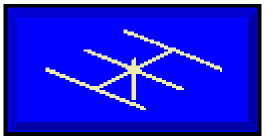

Appreciating DL6WU Wide-Band Long-Boom Yagi Design
Some Preliminary Notes

L. B. Cebik, W4RNL

The design of long-boom, high performance Yagis for the VHF region has seem innovations by a number of very notable designers. The designs of Rainer Bertelsmeier, DJ9BV, tend to group directors on 4s, while the designs of Joe Reisert, W1JR, for HyGain found favor in director pairs. For narrow-band, high gain Yagis with the fewest elements for a given boom length, Lief Asbrink, SM5BSZ, has provided some outstanding designs. More traditionally tapered are the designs of Steve Powlishen, K1FO, as found in any recent edition of *The ARRL Antenna Book*.

Underlying all of these Yagi design efforts is the work of Guenter Hoch, DL6WU. His pioneering designs span the 80s and 90s, beginning with a piece on *UKW-Berichte* in 1982 and culminating in his chapter (7) for the RSGB volume, *The VHF/UHF DX Book*, edited by Ian White, G3SEK. (The volume is published for RSGB by DIR Publishing, Ltd.) Referring to a 23 cm design series by DL6WU, DJ9BV (*DUBUS*, 2/1994, p.46) notes that for the home builder, these designs are a premium choice, unequaled in terms of gain, pattern, match and broadband performance. Whatever the band from 144 MHz to 1296 MHz, DL6WU designs form the touchstone to which all other designs tend to compare themselves.

To say that DL6WU designs are broad-banded is an understatement. With proper care, a long-boom Yagi from the 432-MHz series can cover all of the band with adequate performance in terms of gain, side- and rear-lobe size, and SWR. One can adapt them for either single element drive at 50 Ohms or folded-dipole drive for 200 Ohms. This is no mean accomplishment for a band whose bandwidth is 7% of its center frequency.

However, the notes that I find on the DL6WU designs tend to focus on 432-MHz performance to the exclusion of the total range of performance figures. For example, both the antenna chapter and the 432-MHz chapter of the RSGB book tend to note that certain Yagi lengths (where length can be expressed either in terms of boom length or in terms of the number of elements) have better front-to-back ratios. Although this is true at the 432-MHz design frequency, it is not necessarily true of the entire operating passband for the antenna. Moreover, the individual who wishes to build a DL6WU design has some freedom in tailoring the array characteristics (whatever the boom length) for the desired primary operating sub-range within the band.

Therefore, these notes represent a preliminary appreciation of the DL6WU design, seeking to understand a little better the wide-band nature of the designs. However, finding a starting point is not a wholly simple matter. DL6WU design appear in generally 2 formats: tables and graphs found in books and articles and software-generated designs. Since Hoch's designs evolved over the years, the outputs from different sources do not always agree in every detail.

For this exercise, I have resorted to the 432-MHz designs found in Chapter 10 of the RSGB book. I have modified them only to the extent of adjusting the driver and first director lengths for the best operating bandwidth, and these adjustments are very small. Element spacing and lengths (with only the two noted exceptions) remain very precisely those specified on page 10-35 of the volume. Selecting these dimensions as a basis for the exploration at least provides a consistent beginning.

The exploratory vehicle is NEC-4, which appears to be slightly at variance and presumably more accurate than NEC-2 at 432 MHz. (The actually variance for this set of models is very slight. The variance shows up more fully with larger-diameter elements and a higher segment count. Hence, if available, the use in NEC-2 of the EK extended thin-wire kernel command would be helpful, especially if the segment length to diameter ratio falls under 4:1.) The use of computer modeling software that is adequate to the task holds several advantages over range testing. For example, the test conditions are subject to no variations among models. One can place the arrays in free space and check any and all major parameters for comparative purposes. The condition of the tests is that the elements are presumed to be free, clear, insulated, and isolated from any effects of a conductive boom material. There are numerous resources for discovering what adjustments are required for placing elements near to or through a metallic boom.

A second advantage of computer modeling is access to data not usually measured or measurable in range tests. One particular example of special note for this investigation is the relative current magnitude and phase angle along the elements, with special reference to the current at the center of the driver and of the first director. We shall have occasion to examine these currents for several sample arrays.

A full study of the DL6WU wide-band Yagi designs would sample each array in the sequence. This study is only preliminary in limiting itself to 3 samples: 12, 19, and 26 elements (10, 17, and 24 directors). Interestingly, there is--relative to the 32-element limit in the RSGB book chart--a boom length progression as well as the addition of 7 elements per step. If we assign the 32-element version a length of 1.0, then the selected arrays fall near the 0.25, 0.50, and 0.75 marks. This phenomenon results from the fact that for directors 13 onward, the director spacing is a standard 0.4 wavelength.

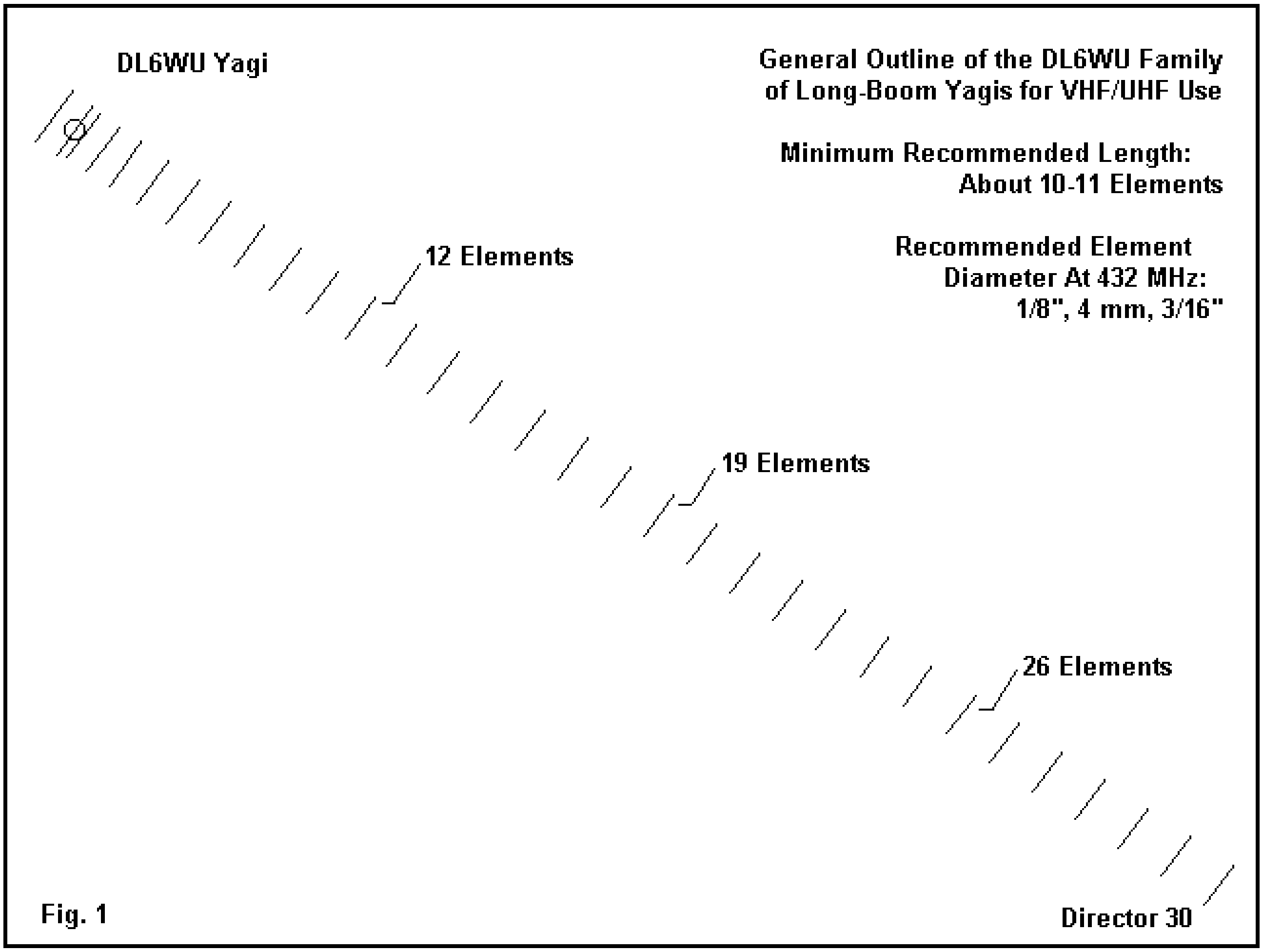

Fig. 1

Fig. 1 shows the outline of all 32 elements, with the lengths of the samples that we shall scan marked for reference. The following table presents the dimensions in millimeters and in wavelengths. The elements are 4-mm diameter aluminum for all models. One characteristic of DL6WU designs is the use of relatively large-diameter elements. 4 mm at 432 is equivalent to nearly 0.5" at 2 meters.

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32-Element DL6WU Yagi for 432 MHz (with 12, 19, and 26 element versions derived)

Element	Element Length		Cumulative Spacing		
	mm	wl	mm	wl	
Reflector	340.6	0.491	---	---	
Driver	330.0	0.476	138.8	0.200	
1	301.6	0.435	190.8	0.275	
2	299.2	0.431	315.8	0.455	
3	295.6	0.426	465.0	0.670	
4	292.2	0.421	638.4	0.920	
5	289.2	0.417	832.8	1.200	
6	286.4	0.413	1040.9	1.500	
7	284.2	0.410	1259.5	1.815	
8	282.2	0.407	1488.6	2.145	
9	280.4	0.404	1728.0	2.490	
10	278.8	0.402	1977.8	2.850	12-Element
11	277.4	0.400	2238.0	3.225	
12	276.0	0.398	2508.7	3.615	
13	274.8	0.396	2786.3	4.015	
14	273.8	0.395	3063.9	4.415	

15	**272.8**	**0.393**	**3341.4**	**4.815**	
16	**271.8**	**0.392**	**3619.0**	**5.215**	
17	**270.8**	**0.390**	**3896.6**	**5.615**	**19-Element**
18	**270.0**	**0.389**	**4174.2**	**6.015**	
19	**269.2**	**0.388**	**4451.8**	**6.415**	
20	**268.4**	**0.387**	**4729.4**	**6.815**	
21	**267.6**	**0.386**	**5007.0**	**7.215**	
22	**267.0**	**0.385**	**5284.5**	**7.615**	
23	**266.2**	**0.384**	**5562.1**	**8.015**	
24	**265.7**	**0.383**	**5839.7**	**8.415**	**26-Element**
25	**265.0**	**0.382**	**6117.3**	**8.815**	
26	**264.5**	**0.381**	**6394.9**	**9.215**	
27	**263.9**	**0.380**	**6672.5**	**9.615**	
28	**263.3**	**0.379**	**6950.1**	**10.015**	
29	**262.8**	**0.379**	**7227.6**	**10.415**	
30	**262.3**	**0.378**	**7505.2**	**10.815**	

Note: Unnamed numbered elements are directors. Dimensions follow those listed in Chapter 10 of the RSGB volume, *The VHF/UHF DX Book*, edited by Ian White, G3SEK, except for the driver and first director lengths, which have been adjusted slightly for maximum bandwidth. See also Chapter 7 by Guenter Hoch, DL6WU. Element diameter is 4 mm (0.1575") (aluminum).

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Among the design notes for this family of arrays, we find reference to certain lengths having better front-to-back ratios than others, with the 14-15, 19-20, 24-25, and 30-31 element ranges being judged the best. Only one of our sample arrays falls within one of the best front-to-back ranges, the 19-element version. The 26-element array is close, but the 12 element array is well outside any of the favorable groupings. Indeed, the 12-element array is close to the minimum recommended length for any DL6WU array.

