2-Meter Yagi Stacks
Part 2: 9- to 18-Element DL6WU Examples

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In the first part of this exercise, we examined a set of OWA Yagis for 2 meters with 6 through 18 elements. Along the way, we discovered that some of the relatively accepted optimal spacings for stacks of 2 vertically spaced Yagis did not correspond to modeled results, either in free-space or when the antennas had a base height of 5 wavelengths, that is, the height of the lower of the 2 Yagis in the stack. The initial investigation showed some general trends that deserve further exploration.

First, the optimal spacing for maximum gain shows a region in which a gain maximum does not occur: between about 1.8 and 2.2 wavelengths spacing between Yagis. We called this region the "forbidden zone," but only because the absolute gain maximum value does not occur in this region. From a practical perspective, the curve is relatively flat for 12- to 15-element Yagis with corresponding boomlengths (2.9 to 4.2 wavelengths). Hence, one may select almost any spacing within this fregion for the subject Yagis and--commensurate with selecting a good spacing for the front-to-back ratio--the results may be indistinguishable from selecting the maximum gain spacing. However, from the investigation of one coherent set of Yagi designs, it is not clear to what degree the forbidden zone is inherent to Yagis of the requisite boomlength or to what degree it is Yagi-design dependent.

Second, the OWA series of Yagis showed beam separations for maximum and minimum front-to-back ratio that are constants for all of the designs in the set. These spacing values applied whether the model was in free space or over ground. Hence, ground reflections are not the source for the uniform front-to-back spacing values. However, investigating only one type of Yagi designs leaves open the question of whether the 180-degree front-to-back results are endemic to Yagis or specific to the OWA design sequence. As noted in Part 1, all of the OWA designs yield similar SWR curves as well as similar curves for both gain and front-to-back ratios. In both of the latter cases, the peak values are designed as close as possible to the center of the design bandwidth to minimize the total range of gain and front-to-back values across the operating passband. Not all Yagi designs use such a tight set of design specifications.

Therefore, as a first-order test of the general trends that we have so far noted, it is necessary to sample a set of Yagis with a similar number of elements and similar boomlengths in order to see what emerges for vertically stacking 2 of them. For this exercise, we shall retrace our steps using samples from the venerable DL6WU Yagi design sequence. As we shall see, almost no set of Yagi designs could be more distant from the OWA series.

Some Basic Properties of DL6WU Yagis

The DL6WU Yagi designs evolved over a 2-decade period. The modern builder can obtain a design program called dl6wu-gg.exe in order to design Yagis of almost any long length. The only restriction is that the shortest countenanced length is about 2.15 wavelength, that is, 10 elements. We shall press this limit just a bit.

The DL6WU Yagis are designed to have very good forward gain combined with a reasonable front-to-back ratio. The impedance-setting cell--composed of the reflector, driver, and first director--is designed to provide a very wide bandwidth. Using 3/16" (0.1875" or 4.76 mm) elements on 2 meters, the operating bandwidth is at least 14-15 MHz, well beyond the limits of the 2-meter band. Hence, obtaining a reasonably successful operating version of a DL6WU Yagi is almost assured, even if a particular incarnation is off the design frequency by some measure that depends on the level of shop skill.

DL6WU 2-Meter (146 MHz) Yagi Dimensions
Dimensions derived from dl6wu-gg.exe

	Spacing	Half-Length		Spacing	Half-Length		Spacing	Half-Length
1	0	19.782	1	0	502.463	1	0	0.244701
2	16.168	19.5815	2	410.667	497.37	2	0.199996	0.242221
3	22.231	18.184	3	564.667	461.874	3	0.274995	0.224934
4	36.783	18.0455	4	934.288	458.356	4	0.455002	0.223221
5	54.164	17.8755	5	1375.77	454.038	5	0.670003	0.221118
6	74.374	17.7075	6	1889.1	449.771	6	0.919998	0.21904
7	97.01	17.5565	7	2464.05	445.935	7	1.2	0.217172
8	121.263	17.424	8	3080.08	442.57	8	1.50001	0.215533
9	146.72	17.309	9	3726.69	439.649	9	1.81491	0.21411
10	173.406	17.208	10	4404.51	437.083	10	2.14501	0.212861
11	201.296	17.118	11	5112.92	434.797	11	2.49001	0.211748
12	230.399	17.0375	12	5852.14	432.753	12	2.85001	0.210752
13	260.715	16.965	13	6622.16	430.911	13	3.22502	0.209855
14	292.243	16.898	14	7422.97	429.209	14	3.61501	0.209026
15	324.58	16.837	15	8244.33	427.66	15	4.01502	0.208272
16	356.916	16.7805	16	9065.67	426.225	16	4.41501	0.207573
17	389.253	16.7325	17	9887.03	425.006	17	4.81502	0.206979
18	421.59	16.678	18	10708.4	423.621	18	5.21502	0.206305
	Dimensions in inches			Dimensions in millimeters			Dimensions in wavelengths	

Notes: 1. Spacing is cumulative; element lengths = 2 times listed half-lengths.
2.. Element diameter: 0.1875" = 4.7625 mm = 0.00232 wl.

Table 1

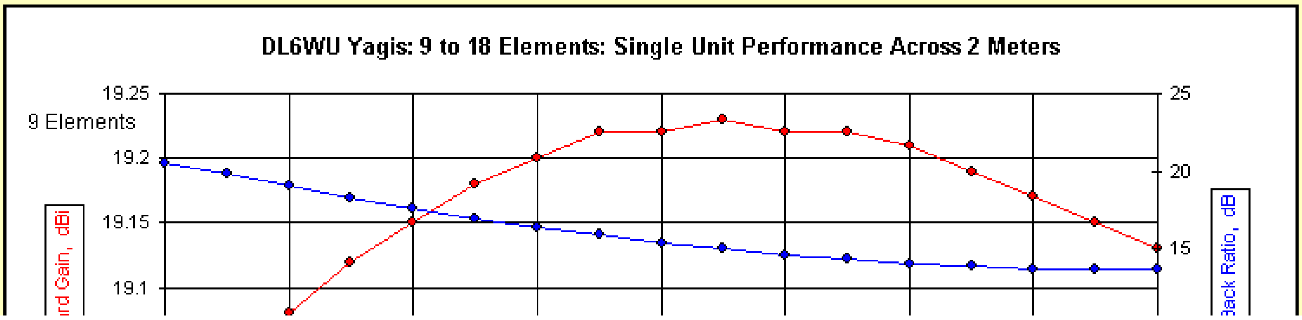
Table 1 shows the dimensions of the 18-element version of the DL6WU Yagi used in this exercise, with all dimension values derived from dl6wu-gg.exe. One of the seeming beauties of the DL6WU Yagi is that to make a shorter-length version, we need only remove directors. Hence, the 9-, 12-, and 15-element versions of the array use the same dimensions as shown in the table, minus the excess directors. **Table 2** shows the boomlengths of the set of Yagis used in this exercise, along with the modeled single-unit performance in both free space and 5 wavelengths above average ground.

