Notes on Medium-Length 2-Meter Quads and Yagis

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Choosing a medium-length (7 to 10 foot boom) 2-meter antenna to build involves a number of choices: gain, front-to-back ratio, band coverage, smoothness of performance across the band, feedpoint impedance, and ease of building, to name a few of the factors. The choices typical fall into the quad vs. Yagi category, since planar and corner reflector arrays tend to require excessive volume at 2 meters. These notes are designed to provide a set of preliminary comparisons of what is possible for a medium-length array, but they do not cover every aspect of the decision-making process.

We shall look at three antennas: a 7-element OWA Yagi, an 8-element OWA Yagi, and a 7-element quad. My rationale is simple: the required boom length of the 7-element quad falls between the boom lengths of the 2 Yagis--and so does the peak gain. With boom lengths from 7.14' to 9.58', perfect for our pre-set definition of a medium-length antenna for 2 meters.

Virtually all (but not absolutely all) 2-meter communications is point-to-point or line-if-sight. Because skip communications is such a small part of 2-meter work, one of the vaunted advantages of the quad disappears--the ability to open and close a band (on HF) due to the combination of horizontally and vertically polarized radiation. In general, then, the quad competes at VHF based upon its basic properties and not by virtue of interaction with the ionosphere.

Let's begin with the quad

A 7-Element Quad

Designing a quad from ordinary materials, like AWG #12 (0.0808" diameter) copper wire is not a trivial exercise. To save weight, most quads use wire elements. Because a quad uses closed loops and requires bends, aluminum and copper tubing tend not to be used. Aluminum tubing is difficult to close durably into a loop, while copper is very heavy, relative to aluminum. Hence, both materials tend to give way to thinner wire. However, a wire quad has a narrow operating bandwidth relative to one with fatter elements. In the end, a many-element quad is a series of compromises.

Perhaps the primary compromise involves the front-to-back ratio. For virtually all quad beam designs, the bandwidth of the front-to-back ratio--as measured against traditional amateur standards--is narrower than the SWR bandwidth--again, as measured against usual amateur standards. The SWR standard is normally a 2:1 ratio relative to the resonant SWR impedance. We can develop a medium boom-length quad with a 50-Ohm resonant impedance--or close enough to achieve an SWR under 2:1 at the edges of the 2-meter band.

However, we shall not be so fortunate with the front-to-back ratio, where a 20-dB ratio registers the most commonly used standard. At the band edges of 2-meters, we shall have to settle for a front-to-back ratio closer to 15 dB if we design carefully. (We should keep in mind that the designs shown here are intended to cover the entire 2-meter band.

The following tables list the dimensions of the 7-element quad, all in inches. The element length is the circumference. Each side of the square design is 1/4 the length listed in the table. The second table samples the free-space performance of the antenna. If used horizontally and several wavelengths above ground, the usable gain will be about 6 dB higher than the listed value (in dBi). If used vertically, the gain will be less but the beamwidth will be wider.

1. 7-Element Quad Dimensions in Inches (AWG #12 Copper Wire)

Element	Circumference	Distance from Reflector
Reflector	86.80	----
Driver	83.20	12.36
Director 1	80.80	29.19
Director 2	78.96	46.18
Director 3	77.76	63.57
Director 4	76.80	77.50
Director 5	76.00	95.99

2. Performance Characteristics

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	11.85	12.10	12.13
180-degree F-B dB	15.30	22.10	16.24
Hor. B/W degrees	48.4	47.0	45.2
Vert. B/W degrees	52.4	50.5	48.2
Feed Z R+/-jX Ohms	44.8 - j30.4	50.7 - j 0.7	49.4 + j32.3
50-Ohm SWR	1.899	1.020	1.896