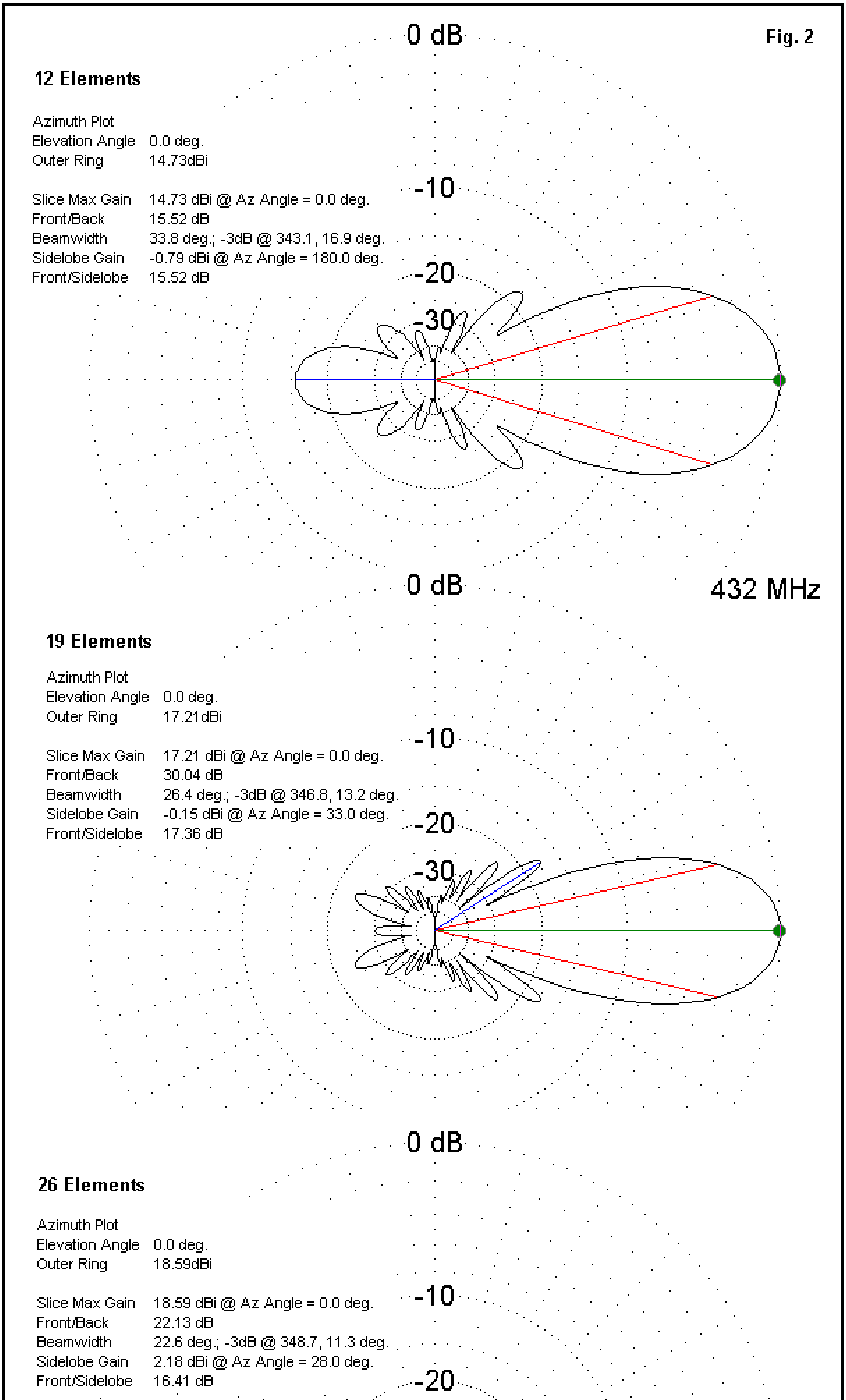

Fig. 2

12 Elements

Azimuth Plot	
Elevation Angle	0.0 deg.
Outer Ring	14.73dBi
Slice Max Gain	14.73 dBi @ Az Angle = 0.0 deg.
Front/Back	15.52 dB
Beamwidth	33.8 deg.; -3dB @ 343.1, 16.9 deg.
Sidelobe Gain	-0.79 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe	15.52 dB

19 Elements

Azimuth Plot	
Elevation Angle	0.0 deg.
Outer Ring	17.21dBi
Slice Max Gain	17.21 dBi @ Az Angle = 0.0 deg.
Front/Back	30.04 dB
Beamwidth	26.4 deg.; -3dB @ 346.8, 13.2 deg.
Sidelobe Gain	-0.15 dBi @ Az Angle = 33.0 deg.
Front/Sidelobe	17.36 dB

26 Elements

Azimuth Plot	
Elevation Angle	0.0 deg.
Outer Ring	18.59dBi
Slice Max Gain	18.59 dBi @ Az Angle = 0.0 deg.
Front/Back	22.13 dB
Beamwidth	22.6 deg.; -3dB @ 348.7, 11.3 deg.
Sidelobe Gain	2.18 dBi @ Az Angle = 28.0 deg.
Front/Sidelobe	16.41 dB

Fig. 2 presents the modeled free-space azimuth patterns and data for 432 MHz for each sample array. In tabular form, the data looks like this:

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Modeled Data for 3 Sample DL6WU Yagi designs at 432 MHz

Elements	**12**	**19**	**26**
Boomlength--wl	**2.850**	**5.615**	**8.415**
Boomlength--mm	**1978**	**3897**	**5840**
Boomlength--inches	**77.87**	**153.41**	**229.9**
Boomlength--feet	**6.49**	**12.78**	**19.16**
Gain: dBi	**14.73**	**17.21**	**18.59**
180-degree F-B: dB	**15.52**	**30.04**	**22.13**
Worst-case F-B: dB	**15.52**	**23.78**	**22.13**
Main-fwd sidelobe: dB	**17.71**	**17.36**	**16.41**
Hor. beamwidth: degrees	**33.8**	**26.4**	**22.6**
Feedpoint Z (R+/-jX Ohms)	**60.2-j11.4**	**57.8+j 6.6**	**50.2-j0.1**
50-Ohm SWR	**1.319**	**1.209**	**1.005**

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Besides the expected variations in gain in accord with boom length and the number of elements, the data also provide certain insights into the Yagi design operation, especially when taken in conjunction with the patterns in **Fig. 2**. The models generally confirm the thesis of the best array sizes for maximum front-to-back performance, at least in terms of the 180-degree front-to-back ratio. However, if we scan the entirety of the rear quadrants, we find that the worst-case front-to-back ratio does not differ by very much between the 19-element and the 26-element arrays.

Equally expected are the development of additional forward and rearward sidelobes with increasing boomlength. If we were to judge only from our three samples, then it would appear that the ratio of the main forward lobe to the strongest forward sidelobe decreases with boom length. However, it remains for further study to determine if, within the total range of possible arrays in the series, there are favored boom lengths where the forward-to-sidelobe ratio is maximum. DL6WU himself lists the average ratio as about 17 dB, with instructions for retuning the array should the ratio prove too much lower or too much higher than the average value. The note is perhaps indicative that the array series inventor himself did not fully appreciate the wide-band characteristics of his offspring.

General Wide-Band Properties of Sample DL6WU Yagis for the 432-MHz Band.

To sample the wide-band properties of the DL6WU arrays, I subjected the 3 test models to frequency sweeps. I extended the sweeps at the low end to 405 MHz, where 50-Ohm SWR just approaches or passes a 2:1 value. For these tests, all arrays use a single driver to achieve a 50-Ohm SWR. Folded dipole models set for a 200-Ohm reference impedance are certainly possible and, when properly constructed with adjustments to the driver and first director lengths and spacing, may provide an even wider operating bandwidth between 2:1 SWR values.

At the upper end of the band, the 2:1 SWR value appears between 452 and 456 MHz, depending on the particular array. I extended the sweep range to 460 MHz in order to reveal something of the seemingly erratic value swings for all parameters at this end of the band. For almost all operating parameters, the upper end of the frequency range is far more variable then the well-behaved lower end of the band.

As one might expect, the results of these sweeps reveal their data best in a series of graphs.

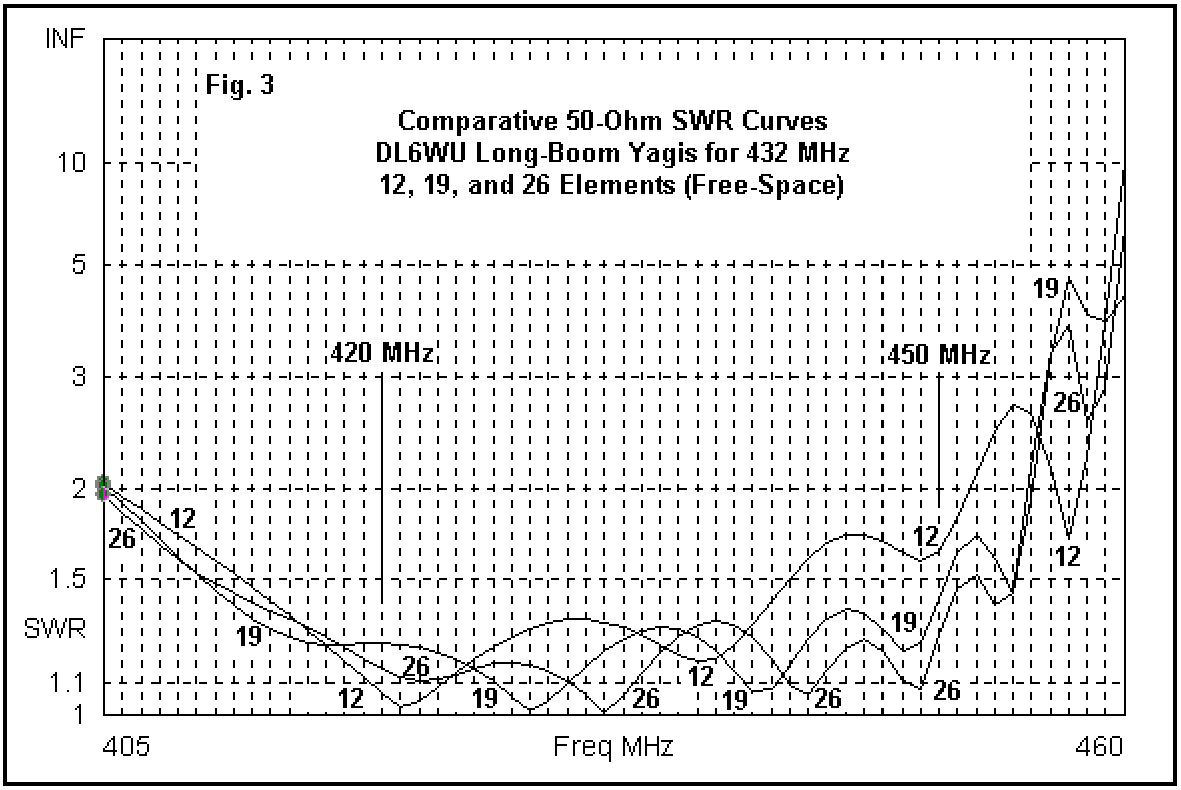
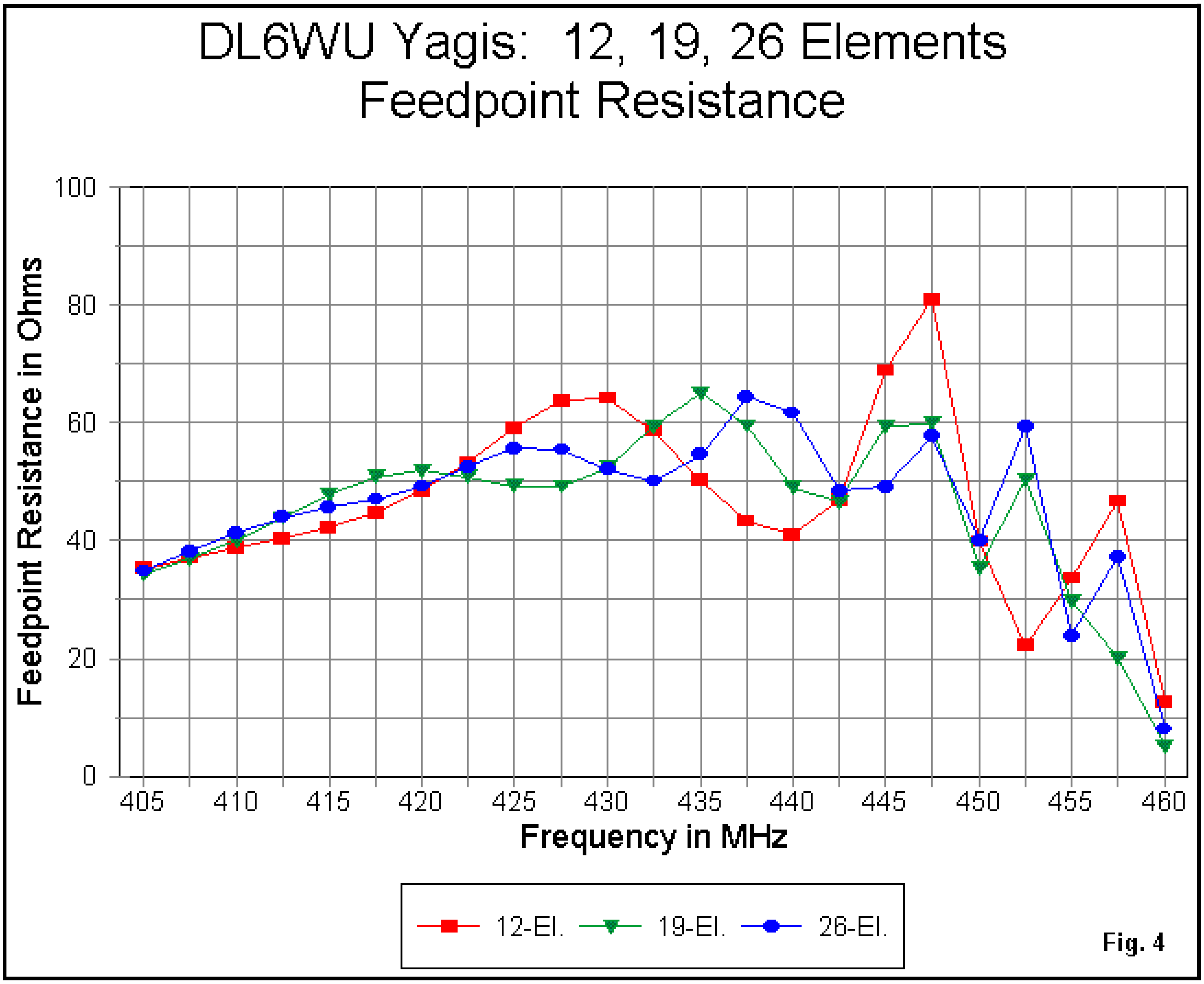