Models and Single-Unit Performance			Design Frequency: 146 MHz						Table 2
Model	Elements	Boom Length	Free-Space Data			5-WL Above Ground			
		Wavelengths	Gain dBi	F-B dB	Feed Z	Gain dBi	TO deg	F-B dB	Feed Z
dl6wu-9	9	1.81	13.36	15.3	73.6 + j4.2	19.22	2.8	15.4	73.4 + j4.1
dl6wu-12	12	2.85	14.79	14.98	58.9 - j8.9	20.63	2.8	15.05	59.0 - j8.9
dl6wu-15	15	4.01	16.08	21.79	47.1 + 11.3	21.9	2.8	21.73	47.0 + 11.2
dl6wu-18	18	5.22	17	20.05	63.1 + j0.8	22.8	2.8	20.23	63.2 + j0.7

The 9-element version of the array is, of course, past the authorized smaller limit of these Yagis, but the operating data is entirely reasonable and acceptable for our purposes. The 4 Yagis in the set have boomlengths of 1.81, 2.85, 4.01, and 5.22 wavelengths. The corresponmding OWA Yagis had boomlengths of 1.78. 2.94, 4.17, and 5.39 wavelengths for 9 through 18 elements. Hence, the 2 sets of Yagis fall within a range of ready comparisons for vertical stacking.

At this stage, the gain advantage of the DL6WU sequence over the corresponding memebers of the OWA sequence is relatively unimportant. The DL6WU sequence also has a much higher level of forward sidelobe strength compared to the OWA models. OWA sidelobes are down by about 25 dB from the main forward lobe. DL6WU sidelobes are down only by about 16 dB. These facts are for the most part also unimportant to our work. However, toward the end of these notes, we shall mention one consequence of the differential in forward sidelobe strength. But for the moment, we may let these differnces merely exist.

More significant are the different performance curves produced by the DL6WU Yagis across the 2-meter band as we increase the number of elements and the boomlength. **Fig. 1** shows the gain and front-to-back curves for each of the Yagis in the test sequence, with modeled data taken 5 wavelengths above average ground.



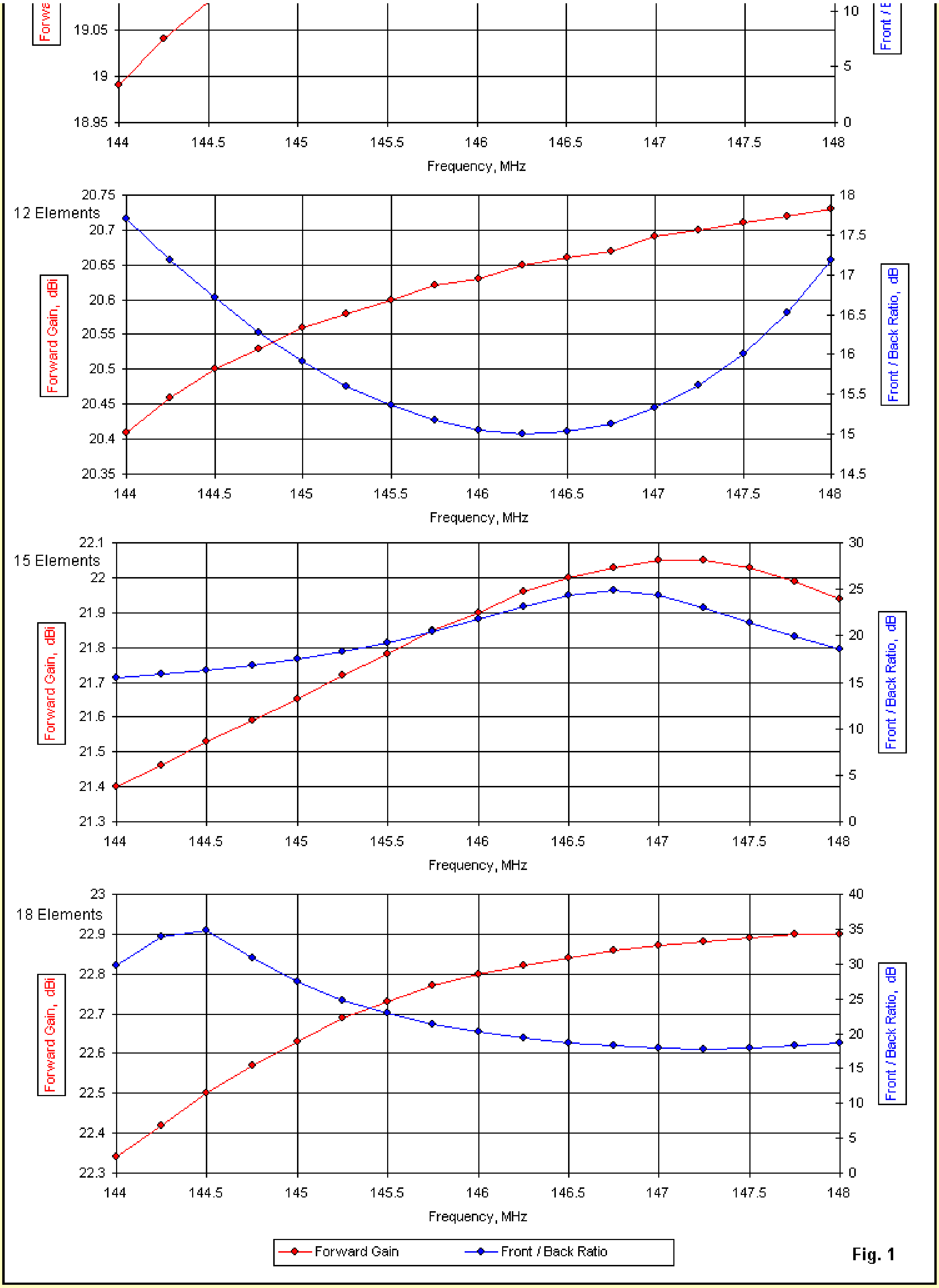


Fig. 1

Unlike the similarity of curves for the OWA sequence of Yagis, every one of the DL6WU curve pairs differs from every other one in the total set. Likewise, we find a comparable difference in the 50-Ohm SWR curves for the DL6WU Yagis, in contrast to the nearly perfectly overlaid SWR curves for the set of OWA Yagis. **Fig. 2** shows the SWR values across 2 meters for each of the 4 DL6WU Yagis.

