A 70-CM Wide-Band, Long-Boom Yagi with High Sidelobe Suppression

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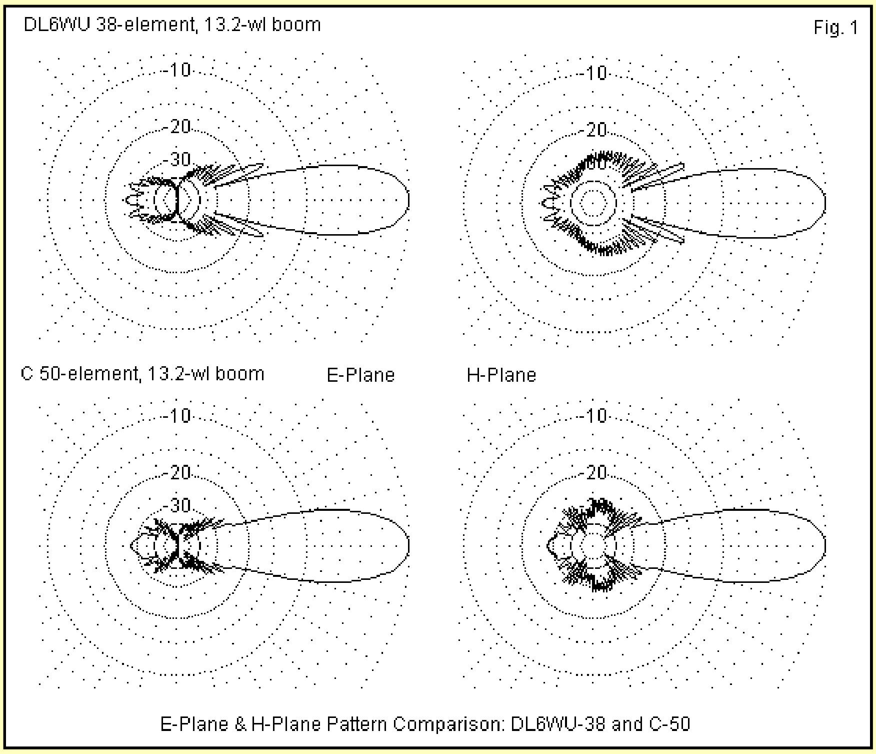
The following small table shows the free-space forward gain and the front-to-sidelobes for both the E-plane and the H-plane for 3 long-boom Yagis. The boomlength is about 13.2 wavelengths in each case, although it will vary slightly, since we can only add elements in whole units. Each design is standard for its type. The DL6WU entry emerges from the program DL6WU-GG.EXE. The entry labeled "LB" (for "long-boom") comes from a modified and extended version of a VK3AUU array. The N6BV entry is an optimized Yagi for the 420-440-MHz range. The first two Yagis, although centered on 432 MHz, cover the entire 70-cm band. The N6BV Yagi used 3/16" (0.1875") diameter elements, while the other two arrays use 4-mm (0.1575") diameter elements. These are, of course, NEC-4 values for 432 MHz and would require adjustment for comparison with any test-range figures.

Series	**Elements**	**Boomlength Wavelengths**	**Gain dBi**	**E-plane Front-to-sidelobe Ratio dB**	**H-plane Front-to-sidelobe Ratio dB**
DL6WU	**38**	**13.215**	**20.18**	**15.91**	**14.84**
LB	**47**	**13.327**	**20.78**	**14.53**	**13.71**
N6BV	**38**	**13.104**	**20.69**	**14.81**	**14.00**

The front-to-sidelobe ratio values shown for the 3 Yagis are typical for beams having this boomlength, although there are not too many designs that reach this length. The numbers are based on NEC-4 models of each array. They come from an archive of data that I developed for a large number of basic designs. I modeled the design for every length of boom within each design series from 2 wavelengths to either as far as the series goes or 14 wavelengths, whichever came first. The data appear in *Long-Boom Yagi Studies*, available from *antenneX*.

The DL6WU Yagi is perhaps the standard against which we measure all other long-boom arrays. The top portion of **Fig. 1** shows the E-plane (horizontal) and H-plane (vertical) patterns of the 38-element version of the array in free space.

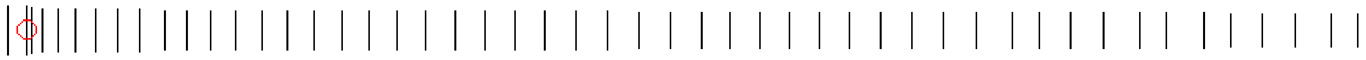


E-Plane & H-Plane Pattern Comparison: DL6WU-38 and C-50

What would you pay for a long-boom Yagi of about the same boomlength that yielded the patterns in the lower portion of **Fig. 1**? In this context, I am not speaking of money. Rather, I am talking in Yagi terms. One way of paying is in dB of reduced gain. The other means of payment is in terms of element weight and wind load. The lower portion of the figure shows sidelobes in both planes that are suppressed by 10 dB or more from the corresponding sidelobes of the upper pattern. For any application in which reduced off-axis sensitivity to noise or signals is important, the sidelobe reductions may be important. As well, Guenter Hoch, DL6WU, reports that at higher UHF frequencies, atmospheric particulates may create enough diffraction to reduce overall gain if sidelobes are not more than 17 dB down relative to the main lobe. So the question remains: what would you pay for front-to-sidelobe ratios that are more than 20 dB over almost the entire 70-cm band?

The Background and Dimensions of the C50 Yagi

The C50 array uses 50 elements in the space that held only 38 elements in older Yagi designs. **Fig. 2** shows the outline of the C50. You may note--despite the difficulty of picking out fine detail--that the element spacing and length values do not adhere to a fixed rate of increase or decrease. There are some cyclical elements built into the design.



General Outline: 50-Element, 13.2-Wavelength, High Front-to-Sidelobe Ratio Yagi

Fig. 2

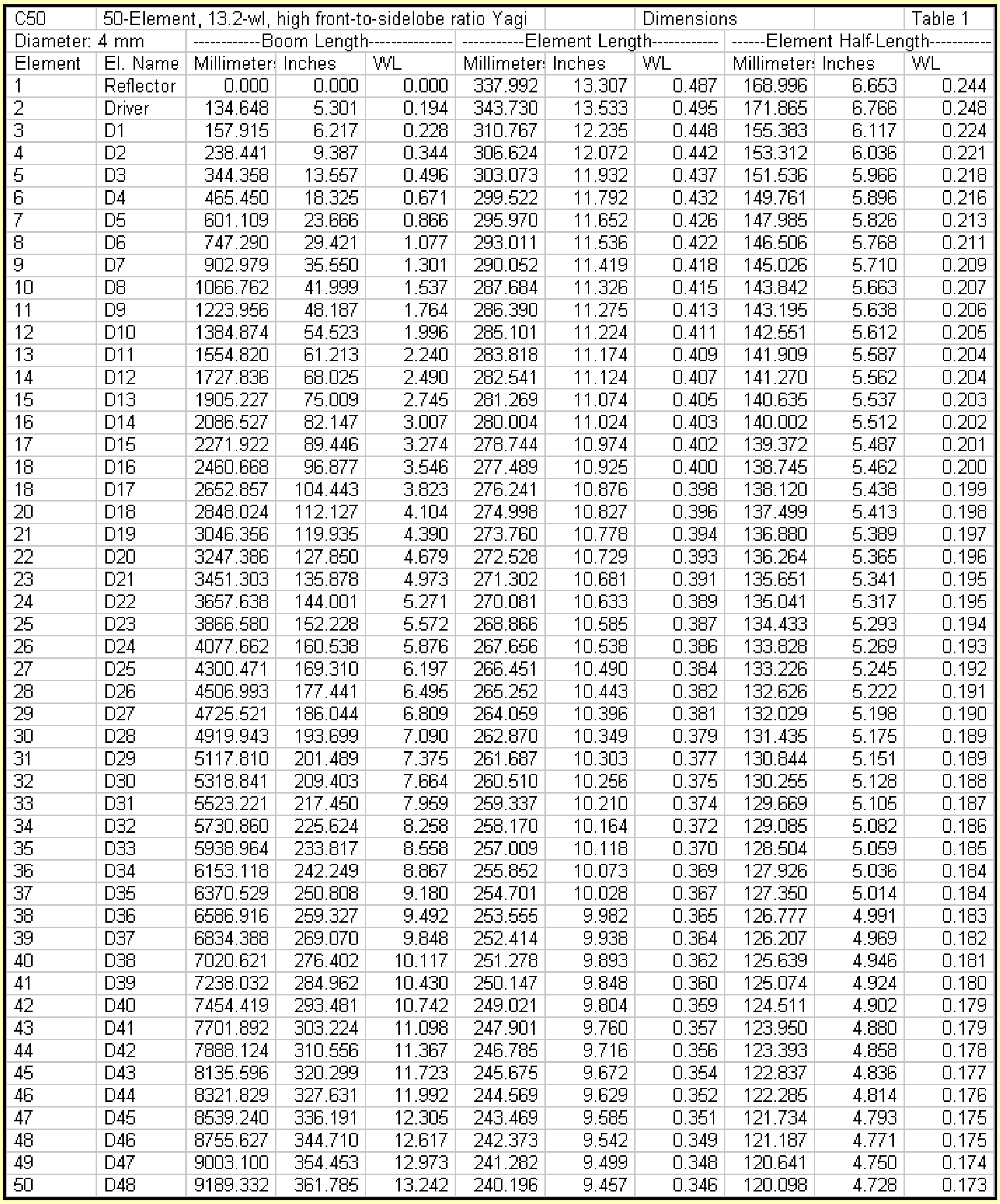
The history of the C50 begins with a 41-element 2-meter design by David Tanner, VK3AUU. His design used a higher element density per boomlength unit than more tradition designs, such as the DL6WU or the W1JR/HyGain beam. The original version of his beam, when transported by scaling to 70 cm, showed promise of raising the front-to-sidelobe ratio in both planes, but especially in the E-plane. Initial variations of his design showed promise of exceeding 19 dB at 432 MHz, but with a decrease in performance away from that design frequency.