Fig. 3 presents the SWR curves in 1-MHz increments from 405 to 460 MHz for the 3 sample arrays. First impressions may limit themselves to seeing how well behaved the arrays are within the 420-450 MHz range. However, there is more to this graph than this simple impression. Note the number of SWR minima for each array. Within the band, the 12- and 19-element arrays have 3, while the 26-element array has 4. These are unusually large numbers, since most wide-band HF arrays show no more than 2. However, those arrays normally have far fewer than even 12 elements, and the number of possible minima seems to increase with the number of elements.

As well, note that the first deep SWR minimum occurs farther along the initial part of the curve as we increase the number of elements in the array. (Note that this appearance is subject to further investigation to determine if it is generally true or if it follows a periodic progression, as does the 432-MHz front-to-back ratio.) The further along the passband that the first deep minimum occurs, the lower the SWR at the upper end of the passband--at least until the value goes wholly out of control.



Since SWR is a function of the feedpoint resistance and reactance relative to some standard impedance, it is useful to sweep both the feedpoint resistance and reactance within the passband. **Fig. 4** sweeps the resistance at 2.5 MHz intervals. (All except SWR graphs use a 2.5 MHz interval due to the need to hand-transfer data to the spreadsheet graphing program.) If you block out the region above 455 MHz, you will see that the 19- and 26-element arrays undergo far smaller excursions of the feedpoint resistance and begin notable excursions at a higher frequency than the 12-element array.

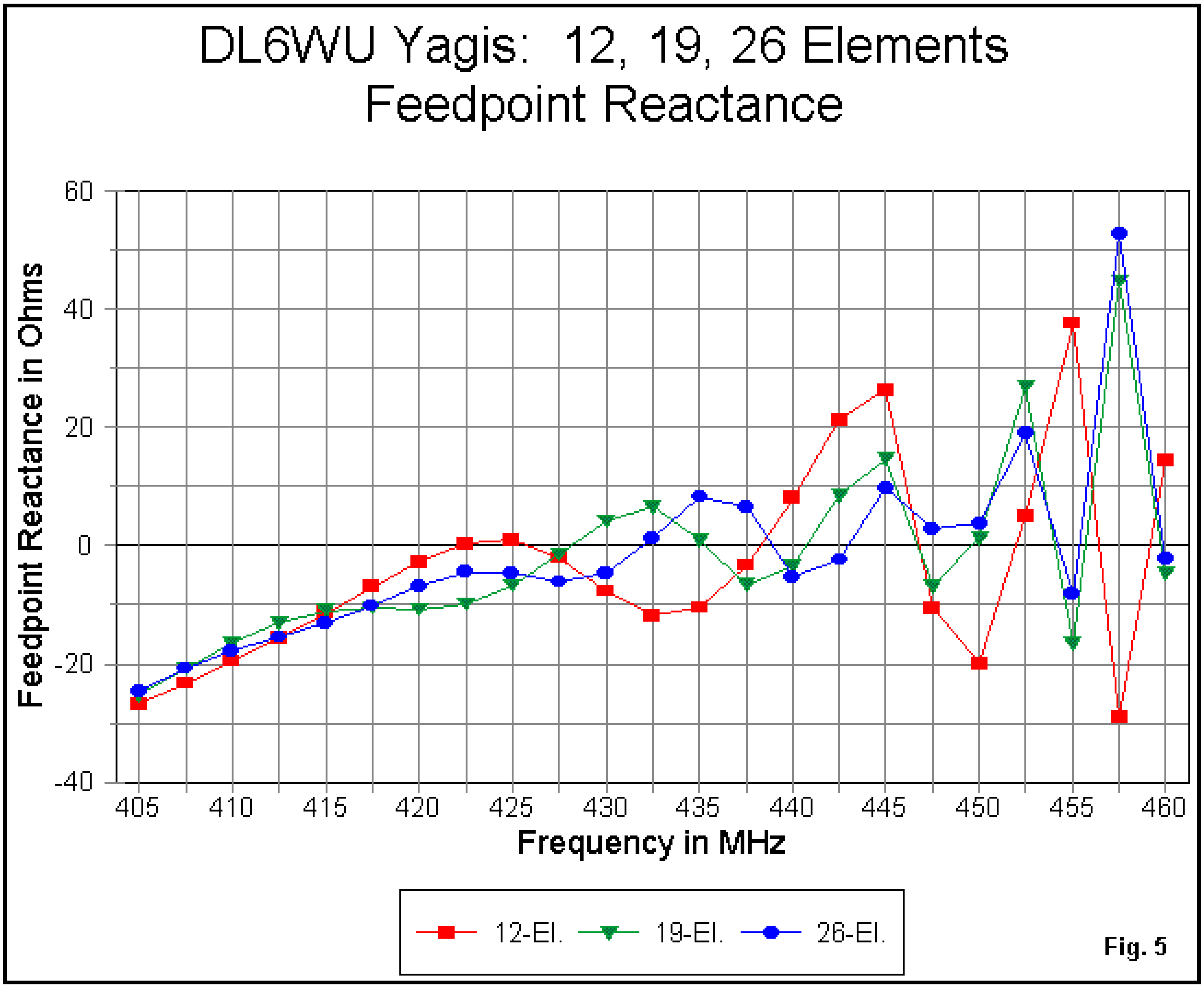


Fig. 5

The feedpoint reactance curves in **Fig. 5** show the same results: lower and fewer excursions in reactance value across the passband until we pass at least 452 MHz. Above this frequency, excursions for all versions of the array are very wide, swinging back and forth between significant values of inductive and capacitive reactance. We may note in passing that for both the resistance and reactance curves, we find the widest in-band excursions between 440 and 450 MHz, even though the SWR in this region remains quite tame.

The exploration of feedpoint values--resistance, reactance, and SWR--does not itself account for the very wide operating bandwidth or for any of the value swings for feedpoint parameters. To more fully account for the curve variations, we must turn to the relationships that exist among the reflector, driver, and first director.

The reflector length, in conjunction with its spacing from the driver, tends to set the feedpoint impedance in narrow-band arrays. The wider the spacing, the higher the feedpoint impedance. This relationship tends to hold for arrays in which the first director is more than 0.1 wavelength from the driver.

DL6WU recognized that the first director spacing that he used--0.075 wavelength--played a role in setting the driver impedance. In fact, he has referred to this director as a matching element. It is the inter-relationship among the reflector-driver and driver-director#1 spacing, along with the specific lengths of these elements, that sets the operating impedance and the operating bandwidth of the array. (Although some folks tend to call this arrangement a version of OWA or optimized wide-band antenna design, I prefer to reserve that term for the more complex system developed by WA3FET and NW3Z, which also includes the second and third directors as part of the bandwidth-setting cell.)

When the first director is closely spaced to the driver--perhaps closer than 0.09 to 0.10 wavelength--several things happen. For a given feedpoint impedance, the reflector may be more closely spaced to the driver than in narrow-band arrays. Second, by proper sizing and spacing of the first director relative to the driver, we may obtain a significant broadening of the operating passband. Under these conditions, the first director serves as something more than a mere matching parasitic element.

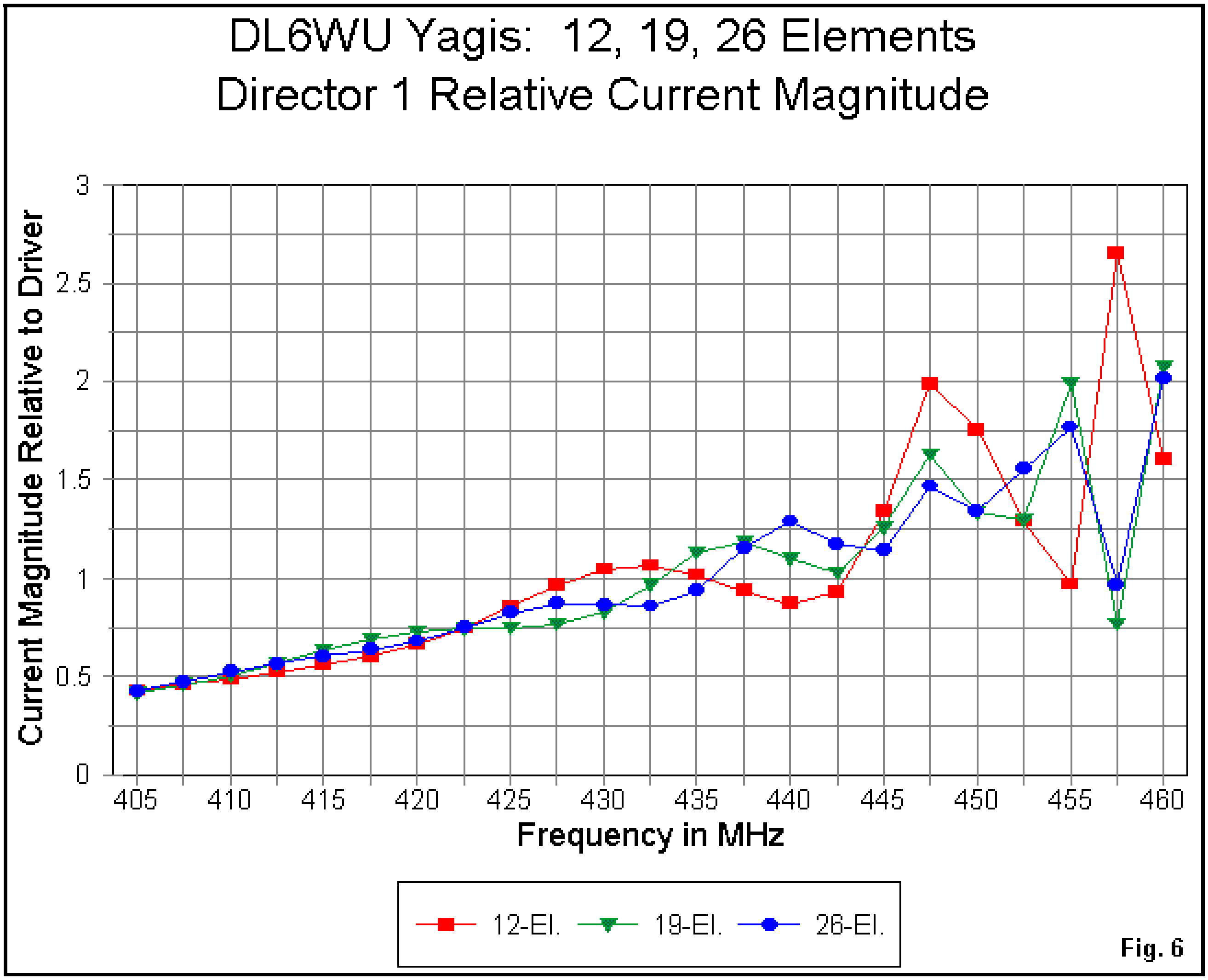


Fig. 6 traces the relative current magnitude on the first director of our 3 sample DL6WU designs. The current magnitude at all points is relative to a feedpoint magnitude of 1.0 on the driven element. In the lower end of the scanned frequency region, the first director current seems normal enough: a goodly and increasing fraction of the feedpoint current.

