Wide-Band Utility Yagis for 420-450 MHz
1. 4- and 6-Element Models

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High-gain narrow-bandwidth Yagis for the 420-450 MHz band abound in the literature, and there are some very fine designs to be found. Less apparent are small wide-band Yagis for this band that can be used for utility purposes. They may be out there and these notes may be a classic case of reinventing the wheel. However, taking a look at a few such designs might still be useful.

The operating goal would be to have useful and relatively even gain across the entire passband. If something must be sacrificed for the operating bandwidth, it may be the front-to-back ratio. However, the SWR curve must be as smooth and low as possible without detracting from the gain. For this reason, I set two goals for the SWR curve.

The first goal was to use a 50-Ohm feedpoint impedance and to eliminate the need for matching fixtures. Although matching fixtures associated with Tee networks can be assembled so as to reduce losses to the negligible level, a utility antenna is likely to be assembled quickly and receive many a thump in its travels from one location to another. The fewer fixtures, the better.

Second, the target maximum SWR at 50 Ohms was set at 1.3:1 across the passband. Achieving this goal for a 7% passband is a challenge, assuming that one wishes to have some reasonable operating characteristics across the same passband.

The choice of 1.3:1 as the SWR limit arose from considering the losses in the cable between the rig and the antenna. The difference in cable loss between a 2:1 and a 1.3:1 SWR for 50' of RG-58 is about 0.375 dB. For RG8X, a commonly used alternative for utility purposes, the difference is about 0.31 dB/50' of line. (Half-inch 50-Ohm hardline would show only a 0.16 dB/50' difference. Exact numbers will vary with the exact cable used, and these numbers are for general guidance only.) Since performance usually decreases toward the band edges--just the place that one tends to find the higher SWR level, even with a wide-band Yagi design--holding the SWR as low as feasible seemed a worthy goal.

Let's begin small, say with 4- and 6-element versions of the antenna. Next time, we shall look at an 8-element wide-band Yagi.

A 4-Element Wide-Band Yagi

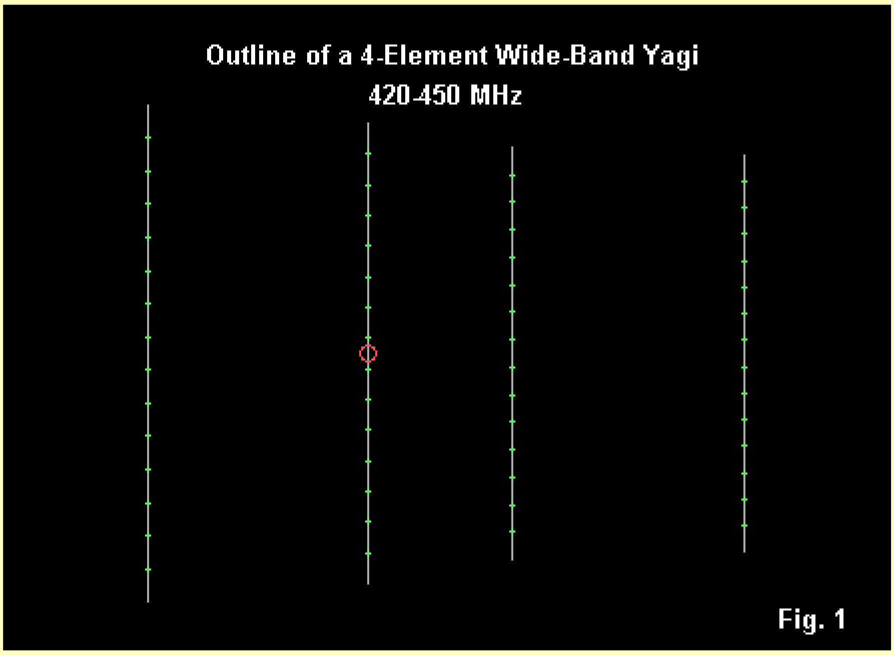


Fig. 1 shows the outline of a wide-band 4-element Yagi. In its design are some of the OWA (optimized wide-band antenna) principles that govern the use of the first director to set--in conjunction with the lengths and spacing of the reflector and driver--the feedpoint impedance curve. However, even OWA principles will not cover the wide passband with an acceptable SWR curve without a second step: using "fat" elements.

There is a near fetish against the use of fat elements at UHF, mostly bred of experience with very long-boom Yagis. It is claimed that their weight and wind load are simple too high to use. For small utility Yagis, these claims become largely irrelevant. Therefore, the designs shown here use 0.5" (12.7 mm) tubing.

Tubing has an advantage over solid rod in UHF design. Even the common 3/16" or 4 mm rods used by most designs show considerable capacitance across the feedpoint at UHF and up due to the faces of the rod ends and the feedpoint gap. Tubing reduces the capacitance. In fact, beveling the tubing from the inside can reduce the capacitance further. Moreover, with some ingenuity, cable or connector connections can be made to the tubing inside, eliminating bumps in the element diameter.

The dimensions for the 4-element design are in the following table, with element lengths and spacing from the reflector shown both in inches and in millimeters.

4-Element Wide-Band Yagi Dimensions

Element	**Length**		**Spacing From Reflector**	
	Inches	**mm**	**Inches**	**mm**
Reflector	**13.15**	**334**	**-----**	**-----**
Driver	**12.17**	**309**	**5.81**	**147.5**
Dir. 1	**10.91**	**277**	**9.63**	**244.5**
Dir. 2	**10.51**	**267**	**15.75**	**400.0**

This design was developed on NEC-4 (NEC-4D shows no differences from NEC-4). However, the design effort is not without some issues of its own. One such issue is convergence. Half-inch elements begin to approach the limits of NEC recommendations for length-to-radius ratios as the level of segmentation is increased. The designs were tested at 11, 15, and 19 segments per element. More than 19 segments per element resulted in initial warnings concerning the recommended segment length-to-radius limits. The following table illustrates the differences in results.