However, two principle components of his design remain in the C50. One is the interesting wide-band impedance-setting cell composed of the reflector, driver, and first director (mainly). Note that the reflector in **Fig. 2** is shorter than the driver, and the first director is spaced close to the driver in a primary-secondary driver arrangement. His array covered all of the 70-cm band with an exceptionally low 50-Ohm SWR with a direct feed.

The second feature of the VK3AUU array retained in the C50 is the compressed element spacing. However, the element spacing is even more compressed in the C50. (The C in C50 stands for Compressed spacing.) Compressed spacing is anther way of referring to high element density for a given boomlength. Whereas the DL6WU and N6BV Yagis used 38 elements in 13 wavelengths, the LB entry uses 47 and follows the VK3AUU spacing schedule--almost. The C50, of course, packs 50 elements on the same boom. So the weight penalty paid for the C50 is almost a half-pound of aluminum rod, relative to the oldest designs with proven wide-band properties, like the DL6WU. Although the DL6WU design uses a different impedance-setting cell design, it, too, is capable of full 70-cm band coverage with a direct feed and low 50-Ohm SWR values.

However, not every design is susceptible to spacing compression with a good outcome in terms of gain and sidelobe performance. My experiments on the DL6WU series came to naught. Rather, the array must use a certain variability of both spacing and element length to eventually yield high sidelobe performance combined with adequate performance in all other categories that apply to wide-band Yagis. I would love to be able to present a series of calculation equations that perfectly describe the structure of the C50. However, the design emerged from what engineering calls manual iterative experimentation. We know it as trial and error.

The dimensions of the C50 appear in **Table 1**. Both the element spacing and the element length values appear in millimeters, inches, and wavelengths. The last of the 3 forms may be useful for scaling the beam to other bands. However, remember to scale the element diameter as well as the cumulative boomlength and element length values. The model presumes a non-conductive boom or elements that are well insulated and isolated from a conductive boom. For through-boom construction, adjust the element lengths according to principles shown in **"Scales"**. The element lengths appear as whole lengths for guidance to any construction and as half-lengths as guidance to modeling the antenna.



C50	50-Element, 13.2-wl, high front-to-sidelobe ratio Yagi						Dimensions			Table 1
Diameter: 4 mm		------------Boom Length---------------			-----------Element Length------------			------Element Half-Length-----------		
Element	El. Name	Millimeter:	Inches	WL	Millimeter:	Inches	WL	Millimeter:	Inches	WL
1	Reflector	0.000	0.000	0.000	337.992	13.307	0.487	168.996	6.653	0.244
2	Driver	134.648	5.301	0.194	343.730	13.533	0.495	171.865	6.766	0.248
3	D1	157.915	6.217	0.228	310.767	12.235	0.448	155.383	6.117	0.224
4	D2	238.441	9.387	0.344	306.624	12.072	0.442	153.312	6.036	0.221
5	D3	344.358	13.557	0.496	303.073	11.932	0.437	151.536	5.966	0.218
6	D4	465.450	18.325	0.671	299.522	11.792	0.432	149.761	5.896	0.216
7	D5	601.109	23.666	0.866	295.970	11.652	0.426	147.985	5.826	0.213
8	D6	747.290	29.421	1.077	293.011	11.536	0.422	146.506	5.768	0.211
9	D7	902.979	35.550	1.301	290.052	11.419	0.418	145.026	5.710	0.209
10	D8	1066.762	41.999	1.537	287.684	11.326	0.415	143.842	5.663	0.207
11	D9	1223.956	48.187	1.764	286.390	11.275	0.413	143.195	5.638	0.206
12	D10	1384.874	54.523	1.996	285.101	11.224	0.411	142.551	5.612	0.205
13	D11	1554.820	61.213	2.240	283.818	11.174	0.409	141.909	5.587	0.204
14	D12	1727.836	68.025	2.490	282.541	11.124	0.407	141.270	5.562	0.204
15	D13	1905.227	75.009	2.745	281.269	11.074	0.405	140.635	5.537	0.203
16	D14	2086.527	82.147	3.007	280.004	11.024	0.403	140.002	5.512	0.202
17	D15	2271.922	89.446	3.274	278.744	10.974	0.402	139.372	5.487	0.201
18	D16	2460.668	96.877	3.546	277.489	10.925	0.400	138.745	5.462	0.200
18	D17	2652.857	104.443	3.823	276.241	10.876	0.398	138.120	5.438	0.199
20	D18	2848.024	112.127	4.104	274.998	10.827	0.396	137.499	5.413	0.198
21	D19	3046.356	119.935	4.390	273.760	10.778	0.394	136.880	5.389	0.197
22	D20	3247.386	127.850	4.679	272.528	10.729	0.393	136.264	5.365	0.196
23	D21	3451.303	135.878	4.973	271.302	10.681	0.391	135.651	5.341	0.195
24	D22	3657.638	144.001	5.271	270.081	10.633	0.389	135.041	5.317	0.195
25	D23	3866.580	152.228	5.572	268.866	10.585	0.387	134.433	5.293	0.194
26	D24	4077.662	160.538	5.876	267.656	10.538	0.386	133.828	5.269	0.193
27	D25	4300.471	169.310	6.197	266.451	10.490	0.384	133.226	5.245	0.192
28	D26	4506.993	177.441	6.495	265.252	10.443	0.382	132.626	5.222	0.191
29	D27	4725.521	186.044	6.809	264.059	10.396	0.381	132.029	5.198	0.190
30	D28	4919.943	193.699	7.090	262.870	10.349	0.379	131.435	5.175	0.189
31	D29	5117.810	201.489	7.375	261.687	10.303	0.377	130.844	5.151	0.189
32	D30	5318.841	209.403	7.664	260.510	10.256	0.375	130.255	5.128	0.188
33	D31	5523.221	217.450	7.959	259.337	10.210	0.374	129.669	5.105	0.187
34	D32	5730.860	225.624	8.258	258.170	10.164	0.372	129.085	5.082	0.186
35	D33	5938.964	233.817	8.558	257.009	10.118	0.370	128.504	5.059	0.185
36	D34	6153.118	242.249	8.867	255.852	10.073	0.369	127.926	5.036	0.184
37	D35	6370.529	250.808	9.180	254.701	10.028	0.367	127.350	5.014	0.184
38	D36	6586.916	259.327	9.492	253.555	9.982	0.365	126.777	4.991	0.183
39	D37	6834.388	269.070	9.848	252.414	9.938	0.364	126.207	4.969	0.182
40	D38	7020.621	276.402	10.117	251.278	9.893	0.362	125.639	4.946	0.181
41	D39	7238.032	284.962	10.430	250.147	9.848	0.360	125.074	4.924	0.180
42	D40	7454.419	293.481	10.742	249.021	9.804	0.359	124.511	4.902	0.179
43	D41	7701.892	303.224	11.098	247.901	9.760	0.357	123.950	4.880	0.179
44	D42	7888.124	310.556	11.367	246.785	9.716	0.356	123.393	4.858	0.178
45	D43	8135.596	320.299	11.723	245.675	9.672	0.354	122.837	4.836	0.177
46	D44	8321.829	327.631	11.992	244.569	9.629	0.352	122.285	4.814	0.176
47	D45	8539.240	336.191	12.305	243.469	9.585	0.351	121.734	4.793	0.175
48	D46	8755.627	344.710	12.617	242.373	9.542	0.349	121.187	4.771	0.175
49	D47	9003.100	354.453	12.973	241.282	9.499	0.348	120.641	4.750	0.174
50	D48	9189.332	361.785	13.242	240.196	9.457	0.346	120.098	4.728	0.173

How does the C50 stack up against the 3 representative designs using essentially the same boomlength? The patterns in **Fig. 1** give some idea, and we may supplement those patterns with a performance report from the NEC-4 model. The data apply to the design frequency of 432 MHz. E BW and H BW refer to the E-plane and H-plane beamwidths, while E F/SL and H F/SL refer to the E-plane and H-plane front-to-sidelobe ratios. The other columns should be self-explanatory.

