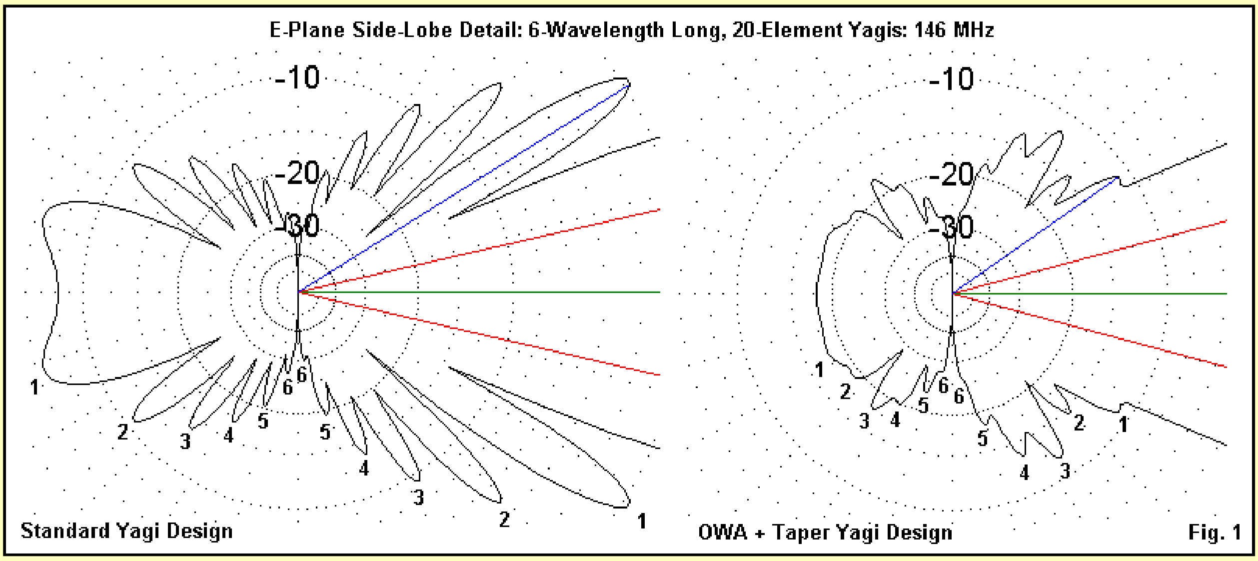
Sidelobe Attenuation and Suppression

L. B. Cebik, W4RNL (SK)

In 2002, I presented a preliminary study of side-lobe suppression to the Southeastern VHF Society, (**Long-Boom Yagi Sidelobe Suppression**). At the time, I had only developed the OWA series of long-boom Yagis to 12 elements. This note is an extension of that work with a couple of special slants. First, we shall use a 20-element OWA Yagi as our subject antenna. In fact, the design is a bit of an improvement over earlier versions of the array, although it still does not--as a design decision--match the gain of some Yagis of more standard design. Second, we shall look not only at the E-plane sidelobes, but also at the H-plane sidelobes. Finally, we shall examine the difference between sidelobe attenuation and sidelobe suppression as a gauge of work yet to be done.

Let's first examine the idea of a sidelobe. **Fig. 1** shows the sidelobe structure for a pair of very different Yagi designs: a somewhat standard 20-element array and a 20-element OWA Yagi. Despite the differences in the strength of the sidelobes, each Yagi shows (on each side of the boom or centerline) 6 forward and 6 rearward sidelobes. In standard designs, the strength of the sidelobes tends to decrease as the angle between the main lobe and the sidelobe increases. Hence, the strongest forward and rearward lobes tend to be those most closely aligned with the main forward or rearward lobe.


E-Plane Side-Lobe Detail: 6-Wavelength Long, 20-Element Yagis: 146 MHz

Standard Yagi Design

OWA + Taper Yagi Design

Fig. 1

The rearward lobes can be tricky to count sometimes, because the main rearward lobe can undergo periodic increases and decreases in strength as the array operating frequency changes. (This phemonenon also makes the 180-degree front-to-back ratio an unreliable indicator of rearward array performance. Comparing the 180-degree and worst-case front-to-back ratios provides a more adequate evaluation.) Perhaps the most troublesome case is the "squared-off" rear main lobe, which usually is a combination of the main lobe and the first rearward sidelobes.

Sidelobes tend to be restricted to end-fire arrays that depend upon the relative current magnitudes and phase angles on the individual elements. Planar and corner reflector arrays--by way of contrast--rarely have any forward sidelobes at any gain level and have few in the rearward direction. Log periodic dipole arrays (LPDAs) tend to have forward lobes that are free of sidelobes if they are well designed with adequate element densities. Sidelobes find their best home in Yagi and related parasitic arrays.

The number of forward Yagi sidelobes is a function of boom length. Hence, we normally do not encounter forward sidelobes until a Yagi has about 7 elements or so, that is, as the boom length approaches 1 wavelength. The samples in **Fig. 1** both use booms that are 6 wavelengths. The question that piques my curiosity is whether the tendency is inevitable for all Yagis or whether it may be possible to eliminate one or more sidelobes.

Classic long-boom VHF/UHF Yagi designs have tended to overlook sidelobe reduction in favor of achieving the maximum gain of which a given boomlength may be capable. Hence, most of the designs have first forward sidelobes that are only about 16-19 dB below the strength of the main forward lobe. A number of investigators, such as VK3AUU and N4FG, have developed Yagis with a far higher level of sidelobe strength reduction, especially in the E-plane. The attenuation as reached front-to-sidelobe ratios of 20-25 dB.

The right side of **Fig. 1** does allow us to make a distinction between sidelobe attenuation and sidelobe suppression. The general idea of sidelobe attenuation includes the reduction in sidelobe strength. Each sidelobe may not reduce is strength in exact proportion to the other sidelobes, but each sidelobe remains a distinct lobe marked by a clear reduction in strength on either side of the lobe bearing. In contrast, sidelobe suppression involves the elimination or near elimination of a sidelobe so that there is at most a reduction in strength on only one side of the detectable peak of strength. In **Fig. 1**, forward sidelobe 6 is an example of a sidelobe that is suppressed to a mere slight bulge. In many long-boom Yagi designs, when operated at the upper limit of their passband range, the first forward sidelobe will become a "bulge" rather than a distinct sidelobe. A second feature of sidelobe suppression is that we begin to lose the distinctness of the individual sidelobes. Sidelobes 3 and 4 show signs of merging into a single sidelobe, although the merger is incomplete.

Because some Yagi designs tend to favor sidelobe attenuation and approach sidelobe suppression, they raise an interesting question: to what degree are Yagi sidelobes capable of suppression rather than just attenuation? Of course, the subject has only restricted interest. First, it is applicable only to those whose operations involve long-boom Yagis. Within that group, some operators prefer to have sidelobes to detect off-axis activity. However, there remains a group for whom insensitivity to off-axis noise is desirable. However, even if there were not such a group, curiosity is enough to attract my attention.