However, as we approach and pass mid-band, the first director current increases to levels above the current on the driver. The amount by which the first director current surpasses that of the driver increases wit increasing frequency. Whenever the current on the first director is near or above that of the driver, we may view the first director as a secondary or parasitic driver for the array.

Equally important to the operation of the DL6WU array are the undulations in the curve of relative current magnitude. There is a tentative correlation to be made between the current transitions through the 1.0 value and the SWR minima and maxima in the upper half of the passband. Downward passages correlate to approaches to SWR minima, while upward transitions correlate to approaches to SWR maxima. Pending further study, at least this much is clear: the current magnitude on the first director strongly influences the feedpoint resistance and reactance and consequently the SWR.

These phenomena are not independent of the other elements in the array. The same feedpoint cell (reflector-driver-director#1) with other arrangements of directors do not yield the same types of impedance excursions or the same operating bandwidth. Even within a systematic development of a series of directors, each new director has a determinate influence on the operation of the feedpoint cell. Within the DL6WU scheme of directors, the feedpoint cell provides an exceptionally wide operating bandwidth at all practical boom lengths, despite variations from one length to the next.

At the heart of the feedpoint cell design are empirically-determined element lengths and spacings that extend the operating bandwidth further than any other design of which I am currently aware. Other feedpoint cell designs can approximate the DL6WU operating bandwidth, but only by using element diameters several times the 4-mm elements in our sample arrays. However, much investigation remains to be done into this arena of Yagi design.

It is one thing to achieve a wide operating bandwidth in terms of feedpoint impedance and quite another to extend the performance parameters of the array over the same bandwidth. The success of the DL6WU array derives as much from its achievements in these categories as it does from its impedance-leveling techniques.

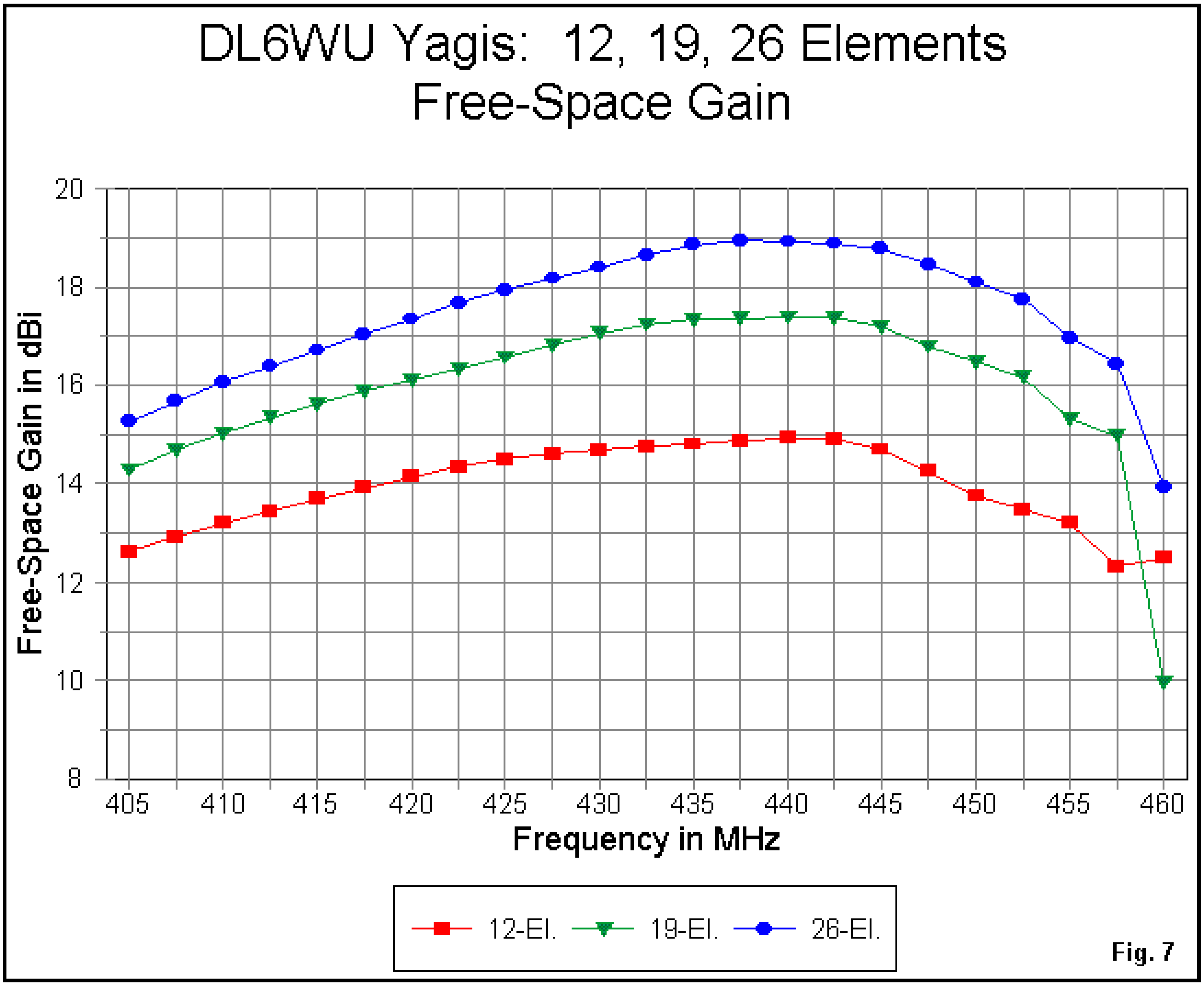


Fig. 7 provides gain curves for the three sample arrays across the 405 to 460 MHz spread of our sweeps. The curves are very well-behaved until at least 445 MHz. From this point onward, we find the gain curves to be slightly erratic, with more variable behavior occurring outside the band limits. However, notice that the largest of our sample arrays forestalls the beginning of such behavior until after the 450-MHz mark. The smaller the array, the lower the gain and the further inside the band that the gain curve shows less than smooth behavior. However, this generalization is tentative, pending more complete study of the entire DL6WU series.

It is notable that the 432-MHz operating point that is most common for the arrays is not coincident with maximum gain. The amount of extra gain obtainable tends to increase with the overall length of the array. Indeed, the DL6WU design seems intentionally set at a stable gain position such that the home constructor can--using reasonable care--obtain a workable version with good, if not absolutely maximum, gain.

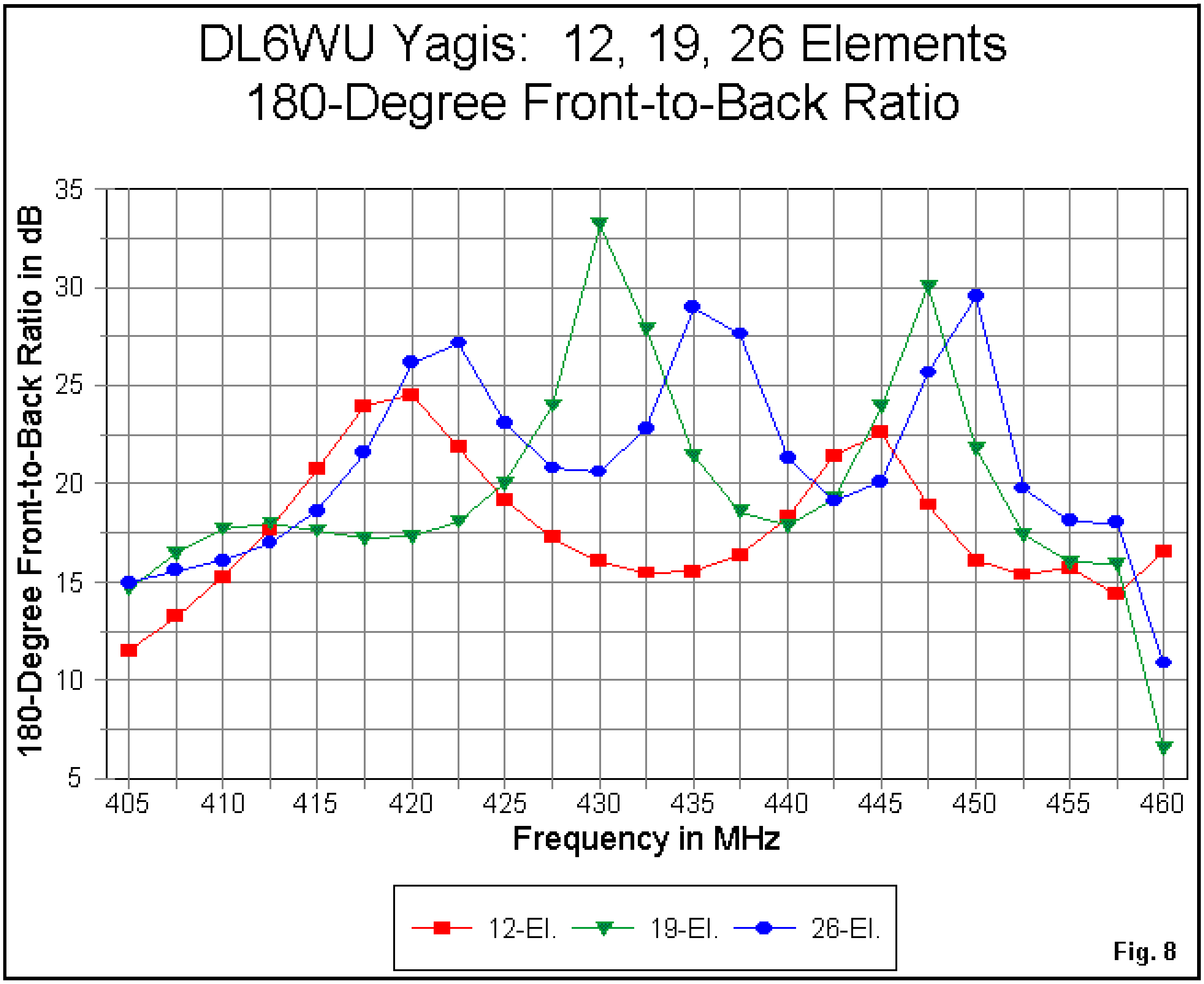


Fig. 8

Perhaps the most striking story emerges from the 180-degree front-to-back curves in **Fig. 8** for our sample arrays across the scanned frequency spread. The curve for each Yagi shows--with the 420-450-MHz operating range--at least 2 peaks, with the 26-element array showing 3. (Flatted peaks only indicate that the maximum value of 180-degree front-to-back ratio occurs between sampled points.) The 12-element array shows peaks at about 418 and 444 MHz. The corresponding peaks for the 19-element Yagi occur at about 430 and 448 MHz. For the smaller array, 432 MHz is near to a minimum value, while for the mid-size array, 432 MHz is near to a maximum.