Elements	Boomlength wavelengths	Gain dBi	180-Deg Front-to-Back Ratio dB	E BW deg.	E F/SL Ratio dB	E BW deg.	H F/SL Ratio dB	Feedpoint Z R +/- jX Ohms	50-Ohm SWR
50	**13.242**	**20.26**	**27.89**	**19.2**	**25.91**	**19.8**	**24.35**	**52.96 + j1.49**	**1.066**

The C50 forward gain in free-space is between the values for the DL6WU and the remaining 2 entries among the standard designs. Among all of the designs, the C50 shows a gain deficit of not more than 0.5 dB relative to the best designs in the group. (Of course, we can obtain more gain at the listed boomlength by using a narrower bandwidth, but that is not one of the goals for this design.) The possible gain deficit is the other cost for the 10-dB improvement in front-to-sidelobe performance.

But are the costs worthwhile? I can give no fixed answer to this question. However, we can perhaps sort out some of the considerations. Consider first installing the beam parallel to the earth, horizontally polarized. Let's compare the DL6WU beam from **Fig. 1** to the C50 at the same height. For modeling purposes, I selected a height of 10 wavelengths above average ground. The height is low--between 22' and 23' at 432 MHz. However, the height is also about as high as we can go and still obtain accurate indications of lobe maximums using an elevation plot with an increment of 0.1-degree. If we compare the elevation plots for both beams we obtain the patterns shown in **Fig. 3**.

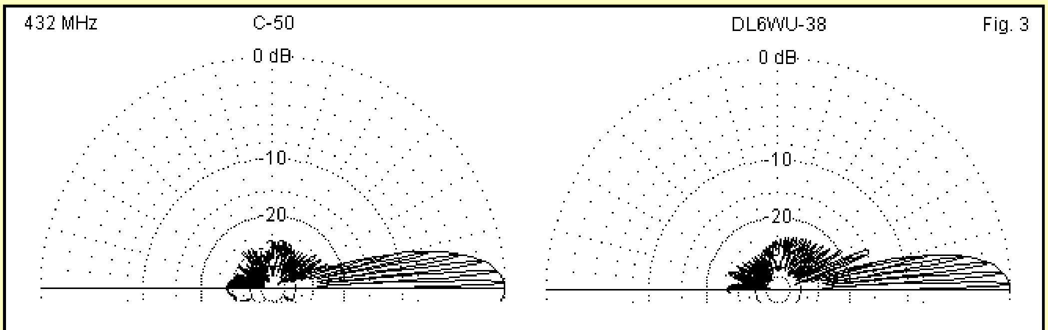


Fig. 3

C-50 & DL6WU-38 13.2-wl Yagis: Elevation Patterns: Antenna Height 10-wl

I have enclosed the multi-lobe elevation pattern structure inside the free-space envelope for several reasons. First, too few folks realize that the fit is perfect, once we adjust for the greater maximum gain of the antenna over ground. However, the peak values of the lobes result from reinforcing combinations of incident and reflected energy. Each one is offset by a null created by cancellation between incident and reflected energy. The result for the antenna over ground is an outline to the multiple lobes that exactly matches the free-space pattern.

Second, there is no significant difference between the cluster of elevation lobes the fit inside the main free-space forward lobe for each Yagi. The significant differences appear in the first 2 sidelobes at higher elevation angles for the DL6WU array. The first sidelobe is less than 15 dB down, while the second is less than 20 dB down. For the C50, both lobes are nearly 25 dB lower than the strength of the main lobe.

Over ground, the main lobe has a gain of over 25 dBi. We may determine the gain of the sidelobes by subtracting the front-to-sidelobe ratio from the forward gain. For a sidelobe that is down by 15 dB, the sidelobe gain is 10 dBi. For a sidelobe ratio of 20 dB, the sidelobe gain is 5 dBi. When the sidelobe ratio reaches 25 dB, the sidelobe gain is about 0 dBi. In terms of basic transmitting and receiving, none of these values is insignificant. However, gains of 5 and 10 dBi are certainly less desirable in sidelobes than a gain of 0 dBi.

How important these sidelobe gains are to a particular operation depends on the operational specifications and needs. For point-to-point terrestrial communications, the high-angle lobes might not be very significant, especially if the beam has excess gain relative to the needs of a given communications path. However, if we angle the antenna upward, we might reach a different conclusion. With the antenna pointed straight up, all sidelobes are in play and the beam gain is essentially the same as the free-space gain. Even at a 45-degree angle, we find the free-space gain (without the benefit of ground reflections) and all sidelobes. Since we have both E-plane and H-plane sidelobes of similar strength, we can picture them as a kind of halo around the main beam. The stronger the sidelobe, the more the antenna is susceptible to off-axis noise and signals. Hence, for operations with non-terrestrial targets--such as EME work--the sidelobe structure may acquire a different level of importance.

The C50 as a Broad-Band Yagi

We have so far concerned ourselves with the performance of the C50 at the design frequency, 432 MHz. However, the C50 design covers of the entire 70-cm band. It is certainly possible to wring more gain out of fewer elements if we are willing to settle for a narrow bandwidth. For expert builders with high precision shops and high precision tune-up equipment, a narrow bandwidth antenna may be suitable to operations that never exceed some small subsection of the band. Most builders do not have access to this level of precision. If nothing else, a wide-band Yagi design tends to assure the careful home builder that the design will likely work at midband and with performance close to the specifications.

When working toward the C50, I used the following design specifications.

- 1. Forward gain: >19.6 dBi free space
- 2. 180-degree front-to-back ratio: >20 dB and desirably >25 dB
- 3. Front-to-sidelobe ratio: >20 dB in both E-plane and H-plane
- 4. Feedpoint impedance: 50 Ohms with <1.25:1 SWR
- 5. Bandwidth: all specifications met from 420 to 450 MHz.

Although I would like to report that the C50 passes all tests, it actually misses a couple of them by a smidgen or 2. Still, it comes closer to meeting all of these specifications than any other long-boom Yagi with which I have any acquaintance. For that reason and despite its imperfections, the design is still worth passing along.

When examining broadband characteristics for any beam, many modelers are content to set the frequency sweep increments wide and to cut off the sweep at the exact band edges. However, I prefer to use a wider sweep passband in order to watch the trends in performance degradation outside the operating portion of the sweep range. Because Yagis tend to show a slower rate of degradation below the lower band limit, I tend to extend that range further than I do the upper end of the sweep, where performance decays more rapidly. The wide-band plots come from AC6LA's EZ-Plots program.

Fig. 4 shows the wide-band gain and front-to-back performance of the array from 400 to 460 MHz in 1-MHz increments. The gain peaks in the 431-433-MHz span, exactly around the design frequency. The peak value of 20.26 dBi compares to 19.76 dBi at 420 MHz and 19.69 dBi at 450 MHz. The maximum change of gain across the 70-cm band is 0.57 dB. Gain falls off very slowly beyond the operating limits and still exceeds 17 dBi at 400 MHz.