The 20-Element 2-Meter OWA Yagi

The OWA (Optimized Wideband Array) Yagis, first presented by NW3Z in short-boom HF versions, showed considerable promise in the pursuit of sidelobe reduction. As I extended the boomlength and number of elements, I eventually arrived at a length that presents a challenging case: 20 elements on a 6-wavelength boom. The latest incarnation of the design appears in the following table of dimensions. For the moment, ignore the elements marked Reflector a and Reflector b. We shall add those elements later. The regular OWA Yagi design includes only the normal reflector, the driver, and the 18 directors.

Dimensions of 20-Element OWA Yagi

Notes

1. **Element diameter: 0.1875" (3/16" or 4.76 mm)**
2. **Versions**
    a. **Regular: Ignore Reflector a and Reflector b; Boomlength 6.08 WL**
    b. **With added Reflectors: Include Reflectors a and b; Boomlength 6.30 WL**
3. **For dimensions in millimeters, multiply by 25.4**

Element	**Length inches**	**Space from Reflector inches**	**Vertical Distance Above/Below Boom**
Reflector a	**46.10**	**-17.96**	**23.05**
Reflector b	**46.10**	**-17.96**	**-23.05**
Reflector	**40.90**	**-----**	
Driver	**39.50**	**8.79**	
D1	**37.06**	**13.47**	
D2	**36.48**	**25.37**	
D3	**36.54**	**40.35**	
D4	**36.41**	**60.56**	
D5	**35.61**	**85.10**	
D6	**34.90**	**113.96**	
D7	**34.34**	**143.87**	
D8	**33.80**	**174.96**	
D9	**33.25**	**205.85**	
D10	**33.25**	**238.11**	
D11	**32.15**	**270.38**	
D12	**31.83**	**302.64**	
D13	**31.52**	**334.90**	
D14	**30.88**	**367.16**	
D15	**30.57**	**399.42**	
D16	**30.25**	**431.68**	
D17	**30.25**	**464.92**	
D18	**29.46**	**491.32**	

The performance across 2 meters appears partially in **Fig. 2**, an EZPlot (AC6LA) track of the free-space gain and the 180-degree front-to-back ratio. Note that both the gain and the front-to-back ratio peak just above the 146-MHz design frequency. Hence, the passband edge values are not too far apart, and the total change of values within the passband is reduced to the minimum achievable so far.

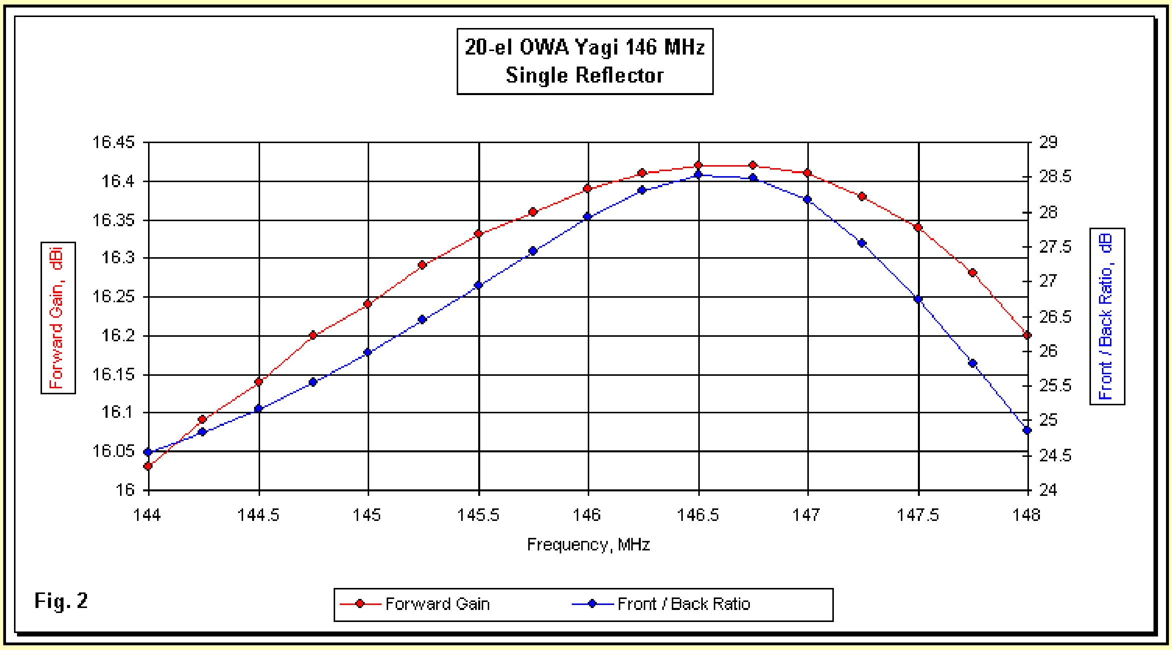


Fig. 2

The impedance performance of the array is quite good, using a direct 50-Ohm feed. **Fig. 3** shows the resistance, reactance, and 50-Ohm SWR across the passband. The maximum SWR is 1.2:1 across the entire band. The minimum SWR occurs just below the top end of the passband, since the resistance and reactance tend to depart rapidly from the flat range at higher frequencies than the ones shown on the plot. In contrast, the impedance remains relatively stable, with only a slowly rising curve well below 144 MHz, but array performance tends to decrease fairly rapidly.

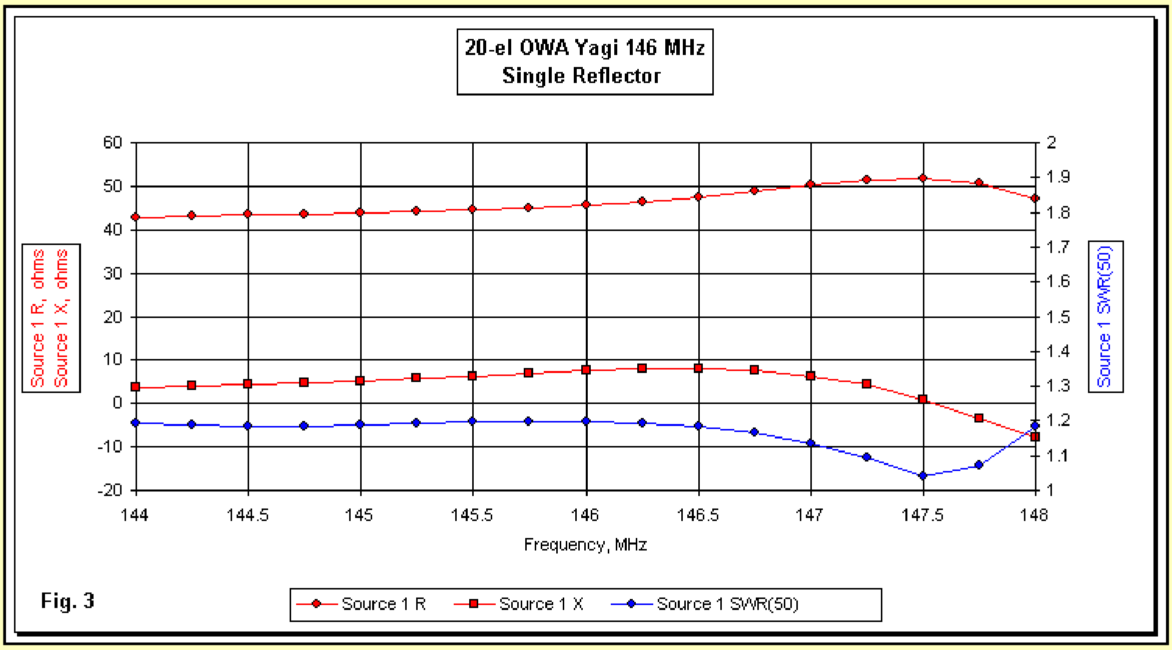


Fig. 3

As a summary, we can present selected values in the form of a modeled-performance table. "Hor F-S/l" is the E-plane front-to-sidelobe ratio, while "Vert F-S/l" is the corresponding H-plane ratio. "Hor BW" and "Vert BW" are the half-power beamwidths for the E and H planes, respectively.