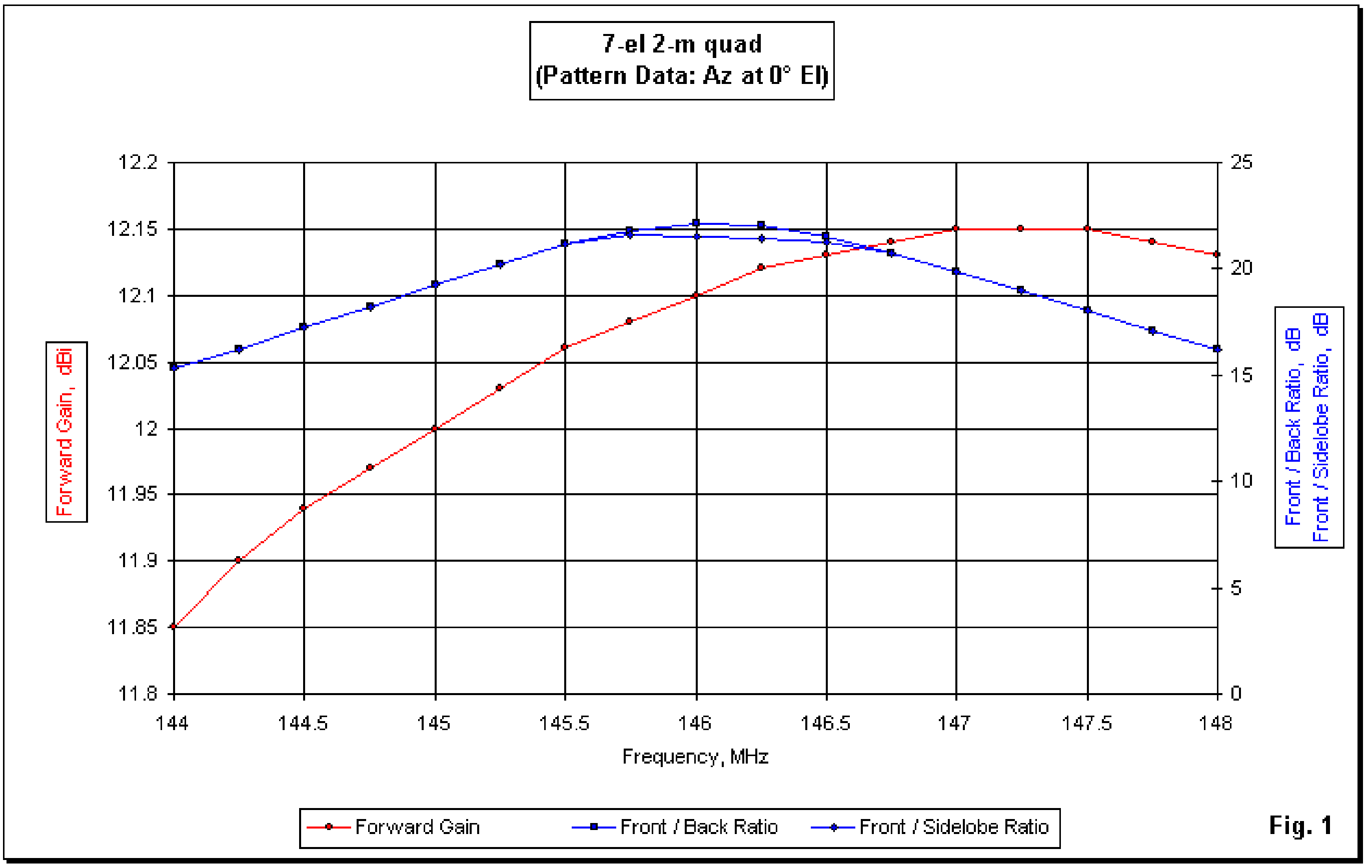


Fig. 1

Fig. 1 shows the curves for gain and front-to-back ratio across the band. The front-to-sidelobe ratio provides a measure of the worst-case front-to-back ratio wherever the forward sidelobes are weaker than the rearward radiation, as they are with the quad design. Note that the gain peaks at about 147.25 MHz, although the front-to-back ratio peaks about mid-band.

The gain differential across the band is only 0.30 dB, while the front-to-back differential is only 6.8 dB. However, the average front-to-back ratio is only 19.2 dB, with serious decreases at the band edges.