Frequency and Parameter	Segmentation Level 11 seg/element	 15 seg/element	 19 seg/element
420 MHz			
Free-Space Gain dBi	9.13	9.13	9.12
Front-to-Back dB	11.50	11.49	11.45
Feed Z (R +/- jX)	45.9 - j 3.0	45.6 - j 3.8	45.0 - j 4.7
50-Ohm SWR	1.113	1.130	1.154
435 MHz			
Free-Space Gain dBi	9.30	9.29	9.29
Front-to-Back dB	12.35	12.34	12.32
Feed Z (R +/- jX)	60.0 - j 0.0	59.9 - j 0.6	59.6 - j 1.1
50-Ohm SWR	1.200	1.198	1.193
450 MHz			
Free-Space Gain dBi	9.58	9.57	9.55
Front-to-Back dB	14.46	14.35	14.21
Feed Z (R +/- jX)	47.1 - j 7.9	48.2 - j 8.4	49.4 - j 9.0
50-Ohm SWR	1.189	1.191	1.198

Despite the numeric fluctuation, the values are sufficiently close to consider the model reliable within the context of NEC-4 modeling. In graphs, unless otherwise indicated, the 15 segment/element model is used.

However, models for designs such as these can be developed on a variety of modeling platforms. Most common is NEC-2, used in most low end versions of modeling software. An alternative is MININEC 3.13, which is used in such software as ELNEC and NEC4WIN. The latter contains an option for running MININEC as is or with a correction factor that will better match it to NEC-2 results. We can compare these programs in a similar table of end and mid-band values to see what we might expect. For example, there are reports of a deviation at UHF and above between NEC-2 and NEC-4 for narrow-band high-gain Yagis. Finding out whether the difference shows up for small wide-band designs is worth the extra modeling effort. The NEC model uses 15 segments per element, while the MININEC model uses 14 segments per element.

Frequency and Parameter	Program NEC-2	 MININEC w/corr	 MININEC w/o corr
420 MHz			
Free-Space Gain dBi	9.17	9.44	8.93
Front-to-Back dB	11.69	10.79	10.28
Feed Z (R +/- jX)	47.8 - j 1.1	47.4 - j 5.4	37.5 - j13.2
50-Ohm SWR	1.053	1.130	1.520
435 MHz			
Free-Space Gain dBi	9.33	9.59	9.14
Front-to-Back dB	12.48	12.01	11.86
Feed Z (R +/- jX)	61.0 - j 0.7	50.6 - j16.2	52.5 - j 1.2
50-Ohm SWR	1.220	1.380	1.060
450 MHz			
Free-Space Gain dBi	9.64	9.90	9.32
Front-to-Back dB	14.99	15.31	12.92
Feed Z (R +/- jX)	42.7 - j 6.6	24.8 - j 9.2	60.0 - j 4.9
50-Ohm SWR	1.236	2.110	1.220

The NEC-2 numbers are systematically slightly higher than the corresponding NEC-4 values, although the coincidence is sufficient for most design purposes for this antenna. Corrected MININEC is about as much above the NEC values as uncorrected MININEC is below them. The amounts are perhaps more clearly shown in **Fig. 2**, a graph of the modeled gain levels across the passband.