Modeled Performance: Regular (single reflector) 20-element OWA Yagi

Freq. MHz	**Free-Space Gain dBi**	**180-Deg. Front-Back Ratio dB**	**Hor F-S/l Ratio dB**	**Vert F-S/l Ratio dB**
144	**16.03**	**24.53**	**20.89 (bulge)** **29.27 (lobe)**	**21.67**
146	**16.39**	**27.93**	**26.21**	**21.13**
148	**16.20**	**24.85**	**23.79**	**19.63**

Freq. MHz	**Hor BW degrees**	**Vert BW degrees**	**Feedpoint Impedance R +/- jX Ohms**	**50-Ohm SWR**
144	**31.2**	**33.2**	**42.7 + j3.7**	**1.19**
146	**30.0**	**31.6**	**45.6 + j7.5**	**1.20**
148	**29.2**	**31.0**	**47.2 - j7.8**	**1.19**

The array gain is a full dB down from the performance of some standard designs with similar boomlengths. However, for some types of operation, the sacrifice of gain may be compensated by some of the other facets of the OWA design. For example, almost all of the sidelobe values are better than 20 dB down from the main forward lobe strength. Add to this feature the relatively small change of values across the passband and the very flat SWR curve, and the design may become more attractive for some applications.

The OWA is not unique for any single feature, but rather for the combination of design features that it employs. Indeed, we need not design an OWA--as originally conceived by NW3Z--for maximum sidelobe reduction. Rather, that aspect of the design occurs in combination with the other features common to all OWA designs.

The first OWA design element is the use of a direct 50-Ohm feed system composed of the reflector, the driver, and the first director. The three elements together largely (but not exclusively) establish the feedpoint impedance. The OWA system uses a reflector-driver spacing of about 0.11 wavelength together with a driver-director1 spacing of about 0.058 wavelength to establish the impedance. Since the first director operates as a secondary driver, energized by close coupling to the fed driver, element lengths are also critical to arriving at the desired impedance across the passband. In fact, the secondary driver has a higher current magnitude for about 2/3 of the passband, with the fed driver dominant only for the lower third of the passband.

Almost any wide-band Yagi uses a similar system of feeding. The DL6WU wide-band Yagis use a reflector-driver spacing of 0.20 wavelength and a driver-director1 spacing of 0.075 wavelength to achieve 50 Ohms. VK3AUU uses the same reflector-driver spacing, but a driver-director1 spacing of 0.035 wavelength. N4FG uses 0.132 wavelength and 0.051 wavelength to achieve the same goal. Within the limits from the widest to the narrowest, it is likely that there are many more spacing combinations that will yield 50 Ohms if we give due attention to the lengths of the elements involved.

The second aspect--perhaps unique or nearly so with the OWA design--is the use of directors 2 and 3 as control elements. Director 3 is the same length as director 2 or slightly longer. Together, these elements permit the designer to center the peak gain and peak front-to-back ratio at or near the center of the passband. The result tends to be nearly equal front-to-back ratio values at the band edges and the minimum feasible change of gain across the antenna's operating passband.

The third feature has the greatest affect on the sidelobe emergence in the array. By tapering all elements--with some equal length pair exceptions--to shorter lengths as we move forward along the line of directors (from about director 4 onward), we obtain lower sidelobe levels at the cost of some gain compared to more standard designs. I have created hybrid designs using the OWA core (reflector through director 4 or so) and only obtained the level of sidelobe emergence accruing to the director chain design that I grafted on the OWA core. The conclusion I have so far reached is that the director taper toward the forward-most director is critical to either attenuation or suppression of sidelobes.

If you refer to the dimension table, you will discover that the forward-most director is shorter than a natural taper would seem to indicate. One of the functions of the forward-most director--for any number of elements from about 8 up in the OWA design--is to act together with the reflector length in setting the SWR passband curve. Once you have achieve a relatively stable combination of reflector and last director lengths, lengthening the reflector will tend to stretch the passband downward in frequency. Likewise, shortening the last director will stretch the passband upward in frequency. These shift, of course, have limits and they are not fully independent of element spacing and interactions with nearby elements. However, final tweaking of a design usually involves iterative adjustments to both elements.

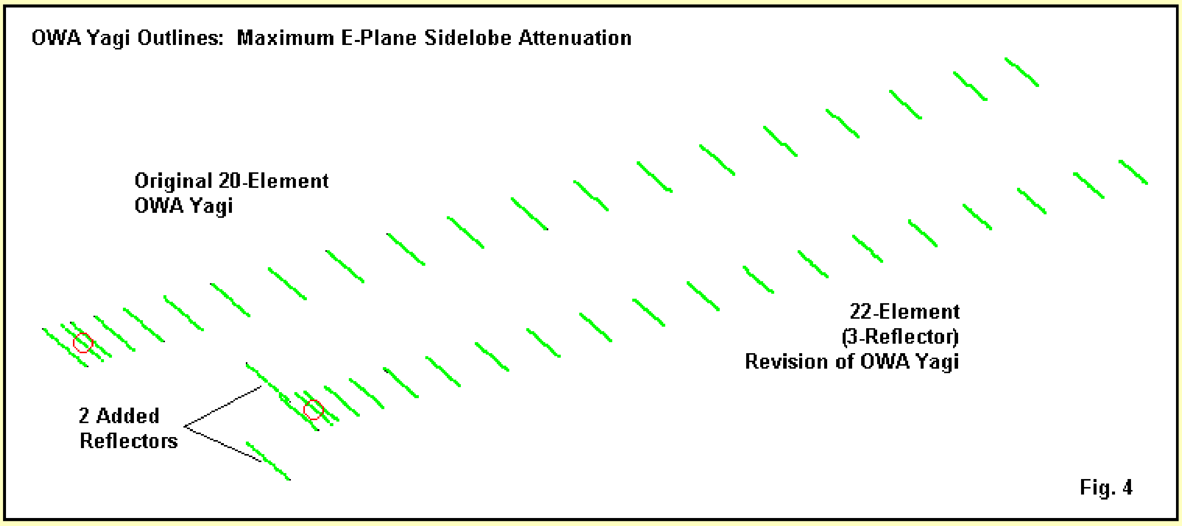


Fig. 4 shows two outlines for OWA Yagis. We shall work with the lower portion of the figure shortly. The upper outline shows the standard 20-element OWA 2-meter array designed for 146 MHz. You may correlate the elements to the table of dimensions and to the brief summary of OWA design features.

