Designing Multi-Band Parasitic Beams
Part 3: A 3-Element 15-Meter, 4-Element 10-Meter Design Example

L. B. Cebik, W4RNL (SK)

Our journey through the edges of multi-band parasitic beam design has taken us to general principles and to their application on a small scale. In this third episode, we shall increase the complexity of our design to one more level: 3-element Yagi performance. Our all-Yagi design will necessarily include 3 elements for 15 meters and 4 elements for 10 meters. However, we should remember that even with the increased complexity, we are still falling short of the level at which the true artists of multi-band Yagis operate: 3 bands with more than 3 element performance. Nevertheless, since we our goal is a somewhat basic tutorial, 2-band designs will be quite sufficient.

Among the preliminary decisions that we must make is the element taper schedule. **Fig. 1** replicates the sketch from Part 1 showing a taper schedule that will withstand 100 mile-per-hour winds, with appropriate de-rating for significant ice loads. The 6063-T832 aluminum tubing in standard 0.125" increments forms smooth but close connections with about 2" to 3" of overlap. The modest taper allows us to model with NEC-4 in full confidence that the results will fall within normal construction variables. The models and the dimensions in various tables will assume that all elements are well insulated and isolated from a conductive boom.

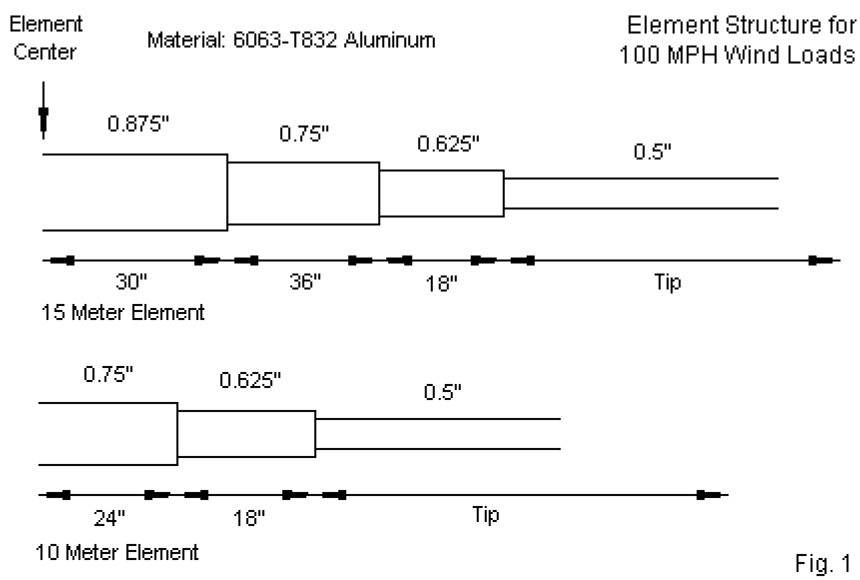


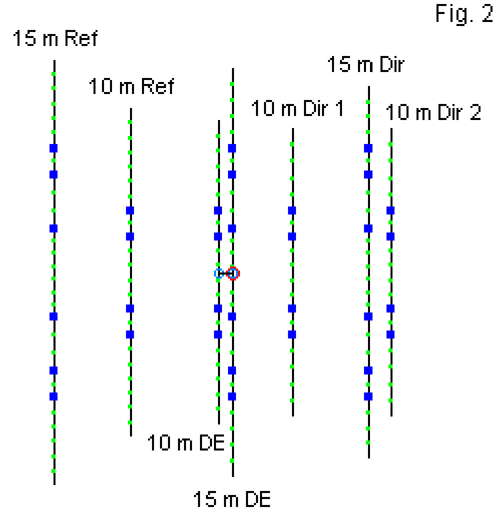
Fig. 1

The entire array will fit within the limits of a 20' boom, which is about normal for a 3-element 15-meter monoband Yagi. Unlike our smaller sample beam, both sections of the antenna will use linear elements. Therefore, the physical size of the new antenna will about 40% wider and 100% longer than our previous design. The boom must be strong enough not only to handle the higher number of elements, but as well to withstand the bending moment of elements farther from the mast. However, we shall not have to be concerned about bending individual elements.

The Overall Design

The multi-band design begins with a 3-element wide-band 15-meter Yagi capable of matching a 50-Ω main feedline. The positions of the 10-meter elements depend initially upon the required placement of the 10-meter driver, with a connecting transmission line that yields a 50-Ω impedance on the upper band. To prevent element overlap, the 10-meter driver is behind the 15-meter driver. This position requires that we add a second 10-meter director ahead of the 15-meter director to preserve performance on that band. The connection line will have a characteristic impedance of 125 Ω with a velocity factor of 1.0. The main feedpoint, that is, the place where we connect the feedline, is the junction of the 15-meter driver and the connecting transmission line. **Fig. 2** shows the overall array outline, with the elements functionally identified. **Table 1** gives the dimensions for our initial design.

