

Wide-Band Utility Yagis for 420-450 MHz

2. An 8-Element Model

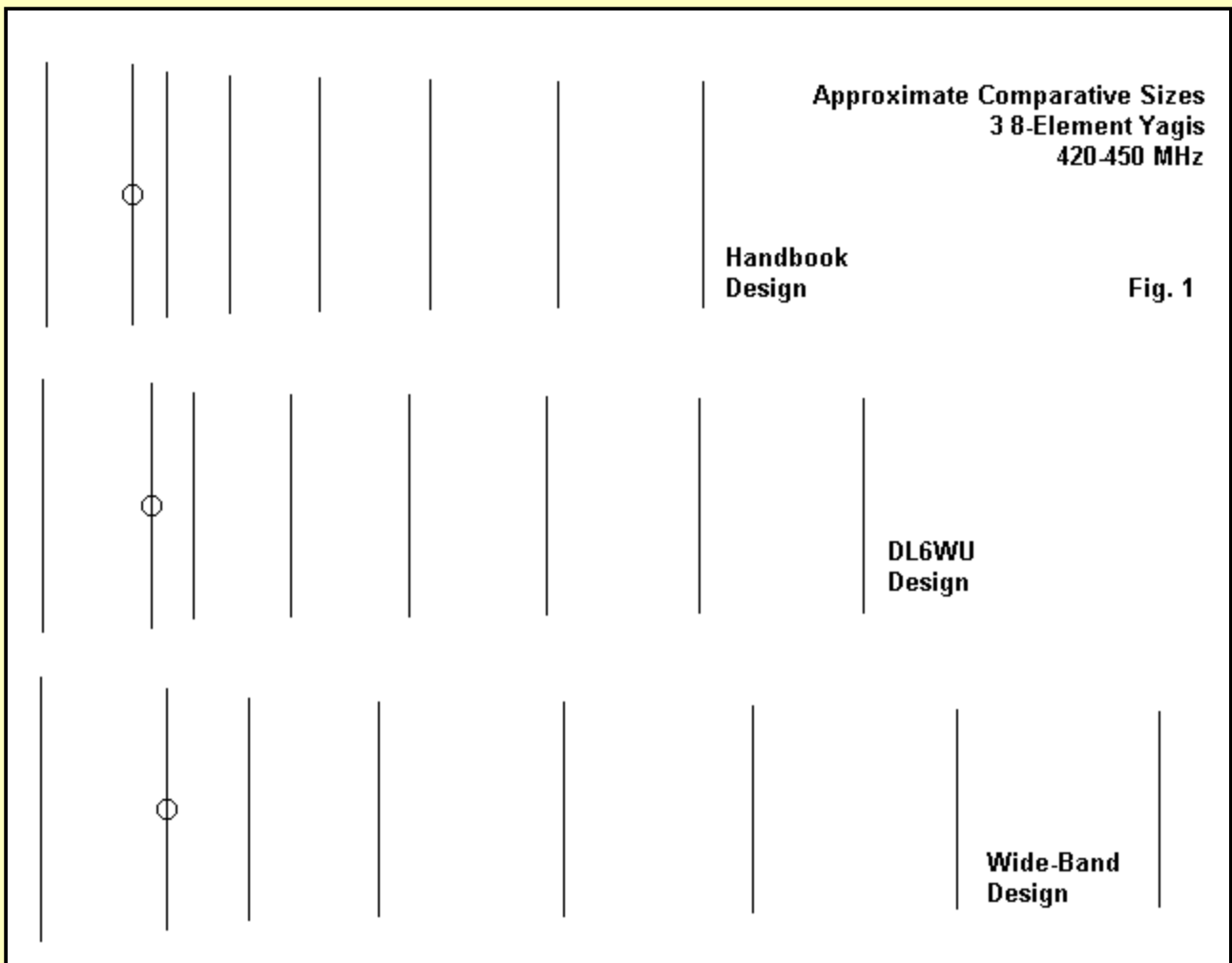
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In our last design adventure, we examined a pair of wide-band Yagis for the 420-450 MHz band. The 4- and 6-element designs used 0.5" (12.7 mm) diameter elements and some OWA principles of spacing for the reflector, driver, and first director to obtain some reasonable operating characteristics across the passband. The chief goal of having worthy gain and a 50-Ohm SWR that never exceeds 1.3:1 from 420 to 450 MHz was achieved in both cases, although the design goals of each model varied somewhat. Either of these small Yagis might serve well as a utility antenna for any purpose for which the gain level might be suitable. The 4-element beam was under 16" (400 mm) long (exclusive of end-mounting boom extensions), while the 6-element version was just over 33" (862 mm) long.

In this episode, I want to turn attention to the next step along the way: an 8-element Yagi having reasonable gain for its boom length and meeting the 50-Ohm SWR goal of under 1.3:1 across the passband. In this instance, I shall return to the goal of having a relatively smooth gain curve, even if the cost is a less even front-to-back ratio.

The 8-element "question" is complicated by the fact that this size Yagi sits on the borderline between a utility antenna and a "serious" antenna, that is, an antenna designed for some specific purpose. Therefore, we find numerous designs for 8-element Yagis. The question is this: do any of them meet the requirements without need for redesign? I would not suggest for a moment that I have seen every design in this category. However, I can note a couple of design directions that are useful for comparison.