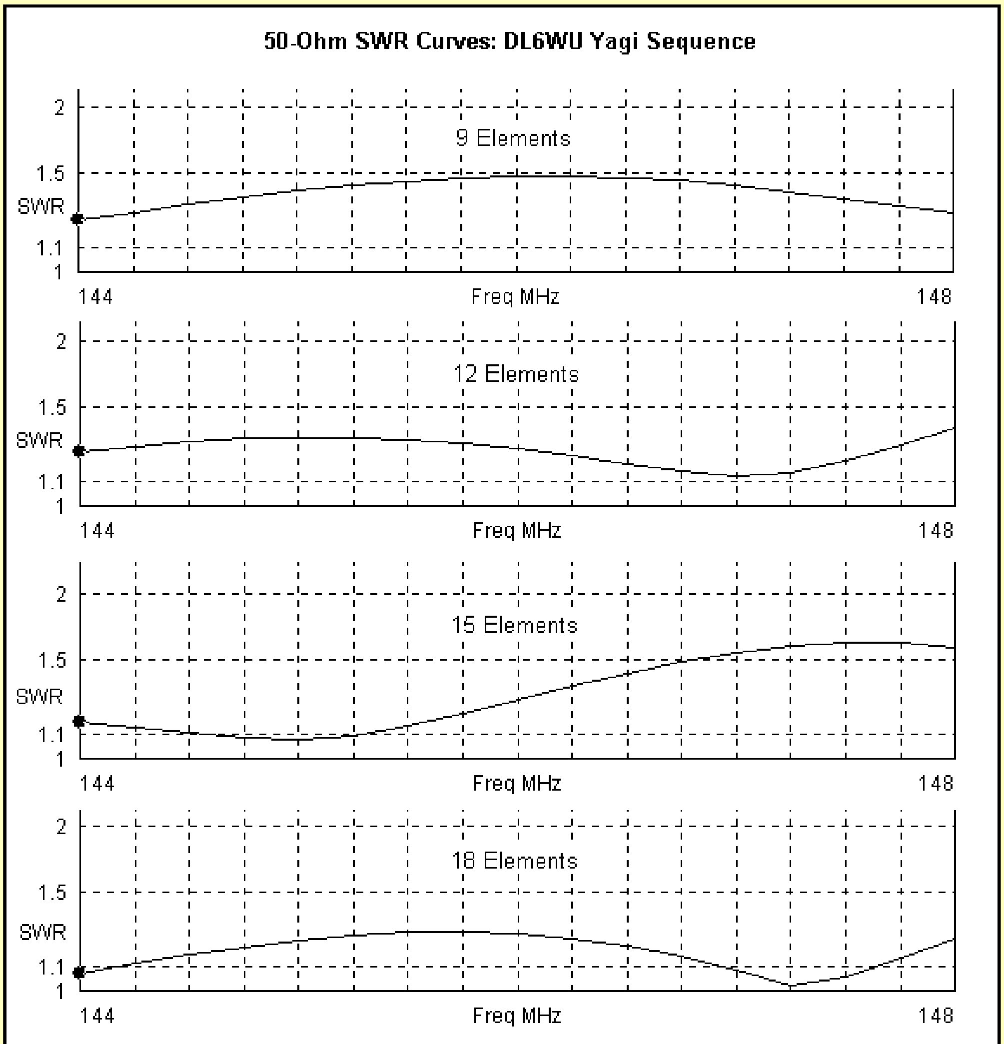


Fig. 2

The variability of the performance curves for various lengths of DL6WU Yagis is almost impossible to grasp without looking at the performance of the Yagis across the entire operating bandwidth. For the element diameter used in these models, that bandwidth extends nearly down to 138 MHz and nearly up to 153 MHz. Therefore, we may look at wider-band properties of selected versions of the antenna.

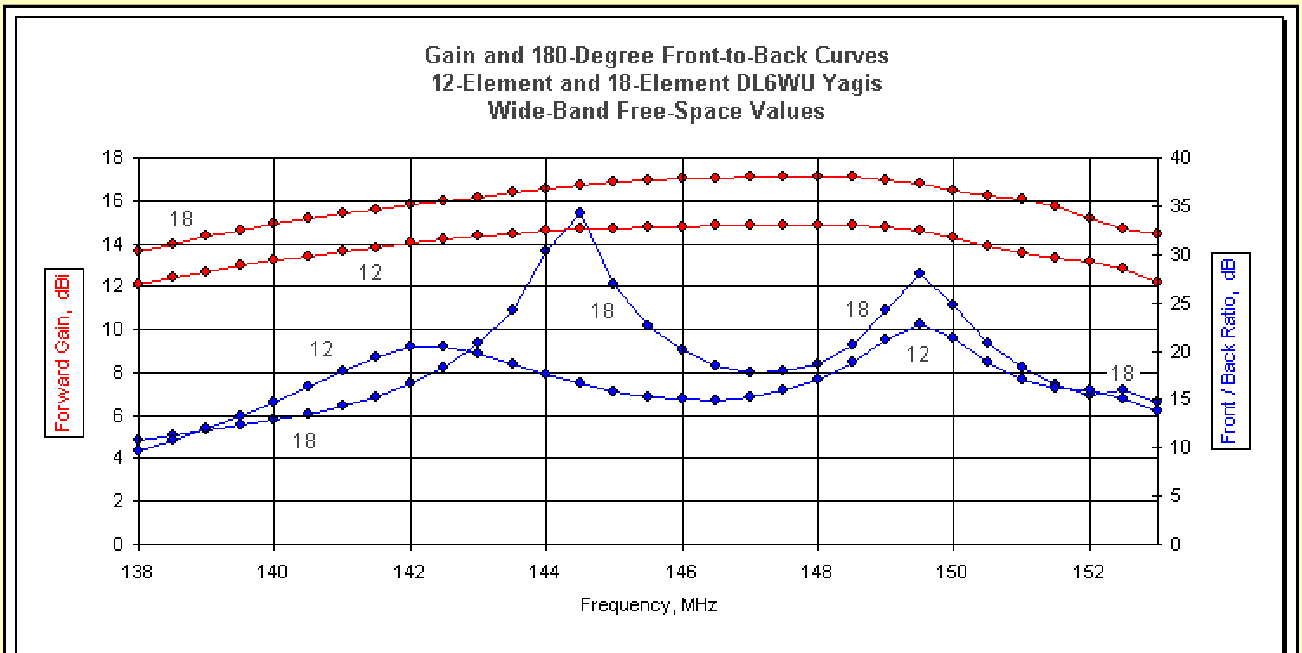


Fig. 3

Fig. 3 shows frequency seeep data for the 12- and 18-element versions of the DL6WU Yagis across the entire operating passband. Note that for both versions, maximum gain occurs at about 148 MHz, at the top of the 2-meter band but well above the 146-MHz design frequency. The front-to-back ratio data is much more fascinating, since the two curves are quite different. The 12-element Yagi has two peak value frequencies, 142 and 149.7 MHz, about 7.5 MHz apart. (For reference, the 9-element version of the Yagis also has 2 front-to-back peaks that are 8 MHz apart.) The 18-element version has 3 peaks, with 2 notable apsects. The first peak occurs further up the band from the lower operating limit: 144.5 MHz. The second peak at 149.5 MHz is only 5 MHz distant from the first peak. The third peak--a small one--occurs 3 MHz higher at 152.5 MHz.