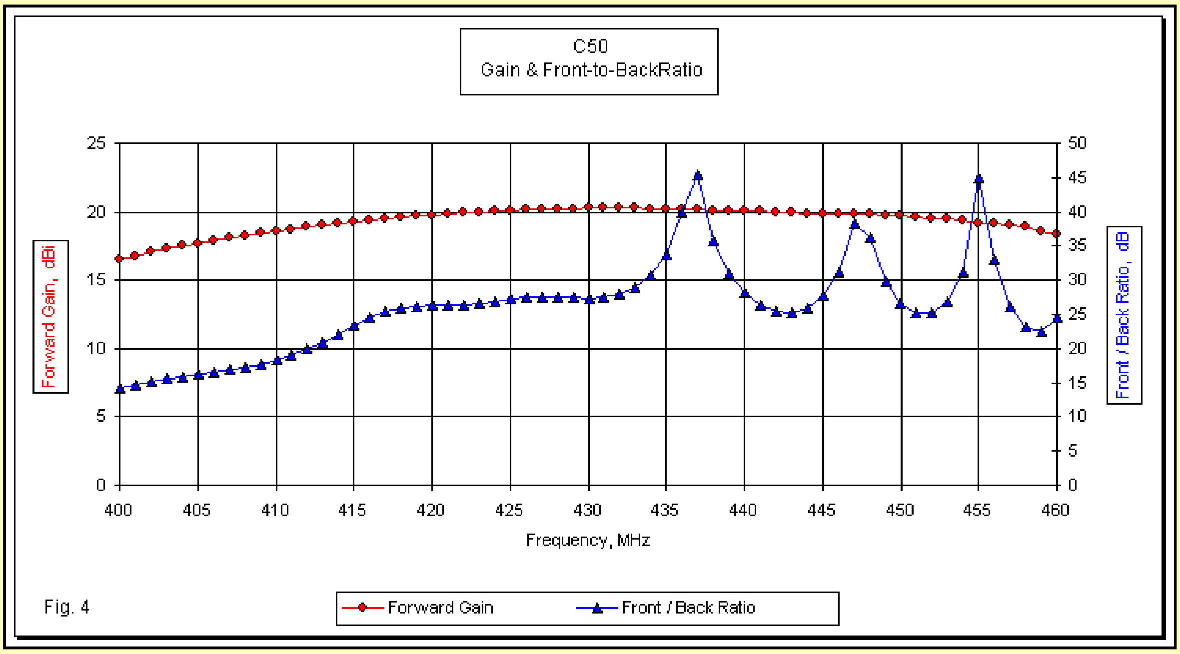


Fig. 4

The 180-degree front-to-back ratio is the easiest parameter to determine automatically in a frequency sweep. Since the lobe structure to the rear changes with frequency, determining a worst-case front-to-back ratio requires a manual investigation at each frequency. Yet, we can obtain a good picture of the worst-case front-to-back ratio simply by connecting dots, specifically the dots at the lowest level of each dip in the 180-degree front-to-back value. Within the operating passband, the lowest front-to-back value exceeds 25 dB. Even at 400 MHz, we still have a front-to-back ratio that exceeds 13 dB.

The wide-band feedpoint data appear in **Fig. 5**. As with all long-boom Yagis that I have examined in detail, there are as many peaks in the resistance and reactance curves, and as many (largely invisible) dips in the SWR curve, as there are peaks in the 180-degree front-to-back curve across equal sweep ranges. In all wide-band impedance-setting cell designs, the resistance peaks and the inductive reactance peaks are offset, which tends to level the SWR. (The capacitive reactance peaks, of course, show up as visual dips, but they are equally offset.)

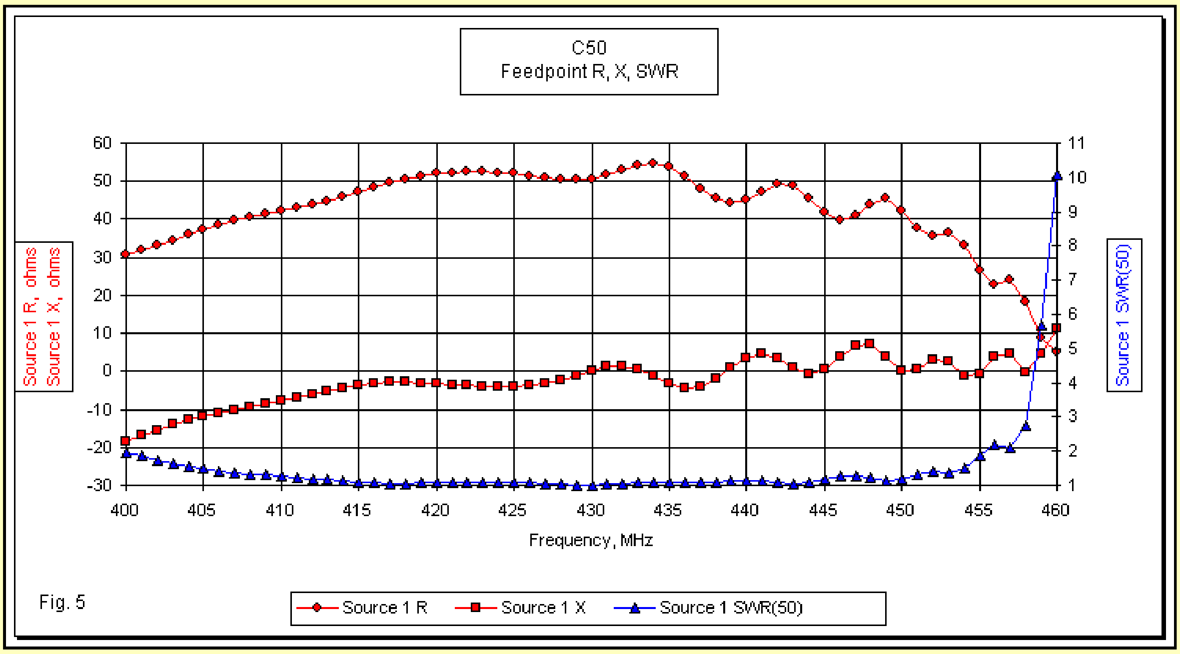


Fig. 5

The resistive component of the feedpoint impedance begins to drop significantly above 450 MHz. Hence, the SWR curve is only usable to about 455 MHz. At the low end of the sweep range, the SWR is usable all the way down to the lowest swept frequency. Between 420 and 450 MHz, the 50-Ohm SWR value only climbs above the specification limit of 1.25:1 at 2 frequencies: 446 and 447 MHz, but it remains below 1.3:1.

In the present context, **Fig. 6** may be the critical sweep. It shows the front-to-sidelobe ratio for the array in both the E-plane and the H-plane. The E-plane ratio remains above 20 dB all the way down to 420 MHz. The H-plane value drops slightly below 20 dB between 422 and 423 MHz, and at the band edge is 19.15 dB. The sidelobe ratios maintain a high ratio above the upper end of the 70-cm band.

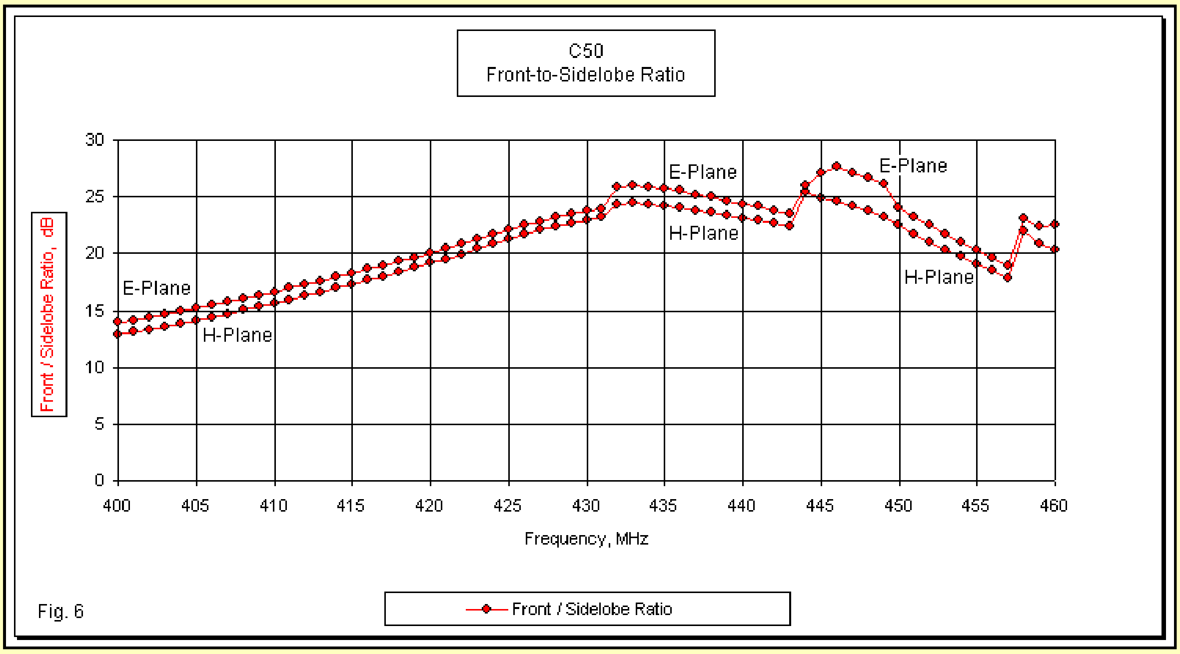


Fig. 6

The jagged nature of the curves calls for some explanation. If we examine the region from 430 to 432 MHz as an example, we shall encounter what amounts to a limitation in the way a modeling program identifies lobes in a pattern. **Fig. 7** presents E-plane patterns for 3 frequencies to show the situation. The graph curves for each plane are nicely parallel so that the explanation also applies to H-plane sidelobe curves.