I shall look at three designs: a typical "Handbook" design, a DL6WU design, and the final half-inch element wide-band design. For reference, their relative sizes appear in **Fig. 1**.



A "Handbook" 8-Element Design

There are numerous design sequences that have emerged from various types of calculations and computer programs. One such "Handbook" design that covers 432-MHz designs from a few to very many elements will be our first subject. I choose it because it is typical of many such designs. What typical means will appear presently. For the moment, typical will simply mean that it uses 3/16" (0.1875" or 4.76 mm) element diameters. First, the dimensions.

"Handbook" 8-Element Yagi Dimensions

Element	Length		Spacing From Reflector	
	Inches	mm	Inches	mm
Reflector	13.39	340	-----	-----
Driver	13.15	334	4.09	104.0
Dir. 1	12.40	315	5.75	146.0
Dir. 2	12.05	306	8.82	224.0
Dir. 3	11.77	299	13.07	332.0
Dir. 4	11.61	295	18.35	466.0
Dir. 5	11.46	291	24.49	622.0
Dir. 6	11.38	289	31.42	798.0

If you looked at the first article in this series, you will note that the boom length is shorter than that of the 6-element wide-band beam (33.94" or 862 mm). As well, if you have digested Jim Lawson's classic study of Yagis, you will expect that this 8-element beam may not have exceptionally high gain for the number of elements. The NEC-4 model of this antenna turns up the following performance numbers.

Frequency and Parameter	Calculated Value
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420 MHz

Free-Space Gain dBi 11.59
Front-to-Back dB 19.53
Feed Z (R +/- jX) 22.9 - j 7.1
50-Ohm SWR 2.235

425 MHz

Free-Space Gain dBi 11.79
Front-to-Back dB 26.59
Feed Z (R +/- jX) 25.2 + j 3.3
50-Ohm SWR 2.000

430 MHz

Free-Space Gain dBi 11.91
Front-to-Back dB 22.01
Feed Z (R +/- jX) 33.7 + j11.8
50-Ohm SWR 1.623

435 MHz

Free-Space Gain dBi 11.89
Front-to-Back dB 16.90
Feed Z (R +/- jX) 43.7 + j 2.3
50-Ohm SWR 1.160

440 MHz

Free-Space Gain dBi 11.69
Front-to-Back dB 22.05
Feed Z (R +/- jX) 22.1 - j 2.9
50-Ohm SWR 2.277

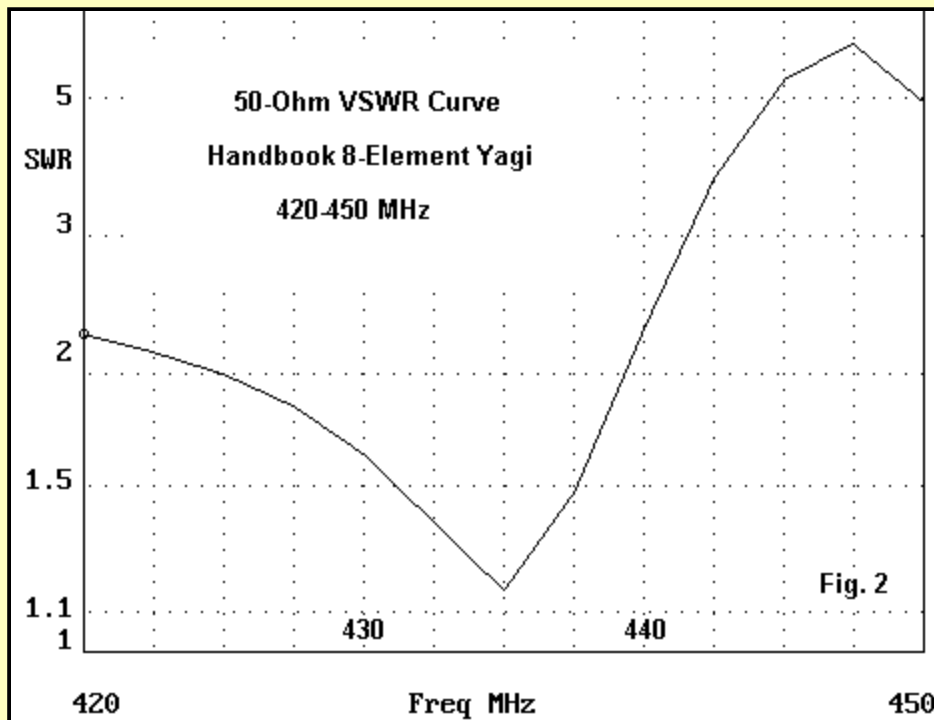
445 MHz

Free-Space Gain dBi 11.30
Front-to-Back dB 15.82
Feed Z (R +/- jX) 10.2 + j15.5
50-Ohm SWR 5.395

450 MHz

Free-Space Gain dBi 10.84
Front-to-Back dB 20.12
Feed Z (R +/- jX) 15.2 + j34.0
50-Ohm SWR 4.903

Clearly, the antenna is not designed for full coverage of the band. Instead, it is designed for a relatively small portion of the band, if we use a direct feed for the driver. **Fig. 2** provides the 50-Ohm SWR curve, which reveals that less than half the band can be covered with under 2:1 SWR. The region available (about 425 MHz to 439 MHz) generally corresponds to the region of peak antenna performance. The element length tapers as one moves forward from the reflector to the front end is one of the give-aways that this is a fairly narrow-band design by nature. Forward of the reflector, all of the elements are longer than any of those on designs that we have so far examined.