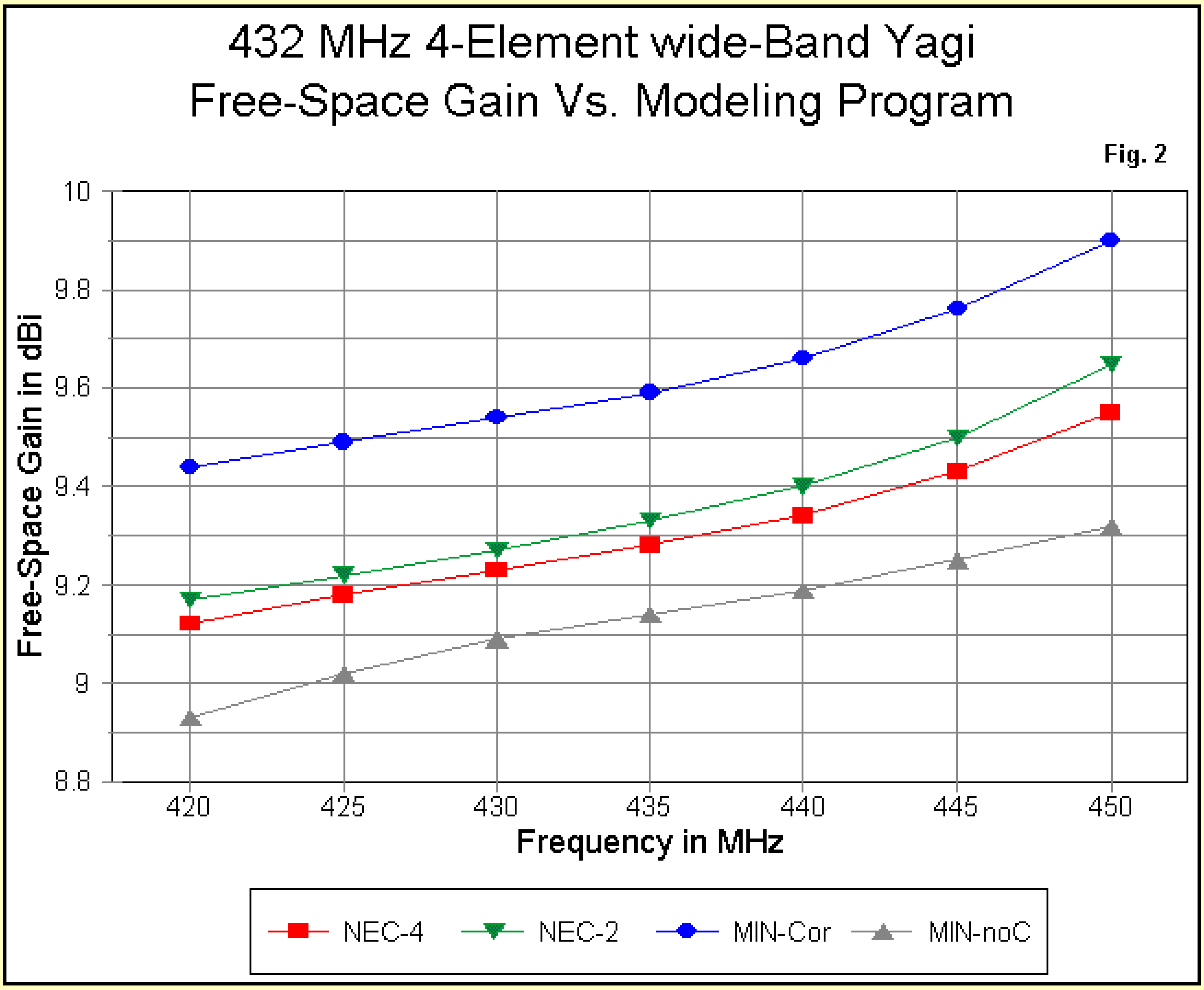
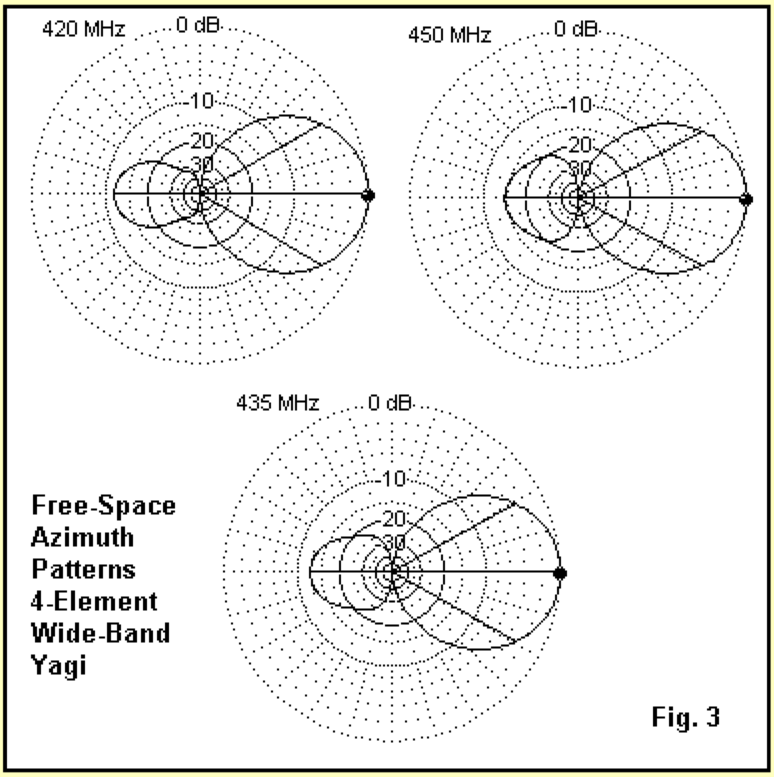


Fig. 2

Note in the graph the slightly different curve shapes that indicate not only a difference in calculated values, but as well a frequency displacement of the curves relative to each other.

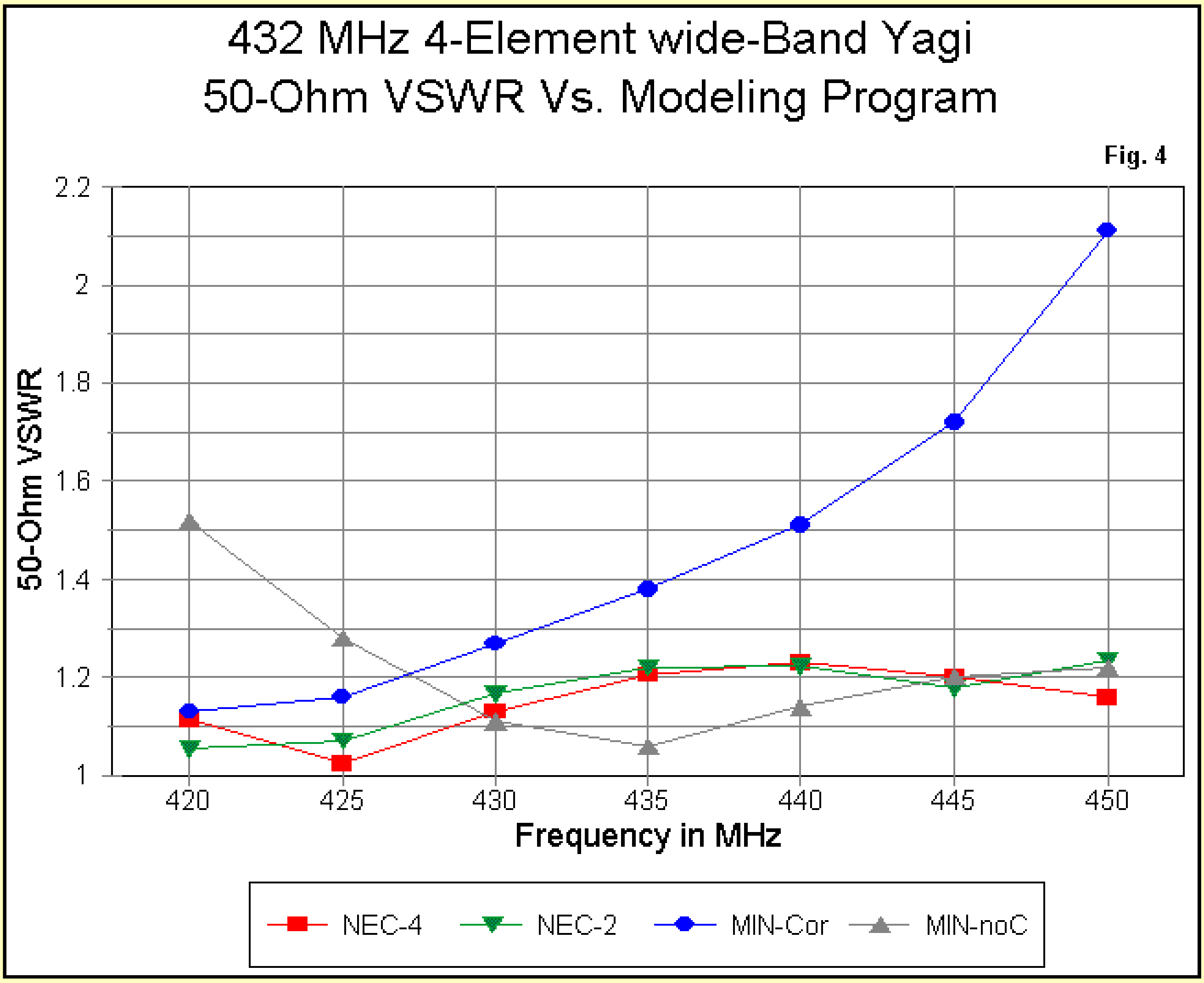
The design of the 4-element wide-band Yagi strove for a relatively smooth gain curve. In the 15-segment/element version, the gain differential across the band is just above 0.4 dB. One consequence is a relatively low front-to-back ratio that varies between 11.6 and 13.3 dB. **Fig. 3** provides free-space azimuth patterns at the end and mid-band frequencies to give a sense of the horizontal pattern of the antenna.



