Notes on the OWA Yagi

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Perhaps the most read source of information on the "Optimized Wideband Antenna (OWA) Yagi" comes from a series of web-site entries by Nathan Miller, NW3Z, and Jim Breakall, WA3FET (http://www.contesting com/wa3fet/owa.htm). Besides providing a very brief background for the design features of the OWA Yagi, the articles present specific designs for the upper HF bands used in contests.

According to the OWA account, when we place a parasitic element close (less than 0.01 wavelength) ahead of a driven element, we obtain wide-band performance, that is, a low SWR relative to 50 Ohms and smooth gain and front-to-back performance over a wide HF amateur band (20, 15, and 10 meters). The authors suggest that the driver and first director perform as if they were a single element having a diameter equal to the spacing between the two elements.

Extensive NEC-4 modeling studies of the actual OWA designs suggest that we may need an expanded account of how these antennas work. As well, these modeling investigations also suggest some unanticipated benefits of OWA design in antennas larger than the typical 6-element HF design. To demonstrate these suggestions, I have transferred the OWA design to 2-meters, where full coverage of 144 to 148 MHz is often a challenge. The band exhibits a 2.7% bandwidth relative to its center frequency (146 MHz), which is wider than most of the HF bands from 20 meters on up, with the exception of the first MHz of 10 meters, which has a bandwidth of about 3.5%. We shall look briefly in these proceedings at even wider bandwidths.

As well, modeling the antennas at 2 meters permits the use of uniform-diameter elements. These elements allow simplified models, from the standpoints of both optimizing a design and reading the results. All of the models that we shall selectively survey will presume elements that are well insulated and isolated from any conductive support boom. A number of the designs have been successfully built, with performance meeting the modeled expectations.

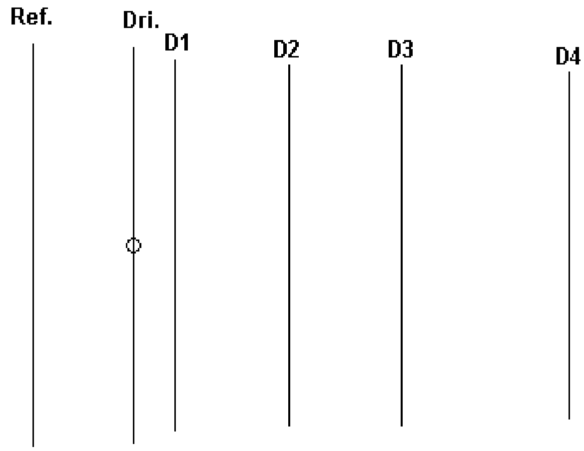
Modeling permits us to view the current magnitude and phase angle on each element (using the element center) relative to the source or feedpoint current. The current data will provide us with important clues in the search for an expanded understanding of OWA operation. The downside of the investigation technique is that our presentation will be heavily laden with graphs and tables.

Despite an appearance of extensive investigation, this study is incomplete. It samples only a few of the many OWA designs in my stock, and even if they seem typical, I cannot make a claim of complete coverage. Hence, the conclusions are only suggestive, but not in any way authoritative. If past Yagi developments teach anything, it is that something new lies ahead in the development of parasitic arrays.

Introduction to a 6-Element 2-Meter OWA Yagi

We shall begin with the 6-element 2-meter OWA Yagi whose outline appears in **Fig. 1**, with dimensions shown in **Table 1**. The outline sketch provides the traditional element designations, which include a single reflector, a single driver, and 4 directors. However, before we are finished with this beam, we shall have occasion to rethink our element designations. The design is an adaptation of an NW3Z/WA3FET 20-meter design.

Fig. 2-1



6-Element 2-Meter OWA Yagi

Model OWA2M616 Dimensions

Element	Length	Cumulative Spacing		Individual Spacing		
	Inches	WL	Inches	WL	Inches	WL
Refl	40.52	0.501	-----	-----	-----	-----
Driver	39.96	0.494	10.13	0.125	10.13	0.125
Dir 1	37.38	0.462	14.32	0.177	4.19	0.052
Dir 2	36.31	0.449	25.93	0.321	11.61	0.144
Dir 3	36.31	0.449	37.28	0.461	11.35	0.140
Dir 4	34.96	0.433	54.22	0.671	16.94	0.210

Table 1. Dimensions of a 6-element 2-meter OWA Yagi, using 0.1875" (3/16") diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 146 MHz.

The dimensions in **Table 1** should arouse our interest. I have given them in terms of inches and wavelengths for convenience. The first director is 0.052 wavelength from the driver, in accord with the general OWA design precepts. However, note the lengths of directors 2 and 3: they are identical. (In actuality, OWA designs of this type may use a 3rd director that is slightly shorter or slightly longer--by up to about 1%--than director 2, according to overall design goals.) The lengths of these two directors are no accident, even if their role in the OWA design is often overlooked.

There is often a vast difference between the exceptionally wide 50-Ohm SWR curve of an OWA design and the intended operating bandwidth of the antenna. **Table 2** presents the modeled characteristics of this 6-element Yagi from 139 to 149 MHz, even though the performance characteristics focus on the 144-148-MHz span. The design goals use typical amateur radio guidelines for the 0.67-wavelength boom: a free-space gain of at least 10 dBi, a 180-degree and worst-case front-to-back ratio of at least 20 dB, and as flat a 50-Ohm SWR as we may achieve. **Fig. 2** shows that the antenna easily meets the gain and front-to-back guidelines from 144 to 148 MHz.

6-Element 2-Meter OWA Yagi

Perform											
Freq.	139	140	141	142	143	144	145	146	147	148	149
FS Gn	9.38	9.68	9.86	9.97	10.06	10.13	10.19	10.23	10.23	10.16	10.01
180FB	8.34	10.61	12.9	15.35	18.23	22.04	28.2	35.39	26.71	22.17	20
R	27.85	32.99	37.33	40.51	42.78	44.79	47.18	49.97	50.82	43.6	27.9
X	-8.58	-3.56	-0.1	2.56	5.07	7.61	9.62	9.52	5.18	-1.719	-0.98
SWR50	1.871	1.529	1.34	1.244	1.21	1.215	1.229	1.21	1.109	1.152	1.793
Currents											
Ref-M	0.805	0.764	0.708	0.647	0.588	0.54	0.503	0.472	0.428	0.34	0.208
REF-P	147.5	138.36	130.1	123.08	117.28	112.2	106.78	99.29	87.69	71.67	57.19
D1-M	0.492	0.592	0.686	0.771	0.856	0.952	1.079	1.257	1.481	1.657	1.641
D1-P	-76.11	-80.96	-86.43	-91.64	-96.19	-100.1	-104.1	-109.5	-118.6	-132.8	-148.4
D2-M	0.369	0.437	0.5	0.558	0.613	0.67	0.733	0.799	0.845	0.809	0.655
D2-P	233.1	224.3	214.8	205.1	195.4	185.5	174.69	161.83	145.43	125.6	107.83
D3-M	0.34	0.403	0.462	0.52	0.58	0.649	0.735	0.844	0.962	1.02	0.949
D3-P	174.94	164.96	154.44	143.9	133.48	122.87	111.43	97.47	79.44	56.65	33.21
D4-M	0.301	0.357	0.41	0.459	0.508	0.561	0.623	0.696	0.763	0.769	0.67
D4-P	92.97	80.21	66.75	53.06	39.26	25.02	9.58	-8.47	-30.94	-58.41	-86.67
D2 vs. D3	Current										
Mag Ratio	1.085	1.084	1.082	1.073	1.057	1.032	0.997	0.947	0.878	0.793	0.69
Ph Dif	58.16	59.34	60.66	61.2	61.92	62.63	63.35	64.36	65.99	68.95	74.62

Table 2. NEC-4 reported performance data for model OWA2M616 from 139 to 149 MHz. Performance data consist of the free-space gain in dBi, the 180-degree front-to-back ratio in dB, the feedpoint resistance and reactance in Ohms, and the 50-Ohm SWR. Current data consist of the relative current magnitude (M) and phase angle (P) on the center segment of each element, where the driver current magnitude is always 1.0 and the driver phase angle is always 0.0 degrees. The Director 2 and Director 3 special current data consist of the ratio of current magnitude from Director 2 to Director 3 and of the current phase angle difference between the two directors. See text for data interpretation.