The sidelobes that emerge with the OWA design are many dB better than with standard Yagi designs using a similar boomlength. The performance table showed that at 144 MHz, there is a nearly suppressed first sidelobe in the E-plane that is only down by about 21 dB, with the first fully formed sidelobe being 29 dB down. Above the low end of the band there are no E-plane or horizontal sidelobes worse than about 24 dB. However, the vertical or H-plane sidelobes average just above 20 dB below the main lobe. For a single-bay Yagi, the element ends and the geometry of the array outline form a means of control for many E-plane array characteristics. In the H-plane, we have no such controls. Hence, as shown in the left portion of **Fig. 5**, the H-plane sidelobes tend to be larger and more nearly at right angles to the Yagi. Even when they are no stronger than the comparable E-plane sidelobes, they contain more energy due to having a wider compass of included angles.

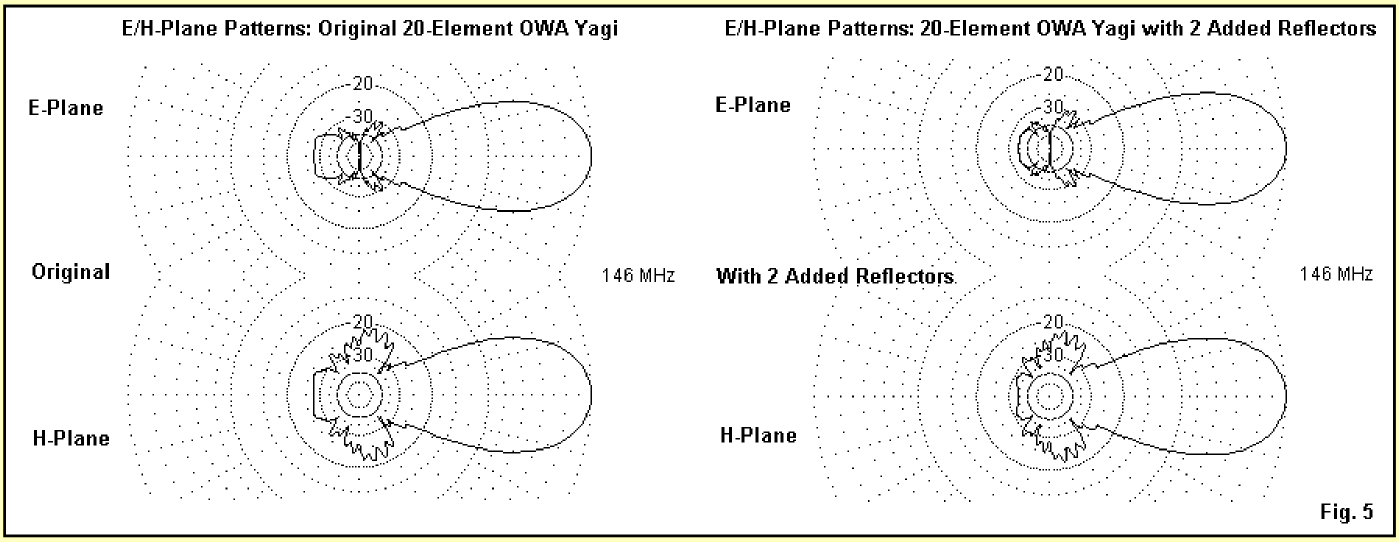


Fig. 5

Compared to a standard Yagi design, the OWA design appears not only to attenuate sidelobes, but as well to suppress some of them. However, the question remains as to how far we can carry this process in a parasitic array. So we should look at some strategies for achieving, if not suppression, then at least greater attenuation.

The 20-Element OWA Yagi with 2 Added Reflectors

One technique for reducing both E-plane and H-plane sidelobes is to add more reflectors to the array. Classic multi-reflector arrays have set them in a flat plane. This arrangement is not the best. As the table of dimensions and the right half of **Fig. 4** show, the optimal position with respect to the OWA array is to place the new reflectors about 0.28 wavelength above and below the original reflector and about 0.22 wavelength to the rear. As well, the new reflectors are considerably longer than the original reflector. In the indicated positions, the new reflectors require no changes to the other elements in the array. The following table summarizes the modeled performance of the revised OWA array.

Modeled Performance: 20-element OWA Yagi with 2 Added Reflectors

Freq. MHz	Free-Space Gain dBi	180-Deg. Front-Back Ratio dB	Hor F-S/I Ratio dB	Vert F-S/I Ratio dB
144	16.10	27.75	28.60	21.97
146	16.46	34.35	27.43	21.66
148	16.23	33.79	22.79	19.29

Freq. MHz	Hor BW degrees	Vert BW degrees	Feedpoint Impedance R +/- jX Ohms	50-Ohm SWR
144	31.2	33.0	42.7 + j3.5	1.19
146	29.8	31.6	45.6 + j7.1	1.19
148	29.0	30.8	46.6 - j8.3	1.20

Additional reflectors add almost nothing to the array forward gain. Years ago, folks thought that reflectors played a key role in determining parasitic array gain, possibly because corner and planar reflectors play such a role. We have since learned that the directors play the dominant role in setting array gain. However, as shown in **Fig. 6**, the added reflectors do play a role in increasing the front-to-back ratio.

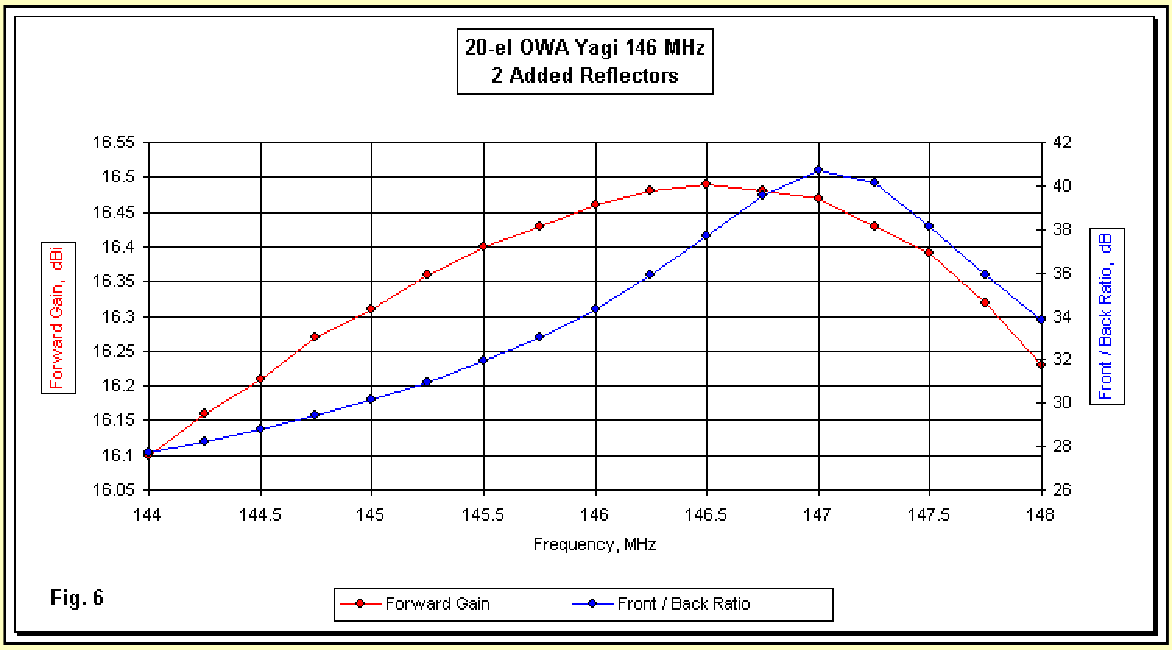


Fig. 6

The key property change evident from the graph is the increase in front-to-back values, a feature that also shows up on the right side of **Fig. 5**. If you look closely at **Fig. 5**, you will see that all of the rearward lobes are diminished relative to the single bay version of the Yagi on the left. As well, the front-to-back peak value has shifted slightly upward in frequency.