The longest of our arrays peaks at about 422, 436, and 449 MHz. The structure of the curves suggests that with the addition of new directors, the front-to-back peaks drift higher in frequency, with a decrease in the frequency span between peaks. At a certain--and yet to be determined--point in the addition of directors, a new low-end peak emerges and the frequency span between peaks diminishes further. As the frequency span between peak values decreases, the lowest level to which the 180-degree front-to-back ratio may decrease rises, setting a minimum value of front-to-back ratio for the array. The graph makes clear the rising value of minimum 180-degree front-to-back ratio as we increase array length.

Subsequent detailed studies of the DL6WU Yagi series at 432 MHz have confirmed the impression reported on the basis of samples. By examining both design-frequency and wide-band behaviors of the array for beam lengths between 10 and 40 elements in 1-element increments, the progression of the front-to-back peaks can be traced and graphed. Each peak does emerge from about 418

MHz and proceeds upward in frequency as we raise the number of elements until it disappears somewhere below about 458 MHz. Over the span from 10 to 40 elements, as many as 10 front-to-back peaks emerge and disappear using a 4-mm element diameter. Recording the number on frequencies of SWR dips toward a 1:1 ratio reveals a very similar set of behaviors.

Also notable is the fact that the lowest front-to-back peak curve is also the widest, if we take an arbitrary value as a marker, for example 20 dB. Curves at high frequencies tend to be sharper. Except for those lengths at which 432 MHz corresponds to a front-to-back maximum, if we were to wish to operate the array at a front-to-back maximum, we might sacrifice gain for the sake of selecting a wide SWR upward curve and thus ease the construction precision necessary to obtain it.

Throughout, I have referred to the 180-degree front-to-back values for the curve, since these are the most easily obtainable from most modeling programs. However, as we saw in **Fig. 2**, the 180-degree front-to-back performance does not always coincide with worst-case front-to-back performance for an array. For any specific design effort, both must be checked, along with the accompanying forward sidelobe ratio value. Indeed, for any array, it pays to examine the power in all lobes other than the main forward lobe.

Wide-Band Flexibility in the DL6WU Design: Changing Element Diameter

Within a limited range, one may change the element diameter of a DL6WU design and obtain the same performance at the design frequency of 432 MHz. The change in element diameter requires that one use elements of a length having the same reactance. The RSGB volume provides equations for performing the calculation of new element lengths for the new element diameter (p. 7-28), and they have been included in some of the software available for designing Yagis in the series.

Equivalent reactance elements of different diameters are equivalent at the frequency of calculation and for some frequency spread that is not easily estimated. Therefore, I used the 12-element array from the group of samples to see what the differences in overall performance across the scanned frequency region might be. Conveniently, the same RSGB volume provided me with pre-calculated dimensions for 1/8", 4 mm, and 3/16" diameter elements, giving a series of element diameters from 0.125 to 0.1575 to 0.1875 inches (or 3.175 to 4.0 to 4.7625 mm). The total span covers a 1.5:1 diameter range, which is seemingly modest but wide enough to detect anything significant in the data output.

The following tables provide the dimensions of the 1/8" and 3/16" element versions of the 4 mm 12-element Yagi we used in the preceding section of these notes.

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12-Element DL6WU Yagi for 432 MHz (using 1/8" diameter elements)

Element	**Element Length**		**Cumulative Spacing**	
	mm	**wl**	**mm**	**wl**
Reflector	**340.9**	**0.491**	**---**	**---**
Driver	**333.2**	**0.480**	**138.8**	**0.200**
1	**306.0**	**0.441**	**190.8**	**0.275**
2	**302.3**	**0.436**	**315.8**	**0.455**
3	**298.9**	**0.431**	**465.0**	**0.670**
4	**295.6**	**0.426**	**638.4**	**0.920**
5	**292.7**	**0.422**	**832.8**	**1.200**

6	**290.2**	**0.418**	**1040.9**	**1.500**	
7	**288.0**	**0.415**	**1259.5**	**1.815**	
8	**286.1**	**0.412**	**1488.6**	**2.145**	
9	**284.4**	**0.410**	**1728.0**	**2.490**	
10	**282.9**	**0.408**	**1977.8**	**2.850**	**12-Element**

12-Element DL6WU Yagi for 432 MHz (using 3/16" diameter elements)

Element	**Element Length**		**Cumulative Spacing**		
	mm	**wl**	**mm**	**wl**	
Reflector	**340.4**	**0.491**	**---**	**---**	
Driver	**329.4**	**0.475**	**138.8**	**0.200**	
1	**299.4**	**0.431**	**190.8**	**0.275**	
2	**296.7**	**0.428**	**315.8**	**0.455**	
3	**292.9**	**0.422**	**465.0**	**0.670**	
4	**289.4**	**0.417**	**638.4**	**0.920**	
5	**286.3**	**0.413**	**832.8**	**1.200**	
6	**283.6**	**0.409**	**1040.9**	**1.500**	
7	**281.3**	**0.405**	**1259.5**	**1.815**	
8	**279.2**	**0.402**	**1488.6**	**2.145**	
9	**277.4**	**0.400**	**1728.0**	**2.490**	
10	**275.7**	**0.397**	**1977.8**	**2.850**	**12-Element**

Note: Unnamed numbered elements are directors. Dimensions follow those listed in Chapter 10 of the RSGB volume, *The VHF/UHF DX Book*, edited by Ian White, G3SEK, except for the driver and first director lengths, which have been adjusted slightly for maximum bandwidth.

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The adjustments to the driver and first director were made to obtain performance at 432 MHz as closely coincident as possible for the 3 models. The following table provides the 432-MHz data.

. . . .

Modeled Data for 3 Sample 12-Element DL6WU Yagi designs at 432 MHz

Element Diameter: inches	**0.125**	**0.1575**	**0.1875**
Element Diameter: mm	**3.175**	**4.000**	**4.7625**
Gain: dBi	**14.75**	**14.73**	**14.73**
180-degree F-B: dB	**15.51**	**15.52**	**15.53**
Main-fwd sidelobe: dB	**17.71**	**17.71**	**17.71**
Feedpoint Z (R+/-jX Ohms)	**57.8-j11.0**	**60.2-j11.4**	**60.2-j11.1**
50-Ohm SWR	**1.283**	**1.319**	**1.315**

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It is possible that the dimensions might be further adjusted to result in even closer alignment of the 432-MHz values.

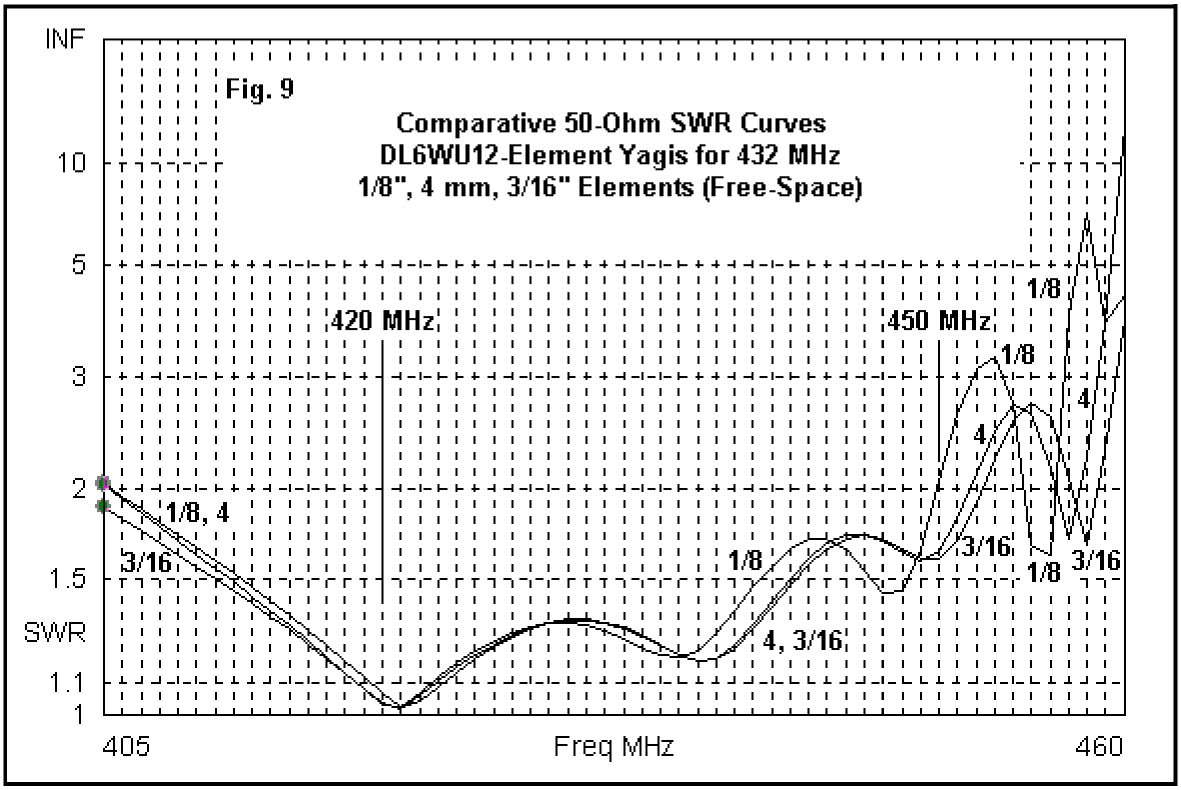


Fig. 9 shows the 50-Ohm SWR curves for the 3 array designs. At the lower end of the frequency range, although the first SWR minimum occurs coincidentally, the largest diameter element version shows a slightly lower SWR at 405 MHz. The difference is not operationally significant, but simply what we would expect from the slight broadband effect of larger elements.

At the upper end of the spectrum, the 1/8" element version shows the larger displacement relative to the 4 mm original. The amount of displacement is in part a result of driver and first-director element adjustments needed to set the 432-MHz operating parameters in coincidence. The differences between the 4 mm and 3/16" element version become noticeable beyond the upper band limit. In short, within the 420-450-MHz region, there is nothing significant relative to the SWR curve alone. Hence, it is unnecessary to review the feedpoint resistance and reactance curves.

