2-Meter Yagi Stacks
6- to 18-Element OWA Examples

L. B. Cebik, W4RNL

> Note: This series of notes prepresents a preliminary study of stacking questions. Much fuller data and analysis appears in my book, *Long-Boom Yagi Notes*. These preliminary notes may be useful to those who do not have access to that volume.

Stacking VHF Yagi antennas increases gain by a hypothetical 3 dB over the gain of a single Yagi unit. Of course, the stacker must subtract any losses that accrue to the power splitting system for in-phase feeding of the two units. The key question for the would-be stacker has always been a simple one: how far apart should I stack two (or more) Yagis to optimize the gain of the system.

Some Background

HF modeling generally uses shorter Yagis, when measured in terms of either the number of elements or the boom-length. Most data involves 3- to 8-element Yagis. I have looked at the HF question in the past, and the results are at my site: **Stacking Yagis**. Two conclusions emerged. First, the required stacking space between two Yagis depends on the gain of the individual units. The higher the gain, the wider the spacing that we need to obtain maximum gain from the stack of 2. Second, the spacing that yields maximum gain is not necessarily the spacing that yields maximum front-to-back ratio. Maximum front-to-back ratio for a stack of 2 is usually close to the value of maximum front-to-back ratio for a single unit. Hence, failure to preserve the maximum front-to-back ratio results normally in a degradation of that value.

Similar conclusions are shown in the discussion of stacking in *The ARRL Antenna Book*, 20th ed., in the VHF discussion on pages 18-10 through 18-12. There are graphs of both the gain and the front-to-back ratio (called the front-to-rear ratio and meaning the worst-case front-to-back ratio rather than an averaged front-to-rear ratio). However, the samples do not show a regular progression from which one might draw more detailed conclusions other than the seemingly random variations in the front-to-back lines.

RSGB's *The VHF/UHF DX Book* contains an interesting discussion of the same topic. On page 7-8, the author presents a way of calculating the required spacing for maximum gain:

> Dopt = lambda / (2 sin (phi / 2))

where lambda is a wavelength in any desired unit of measure, and phi is the relevant half-power beamwidth of a single antenna unit in degrees or radians, as preferred. Dopt is the optimal distance or spacing between Yagis in the same unit of measure as specified for lambda. The equation produces very plausible numbers that require increased spacing with a narrowing beamwidth. Of course, the half-power beamwidth is related to forward gain such that the higher the forward gain, the narrower that the beamwidth tends to be. Before we close this discussion, we shall return the the equation in the RSGB source.

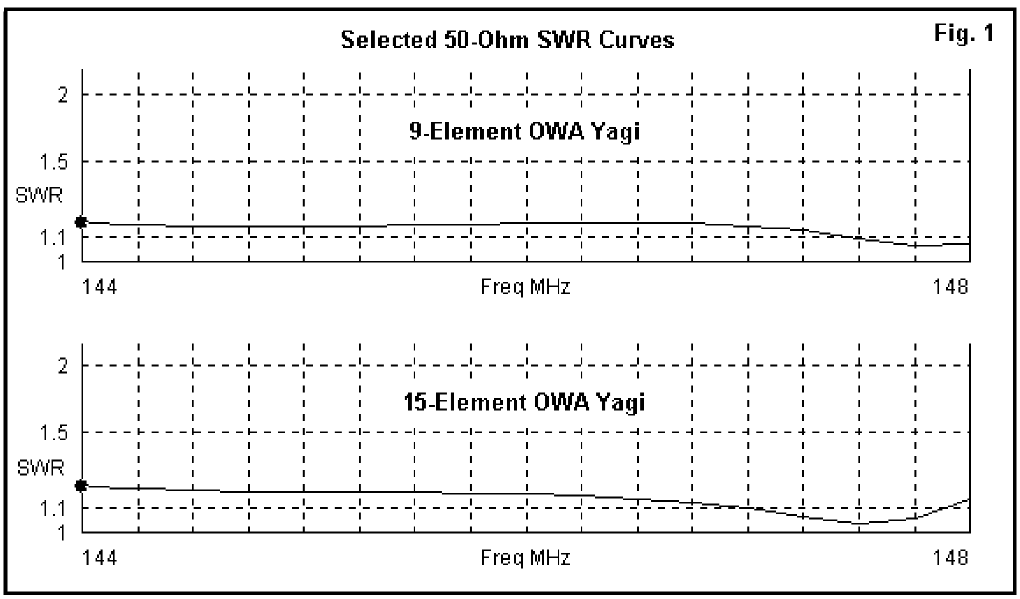
Unfortunately, vertical stacks of horizontally oriented Yagis tend not to be quite so neat an affair as the equation suggests, but may be more orderly than the *Antenna Book* discussion might lead us to believe. So a systematic modeling exercise appears to be in order if we are to find the middle ground.

Setting Up the Models

The first step in the process of developing a useful modeling exefcise involves setting its limits. For this exercise, we shall limit ourselves to stacks of 2 identical Yagis. The antennas will be horizontally oriented and stacked vertically. Very often, such exercises are conducted in a free-space environment, where Yagis are hardly ever used. For this collection of models, we shall use a base height of 5 wavelengths or about 33.68' or 10.27 m above average ground. The second beam in the stack will be spaced above the first by a distance that we shall specify in 10ths of a wavelength as the increment of change. Limiting the base height to 5 wavelengths allows accurate elevation plots when the pattern uses a 0.1-degree increment. As we increase the height further, we reach a level for which the 0.1-degree increment of elevation is insufficiently accurate to capture the maximum gain and its take-off (TO) angle. The height is also sufficient to ensure that the feedpoint impedances of the upper and lower Yagis do not differ from each other in any degree likely to occasion problems with standard in-phase feeding systems.

As a measure of the front-to-back ratio, we shall use the 180-degree ratio value. For this exercise, the 180-degree value is the most sensitive to change and hence will yield a clear indication of maximum and minimum values as we check different spacing values between the upper and the lower Yagi. Because the front-to-back ratio is taken at the same elevation angle as the record of maximum gain, there is a minor and generally insignificant vaguery to the value at certain points in tables of results. As we raise the height of the upper Yagi--or, in other words, increase the spacing--the TO angle will slowly decrease. Between two entries with angles that differ, the change in front-to-back value may be off the mark by up to 0.1 dB. However, the trends remain accurate reflections of beam performance.

The second major step in the set-up process is to select a coherent set of Yagis to test. The ones that I chose come from the 2-meter OWA series. You may obtain the physical specifications for each beam from other articles that presented the series. See **An OWA Family of 2-Meter Yagis from 6 to 12 Elements** and **Extending the 2-Meter OWA Family**. The family consists of a unified collection of Yagis using OWA design techniques. As a result, all of the family members have very similar patterns of gain, front-to-back ratio, and SWR values across the band, with gain adjustments varying with the boom length and the resulting number of elements. **Fig. 1** shows 2 sample SWR curves across 2-meters for represetatives of the family.



From the total family, I selected Yagis having 6, 9, 12, 15, and 18 elements. **Table 1** shows the modeled performance of single units both in free space and at a height of 5 wavelengths above average ground at the design frequency of 146 MHz. The individual Yagis cover the entire 2-meter band with only small changes in values between maximum and minimum values. The boomlengths vary from 0.67 wavelength for the smallest Yagi in the set up to 5.39 wavelengths for the 18-element version. Gain is largely a function of boomlength rather than the number of elements. Hence the rate of gain increase dwindles rapidly for the longest members of the family. However, the selection will prove useful in eliciting some significant factors in the separation of Yagis in a stack of 2.

Models and Single-Unit Performance				Design Frequency: 146 MHz							Table 1
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
owa2m616	6	0.67		10.23	35.37	50.0 + j9.5		16.11	2.8	36.13	50.1 + j9.4
owa2m916	9	1.78		13.01	21.9	45.3 + j5.5		18.88	2.8	21.94	45.1 + j5.4
owa2m126	12	2.94		14.35	24.65	47.5 + j6.2		20.21	2.8	24.69	47.5 + j6.1
owa2m156	15	4.17		15.04	25.97	46.8 + j6.7		20.89	2.8	25.97	46.7 + j6.6
owa2m186	18	5.39		15.42	26.37	46.8 + j6.7		21.26	2.8	26.35	46.8 + j6.7
Note: All models use 21 segments per element, and all elements are 0.1875" diameter aluminum.											

Since height above ground is the leading determinant for the TO angle, and since all of the single-unit Yagis are at the same height, they all show the same TO angle. However, we we look at stacks of 2 Yagis, the situation changes. The effective height relative to the TO angle for a stack of 2 antennas is about 2/3 of the upward distance between the antenna units. Hence, as we increase separation, the TO angle will slowly decrease. The information in **Table 1** is also sufficient to verify that the antenna height is enough to avoid any changes in feedpoint impedance relative to free-space design values. Finally, the data shows that ground reflections increase the gain--relative to the free-space value--by between 5.8 and 5.9 dB. We shall return later to the gain over ground values vs. free-space gain after we have had a chance to look at 2-stacks of each Yagi in the group.