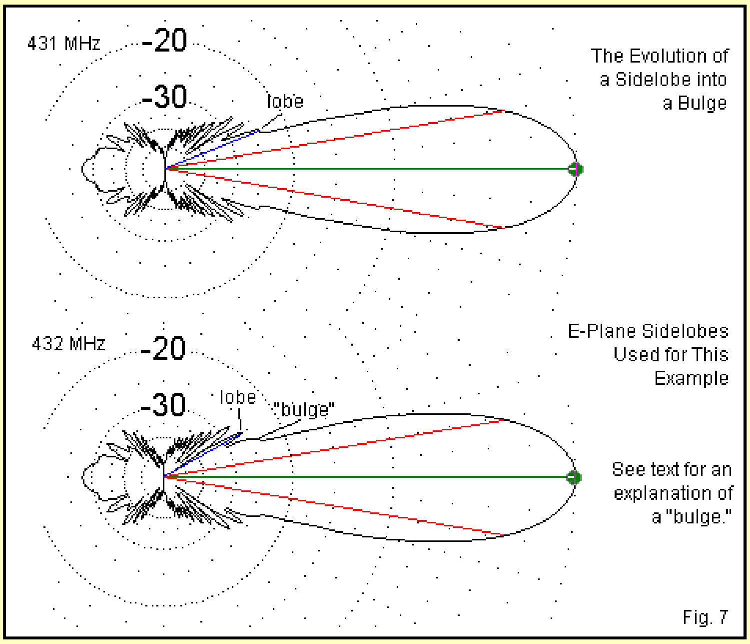


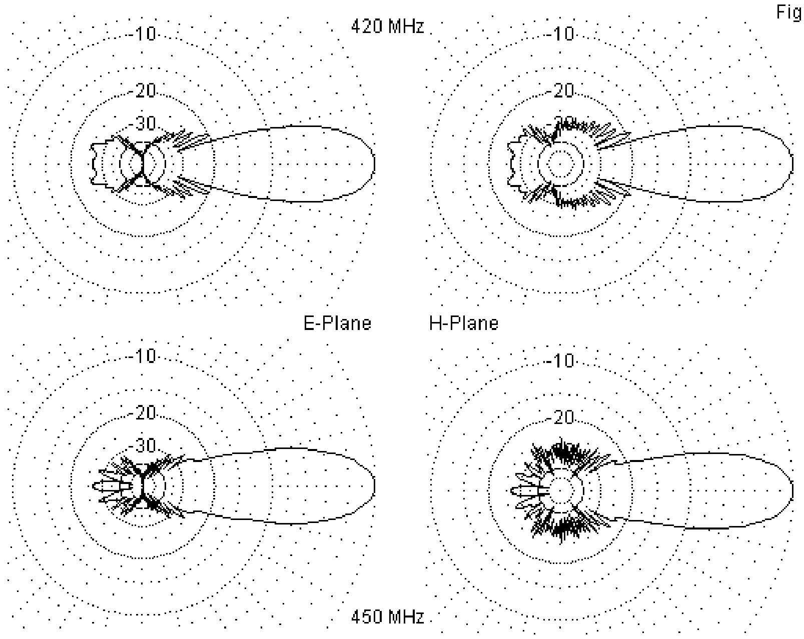
Fig. 7

In the pattern for 431 MHz, the sidelobe line identifies the strongest sidelobe. Modeling programs identify a lobe by detecting the fact that the gain value for a given direction in the pattern is higher than the gain values for both adjacent headings in the pattern. As earlier noted, the front-to-sidelobe ratio is the difference between the maximum forward and the gain at the identified sidelobe.

The most critical part of the exercise lies in the transition to 432 MHz. Sidelobes do not pop in and out of existence. Rather, they evolve. The first forward sidelobe both diminishes and folds into the main lobe as we increase the operating frequency. At a certain point in its life, it no longer presents a lower gain value on both sides of a peak value for some given increment of pattern survey. The patterns shown used an angular increment of 1 degree. At 432 MHz, the sidelobe does not show a lower gain value at this increment as we move toward the main-lobe bearing. (It might show such a lower gain value if we use a finer survey increment, such as 0.1 degree.) As a result, we may only view the remnant of the sidelobe as a "bulge" in the main lobe. In general, virtually all long-boom Yagis have "impure" main lobes, especially away from their design frequencies. Rather, the main lobe is the sum of numerous bulges. For shorter boomlengths, Yagi patterns at the upper ends of their operating ranges often show a "bullet" shaped pattern rather than the "tear-drop" pattern that appears at the design frequency.

The evolution of sidelobes affects not only the first forward sidelobe, but all sidelobes. Since the array shows its highest forward gain at a certain frequency (here, 432 MHz), the gain deficit at the band edges represents energy going elsewhere. Below the design frequency, part of this energy appears as a wider beamwidth. At 420 MHz, the beamwidth is over 1 degree wider than at 432 or 450 MHz. As well, some of the energy appears in the collection of sidelobes, both fore and aft of the headings at right angles to the main lobe heading. The result is often a more complex arrangement of lower order sidelobes. **Fig. 8** shows the E-plane and H-plane patterns of the C50 for both the E-plane and the H-plane. Compare the patterns to the lower part of **Fig. 1**, especially for the H-plane in which the geometry of the element tips along the total boomlength exerts less control over the sidelobe direction.

Fig. 8



E-Plane and H-Plane Patterns of the C50 at 420 and 450 MHz

Although the patterns shown have too small a scale to give more than a general impression, sidelobe analysis is significant to the overall evaluation of a Yagi design. For every wavelength of boom, there will be 4 sidelobes, 2 forward and 2 aft. Hence, the longer the boomlength, the more difficult it becomes to evaluate all sidelobes, especially if we examine patterns at low angular resolutions. (There are exceptions to the 4-lobe-per-boom-wavelength rule. Some Yagi design techniques may result in overlapping lobes so that the total number is fewer than the norm. However, techniques of true sidelobe suppression, rather than the attenuation shown by the C50, are still in their infancy and of uncertain utility.)