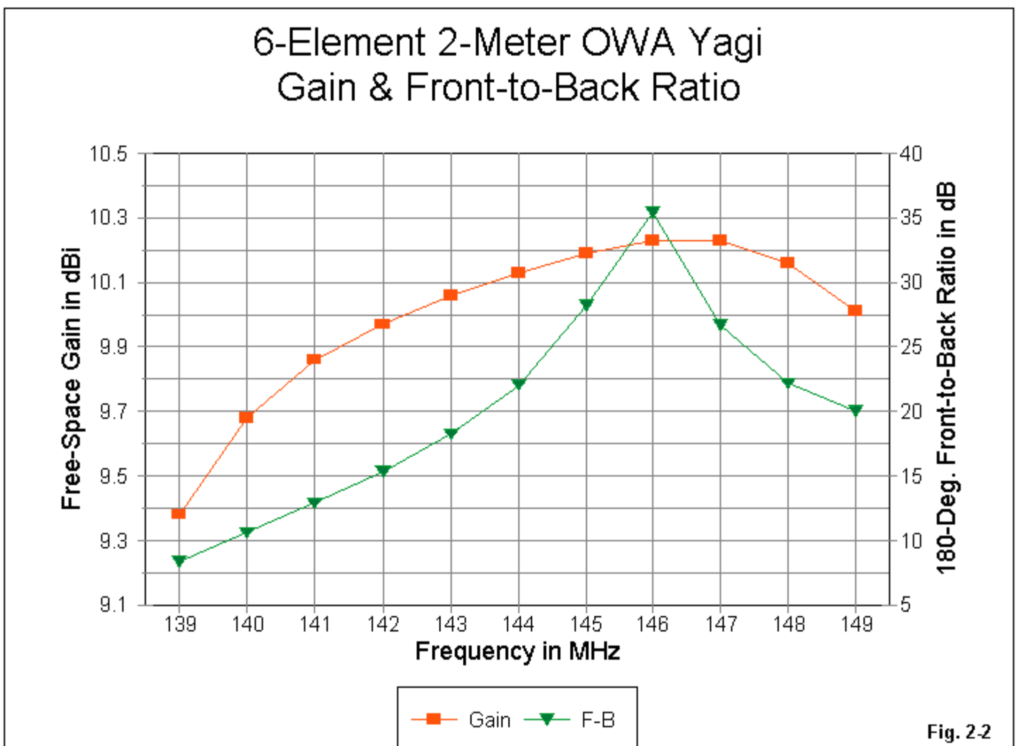


Fig. 2-2

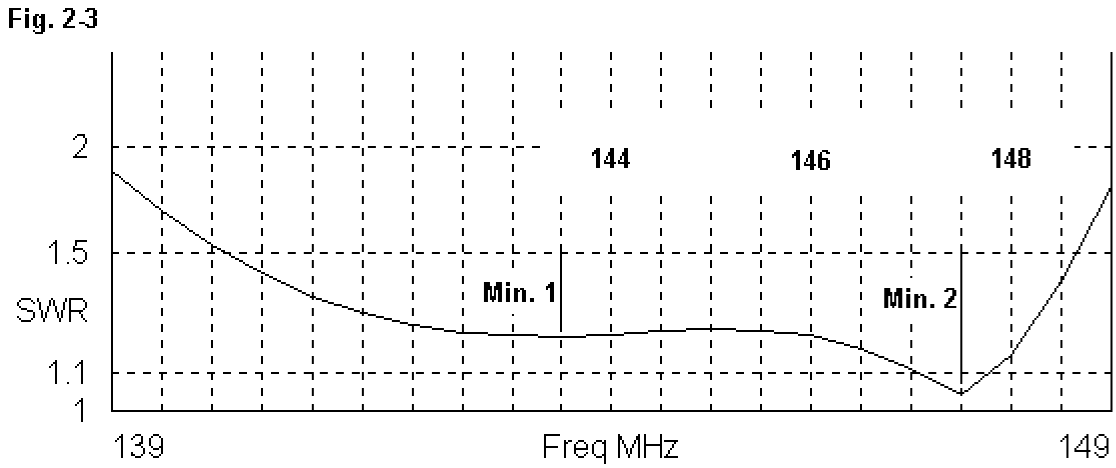
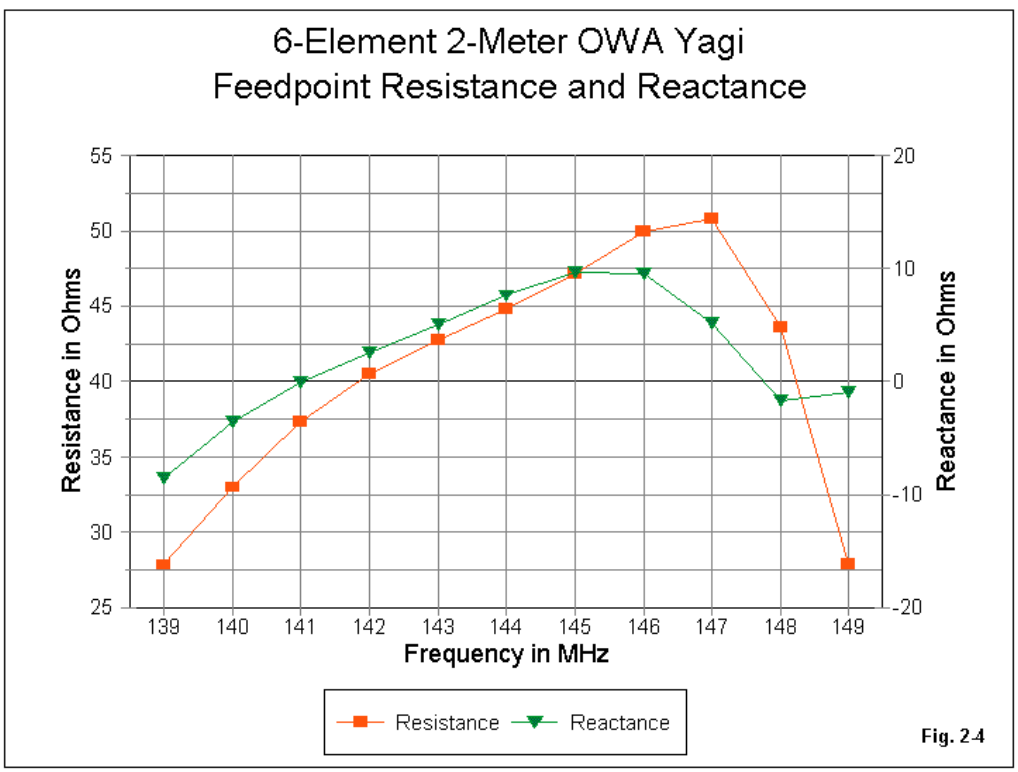


Fig. 3 presents the 50-Ohm SWR curve for the array from 139 to 149 MHz. The curve is typical of optimized OWA designs. (Yes, even an optimized wideband antenna may be optimized within its overall design parameters.) Most noticeable and telling is the presence of two dips in the SWR, one shallow dip at 143 MHz and one very sharp dip near 147.5 MHz. The rise in SWR above 148 MHz is very steep, while below the operating passband for the antenna, the SWR rises very slowly.



The graph of resistance and reactance across the entire scanned spectrum, **Fig. 4**, shows us why the SWR remains so flat. The feedpoint resistance and reactance both vary across an extremely small range, with the largest incremental changes occurring above the operating passband. The reactance begins as a small capacitive value, changes to a set of inductive values, and returns to capacitive values at the high end of the scanned passband. We might miss these patterns if we only look only within the operating passband for the antenna.

Most OWA designs place the operating passband near the upper end of the SWR passband. In this region, we usually find the lowest SWR value in conjunction with the flattest curve at the lower end of the impedance passband. However, the steep rise in SWR above the operating passband requires significant care in array construction to avoid moving the SWR curve into the region of rapid change. In fact, nothing dictates that the operating passband must be in this region. Indeed, with lesser levels of gain and front-to-back ratio, we may spread the operating region across most of the low SWR region. Moreover, the width of the "low" SWR region is limited mostly by the level to which we are willing to allow the SWR to rise between the minima. Most, but not all, extant OWA designs try to keep the mid-region values as low as feasible.

Designing an OWA Yagi, then, is a balance between the operating specifications (and possibilities for a given boom length) on the one hand and the desired SWR level and curve on the other. Changing one or the other set of specifications will alter the resulting physical design. Hence, there can be no "ultimate" OWA design. However, with a given set of operating and SWR specifications, we can try to see how the OWA achieves its goals.

OWA-1: Understanding the OWA with Reference to the Reflector, Driver, and First Director

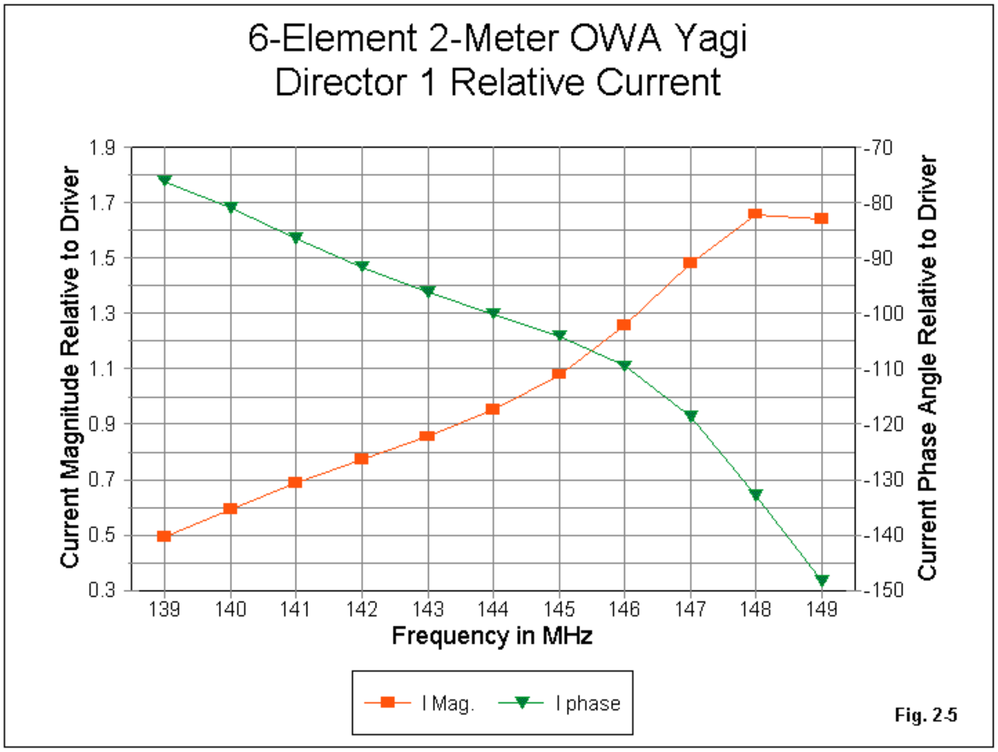
The initial perspective that we shall take on the OWA follows the received account of its operation. The spacing between the driver and the first director sets the 50-Ohm SWR curve for the array. Of course, the length and spacing of the reflector play a significant role in establishing the reference impedance for the SWR curve--in addition to playing a smaller role in setting the operational band-edge performance of the array.

With this perspective applied to our initial 6-element OWA Yagi, we find a reflector about 1/8-wavelength behind the driver, with the first director spaced about 0.052-wavelength ahead. If we set the driver current magnitude to a value of 1.0 and a phase angle of 0.0 degrees for every scanned frequency, we may track the relative current magnitude and phase angle on the first (close-spaced) director. **Fig. 5** shows the results of this exercise.

As expected, the first director shows a negative current phase angle relative to the driver. However, note that the curve steepens, indicating a greater rate of change above about 146 MHz. At the same time, the current magnitude on the first director continuously increases with a rising frequency--until we reach 148 MHz. The current magnitude is actually greater on the first director than on the driver from 145 MHz upward.

In effect, the driver and first director actually form a primary (fed) driver and secondary (parasitic) driver pair. (When applied to different frequency bands, the pair sometimes go under the names master and slaved driver. However, for in-band applications, the terms primary and secondary may be more apt.) As the secondary driver becomes dominant, the rate of change of its current phase-angle increases.

The question that remains is this: is the account sufficient to set the OWA design apart as unique?

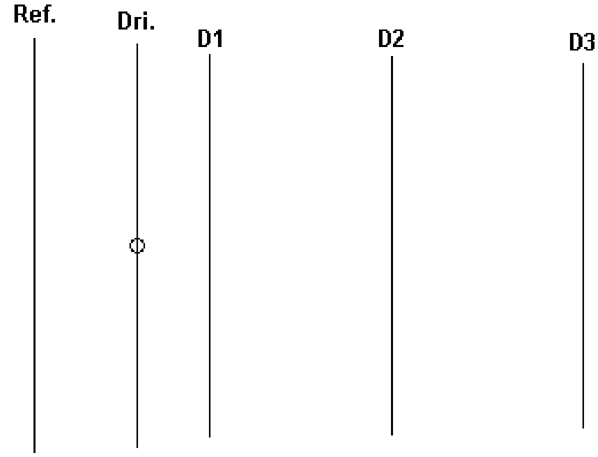


If we limit our investigation only to the reflector/driver/first-director trio of elements, then the concept is not new, but only refined by the use of very close spacing of director 1 to the driver. For example, the DL6WU family of VHF/UHF Yagis uses 0.075-wavelength spacing for director 1 to obtain very wide-band operation for Yagis ranging from 6 to *n* elements. See Chapter 7 (by Gunter Hoch, DL6WU) of the RSGB publication, *The VHF/UHF DX Book*, edited by Ian White, G3SEK, for perhaps the last iteration of this classic set of Yagis. Experimental Yagi designs using "fat" elements have achieved operating bandwidths (including usable gain and front-to-back ratios) of greater than 23% of the central frequency of the passband.