In terms of general properties of the DL6WU Yagi series, the more elements that we add, the closer to each other grow the front-to-back peaks. The first peak moves further up the band with each additional director. Because the lower end of the operatian passband shows slower development of these curves than the upper end of the passband, it is not possible to note that at a certain boom length, a new front-to-back peak will appear at the lower frequency limit. As well, as we add more elements, the upper end of the passband is subject to more closely spaced peaks and nulls. Since we may make DL6WU Yagis up to 30 and perhaps even 40 elements, our sample cannot show the full complexity of the front-to-back curves that may emerge. For additional information on the broadband properties of the DL6WU designs, see **"Appreciating DL6WU Wide-Band, Long-Boom Yagis for 420-450 MHz"**.

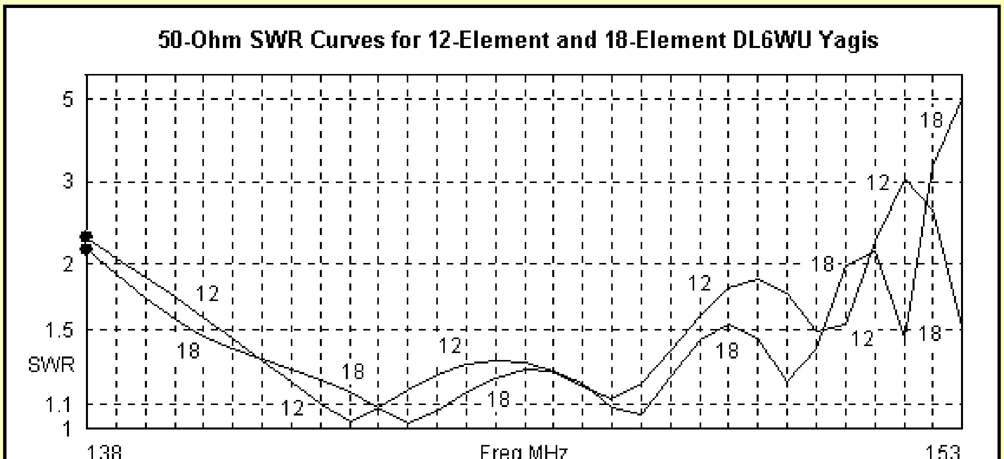


Fig. 4

The 50-Ohm SWR curves for the 12- and 18-element DL6WU Yagis show a similar pattern to the front-to-back curves. **Fig. 4** shows the cruves. The 12-element curve shows 3 dips toward minimum value, while the 18-element curve shows 4 distinct dips. As well, the first dip for the 18-element version occurs at a higher frequency than does the first dip of the 12-element Yagi. This pattern coincides with the basic properties of the front-to-back curves. The article mentioned above provides (for the 70-cm band) information relating the resistance and reactance curves to the front-to-back curves.

The key point to note is that, although the curves for any length DL6WU Yagi are similar, as we add more elements, the curves become more compressed within the total operating passband. As a result, the operating performance curves for any limited section of the total passband--for example, 144 through 148 MHz--will not correspond from one boom length to the next. However, if you carefully examine the front-to-back curves in **Fig. 1** and the SWR curves in **Fig. 2**, you can generally see where along the total span of the curves that these segments fit. The DL6WU series of Yagis forms a coherent set so long as we understand both the design criteria and the general trends of the operating curves as we add more elements.

The variability of front-to-back and SWR performance from one Yagi to the next in the DL6WU series is very much what we need to test the outstanding questions left over from the first installment. Because within the 2-meter band, there are significant performance differences from the values obtained for the OWA series, we can put both the forbidden zone phenomena and the seeming universality of front-to-back maximums and minimums to a fair test for 2-stacks.

The DL6WU Yagis in Stacks of 2

To determine the optimal spacing for maximum 2-stack gain and to find the maximum and minimum front-to-back spacing values, I ran each of the 4 DL6WU Yagis through the same range of separation. In all cases, coincident with the OWA tests, the lower Yagi is 5 wavelengths above average ground. The upper Yagi uses spacings of 1.2 wavelengths through 3.0 wavelengths. If our goal were only to find the spacing for maximum gain, we might easily have skipped many spacing values for each Yagi in the set. However, the values obtained may tell us something about our unanswered questions.

Table 3 presents the data from the 9-element version of the DL6WU Yagi. Remember that this beam is 1 element and about 0.3 wavelength shy of the minimum recommended length for the design sequence. However, the gain is good, and the front-to-back ratio is equal in general to the value produced by the 12-element version. Remember that the Yagi series was not designed for front-to-back ratio, and a high value in this category is a function of how close the peak occurs relative to the test frequency. In this instance, the peak values of front-to-back are well above and well below the test frequency.

Model dl6wu-9x2			Table 3
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	21.84	2.5	16.16
1.3	22.01	2.5	16.23
1.4	22.13	2.4	16.27
1.5	22.21	2.4	16.25
1.6	22.23	2.4	15.94
1.7	22.17	2.4	15.34
1.8	22.1	2.3	14.94
1.9	22.05	2.3	14.82
2	22.01	2.3	14.81
2.1	21.96	2.3	14.89
2.2	21.91	2.2	15.08
2.3	21.88	2.2	15.36
2.4	21.87	2.2	15.65
2.5	21.86	2.2	15.82
2.6	21.84	2.1	15.79
2.7	21.8	2.1	15.53
2.8	21.76	2.1	15.29
2.9	21.74	2.1	15.18
3	21.72	2.1	15.13

The gain peaks at a spacing of 1.6 wavelengths. The front-to-back ratio shows peaks at spacing values of 1.4 and 2.5 wavelengths, with a null at 2.0 wavelength. Interestingly, and as shown in **Table 4**, the gain peak for the 12-element version of the beam also occurs with a spacing of 1.6 wavelengths. However, the front-to-back peak values occur with slightly more separation than required by the 9-element version: at 1.5 and 2.6 wavelengths. The front-to-back minimum value occurs with a spacing of 2.0 wavelengths. The average front-to-back ratio for the 12-element version is slightly lower than for the 9-element model.

