Extending the 2-Meter OWA Family
Part 1: 13 to 20 Elements and a Self-Limiting Design

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In another 2-part series devoted to developing the optimized wide-band antenna (OWA) concept to full-band Yagi antennas for 2 meters, we examined a connected series of antennas ranging from 7 to 12 elements. See "An OWA Family of 2-Meter Yagis from 6 to 12 Elements," Parts 1 and 2.

That series elicited a number of requests for longer versions of the antenna, given its adequate but stable gain, very good front-to-back ratio, exceptional SWR curve across the band, and general attenuation of sidelobes to more than 20 dB down from the main forward lobe. The development of the next set of beams had to await available time, since the optimizing process is unlike a number of Yagi designs that use a single algorithm to calculate each added element. The OWA series requires resetting the former forward-most element and then placing a new (added) element at the correct position. However, the work of extending the sequence from 13 through 20 elements is now complete.

The results, using a design frequency of 146 MHz, have yielded some surprises. First, as the boom gets longer, the addition of new elements is almost stable in its requirements, with each new addition requiring a 5" spacing jump for the former forward-most elements, along with the 1" lengthening. The new element would be about 28" ahead of the previous director for a total boom length increase of about 33". The forward-most element would be about 1.5" shorter than the preceding director.

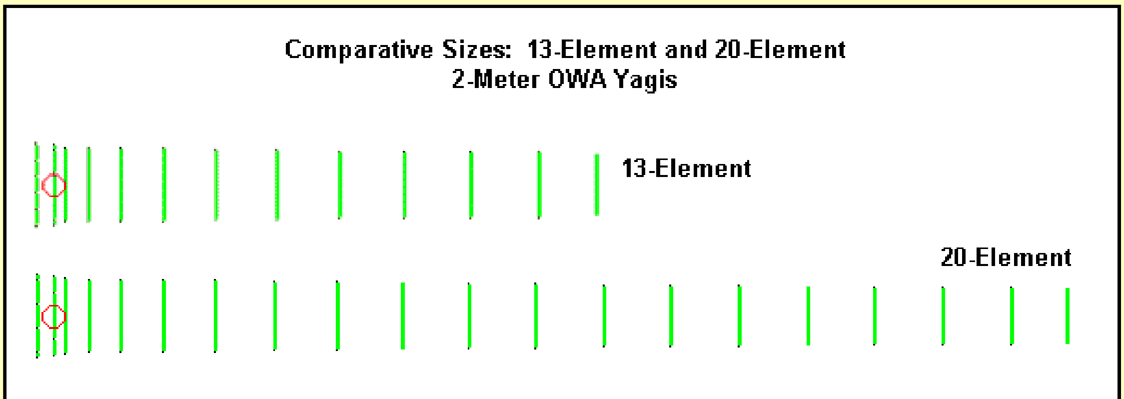

Fig. 1

Fig. 1 shows the general outline of the shortest and longest Yagis in the new series. Below is a table of boom lengths for the series of antennas, including the 12-element version as a reference. Although the dimensions of the boom length are given in several units of measure, future tables of element lengths and spacing will all be in inches, since the conversions should be second nature to any antenna enthusiast.

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OWA Yagi Series Boom Lengths: 12 to 20 Elements

Note: Wavelength measurement is for a frequency of 146 MHz.

No. of	Boom Length			
Elements	Inches	Feet	Meters	Wavelengths
12	238	19.83	6.05	2.94
13	271	22.58	6.88	3.35
14	304	25.33	7.72	3.76
15	337	28.48	8.56	4.17
16	370	30.83	9.40	4.58
17	403	33.58	10.24	4.99
18	436	36.33	11.07	5.39

19	**469**	**39.08**	**11.91**	**5.80**
20	**502**	**41.83**	**12.75**	**6.21**

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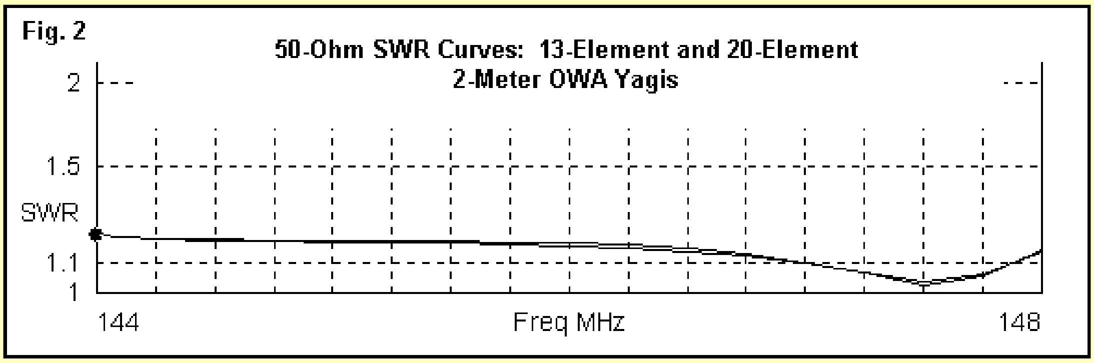
OWA Basics and The Criteria of Design

The key elements in a true OWA design are the reflector through director 3, that is, the rear-most 5 elements of the array. There are numerous wide-band Yagi arrangements that essentially involve only the rear-most three elements, for example the well-known DL6WU design. For a 50-Ohm wide-band match with a single linear driver elements, Guenter Hoch used a reflector-to-driver spacing of 0.200 wavelength and a driver-to-director-1 spacing of 0.075 wavelength. The element lengths depend upon the diameter of the individual elements. In any wide-band design (including the OWA design), the first director acts as a secondary driver, and its current magnitude exceeds that of the driver over the upper (approximate) half of the operating passband.