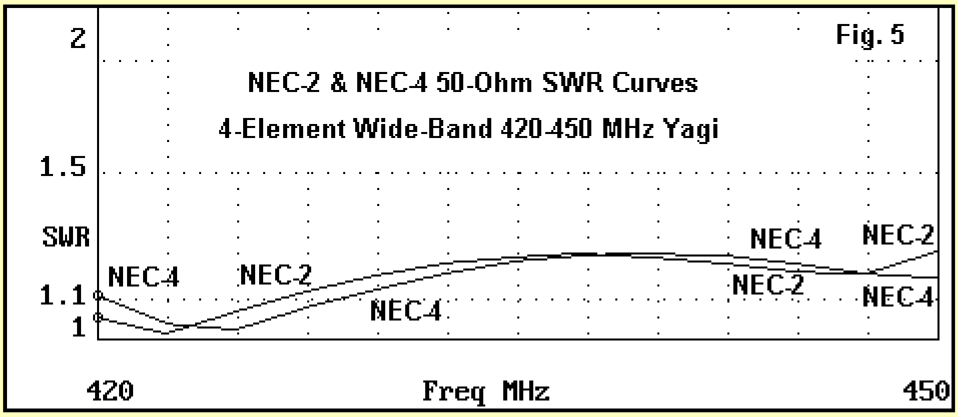
Free-Space Azimuth Patterns 4-Element Wide-Band Yagi

Fig. 3

The key displacement among modeling programs occurs with respect to the SWR curves. **Fig. 4** graphs the 50-Ohm SWR curves for all 4 models. Corrected MININEC appears to displace the curve to lower frequencies relative to the desired passband, since the rapid rise in SWR is typical of the NEC-2/-4 curves above the 450 MHz mark. In contrast, uncorrected MININEC appears to shift the passband in the opposite direction, as the rise in SWR at the low end of the band parallels the NEC model curves below 420 MHz.



In **Fig. 5**, I have isolated the NEC-2 and NEC-4 curves for closer examination. Note that there is an approximate 5 MHz displacement of one curve relative to the other. Both curves show the characteristic OWA pattern.



For the average home builder, the differences illustrated here would likely wash out in the relative imprecision and trial-until-it-works techniques of construction. However, for precision shops capable of measurements to a millimeter or less and with techniques to control the feedpoint variables, the differences may become very significant. My own shop tools and instruments are not sufficiently precise to judge among the variants on the model.

All of the models presume an insulated boom with good RF properties at UHF. Perhaps polycarbonate (trade name Lexan) material would make a good choice for the 16" boom (with whatever extension may be needed for mounting hardware. A metal boom may require adjustment to all of the element lengths.