These notes are not intended in any way to denigrate the design, which I think is quite good for the category of antenna involved. For a short-boom narrow band design, it achieves its goals well, with a good front-to-back ratio in the region of peak gain. Nevertheless, like many other designs of its ilk, it will not satisfy the criteria set up for this exercise.

A Modified DL6WU 8-Element Design

Guenter Hoch, DL6WU, one of the pioneers in the mathematical design of UHF Yagis, remains the premier designer of wide-band Yagis for the 432-MHz band. His designs have withstood the test of time and amateur experimentation/modification. Granted, one can achieve narrow-band gain with shorter booms than he used, but exceeding his gain vs. bandwidth "product" is a major challenge.

We often think of DL6WU designs as very long-boom affairs with more elements than anyone except the builder wishes to count. However, one of the advantages of his log-based designs is the fact that--within reason--one can chop off almost any number of directors and still end up with a Yagi of very respectable wide-band performance. From a 31-element design, I have in past design exercises derived numerous sub-designs down to about 12 elements, each with similar coverage of the band. However, in this case, we shall reduce the total element count to 8. The resulting design, using 4 mm diameter elements, has the following dimensions.

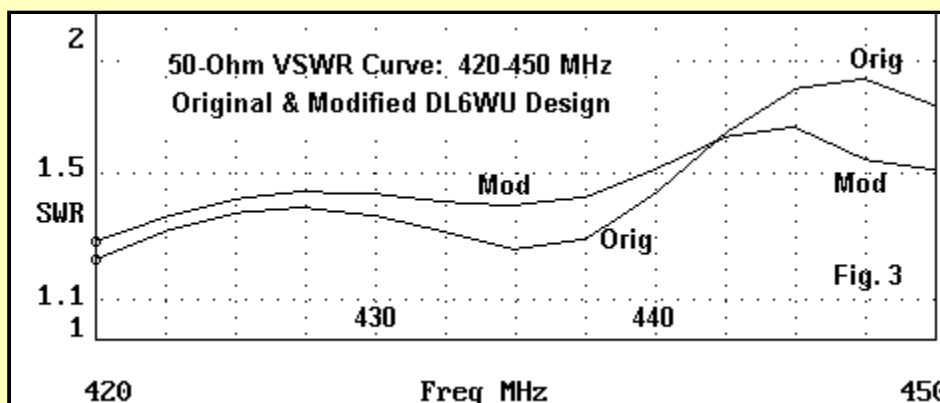
DL6WU 8-Element Wide-Band Yagi Dimensions

Element	Length		Spacing From Reflector	
	Inches	mm	Inches	mm
Reflector	13.41	340.6	-----	-----
Driver	12.99	330	5.46	138.8
Dir. 1	11.97	304	7.51	190.8
Dir. 2	11.78	299.2	12.43	315.8
Dir. 3	11.64	295.6	18.31	465.0
Dir. 4	11.50	292.2	25.13	638.4
Dir. 5	11.39	289.2	32.79	832.8
Dir. 6	11.28	286.4	40.98	1040.9

Director 5 already exceeds the boom length of the "Handbook" design. The DL6WU element taper is slightly more severe than that of the shorter beam. Let's look at the antenna's modeled performance.

Frequency and Parameter	Calculated Value
420 MHz	
Free-Space Gain dBi	12.18
Front-to-Back dB	13.87
Feed Z (R +/- jX)	58.1 - j 9.9
50-Ohm SWR	1.267
425 MHz	
Free-Space Gain dBi	12.34
Front-to-Back dB	13.93
Feed Z (R +/- jX)	59.1 - j16.0
50-Ohm SWR	1.401
430 MHz	
Free-Space Gain dBi	12.48
Front-to-Back dB	14.57
Feed Z (R +/- jX)	49.7 - j17.8
50-Ohm SWR	1.426
435 MHz	
Free-Space Gain dBi	12.64
Front-to-Back dB	16.44
Feed Z (R +/- jX)	38.6 - j 8.6
50-Ohm SWR	1.381
440 MHz	
Free-Space Gain dBi	12.79
Front-to-Back dB	20.06
Feed Z (R +/- jX)	35.0 + j 9.0
50-Ohm SWR	1.513
445 MHz	
Free-Space Gain dBi	12.70
Front-to-Back dB	19.08
Feed Z (R +/- jX)	52.9 + j26.9
50-Ohm SWR	1.681
450 MHz	
Free-Space Gain dBi	12.05
Front-to-Back dB	14.18
Feed Z (R +/- jX)	52.1 - j21.1
50-Ohm SWR	1.510

Considering the boom length and operating bandwidth, the DL6WU would be quite hard to beat. It has a 50-Ohm SWR curve that remains below 1.7:1 all across the band, with a total gain variation of only about 0.7 dB. The front-to-back ratio varies by about 6 dB. The model used here has one variation on the original from which it is derived. Director 1 was increased in length by about 1.2 mm in order to smooth the SWR response. As **Fig. 3** reveals, the original SWR curve showed an unnecessary peak in the 445 to 440 MHz region. Lengthening the first director reduced this peak at a very slight cost in the SWR in the lower 2/3 of the band.