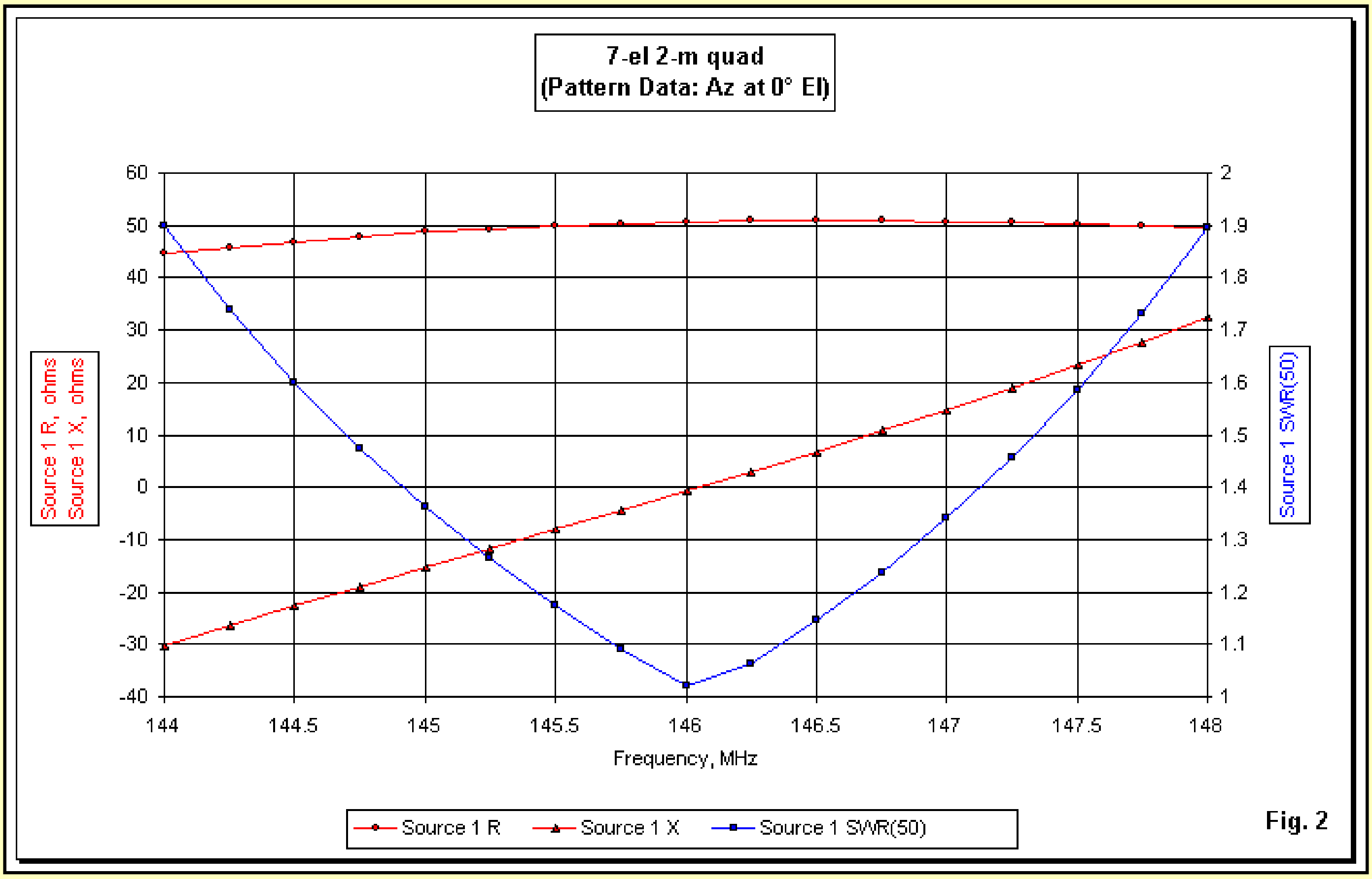


Fig. 2

Fig. 2 shows the feedpoint resistance and reactance, along with the 50-Ohm SWR curve across the 2-meter band. The design achieves full band SWR coverage, but just barely. The feedpoint resistance does not change much, but the feedpoint reactance undergoes a 60-Ohm swing from one end of the band to the other.

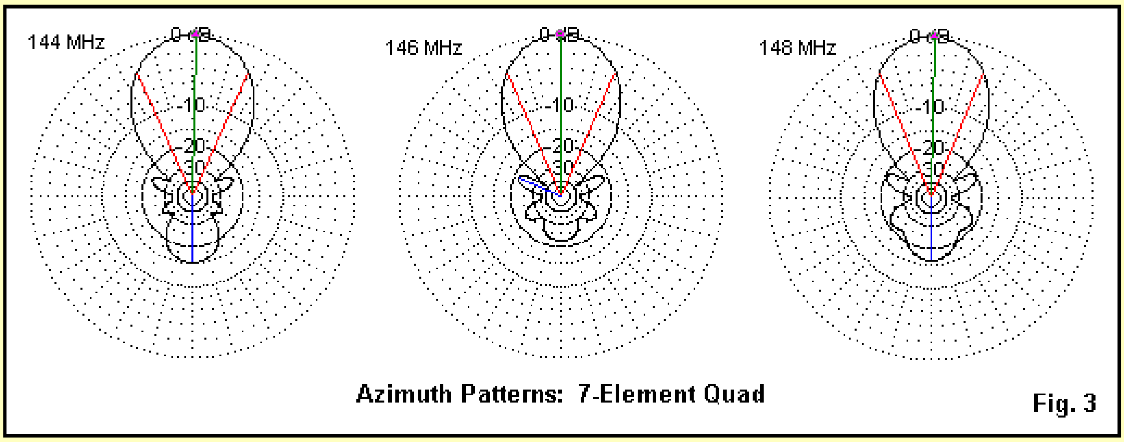


Fig. 3

Fig. 3 shows the E-plane (azimuth) patterns of the array across the band. Two features are notable. First, the forward sidelobes are better than 20-dB down all across the band. Second, at the band edges, the rearward radiation is considerable across a significant beamwidth.

A 7-Element OWA Yagi for 144-148 MHz

The smaller of the two Yagis uses a variation of the optimized wideband antenna (OWA) arrangement pioneered at HF by WA3FET and NW3A. It consists of a reflector about 0.13-wavelength behind the driver and a fairly closely spaced 1st director 0.06-wavelength or less ahead of the driver. (The exact spacing depends upon the desired operating bandwidth and the diameters of the elements.) These elements essentially control the feedpoint impedance. The 2nd and 3rd directors are of equal length and stabilize the array's performance across a design passband (in this case, 144-148 MHz), and have a role to play in suppressing forward sidelobes. The remaining directors control the array gain and front-to-back ratio.

The following tables list the dimensions of the 7-element OWA Yagi, all in inches. The element length is the overall linear length of each 3/16" diameter aluminum rod. The second table samples the free-space performance of the antenna.

1. 7-Element OWA Yagi Dimensions in Inches (3/16" [0.1875"] diameter aluminum)

Element	Length	Distance from Reflector
Reflector	40.70	----
Driver	39.66	10.81
Director 1	37.00	15.47
Director 2	36.32	27.38
Director 3	36.32	42.72
Director 4	36.20	63.38
Director 5	34.50	85.67

2. Performance Characteristics

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	11.50	11.61	11.37
180-degree F-B dB	21.06	28.73	20.35
Hor. B/W degrees	47.8	46.0	44.0
Vert. B/W degrees	57.8	54.8	51.6
Feed Z R+/-jX Ohms	45.7 + j 3.4	51.1 + j 9.0	47.0 - j 6.9
50-Ohm SWR	1.122	1.195	1.168

From the tables, we can glean some interesting information. For example, the 7-element Yagi has a horizontal beamwidth that is less than that of the quad. However, the vertical beamwidth is wider than that of the quad.

The remaining data is suggestive of what will emerge in the frequency-sweep graphs to come.