A 6-Element Wide-Band Yagi

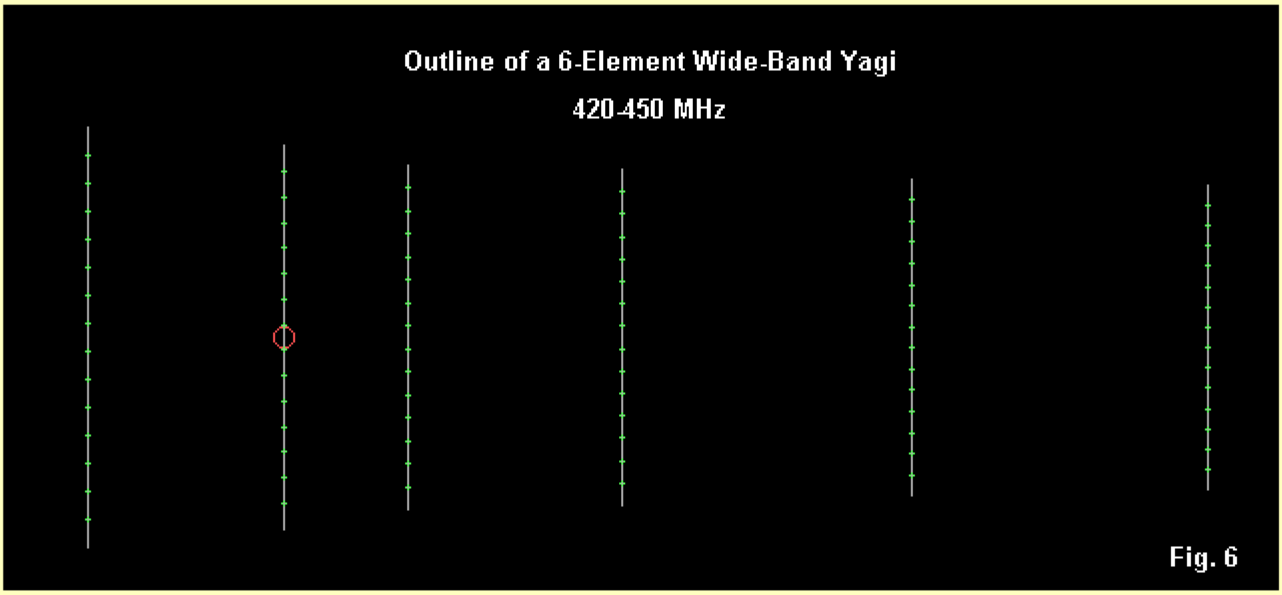


Fig. 6

For a bit more gain, we can try a 6-element wide-band Yagi. The general outline appears in **Fig. 6**. Adding 2 elements to the utility beam more than doubles its length. The NEC-4 modeled dimensions for the antenna appear in the following table--both in inches and millimeters.

6-Element Wide-Band Yagi Dimensions

Element	**Length**		**Spacing From Reflector**	
	Inches	**mm**	**Inches**	**mm**
Reflector	**13.46**	**342**	**-----**	**-----**
Driver	**11.89**	**302**	**5.95**	**151.0**
Dir. 1	**11.01**	**282**	**9.72**	**247.0**
Dir. 2	**10.79**	**274**	**16.18**	**411.0**
Dir. 3	**10.20**	**259**	**24.94**	**633.5**
Dir. 4	**9.80**	**249**	**33.94**	**862.0**

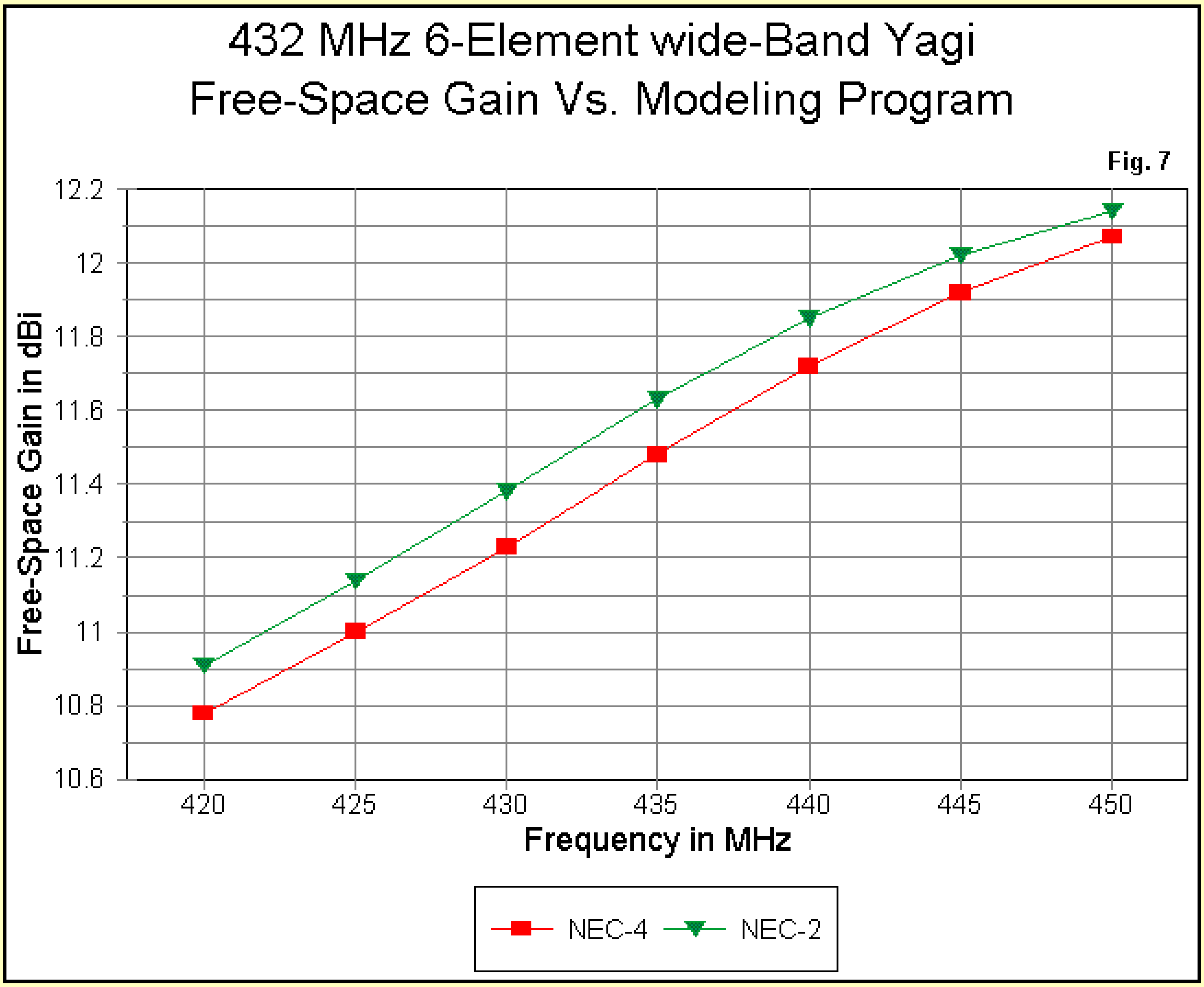
The design is obviously different with respect to element lengths and spacing relative to the 4-element design. It is not a case of trying to simply add 2 directors to the earlier design and fudge everything back into a satisfactory SWR pattern. Instead, the design strove to see what might occur if the front-to-back ratio as well as the gain were maximized while sustaining the desired SWR level at 1.3:1 or less.