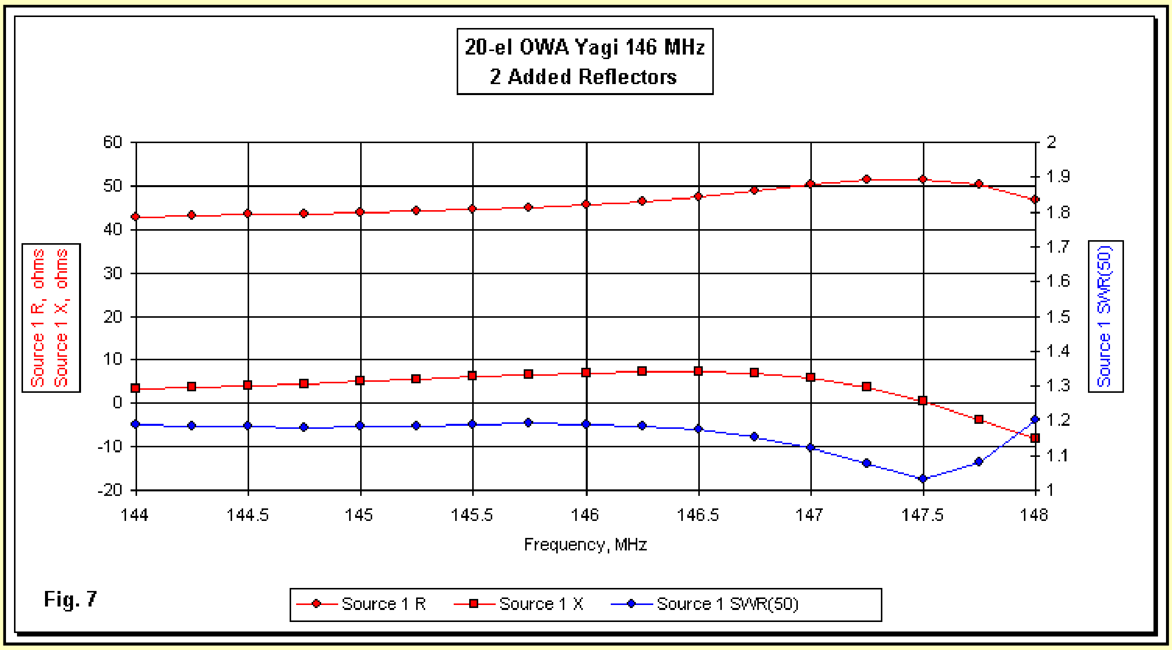


Fig. 7

Although the performance characteristics have changed a bit, the feedpoint characteristic remain unchanged. **Fig. 7** shows the resistance, reactance, and 50-Ohm SWR across the band. The maximum resistance and reactance changes are under 1 Ohm, relative to the regular OWA Yagi.

Fig. 5 holds a potential misimpression, since it provides E-plane and H-plane patterns for only the design frequency. We can correct any potential idea that the sidelobe development remains constant across the passband by looking at **Fig. 8**. This set of details on the development of sidelobes at 3 points along the band shows the evolution of the sidelobes as we increase frequency. These graphs use an outer ring value of 0 dBi. Thus, to arrive at a true value of suppression of the side and rear lobes, add the array gain for each frequency to the amount down that the graph shows. You can extract those numbers from the performance table shown above.

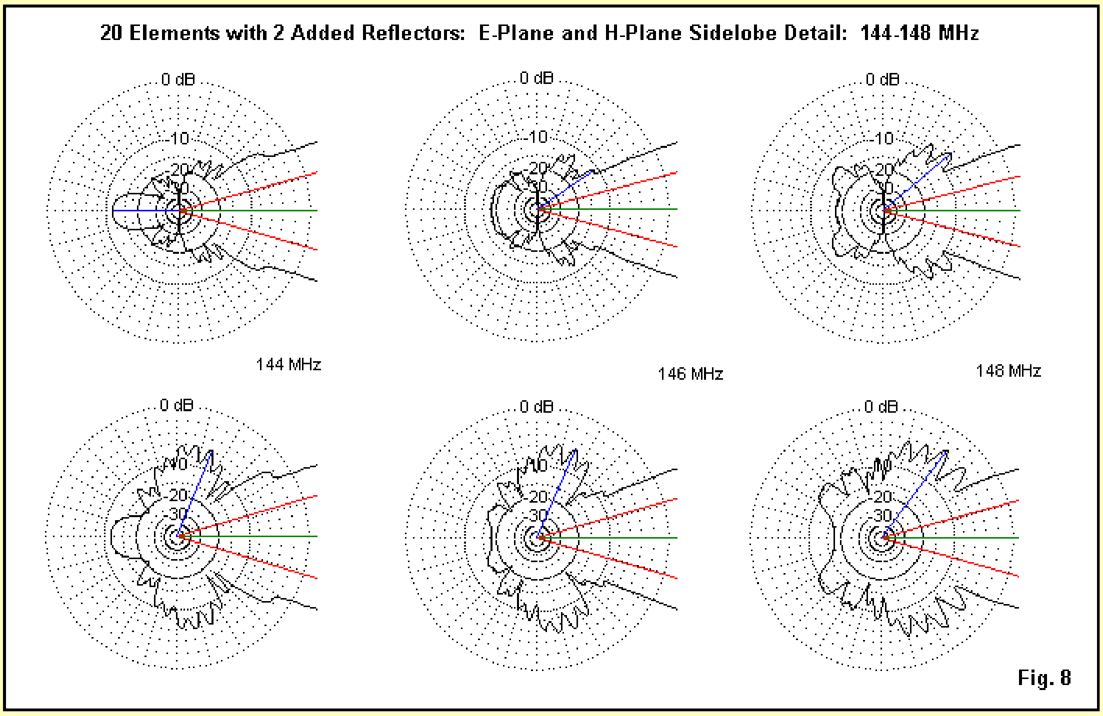


Fig. 8

The E-plane attenuation of sidelobes is clearly superior to the H-plane attenuation, despite the addition of the new reflectors. As well, above the design frequency, there is more energy in the sidelobe directions than at or below the design frequency. Nevertheless, the added reflectors do make a noticeable improvement on the original array, especially with respect to the rearward lobes.

In many ways, the 20-element OWA Yagi has reached a limit of improved performance and sidelobe attenuation. Part of the reason that it achieves the level of sidelobe reduction shown in the various figures lies in the pattern of current magnitudes along the elements. **Fig. 9** shows these current levels as vertical lines of varying length. Note that the added reflector having very low current magnitudes, which is a desirable condition relative to their function. As a result, the regular version of the same antenna would have virtually identical current lines for the 20 main elements.