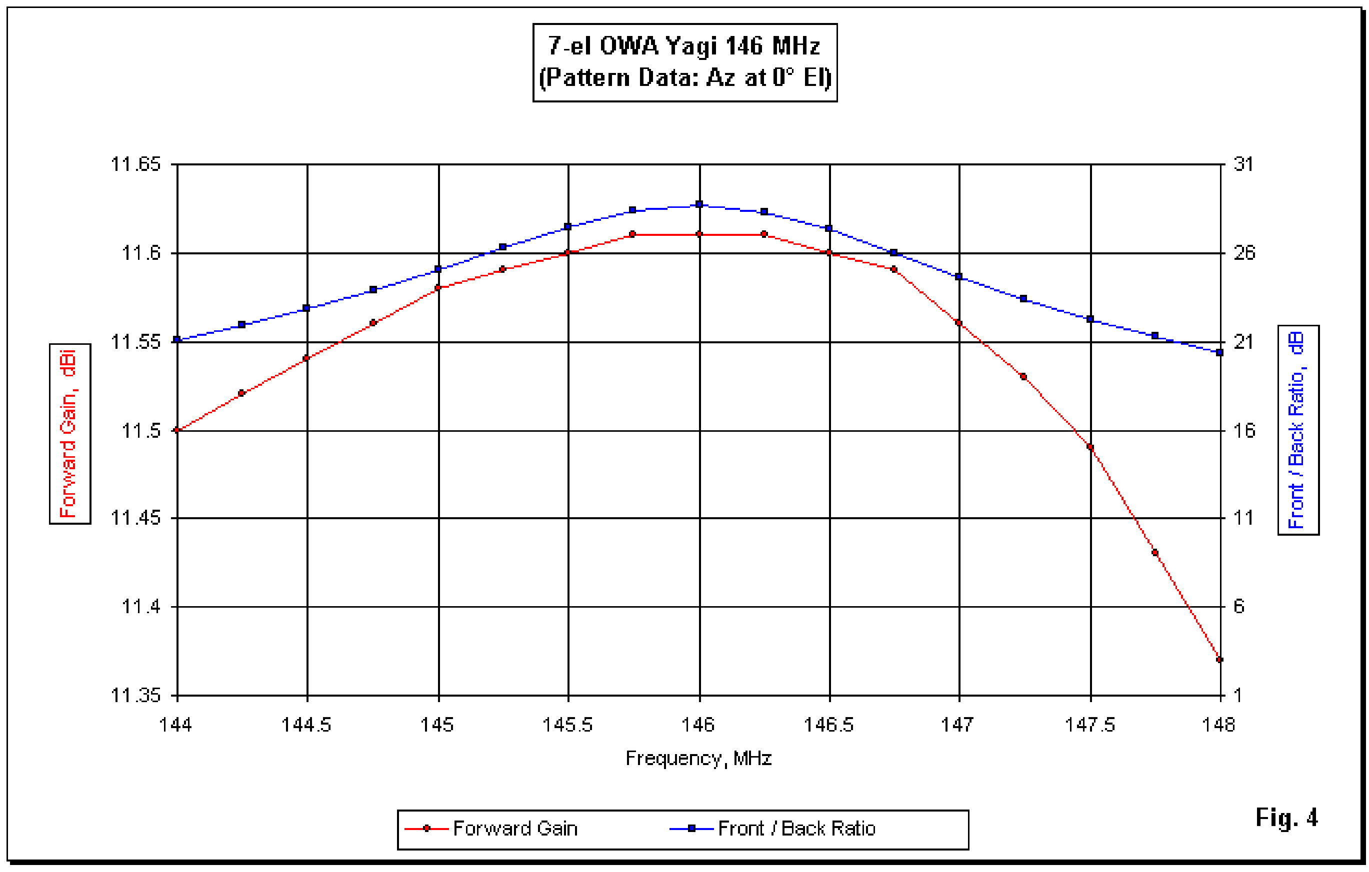


Fig. 4

Fig. 4 shows the gain and the 180-degree front-to-back ratio. The worst-case front-to-back does not appear because the higher general levels of front-to-back performance of the 7-element Yagi leave some forward lobes that are stronger than any rearward lobe. Hence, the front-to-sidelobe ratio would alternate between a forward and a rearward lobe.

The array gain varies by only 0.24 dB across the band. Its average gain level is almost exactly 0.5 dB less than the longer 7-element quad. On the other hand, the Yagi's front-to-back ratio is everywhere above 20 dB, with an average value of 24.7 dB, about 5 dB better than the quad. Unlike the quad, the OWA Yagi's gain and front-to-back peaks both occur about in the center of the band.