The following table lists the performance reports from both NEC-4 and NEC-2. Somewhat more detail (5-MHz intervals) is listed.

Frequency and	**Program**	
Parameter	**NEC-4**	**NEC-2**
420 MHz		
Free-Space Gain dBi	**10.78**	**10.91**
Front-to-Back dB	**18.27**	**19.25**
Feed Z (R +/- jX)	**44.4 - j 9.6**	**44.2 - j 8.1**
50-Ohm SWR	**1.266**	**1.237**
425 MHz		
Free-Space Gain dBi	**11.00**	**11.14**
Front-to-Back dB	**21.02**	**22.48**
Feed Z (R +/- jX)	**44.7 - j 5.7**	**44.1 - j 3.9**
50-Ohm SWR	**1.179**	**1.161**
430 MHz		
Free-Space Gain dBi	**11.23**	**11.38**

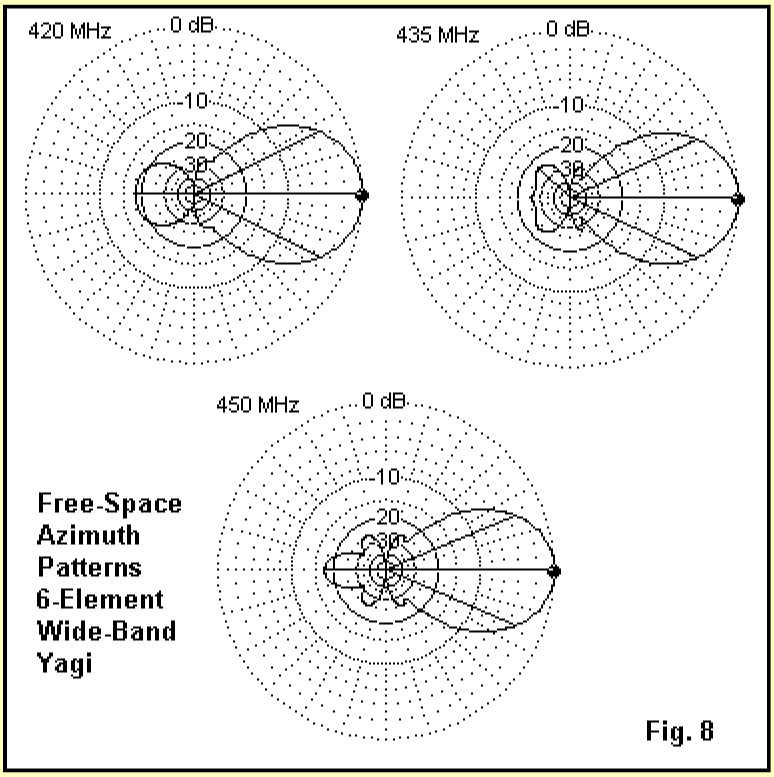
Front-to-Back dB	**24.43**	**26.15 +**
Feed Z (R +/- jX)	**44.7 - j 1.0**	**44.1 + j 1.2**
50-Ohm SWR	**1.121**	**1.136**
435 MHz		
Free-Space Gain dBi	**11.48**	**11.63**
Front-to-Back dB	**25.78 +**	**25.18**
Feed Z (R +/- jX)	**45.1 + j 4.3**	**44.9 + j 6.8**
50-Ohm SWR	**1.147**	**1.196**
440 MHz		
Free-Space Gain dBi	**11.72**	**11.85**
Front-to-Back dB	**22.56**	**21.11**
Feed Z (R +/- jX)	**46.6 + j 9.5**	**47.2 + j11.5**
50-Ohm SWR	**1.231**	**1.275**
445 MHz		
Free-Space Gain dBi	**11.92**	**12.02**
Front-to-Back dB	**19.29**	**18.22**
Feed Z (R +/- jX)	**49.5 + j12.5**	**50.3 + j12.1**
50-Ohm SWR	**1.285**	**1.273**
450 MHz		
Free-Space Gain dBi	**12.07**	**12.14**
Front-to-Back dB	**17.31**	**16.93**
Feed Z (R +/- jX)	**50.7 + j 9.7**	**46.6 + j 5.6**
50-Ohm SWR	**1.213**	**1.146**

From the marked (+) front-to-back values, we can once more see an approximate 5 MHz displacement in the curves for identical models run through NEC-2 and NEC-4 in the 430-MHz range. The displacement also appears when we graph the gain values across the band, as in **Fig. 7**.



At first sight, the two curves seem to indicate that one calculated value is simply higher than the other. However, the NEC-2 curves tapers off more rapidly at the high end of the passband. The NEC-4 curve would also reach a similar peak to that of the NEC-2 curve, but at a slightly higher frequency.

Compared to the 4-element gain curves, the 6-element gain changes much more radically across the passband--nearly 1.3 dB total change. This is the price to be paid for having a higher front-to-back ratio. **Fig. 8** shows the free-space azimuth patterns for the end and mid-band frequencies to give a general idea of the horizontal pattern performance of the antenna across the band.



Free-Space Azimuth Patterns 6-Element Wide-Band Yagi

Fig. 8

Although the two modeling platforms would be equally apt for the design of this wide-band antenna, the displacement of curves must be kept in mind throughout the process. **Fig. 9** shows the displacement of the 50-Ohm SWR curves using the same model with different cores. The NEC-2 model would show a reversal of reactance type and a relatively rapid rise of SWR thereafter at a frequency just above the passband edge. The NEC-4 curve would trail by about 5 MHz.