At a more modest size--in fact, very comparable in boom length to our 6-element OWA Yagi--is an adaptation of a 5-element wide-band Yagi design that originated from the work of Jack Reeder, W6NGZ (now WW7JR), and that appeared in *CQ* for October, 1996. The design made no pretense about using OWA principles, but simply strove to cover 20 meters within the usual standards for good amateur radio performance. I have adapted the design to 3/16" elements and 2 meters for comparison with the 6-element OWA design.

Fig. 6 shows the array outline for comparison with the OWA outline in **Fig 1**. **Table 3** provides the dimensions, which show the boom length to be about 3/4" shorter than the 6-element OWA. However, there are only 5 elements. The reflector is about 0.123 wavelength behind the driver, with the first director 0.089 wavelength ahead.

Fig. 2-6



5-Element 2-Meter Wide-Band Yagi

Model 2M5EL16 Dimensions

Element	Length	Cumulative Spacing		Individual Spacing		
	Inches	WL	Inches	WL	Inches	WL
Refl	40.46	0.501	-----	-----	-----	-----
Driver	39.26	0.486	9.90	0.123	9.90	0.123
Dir 1	37.19	0.460	17.10	0.212	7.20	0.089
Dir 2	36.88	0.456	34.80	0.431	17.70	0.219
Dir 3	35.64	0.441	53.50	0.662	28.70	0.231

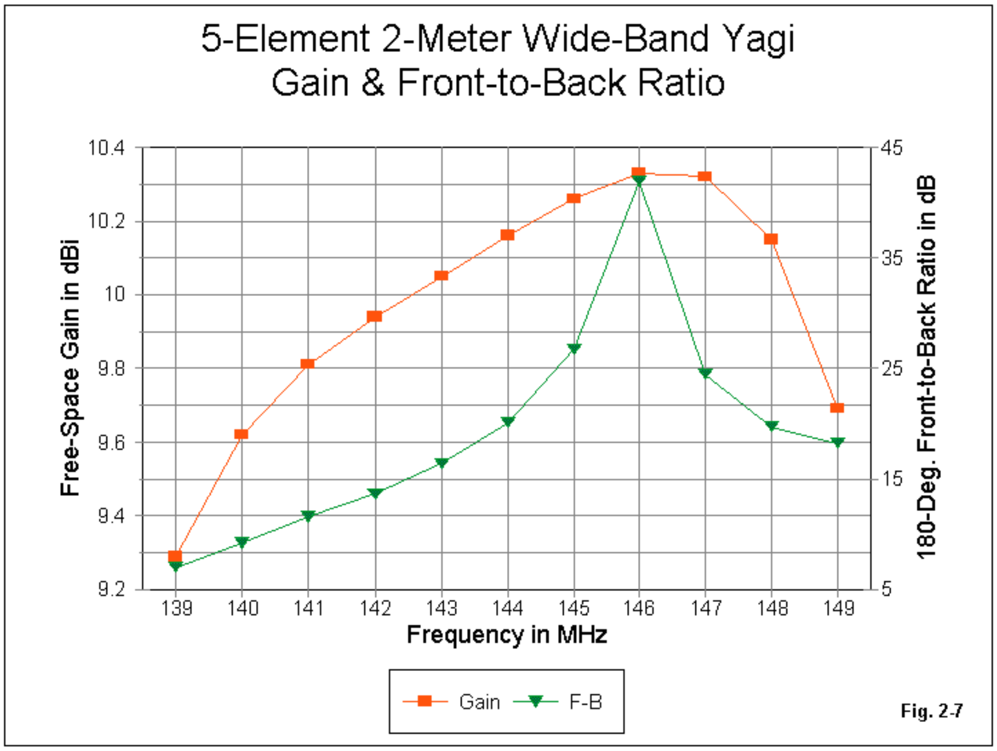
Table 3. Dimensions of a 5-element 2-meter wide-band Yagi, using 0.1875" (3/16") diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 146 MHz.

5-Element 2-Meter Wide-Band Yagi

Performance											
Freq.	139	140	141	142	143	144	145	146	147	148	149
FS Gn	9.29	9.62	9.81	9.94	10.05	10.16	10.26	10.33	10.32	10.15	9.69
180FB	7.02	9.18	11.53	13.65	16.37	20.11	26.75	41.94	24.47	19.73	18.23
R	25.09	29.83	33.44	35.21	35.43	35.08	35.46	38.1	43.5	39.13	15.36
X	-20.77	-15.5	-12.09	-9.41	-6.26	-1.99	3.23	8.02	7.52	-4.93	-1.75
SWR50	2.427	1.911	1.643	1.514	1.454	1.43	1.422	1.387	1.237	1.309	3.26
Currents											
Ref-M	0.818	0.77	0.699	0.618	0.542	0.484	0.45	0.438	0.426	0.319	0.099
REF-P	152.42	143.2	135.02	128.74	124.83	123	121.82	118.4	107.48	83.68	80.34
D1-M	0.507	0.61	0.7	0.77	0.824	0.873	0.942	1.081	1.379	1.759	1.658
D1-P	-78.73	-85.44	-93.02	-100.3	-106.3	-110.6	-112.9	-114.3	-119.4	-137.9	-161.6
D2-M	0.381	0.461	0.539	0.613	0.689	0.779	0.904	1.099	1.399	1.537	1.221
D2-P	206.8	197.5	187.3	177.03	167.1	157.41	147.13	134.2	113.77	78.54	40.69
D3-M	0.316	0.379	0.437	0.487	0.531	0.579	0.641	0.734	0.869	0.91	0.623
D3-P	108.7	95.73	81.74	67.54	53.54	39.65	25.09	7.86	-16.82	-56.15	-97.8
D1 vs. D2	Currents										
Mag Ratio	1.331	1.323	1.299	1.256	1.196	1.121	1.042	0.984	0.986	1.144	1.358
Ph Dif	285.53	282.94	280.32	277.33	273.4	268.01	260.03	248.5	233.17	216.44	202.29

Table 4. NEC-4 reported performance data for model 2M5EL16 from 139 to 149 MHz. Performance data consist of the free-space gain in dBi, the 180-degree front-to-back ratio in dB, the feedpoint resistance and reactance in Ohms, and the 50-Ohm SWR. Current data consist of the relative current magnitude (M) and phase angle (P) on the center segment of each element, where the driver current magnitude is always 1.0 and the driver phase angle is always 0.0 degrees. The Director 1 and Director 2 special current data consist of the ratio of current magnitude from Director 1 to Director 2 and of the current phase angle difference between the two directors. See text for data interpretation.

Table 4 supplies a complete performance table comparable to the data in Table 2 for the 6-element OWA Yagi. We can begin by comparing **Fig. 7** to **Fig. 2** to gauge the success of the 5-element design in achieving the performance goals. In fact, the performance curves in the two figures have very similar shapes, with the smaller design having lower performance numbers at the scanning limits. From the table, you may determine that over the 144-148-MHz operating passband, the 5-element Yagi misses the 20-dB front-to-back ratio guideline by an amount too small to make any difference.



The feedpoint resistance and reactance curves in **Fig. 8** also show considerable similarity to those for the OWA Yagi in **Fig. 4**. The median resistance is in the 35-40-Ohm range due to the spacing of the reflector from the driver. The original array for 20 meters was designed to a certain boom length limit, so long as the 50-Ohm SWR values remained below 2:1 within the operating passband. **Fig. 9** shows the 5-element Yagi 50-Ohm SWR curve. It exhibits the same general shape as the one for the OWA Yagi (**Fig. 3**), but without a definite minimum within the lower frequency region of the span. Had we used a reference impedance of 35 to 40 Ohms, the overall curve would have come closer to achieving better than 2:1 values across the scanned passband.

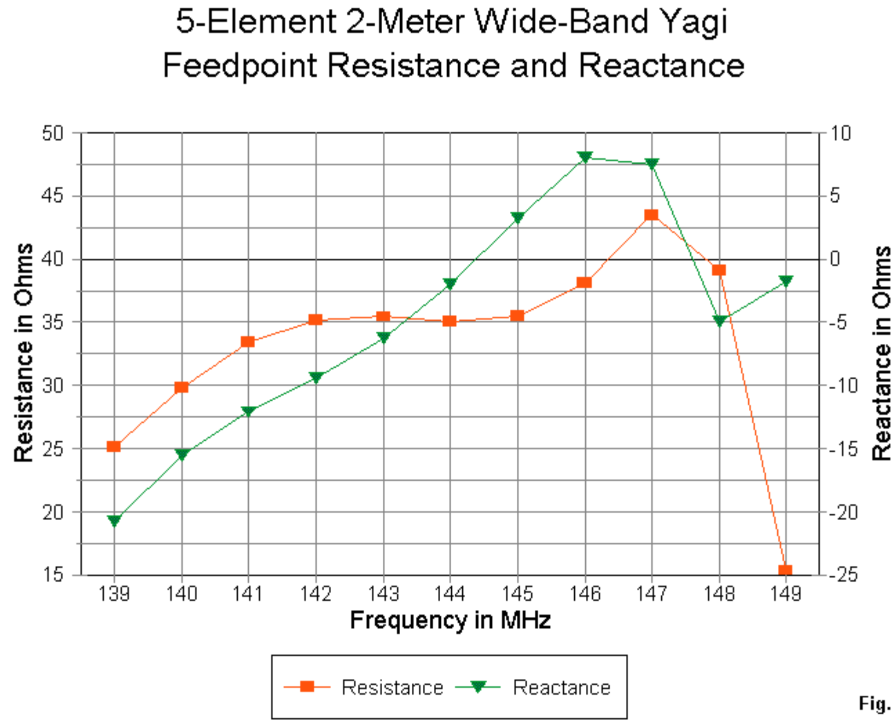
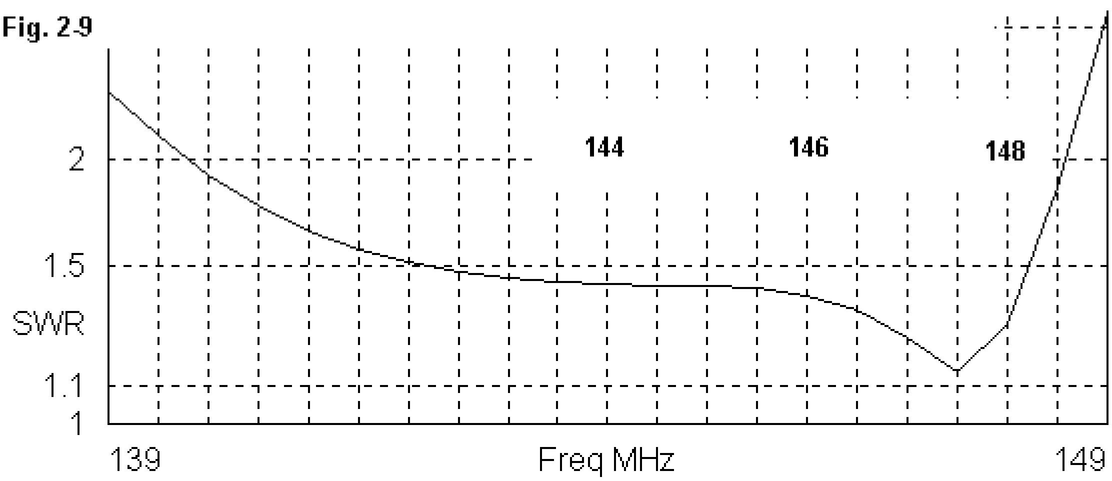


Fig. 2-8

Fig. 2-9



Like the 6-element OWA Yagi, the first director functions as a secondary driver. Between 145 and 146 MHz, the current magnitude exceeds a ratio of 1.0:1 relative to the current magnitude on the primary driver, as shown in **Fig. 10**. Indeed, allowing for the difference in curve shapes that is due to changes in the axis increments, the curves for both current magnitude and phase angle a remarkably similar. Only the current phase angle of the smaller array increases at a higher rate at the upper limit of the scanned frequency range.