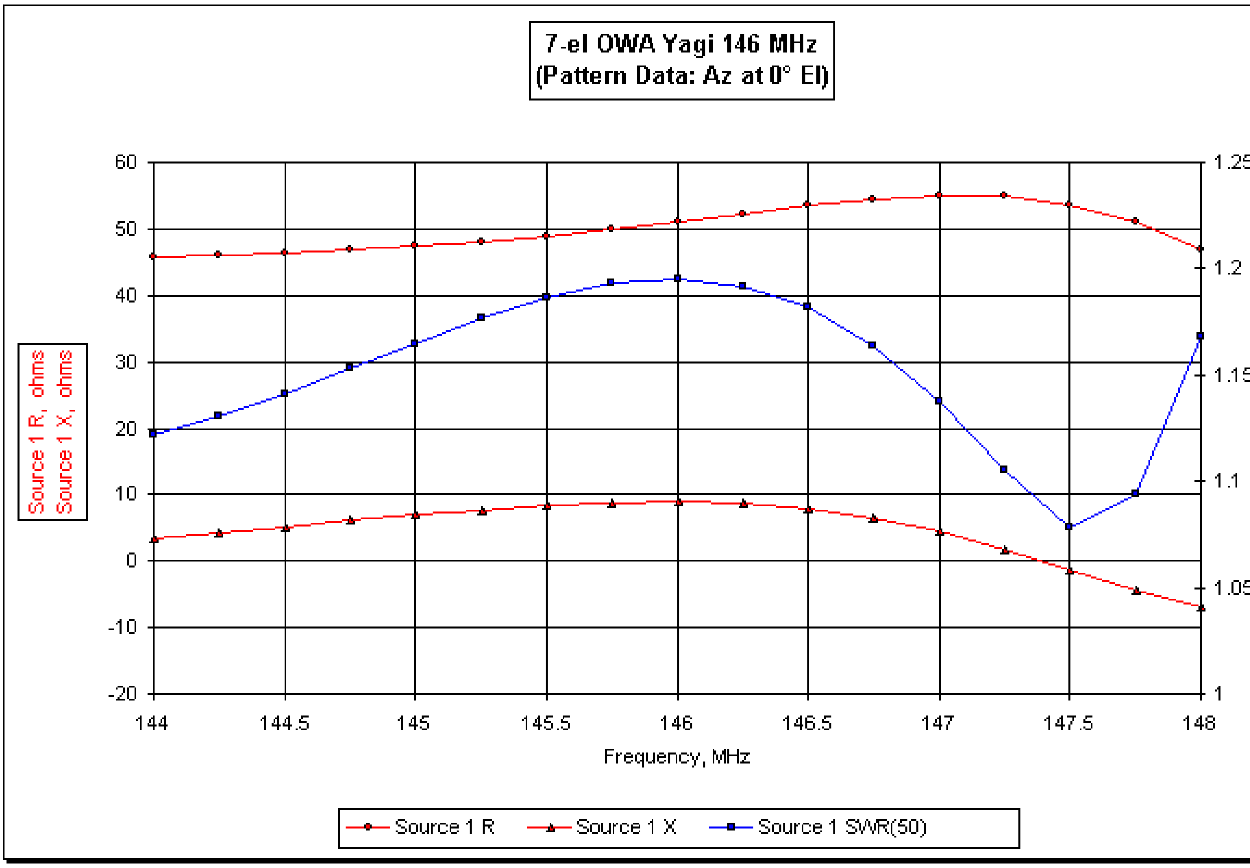
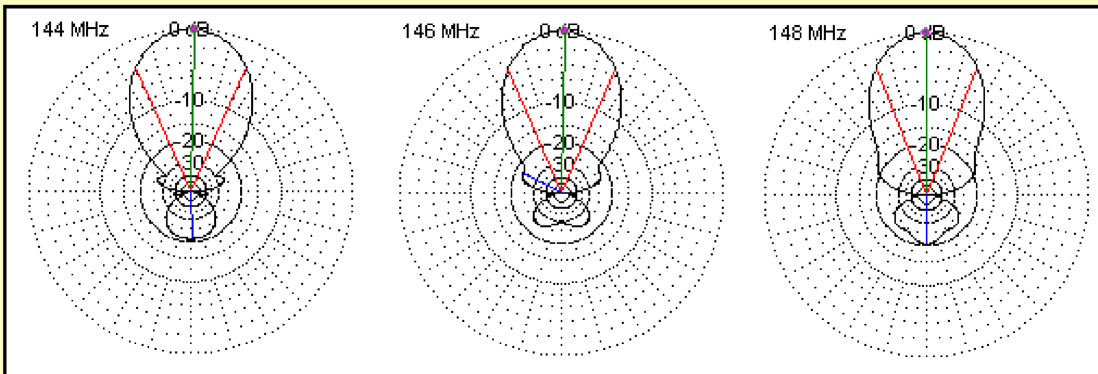


Fig. 5

Fig. 5 shows the resistance, reactance, and 50-Ohm SWR associate with the 7-element Yagi feedpoint. The OWA feedpoint system of elements provides a very wide operating bandwidth with less than a 1.25:1 50-Ohm SWR all across the band. Note that the typical OWA SWR curve shows more than one minimum: a broad one at the low end of the band and a sharper one at the high end. Above 148 MHz, the 2:1 SWR limit appears quickly, but below the lower end of the band, the SWR remains low for several MHz. However, gain and front-to-back ratio are both reduced below 144 MHz.



Azimuth Patterns: 7-Element OWA Yagi

Fig. 6

Fig. 6 shows the E-plane (azimuth) patterns of the 7-element Yagi. Especially interesting are the much diminished rearward radiation lobes, compared to those of the 7-element quad.

An 8-Element OWA Yagi for 144-148 MHz

The 8-element OWA Yagi is an extension of the 7-element design and uses essentially the same first 6 elements. Only slight changes have been made to perfect the operating passband. However, unlike some

Yagi families, adding an element requires a very significant adjustment to the previously forward-most element. Compare element 7 in the dimension tables for the two designs.

