and operating bandwidth reductions. The solution is to redesign the array for dual-wire elements using #14 or #12 wire. However, the substitutions will require extensive re-optimization of element lengths to restore the performance curves. Because the closely-spaced loops would require between 2 and 3 times the number of segments per element, with an increase in the number of modeling wires, the slow process was not endured for this exercise. Nonetheless, more extensive work on 2-element quads, described in past articles, strongly suggests that the substitution is quite achievable.

For anyone who wishes to work further with this type of design, the following table is the EZNEC model description.

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6 el 20 meter owa quad   Frequency = 14.175 MHz.

Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

--------------- WIRES ---------------

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Wire Conn. --- End 1 (x,y,z : ft)  Conn. --- End 2 (x,y,z : ft)   Dia(in) Segs

1     W4E2  -9.270,  0.000, -9.270  W2E1   9.270,  0.000, -9.270 5.00E-01  21
2     W1E2   9.270,  0.000, -9.270  W3E1   9.270,  0.000,  9.270 5.00E-01  21
3     W2E2   9.270,  0.000,  9.270  W4E1  -9.260,  0.000,  9.270 5.00E-01  21
4     W3E2  -9.260,  0.000,  9.270  W1E1  -9.270,  0.000, -9.270 5.00E-01  21
5     W8E2  -8.950,  9.056, -8.950  W6E1   8.950,  9.056, -8.950 5.00E-01  21
6     W5E2   8.950,  9.056, -8.950  W7E1   8.950,  9.056,  8.950 5.00E-01  21
7     W6E2   8.950,  9.056,  8.950  W8E1  -8.950,  9.056,  8.950 5.00E-01  21
8     W7E2  -8.950,  9.056,  8.950  W5E1  -8.950,  9.056, -8.950 5.00E-01  21
9    W12E2  -8.530, 15.320, -8.530 W10E1   8.530, 15.320, -8.530 5.00E-01  21
10    W9E2   8.530, 15.320, -8.530 W11E1   8.530, 15.320,  8.530 5.00E-01  21
11   W10E2   8.530, 15.320,  8.530 W12E1  -8.530, 15.320,  8.530 5.00E-01  21
12   W11E2  -8.530, 15.320,  8.530  W9E1  -8.530, 15.320, -8.530 5.00E-01  21
13   W16E2  -8.420, 27.388, -8.420 W14E1   8.420, 27.388, -8.420 5.00E-01  21
14   W13E2   8.420, 27.388, -8.420 W15E1   8.420, 27.388,  8.420 5.00E-01  21
15   W14E2   8.420, 27.388,  8.420 W16E1  -8.420, 27.388,  8.420 5.00E-01  21
16   W15E2  -8.420, 27.388,  8.420 W13E1  -8.420, 27.388, -8.420 5.00E-01  21
17   W20E2  -8.410, 41.383, -8.410 W18E1   8.410, 41.383, -8.410 5.00E-01  21
18   W17E2   8.410, 41.383, -8.410 W19E1   8.410, 41.383,  8.410 5.00E-01  21
19   W18E2   8.410, 41.383,  8.410 W20E1  -8.410, 41.383,  8.410 5.00E-01  21
20   W19E2  -8.410, 41.383,  8.410 W17E1  -8.410, 41.383, -8.410 5.00E-01  21
21   W24E2  -8.150, 61.200, -8.150 W22E1   8.150, 61.200, -8.150 5.00E-01  21
22   W21E2   8.150, 61.200, -8.150 W23E1   8.150, 61.200,  8.150 5.00E-01  21
23   W22E2   8.150, 61.200,  8.150 W24E1  -8.150, 61.200,  8.150 5.00E-01  21
24   W23E2  -8.150, 61.200,  8.150 W21E1  -8.150, 61.200, -8.150 5.00E-01  21

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.    Actual      (Specified)