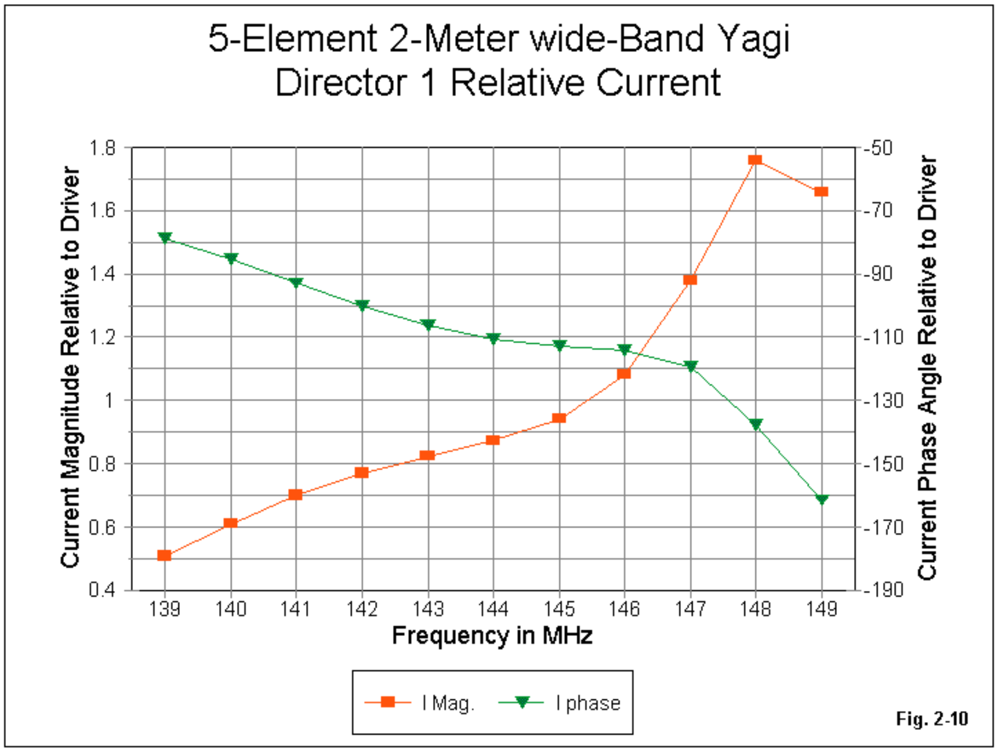


Fig. 2-10

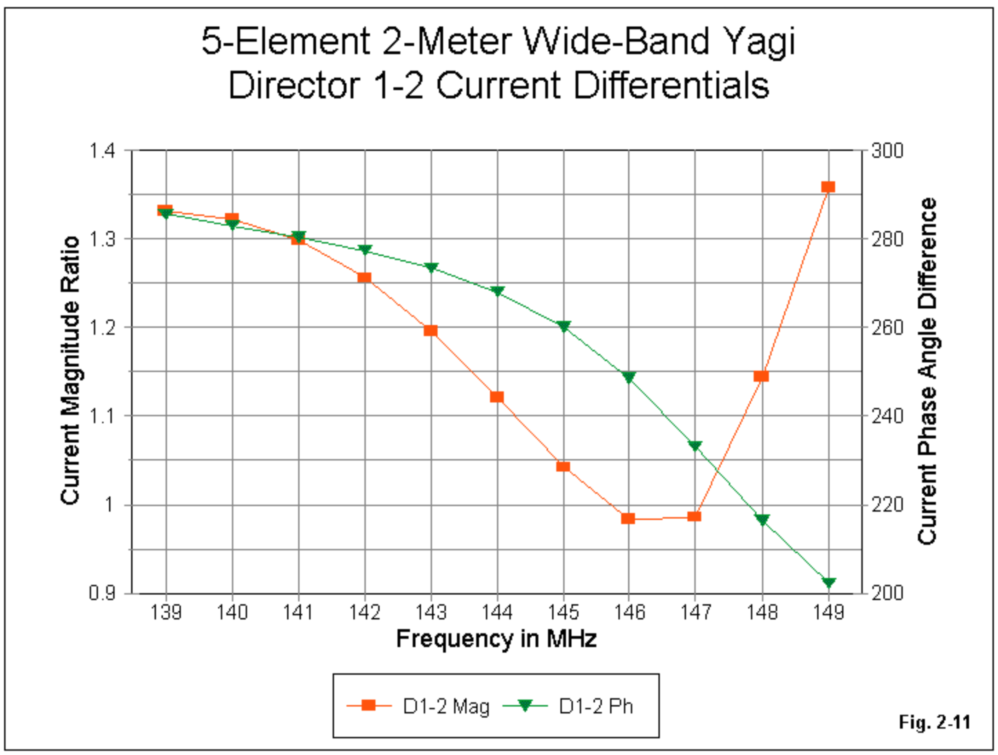


Fig. 2-11

An interesting facet of the wide-band 5-element array appears in **Fig. 11**, a graph of the differentials in current magnitude and phase angle between director 1 (the secondary driver) and director 2. The ratio of director 1 to director 2 current magnitude varies over a quite small range, much smaller than the current magnitude excursions for any other element pair in the array. The current phase angle difference also remains relatively constant for nearly the full lower half of the scanned frequency range, decreasing ever more rapidly thereafter. In this upper portion of the frequency range, the secondary driver/first director becomes ever more dominant in driving the array.

In short, there is little in the reflector-driver-director 1 portion of the array to distinguish the 6-element OWA Yagi from the 5-element wide-band Yagi. Granted, the larger array has a measurably wider impedance bandwidth and slightly narrower boundaries to the range of impedance and current values sampled from 139 to 149 MHz. However, it does not appear that the reflector-driver-director-1 portion of the array is sufficient to account for the smoother performance of the OWA.

OWA-2: Understanding the OWA with Reference Also to the Second and Third Directors

Often overlooked are the second and third directors of the 6-element OWA design. These elements are the ones having almost, if not actually, identical lengths. They show some interesting properties within the overall OWA structure.

A glance at **Table 2** would show that the first and second directors of the OWA array do not present the same level of close correlation among the current numbers as the corresponding elements in the 5-element Yagi. Indeed, it appears that the first director of the smaller beam does double duty relative to the OWA array with its extra element. The 5-element Yagi first director serves both as a secondary driver and as a stabilizing director for wide-band operation. From the perspective of the 6-element OWA Yagi, the second and third directors provide the relatively close correlation of current values independently of the first director, which also serves as the secondary driver.

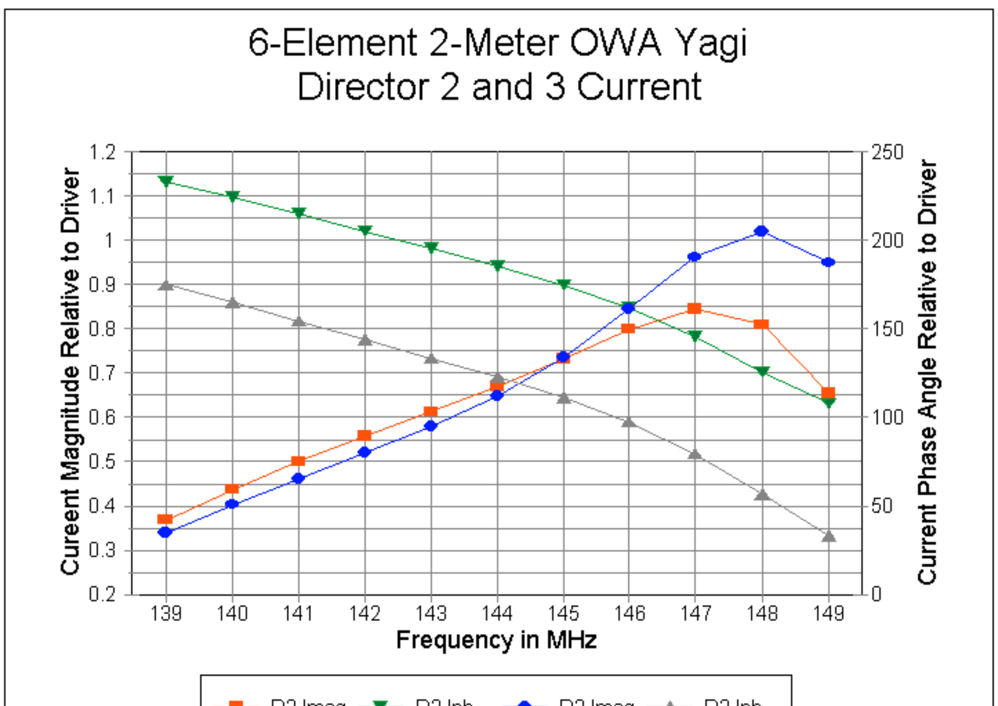


Fig. 2-12

Fig. 12 presents the current magnitudes (relative to a primary driver value of 1.0) for the second and third directors of the OWA array. Using the left axis as a guide, we find the values to be almost identical until the curves diverge above 145 MHz. In the upper region of the frequency scan, where the secondary driver dominates, the curves diverge in value but have similar shapes.

The figure also shows the current phase angles for the same two elements (relative to a constant primary driver value of 0.0 degrees). The parallel nature of the curves can hardly escape detection.