The following tables list the dimensions of the 8element OWA Yagi, all in inches. The element length is the overall linear length of each 3/16" diameter aluminum rod. The second table samples the free-space performance of the antenna

8-Element OWA Yagi Dimensions in Inches (3/16" [0.1875"] diameter aluminum)

Element	**Length**	**Distance from Reflector**
Reflector	**40.70**	**----**
Driver	**39.50**	**10.81**
Director 1	**37.00**	**15.47**
Director 2	**36.32**	**27.38**
Director 3	**36.32**	**42.72**
Director 4	**36.20**	**63.38**
Director 5	**35.20**	**88.50**
Director 65	**33.30**	**115.0**

4. Performance Characteristics

Parameter	**144 MHz**	**146 MHz**	**148 MHz**
Gain dBi	**12.28**	**12.42**	**12.15**
180-degree F-B dB	**20.26**	**23.41**	**21.42**
Hor. B/W degrees	**45.0**	**43.0**	**41.2**
Vert. B/W degrees	**52.6**	**49.8**	**47.2**
Feed Z R+/-jX Ohms	**47.2 + j 0.4**	**49.6 + j 4.9**	**49.6 - j 9.0**
50-Ohm SWR	**1.106**	**1.104**	**1.197**

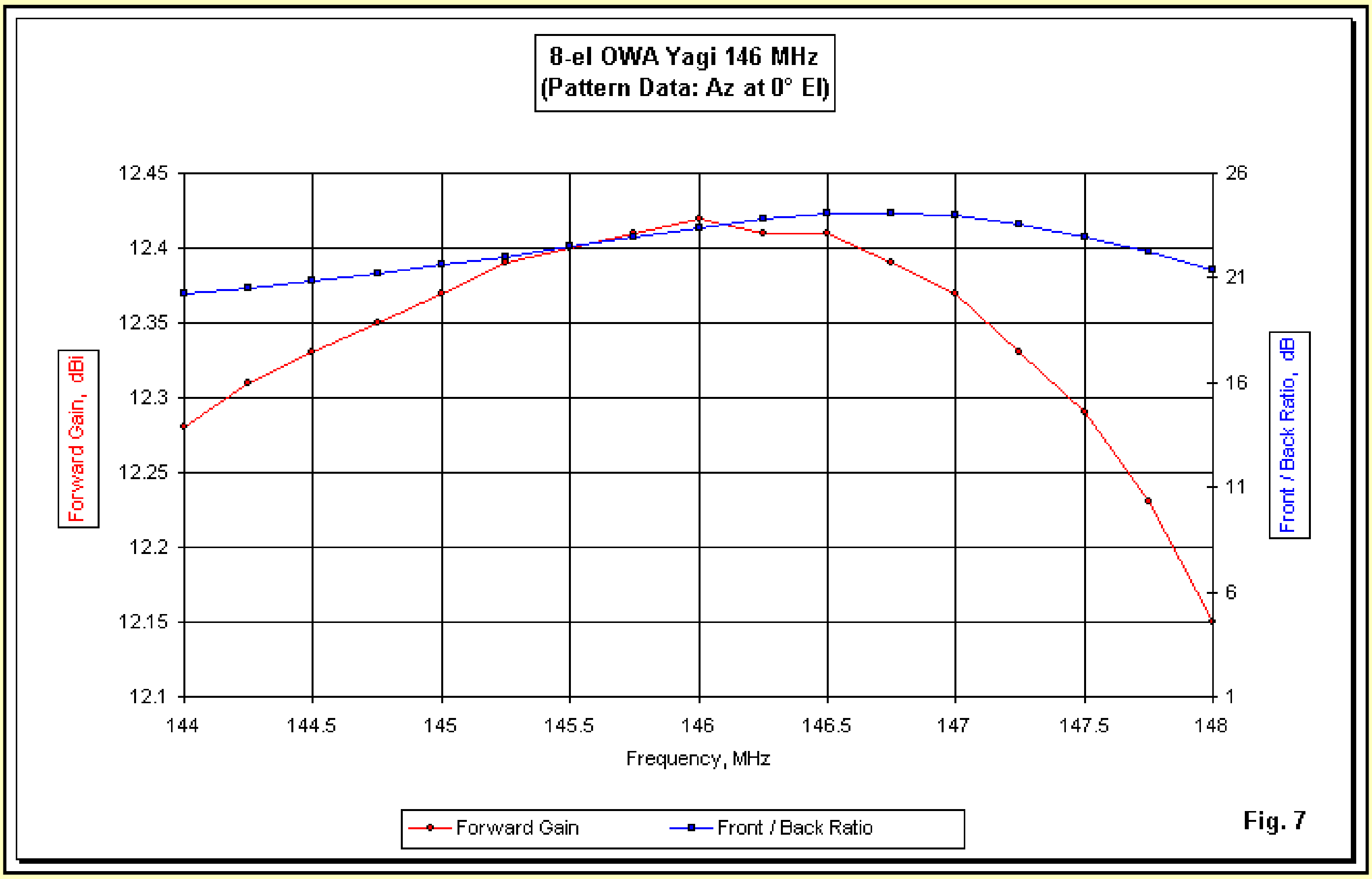


Fig. 7

As shown in **Fig. 7**, the gain varies by only 0.27 dB across the band, with its peak at mid-band. The front-to-back ratio peaks slightly above the mid-band point but is everywhere greater than 20 dB. As with the 7-element OWA, the front-to-sidelobe ratio does not reliably shows the worst-case front-to-back ratio and is therefore omitted.

The average forward free-space gain of the 8-element Yagi is 12.42 dBi, about 1/3 dB higher than the 7-element quad. The front-to-back ratio averages about 4 dB greater than the values for the quad.