The modeling test procedure is straightforward. For each Yagi stack, I shall increase spacing in 0.1-wavelength increments. Each set of tests will extend beyond peak gain and peak front-to-back ratio values by at least one step to verify that a peak has occurred. I shall record the results using the spacing between Yagis as a reference. In all cases, the lower Yagi remains at 5 wavelengths above ground. Hence, the height of the upper Yagi is simply 5 plus the tabulated spacing.

Modeling Exercise Results For each Yagi, I shall present both a table and a graph of the key stacking data. Tabular information is more precise to the eye, but trends are clearer in graphical form.

Model owa2m616x2: Although all of the longer Yagis in this group of OWA designs use the same first five elements, the 6-element Yagi uses a somewhat different set of dimensions. Hence, its 180-degree front-to-back ratio shows a higher maximum value than the other designs. When stacked, the maximum-gain spacing is between 1.0 and 1.1 wavelength. However, the maximum front-to-back separation is 1.3 wavelength, as shown in **Table 2** and in **Fig. 2**.

Model owa2m616x2			Table 2
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
0.9	19.07	2.6	22.62
1	19.15	2.6	25.9
1.1	19.15	2.5	29.59
1.2	19.11	2.5	32.81
1.3	19.07	2.5	33.4
1.4	19.03	2.4	31.61

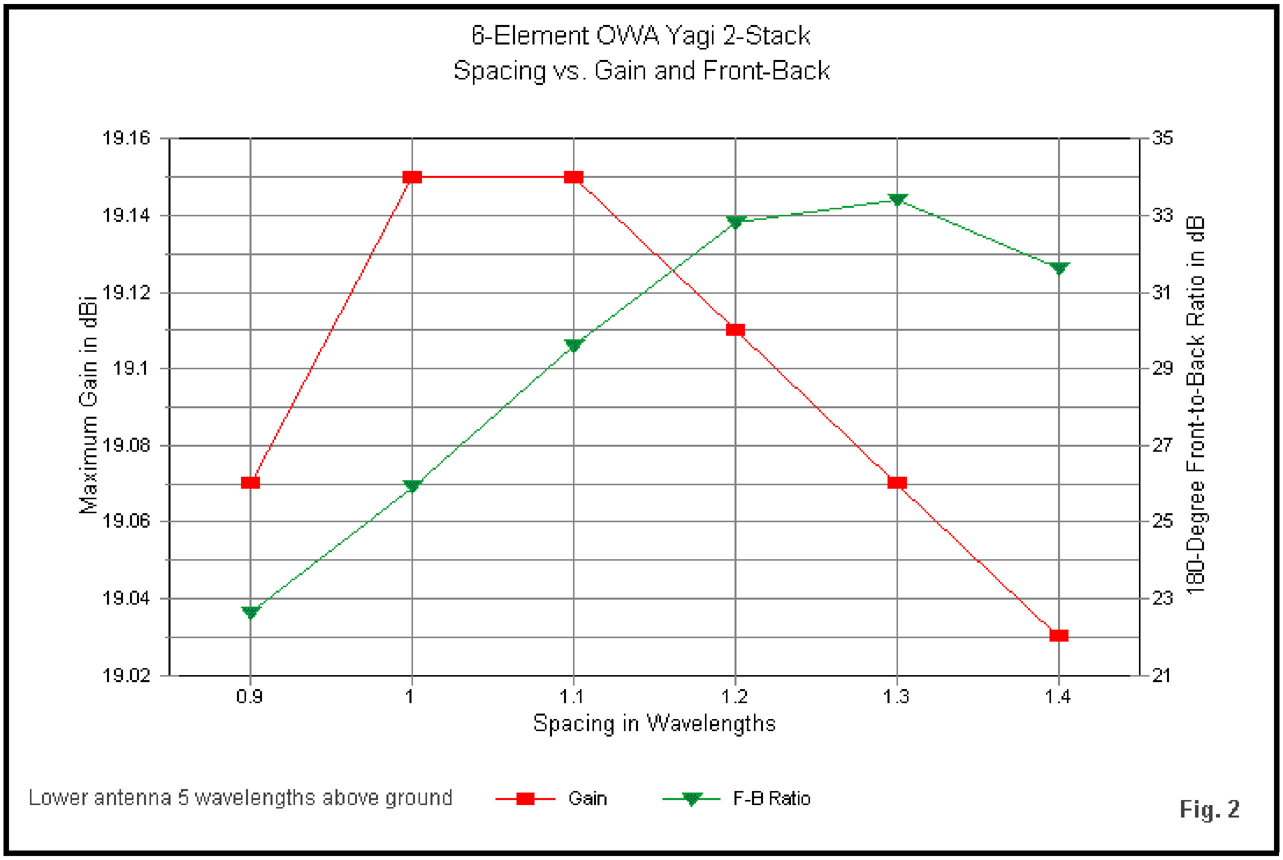


Fig. 2

As we shall see in subsequent Yagi stacks, the maximum front-to-back spacing is a constant. All designs will show a front-to-back maximum at a spacing of 1.3 wavelengths. We shall also note some other key spacing values related to the front-to-back ratio. The maximum gain spacing, however, is a variable. For the short Yagi (0.67-wavelength boom), the maximum gain occurs with a smaller spacing than the first front-to-back maximum, so--from a practical perspective--we have no reason to carry the curves further.

Model owa2m916x2: The 9-element Yagi uses a 1.78-wavelength boom, and we naturally expect that we need a wider spacing for maximum gain. The modeling evidence does not disappoint us. The boom is nearly 3 times the length of the first Yagi in the set, and the required spacing becomes about 1.5 wavelength. See **Table 3** and **Fig. 3**.

Model owa2m916x2			Table 3
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1	21.36	2.6	22.14
1.1	21.56	2.5	22.97
1.2	21.71	2.5	23.44
1.3	21.79	2.5	23.58
1.4	21.83	2.4	23.36
1.5	21.84	2.4	22.66
1.6	21.8	2.4	21.55

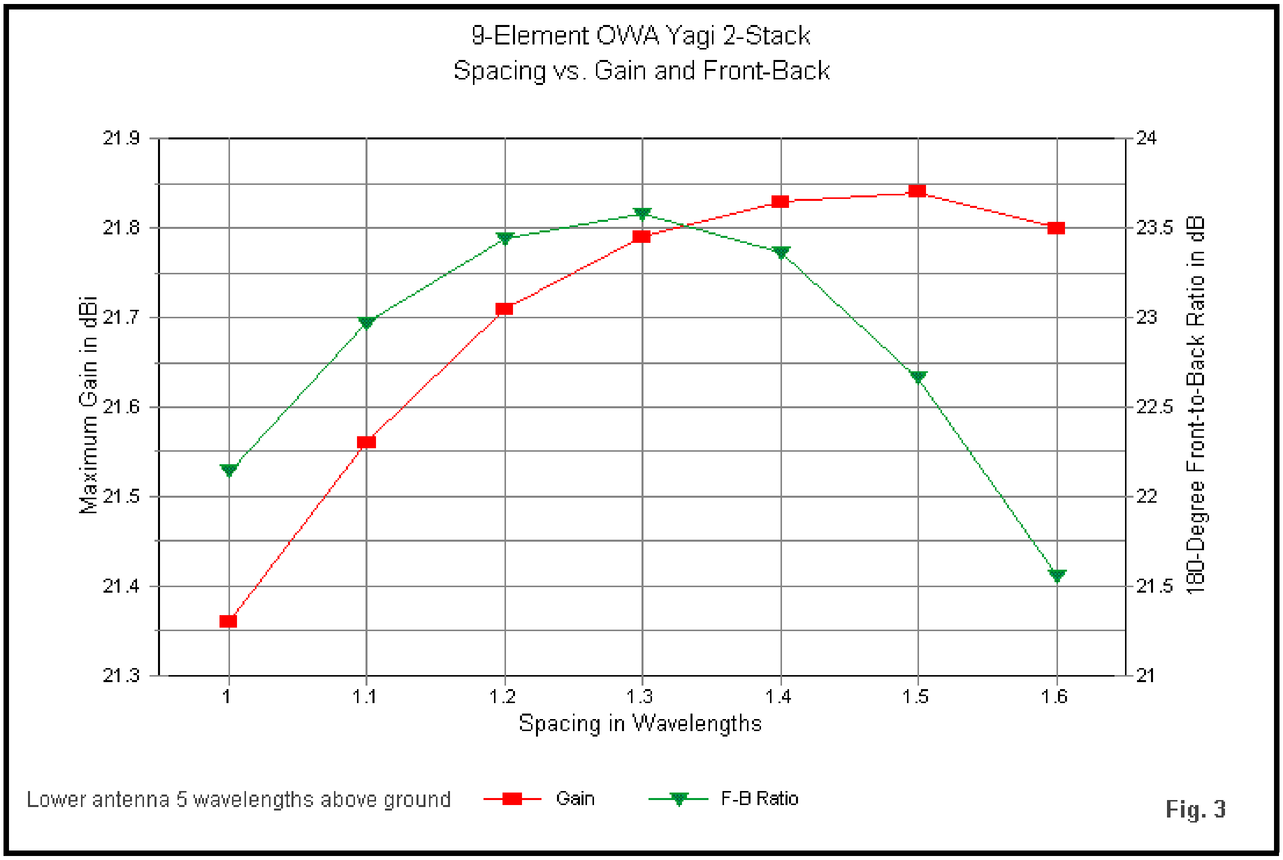
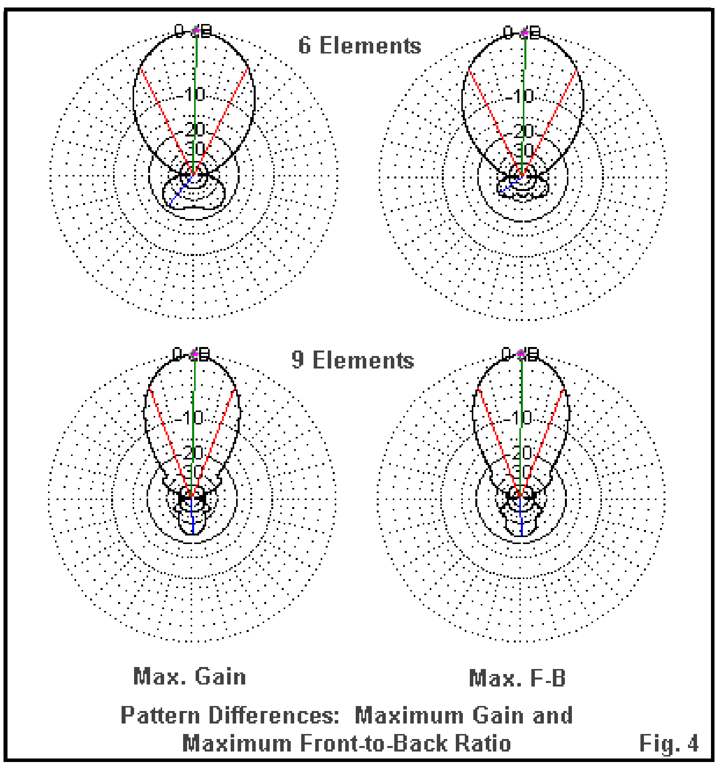