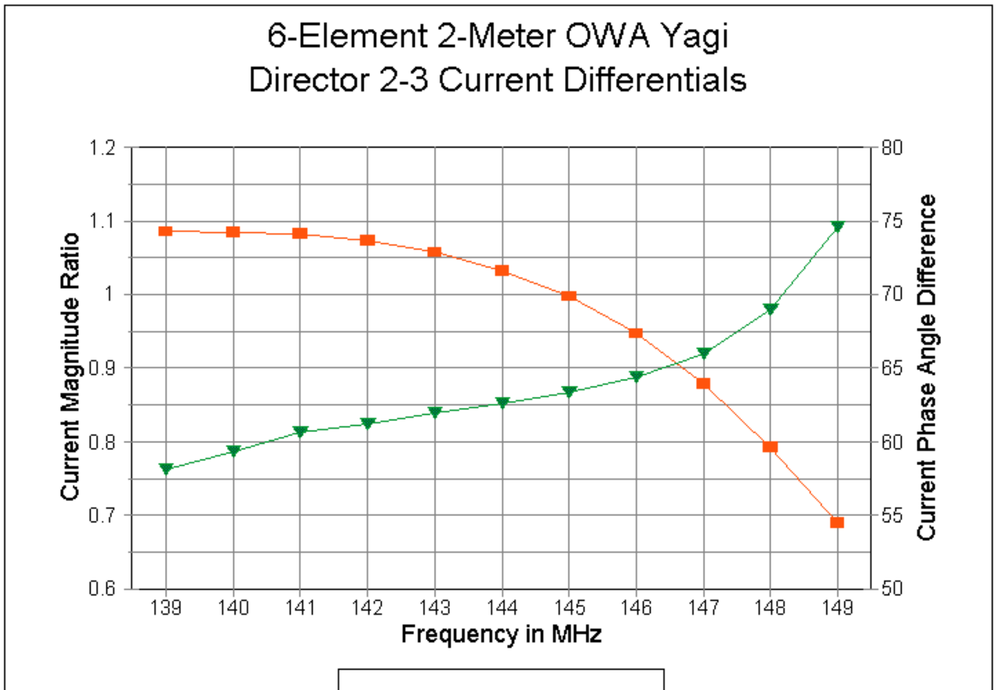


Fig. 2-13

In **Fig. 13**, the raw data in **Fig. 12** becomes as set of differentials. The ratio of current between director 2 and director 3 becomes a smooth curve, with only small changes in value in the lower half of the frequency range. (Compare this smooth curve to the "dipper-shaped" curve for the current magnitude ratio of director 1 to director 2 in **Fig. 11** for the 5-element beam.) The amount of phase-angle difference change is even more startling--less than 16.5 degrees overall from 139 to 149 MHz. (Likewise, compare this value to the 72-degree change in difference in Fig. 11 across the same range for the first and second directors of the 5-element array.) Indeed, we might categorize the second and third directors of the OWA as "stabilizing" directors.

Achieving the greatest impedance bandwidth from the OWA array appears to require the added element within the same boom length in order to arrive at the most stable wide-band operation. Indeed, what sets the OWA design apart from past wide-band parasitic arrays is the combination of a close-spaced secondary driver and the pair of stabilizing directors of equal or very nearly equal length. Closer spacing of the secondary driver permits the achievement of a higher median impedance with the same reflector spacing. Since one would have to have an added director to fill the void in order to reach performance specifications for a given boom length, the new director and the next together--when properly set in length and spacing--

complete the broad-banding design operation. Indeed, the impedance bandwidth of the OWA Yagi tends to decrease as the second and third directors diverge in length for a given spacing. In short, it is the entire array design--or at least the first 5 elements of it--that marks out an OWA Yagi from wide-band Yagis of the past.

The 6-element OWA Yagi used as a comparator so far is only one of many possible designs. It is relatively short, and has a narrow operating passband relative to the impedance passband. As a result, there is still considerable OWA ground to examine.

Some Additional OWA Benefits

The OWA basic platform consists of the reflector through director 3--at least. In a 6-element design, only one director remains to control performance at the band edges (in conjunction with small changes to the reflector length). Achieving a wider operating passband--perhaps one that covers most of the impedance passband--becomes considerably easier with the addition of an extra director or two. Ahead of the basic OWA "cell," we may stagger tune the directors to arrive at a very significant operating passband.

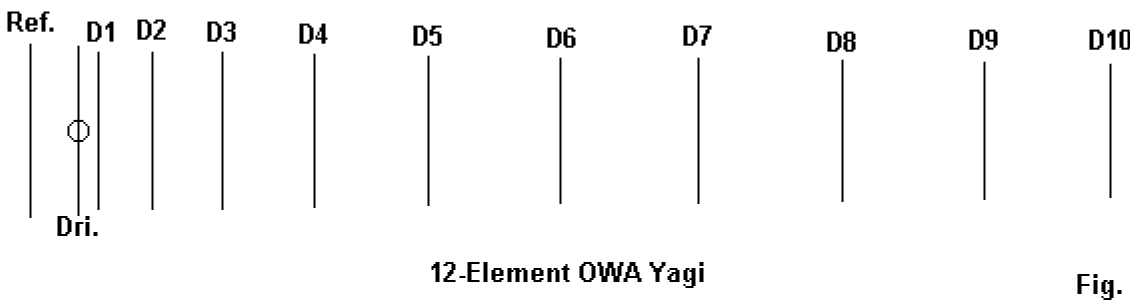


Fig. 2-14

Model OWA432E Dimensions

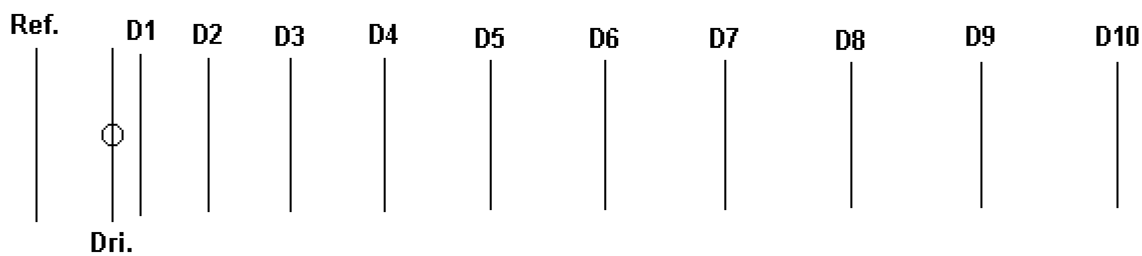
Element	Length		Cumulative Spacing		Individual Spacing	
	mm	WL	mm	WL	mm	WL
Refl	334.4	0.482	-----	-----	-----	-----
Driver	331.0	0.477	106.6	0.154	106.6	0.154
Dir 1	302.0	0.435	149.5	0.215	42.9	0.061
Dir 2	297.4	0.429	244.8	0.353	95.3	0.138
Dir 3	297.4	0.429	377.0	0.543	132.2	0.190
Dir 4	296.4	0.427	550.8	0.794	173.8	0.251
Dir 5	288.2	0.415	762.0	1.098	211.2	0.304
Dir 6	281.0	0.405	1010.3	1.456	248.3	0.358
Dir 7	275.2	0.397	1267.8	1.827	257.5	0.371
Dir 8	269.4	0.388	1535.4	2.213	267.6	0.386
Dir 9	263.6	0.380	1770.5	2.551	235.1	0.338
Dir 10	255.6	0.368	2032.5	2.929	262.0	0.378

Table 5. Dimensions of a 12-element 420-450-MHz OWA Yagi, using 0.1575" (4 mm) diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 435 MHz.

For a better test of wide-band performance potential, we may move our discussion to the 420-450-MHz band, which has a bandwidth that is nearly 7% of the center frequency. **Fig. 14** presents the outline of a 12-element OWA Yagi that will cover the entire band with reasonable performance. The dimensions for model OWA432E appear in **Table 5**. Like many Yagis for this band, the array uses 4-mm-diameter aluminum elements. The remaining dimensions appear in terms of both millimeters and wavelengths. At a boom-length (minus any extensions) of 2.93 wavelengths, the array is comparable to other 12-element Yagis for this band.

The overall performance of the Yagi is quite adequate for many purposes. The 50-Ohm SWR is only 1.5:1 at the band edges. Free-space gain ranges from 13.35 dBi to 14.70 dBi across the band, with a peak in the vicinity of 445 MHz. The 180-degree and worst-case front-to-back ratios tend to parallel the gain curve, although with a much sharper peak.

The only assessment that we can reach at this stage is that the array is capable of providing service across the entire band. Further assessment requires some sort of standard against which to measure the OWA Yagi. Perhaps the most notable wide-band Yagis for the 420-450-MHz band are those developed by Gunter Hoch, DL6WU. His sequence of arrays evolved over 2 decades of work, with perhaps the last iteration in the RSGB VHF/UHF dx volume. 12 elements is close to the shortest recommended length for a DL6WU array, but it does provide an interesting comparator against which to set the OWA design just described.



12-Element DL6WU Yagi

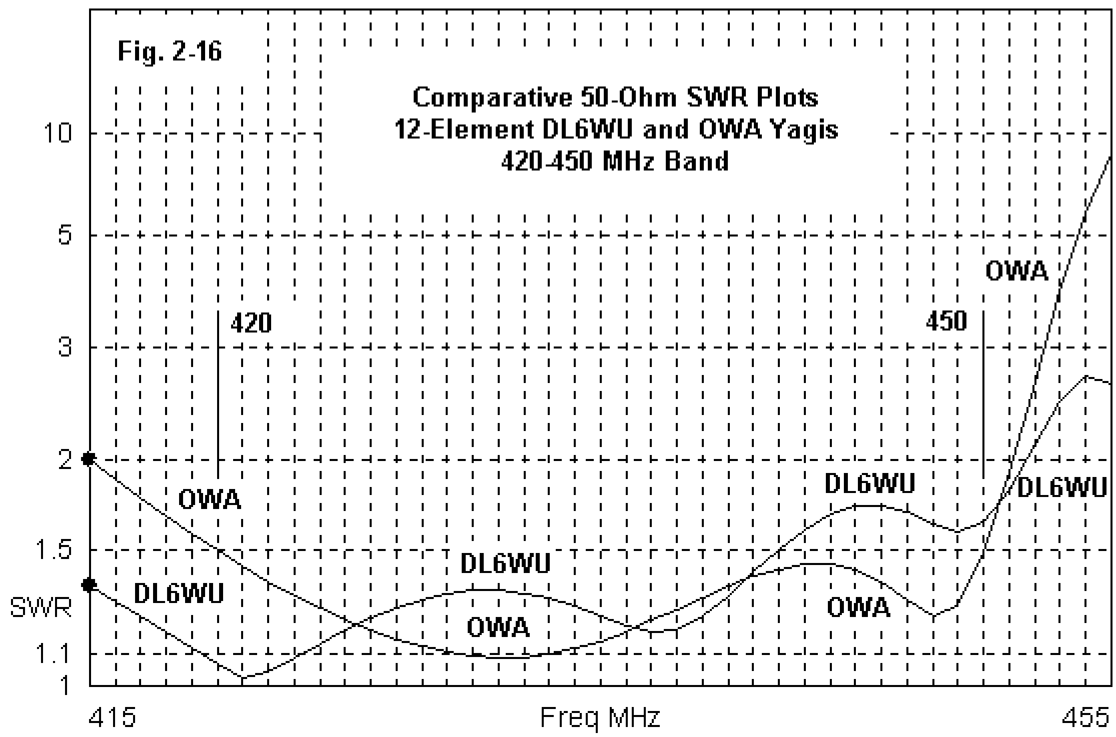
Fig. 2-15

Model DL6WU12 Dimensions

Element	Length	Cumulative Spacing			Individual Spacing	
	mm	WL	mm	WL	mm	WL
Refl	340.6	0.491	-----	-----	-----	-----
Driver	330.0	0.476	138.8	0.200	138.8	0.200
Dir 1	301.6	0.435	190.8	0.275	52.0	0.075
Dir 2	299.2	0.431	315.8	0.455	125.0	0.180
Dir 3	295.6	0.426	465.0	0.670	149.2	0.215
Dir 4	292.2	0.421	638.4	0.920	173.4	0.250
Dir 5	289.2	0.417	832.8	1.200	194.4	0.280
Dir 6	286.4	0.413	1040.9	1.500	208.1	0.300
Dir 7	284.2	0.410	1259.5	1.815	218.6	0.315
Dir 8	282.2	0.407	1488.6	2.145	229.1	0.330
Dir 9	280.4	0.404	1728.0	2.490	239.4	0.335
Dir 10	278.8	0.402	1977.8	2.850	249.8	0.360