1         11     5 / 50.00   (  5 / 50.00)      1.000       0.000       V

No loads specified

No transmission lines specified

Ground type is Free Space
 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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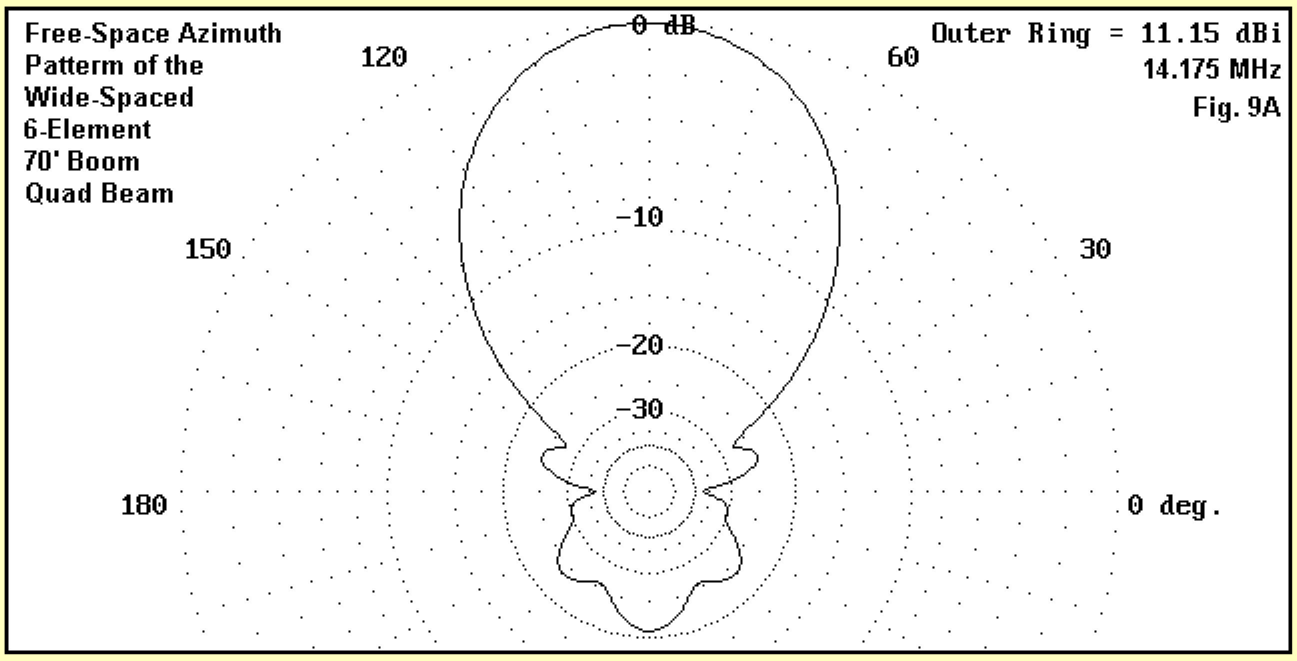
3. The Wide-Spaced Approach

A third approach to long-boom quad design employs relatively wide but uniform spacing between elements. Beginning with a driver-reflector spacing that approaches the optimum for a 2-element maximum front-to-back ratio design, the directors are then added at similar spacing from each other. The director element lengths show a consistent decrease in length as one moves forward from the driver. **Fig. 9** shows the side view to give some perspective on the overall design of a 6-element array capable of 11 dBi free-space gain.

Fig. 9

The design-frequency free-space azimuth pattern appears in **Fig. 9A**. The pattern is as well-behaved at the center of the passband as either of the other designs.



As a design exercise, I optimized the 6-element wide-spaced array using #8 AWG wire (0.1285" diameter). In part, I wanted to see what differences might result for the operating bandwidth, especially with respect to the front-to-back ratio. The following table provides the physical dimensions of the model. As usual, all dimensions are in feet.

Element	**Length/Side**	**Circumference**	**Distance from Reflector**
Reflector	**18.43**	**73.73**	**-----**
Driver	**17.70**	**70.80**	**13.95**
Director 1	**17.23**	**68.92**	**28.29**
Director 2	**16.83**	**67.32**	**42.78**
Director 3	**16.57**	**66.27**	**57.60**
Director 4	**16.13**	**64.51**	**69.82**

Immediately apparent is the greater length of the array compared to the OWA version of a wide-band quad: 70' vs. 61'. More subtle are the required variations from uniformity in the element spacing. Although the average spacing is nearly 0.2 wl, the director spacings cannot be set by simple adherence to the average. Performance deteriorates rapidly using mere rules of thumb as guidance.