The displacement is a function of the use of fat elements. As a result, the length of each segment is reduced as a function of the element radius. You may avoid most of the displaement effect in NEC-2--relative to NEC-4--by invoking the EK command. Some programs automatically invoke the command (without necessarily notifying the user) whenever the ratio of segment length to wire radius drops to a certain level. The test comparison ran without using the EK command for the NEC-2 data.

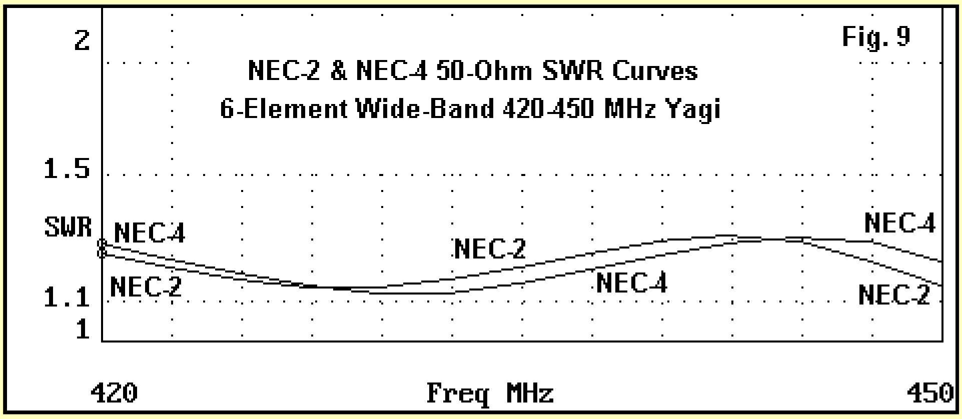


Fig. 9

NEC-2 & NEC-4 50-Ohm SWR Curves
6-Element Wide-Band 420-450 MHz Yagi

Applications

All construction suggestions applicable to the 4-element utility Yagi also apply to the 6-element design. It hardly needs to be added that the 6-element design, if supported at the rear, needs closer attention to the strength of the 33+" boom.

Wide-band Yagis for the 420-450 MHz range are likely to be used most of the time vertically polarized--largely for use with repeaters and mobiles. Besides adding some further constraints to construction, vertical polarization also changes the anticipated patterns somewhat. I modeled the antennas with the booms set to a height of 10 wavelengths--about 23' above good ground.

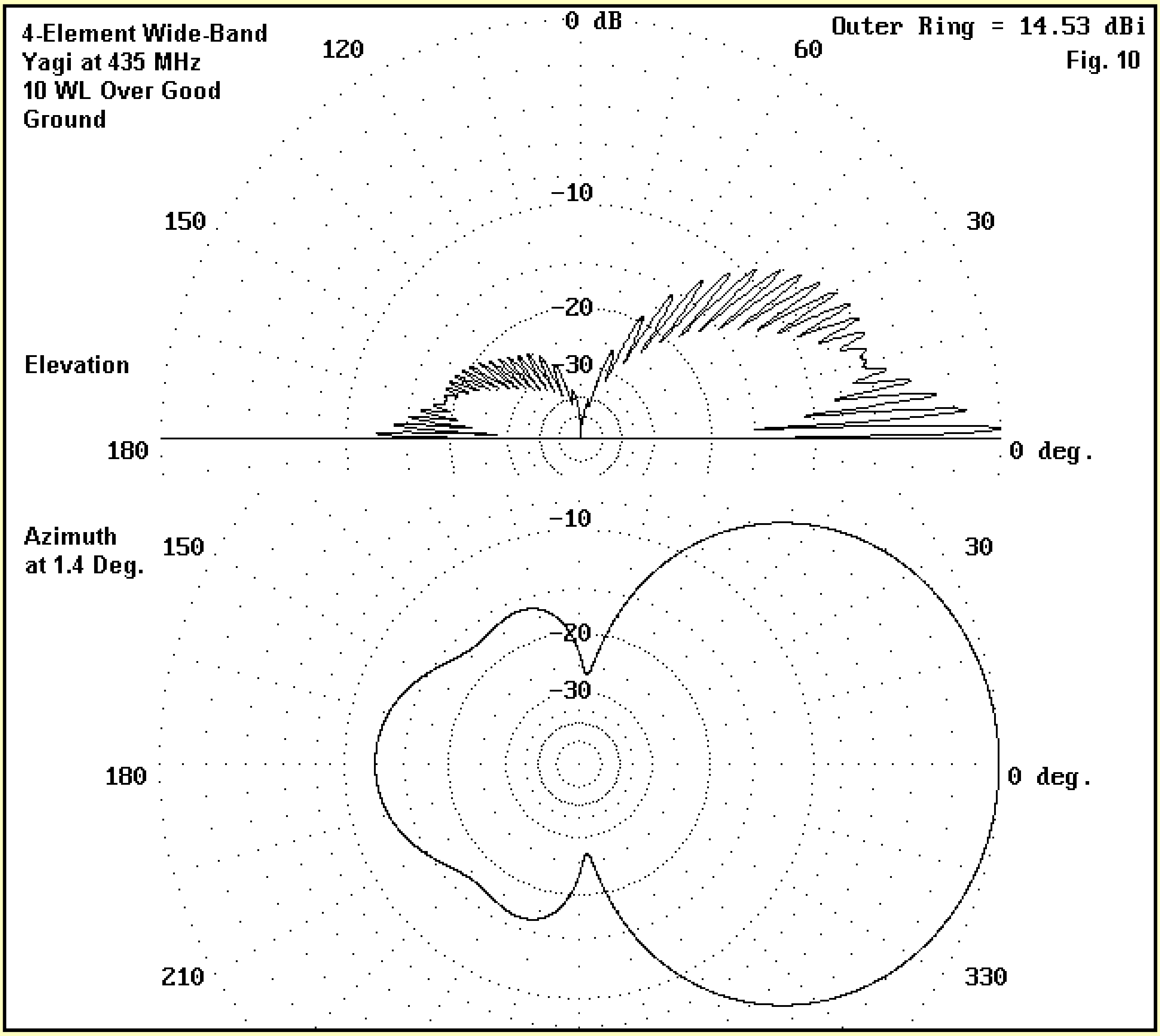


Fig. 10 shows the elevation and azimuth patterns for the 4-element Yagi at 435 MHz. The azimuth pattern is taken at an elevation angle of 1.4 degrees to match the strongest lobe from the elevation pattern. Of special note for those who have not compared Yagis in horizontal and vertical positions is the wider beamwidth for the vertical antenna--about 82 degrees between -3 dB (half-power) points. As well, the rear lobe structure differs considerably from that of the antenna when set up horizontally.