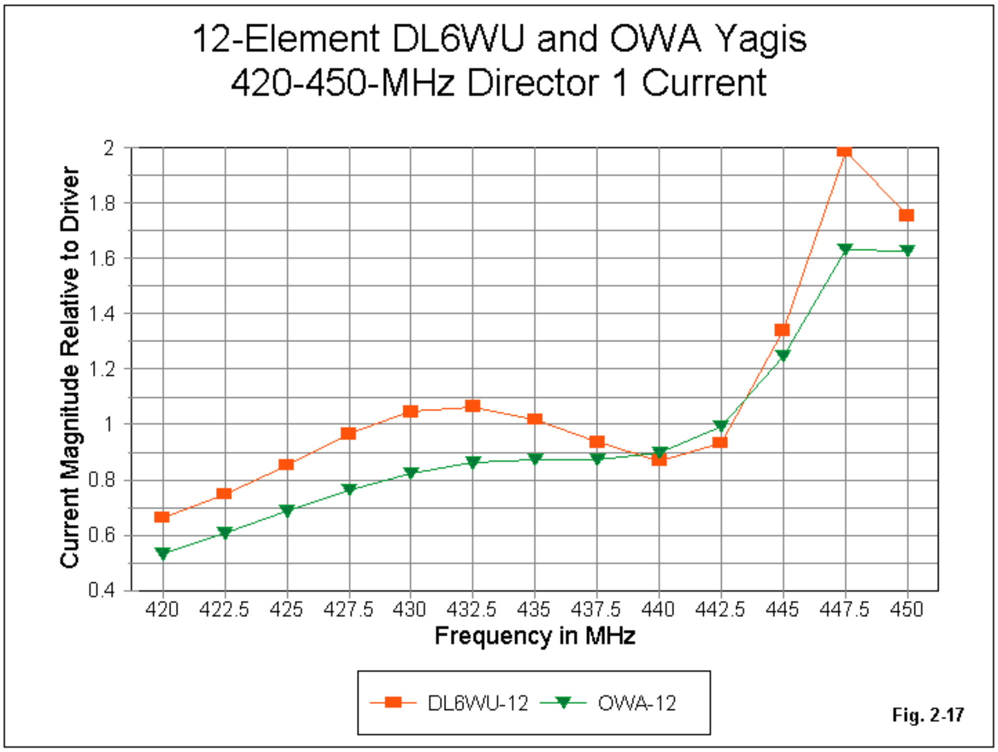
Table 6. Dimensions of a 12-element 420-450-MHz DL6WU Yagi, using 0.1575" (4 mm) diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 432 MHz. Dimensions are adapted from Chapter 10 of *The VHF/UHF DX Book*, from RSGB.

Fig. 15 presents an outline of the DL6WU 12-element Yagi, revealing the operative regularity of element spacing and length used throughout the sequence. **Table 6** provides the dimensions, once more using 4-mm elements and presented in terms of millimeters and wavelengths. At 2.85 wavelengths long, the DL6WU array reasonably approximates the boom-length of the OWA Yagi.

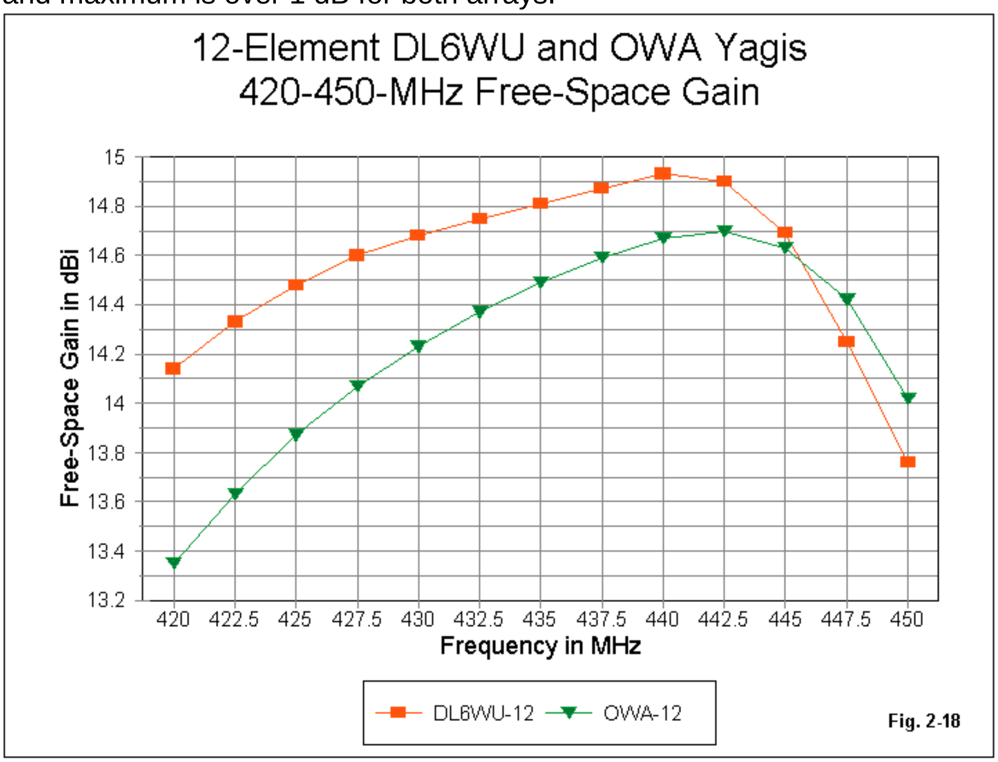


The DL6WU arrays all place the driver 0.2 wavelengths ahead of the reflector, with the first director spaced 0.075 wavelength further forward. This combination--suited to the 4-mm elements--warrants the label "wide-band" to a very high degree. **Fig. 16** overlays the 50-Ohm SWR curves for both the OWA and the DL6WU Yagis between 415 and 455 MHz. The extended range illustrates the "reserve" bandwidth provided by the DL6WU array, compared to the relative tightness of the fit between the band limits and the OWA SWR curve. More significantly for the DL6WU design is the fact that the SWR curve show 3 minimums, compared to the standard 2 for the OWA.

The SWR curves are related to the progression of the relative current magnitude on the first directors of the respective arrays. In **Fig. 17**, the OWA curve hovers just under a relative magnitude (to a driver value of 1.0) of 0.9. Then, at about 442 MHz, the director current magnitude surpasses that of the driver for the remainder of the operating passband. In contrast, the DL6WU curve rises above a value of 1.0 in two places. The rise and fall of the first director relative current magnitude correlates also to SWR maximums and minimums.



These and other performance figures for the DL6WU and OWA models appear in **Table 7**. For the record, **Fig. 18** compares the free space gain of the two antenna models. The DL6WU version reaches a peak gain about a quarter dB higher than the OWA model, but the OWA gain falls off more slowly at the high end of the band. The gain differential between minimum and maximum is over 1 dB for both arrays.



Comparative Performance Data: OWA2M126A and DL6WU-12

OWA2M126A					
Freq. MHz	420	427.5	435	442.5	450
F-S Gain dBi	13.35	14.07	14.49	14.70	14.02
180-Deg. F-B	16.36	17.58	18.16	25.28	22.47
Worst-Case F-B	16.36	17.58	18.16	23.48	20.21
F-Fwd Sidelobe	21.24	23.03	24.82	26.87	22.42
-3 dB Beamwidth	40.2	38.4	35.0	35.0	34.2
Feedpoint Resistance	33.41	44.86	44.58	46.38	39.05
Feedpoint Reactance	-2.68	3.16	3.23	16.98	-14.23
50-Ohm SWR	1.504	1.136	1.143	1.431	1.497

DL6WU-12					
Freq. MHz	420	427.5	435	442.5	450
F-S Gain dBi	14.14	14.60	14.81	14.90	13.76
180-Deg. F-B	24.47	17.26	15.53	21.40	16.11
Worst-Case F-B	20.83	17.26	15.53	21.40	16.11
F-Fwd Sidelobe	18.21	18.12	17.36	15.74*	19.78*
-3 dB Beamwidth	37.2	35.0	33.0	31.4	30.8
Feedpoint Resistance	48.39	63.76	50.23	46.93	39.87
Feedpoint Reactance	-2.75	-1.96	-10.44	21.30	-19.85
50-Ohm SWR	1.067	1.278	1.231	1.554	1.639

Table 7. Comparative 420-450-MHz performance data from models OWA432E and DL6WU12. Data includes free-space gain in dBi, 180-degree and worst-case front-to-back ratios in dB, main forward lobe to strongest forward sidelobe ratio in dB, half-power horizontal beamwidth in degrees, feedpoint resistance and reactance in Ohms, and 50-Ohm SWR. * signals the existence of a main forward lobe bulge rather than a true sidelobe with an intervening pattern depression. See text for discussion.