Fig. 2



General Outline: 15-Meter 3-Element Yagi
and 10-Meter 4-Element Yagi Combination

Table 1. 3-element 15-meter Yagi—4-element 10-meter Yagi dimensions

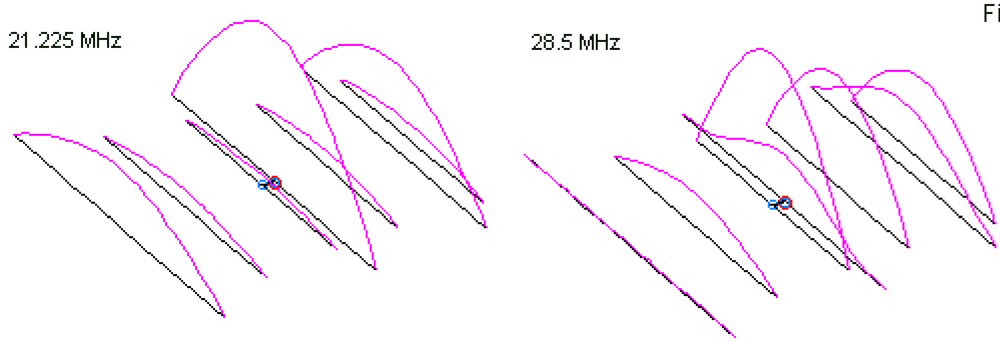
15-meter Yagi			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.875”	30”	Both	0.75”	24”
	0.75	66		0.625	42
	0.625	84	Ref tip	0.5	110
Ref tip	0.5	143	DE tip	0.5	102
DE tip	0.5	137	Dir 1 tip	0.5	96.5
Dir tip	0.5	125	Dir 2 tip	0.5	96.5

Array Spacing	
15-m ref	0
10-m ref	51
10-m DE	111
15-m DE	120
10-m dir 1	161
15-m dir	212
10-m dir 2	227

Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 1.
3. Spacing values progressive from rear element.
4. Driver-to-driver TL = 125 Ω, VF 1.0
5. Feedpoint: 15-meter DE

Unlike the smaller array that we examined in Part 2, the larger 2-band Yagi shows extensive element interaction. **Fig. 3** shows the relative current magnitude on each element for frequencies at the center of each passband.

Fig. 3



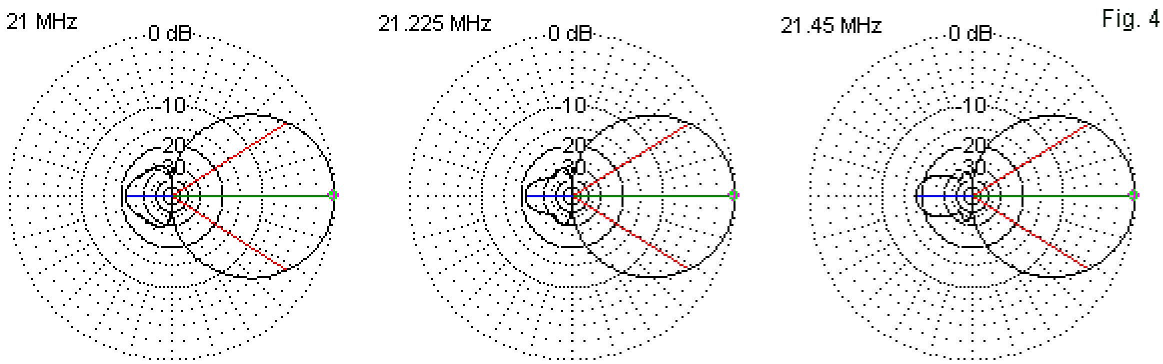
Relative Current Magnitudes on the Elements of a 2-Band Multi-Element Yagi on 15 and 10 Meters

On 15 meters, the activity on the 10-meter elements is low but not wholly insignificant. The forward stagger effect will increase 15-meter gain slightly, but also reduce the front-to-back ratio equally slightly. More significant is the activity of the 15-meter elements on 10 meters. The 15-meter driver shows considerable current, but the curve is controlled largely by the 10-meter driver, as indicated by the bends in the curves on the lower-band driver just outside the limits of the 10-meter driver element. Even more important is the activity on the 15-meter director. Without the additional 10-meter director, the 15-meter director would exhibit considerable control over the 10-meter performance. Hence, in this type of multi-band design, the additional higher-band director is not just a convenience; it is a necessity to preserve the integrity of the 10-meter Yagi element collection. Its function is to control performance more than it is to enhance performance. Hence, the director is relatively close to the lower-band director and has the same length as the first 10-meter director.

The wide-band 15-meter design uses a reflector that is about 0.2-λ behind its driver to achieve the desired 50-Ω match. The 10-meter reflector is more closely space to its driver: about 0.15-λ. We would expect a lower natural impedance for the 10-meter section if it was independent of the multi-band assembly. However, the transmission-line connector between the drivers raises the impedance to the desired matching level.