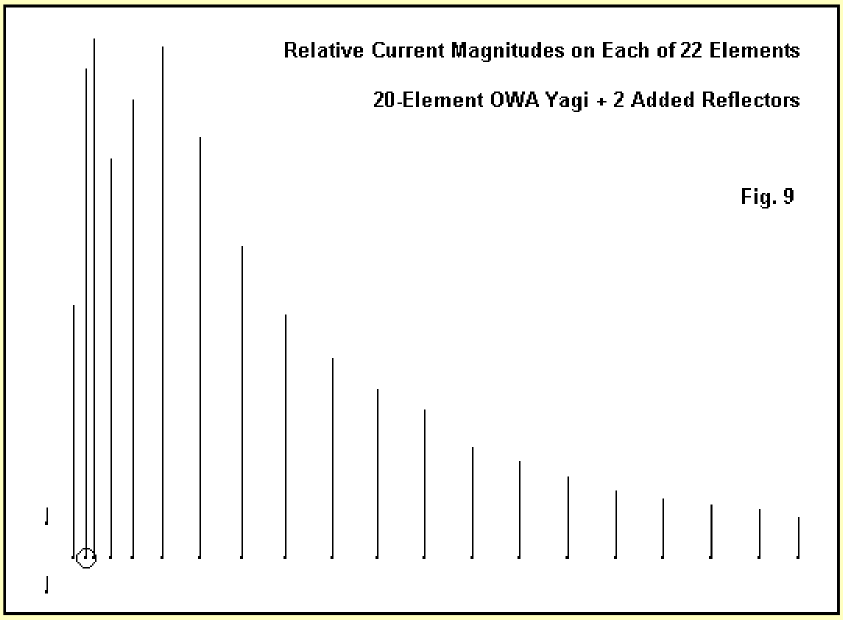


Fig. 9

First note that secondary driver (main element 3 or director 1) has a higher current magnitude than the fed driver, indicating its role at the 146-MHz design frequency. The next two elements are the control directors and have lower current levels than the next following director. From that point onward, the current magnitude decreases as we move forward along the progression of directors. This feature--more than any other in the design--controls the emergence of sidelobes.

Although adding supplemental reflectors provides a modicum of performance improvement, the amount of further sidelobe attenuation and/or suppression is too small to be noticed. We are still faced with the fact that H-plane or vertical sidelobes are noticeably stronger than the E-plane sidelobes. Hence, we need another strategy to make improvements in this department.

A Stack of 2 20+ Element OWA Yagis

A time-tested method of reducing vertical and near-vertical components to a radiation pattern is to place two identical antennas in a vertical stack with a separation of about 1/2 wavelength. This technique is worth exploring if only to learn what happens when we do so. The vertical stack will have the appearance of **Fig. 10**, give or take a little separation as we determine the best distance apart for the arrays.

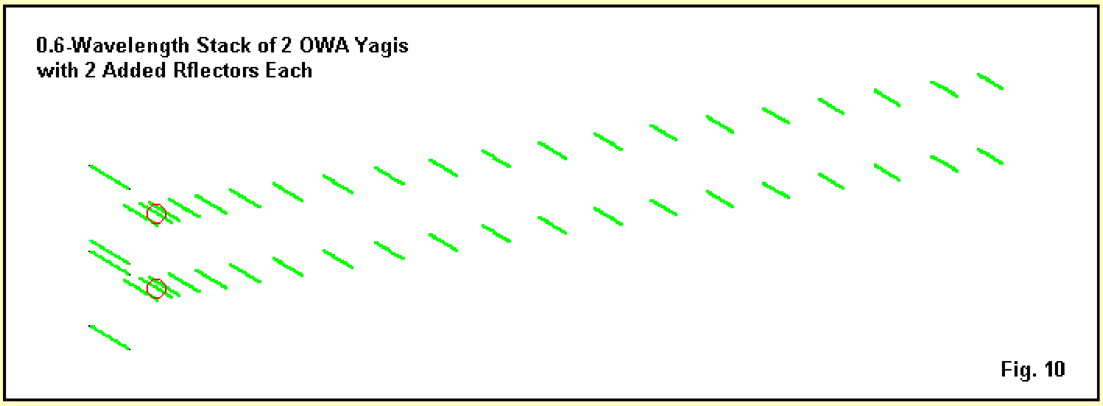


Fig. 10

In fact, for the arrays in question, 0.5-wavelength is not the best separation of the two arrays. First, the closer the two arrays are to each other, the greater the mutual effects on the feedpoint impedance of each array. Second, we are not trying to reduce only the radiation that is perfectly vertical relative to the arrays. Instead, we are hoping to reduce the angular radiation that may be 45 degrees or more off vertical. Hence, a series of trial models produced a separation between 0.6 and 0.625 wavelength as most effective in reducing the H-plane or vertical sidelobes. The following table summarizes the performance for the two limiting separation distances.

Modeled Performance: 20-element OWA Yagis with 2 Added Reflectors
Stack of 2: Boom Separation: 0.6 WL (at 146 MHz)

Freq. MHz	Free-Space Gain dBi	180-Deg. Front-Back Ratio dB	Hor F-S/l Ratio dB	Vert F-S/l Ratio dB
144	17.97	31.29	21.63	25.42
146	18.06	49.66	24.84	30.14
148	17.66	30.14	21.33	25.60

Freq. MHz	Hor BW degrees	Vert BW degrees	Feedpoint Impedance R +/- jX Ohms	50-Ohm SWR
144	26.6	24.8	38.9 + j1.8	1.29
146	26.0	24.2	43.6 + j8.1	1.25
148	26.0	24.2	43.2 - j10.8	1.32

Modeled Performance: 20-element OWA Yagis with 2 Added Reflectors
Stack of 2: Boom Separation: 0.625 WL (at 146 MHz)

Freq. MHz	Free-Space Gain dBi	180-Deg. Front-Back Ratio dB	Hor F-S/l Ratio dB	Vert F-S/l Ratio dB
144	17.98	30.83	21.42	25.61
146	18.08	48.20	24.54	27.72
148	17.69	30.26	21.24	26.54

Freq. MHz	Hor BW degrees	Vert BW degrees	Feedpoint Impedance R +/- jX Ohms	50-Ohm SWR
144	26.6	24.6	38.8 + j2.2	1.29
146	26.0	24.0	43.5 + j8.1	1.25
148	26.0	24.0	43.4 - j10.1	1.30

In most respects, the two performance tables shows no significant difference. However, at the 0.6-wavelength separation distance (at 146 MHz), the performance curves are better centered without need for revising any of the elements within the arrays. **Fig. 11** shows the gain and 180-degree front-to-back curves. Peak front-to-back ratio occurs on the design frequency, while the peak gain occurs just below that frequency. Since the high-gain individual antennas are not spaced apart by an amount designed to maximize gain, the total gain increase over a single antenna is only about 1.5 dB.