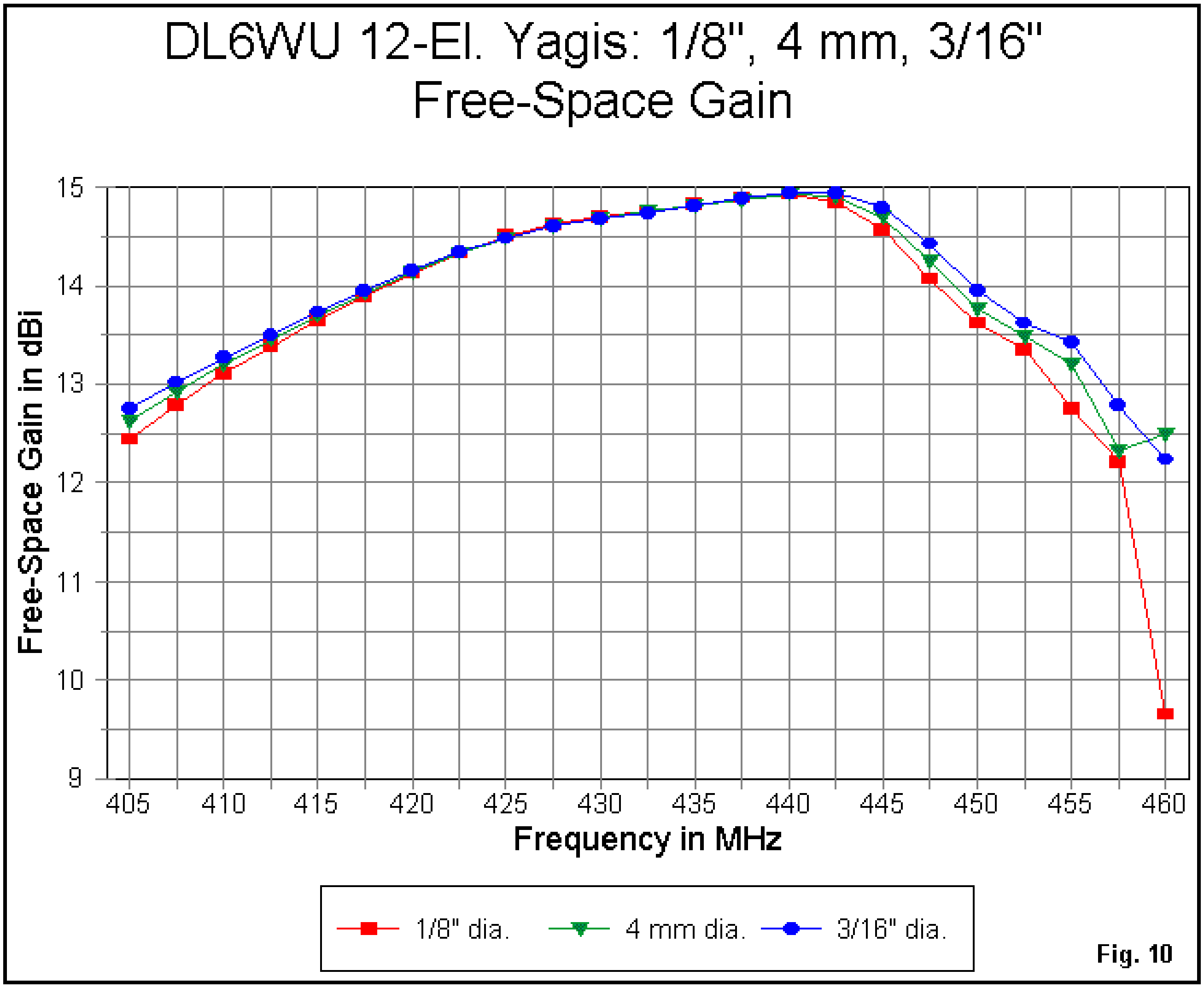
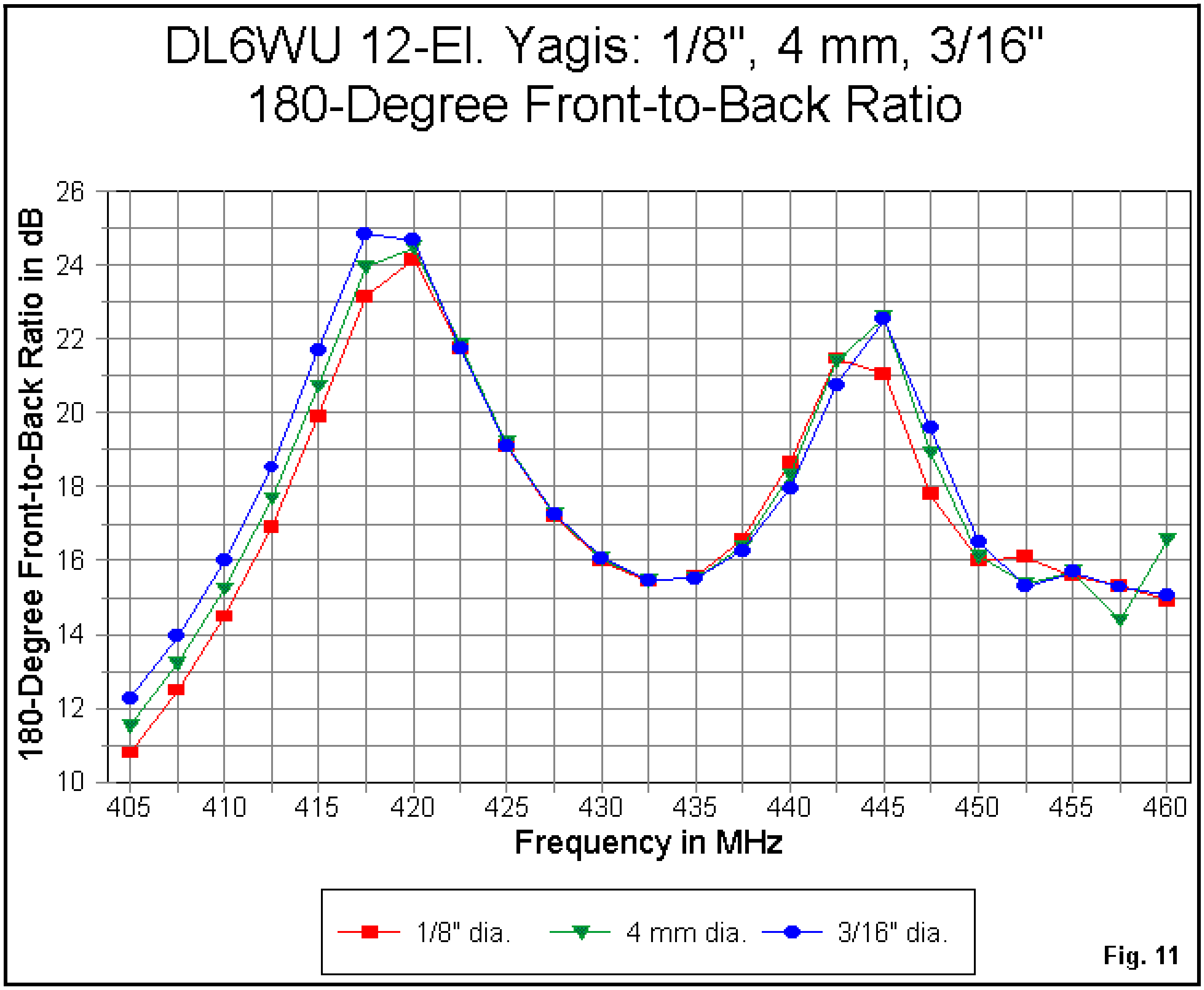


Fig. 10

Fig. 10 presents the gain curves for the 3 Yagis. Between 420 and 440 MHz, the curves are indistinguishable, a fact that results from the careful setting of 432-MHz characteristics. The low end of the scanned spectrum reveals a well behaved separation of gain values in accord with element size. A similar separation occurs at the upper end of the spectrum, but with some erratic results as the curves pass out of the scanned range. Such odd variations are not unexpected as the driver cell begins to lose control over array operation.



The 180-degree curves for the 3 arrays appear in **Fig. 11**. If we extrapolate the peaks in front-to-back performance from the sampled frequencies, we can see that the larger the element diameter, the lower (by a very slight amount) the frequency of the first peak. In contrast, using the same extrapolation procedure (or performing frequency sweeps over narrow ranges), we find that the larger the element diameter, the higher the frequency of the peak (again, by a very slight amount). Beyond 450 MHz, we again encounter erratic excursions in the curves, but over a relatively small range.

In principle, then, nothing in the performance curves indicates any unwanted effects of using element diameters within a 1.5:1 range for the DL6WU series of Yagis. I used the 12-element version of the array because it appeared to be most sensitive to changes, and yet, changes of significant proportions did not emerge.

However, note the procedure used to obtain these results. For the feedpoint cell (reflector, driver, and first director), the pre-calculated results underwent adjustment in order to set the arrays to coincident performance at 432 MHz. For any specific boom length, I would recommend that one check the feedpoint cell element lengths with NEC-4 to arrive at final values that provide the operating curve desired for as much of the spectrum as one plans to use. (Similar advice is apt to the use of a folded dipole driver.)

The use of such software to optimize the feedpoint cells to achieve coincident operating properties, of course, simply placed the 12-element array at a low front-to-back ratio region, a bit below the maximum gain possible with the array. While one is using the software--and assuming that one does not need to cover the entire 420-450 MHz band--one might as well change the operating point of the array.

Wide-Band Flexibility in the DL6WU Design: Changing the Array Operating Point

To sample the effects of moving the operating point of the array, I performed a 2-step operation.

1. First, I scaled the array from the frequency of the desired operating condition to 432 MHz. Included in the scaling was returning the element diameter to its original value and rechecking the operating curve in the vicinity of 432 MHz to assure myself that the desired characteristics did not move significantly in frequency. Since the movement was well under a 5% frequency shift, no further readjustment proved necessary.

2. Second, I adjusted the driver length to provide the lowest 50-Ohm SWR at 432 MHz. The desired operating points do not always occur at the lowest SWR points. Therefore, attaining the lowest possible SWR is desirable. The process can include readjustment of any and all elements in the feedpoint cell. However, for this exercise, I limited myself to driver length changes.

To implement this procedure, one must first locate the desired operating points. For the purposes of showing the consequences of these moves, I chose one operating point above 432 MHz and another below the design frequency. The upper operating point was the maximum gain frequency. For the 12-element array, this frequency is about 442 MHz, resulting in a scaling downward by 10 MHz. Frequency scaling downward results in a slightly longer array with slightly longer elements. The following table shows the results of both the scaling and driver adjustment.

. . . .

12-Element DL6WU Yagi for 432 MHz (scaled for maximum gain)

Element	**Element Length**		**Cumulative Spacing**		
	mm	**wl**	**mm**	**wl**	
Reflector	**348.5**	**0.502**	**---**	**---**	
Driver	**330.4**	**0.476**	**142.0**	**0.205**	
1	**308.6**	**0.445**	**195.2**	**0.281**	
2	**306.1**	**0.441**	**323.1**	**0.466**	
3	**302.4**	**0.436**	**475.8**	**0.686**	
4	**299.0**	**0.431**	**653.2**	**0.941**	
5	**295.9**	**0.426**	**852.1**	**1.228**	
6	**293.0**	**0.422**	**1065.0**	**1.535**	
7	**290.8**	**0.419**	**1288.7**	**1.857**	
8	**288.7**	**0.416**	**1523.1**	**2.195**	
9	**286.9**	**0.413**	**1768.0**	**2.548**	
10	**285.2**	**0.411**	**2023.6**	**2.916**	**12-Element**

Note: Unnamed numbered elements are directors. Element diameter is 4 mm (0.1575") (aluminum).

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For an upward scaling, I selected the frequency of best front-to-back ratio, where the curve is the broadest. That frequency for the 12-element array was about 418 MHz, for a 24 MHz upward scaling to 432 MHz. The resultant array was shorter than the original, as shown in the following table of dimensions. The dimensions include the return to 4 mm diameter elements and readjustment of the driver length.

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12-Element DL6WU Yagi for 432 MHz (scaled for best front-to-back performance)

Element	**Element Length**		**Cumulative Spacing**		
	mm	**wl**	**mm**	**wl**	
Reflector	**340.4**	**0.475**	**---**	**---**	
Driver	**329.4**	**0.464**	**134.3**	**0.194**	
1	**299.4**	**0.421**	**184.6**	**0.266**	
2	**296.7**	**0.417**	**305.6**	**0.440**	
3	**292.9**	**0.412**	**449.9**	**0.648**	
4	**289.4**	**0.407**	**617.7**	**0.890**	
5	**286.3**	**0.403**	**805.8**	**1.161**	
6	**283.6**	**0.399**	**1007.2**	**1.451**	
7	**281.3**	**0.396**	**1218.7**	**1.756**	
8	**279.2**	**0.393**	**1440.4**	**2.076**	
9	**277.4**	**0.391**	**1672.0**	**2.409**	
10	**275.7**	**0.389**	**1913.7**	**2.758**	**12-Element**

Note: Unnamed numbered elements are directors. Element diameter is 4 mm (0.1575") (aluminum).

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The question we might now pose is this: what did we achieve for our trouble?