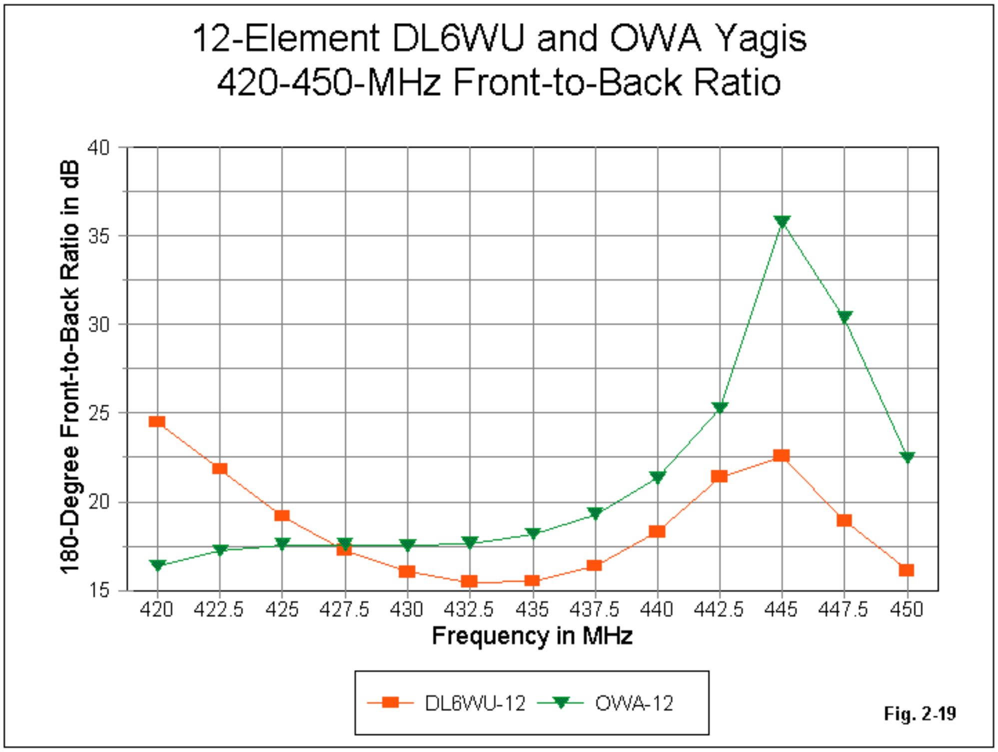
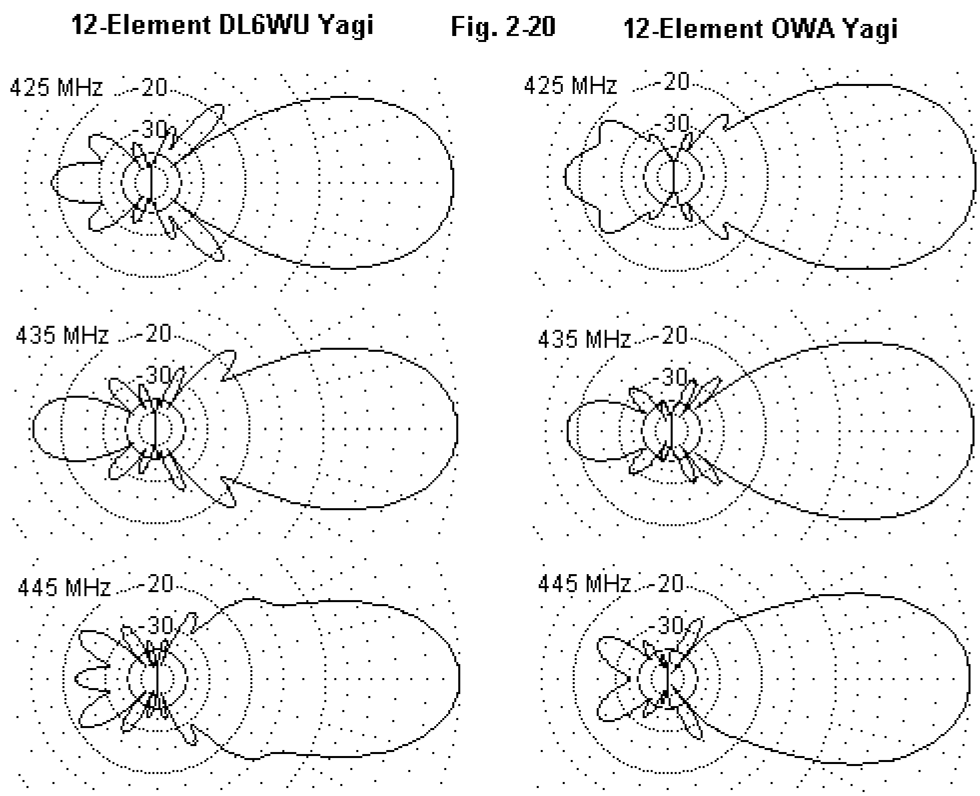


Fig. 2-19

The OWA array shows a single peak in its 180-degree front-to-back performance, as indicated clearly by **Fig. 19**. In contrast, the DL6WU array shows two maximums, one slightly below the lower end of the band and the other slightly higher in frequency than the gain peak. The twin front-to-back peaks are related to the number of directors in the array. As one adds directors according to the DL6WU scheme, the front-to-back peaks move upward in frequency. At a certain point, a new low-end peak emerges and the remaining peaks are closer together in frequency. A 26-element array has 3 front-to-back peaks. The proximity of peaks in turn limits the amount that the front-to-back value can decrease between peaks. Hence, very long DL6WU Yagis tend to have high minimum front-to-back values.

In terms of SWR bandwidth, gain, and possibly also front-to-back performance, the DL6WU 12-element array tends to outperform the OWA Yagi. At the present stage of development, it is not clear that the OWA design has reached the limits of its performance. Many folks view the first director in HF OWA Yagis as an added element, so that a 6-element 20-meter OWA is comparable in length and performance to a standard 5-element 20-meter Yagi, both with boom-lengths in the vicinity of 48'. However, the OWA design used in the example that we have explored extends the element spacing so that the 12-element boom-length is comparable to that of a standard--or at least a DL6WU--design. Whether element spacing compression to add an 11th director in the same boom length--with appropriate setting of element lengths--can broaden the SWR curve and/or increase the basic gain and front-to-back values across the band remains for further design efforts.



Free-Space Azimuth (E-Plane) Patterns of DL6WU and OWA Yagis

There is one department--little recognized by many Yagi builders--in which the OWA

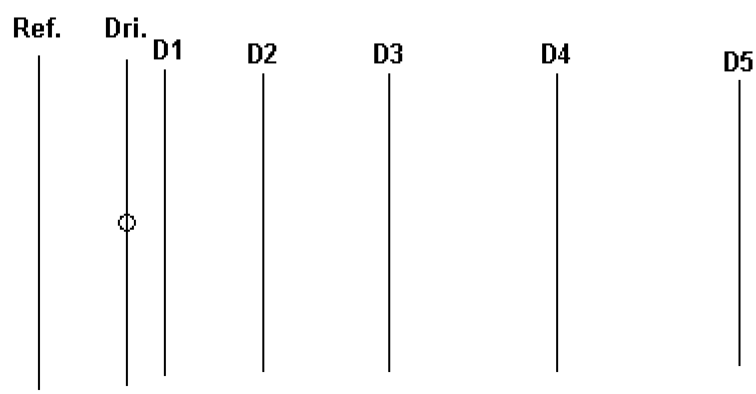
Yagi shows superiority over almost all other Yagi designs of comparable length. **Fig. 20** illustrates the region of concern with a set of free-space azimuth (E-plane) patterns taken at selected frequencies across the band. Numerical data appears in **Table 7**. DL6WU himself registers the forward sidelobe strength of his designs as about 17 dB. The 12-element version of his array shows slightly better figures up until the region of highest gain. From about 440 MHz upward, the first forward sidelobe becomes so wide that it merges with the main forward lobe. The result is a "bulge" in the main forward lobe, since the pattern cannot show a depression by which most computer model programs would recognize a new lobe. In Table 7, the bulge for the first forward lobe is almost invisible in the -12 dB region, leaving one with a value for the forward side lobe that actually applies to the second lobe.

Strong forward sidelobes have an interesting consequence beyond radiating power in directions other than the desired one. They also tend to narrow the half-power beamwidth significantly, perhaps by as much as 3 degrees or nearly 10% of the 30-35-degree beamwidth for these arrays.

In contrast to the strong forward sidelobes of the DL6WU array (and many others used in the 420-450-MHz band), the OWA Yagi exhibits a forward side lobe value averaging about 23.7 dB down from the main lobe. The result is a main forward lobe about 3 degrees wider than that of the DL6WU beam. Over narrower operating regions, the OWA Yagi is capable of even better horizontal (E-plane) forward sidelobe suppression. (The quest for such suppression does not itself address the equally important question of vertical or H-plane sidelobe suppression.)

A second advantage offered by the OWA structure is that it offers a stable basic platform for the development of families of Yagis. The DL6WU Yagi family is perhaps most familiar to builders of VHF and UHF arrays, since the builder can select a boom length and--with reference to a chart provided by DL6WU--the appropriate number, length, and spacing of elements to fill the boom. For any boom length above about 8 elements, the impedance performance of the array will be similar with almost any number of directors.

Fig. 2-21



7-Element 2-Meter OWA Yagi

Table 8 provides the dimensions of a 7-element 2-meter OWA Yagi that is quite capable of forming the basic unit for a family of 2-meter OWA Yagis. The outline appears in **Fig. 21**. The design improves upon the 6-element OWA--itself a perfectly good antenna--by optimizing the element spacing for the 0.1875" elements. Since these elements are larger in diameter--

when measured in wavelengths--than the HF arrays upon which the VHF designs are based, wider element spacing goes some distance in optimizing the mutual coupling between elements. Compare the dimensions to those in Table 1 for the 6-element array.

Model OWA2M716A Dimensions

Element	Length		Cumulative Spacing		Individual Spacing	
	Inches	WL	Inches	WL	Inches	WL
Refl	40.70	0.504	-----	-----	-----	-----
Driver	39.66	0.491	10.81	0.134	10.81	0.124
Dir 1	37.00	0.458	15.47	0.191	4.66	0.057
Dir 2	36.32	0.449	27.38	0.339	11.91	0.148
Dir 3	36.32	0.449	42.72	0.529	15.34	0.190
Dir 4	36.20	0.448	63.38	0.784	20.66	0.255
Dir 5	34.50	0.427	85.67	1.060	22.28	0.276

Table 8. Dimensions of a 7-element 2-meter OWA Yagi, using 0.1875" (3/16") diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 146 MHz.

7-Element 2-Meter OWA Yagi

Perform											
Freq.	139	140	141	142	143	144	145	146	147	148	149
FS Gn	10.75	11	11.17	11.29	11.4	11.5	11.58	11.61	11.56	11.37	10.99
180FB	11.02	12.86	14.58	16.33	18.35	21.05	25.03	28.73	24.68	20.37	18.11
R	30.89	36.35	40.81	43.62	44.94	45.7	47.3	51.01	55.07	46.97	25.4
X	-10.72	-6.21	-3.47	-1.62	0.46	3.41	6.92	8.952	4.47	-6.87	-3.62
SWR50	1.734	1.419	1.242	1.151	1.113	1.122	1.165	1.195	1.137	1.167	1.982
Currents											
Ref-M	0.776	0.739	0.685	0.621	0.557	0.505	0.472	0.458	0.438	0.344	0.169
REF-P	144.28	135.41	127.16	120.13	114.78	110.99	107.63	101.98	89.74	69.2	54.97
D1-M	0.49	0.582	0.667	0.738	0.798	0.859	0.946	1.098	1.339	1.514	1.359
D1-P	-76.13	-81.3	-87.23	-93.04	-97.94	-101.5	-103.9	-106.9	-115	-132.2	-150.5
D2-M	0.396	0.463	0.526	0.585	0.639	0.692	0.752	0.819	0.865	0.783	0.611
D2-P	231.5	223.6	215	206.1	197.3	188.7	179.79	169.31	155.34	139.86	139.76
D3-M	0.399	0.464	0.526	0.582	0.637	0.7	0.79	0.934	1.144	1.299	1.234
D3-P	156.31	145.99	135.17	124.45	114.33	104.9	95.57	84.54	68.13	43.8	20.21
D4-M	0.365	0.437	0.509	0.58	0.653	0.737	0.847	1.002	1.194	1.271	1.085
D4-P	65.02	52.36	38.78	24.77	10.62	-3.76	-19.15	-37.43	-62.18	-95.43	-127.8
D5-M	0.256	0.302	0.346	0.387	0.425	0.467	0.519	0.59	0.671	0.675	0.539
D5-P	-40.82	-55.52	-71.18	-87.34	-103.7	-120.3	-138	-158.7	174.17	138.53	103.75
D2 vs. D3	Current										
Mag Ratio	0.992	0.998	1	1.005	1.003	0.989	0.952	0.877	0.756	0.602	0.495
Ph Dif	75.19	77.61	80.23	81.65	82.97	83.8	84.22	84.77	87.21	96.06	119.55

Table 9. NEC-4 reported performance data for model OWA2M716A from 139 to 149 MHz. Performance data consist of the free-space gain in dBi, the 180-degree front-to-back ratio in dB, the feedpoint resistance and reactance in Ohms, and the 50-Ohm SWR. Current data consist of the relative current magnitude (M) and phase angle (P) on the center segment of each element, where the driver current magnitude is always 1.0 and the driver phase angle is always 0.0 degrees. The Director 2 and Director 3 special current data consist of the ratio of current magnitude from Director 2 to Director 3 and of the current phase angle difference between the two directors. See text for data interpretation.