Model dl6wu-12x2			Table 4
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	22.83	2.5	15.52
1.3	23.04	2.5	15.79
1.4	23.23	2.4	16
1.5	23.39	2.4	16.14
1.6	23.48	2.4	16
1.7	23.47	2.4	15.42
1.8	23.43	2.4	14.88
1.9	23.42	2.3	14.65
2	23.42	2.3	14.59
2.1	23.42	2.3	14.61
2.2	23.42	2.2	14.7
2.3	23.42	2.2	14.86
2.4	23.4	2.2	15.08
2.5	23.38	2.2	15.31
2.6	23.33	2.2	15.39
2.7	23.25	2.1	15.23
2.8	23.17	2.1	14.99
2.9	23.11	2.1	14.85
3	23.08	2.1	14.83

The gain data for the 15-element DL6WU array, shown in **Table 5**, gives evidence of the forbidden zone at work. Maximum gain occurs with a spacing between 2.4 and 2.5 wavelengths, but with an almost level set of values down to a spacing of 1.9 wavelengths. The data for the front-to-back maximum and minimum values shows perhaps the most variability in the set of tested designs. There are front-to-back peaks with spacings of 1.3, 1.6, and 2.7 wavelengths, although the 1.6-wavelength peak is a one-shot peak. Minimum values occur with spacing values of 1.5 and 2.2 wavelengths.

Model dl6wu-15x2			Table 5
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	23.87	2.5	24.62
1.3	24.01	2.4	23.96
1.4	24.17	2.4	23.45
1.5	24.32	2.4	23.3
1.6	24.44	2.4	23.52
1.7	24.5	2.4	23.46
1.8	24.53	2.3	22.56
1.9	24.58	2.3	21.68
2	24.62	2.3	21.14
2.1	24.65	2.3	20.86
2.2	24.66	2.2	20.74
2.3	24.67	2.2	20.75
2.4	24.68	2.2	20.93
2.5	24.68	2.2	21.3
2.6	24.65	2.1	21.8
2.7	24.59	2.1	22.19
2.8	24.53	2.1	22.19
2.9	24.47	2.1	21.98
3	24.43	2.1	21.8

The data for the 18-element DL6WU Yagi appears in **Table 6**. Maximum gain occurs with a spacing of 2.5 wavelengths. Spacing values of 1.5 wavelength and 2.3 wavelengths produce maximum front-to-back values. Minimum values occur with spacing values of 1.8 and 2.9 wavelengths.

Model dl6wu-18x2			Table 6
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	24.55	2.5	18.92
1.3	24.69	2.4	19.71
1.4	24.83	2.4	20.56
1.5	24.97	2.4	21.19
1.6	25.08	2.4	21.16
1.7	25.14	2.4	20.59
1.8	25.18	2.3	20.33
1.9	25.26	2.3	20.51
2	25.35	2.3	20.73
2.1	25.42	2.3	20.86
2.2	25.48	2.2	20.93
2.3	25.53	2.2	20.98
2.4	25.56	2.2	20.96
2.5	25.57	2.2	20.81
2.6	25.55	2.1	20.46
2.7	25.51	2.1	20.03
2.8	25.46	2.1	19.77
2.9	25.42	2.1	19.73
3	25.38	2.1	19.78

The best way to summarize these results is in separate graphs of the gain and of the front-to-back curves across the range of separation values. **Fig. 5** shows the gain curves for the 4 test models.

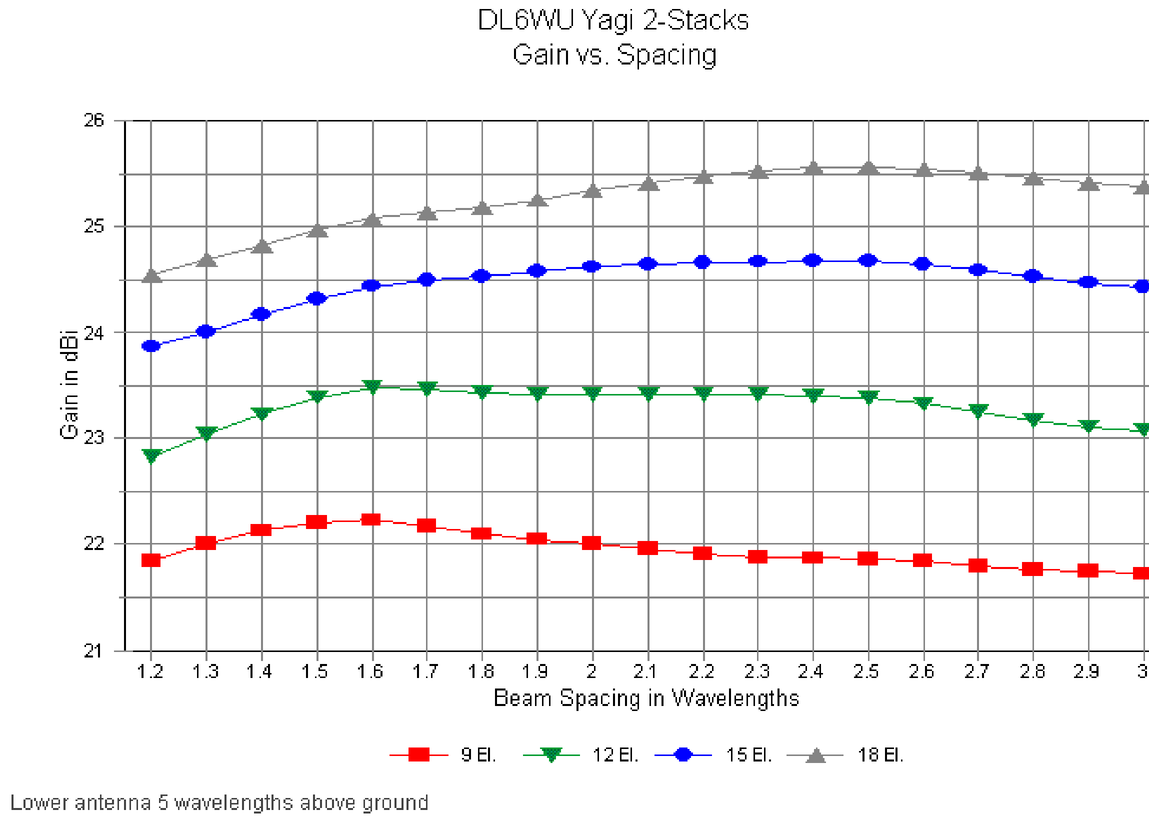


Fig. 5

The so-called forbidden zone appears in the DL6WU gain graphs as vividly as it does in the corresponding graphs for the OWA series of Yagis. Spacing values between about 1.9 and 2.2 wavelengths produce a relatively flat line and show no peak values for any of the test models. Indeed, the DL6WU test series is interstring because the two shorter versions show the same spacing for maximum gain, while the two longer versions show almost identical spacing values for maximum gain. There is a gap between 1.7 and 2.3 wavelengths, and standard means of estimating optimal spacing suggest that the 12- and 15-element versions of the beam should have shown gain maximum values within this range.