Fig. 3

Since the gain changes slowly as we move the spacing on either side of the maximum gain value, we do not lose much if we select a compromise spacing between the maximum gain and the maximum front-to-back values. In this case, a spacing of about 1.4 wavelengths would be a very practical value.



Pattern Differences: Maximum Gain and Maximum Front-to-Back Ratio
Fig. 4

The differences in the designs of the 6-element and 9-element Yagis yield different patterns for the rear quadrants. As a result, the difference between a maximum gain and a maximum front-to-back spacing have diffeent effects on the rearward pattern. **Fig. 4** shows something of the difference. The 9-element design (along with all of the larger Yagis in the set) has a single major rearward lobe with only small sidelobes. Hence, the 180-degree front-to-back ratio and the worst-case front-to-back ratio are the same. The range of variation from minimum to maximum front-to-back ratio is only about 3.5 db at worst.

In contrast, the design-frequency front-to-back ratio of the 6-element design shows a deep null directly opposite the forward lobe. As we move away from the design frequency, the pattern becomes more rounded into a single lobe at lower frequencies and becomes multi-lobe at high frequencies. Nevertheless, at stacking spaces widely divergent from the maximum front-to-back value, the entire rear-lobe structure grows larger, as shown in the figure that shows the pattern for maximum gain. Hence, by any interpretation of the concept of front-to-back ratio, a lower front-to-back value in dB indicates a considerable increase in the gain of the rearward lobes.

Model owa2m126x2: The boomlength of the 12-element design is 2.94 wavelengths, about 65% longer than the boomlength of the 9 element design. However, the gain increase of the longer over the shorter Yagi is only about 1.3 dB. As a result we would expect that the required increase in spacing for maximum gain would be somewhat smaller than the increase between 6- and 9-element designs. However, the maximum-gain separation is not a smooth function. The required separation for maximum gain is only 1.6 wavelength, just 0.1 wavelength wider than for the smaller beam. **Table 4** and **Fig. 5** provide the details.

Model owa2m126x2			Table 4
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	22.69	2.5	26
1.3	22.82	2.5	26.15
1.4	22.93	2.4	25.9
1.5	23.01	2.4	25.02
1.6	23.04	2.4	23.71
1.7	23.03	2.4	22.77
1.8	23	2.3	22.81
1.9	22.99	2.3	23.35
2	22.99	2.3	23.9
2.1	22.98	2.3	24.46
2.2	22.96	2.2	25.08
2.3	22.95	2.2	25.67
2.4	22.92	2.2	25.93
2.5	22.89	2.2	25.61

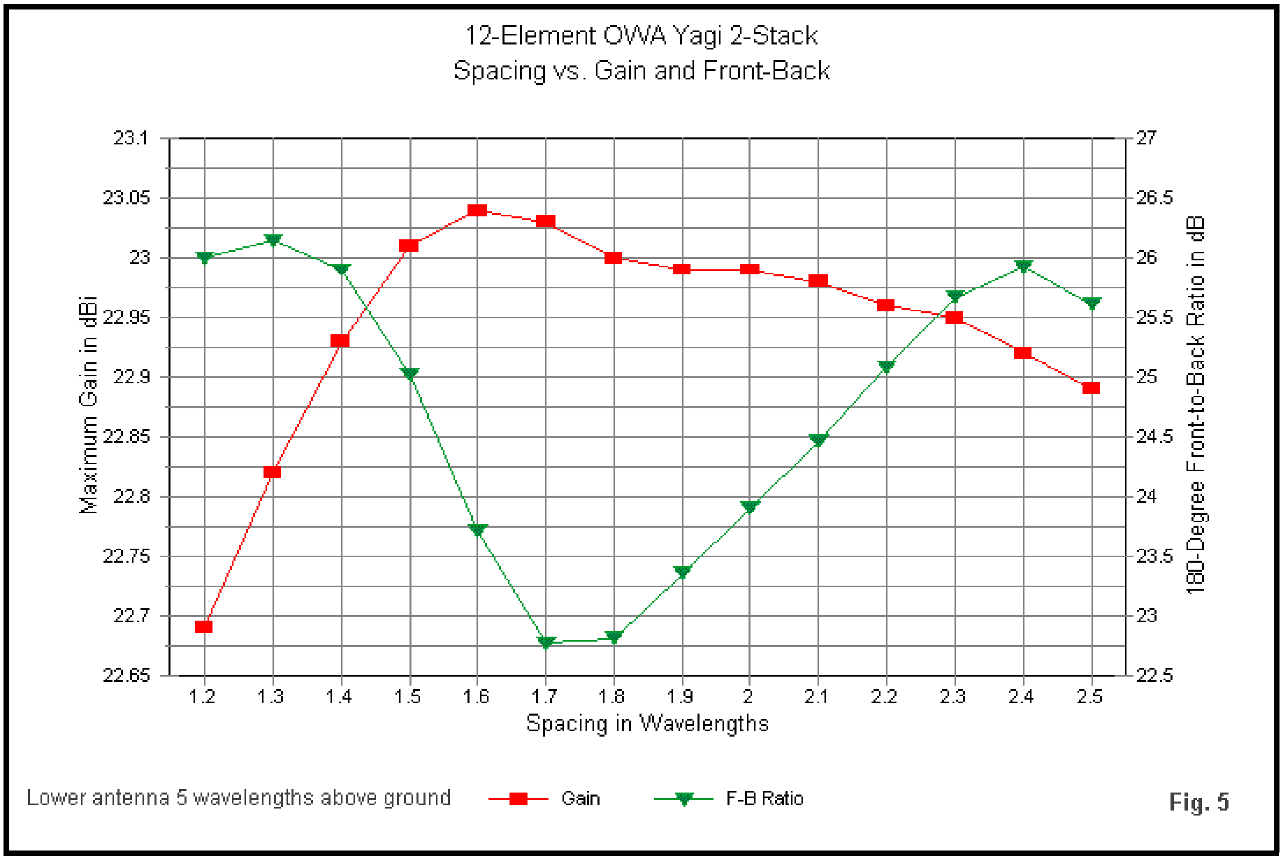


Fig. 5

I have carried out the spacing values further in this instance for 2 reasons. First, the curve above the maximum gain value shows a flattening. It seemed wise to determine whether there might be a secondary peak in the gain-vs.-spacing curve. Despite the flat region of the curve between 1.8 and 2.1 wavelengths, no secondary peak appeared. Nevertheless, this region of the curve will become important as we look at still longer Yagis.

The second reason for extending the range of trial spacing values is to locate the minimum and next maximum front-to-back spacing values. The minimum occurs at a spacing of 1.7 wavelength, very close to the spacing for maximum gain. The second maximum front-to-back value occurs at a spacing of 2.4 wavelength. Like the front-to-back maximum value at 1.3 wavelengths, these new values are also constant for any Yagi in the set under test.

Model owa2m156x2: Even though the boomlength of the 15-element Yagi is 40% longer than the length of the 12-element design, the gain increase for a single unit is only about 0.7 dB. Theoretically, we should see an even smaller increment in spacing increase to achieve maximum gain. However, the actual required spacing--as shown in **Table 5** and in **Fig. 6**--is considerably larger: between 2.1 and 2.3 wavelengths.