The trick to maintaining an acceptable SWR across the band is keeping the total change of feedpoint resistance and reactance under control. The DL6WU design manages to hold the change of resistance to about 14 Ohms. However, the reactance changes by about 48 Ohms across the band. Some improvement may be possible if we consider the numbers for the 4- and 6-element designs. The 4-element design, which stressed a smooth gain curve over front-to-back ratio, showed a resistance range of about 15 Ohms with a reactance range of only 9 Ohms. The 6-element design, which strove for a better balance of gain and front-to-back ratio, showed a resistance range of only 6.2 Ohms, but a reactance range of 22 Ohms. It would appear that some improvement over the DL6WU design is possible in terms of feedpoint impedance control.

If a slight improvement in feedpoint impedance were the only improvement to be obtained, trying to advance on the DL6WU design might be an exercise in futility. Indeed, the DL6WU design would make an excellent thin-element utility antenna for many, if not most purposes. Enlarging the elements to 0.5" (12.7 mm) is non-standard practice to begin with. As well, increasing element diameters will also involve lengthening the boom further in order to achieve something close to the most effective inter-element coupling. Nevertheless, as a design exercise, it may be worth going through the process.

An 8-Element Wide-Band Yagi Design

The resulting 8-element wide-band design, using 0.5" diameter elements, has the following dimensions.