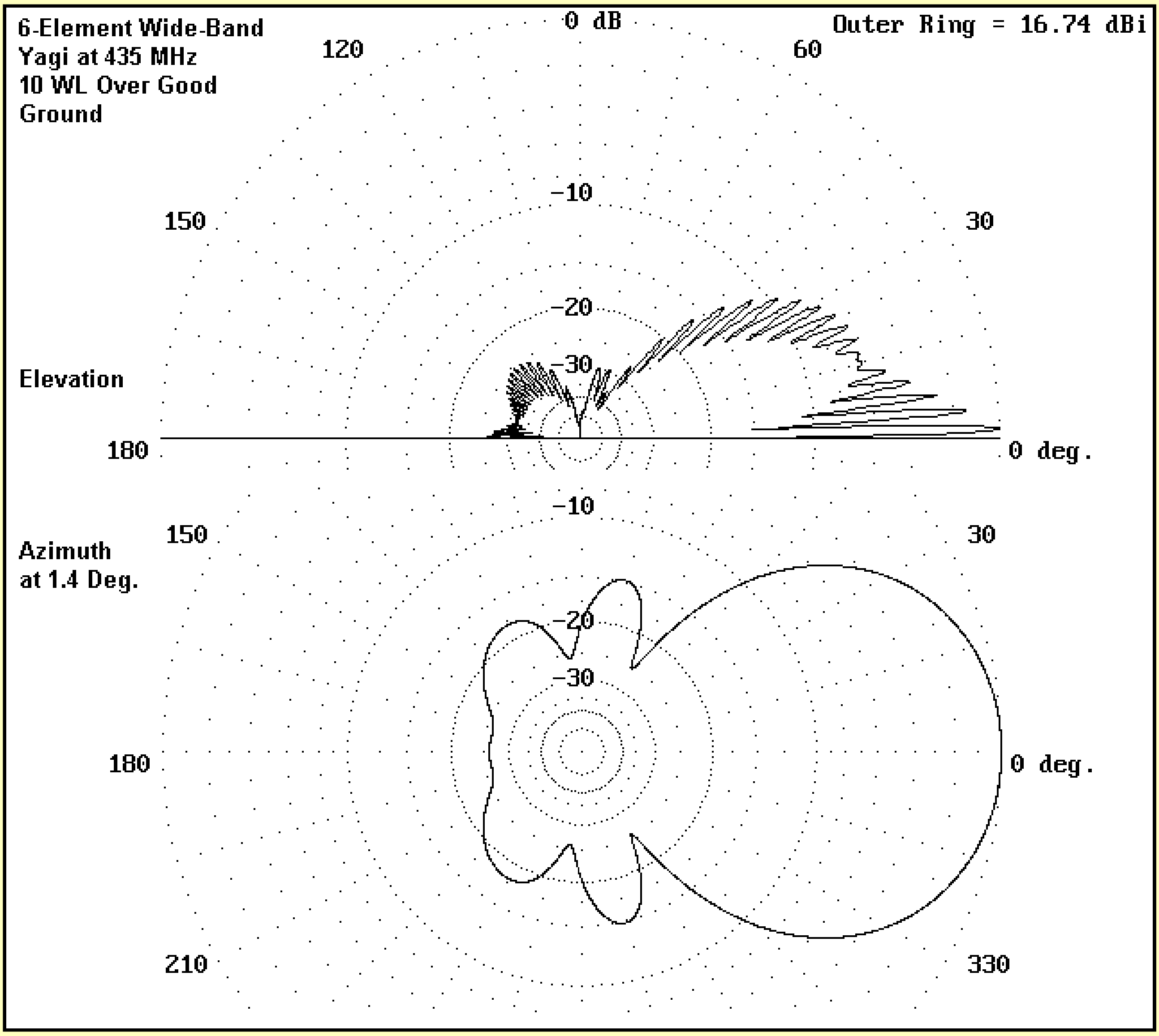


Fig. 11 shows a similar situation for the 6-element Yagi at the same frequency. The longer antenna has a beamwidth of about 60 degrees. Although the 180-degree front-to-back ratio is the same as for the antenna set up horizontally (see **Fig. 8**), the overall front-to-rear performance is reduced. The difference is largely a function of the ability of the element end geometry to limit lobe formation to the sides in the horizontal position. When placed vertically, the side lobe formation is not limited by element ends and is consequently larger in most cases.

Nonetheless, small wide-band utility Yagis with reasonable patterns and excellent 50-Ohm SWR performance may have a place in some station operations. Wide-band designs can be obtained if one is willing to use larger diameter elements than is conventional for Yagis in the 420-450 MHz band. Application of OWA principles is not limited to a single set of design goals, as the variations between the two designs shown here illustrate.

Next time, we shall look into the design of an 8-element Yagi of equal SWR performance. Since 8-elements approaches the border of numerous present designs for which the number of elements is somewhat optional according to one's desire for gain, we shall also look into a couple of these designs to see whether we really need to apply OWA principles or can use something that already exists.

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