Model owa2m156x2			Table 5
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	23.21	2.5	26.25
1.3	23.31	2.5	26.53
1.4	23.4	2.4	26.49
1.5	23.48	2.4	25.81
1.6	23.54	2.4	24.66
1.7	23.56	2.4	23.82
1.8	23.57	2.3	23.96
1.9	23.6	2.3	24.66
2	23.64	2.3	25.45
2.1	23.66	2.3	26.24
2.2	23.66	2.2	26.99
2.3	23.66	2.2	27.54
2.4	23.65	2.2	27.62
2.5	23.62	2.2	27.06

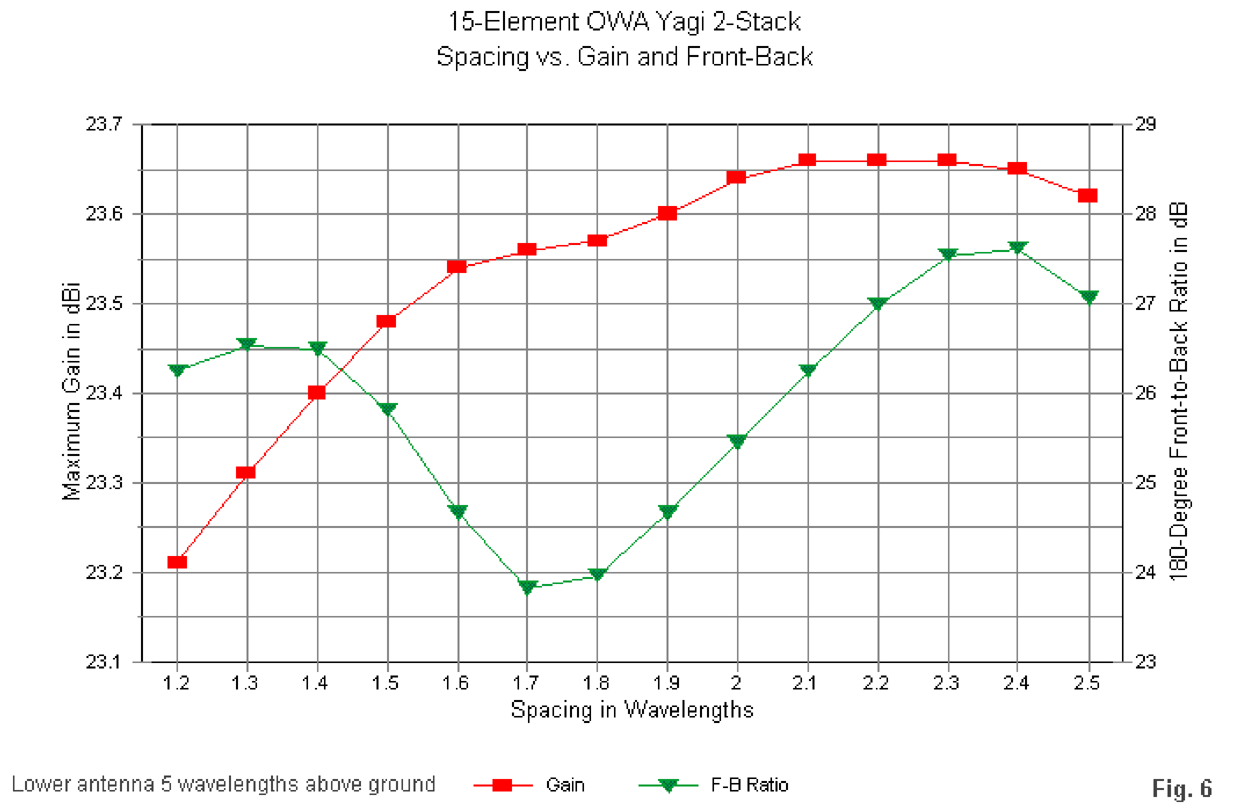


Fig. 6

The gain-vs.-spacing curves for the 12-element and the 15-element Yagis deserve closer inspection. Both curves have similar properties, but nearly in mirror image. There is in both **Fig. 5** and in **Fig. 6** a rise near the 1.6-wavelength mark, followed by a relatively flat region. For the shorter beam, the flatter region leads to a more rapidly decreasing gain value at a spacing of about 2.1 wavelengths, although some leveling is apparent until we reach 2.3 wavelengths. For the 15-element Yagi. the gain-value flattening after a space of about 1.6 wavelength is actually a very slowly rising curve that peaks in a very broad way between 2.1 and 2.3 wavelength.

The net effect for the set of Yagis is a stacking-space region of some interest. If the single unit gain is only a bit lower, the required stacking space for maximum gain is smaller than previous spacing increments would suggest. However, with only a small increase of gain, the required spacing "jumps" to a larger-than-expected values. Once over the "forbidden" zone between 1.8 and 2.0 wavelength spacing, we might anticipate a smaller increment for the next Yagi in the set.

Model owa2m186x2: The 18-element Yagi has a boomlength of 5.39 wavelengths and a gain improvement of about 0.35 dB over the 15-element design. As noted in earlier articles on this family of Yagis, the gain increments are somewhat smaller than for other design series, such as the DL6WU Yagis. The smaller growth in gain is the price paid for maintaining very small sidelobes across the entire 2-meter band.

As shown in **Table 6** and in **Fig. 7**, the required spacing for maximum and minimum values of front-to-back ratio have not changed from those associated with any of the smaller Yagis. However, the spacing required for maximum gain continues to grow, reaching a peak-gain value at 2.4 wavelengths. Interestingly, this spacing coincides with the spacing required for a front-to-back ratio peak.

Model owa2m186x2			Table 6
Spacing	Gain	TO Angle	F-B Ratio
wl	dBi	degrees	dB
1.2	23.55	2.5	27.02
1.3	23.62	2.5	27.4
1.4	23.68	2.4	27.35
1.5	23.74	2.4	26.61
1.6	23.78	2.4	25.31
1.7	23.8	2.4	24.36
1.8	23.82	2.3	24.47
1.9	23.86	2.3	25.14
2	23.91	2.3	25.87
2.1	23.96	2.3	26.59
2.2	23.98	2.2	27.24
2.3	24	2.2	27.71
2.4	24.01	2.2	27.77
2.5	24	2.2	27.26
2.6	23.97	2.2	26.34