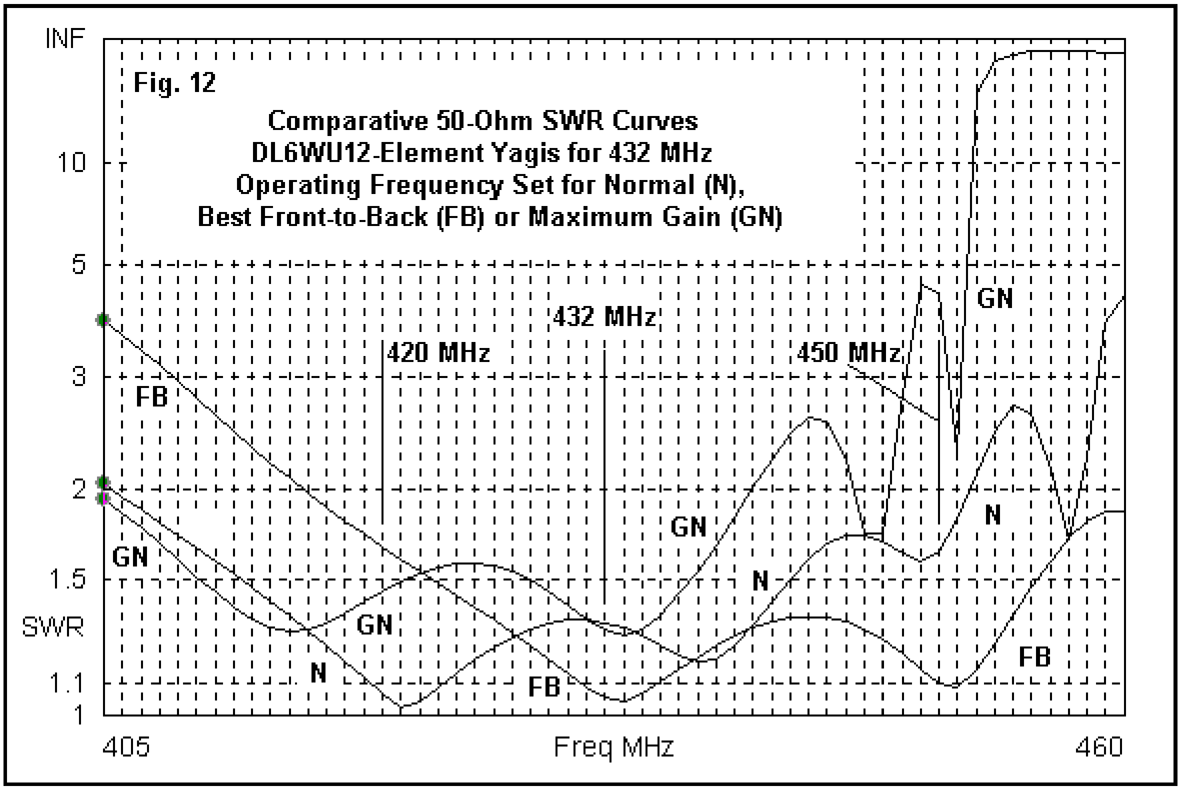


Fig. 12 shows the consequential SWR curves, using the original span from 405 to 450 MHz as our limits. Shown on the graph is the SWR curve for the original 12-element array to provide a reference curve. The high-gain curve results in a narrowed overall SWR passband. The low end value is not much below the value for the original design, but the upper end of the band shows

considerable shrinkage. Portions of the upper-end curve formerly beyond the scan range now come into view. After one large climb and dip that marks the 460-MHz portion of the original arrangement, the curve climbs into a wholly unusable range.

The upward scaling for the front-to-back adjustment is more benign in its effects on the 50-Ohm SWR. Although the curve shows an SWR above 3:1 at 405 MHz, it is below 2:1 at 420 MHz. In fact, the spread between SWR minima within the curve is wider than for the original curve by 2 MHz (18 vs. 16 MHz), indicating that the overall curve may be wider. The ultimate width, however, will depend to some degree on the SWR that we are willing to accept at 432 MHz, since we adjusted the driver for the lowest obtainable SWR at that frequency.

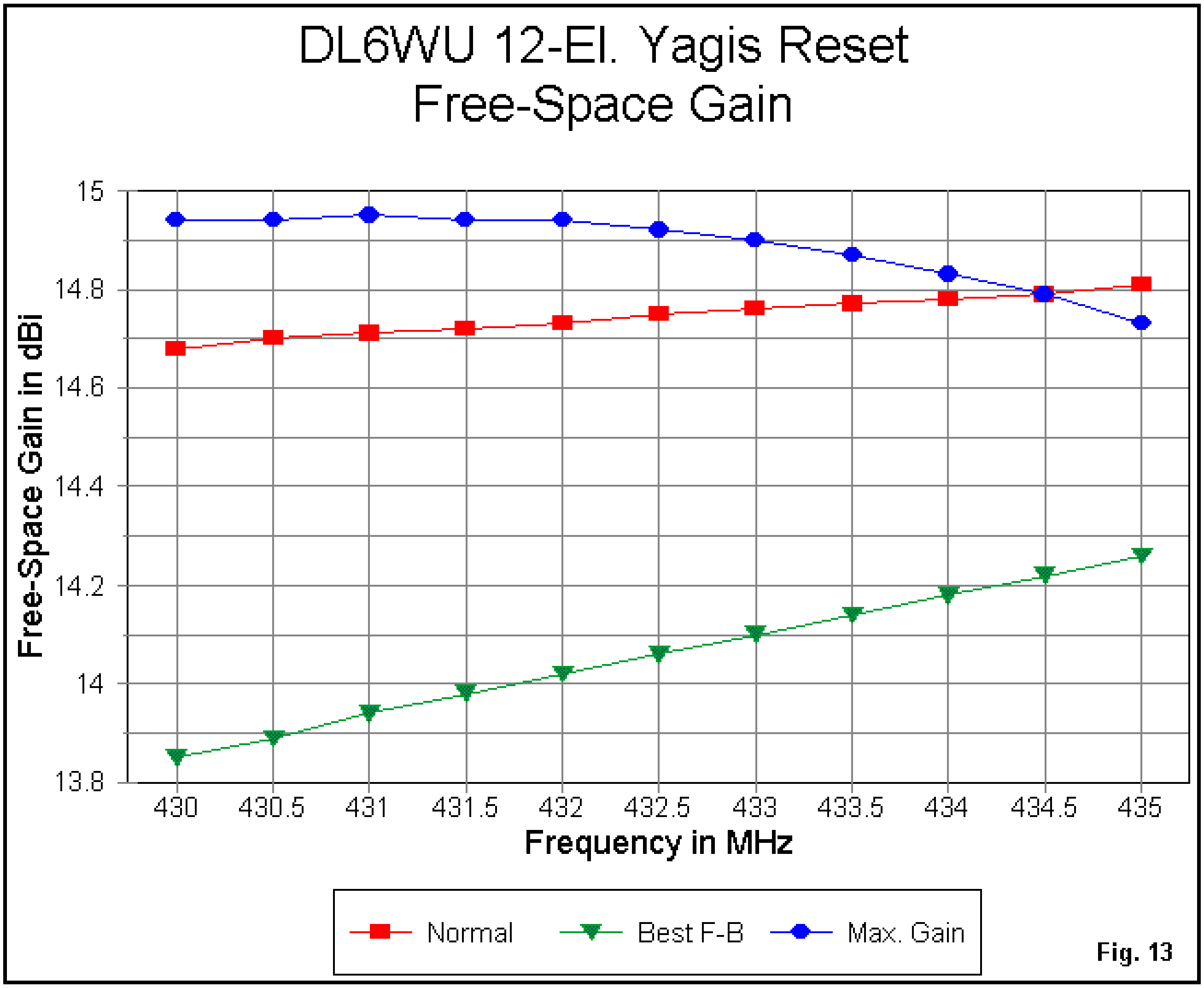


Fig. 13

Fig. 13 shows the consequences of our redesign work on the array gain between 430 and 435 MHz. The curves are precisely what we might expect before undertaking the re-scaling operations. The "best front-to-back" performance curve is considerably lower than the others and is on the rise. The free-space gain is bout 14.02 dBi at 432 MHz, compared to the 14.73 dBi value we obtained for the original version.

The maximum gain point for the array has been moved to 431 MHz rather than 432 MHz for a reason. For the 12-element array, the maximum gain frequency occurs at a 180-degree front-to-back ratio below 20 dB. By sacrificing a mere 0.01 dB of gain, we acquire about 2 dB of added front-to-back ratio.

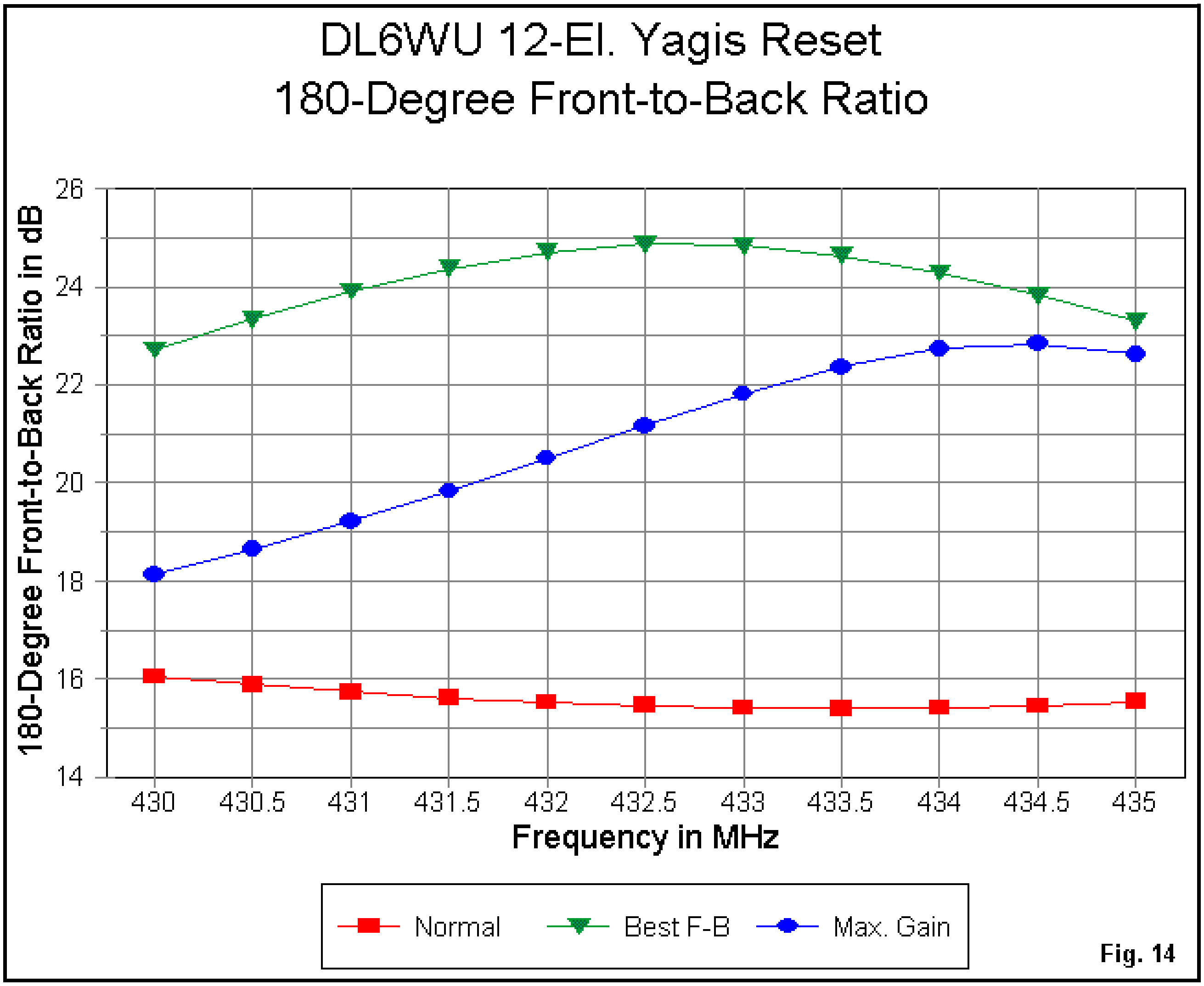


Fig. 14

The 180-degree front-to-back figures appear in **Fig. 14**. The Normal or pre-scaling version of the array reveals how close to the minimum front-to-back ratio the original design had been. The high-gain version shows the fairly rapid change in front-to-back ratio that occurs in the region of high gain for the 12-element array. Much more stable is the curve for the best front-to-back version of the array, despite the sacrifice in gain necessary to achieve that goal.