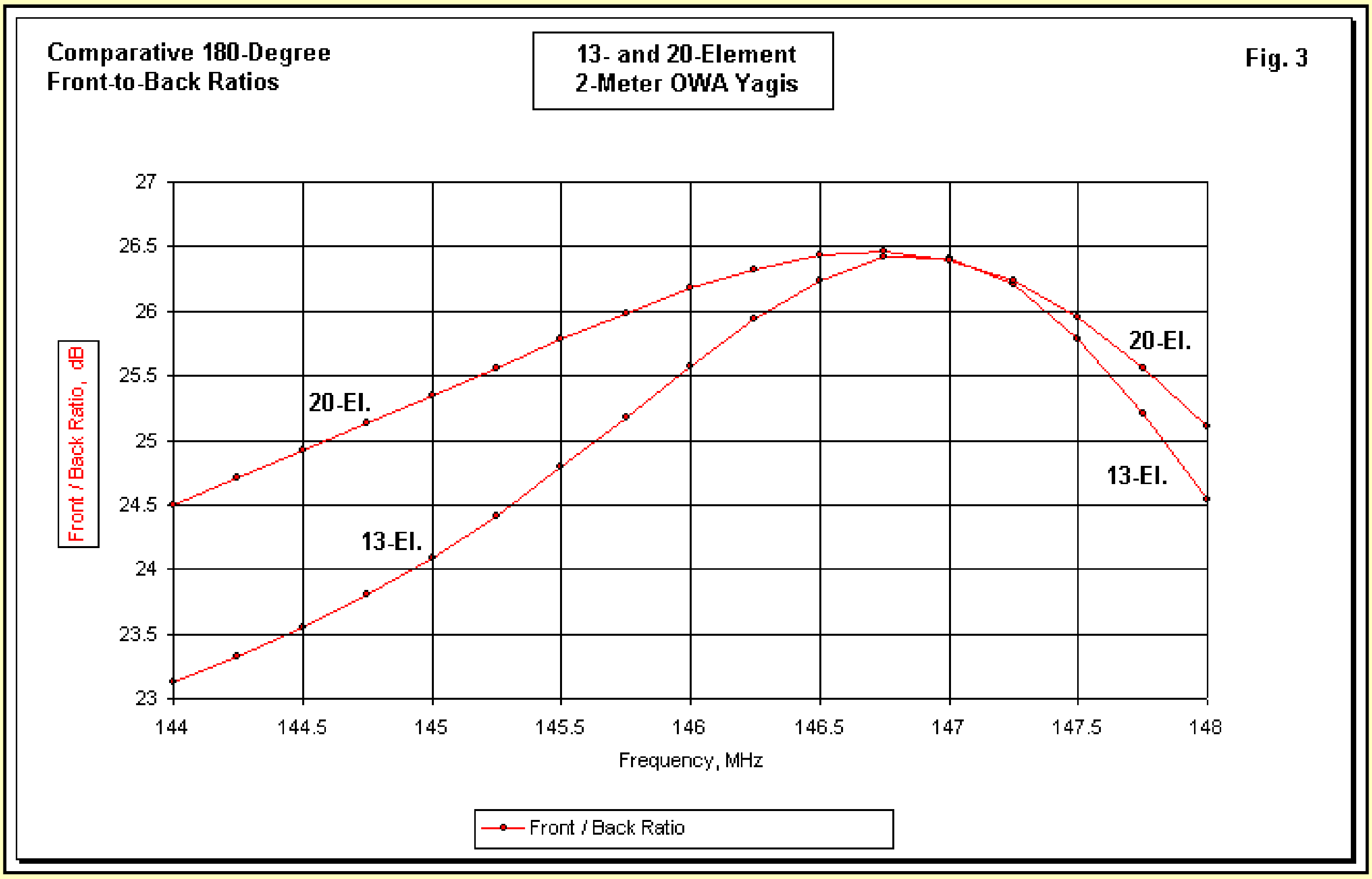
The OWA system begins with a different combination of element spacing. The reflector-to-driver spacing may range from 0.10 to 0.13, while the driver-to-director-1 spacing might range from 0.05 to 0.06 wavelength, depending upon both the element diameter and the disposition of directors 2 and 3. These controlling directors are either the same length or the forward of the two is slightly longer than the rearward. The benefits of having the controlling directors is to permit the gain peak and the front-to-back peak to occur at roughly the center of the operating passband without significant disturbance to the SWR curve for the passband. As one increases the number of elements of an OWA Yagi, it becomes more difficult to achieve true centering so that designers are generally required to settle for a slightly lesser standard: that the peaks both occur within the passband, even if they lean toward the upper passband edge.

In designing the family of 2-meter OWA Yagis, I have used several criteria to mark success--even if a relative rather than an absolute success. These criteria include the following items.

1. The 50-Ohm SWR curves for the antennas in the family should not exceed 1.2:1 anywhere within the pass band. **Fig. 2** shows the curves for the 13-element and the 20-element members of the family. The two curves are so coincident that their difference is scarcely visible. (Telling which curve is which is an exercise left to the reader. However, the later modeled performance data at 146 MHz will provide a small clue as to which line belongs to which antenna.)