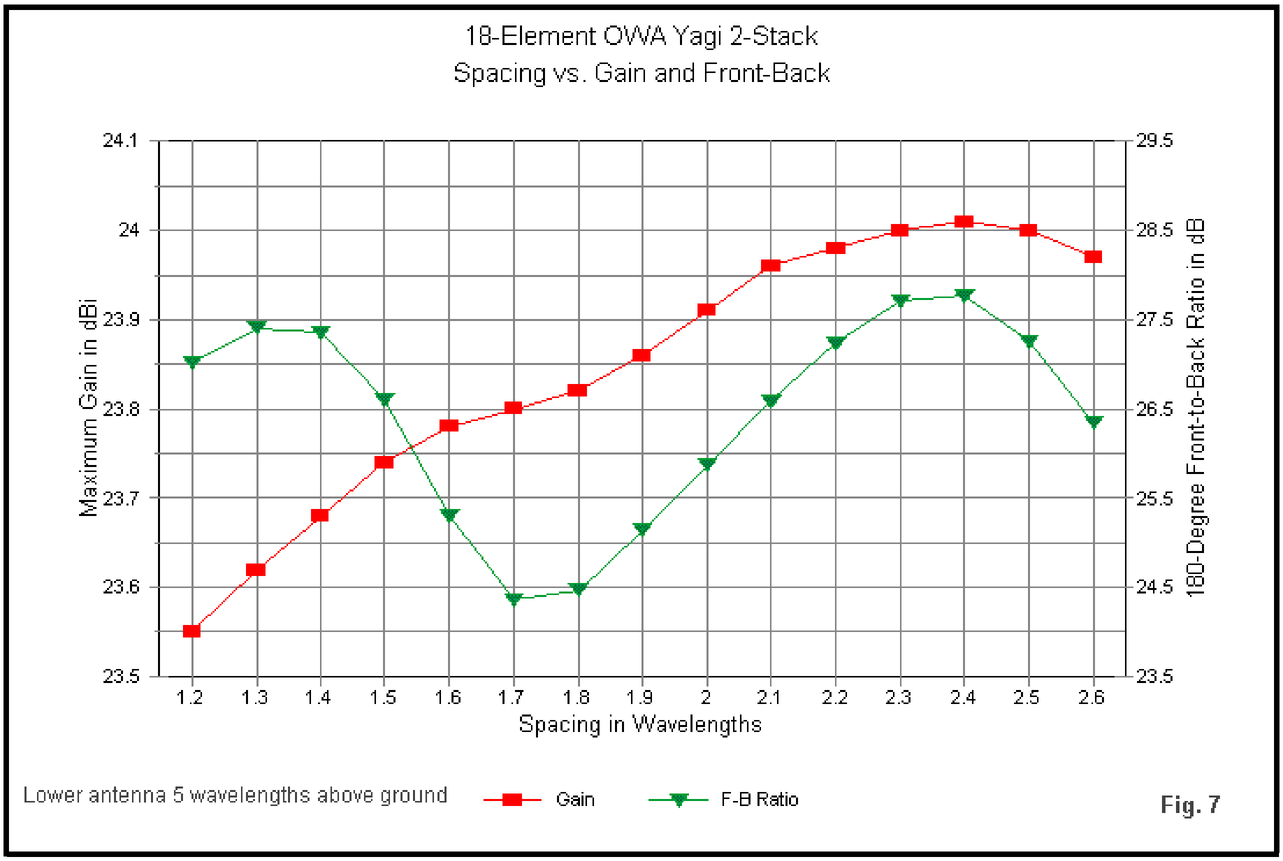


Fig. 7

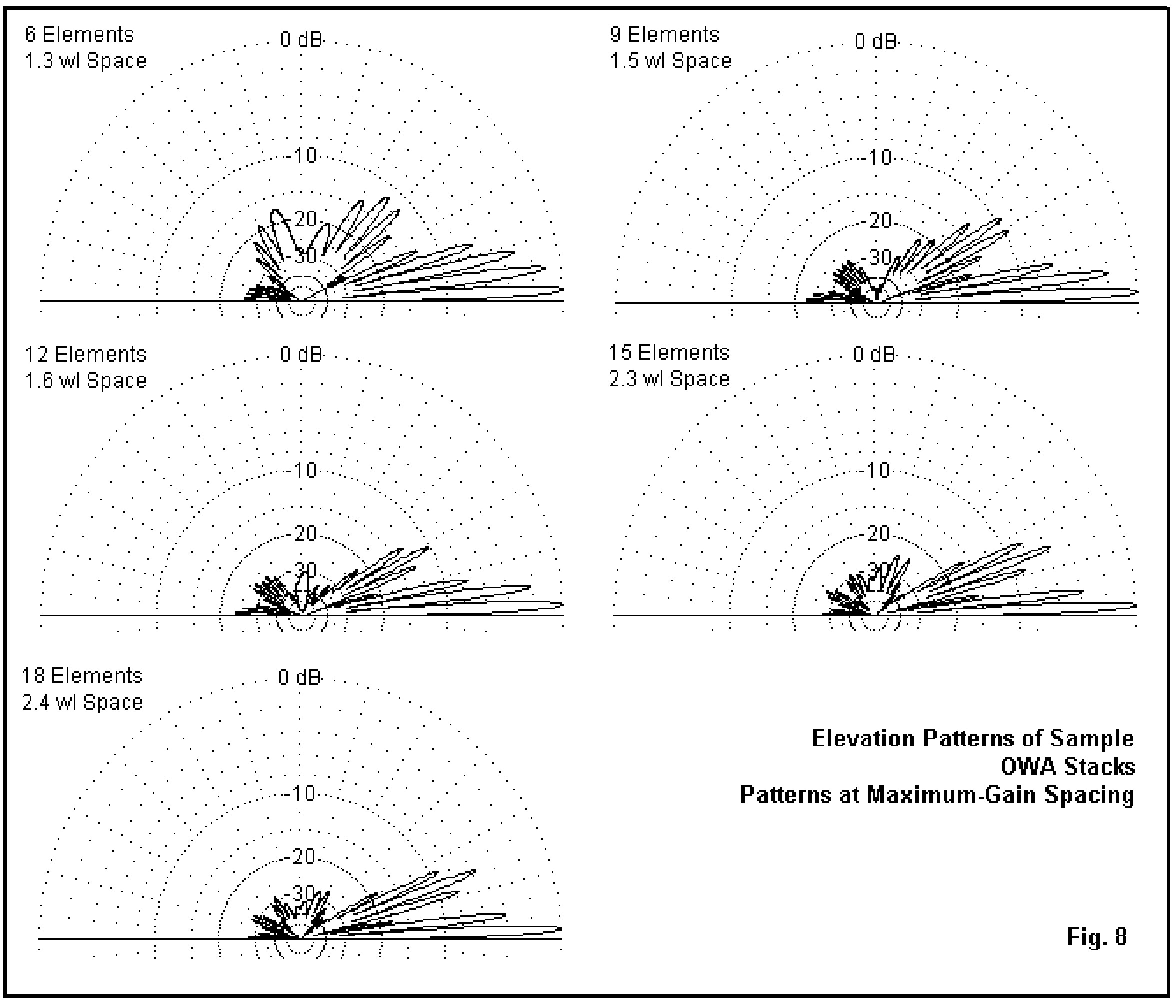
Although the gain-vs.spacing curve is shallow, its peak is distinct at a single spacing value. The relevant portion of the curve in the maximum gain region shows a behavior similar to the curves for the smallest Yagis in the tested set. However, the "double-hump" (or flat region or forbidden zone) continues to appear between 1.6 and 2.0 wavelengths in the form of a decreased rate of gain increase, followed by a faster rise in gain as we approach the spacing that yields maximum gain.

Some General Trends

As we increase the length and gain of the individual Yagis, we see that the amount of gain from the stack of 2 decreases steadily. **Table 7** tracks the steady decrease in stack-gain. The decrease is not serious enough to suggest not using a stack, although split feed losses must be added to the decrease to arrive at a final value for what a stack of 2 can do for us. At the limits of practical boom lengths, stacking offers an increase of gain that would require highly impractical boomlengths to achieve.

Gain Improvement From Stacking			Table 7
Model	Single Unit Gain dBi	Stack of 2 Gain dBi	Stack Gain Increase dB
owa2m616	16.11	19.15	3.04
owa2m916	18.88	21.84	2.96
owa2m126	20.21	23.04	2.83
owa2m156	20.89	23.66	2.77
owa2m186	21.26	24.01	2.75

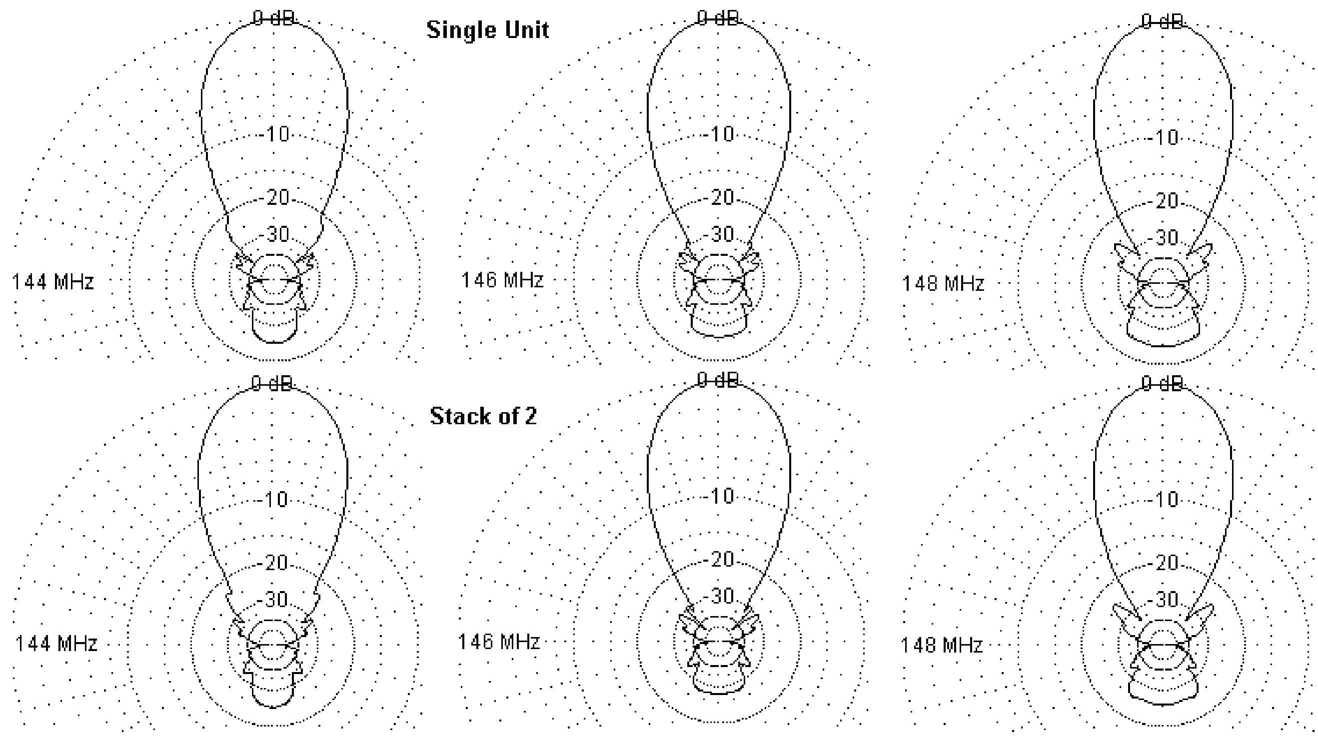
Many stack users are unfamiliar with the elevation patterns that emerge from stacks. An individual Yagi beam tends to produce a series of lobes at regular angular intervals. A stack, however, produces an irregular elevation pattern, as shown in the patterns for the test beams in **Fig. 8**. The interactions between vertically spaced elements both locally and at the points where the individual patterns merge (including both incident and reflected components) result in deep nulls that tend to vary with the individual beam gain values and with the spacing between them. As we increase the spacing between the beams, the number of lobes lower than the first major stack-null tends to decrease.