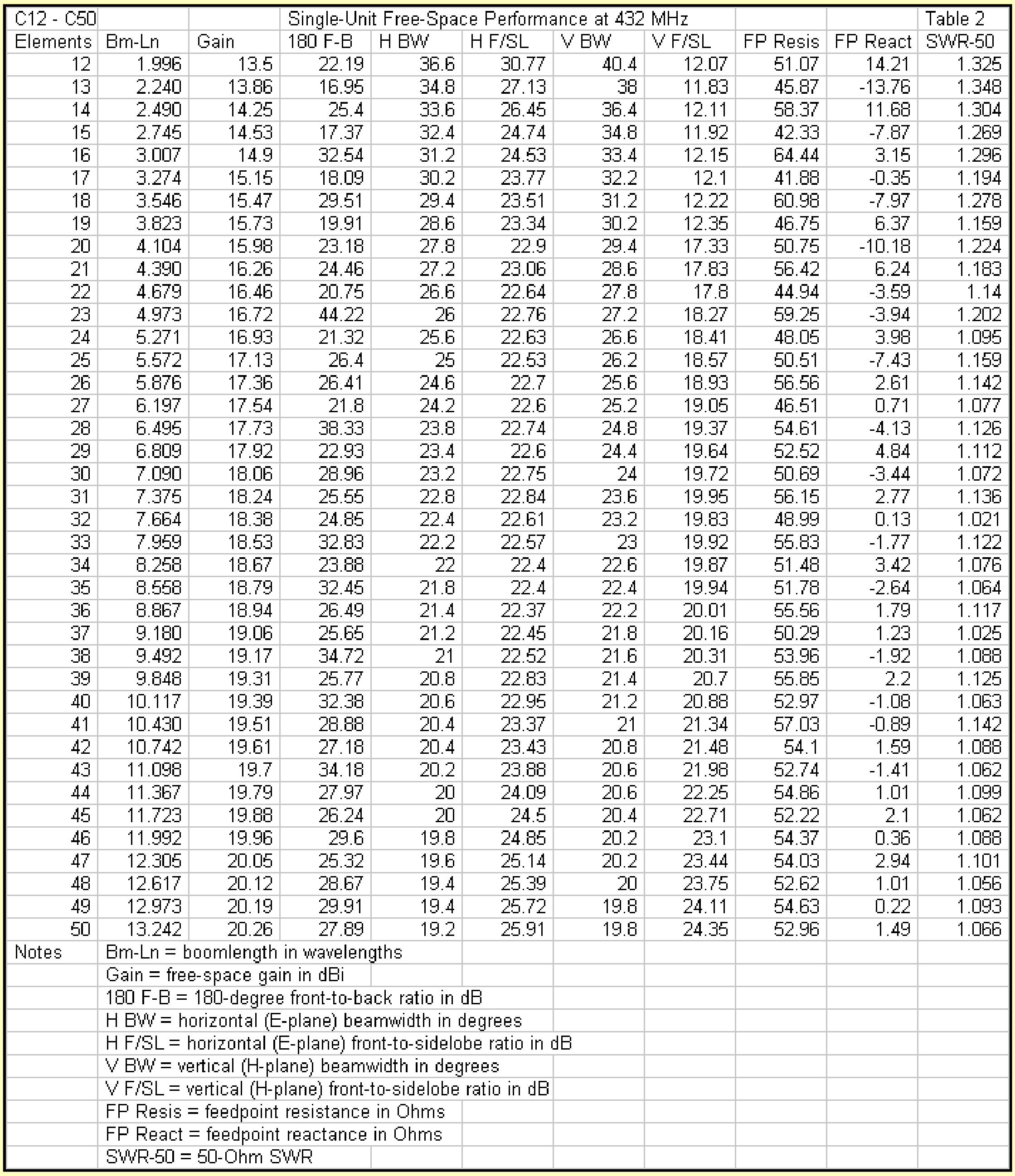
The extended sweep of the C50 shows that it almost meets every design specification. Where it falls short, it does so only in a minor way. Hence, as a long-boom Yagi for 432 MHz and surrounding frequencies, it appears to have adequate gain and other basic properties combined with high sidelobe attenuation. As I reported at the beginning of these notes, the sidelobes are down about 10 dB relative to more standard Yagi designs. The cost is small: a maximum forward gain level that is very slightly less than the maximum I have been able to squeeze from standard designs and the added weight of several more elements.

The C50 as a "Trimming" Yagi

The classic DL6WU Yagi design has some interesting properties. Foremost among them is the fact that it forms a "trimming" Yagi series. That is, to form a perfectly usable Yagi with a sorter boomlength than may be at hand, simply remove the forward-most directors down to the desired boomlength. The resulting Yagi will perform at the gain appropriate to the new boomlength and will have an adequate front-to-back ratio and a wide-band feedpoint impedance curve. In the history of long-boom Yagi design, there have been numerous other trimming Yagi series. They tend to result from the fact that a well-designed impedance-setting cell and the immediate directors ahead of it remain relatively stable, regardless of the number of added directors. For example, the DL6WU series is rated for booms from about 2 wavelengths up to about 39 wavelengths.

We may treat the C50 in the same manner, trimming directors one at a time down to a boomlength of about 2 wavelengths (12 elements). I do not recommend the trimming unless the operating properties are adequate to a particular application. Indeed, for the shortest lengths in the series, you may wish to optimize a particular design within whatever operating specifications you set. In the present context, the trimming exercise has a different function. It may tell use something about the design itself.

The exercise is simple enough at the design frequency. I simply removed the forward-most director and recorded data on the slightly shorter model at 432 MHz. The results of that exercise appear in tabular form in **Table 2**.



C12 - C50			Single-Unit Free-Space Performance at 432 MHz							Table 2
Elements	Bm-Ln	Gain	180 F-B	H BW	H F/SL	V BW	V F/SL	FP Resis	FP React	SWR-50
12	1.996	13.5	22.19	36.6	30.77	40.4	12.07	51.07	14.21	1.325
13	2.240	13.86	16.95	34.8	27.13	38	11.83	45.87	-13.76	1.348
14	2.490	14.25	25.4	33.6	26.45	36.4	12.11	58.37	11.68	1.304
15	2.745	14.53	17.37	32.4	24.74	34.8	11.92	42.33	-7.87	1.269
16	3.007	14.9	32.54	31.2	24.53	33.4	12.15	64.44	3.15	1.296
17	3.274	15.15	18.09	30.2	23.77	32.2	12.1	41.88	-0.35	1.194
18	3.546	15.47	29.51	29.4	23.51	31.2	12.22	60.98	-7.97	1.278
19	3.823	15.73	19.91	28.6	23.34	30.2	12.35	46.75	6.37	1.159
20	4.104	15.98	23.18	27.8	22.9	29.4	17.33	50.75	-10.18	1.224
21	4.390	16.26	24.46	27.2	23.06	28.6	17.83	56.42	6.24	1.183
22	4.679	16.46	20.75	26.6	22.64	27.8	17.8	44.94	-3.59	1.14
23	4.973	16.72	44.22	26	22.76	27.2	18.27	59.25	-3.94	1.202
24	5.271	16.93	21.32	25.6	22.63	26.6	18.41	48.05	3.98	1.095
25	5.572	17.13	26.4	25	22.53	26.2	18.57	50.51	-7.43	1.159
26	5.876	17.36	26.41	24.6	22.7	25.6	18.93	56.56	2.61	1.142
27	6.197	17.54	21.8	24.2	22.6	25.2	19.05	46.51	0.71	1.077
28	6.495	17.73	38.33	23.8	22.74	24.8	19.37	54.61	-4.13	1.126
29	6.809	17.92	22.93	23.4	22.6	24.4	19.64	52.52	4.84	1.112
30	7.090	18.06	28.96	23.2	22.75	24	19.72	50.69	-3.44	1.072
31	7.375	18.24	25.55	22.8	22.84	23.6	19.95	56.15	2.77	1.136
32	7.664	18.38	24.85	22.4	22.61	23.2	19.83	48.99	0.13	1.021
33	7.959	18.53	32.83	22.2	22.57	23	19.92	55.83	-1.77	1.122
34	8.258	18.67	23.88	22	22.4	22.6	19.87	51.48	3.42	1.076
35	8.558	18.79	32.45	21.8	22.4	22.4	19.94	51.78	-2.64	1.064
36	8.867	18.94	26.49	21.4	22.37	22.2	20.01	55.56	1.79	1.117
37	9.180	19.06	25.65	21.2	22.45	21.8	20.16	50.29	1.23	1.025
38	9.492	19.17	34.72	21	22.52	21.6	20.31	53.96	-1.92	1.088
39	9.848	19.31	25.77	20.8	22.83	21.4	20.7	55.85	2.2	1.125
40	10.117	19.39	32.38	20.6	22.95	21.2	20.88	52.97	-1.08	1.063
41	10.430	19.51	28.88	20.4	23.37	21	21.34	57.03	-0.89	1.142
42	10.742	19.61	27.18	20.4	23.43	20.8	21.48	54.1	1.59	1.088
43	11.098	19.7	34.18	20.2	23.88	20.6	21.98	52.74	-1.41	1.062
44	11.367	19.79	27.97	20	24.09	20.6	22.25	54.86	1.01	1.099
45	11.723	19.88	26.24	20	24.5	20.4	22.71	52.22	2.1	1.062
46	11.992	19.96	29.6	19.8	24.85	20.2	23.1	54.37	0.36	1.088
47	12.305	20.05	25.32	19.6	25.14	20.2	23.44	54.03	2.94	1.101
48	12.617	20.12	28.67	19.4	25.39	20	23.75	52.62	1.01	1.056
49	12.973	20.19	29.91	19.4	25.72	19.8	24.11	54.63	0.22	1.093
50	13.242	20.26	27.89	19.2	25.91	19.8	24.35	52.96	1.49	1.066
Notes	Bm-Ln = boomlength in wavelengths									
	Gain = free-space gain in dBi									
	180 F-B = 180-degree front-to-back ratio in dB									
	H BW = horizontal (E-plane) beamwidth in degrees									
	H F/SL = horizontal (E-plane) front-to-sidelobe ratio in dB									
	V BW = vertical (H-plane) beamwidth in degrees									
	V F/SL = vertical (H-plane) front-to-sidelobe ratio in dB									
	FP Resis = feedpoint resistance in Ohms									
	FP React = feedpoint reactance in Ohms									
	SWR-50 = 50-Ohm SWR									

Because the data may form a confusing mass, I have also constructed a few graphs to chart the progressions with increasing numbers of elements. (Graphing by pure boomlength would have added a complication to the graphs, and we can effectively only add a whole element at a time.) **Fig. 9** shows the free-space forward gain and the 180-degree front-to-back ratio.