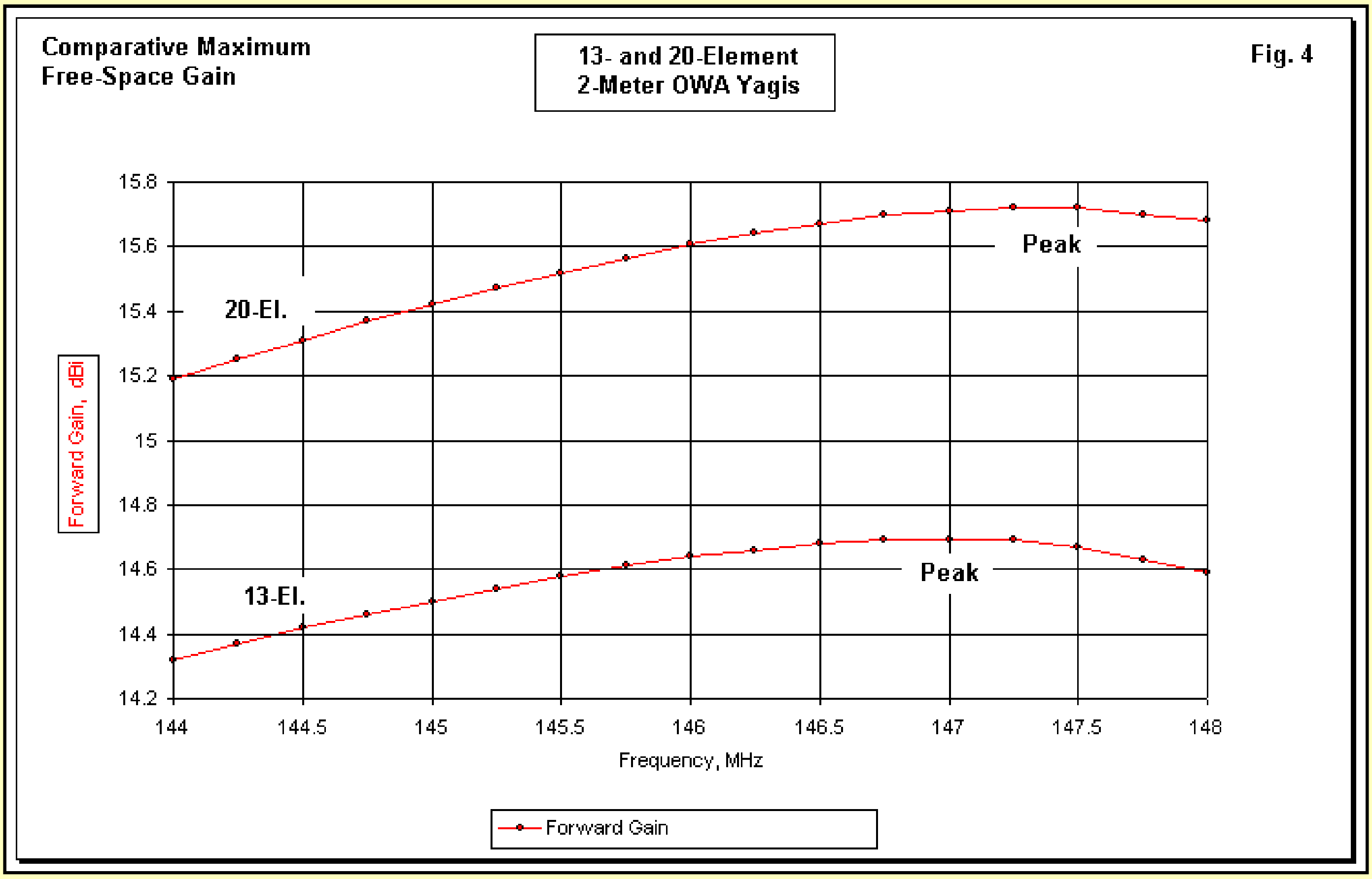
2. The front-to-back ratio, whether taken as the 180-degree value or the worst-case value, should exceed 20 dB throughout the operating passband. **Fig. 3** compares the 50-Ohm front-to-back curves for the 13-element and the 20-element members of the family. As is readily apparent, both curves--and by extension, the curves of intermediate family members--easily meet the criterion. However, as we increase the number of elements, the slope of the curve diminishes.



3. The front-to-sidelobe ratio should exceed 20 dB by the highest possible margin. The front-to-sidelobe ratio is the ratio, in dB, between the maximum forward gain and the gain of the strongest forward sidelobe. In most cases where a longer-boom Yagi is involved, there are forward sidelobes as well as the main lobe. In most conventional Yagi designs, the strongest sidelobe--usually the first, but occasionally the second--will be down by only 15 to 18 dB relative to the maximum forward gain. The OWA design permits an additional 5- to 10-dB improvement, reducing sensitivity of the antenna to off-axis signals.

The worst-case value of the front-to-sidelobe ratio occurs in the shorter members of the family, hovering between 23.5 and 24 dB at 144 MHz, when a new sidelobe emerges. (The number of forward sidelobes--and rear sidelobes as well--tends to be a function of the boom length. The number of sidelobes is roughly equal to the boom length in wavelengths, reduced to an integer.) The most general worst-case value occurs at 148 MHz. It ranges from about 24.3 dB for the shortest Yagi in the group to close to 27 dB for the longest Yagi in the family.

4. The gain of the array should peak as close to the passband center as is feasible and will be whatever the other design considerations permit it to be. As is evident in **Fig. 4**, the longer we make the boom and the more elements that we add in the prescribed design sequence, the more the gain peak shifts upward within the passband.