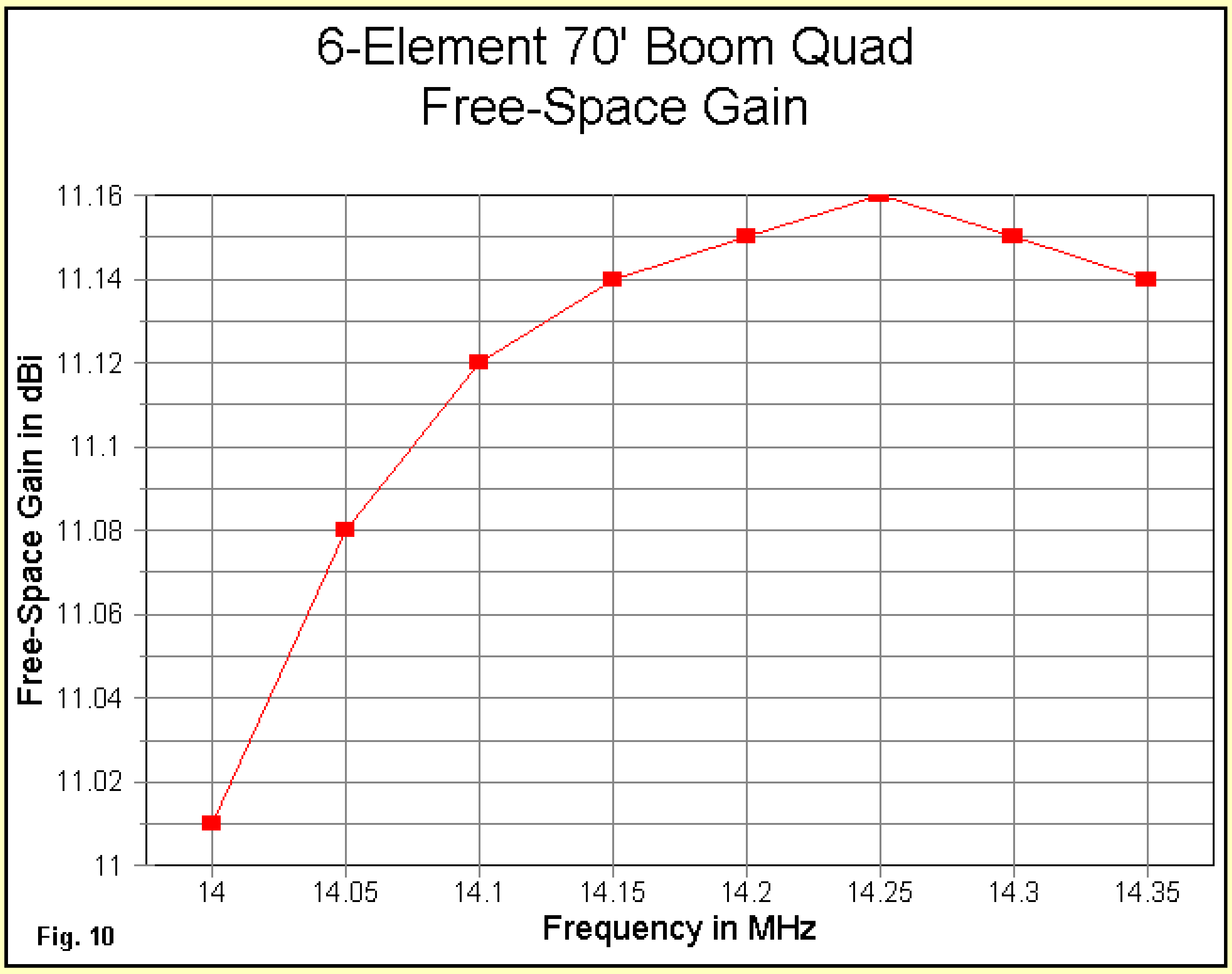


Fig. 10 shows the gain curve across 20 meters for the wide-spaced array. Like the OWA array, the curve shows good stability, with a net variance of only 0.15 dB across the band. Note especially that a wide-spaced design is capable of placing the peak gain of the antenna well within the boundaries of the operating passband.