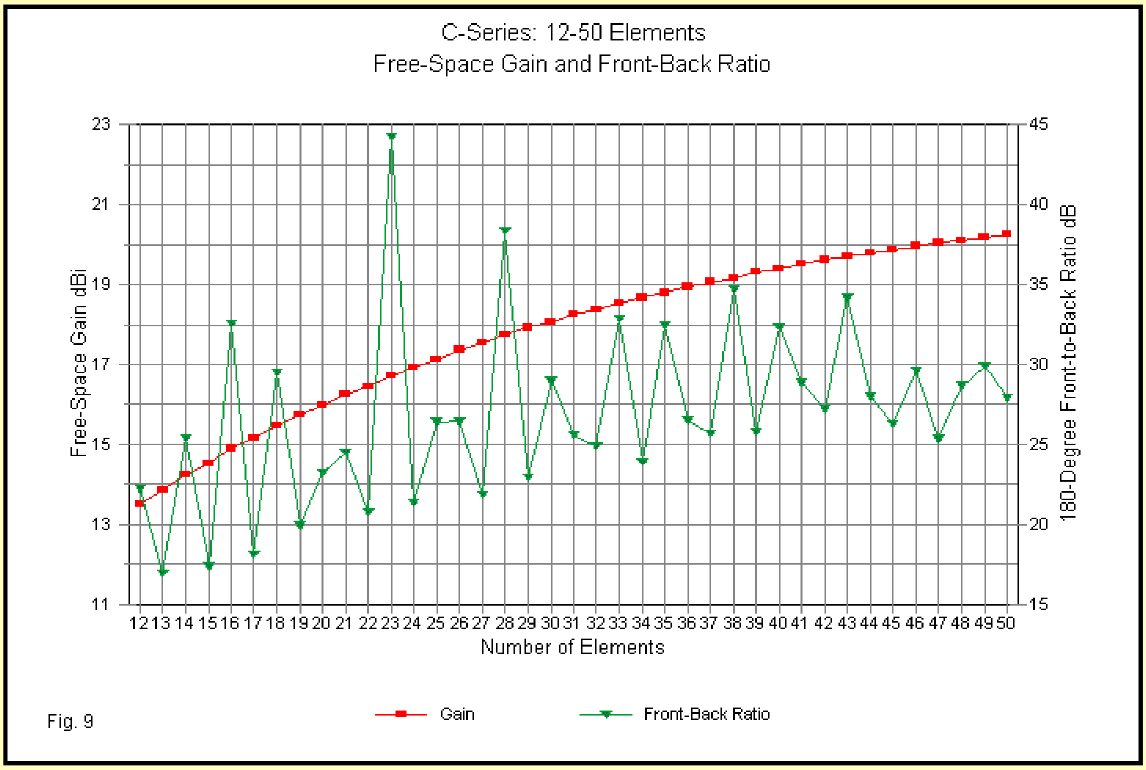


Fig. 9

The gain curve is entirely normal, with gain levels comparable to standard Yagi designs for each boomlength represented by the element count. The front-to-back ratio curve (or picket fence?) perhaps calls for a note. The 180-degree front-to-back peak value shifts in frequency for each added element. Sometimes, the peak is at or very close to the design frequency, and sometimes it is more distant, resulting in a lower value at 432 MHz. For any range of boomlengths (represented by the element count in the graph), the number of peaks that occur from the shortest to the longest boom is a function of the element density or average number of elements per unit of boomlength. Equally dense Yagi designs, even if different in in element placement and length, tend to show the same number of peaks for the same range of boomlengths. Both the DL6WU and the N6BV series of Yagis would show about 5 peaks for the range in which the C-series shows 16. Both of those other series use 38 elements total, whereas the C-series uses 50 total. The rise in the number of peaks is hence exponential with increases in element density.

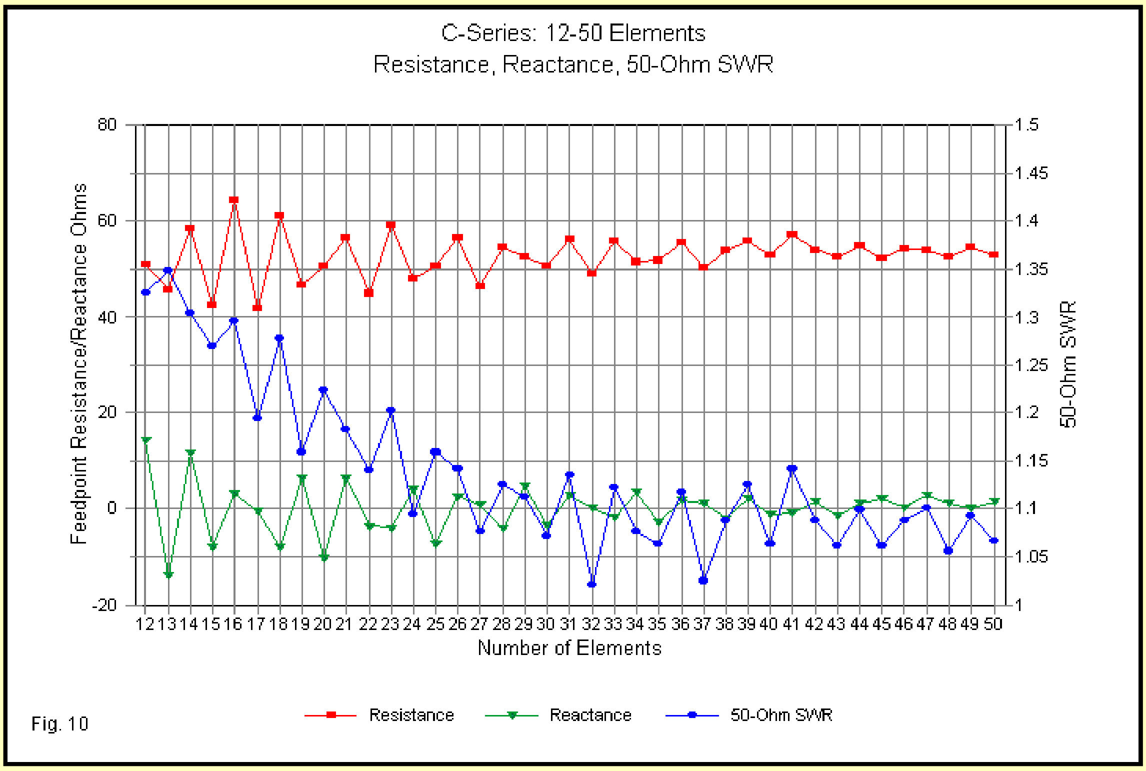


Fig. 10

Fig. 10 provides use with the feedpoint data across the range of possible C-series Yagis from 12 to 50 elements. Although the values are useable for the entire set, the fluctuations tend to flatten out noticeably somewhere close to the 28-element mark. The leveling out is not solely a function of the 50-Ohm SWR, but also appears in the resistance and reactance curves. Perhaps the most significant reason for showing this graph is to note that the number of peaks in either the resistance or the reactance (taking either the inductive or capacitive peak values) curve is close to the number of peaks in the front-to-back curve, usually the same or only 1 more or less. In our frequency sweep of the C50, we noted a similar relationship between the feedpoint conditions and the 180-degree front-to-back ratio value.