Table 9 supplies the complete performance and current data for the model, again inviting a comparison with Table 2, the same data for the original 6-element OWA Yagi. **Fig. 22** samples the data by showing the free-space gain and the 180-degree front-to-back ratio of the larger beam across the scanned frequency range. Across the operating range from 144 to 148 MHz, the gain varies by less than a quarter dB, from a low of 11.37 dBi to a high of 11.6 dBi for a boom length of 1.06 wavelengths. The 180-degree and worst-case front-to-back ratios exceed 20 dB across the same range.

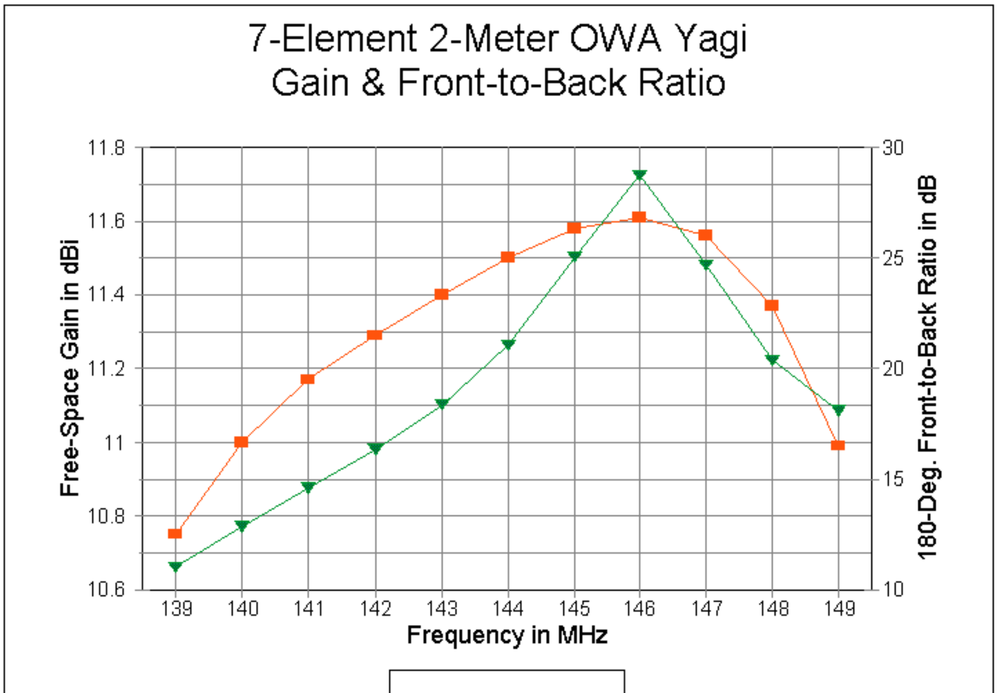


Fig. 2-22

More significant for the moment is the fact that the 7-element OWA Yagi is the basis for a family of OWA Yagis ranging from 7 to 12 elements. However, the design requirements for increasing the number of elements vary from those applicable to the simple scheme of a typical DL6WU design. For each additional element, the designer must reset the length and spacing of the former forward-most element to establish it in its new role as next to the most forward element. This step enables the designer to replicate the impedance curve and the shape of the performance curves for the larger array. The final step is setting the length and spacing of the new forward-most element to set the band-edge performance.

Model OWA2M126A Dimensions

Element	Length		Cumulative Spacing		Individual Spacing	
	Inches	WL	Inches	WL	Inches	WL
Refl	40.70	0.504	-----	-----	-----	-----
Driver	39.66	0.491	10.81	0.134	10.81	0.124
Dir 1	37.00	0.458	15.47	0.191	4.66	0.057
Dir 2	36.32	0.449	27.38	0.339	11.91	0.148
Dir 3	36.32	0.449	42.72	0.529	15.34	0.190
Dir 4	36.20	0.448	63.38	0.784	20.66	0.255
Dir 5	35.20	0.435	88.85	1.095	25.47	0.311
Dir 6	34.30	0.424	118.0	1.460	29.15	0.365
Dir 7	33.60	0.416	148.6	1.838	30.60	0.378
Dir 8	32.90	0.407	180.4	2.232	31.80	0.394
Dir 9	32.20	0.398	212.0	2.622	31.60	0.390
Dir 10	31.20	0.386	240.0	2.969	28.00	0.347

Table 10. Dimensions of a 12-element 2-meter OWA Yagi, using 0.1875" (3/16") diameter elements. WL = wavelength(s). The design center frequency on which dimensions in wavelengths are based is 146 MHz.

Table 10 presents the dimensions of a 12-element OWA Yagi that is the outgrowth of applying the procedure just given. The outline of the array is the same as for the 12-element 420-450-MHz array in **Fig. 14**. The first 6 elements are identical to those in the 7-element array. The 7th element (5th director) changed length and spacing, growing in both departments, as it entered the 8-element member of the family.

Fig. 2-23

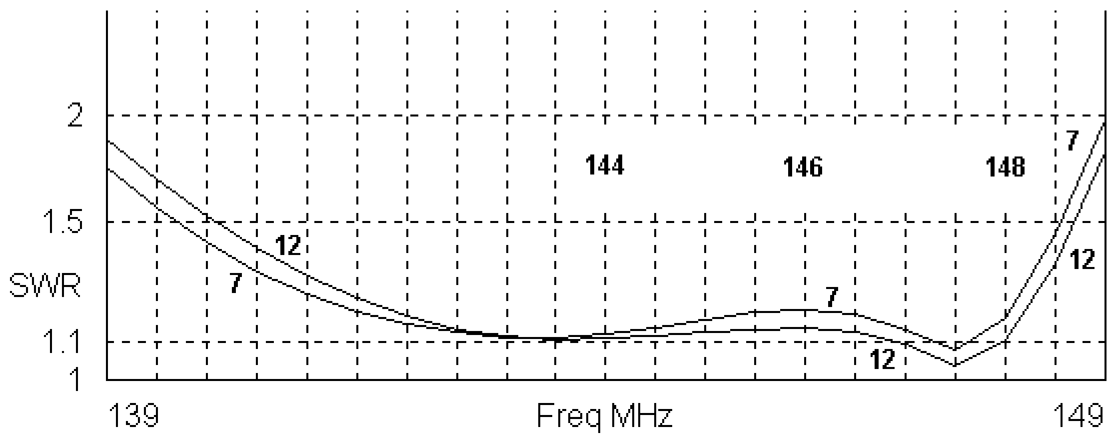


Fig. 23 provides 50-Ohm SWR scans for both the 7-element and 12-element members of the OWA 20-meter family, using the 139-149-MHz sweep with which we started. The scans testify to the stability of the OWA core to support long-boom Yagis while maintaining easily controlled impedance conditions. The performance curves for the 12-element OWA Yagi resemble those for the 7-element cousin, but at a higher gain level. (Performance data appears in **Table 11**.) Within the 144-148-MHz operating range, the free-space gain averages 14.3 dBi, with a 0.34 dB variation across the band. The lowest worst-case front-to-back ratio is 22.9 dB, with the highest front-to-back ratio only 1.7 dB higher. In short, performance is very even across the band.

Modeled Performance Data: OWA2M126A

Freq. MHz	144	145	146	147	148
F-S Gain dBi	14.10	14.27	14.40	14.44	14.30
180-Deg. F-B	22.90	23.76	24.63	24.65	22.97
Worst-Case F-B	22.90	23.76	24.60	24.37	22.97
F-Fwd Sidelobe	25.16	26.69	27.92	26.67	25.06
Feedpoint Resistance	48.61	50.22	51.79	53.01	47.49
Feedpoint Reactance	4.98	6.07	6.43	3.70	-4.36
50-Ohm SWR	1.111	1.129	1.140	1.097	1.109

Table 11. 2-meter performance data from model OWA2M126A. Data includes free-space gain in dBi, 180-degree and worst-case front-to-back ratios in dB, main forward lobe to strongest forward sidelobe ratio in dB, feedpoint resistance and reactance in Ohms, and 50-Ohm SWR.

As significant is the forward sidelobe suppression figure, which averages 26.3 dB across the 2-meter band. Since the worst-case front-to-back ratio is in almost all cases related directly to the main rear lobe, there appears to be a secondary effect, namely, some reduction in the sidelobes in the rear quadrants.

Conclusion

If the concept of an optimized wideband antenna (OWA) refers only to the arrangement of the reflector, driver, and first director, then there is little to distinguish it from past attempts to achieve wide-band performance. The one possible exception is the closer than usual spacing between the driver and the first director. However, this close spacing does not affect the role of the first director as a secondary or parasitic driver for the array.

In contrast, treating the OWA concept as including all array elements at least through the third director opens the way to more fully appreciating the potentials of this Yagi arrangement. The relative stability of the current ratio and phase-angle difference between the second and third directors tends to permit increased impedance bandwidth with lower levels of variation. In combination with the reflector-driver-first director arrangement, the entire assembly offers excellent control over the feedpoint impedance throughout at least a 7% overall bandwidth, with greater bandwidths possible.

Although OWA Yagi arrangements often have operational passbands that cover only part of the impedance passband, it is possible to design Yagis for nearly full impedance passband coverage, although present designs have lower average performance than those using only a portion of the impedance passband. As well, the OWA arrangement holds potential to form the basis for families of long-boom Yagis with only slight reductions in gain relative to gain-oriented designs. However, the OWA designs offer superior front-to-back performance and greater suppression of forward sidelobes than most extant Yagi designs.

The OWA Yagi arose from experimental results using computerized optimizing routines. To date, amateur literature has not seen a full analysis of how the OWA acquires its interesting properties relative to other Yagi designs. These notes are but a partial contribution in the direction of more fully understanding the OWA Yagi. As others develop understandings to supplant this one, it is very likely that the proof-of-principle designs used as examples in these notes will also be supplanted by far more capable Yagi arrays.