One result of the shifting gain peak is an increasing gain differential across the band as we increase the number of elements. The shortest Yagi has a differential of just over 0.35 dB across the passband, while the longest OWA has a differential of about 0.55 dB. However, these values tend to be considerably smaller than the differentials obtained from many other types of designs over a similar passband. A typical 20-element DL6WU Yagi might show as much as a full dB differential in gain across 2 meters, although the design has sufficient operating bandwidth to allow one to select an operating point with less gain differential. However, obtaining this result with a well-centered front-to-back maximum may be difficult.

Because the OWA series is designed for other than maximum gain as the primary criterion of success, we shall discover that the series is self-limiting in effective boom length or the number of elements. Indeed, 20 elements may exceed the maximum practical length for the design--when compared to others--by 4 or 5 elements for all but a special purpose antenna in which sidelobe attenuation is a paramount concern.

The Family Dimensions

The design of the added members of the OWA 2-meter family proved to be a more stable operation than the design of the members with 7 through 12 elements. Indeed, the 12-to-13-element range seems to be a turning point in the design work. The addition of each new element requires that the previous forward-most element be moved further forward by about 5". The length required an average 1" addition. The new forward director required an average 28" space from the repositioned director, so that the total boom growth for the 146-MHz designs was 33" on average. This value is close to 0.4 wavelength at the design frequency, a value similar to the spacing used in DL6WU arrays. The length of the new forward-most director is about 1.5" (average) shorter than the re-adjusted preceding director.

The deciding factors in settling upon a set of dimensions for each member of the series included the coincidence of the SWR curves, the maintenance of front-to-back ratios across the passband, and the achievement of a worst-case front-to-sidelobe value equal to or better than the next shorter member of the overall family. All of the antennas in the new series--like their shorter brethren--use 0.1875" (3/16") aluminum elements. For elements up to about 1.5 times fatter or .67 times thinner, the standard element adjustment factors in manual may be applied. However, if the new elements are twice as fat or half as thin, then the array may require re-design of the element spacing throughout.

The following table presents all of the dimensions together. For each added element, the table shows only those elements requiring changes from the original and subsequent entries preceding the entry in focus.

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OWA 2-Meter Yagi Dimension Table From 12 to 20 Elements

Note: after the initial listing, only the last two elements in each design change--hence, the abbreviated listings.

Element diameter: 0.1875" (3/16") Maximum 50-Ohm SWR: 1.20:1

Dimensions (in inches):

12-Elements

Element	Length	Space from Reflector
Reflector	40.90	----
Driver	39.50	8.79
Director 1	37.00	13.47
Director 2	36.33	25.38
Director 3	36.40	40.72
Director 4	36.21	61.38
Director 5	35.20	86.49
Director 6	34.30	116.00
Director 7	33.60	146.00
Director 8	32.90	178.40
Director 9	32.20	210.00
Director 10	31.20	238.00

13 Elements

Director 10	32.20	243.00
Director 11	30.00	271.00

14 Elements

Director 11	30.80	276.00
Director 12	29.00	304.00

15 Elements

Director 12	30.40	309.00
Director 13	29.20	337.00

16 Elements

Director 13	30.00	342.00
Director 14	28.40	370.00

17 Elements

Director 14	29.20	375.00
Director 15	28.00	403.00

18 Elements

Director 15	28.80	408.00
Director 16	27.60	436.00

19 Elements

Director 16	28.40	441.00
Director 17	27.40	469.00

20 Elements

Director 17	28.40	475.00
Director 18	27.40	502.00

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For example, if we want to build a 20-element version, we would use the first 11 elements from the initial table, followed by the last value shown for each added element. This procedure boils down to using the upper director length and spacing for each entry except the last, in which case, we use the values of both the 17th and 18th directors. The spacing, of course, is the cumulative spacing from the reflector, which is set to zero for counting purposes. The lengths are full element lengths and should be halved if one wishes to reconstruct the NEC-4 models that formed the basis of these designs.

As was true of the initial family members in this OWA Yagi group, the dimensions presume that the elements are well-insulated and isolated from any conductive boom material (by at least 1 boom diameter distance). There are algorithms for calculating the element length adjustments necessary when using insulated through-boom construction. Direct element-to-boom construction requires further element-length adjustments, but is not recommended unless one has access to industrial-grade welding equipment that can assure a very durable bond with high and constant conductivity.

Individual Performance and Pattern Portraits

Perhaps the most direct way to show the potential performance of the extended OWA series of Yagis is simply to show selected tabular performance reports from the NEC-4 models, along with free-space E-plane (azimuth) patterns. For each design, the data will cover 144, 146, and 148 MHz.

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Modeled Performance: 13 Elements (See Fig. 5)

Parameter	**144 MHz**	**146 MHz**	**148 MHz**
Gain dBi	**14.32**	**14.64**	**14.59**
180-deg F-B	**23.13**	**25.57**	**24.54**
Impedance (R+/-jX)	**42.8 + j 4.4**	**46.8 + j 6.9**	**45.4 - j 4.5**
50-Ohm SWR	**1.20**	**1.17**	**1.15**