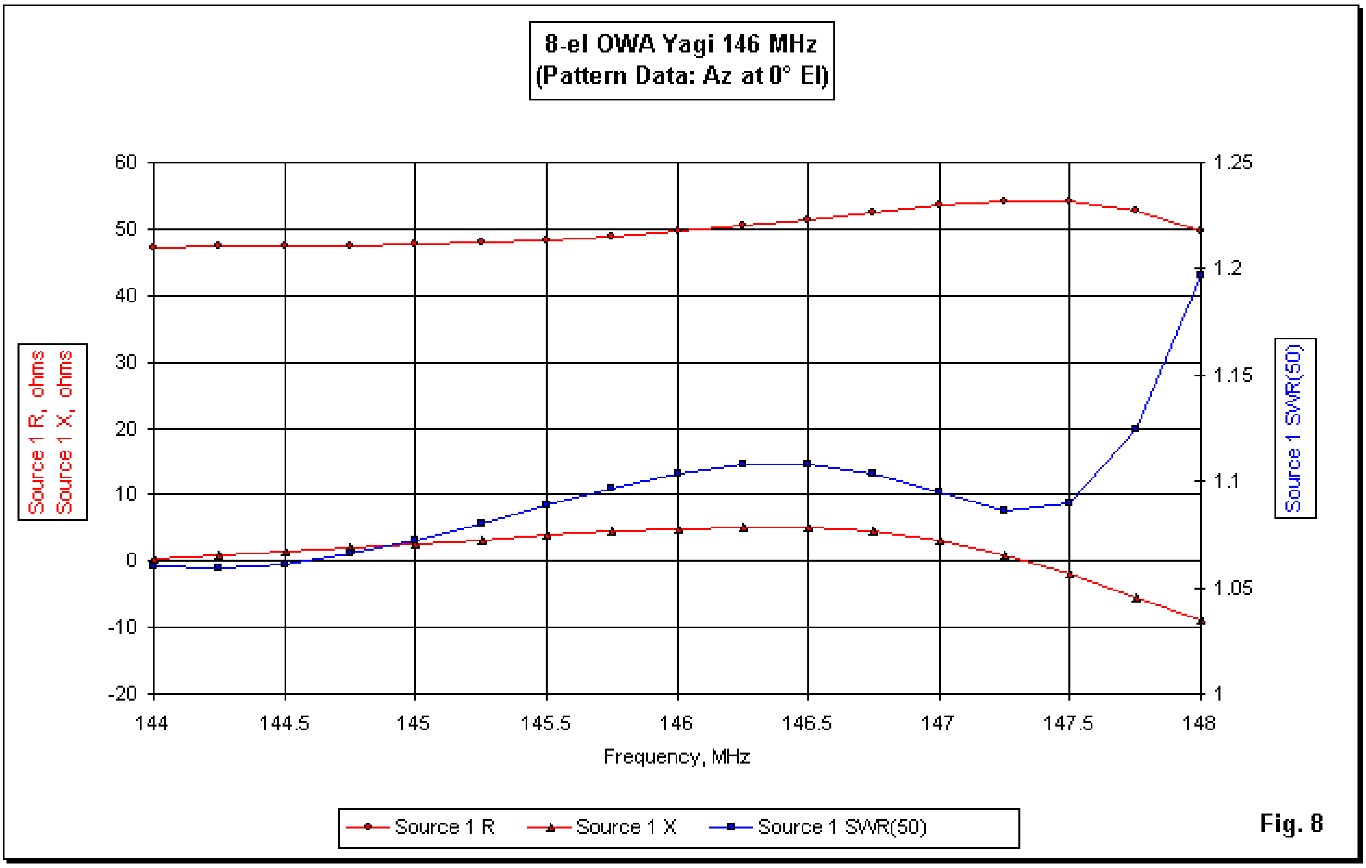
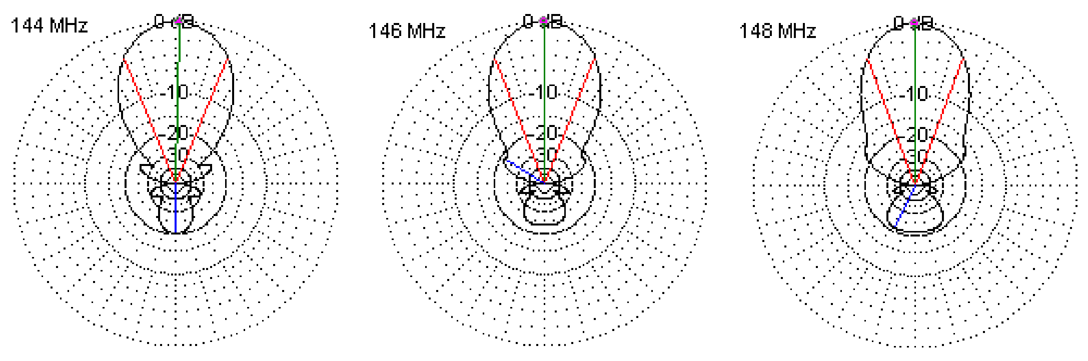


Fig. 8

The resistance, reactance, and 50-Ohm SWR curves for the 8-element Yagi, shown in **Fig. 8**, are very similar to those for the 7-element Yagi. The minimum SWR values occur at 144.25 and 147.25 MHz. For both the Yagi designs, both the resistance and the reactance undergo very small excursions within the 2-meter band.