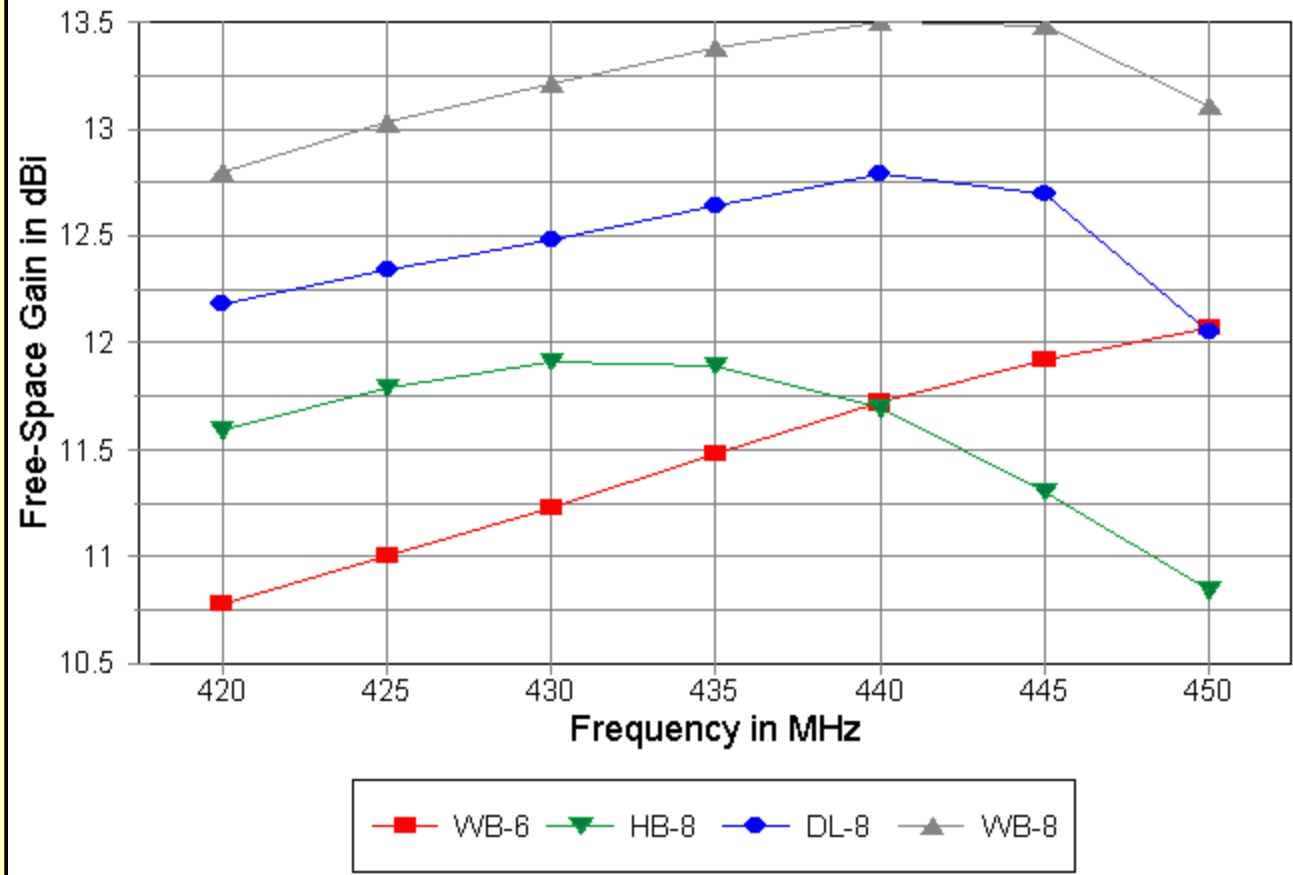
An 8-Element Wide-Band Yagi Dimensions

Element	Length		Spacing From Reflector	
	Inches	mm	Inches	mm
Reflector	13.46	342	-----	-----
Driver	12.28	312	5.95	151.0
Dir. 1	11.26	286	9.90	251.0
Dir. 2	10.91	277	16.14	410.0
Dir. 3	10.91	277	24.96	634.0
Dir. 4	10.47	266	34.06	865.0
Dir. 5	10.16	258	43.74	1111.0
Dir. 6	9.96	253	53.43	1357.0

For the extra foot of boom length, the antenna does achieve a usable gain advantage. **Fig. 4** shows the gain curves of the present antenna (at the top), with the DL6WU antenna (just below). The two curves are reasonably congruent. The remaining curves for the "Handbook" narrow-band design and the 6-element design--of similar boom lengths--show the next echelon down of gain values.

432 MHz 6- & 8-Element Yagis Free-Space Gain

Fig. 4



The gain and front-to-back ratio of the longer design are fairly well controlled, as shown in **Fig. 5**. Like the DL6WU design, the gain varies by only 0.7 dB across the band. The front-to-back variation is about 6 dB.

432 MHz 8-Element Wide-Band Yagi Free-Space Gain & Front-to-Back Ratio

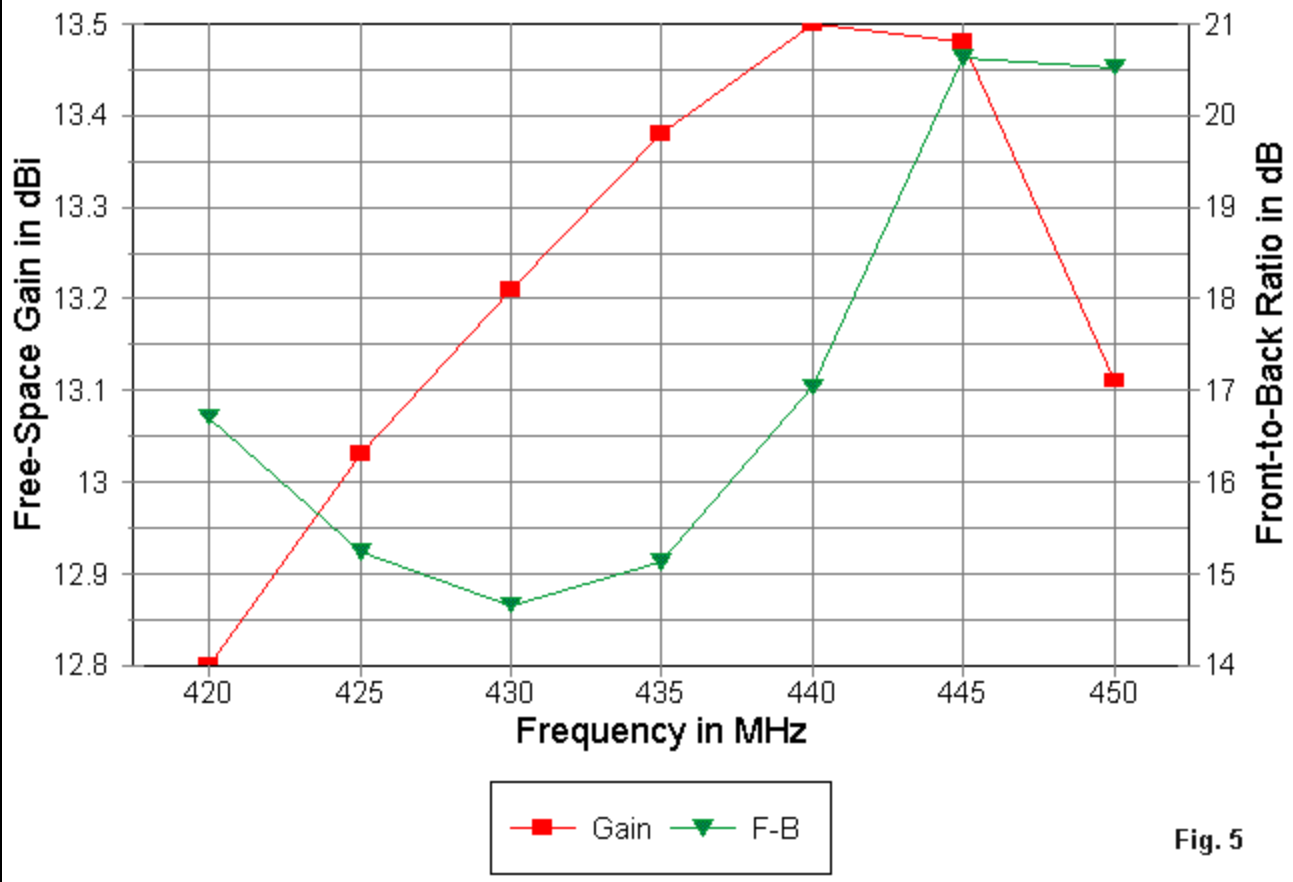


Fig. 5

As with all designs for this frequency range, there are differences between NEC-4 and NEC-2 results: about a 5 MHz displacement in curves due to not using the EK command in NEC-2. **Fig. 6** shows the 50-Ohm SWR curves for both NEC-2 and NEC-4 models of the wide-band design. The upturn in SWR for the NEC-4 model occurs above 450 MHz and thus does not appear on the graph. The NEC-4 curve remains below 1.31:1 across the band.