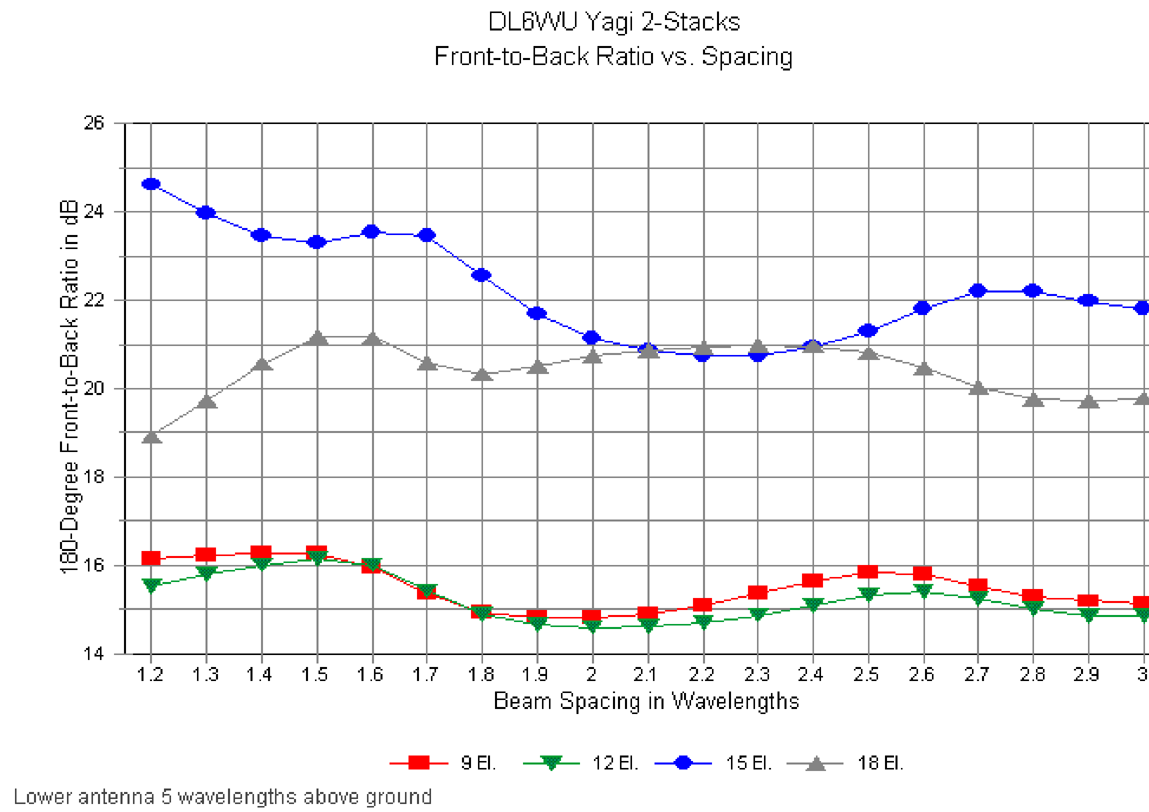


Fig. 6

Fig. 6 provides a composite graph of the front-to-back behavior of the DL6WU 2-stacks across the range of spacing values. The shorter pair of models have overlapping curves that look similar to those for the OWA series.

However, although the maximum points correspond fairly cosely to those of the OWA Yagi series, the minimum at a spacing of 2.0 wavelengths does not. The OWA Yagis showed a consistent minimum front-to-back value with a spacing of 1.7 wavelengths.

The curves for front-to-back maximums and minimums for the longer two versions of the DL6WU Yagi differ frm the shorter Yagi curves and from each other as well. At most, we can detect in both of the long-boom front-to-back curves a maximum associated with closer spacing and a maximum associated with wider spacing of the Yagis in the stack. However, anything resembling the neatness that we found in the OWA curves seems remote, at best.

The DL6WU tests put to rest the idea that the front-to-back curves for a 2 stack form a set of relatively constant spacing values for maximum and minimum values. The net result is that there are no reliable guides for Yagis of certain numbers of elements or certain boomlengths for the spacing values needed to maximize the front-to-back ratio. Indeed, this note also applies to the required spacing for maximum gain. Whatever the Yagi design, to find the optimal spacing for any desired condition--or for the best compromise between gain and front-to-back ratio--we must model the specific Yagi designs in the proposed stack at the proposed height above the type of ground at the installation.

The OWA and DL6WU Yagis do share something in common: the amount of gain yielded by a 2-stack for Yagis of similar boomlength and numbers of elements. **Table 7** summarizes the results for the DL6WU series. Within about 0.01 dB, the results are identical to those for the OWA series.

Gain Improvement From Stacking				Table 7
Model	Single Unit Gain dBi	Stack of 2 Gain dBi	Stack Gain Increase dB	
dl6wu-9	19.22	22.23	3.01	
dl6wu-12	20.63	23.48	2.85	
dl6wu-15	21.9	24.68	2.78	
dl6wu-18	22.8	25.57	2.77	

There is a second shared property in the modeled OWA and DL6WU Yagi 2-stacks: the inadequacy of standard calculations to predict what modeling suggests as the optimal spacing for maximum gain. **Table 8** summarizes the results. In both cases, the vertical beamwidth applied to the standard equation comes from a free-space model of the beam. The standard equation comes up shy of the modeled mark in virtually every case. The DL6WU estimates of optimal spacing include an extra set of figures drawn from the dl6wu-gg.exe program. The beamwidth values tend to coincide closely with those modeled (with the 9-element value being merely an estimate, since the program does not countenance so short a boom). Hence, the algorithm used in the program differs from the standard equation from the RSGB book and yields even narrower spacing values that are thus further from the modeled values.

Calculated vs. Modeled Maximum Gain Stack Spacing: DL6WU Yagis						Table 8
Model	dl6wu-gg.exe Values		Calculated from Free-Space BW			
	Phi-h	Dopt	Phi-h	Dopt	Modeled	
	degrees	wavelengths	degrees	wavelengths	wavelengths	
dl6wu-9x2	38	1.33	43.8	1.34	1.6	
dl6wu-12x2	35.5	1.44	36	1.62	1.6	
dl6wu-15x2	31.4	1.63	31.2	1.86	2.4	
dl6wu-18x2	28.3	1.8	28.2	2.05	2.5	
Calculated vs. Modeled Maximum Gain Stack Spacing: OWA Yagis						
Model	Phi-h	Dopt	Modeled			
	degrees	wavelengths	wavelengths			
owa2m916	46.8	1.26	1.5			
owa2m126	40.5	1.44	1.6			
owa2m156	37.4	1.56	2.2			
owa2m186	35.6	1.64	2.4	Dopt = lambda/[2 sin (phi-h/2)]		

The standard equation comes closest to the modeled value for the 12-element DL6WU design, even though the modeled 1.6-wavelength spacing appears to be narrower than if there were no forbidden zone. In general, the standard equation yields greater separation values for the DL6WU antennas than for the OWA beams due to the narrower main-lobe beamwidth of the DL6WU Yagis. The narrower main-lobe beamwidth is in turn a function of the strong sidelobes associated with the design. These sidelobes are down only 16 to 17 dB from the main forward lobe, in contrast to the OWA series, in which the sidelobes are down by about 25 dB. The absence of strong sidelobes results in wider main lobe beamwidths. The OWA series shows H-plane beamwidths that run from 12% to 25% wider than beamwidths for corresponding DL6WU models. Interestingly, the disparity in modeled optimal spacing values for maximum gain does not match the difference in beamwidths.