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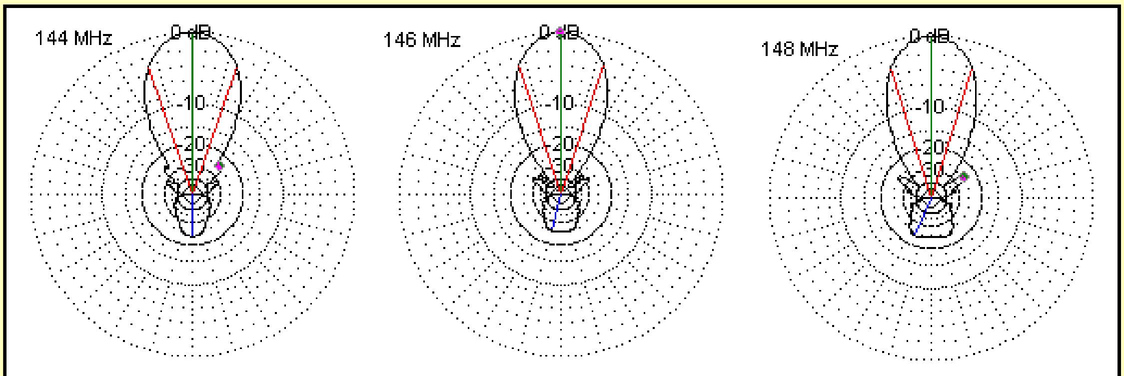

13-Element OWA Yagi: E-Plane Patterns Fig. 5

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Modeled Performance: 14 Elements (See Fig. 6)

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	14.50	14.84	14.82
180-deg F-B	23.22	25.65	25.15
Impedance (R+/-jX)	42.9 + j 4.2	46.4 + j 6.9	45.8 - j 4.2
50-Ohm SWR	1.20	1.18	1.13

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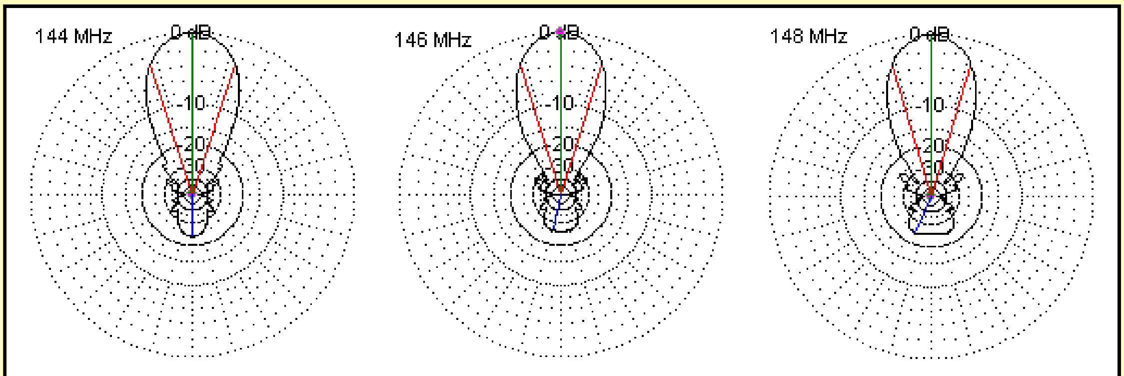
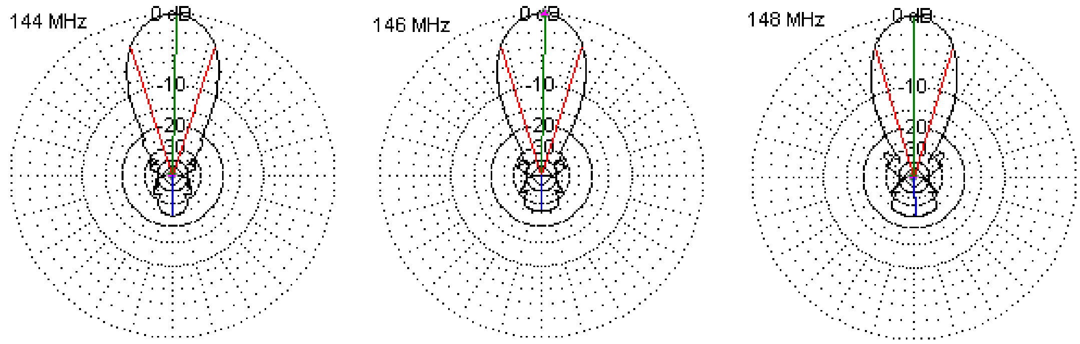


14-Element OWA Yagi: E-Plane Patterns Fig. 6

Modeled Performance: 15 Elements (See Fig. 7)

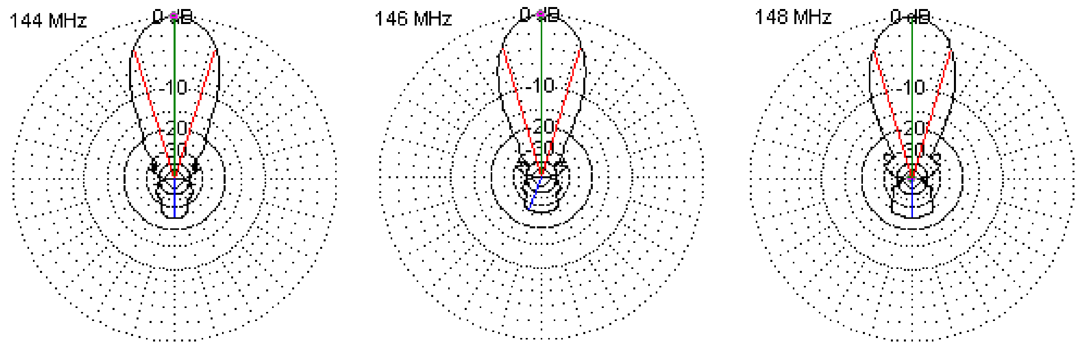
Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	14.68	15.04	15.05
180-deg F-B	23.97	25.96	24.27
Impedance (R+/-jX)	42.8 + j 4.4	46.8 + j 6.7	45.2 - j 3.9
50-Ohm SWR	1.20	1.17	1.14