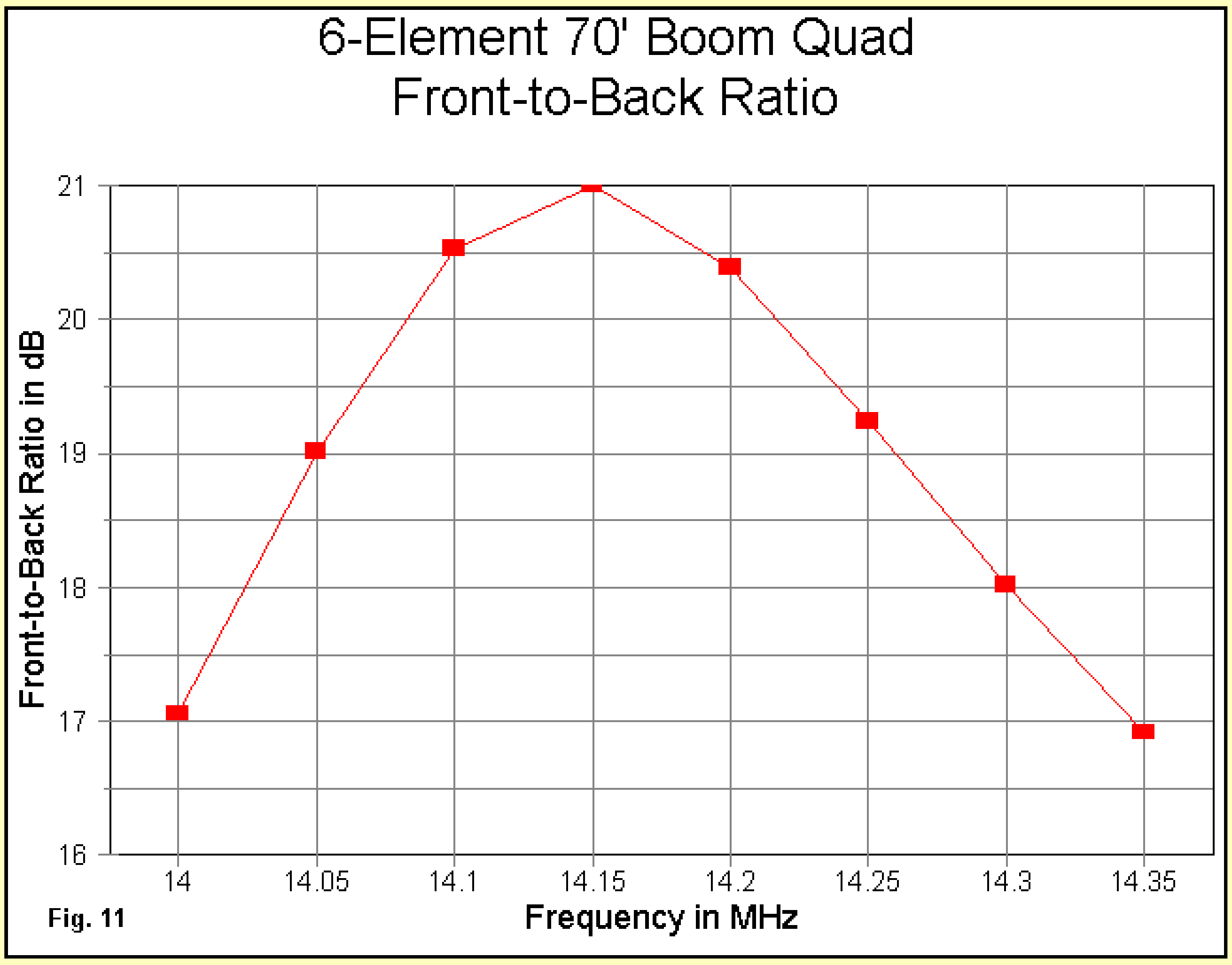


Fig. 11

Fig. 11, the front-to-back curve across 20 meters, shows the effect of using small diameter wire for the elements. The band-edge front-to-back ratio is about 17 dB, and the peak value is 21 dB. To the present, I have found no way to increase the front-to-back performance within the constraints of the overall length and the wire size. However, the use of large-diameter elements or dual-wire substitutes shows promise of improving this aspect of performance considerably.