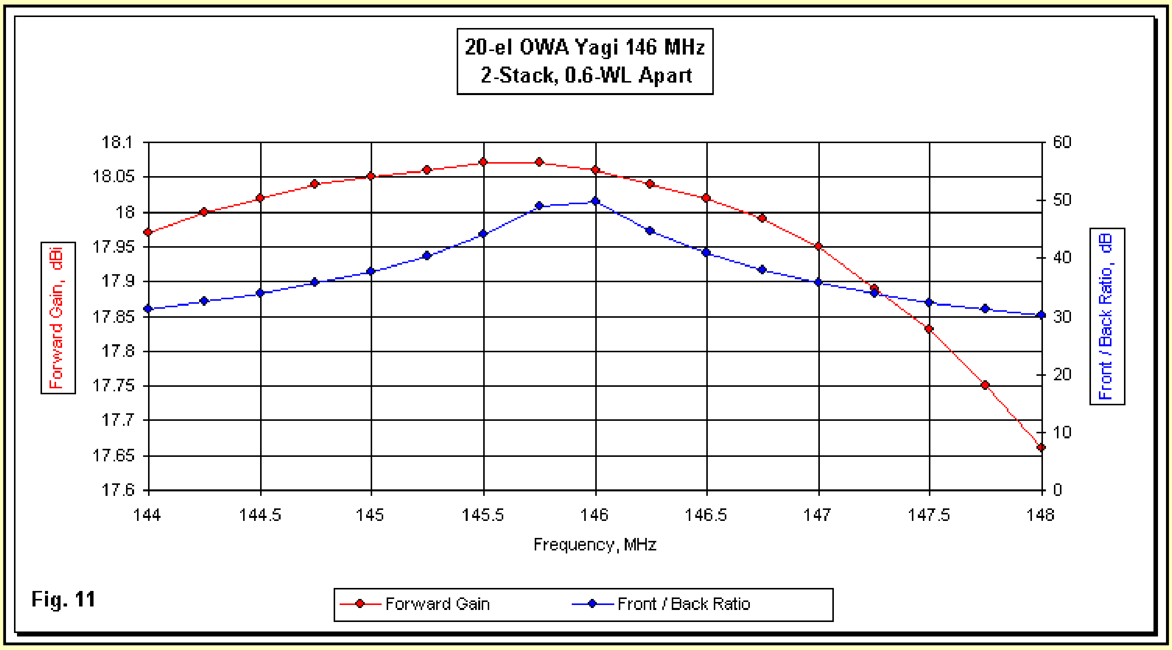


Fig. 11

For separations under 1 wavelength or so, there will be interactions among the elements such that the feedpoint impedance will change slightly. Relative to a single bay, the resistance on each feedpoint has decreased by about 3 Ohms, while the reactance is about 1.5-Ohm more capacitively reactive. **Fig. 12** shows the resistance, reactance, and 50-Ohm SWR values for the 2-stack at 0.6-wavelength separation.

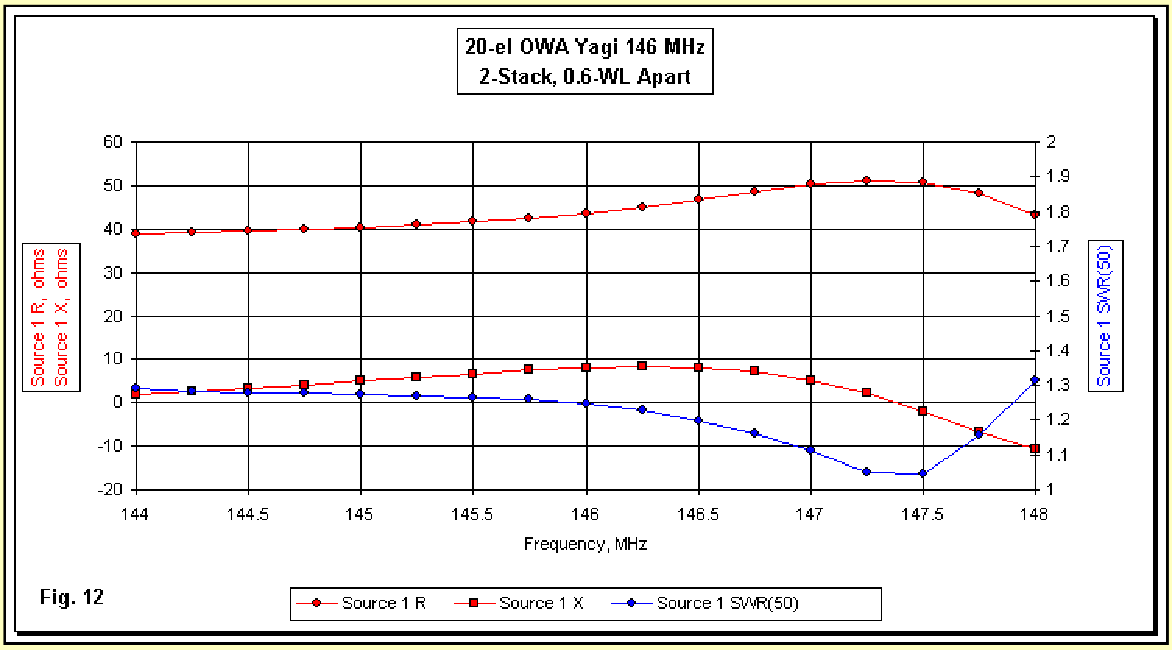


Fig. 12

To show the level of uncorrected detuning, **Fig. 13** overlays SWR curves for the single and double arrays. It is likely that some tweaking of the reflector, driver, and forward-most director would re-flatten the 2-stack SWR curve. However, the values shown are for each feedpoint in the array. To feed the 2-stack, you would need to employ standard line-length techniques to transform each impedance to about 100 Ohms so that the parallel result matched the main 50-Ohm line.

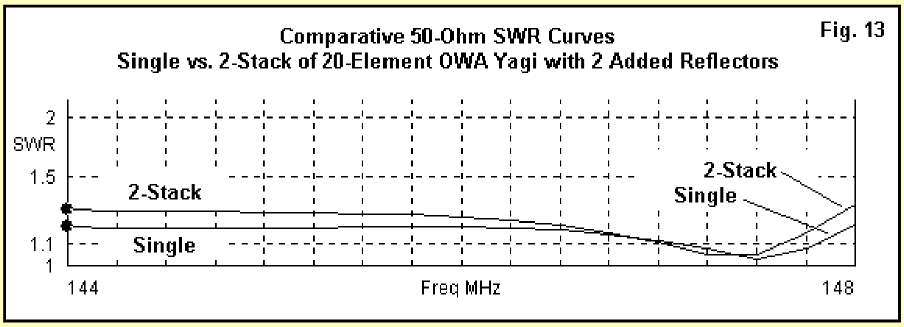
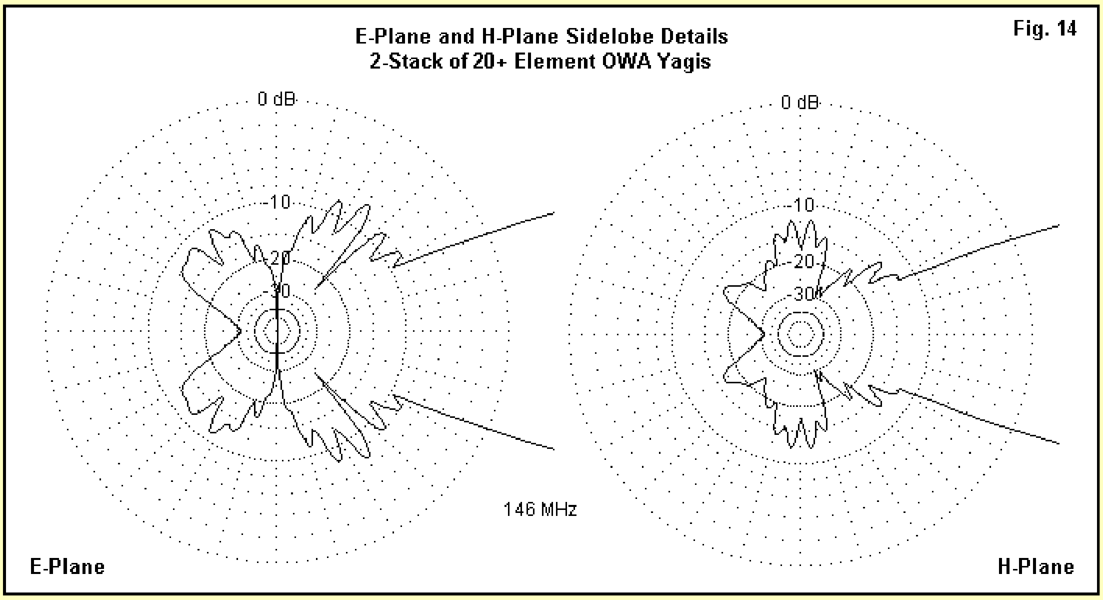