15-Element OWA Yagi: E-Plane Patterns Fig. 7

Modeled Performance: 16 Elements (See Fig. 8)

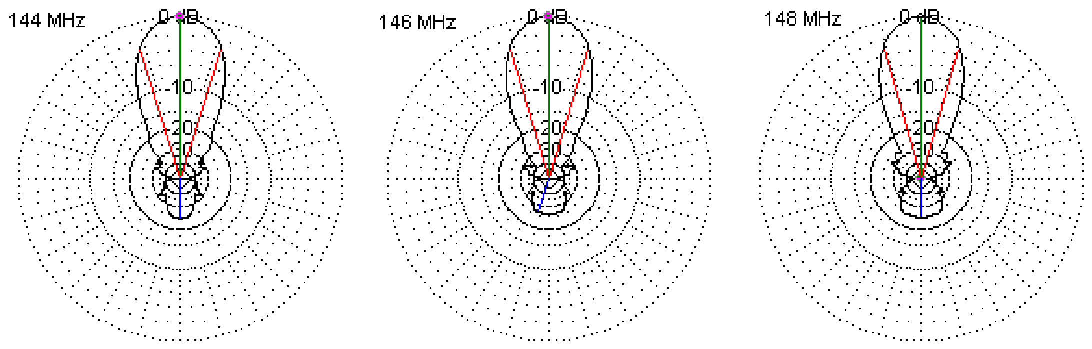
Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	14.82	15.19	15.21
180-deg F-B	24.08	26.34	24.18
Impedance (R+/-jX)	42.8 + j 4.5	47.0 + j 6.7	44.9 - j 4.0
50-Ohm SWR	1.20	1.16	1.15



16-Element OWA Yagi: E-Plane Patterns Fig. 8

Modeled Performance: 17 Elements (See Fig. 9)

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	14.93	15.32	15.35
180-deg F-B	24.00	26.55	24.45
Impedance (R+/-jX)	42.8 + j 4.4	46.9 + j 6.7	44.9 - j 4.2
50-Ohm SWR	1.20	1.17	1.15

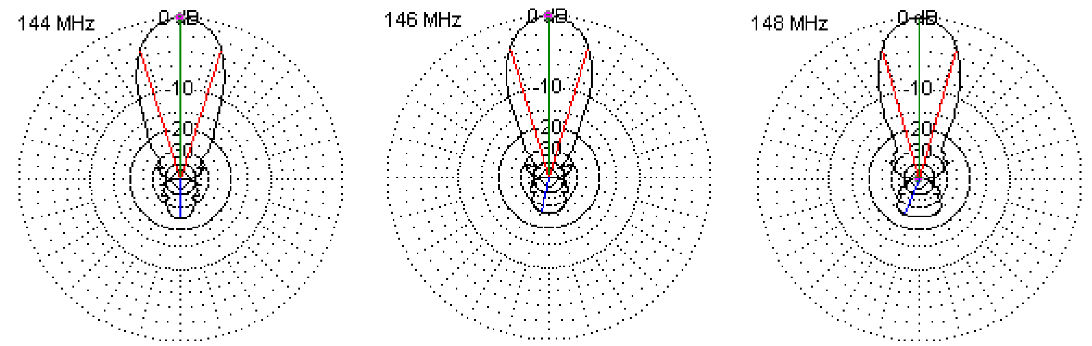


17-Element OWA Yagi: E-Plane Patterns

Fig. 9

Modeled Performance: 18 Elements (See Fig. 10)

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	15.03	15.42	15.47
180-deg F-B	24.12	26.37	24.94
Impedance (R+/-jX)	42.8 + j 4.4	46.8 + j 6.7	45.1 - j 4.2
50-Ohm SWR	1.20	1.17	1.15

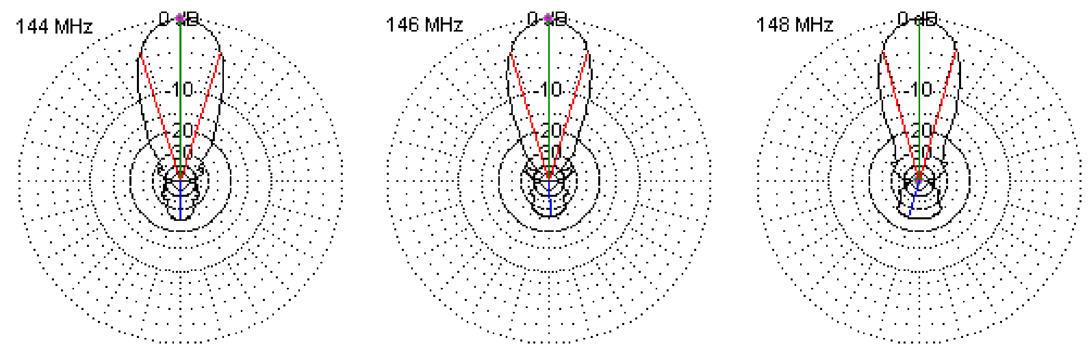


18-Element OWA Yagi: E-Plane Patterns

Fig. 10

Modeled Performance: 19 Elements (See Fig. 11)

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	15.11	15.52	15.58
180-deg F-B	24.44	26.20	25.07
Impedance (R+/-jX)	42.9 + j 4.5	46.8 + j 6.7	45.1 - j 4.1
50-Ohm SWR	1.20	1.16	1.14