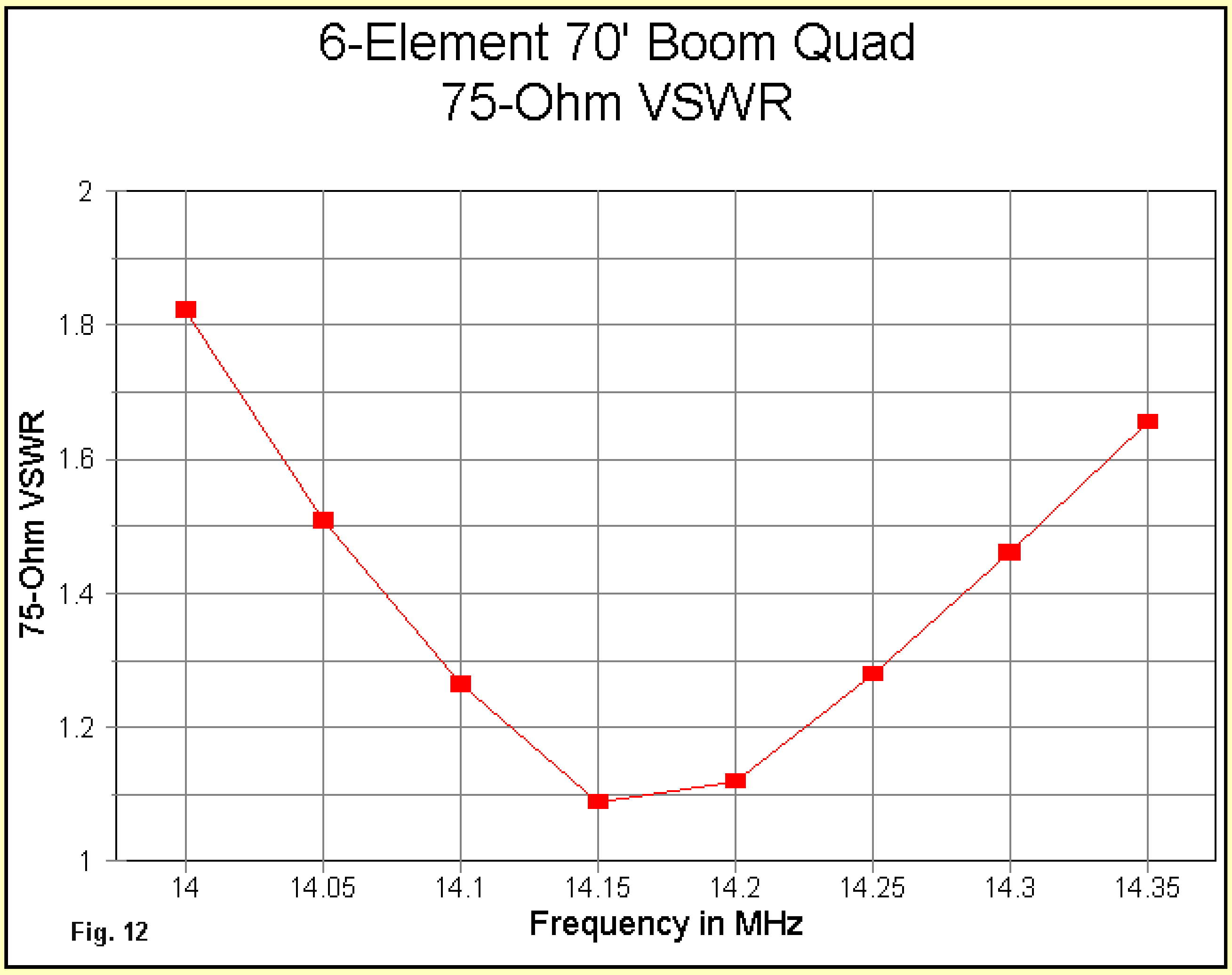


Fig. 12

The SWR curve for the wide-spaced 6-element array appears in **Fig. 12**. Unlike the other curves, this one is a 75-Ohm VSWR curve, the inherent feedpoint impedance of the antenna. Matching the antenna to a 50-Ohm feedline requires the use of a simple transmission-line transformer. The band-edge reactance is well under +/-j40 Ohms for mid-band resonance of the driver.

The wide-spaced 6-element array has considerable potential for further development through the use of larger diameter elements or substitutes. Nevertheless, the key limiting factor in this direction is the boom length. Comparable Yagi designs with the same boom length would likely use 7 elements and provide equal gain, but superior front-to-back, performance.

Those who might wish to further optimize the design can refer to the following EZNEC model description.