Azimuth Patterns: 8-Element OWA Yagi

Fig. 9

Fig. 9 shows the E-plane (azimuth) patterns of the 8-element Yagi, once more revealing well controlled rearward radiation lobes and forward sidelobes.

Horizontal or Vertical?

It is well known that when a horizontally oriented beam is placed above ground, its azimuth pattern is almost identical to the free-space (E-plane) counterpart, including the beamwidth. Less well known is the fact that when we vertically orient an array well above ground, its pattern will also closely resemble its free-space counterpart, the H-plane pattern. As well, the more elements or the longer the boomlength of an array, the closer together grow the horizontal and vertical beamwidth values.

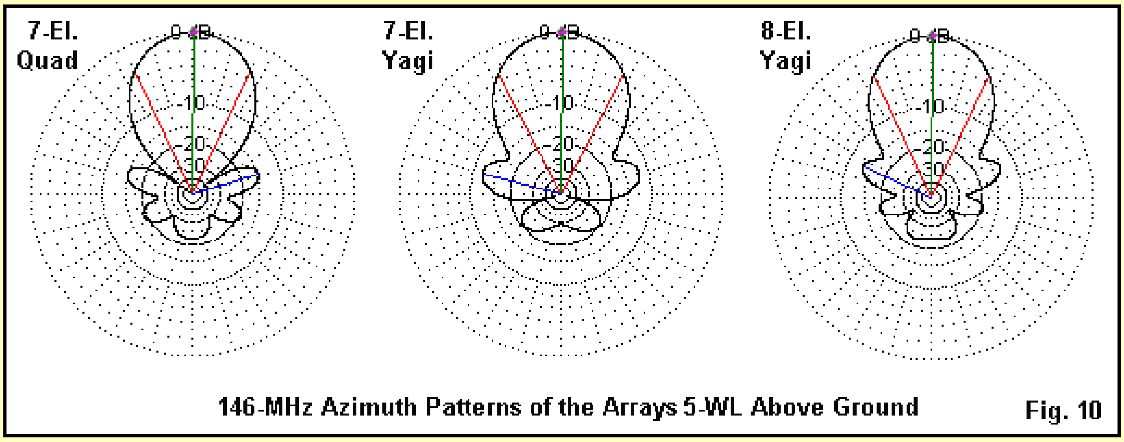


Fig. 10 provides 146-MHz azimuth patterns of the 3 antennas. Each is 5 wavelengths above average ground--somewhere between 33 and 34 feet. In each case, the height is the height of the boom. Each antenna is vertically oriented. Each has a beamwidth that is the same as the vertical beamwidth listed in the free-space performance charts.

The quad begins to show an improved pattern relative to the Yagis in this orientation, especially with respect to sidelobes--about a 3 dB improvement on maximum strength. As well, one may more easily experiment with circular polarization with a quad than with a Yagi. For circular polarization of a Yagi, we need essentially two Yagis at right angles to each other with some form of quadrature feed. We also need quadrature feed with the quad, but we may run the line or network from one standard feedpoint to another 90-degrees away. This system is often inconvenient with a square quad, but if we use a diamond-shaped quad, we may place the two feedpoints at the corners and use the element support as additional bracing. We can change the direction of circular polarization simply by placing the main feedline at one or the other junctions of the quadrature network or line.

The Bottom Line

There is no effective bottom line to this analysis. There are many variables in the building situation for each beam-maker that may make one design easier to execute than the other. As well, special needs or operating foci may give one design an advantage over the other. Hence, the data must speak for themselves to the situation of the builder.

Interpreting the data requires a few cautions. First, as modeled arrays, the elements presume insulation and isolation from conductive booms--although for the Yagis, a non-conductive boom is not out of the building picture. The quads may use a central metal boom with non-conductive element supports. If one wishes to build one of the Yagis using insulated through-boom techniques, then element length adjustments will be needed. Information on that topic appears elsewhere in the VHF/UHF notes at my web site. See **Scaling and Adjusting VHF/UHF Yagis** .

Second, the designs each use a specific size material for the elements. Changes in the element lengths are required for changes in the element diameters. Yagi adjustments that are good for at least a 1.5:1 increase or decrease in diameter also appear elsewhere at my website (see **Scaling and Adjusting VHF/UHF Yagis**), as well as in VHF/UHF antenna literature. Quad adjustments are less well formulated for changes in diameter. However, for fatter elements, expect each element to be somewhat shorter in circumference.

When a proposed diameter change exceeds about 2:1 relative to the original, it is time to re-design both the element lengths and their spacing. The mutual coupling between elements changes to the point where it is no longer optimum to preserve and enhance performance. For example, two 6-element OWA Yagi designs, one by me and one by Dean Straw, N6BV, are nearly 6" different in length, with the longer version having elements about twice as fat as the shorter Yagi design. Likewise, a fat-element quad will likely require a significantly longer boom that the AWG #12 model shown here.

Automated programs for calculating the dimensions of quads exist for 1 to 4 elements. See **New Quad Studies**. However, the number of variables involved in longer-boom quads--such as the 7-element antenna shown here--have so far precluded automation of the design process. A new generation of optimizing software is beginning to appear for general antenna design, so the future may ease the design process considerably.

In the interim, I hope these notes are useful in the process of selecting a 2-meter beam to build.

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