Elevation Patterns of Sample OWA Stacks Patterns at Maximum-Gain Spacing

Fig. 8

Azimuth patterns for 2-stacks, on the other hand, tend to retain almost all of the characteristics of the individual beams when used alone. **Fig. 9** provides a comparative view of the 15-element Yagi when used alone and in a 2-stack spaced for maximum gain. In addition, the figure provides band-edge paterns as well as design-frequency patterns. In all cases, the modifications to the sidelobe structure are minor.



Comparative Azimuth Patterns: Model owa2m156 and owa2m156x2
144, 146, and 148 MHz Patterns
Fig. 9

Finally, we should return to the equation for calculating the optimal beam separation for a stack of 2 Yagis. **Table 8** shows the calculated and the modeled spacing required for each beam in the test series. The calculated optimal spacing is based on a regular sin function of the free-space H-plane (vertical) beamwidth. For the calculations, the vertical beamwidth is derived from a free-space model of the array.

Calculated vs. Modeled Maximum Gain Stack Spacing					Table 8
Dopt = lambda/[2 sin (phi-h/2)]					
Model	Phi-h	Dopt		Modeled	
	degrees	wavelengths		wavelengths	
owa2m616	68.2	0.89		1.1	
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	

The calculated values fall short of the modeled space over ground in every case. Of greater importance may be the fact that the calculated spacing cannot show the irregularity in the development of the maximum-gain spacing curve and the seeming "forbidden zone" effect. Indeed, in the final analysis, anyone contemplating creating a 2-stack for beams of significant length owes it to himself to obtain modeling software and to re-create to the degree possible the stacking conditions.

Perhaps the most important trends that we have seen in this set of beams deserve further attention. Especially notable are the differences between calculated and modeled optimal spacing distances and the double-humped curve associated with longer booms and their wider-than-expected spacing. One possible explanation for both phenomena is ground effects, that is, unexpected irregularities in the optimal spacing that result from the ground reflections. Therefore, I modeled the entire set of OWA Yagis in free space to see if there might be some significant differences.

The shorter (6- and 9-element) Yagis showed no differences in either the required spacing for maximum gain or in the spacing for maximum front-to-back ratio. At the other end of the scale, the 18-element Yagi also showed no differences in maximum gain and front-to-back spacings. **Table 9** shows the tabulated values for both the free-space version and the model with a base height of 5 wavelengths.

Model owa2m186x2				Table 9	Model owa2m186x2-fs		
Spacing	Gain	TO Angle	F-B Ratio		Spacing	Gain	F-B Ratio
wl	dBi	degrees	dB		wl	dBi	dB
1.2	23.55	2.5	27.02		1.2	17.82	27.22
1.3	23.62	2.5	27.4		1.3	17.91	27.56
1.4	23.68	2.4	27.35		1.4	17.99	27.48
1.5	23.74	2.4	26.61		1.5	18.06	26.7
1.6	23.78	2.4	25.31		1.6	18.11	25.38
1.7	23.8	2.4	24.36		1.7	18.15	24.31
1.8	23.82	2.3	24.47		1.8	18.18	24.24
1.9	23.86	2.3	25.14		1.9	18.24	24.99
2	23.91	2.3	25.87		2	18.32	25.87
2.1	23.96	2.3	26.59		2.1	18.38	26.68
2.2	23.98	2.2	27.24		2.2	18.44	27.41
2.3	24	2.2	27.71		2.3	18.48	27.86
2.4	24.01	2.2	27.77		2.4	18.51	27.87
2.5	24	2.2	27.26		2.5	18.53	27.32
2.6	23.97	2.2	26.34		2.6	18.52	26.38

Maximum 180-degree front-to-back ratio occurs at a spacing of 1.3 wavelengths and again at 2.4 wavelengths. The minimum front-to-back ratio occurs in the 1.7-1.8-wavelength region. Gain peaks in the 2.4-2.5-wavelength region, with the free-space model show a slightly more distinct peak relative to adjacent values.

As we move downward to the 15-element OWA Yagi, we encounter a more significant difference in the required spacing for maximum gain. Contrary to possible expectations, the free-space model does not show a smaller required spacing for maximum gain. Instead, the free-space model requires a wider spacing, as shown in **Table 10** and in **Fig. 10**.

Model owa2m156x2				Table 10	Model owa2m156x2-fs		
Spacing	Gain	TO Angle	F-B Ratio		Spacing	Gain	F-B Ratio
wl	dBi	degrees	dB		wl	dBi	dB
1.2	23.21	2.5	26.25		1.2	17.47	26.37
1.3	23.31	2.5	26.53		1.3	17.58	26.63
1.4	23.4	2.4	26.49		1.4	17.69	26.54
1.5	23.48	2.4	25.81		1.5	17.79	25.86
1.6	23.54	2.4	24.66		1.6	17.87	24.7
1.7	23.56	2.4	23.82		1.7	17.91	23.74
1.8	23.57	2.3	23.96		1.8	17.93	23.74
1.9	23.6	2.3	24.66		1.9	17.98	24.54
2	23.64	2.3	25.45		2	18.03	25.46
2.1	23.66	2.3	26.24		2.1	18.08	26.34
2.2	23.66	2.2	26.99		2.2	18.12	27.12
2.3	23.66	2.2	27.54		2.3	18.14	27.64
2.4	23.65	2.2	27.62		2.4	18.15	27.67
2.5	23.62	2.2	27.06		2.5	18.15	27.1
2.6	23.58	2.2	26.1		2.6	18.13	26.12

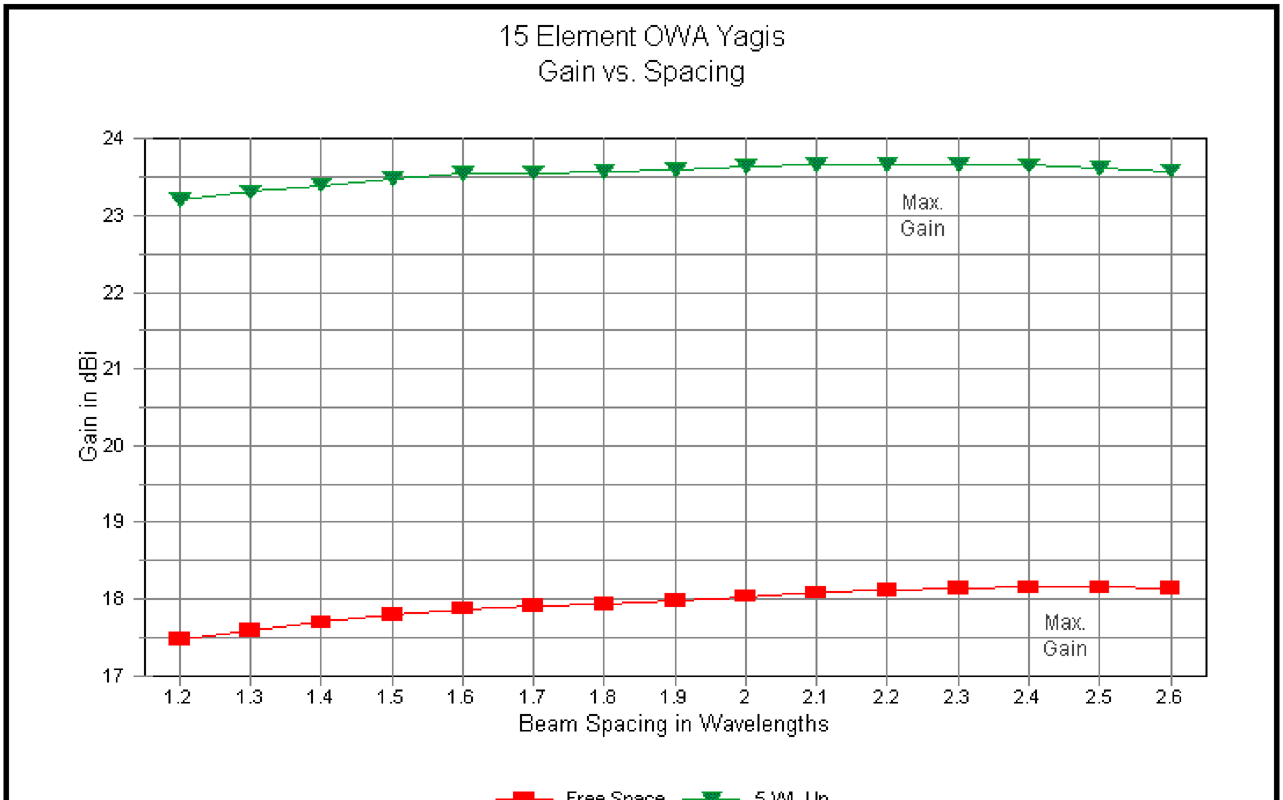


Fig. 10

The model whose base height is 5 wavelengths above ground shows a broad peak gain between 2.1 and 2.3 wavelengths spacing. However, the free-space version places the optimal separation for maximum gain between 2.4 and 2.5 wavelengths. In both cases, the adjacent values are sufficiently close to optimal so the the difference has no great significance in practice. However, the fact that it is counter-intuitive does have some significance. Rather than expanding the stack spacing, ground effects appear to narrow it slightly for some longer-boom Yagis.