19-Element OWA Yagi: E-Plane Patterns

Fig. 11

Modeled Performance: 20 Elements (See Fig. 12)

Parameter	144 MHz	146 MHz	148 MHz
Gain dBi	15.19	15.61	15.68

180-deg F-B	24.50	26.18	25.11
Impedance (R+/-jX)	42.9 + j 4.5	46.8 + j 6.6	45.1 - j 3.9
50-Ohm SWR	1.20	1.16	1.14

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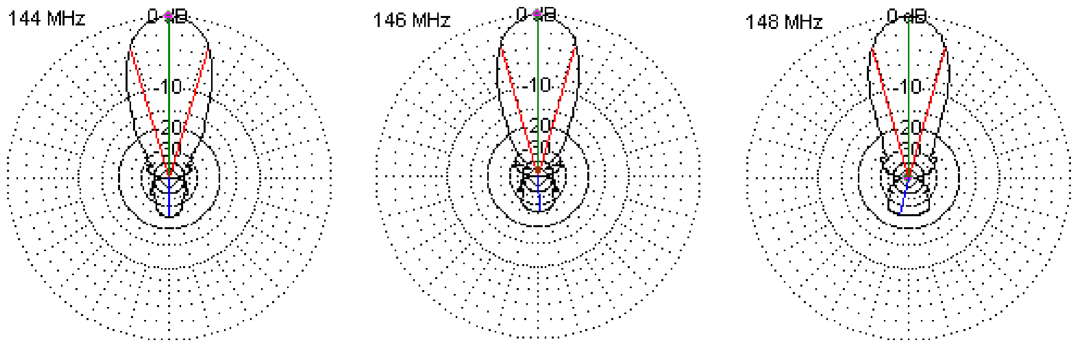

20-Element OWA Yagi: E-Plane Patterns Fig. 12

Some Curiosities of the Family

The OWA family becomes downright sedate as we increase the number of elements and the boom length. For example, for the 20-element version, we can extend the forward-most director an additional 5" without noticeable change in any of the performance figures. Moreover, the gain increase does not match the boom-length increase when we compare it to other design series. As a quick example, the following table compares the gain increase with each new element in the OWA series with the corresponding gain increase in a typical DL6WU series. The example is suggestive because the boom lengths for the two series, while not identical, are close enough to be comparable. In addition, each column uses simply the modeled gain value at mid-band, not the peak achievable gain.

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Change of Gain per Added Element

Note: Free-space gain values taken at 146 MHz, which is not the peak gain for either antenna series, but a representative mid-band value. Boom lengths for each value are comparable, but not exactly the same. 20-element boom length for the OWA series is 41.83' and for the DL6WU series is 40.52'. Hence, the comparison is suggestive, but not definitive.

Antenna	**OWA Series**		**DL6WU Series**	
Elements	**Gain (dBi)**	**Delta Gain**	**Gain (dBi)**	**Delta Gain**
12	**14.35**	**-----**	**14.70**	**-----**
13	**14.64**	**0.29**	**15.22**	**0.52**
14	**14.84**	**0.20**	**15.62**	**0.40**
15	**15.04**	**0.20**	**15.91**	**0.29**
16	**15.19**	**0.15**	**16.20**	**0.29**
17	**15.32**	**0.13**	**16.52**	**0.32**
18	**15.42**	**0.10**	**16.85**	**0.33**
19	**15.52**	**0.10**	**17.13**	**0.28**
20	**15.61**	**0.09**	**17.34**	**0.21**

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The OWA series at the 12-element baseline already has a gain about 1/3 dB less than a comparable DL6WU design. At 16 elements, the differential is a whole dB. At 20 elements, the differential is 1-3/4 dB. Clearly, we have embarked upon a trail of diminishing returns with respect to array gain.

Part of the reason behind the smaller increment of gain increase for each added OWA director is the lesser activity on the directors in the OWA design. Activity refers to the relative current magnitude on the sequence of forward directors, especially those from 11 or 12 up to 18. **Fig. 13** shows in roughly equal scale the current magnitude on the elements of three 6-wavelength boom Yagis. On both of the non-OWA designs, we can immediately see the higher current magnitude on each of the forward directors, relative to the lower values for the OWA model.