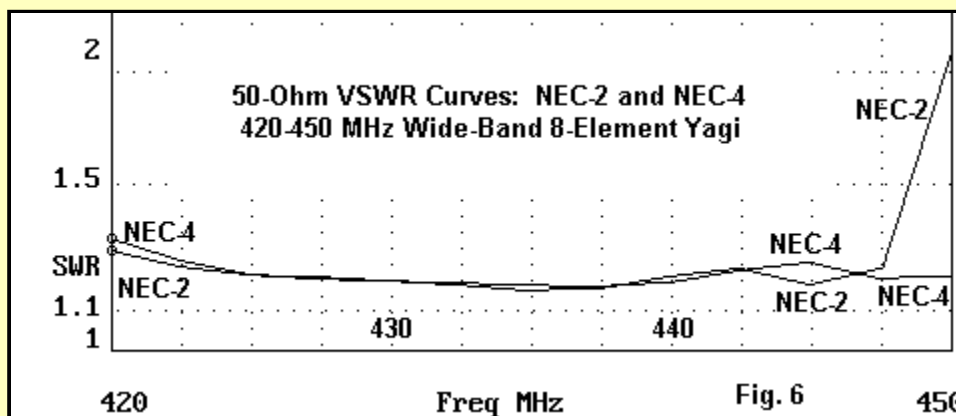


Fig. 6

The control of the feedpoint resistance and reactance is presented in **Fig. 7**. The total resistance range is about 16 Ohms, while the reactance range is about 19 Ohms. In general, where the resistance depart most widely from 50 Ohms, the reactance value is quite low, while the extremes of reactance values occur with the resistance quite close to 50 Ohms.