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6-element wide-spaced 20m quad   Frequency = 14.175 MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

--------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : ft) Conn. --- End 2 (x,y,z : ft)   Dia(in) Segs

```
1    W4E2  -9.216,  0.000, -9.216  W2E1   9.216,  0.000, -9.216   #  8   21
2    W1E2   9.216,  0.000, -9.216  W3E1   9.216,  0.000,  9.216   #  8   21
3    W2E2   9.216,  0.000,  9.216  W4E1  -9.216,  0.000,  9.216   #  8   21
4    W3E2  -9.216,  0.000,  9.216  W1E1  -9.216,  0.000, -9.216   #  8   21
5    W8E2  -8.850, 13.945, -8.850  W6E1   8.850, 13.945, -8.850   #  8   21
6    W5E2   8.850, 13.945, -8.850  W7E1   8.850, 13.945,  8.850   #  8   21
7    W6E2   8.850, 13.945,  8.850  W8E1  -8.850, 13.945,  8.850   #  8   21
8    W7E2  -8.850, 13.945,  8.850  W5E1  -8.850, 13.945, -8.850   #  8   21
9   W12E2  -8.615, 28.289, -8.615 W10E1   8.615, 28.289, -8.615   #  8   21
10   W9E2   8.615, 28.289, -8.615 W11E1   8.615, 28.289,  8.615   #  8   21
11  W10E2   8.615, 28.289,  8.615 W12E1  -8.615, 28.289,  8.615   #  8   21
12  W11E2  -8.615, 28.289,  8.615  W9E1  -8.615, 28.289, -8.615   #  8   21
13  W16E2  -8.415, 42.775, -8.415 W14E1   8.415, 42.775, -8.415   #  8   21
14  W13E2   8.415, 42.775, -8.415 W15E1   8.415, 42.775,  8.415   #  8   21
15  W14E2   8.415, 42.775,  8.415 W16E1  -8.415, 42.775,  8.415   #  8   21
16  W15E2  -8.415, 42.775,  8.415 W13E1  -8.415, 42.775, -8.415   #  8   21
17  W20E2  -8.284, 57.600, -8.284 W18E1   8.284, 57.600, -8.284   #  8   21
18  W17E2   8.284, 57.600, -8.284 W19E1   8.284, 57.600,  8.284   #  8   21
19  W18E2   8.284, 57.600,  8.284 W20E1  -8.284, 57.600,  8.284   #  8   21
20  W19E2  -8.284, 57.600,  8.284 W17E1  -8.284, 57.600, -8.284   #  8   21
21  W24E2  -8.064, 69.822, -8.064 W22E1   8.064, 69.822, -8.064   #  8   21
22  W21E2   8.064, 69.822, -8.064 W23E1   8.064, 69.822,  8.064   #  8   21
23  W22E2   8.064, 69.822,  8.064 W24E1  -8.064, 69.822,  8.064   #  8   21
24  W23E2  -8.064, 69.822,  8.064 W21E1  -8.064, 69.822, -8.064   #  8   21

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.    Actual      (Specified)

1          11     5 / 50.00   (  5 / 50.00)      1.000        0.000         V

No loads specified

No transmission lines specified

Ground type is Free Space
 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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Conclusion

Long-boom, high-performance, wide-bandwidth monoband quad design is not easily obtained. Although only three design approaches have been employed in this exercise, they indicate several trends in large quads:

- 1. A wide operating bandwidth is improbable for quad lengths similar to corresponding Yagi lengths, if superior performance is expected. Wide-band quads with superior performance will likely require greater boom lengths.
- 2. A key limiting factor in quad design is the use of small-diameter elements. Large-diameter elements, or suitable substitute dual-wire elements having similar inter-element coupling potential, are necessary for achieving high gain, high front-to-back ratios, and 2:1 SWR curves across the wider amateur bands.
- 3. Of the designs so far surveyed, perhaps the OWA version holds the most potential for the wider amateur bands (20, 15, and 10 meters). The 5-element array should be adequate for 30, 17, and 12 meters, assuming that one can compensate for the mechanical difficulty presented by the use of an odd number of elements.

Of course, this exercise is limited by exploring only three design approaches to the development of quads meeting the original design criteria. Hopefully, it will serve as a stepping stone in a more thorough exploration of all relevant design approaches. What seems clear is that the design of high-performance quads can no longer be left to haphazard approaches. Expecting wide operating bandwidths and high performance requires a full appreciation of parasitic element principles. Equally key to the process is an understanding of how quad elements resemble their corresponding Yagi elements and how quad elements differ in the process of inter-element coupling. None of the designs we have investigated can yet be said to have come close to the full potential of long-boom quads. At best, they are merely "pretty good."

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