Fig. 13

The key question in all of this is to what degree the stacking of two reflector-supplemented 20-element OWA Yagis has managed to reduce sidelobes. With respect to the vertical or H-plane sidelobes, the improvement is a very noticeable 5+ dB improvement. However, the stacking has reduce the E-plane attenuation of sidelobes by almost the same amount. By comparing **Fig. 14** with ealier single-bay graphics, you can observe to what degree the preponderance of attentuation has shifted. Although the E-plane lobe peaks are more definite in the 2-stack, you can also see that some of the lobe merging remains in place.



Although the stack of 2 augmented 20-element Yagis does not reach the E-plane sidelobe reduction level as the single bay, the reduction in vertical sidelobes does have some advantages. They show up best when modeling the array over ground. I place the single bay at 5 wavelengths (33.7') above average ground. Then I placed the lower array in the 2-stack at the same level, resulting in an upper bay at 5.6 wavelengths (37.7') above ground. To show the results, let's combine a modeled performance table with a pair of elevation and azimuth plots. In the table, remember that feedpoint impedances values for the 2-stack apply to each of the 2 feedpoints.

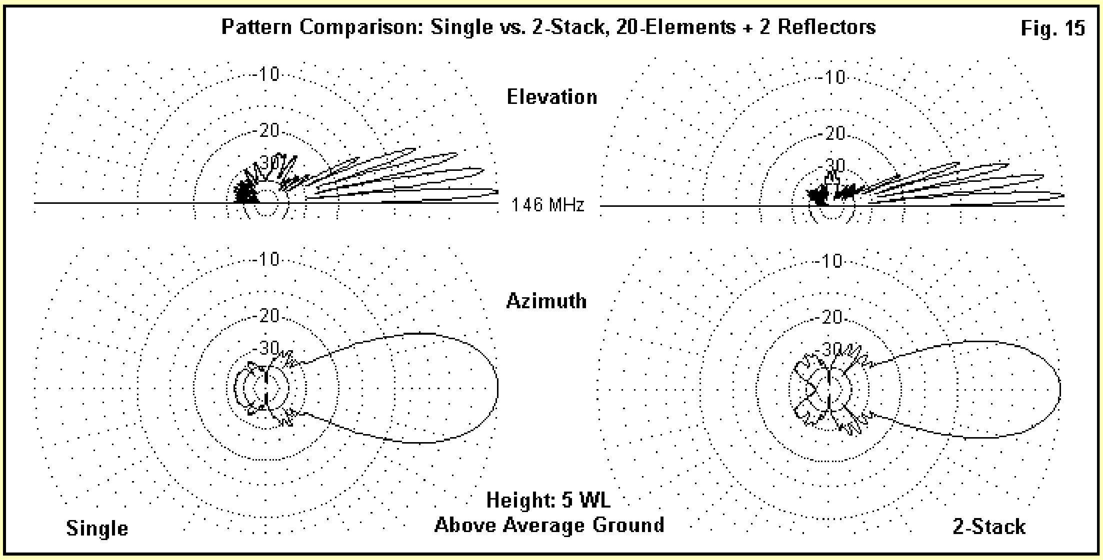
Modeled Performance: Single and 2-Stack 20-element OWA Yagis with 2 Added Reflectors at 146 MHz
5 WL Above Average Ground (2nd Yagi in stack 5.6 WL Above Ground)

Single Yagi

Freq. MHz	**Gain dBi**	**TO Angle degrees**	**180-Deg. Front-Back Ratio dB**	**Hor F-S/I Ratio dB**	**Hor BW degrees**	**Impedance R+/-jX Ohms**	**50-Ohm SWR**
146	**22.28**	**2.8**	**34.26**	**27.30**	**29.6**	**45.6 + j7.0**	**1.19**

Stack of 2 Yagis, 0.6-WL Separation

Freq. MHz	**Gain dBi**	**TO Angle degrees**	**180-Deg. Front-Back Ratio dB**	**Hor F-S/I Ratio dB**	**Hor BW degrees**	**Impedance R+/-jX Ohms**	**50-Ohm SWR**
146	**23.83**	**2.6**	**49.34**	**24.74**	**25.8**	**43.7 + j8.0**	**1.25**



The azimuth pattern for the single bay is clearly cleaner than the corresponding pattern for the 2 stack. However, the 2-stack shows far less wasted energy at near-vertical angles. As well, there is less energy in the upper elevation lobes. Whether these small margins justify the construction, support, and maintenance of a second and higher 22-element array is strictly a user judgment.

Some Mid-Stream Conclusions

Clearly, the matter of suppressing sidelobes is still short of its ultimate goal: the total suppression of sidelobes in parasitic arrays of any length. These notes only record progress so far with respect to both horizontal and vertical sidelobes in arrays using about 6-wavelength booms. The addition of two relatively passive reflectors displaced to the rear of the Yagi does reduce rearward lobes of all sorts. The element taper and spacing achieves well over 20 dB sidelobe attenuation horizontally, and a stack of 2 such arrays, spaced about 0.6 wavelength apart achieves the same goal with respect to vertical sidelobes.

However, the two results do not yet combine. Although some lobe merging is apparent with the reduction in lobe strength, full suppression to wholly minimal levels remains as an unfinished task. There are, however, a number of possible directions for future experimentation. The use of more elements per wavelength may reduce design frequency sidelobes further, but a magic formula for maintaining sidelobe-suppression bandwidth (all of 2 meters in this case) is elusive.

In the end, many classic Yagi designs are perfectly adequate for contemporary communications needs. The question of the ultimate suppression of parasitic sidelobes is more a matter of curiosity than necessity. Still, some of the most interesting challenges in life emerge from curiosity.

Go to Part 2: Some Further Notes on 12-Element Yagis

Return to Index