The most dramatic effects appear in connection with the 12-element Yagi. The original graph of gain vs. separation for the 12-element antenna 5 wavelengths above ground (**Fig. 5**) showed a peak gain with 1.6-wavelength spacing. Beyond that point, the gain remained level or descended very slowly until we reached a spacing of about 2.3 wavelengths. The level area for this model combined with the nearly level curve as the 15-element Yagi approached optimal spacing to produce the rough notion of a "forbidden zone." The notion does not indicate that a practical pair of Yagis might not use the spacings in the zone. Rather, it only indicated that we could expect no gain peak in the zone.

Table 11 and **Fig. 11** provide comparisons of the free-space and above-ground models of the 12-element OWA Yagi.

Model owa2m126x2				Table 11	Model owa2m126x2-fs		
Spacing	Gain	TO Angle	F-B Ratio		Spacing	Gain	F-B Ratio
wl	dBi	degrees	dB		wl	dBi	dB
1.2	22.69	2.5	26		1.2	16.93	26.12
1.3	22.82	2.5	26.15		1.3	17.09	26.29
1.4	22.93	2.4	25.9		1.4	17.22	25.99
1.5	23.01	2.4	25.02		1.5	17.31	25.07
1.6	23.04	2.4	23.71		1.6	17.36	23.75
1.7	23.03	2.4	22.77		1.7	17.37	22.7
1.8	23	2.3	22.81		1.8	17.36	22.6
1.9	22.99	2.3	23.35		1.9	17.37	23.19
2	22.99	2.3	23.9		2	17.39	23.85
2.1	22.98	2.3	24.46		2.1	17.4	24.5
2.2	22.96	2.2	25.08		2.2	17.41	25.18
2.3	22.95	2.2	25.67		2.3	17.42	25.78
2.4	22.92	2.2	25.93		2.4	17.42	26.01
2.5	22.89	2.2	25.61		2.5	17.41	25.66

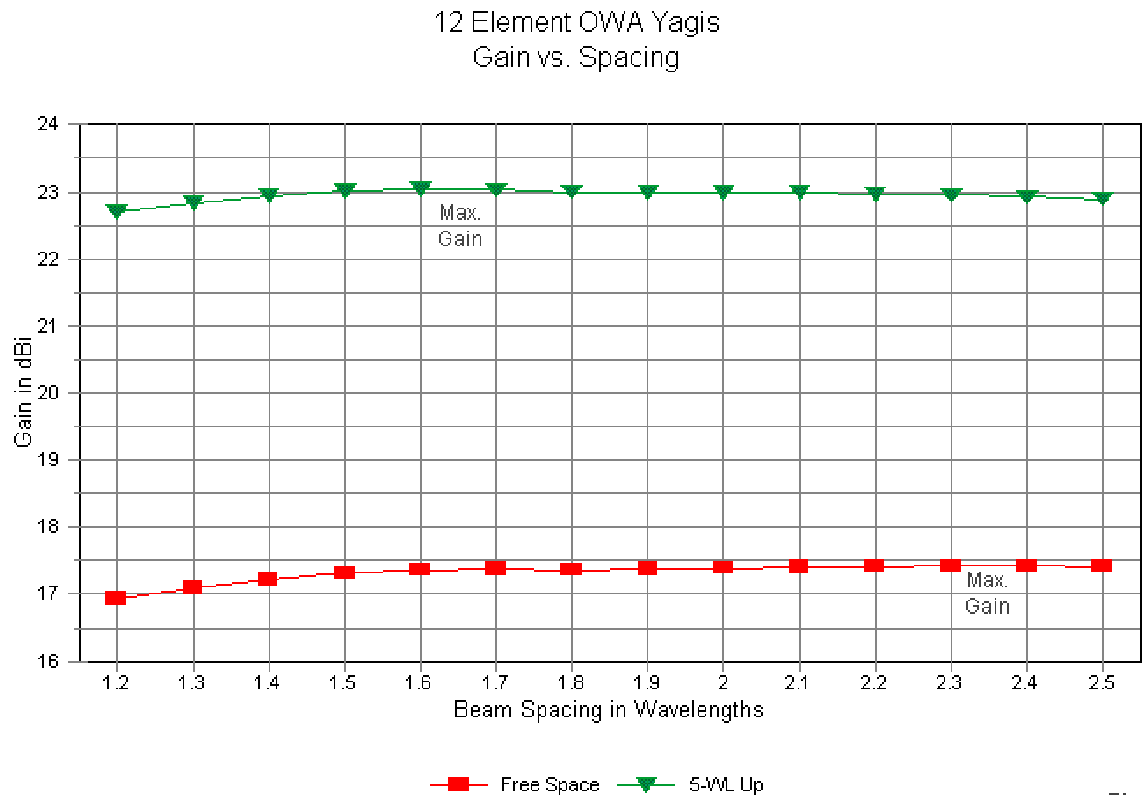


Fig. 11

The free-space model not only preserves the forbidden zone, but places maximum gain at a spacing of 2.3 to 2.4 wavelengths, far above the 1.6-wavelength spacing indicated by the model with a 5-wavelength base height. Again, the gain differentials are small enough across the spacing region from 1.6 to 2.4 wavelengths to permit a set-up at any height in the region. Indeed, the best height--apart from physical constraints--might be a spacing that yields the best combination of gain and front-to-back ratio. In practical terms, the forbidden zone might also be called the ideal zone. However, from the perspective of understanding stacking phenomena, the zone appears to forbid maximum gain values from appearing in models. Calculated spacing values, of course, do not acknowledge such a zone, but then, calculations tend to err on the low side compared to models for all of the Yagis in the set.

Throughout both the free-space and above-ground modeling of OWA Yagi 2-stacks, the front-to-back maximums and minimums occur at the same separations, with an occasional deviation of 0.1 wavelength. There are two possible explanations for this phenomena. First, it might simply be a relatively universal condition for all stacks of 2 Yagis. Second, it might be a function of the particular desgn considerations that guided the development of the

OWA series. In **Fig. 1** we saw the coincidence of the SWR tracks across 2 meters, as exemplified by the curves for the 9- and 15-element versions. Further design guidelines--possible with few other types of Yagi designs--included centering to the degree possible both the gain and front-to-back curves within the 144-148-MHz passband. **Fig. 12** provides gain and 180-degree frnt-to-back ratio curves for the 12- and 18-element versions of the OWA Yagi.

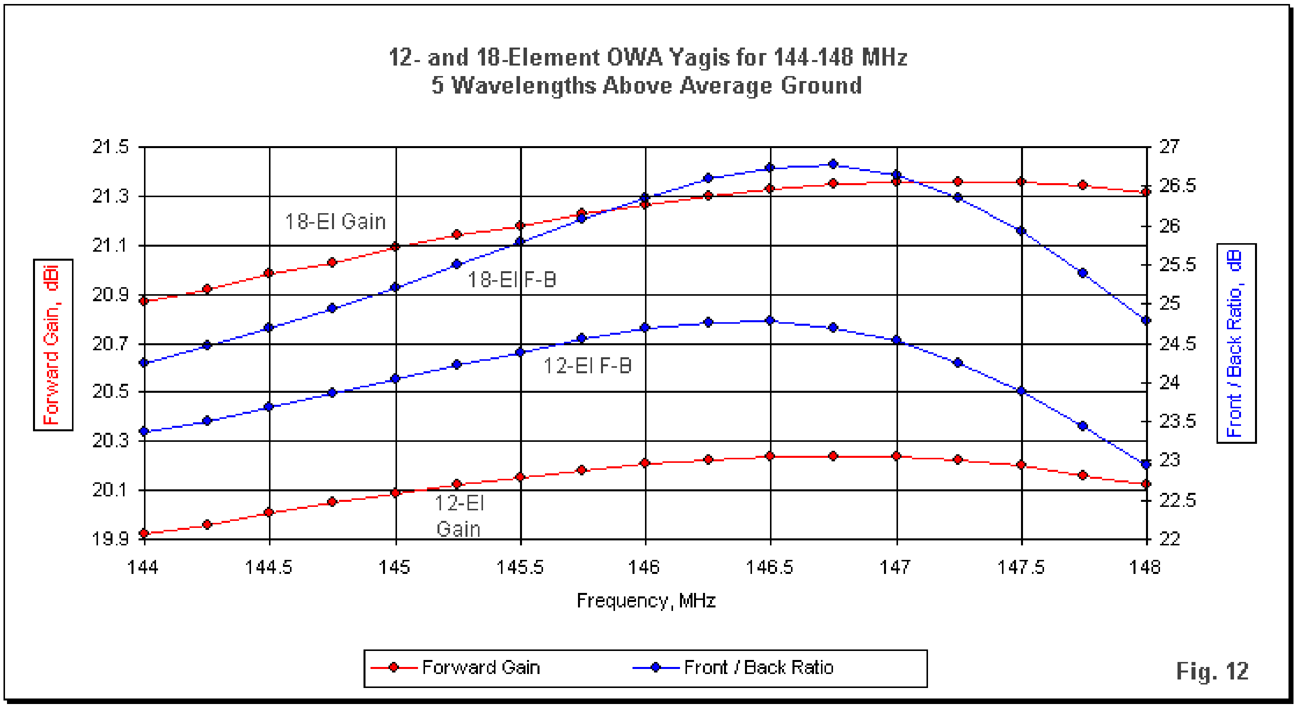


Fig. 12

The 12-element OWA Yagi show both peak gain and peak front-to-back ratio at 146.5 MHz. For the 18-element version of the antenna, peak gain occurs at 147.25 MHz, while peak front-to-back ratio appears at 146.75 MHz. As Yagi designs go, both sets of figures represent well-centered curves that minimize differences at the band edges. The centering of the front-to-back curves (especially) may be resonsible for the constant value of separation for stacked-Yagi maximum and minimum front-to-back ratios. The free-space tables show that ground effects are not responsible for those values or their relative constancy across the range of Yagi boom lengths.