432 MHz 8-Element Wide-Band Yagi Feedpoint Resistance and Reactance

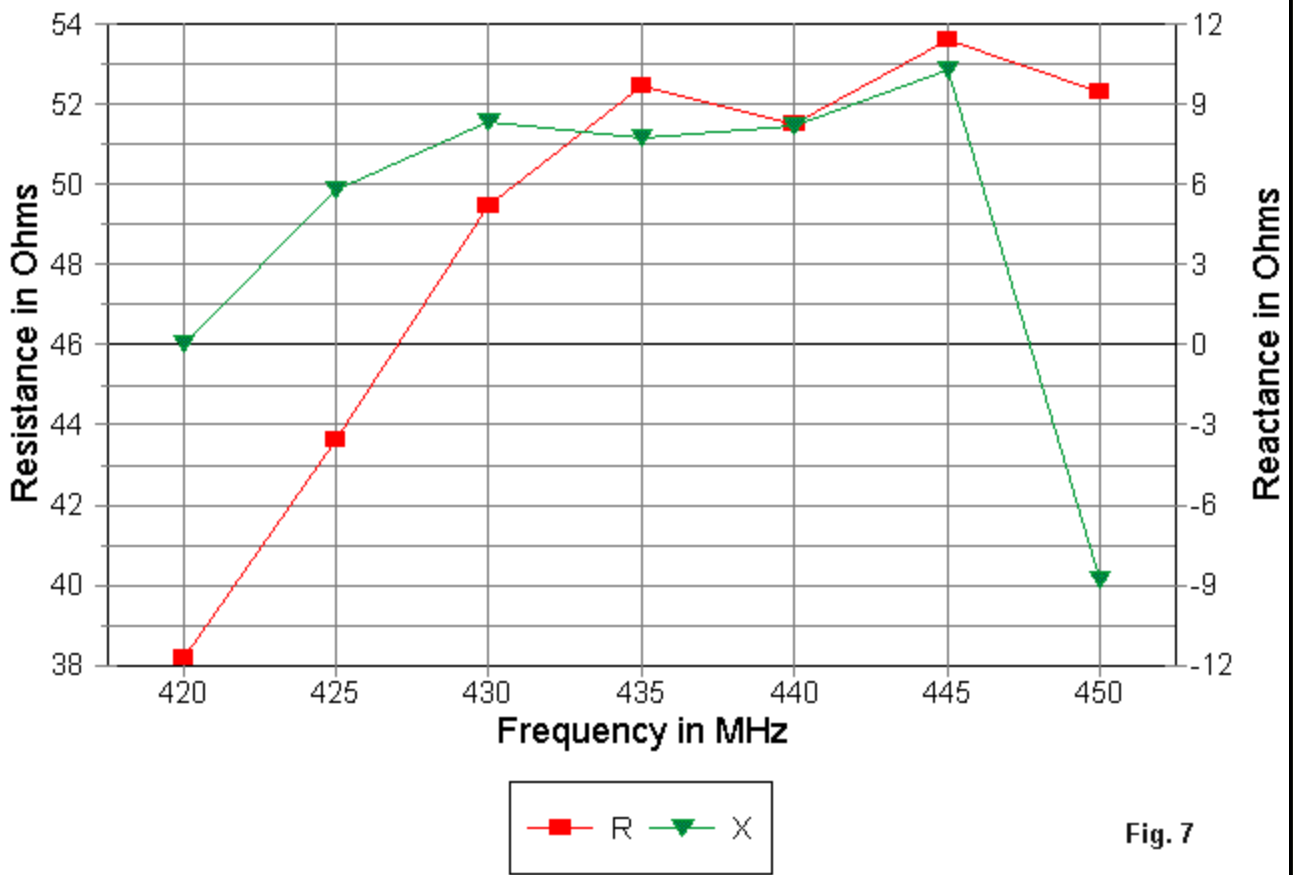


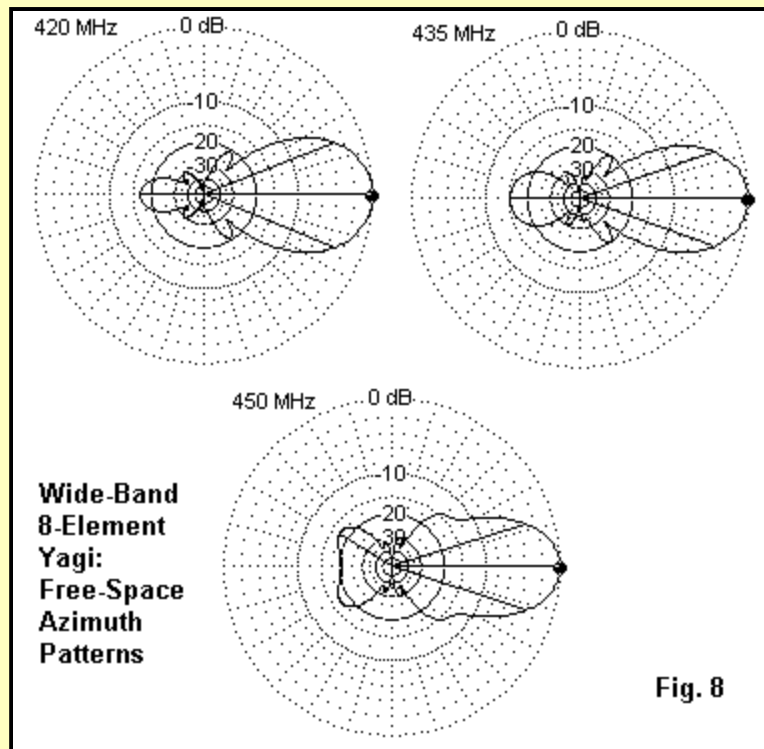
Fig. 7

For the record, here are the modeled (NEC-4) performance figures in tabular form.