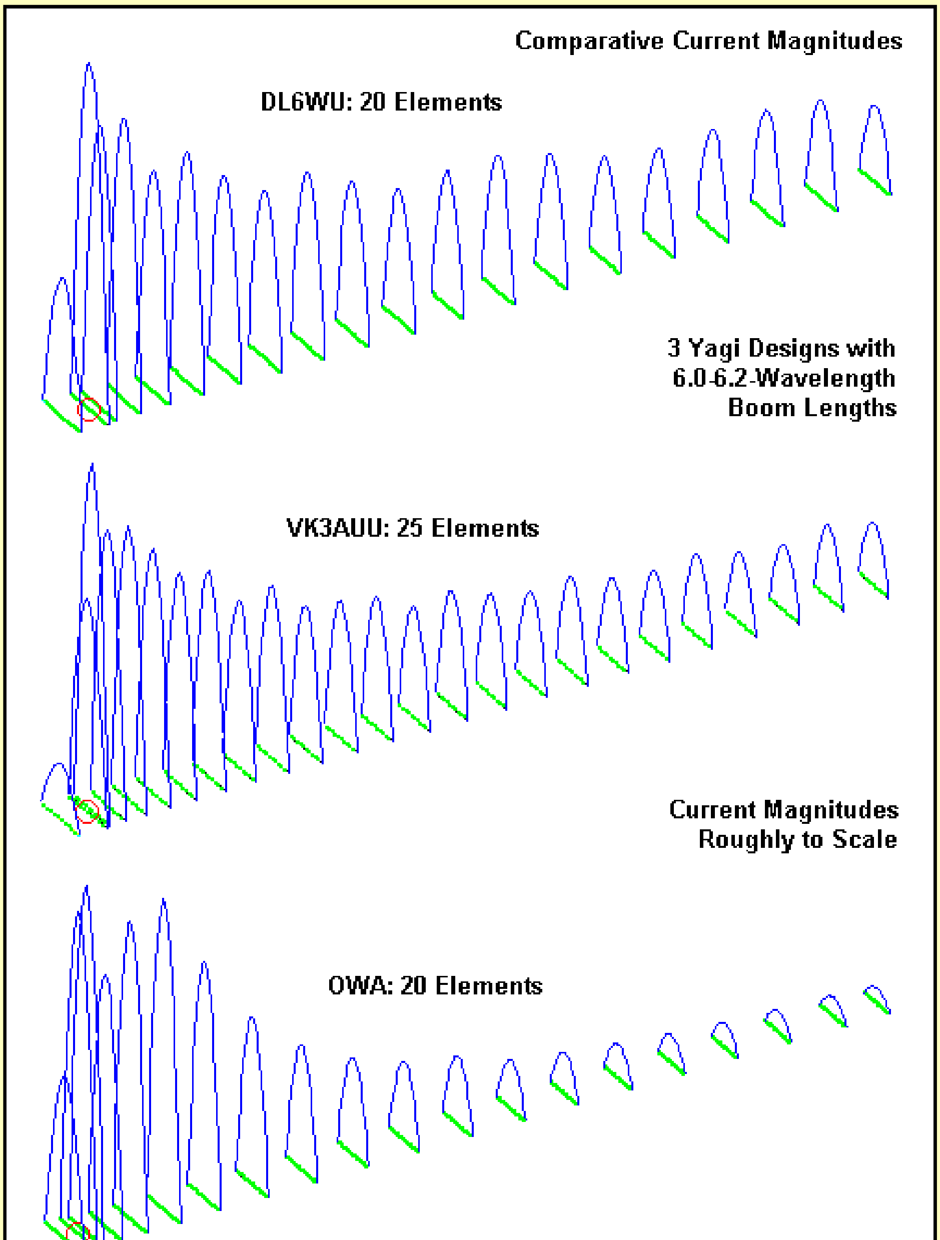

Fig. 13

A second curiosity concerns the side and rear lobe development as we increase the boom length and the number of elements. Ordinarily, we expect to see a number of forward side lobes that is roughly equal to the number of wavelengths of boom length, rounded to an integer. However, examine **Fig. 14**. The 13-element design is about 3.35 wavelengths long and shows 3 forward sidelobes (and three rearward sidelobes, if we count bumps carefully). The 6.21-wavelength 20-element version should show us 6 sidelobes. However, we can count only 4, including the extremely minute first sidelobe closest to the main lobe itself. The rearward sidelobes are equally deficient relative to expectations. Relating the number of forward sidelobes to gain instead of boom length should still net us at least 5. Moreover, the figures do give us a better impression of just how well the OWA design attenuates or suppresses sidelobe development compared to more traditional designs in the field.

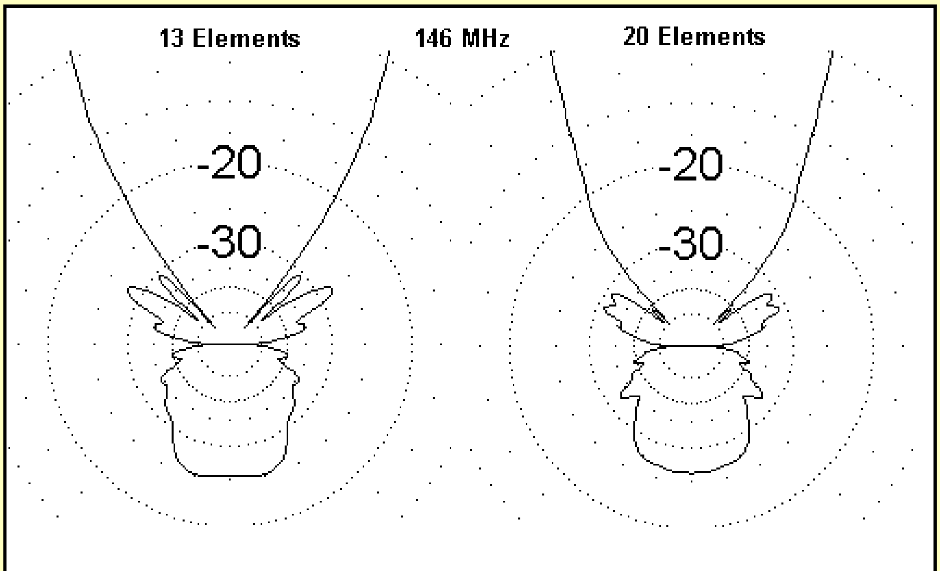

Fig. 14 Side and Rear Lobe Development on 13-Element and 20-Element 2-Meter OWA Yagis

These questions bear further investigation, and hence a Part 2 (and Part 3) to this continuing saga of the OWA 2-meter family of Yagis. We need to make more detailed comparisons, looking at not only boom length, but the element population as well as we seek means of suppressing forward sidelobes and achieving more adequate gain values.

Go to Main Index