With respect to gain, I have referred to the erstwhile forbidden zone as a double-humped curve. For arrays with a base height 5 wavelengths above ground, the actual double hump occurs somewhere between 12 and 15 elements. In fact, as shown in the gain plots in **Fig. 13**, the 13-element Yagi in the OWA series provides a true double peak, with maximum gain occuring at spacing values of 1.6 to 1.7 wavelengths and again at 2.0 to 2.1 wavelengths. The continuum of 12 through 15 elements provides added evidence that a peak gain value does not occur in the 1.8- to 1.9-wavelength region, although for the 13-element version of the OWA Yagi, the gain values in the region are highly usable, except for the lower front-to-back ratio in this region.

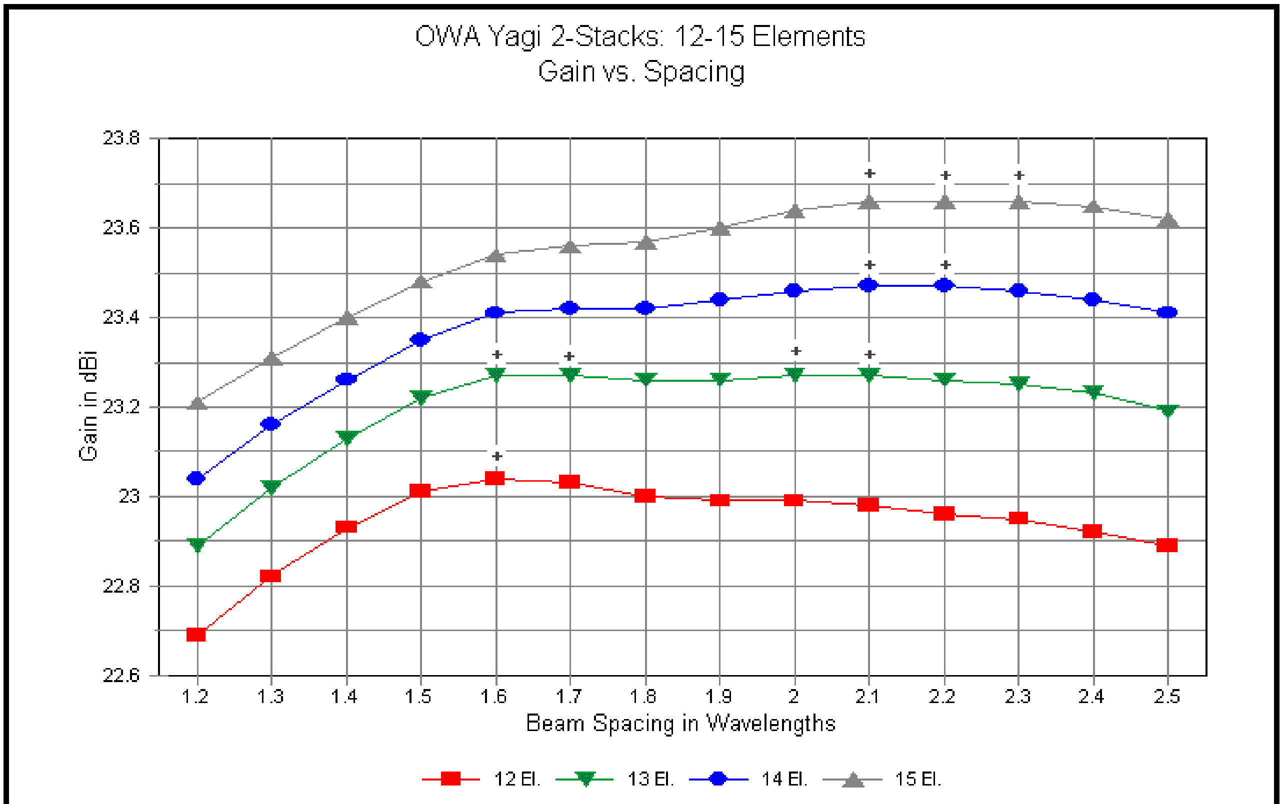


Fig. 13

Although the relative constancy of the spacing values for both maximum and minimum front-to-back ratios hardly needs further evidence, it was convenient to gather this data for the sequence with smaller boomlength steps. **Fig. 14** shows the 4 relevant curves of front-to-back vs. spacing between the two beams in each stack. The deviation from the statistical norm is no more than 0.1 wavelength for either minimum or maximum values.

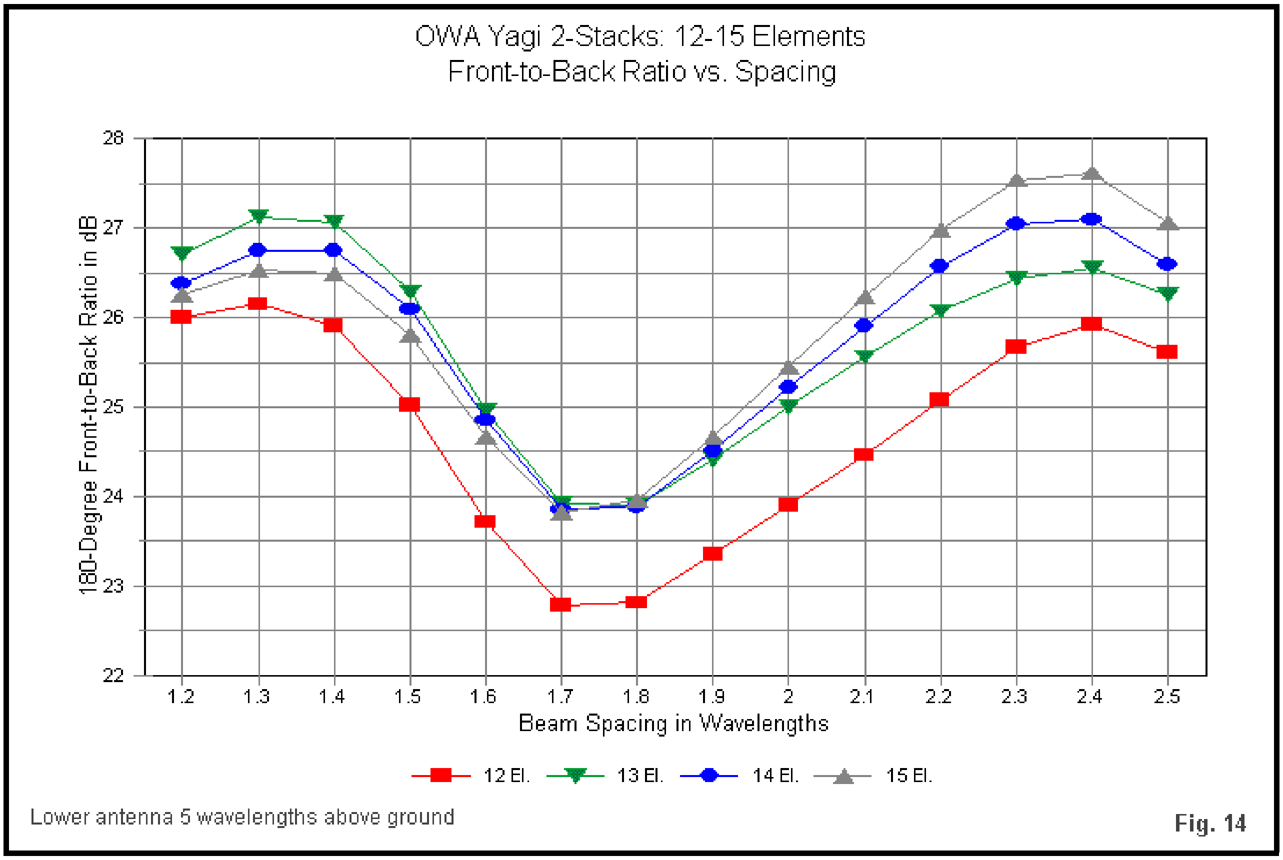


Fig. 14

Modeling one coherent set of beams is neither a necessary nor a sufficient condition for establishing the trends that we have seen as relatively universal. To obtain a sense of their universality, we need to sample other coherent lines of Yagi designs. If the trends are replicated in a second line of Yagis, we do not have yet a sufficient condition of universality. However, we may at least have a stronger suggestion in that direction. And even if the trends do not hold up, we may reach a better understanding of what may be responsibile for the stacking phenomena that we uncover.