The patterns that we obtain for the arrays also have something to teach us, and they appear in **Fig. 15**.

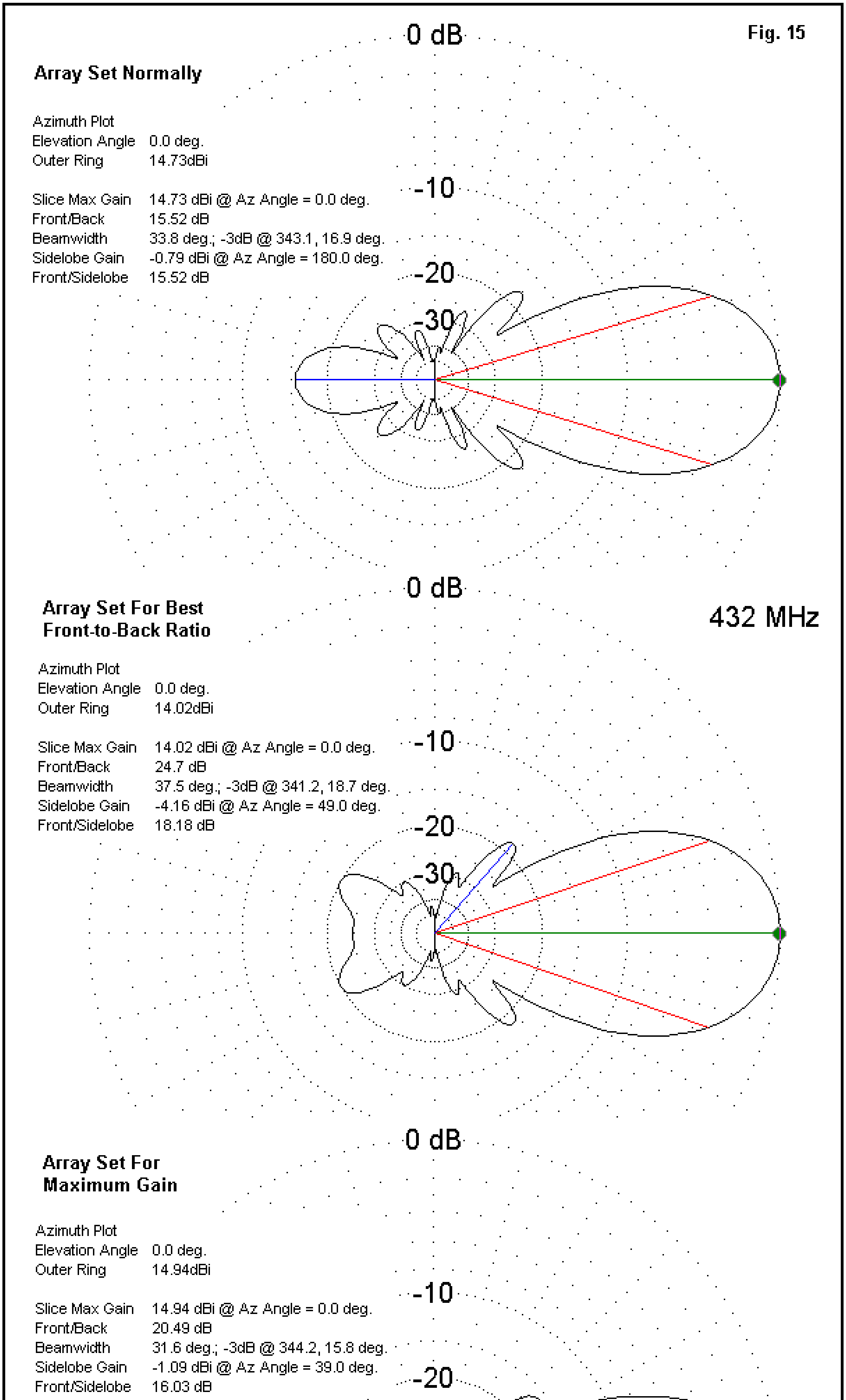


Fig. 15

Array Set Normally

```
Azimuth Plot
Elevation Angle   0.0 deg.
Outer Ring        14.73dBi

Slice Max Gain    14.73 dBi @ Az Angle = 0.0 deg.
Front/Back        15.52 dB
Beamwidth         33.8 deg.; -3dB @ 343.1, 16.9 deg.
Sidelobe Gain     -0.79 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe    15.52 dB
```

Array Set For Best Front-to-Back Ratio

```
Azimuth Plot
Elevation Angle   0.0 deg.
Outer Ring        14.02dBi

Slice Max Gain    14.02 dBi @ Az Angle = 0.0 deg.
Front/Back        24.7 dB
Beamwidth         37.5 deg.; -3dB @ 341.2, 18.7 deg.
Sidelobe Gain     -4.16 dBi @ Az Angle = 49.0 deg.
Front/Sidelobe    18.18 dB
```

Array Set For Maximum Gain

```
Azimuth Plot
Elevation Angle   0.0 deg.
Outer Ring        14.94dBi

Slice Max Gain    14.94 dBi @ Az Angle = 0.0 deg.
Front/Back        20.49 dB
Beamwidth         31.6 deg.; -3dB @ 344.2, 15.8 deg.
Sidelobe Gain     -1.09 dBi @ Az Angle = 39.0 deg.
Front/Sidelobe    16.03 dB
```

The original array pattern appears at the top, with associated performance figures that are now quite familiar. Since the front-to-back performance is so poor, the forward sidelobe ratio (to the main forward lobe) does not appear, but remains about 17.71 dB. We shall passingly note the horizontal -3 dB beamwidth of 33.8 degrees.

The best front-to-back performance version of the array shows a slightly lower gain, as expected from the graphs, along with a worst-case front-to-back ratio that is just about 20 dB (in contrast to the higher 180-degree front-to-back figure). In some ways, we may consider the performance of the array in this arrangement to be tamer, since the sidelobe structure is simpler or less developed than for the normal array. The forward sidelobe is 18.18 dB down, a slight improvement. As well the horizontal beamwidth is 37.5 degrees. The increased beamwidth is not solely a function of the reduced gain, but as well is a function of the reduced sidelobe structure.

The high-gain version of the array illustrates in part the effects of increased sidelobe structure on the -3 dB beamwidth. The primary or first forward lobes are not only stronger than in the other two versions of the array (-16.03 dB), but as well are wide enough to merge with the main lobe. In some designs, the sidelobes are wide enough to create mere "bulges" in the main lobe, sometimes sufficiently to the rear to give the forward lobe a bullet shape. The consequence of strong, wide sidelobes or bulges is generally to narrow the main lobe beamwidth, in this case to 31.6 degrees. The added gain (0.2 dB) is insufficient to account for the degree of added narrowing of the beamwidth from its original level (2.2 degrees).

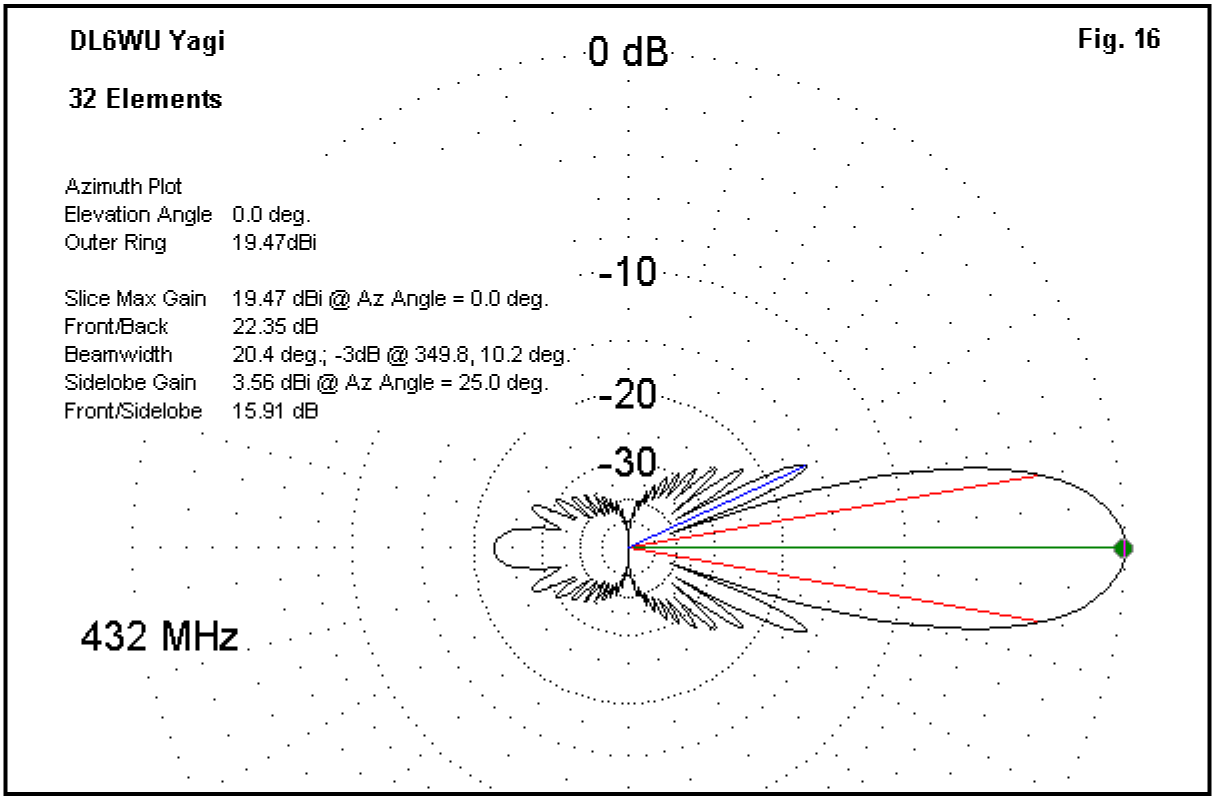
The failure of most simple formulas to accurately calculate the beamwidth of many arrays stems in part from the fact that they do not take into account the effects of forward sidelobes on the beamwidth. The greater the suppression of forward sidelobes, the wider the half-power beamwidth--up to certain limits, of course. In surveying designs with sidelobes ranging from -12 dB through -30 dB, the relationship has held throughout.

What About the 32-element Array?

The purpose of these notes has been to gain an appreciation of the wide-band characteristics of the DL6WU family of long-boom Yagis. As well, a secondary purpose has been to show some of the flexibility that the wide-band designs offer in terms of tailoring the design for a frequency and a subset of the array's operating characteristics.

In setting up examples of how we might change matters to get a particular set of performance characteristics at a desired frequency, we have not stressed gain. Nor have we recommended any of the alterations made to the array. Instead, the goal has been to illustrate and understand how we might use the wide-band performance in various ways. There is not a thing wrong with using a DL6WU array as designed to cover all of the band with very good performance.

Nevertheless, a certain curiosity is natural concerning the longest version of the array in the original dimension chart. The full 32-element (30-director) Yagi is just about 11 wavelengths long, or about 24.6'. The rest of the story appears in **Fig. 16**.



The free-space gain is 19.47 dBi, with a combined 180-degree/worst-case front-to-back ratio of 22.35 dB. The longer array shows increased development of sidelobes. Indeed, if the array has a weakness, it lies in the front-to-sidelobe ratio of only 15.91 dB.

Despite this performance, let's remember that the longer the array, the greater the differential between the design frequency gain and the maximum gain. For this version of the DL6WU family, the maximum gain is about 19.91 dBi, almost a half dB higher, with an improved front-to-back ratio to boot. I will not speculate on whether these improvements constitute sufficient reason to exercise some of the flexibilities offered by the DL6WU wide-band long-boom Yagi designs.