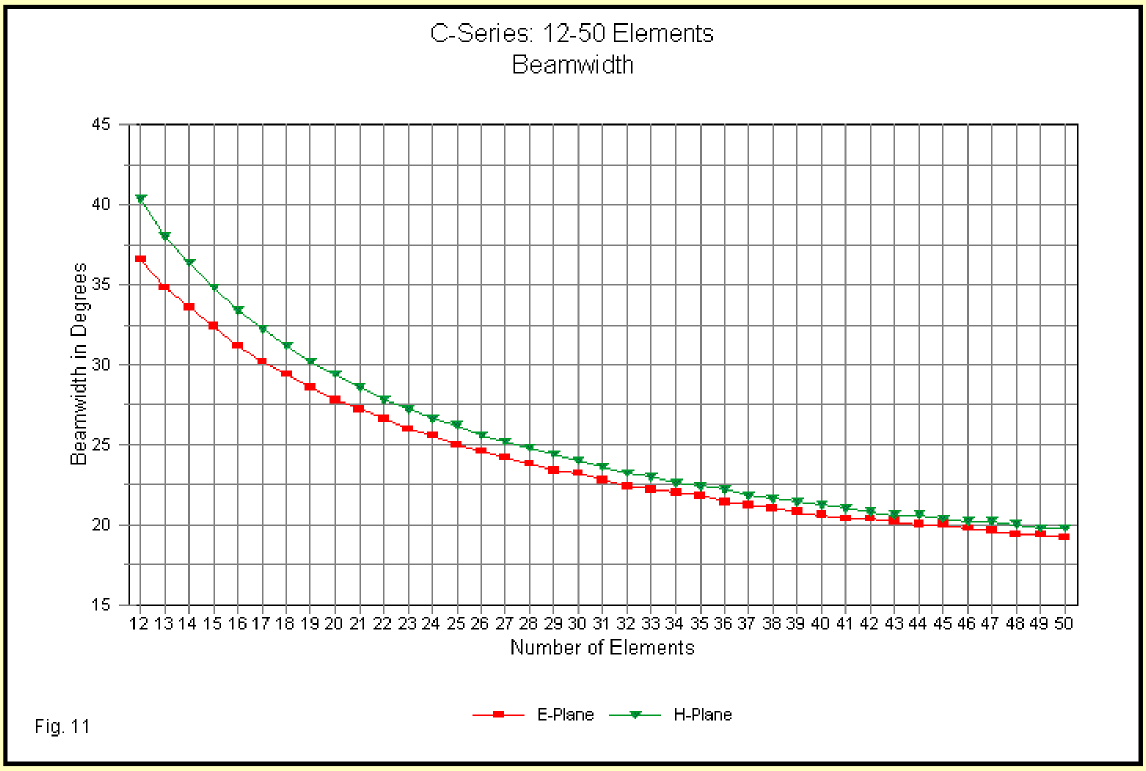


Fig. 11

In **Fig. 11**, we find something very normal: a smooth curve of both the E-plane and the H-plane beamwidth values. The longer the boom, the narrower the beamwidth, with the E-plane value always slightly narrower than the H-plane value. The longer the boom, the closer the two values grow toward each other. At the longest booms, we find a limitation within the modeling environment. The technical definition of a half-power point is that point in the pattern where the gain is 3-dB below the highest gain. With a limited sample of directions, the reported -3-dB points will rarely appear with precision. Therefore, any program must do one of two things. First, it can simply use the closest value to -3 dB or perhaps even the value that first exceeds -3 dB. Or, more complexly, it can interpolate the -3 dB point from the values at sampled headings just above and below that value, with a resulting interpolation of the heading at which the calculated values would occur. For such cases, it does not make much sense to carry the heading values (and the angular distance between them) to many decimal places. Whatever the system actually used, EZNEC gives the beamwidth heading values to 1 decimal place, with a resulting step of 0.2 degrees per total beamwidth change (a 0.1-degree change in heading on each side of the main lobe).

Most standard design Yagis would end the sequence of graphs at this point. Traditionally, Yagi designers have let the front-to-sidelobe ratio be what emerged from the design. However, we have treated the C-series as a design for applications where higher sidelobe attenuation is needed. Hence, **Fig. 12** is a necessary addition to the record of data trends.

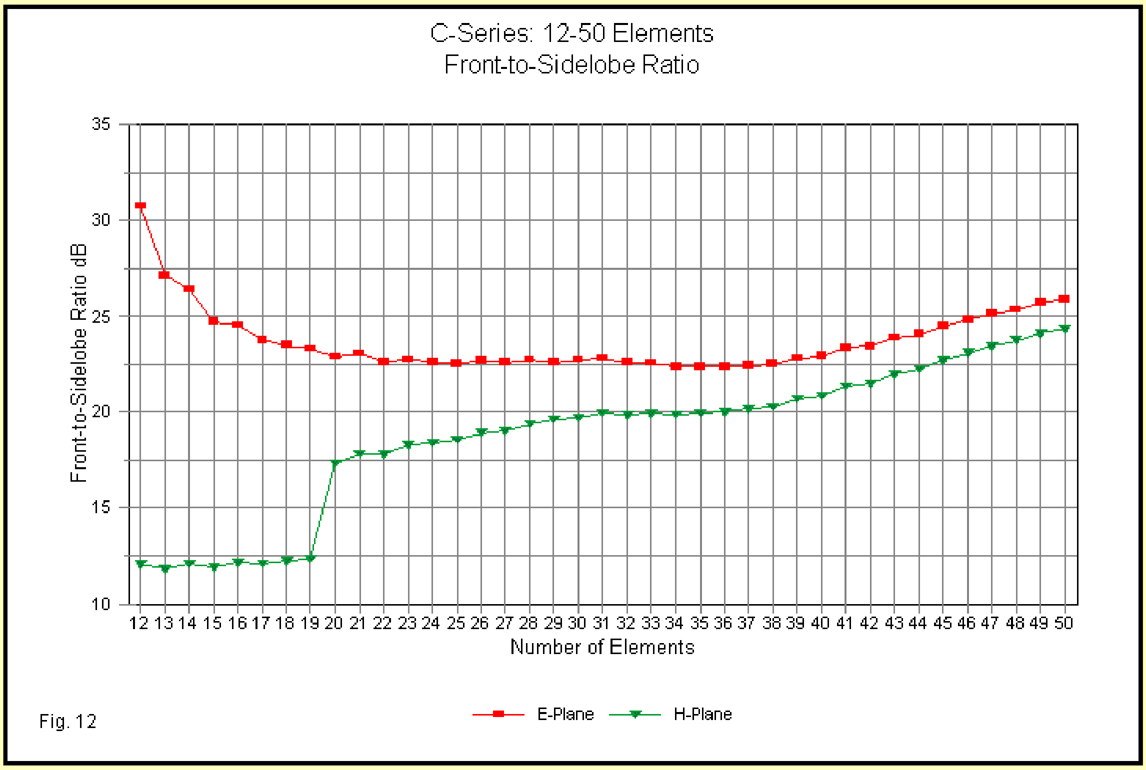


Fig. 12

First, let's tackle the sudden drop in the H-plane front-to-sidelobe ratio between 20 and 19 elements. The drop is not nearly so sudden as the graph makes it appear. At 20 elements, the main sidelobe is actually a bulge of the order that we examined earlier. However, it is the main bulge, with other sidelobes very much weaker. At 19 elements, the modeling program can detect with a 1-degree pattern increment a lower gain on either side of the bulge. Hence, the bulge takes its place among the identified sidelobes. However, the bulge is large enough to make the use of the C-series questionable with respect to sidelobe reduction for many elements longer than the 20-element transition point.

In fact, the imperfection of the C-series as a trimming-Yagi series shows itself at the opposite end of the scale. The sidelobe ratio in both planes is on a rising curve relative to increasing boomlength at the 50-element mark. Every unit shorter reduces the sidelobe performance by a small amount. At the design frequency, the sidelobe properties level off in the 20-dB region, with usable lengths down to perhaps 31 elements (a little under 7.4 wavelengths of boom). However, expect sidelobe performance that is poorer as we move away from the design frequency, especially downward. Hence, the shorter the C-series Yagi, the more it becomes a spot-frequency Yagi in terms of its sidelobe performance, even though it retains quite usable performance in all other categories for even shorter versions. As well, in general, the sidelobe performance will exceed that of most other designs from the 25-element range upward. For truly wide-band use with very high sidelobe performance, perhaps the minimum recommended element count is 43 (or 11 wavelengths of boom).

A more perfect Yagi with sidelobe performance as one of the design specifications would show more level properties of front-to-sidelobe ratio throughout more of its range. Whether achieving this goal is possible in a trimming series is not known at this time. Detailed revisions to both element spacing and element length are the routes to discovering if the C-series is amenable to being a truly adequate trimming Yagi in all respects. However, it may also be the case that for each length of boom, individual optimization may be required to achieve the added 10 dB of sidelobe attenuation attained by the C50 itself. Of course, anyone is free to develop a C60.

The design exercise that we have examined in these notes has aimed to show that it is possible to design a long-boom Yagi with high sidelobe performance while retaining both wide-band operation and reasonably good gain and front-to-back performance. The compression of element spacing combined with a usable element-length schedule has produced such a design, whatever the practicality of its use. But the study also shows that we still have a considerable ways to go before we can master the art of long-boom Yagis. Along that route, the techniques used to develop the C50 are but clues to a complex set of design parameters.

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