From a practical standpoint of planning a 2-stack of 2-meter Yagis, the differentials noted in this study may seem far too finicky. Still, the object of the exercise is not to set standards for the construction of effective Yagi stacks. Rather, the goal is a better understanding of Yagi operation in 2-stacks when we move from the relatively short HF beams to the longer booms that are both possible and common on 2 meters. To achieve that aim, we should be as precise as possible within the limits of the method of investigation.

Some Supplementary Notes on DL6WU Front-to-Back Spacing Values

The general conclusion to be reached from the study is that every Yagi design deserves 2-stack modeling prior to making final decisions about the spacing to be used between the beams. While general equations and esitmates may work, they also may leave some disappointments relative to optimal stack performance expectations. The differences in modeled spacing values for the best compromise between gain and front-to-back ratio that emerge from looking at the OWA and the DL6WU Yagi series make a strong recommendation for some pre-construction modeling work.

Having reached that conclusion still leaves a few remnant questions concerning the diversity of front-to-back results for the DL6WU series of Yagis. There are a number of possibilities that might form the strongest reason for the diversity. Although we may not be able to reduce the list to a single item, we might with a little extra work reduce the list and understand in a slghtly more firm way what the main influence is (or influences are).

We might begin by listing some possibilities, along with the conclusions provided by our work so far.

1. One possible source of the front-to-back curve variability in the DL6WU Yagi set is the placement of the stack above real ground. However, as we saw in the OWA series tests, the use of free space makes virtually no difference to the spacing required for maximum and minimum front-to-back ratios. Hence, if there is any effect at all, it is likely to be very small.

2. A second possible cause of the variability is where in the wide-band front-to-back curve we place the test situation. The 146-MHz test frequency is in the downslope of the front-to-back curves for the 9-, 12-, and 18-element Yagis, but in the upslope for the 15-element model. If we allow for differences of absolute values and for some variations at the limits of the graphs in **Fig. 6**, the upslope graphs following generally similar tracks. The 15-element upslope model shows the greatest difference from its downslope cousins.

3. The position of the test frequency in the wide-band front-to-back curve alone would not likely create the differences in the required spacing values for front-to-back maximum and minimum values without some other effect, such as a frequency shift in the curves. **Fig. 7** shows the wide-band front-to-back curves for the 12-element DL6WU Yagi using a selected minimum and maximum spacing. Note that the maximum spacing curve shows its peaks at a slightly lower frequency (perhaps about 0.3 MHz or so) than the peaks in the minimum spacing curve.

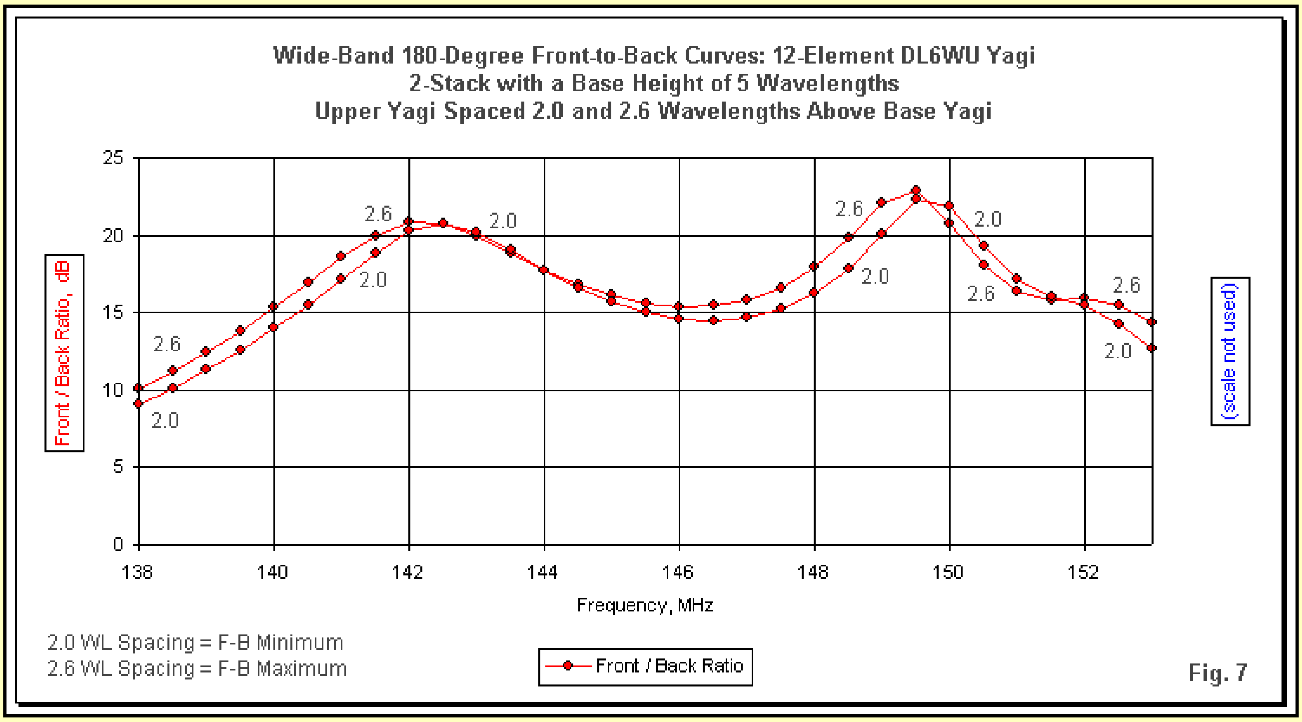
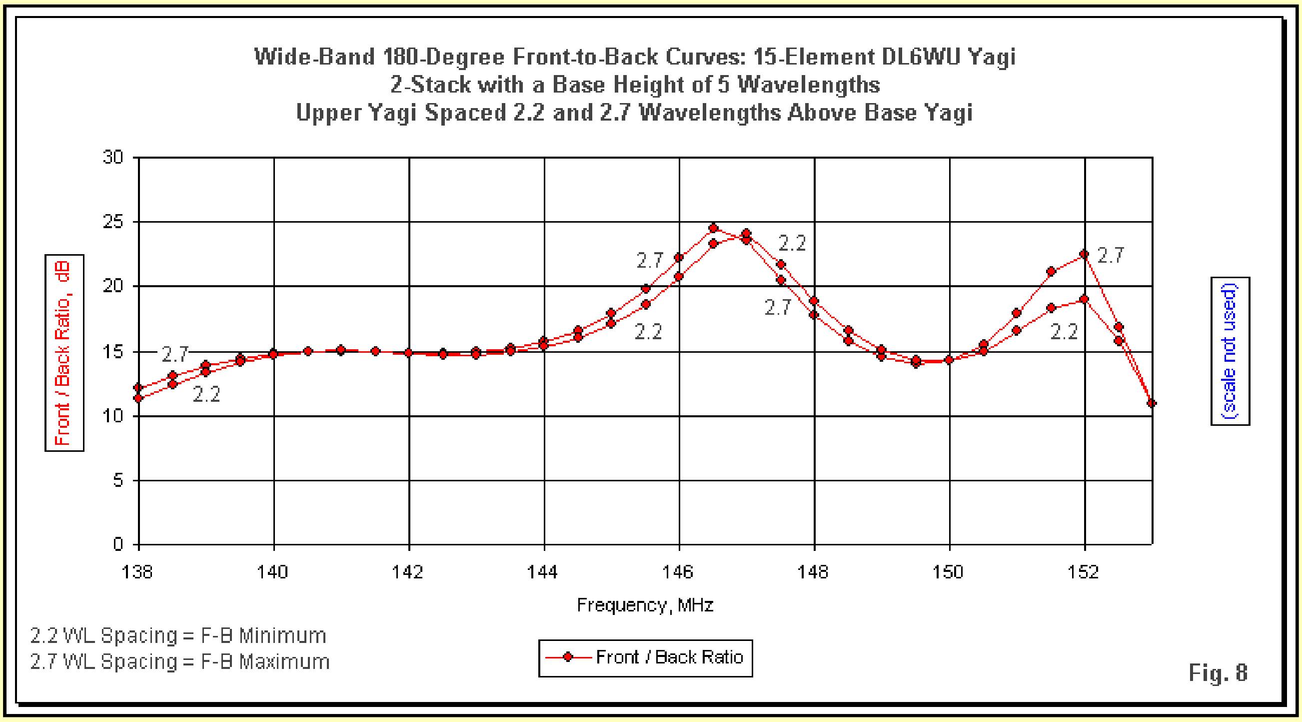