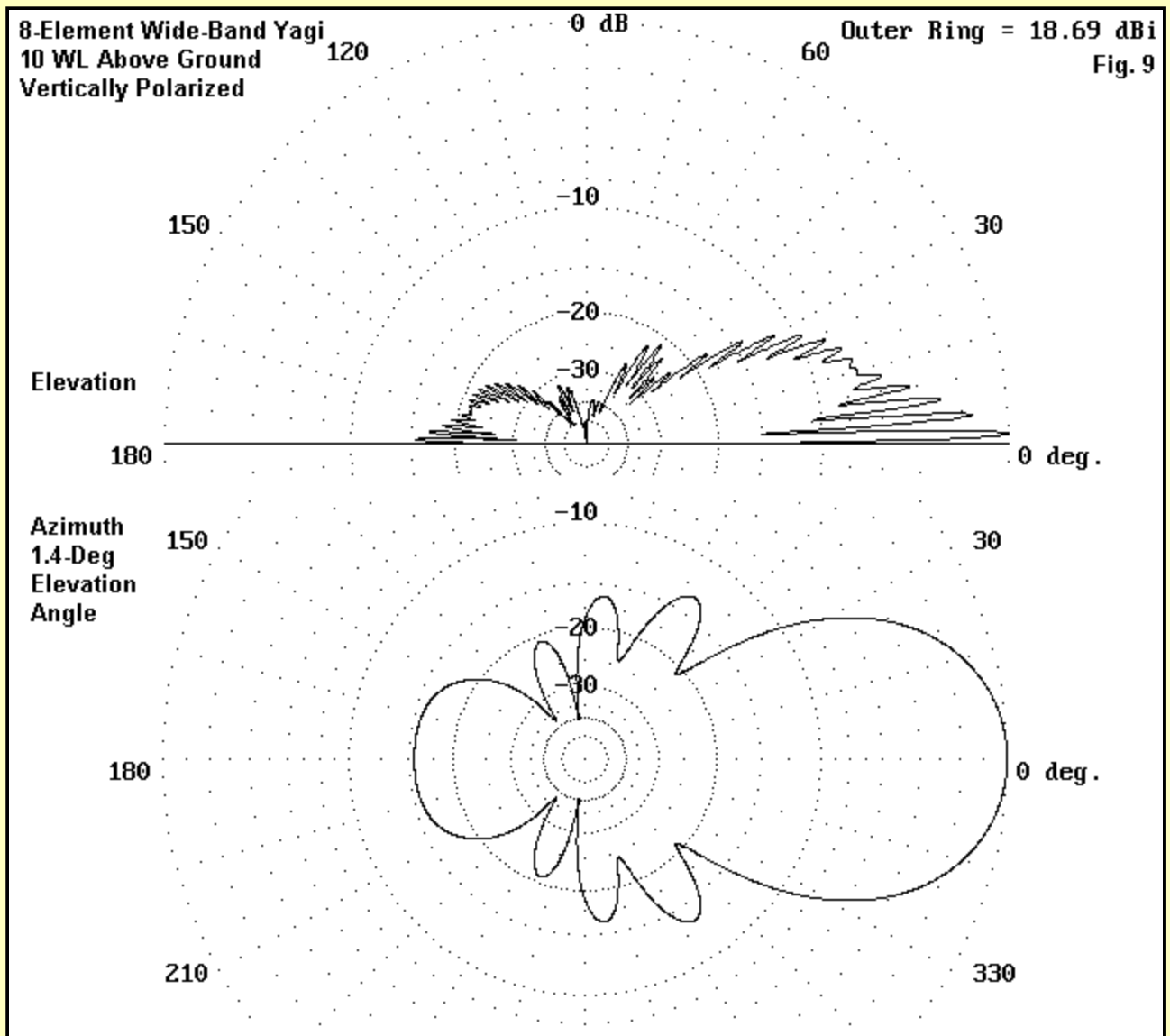
Frequency and Parameter	Calculated Value
420 MHz	
Free-Space Gain dBi	12.80
Front-to-Back dB	16.71
Feed Z (R +/- jX)	38.2 + j 0.0
50-Ohm SWR	1.309
425 MHz	
Free-Space Gain dBi	13.03
Front-to-Back dB	15.24
Feed Z (R +/- jX)	43.6 + j 5.8
50-Ohm SWR	1.202
430 MHz	
Free-Space Gain dBi	13.21
Front-to-Back dB	14.66
Feed Z (R +/- jX)	49.5 + j 8.3
50-Ohm SWR	1.183
435 MHz	
Free-Space Gain dBi	13.38
Front-to-Back dB	15.13
Feed Z (R +/- jX)	52.5 + j 7.7
50-Ohm SWR	1.171
440 MHz	
Free-Space Gain dBi	13.50
Front-to-Back dB	17.04

Feed Z (R +/- jX)	51.5 + j 8.2
50-Ohm SWR	1.178
445 MHz	
Free-Space Gain dBi	13.48
Front-to-Back dB	20.63
Feed Z (R +/- jX)	53.6 + j10.3
50-Ohm SWR	1.234
450 MHz	
Free-Space Gain dBi	13.11
Front-to-Back dB	20.53
Feed Z (R +/- jX)	52.3 - j 8.8
50-Ohm SWR	1.194

To give a sense of the pattern shapes, when the antenna is horizontally positioned, **Fig. 8** shows the band edge and mid-band free-space azimuth patterns for the wide-band design. The evolution of side lobe development--both forward and rearward--is clearly evident from the patterns.



When used vertically positioned, the antenna patterns deviate significantly from those just shown. Therefore, **Fig. 9** positions the antenna vertically with the boom 10 wavelengths above ground (about 23'). The azimuth pattern is taken at an elevation angle of 1.4 degrees, corresponding to the take-off or elevation angle of maximum radiation.



Conclusions

The wide-band design has been allowed to speak for itself in terms of performance. Whether it amounts to an advance on the DL6WU design depends largely on one's perspective. The DL6WU antenna has a bit lower gain in accord with its shorter boom length. The front-to-back values vary in the same amount but in a different pattern from the corresponding variations for the wide-band design. The DL6WU SWR values are not as flat as those of the wide-band design, but they do not exceed 1.7:1. Finally, the DL6WU design uses a common element diameter that is familiar to most beam builders for the 420-450 MHz band.

The wide-band Yagi has more gain and a flatter SWR pattern. However, it also requires a longer boom and fatter elements. Whether the benefits of the wide-band design are sufficient to override the requirement to rethink and redesign the mechanical aspects of constructing the beam is a user decision. I suspect that those who build beams as simply a means to operational goals may stick with the tried and true. Those who love to experiment with what may be possible in antenna performance may wish to develop construction techniques that one day might make fat elements as common on 432 MHz as thin elements currently are.

Nevertheless, the exercise has been useful in comparing Yagi types for the 420-450 MHz region. If the 8-element design proves insufficiently beneficial to warrant its use as a wide-band utility antenna for the band, perhaps the smaller 4- and 6-element versions may find a niche. In any event, these design endeavors have shown that it is possible to develop Yagis with reasonable performance figures that can cover all of the band with a 1.3:1 or better 50-Ohm SWR.



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