Fig. 7

For comparison, **Fig. 8** shows a corresponding set of wide-band front-to-back curves for the 15-element DL6WU Yagi. In this case the exact spacing values for maximum and minimum values of front-to-back at 146 MHz differ from those used in the 12-element graph. However, we find the same result: the maximum spacing curve places its peak values at a lower frequency the the peaks of the minimum spacing curve.



In order to correlate these curves with the reported values, we cannot perform a simple uniform frequency shift. Rather, the upslope models, such as 15-element Yagi, find their corresponding front-to-back values at a frequency higher than the test frequency. In contrast, the downslope models, such as the 12-element DL6WU array, find their corresponding values at a frequency lower than the test frequency.

This first-order account of the variability in the required spacing for maximum and minimum frnt-to-back values is far from complete. At best, it describes the penomena. Ultimately, the reasons for the phenomena will involve a detailed analysis of the interactions between the two beams in each stack. Such an account might permit the redesign of the stacked beams to maximize front-to-back at the same spacing as required for maximum gain. However, that task does not reduce to a simple adjustment of the reflector. In fact, as other studies have shown, the front-to-back ratio and pattern is as much or more a function of the directors as it is of the reflector. The reflector's chief tasks are setting the lower limit to the passband and setting (in conjunction with the driver and first director) the feedpoint impedance across the passband.

From a practical perspective, making such adjustments to the DL6WU Yagis would be futile, since the range of front-to-back values between minimums and maximums is so small. For all but the 15-element version, the front-to-back range is 1.5 dB or less. Hence, from a practical standpoint, the difference hardly makes a difference to operation. For the 15-element DL6WU Yagi, only the high value of front-to-back ratio at the closest spacing tested yields a significant difference in front-to-back ratio between maximum and minimum values--about 3.7 dB. Above smaller spacing, the differential shrinks to the levels noted for the other members of the group.

In contrast, the OWA series of beams, when stacked, show variations ranging from 3.4 to 3.8 dB from maximum to minimum. In many practical cases, this range is entirely acceptable. However, from a perspective of theoretical interest, the differentials keep the question alive.

Conclusion

Perhaps this study may arrive at two tentative cnclusions based on the divergent sets of Yagi designs modeled in stacks of 2 at 2 meters. Since the study has not surveyed all Yagi series and desgns, the conclusions are more suggestive than firm.

1. As we increase the boomlength and the number of elements in a Yagi design, the required spacing for maximum gain increases in a somewhat surprising way. At shoter boomlengths (perhaps 3 wavelengths or less), the required spacings are fairly close, but still greater than those predicted by standard equations. As the boomlength reaches about 4 wavelengths, the required spacing for maximum gain increases both suddenly and considerably.

Between the shorter and longer boom values for maximum gain, the gain values are fairly constant with only slow increases or decreases, according to the boomlength. Although no peak gain values show up in the spacing region from about 1.8 to 2.2 wavelengths, this region represents a set of useful separations that is not subject to more than tiny changes in gain with significant changes in spacing. It may be especially useful for stacks of Yagis having boomlengths between 2.5 and 4.5 wavelengths.

2. The required spacing for maximum front-to-back ratios is only rarely the same as the spacing required for maximum gain. The spacings may be relatively uniform with changing boom lengths--as in the case of the OWA series of Yagis--or vary considerably from one boomlength to the next--as in the case of the DL6WU series. Whether the spacing for maximum front-to-back is a constant or a variable depends on fundamental Yagi design considerations, as shown by the contrasting criteria used for the two tested Yagi series. However, the maximum spread of front-to-back values for the worst case in the 2 series was under 4 dB. Hence, from a practical perspective, the front-to-back ratio may be a very secondary consideration, especially for design that yield ratios in the 20-dB or greater range.

In all cases, the variability of the required spacing for both maximum gain and an acceptable front-to-back ratio requires the stack-builder to look beyond simple standard equations if he or she is to obtain peak array performance. Hence, my earlier suggestion applies as perhaps the most general conclusion of these notes: in all cases, the builder should invest some time in detailed and correct modeling to determine the best spacing for a stack relative to a. the exact Yagi design, b. the boomlengths and number of elements, c. the height above ground, and d. the type of ground and terrain in the antenna region. The builder must then weigh the modeling data against a. any physical constraints of the antenna installation and b. the operating goals and specifications for the stack.

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