15-Meter Performance

The 15-meter elements derive from a nearly identical monoband beam. In fact, the only difference in the designs is that the monoband version uses a driver that is 2" shorter than its counterpart in the multi-band array. Despite the influences of the upper-band elements, the 15-meter section provides very good performance, as evidenced by the free-space E-plane patterns in **Fig. 4**. The pattern set for the band edges and the mid-band frequency show a well-formed man forward lobes and well-behaved rearward lobes of only modest proportions. **Table 2**, below the patterns, lists basic performance information for the 15-meter section of the array, with the addition of the performance figures for the monoband version of the antenna.



Free-Space E-Plane Patterns: Yagi-Yagi Combination: 15 Meters

Table 2. Yagi-Yagi: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	7.81	7.91	8.05
Front-to-back ratio dB	21.50	21.42	18.12
Feedpoint Z (R +/- jX Ω)	41.5 – j9.3	42.0 + j0.3	42.2 + j11.7
50-Ω SWR	1.32	1.19	1.36

Monoband version performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	7.58	7.68	7.83
Front-to-back ratio dB	19.64	22.17	20.91
Feedpoint Z (R +/- jX Ω)	45.6 – j11.0	44.3 – j1.9	42.0 + j8.2
50-Ω SWR	1.28	1.13	1.28

The gain improvement averages about 0.2-dB in the multi-band version of the Yagi. The front-to-back performance is down by about a half dB, allowing for the slight downward frequency shift in the peak value. The resistive component of the feedpoint impedance also drops by a few Ohms due to the influence of the transformed off-band impedance of the 10-meter driver.

Fig. 5 graphs the free-space forward gain and the 180° front-to-back ratio (which is also the worst-case front-to-back ratio for this set of elements). The front-to-back ratio peaks about 100 kHz below mid-band. The gain shows a rising curve natural to Yagis with at least one director, but the overall change in gain across the band is only about 0.25 dB. Most wide-band Yagis set for a feedpoint impedance of 50-Ω would show a general gain value of just above 7 dBi in free space. With the same boom length, achieving a forward gain of 8 dBi would normally lower the feedpoint impedance to between 25 and 30 Ω. The monoband Yagi design, which underlies the 15-meter section of the 2-band beam, is set for an intermediate impedance level in the 40's. The result is a higher forward gain level, slightly enhanced by the 10-meter element activity.

The feedpoint behavior of the beam on 15 meters is equally tame, as shown by the curves in **Fig. 6**. The resistive component of the impedance changes by less than 1 Ω across the band. The reactance changes by about 20 Ω. The net result is a 50-Ω SWR curve that does not rise to 1.4:1 anywhere in the band.

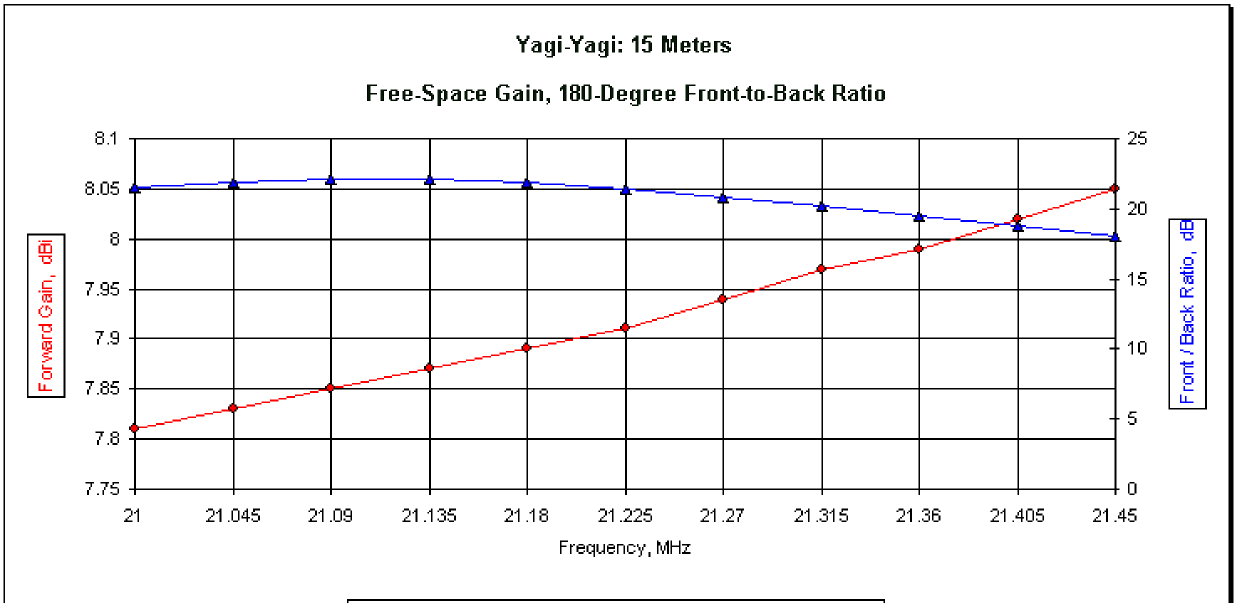


Fig. 5

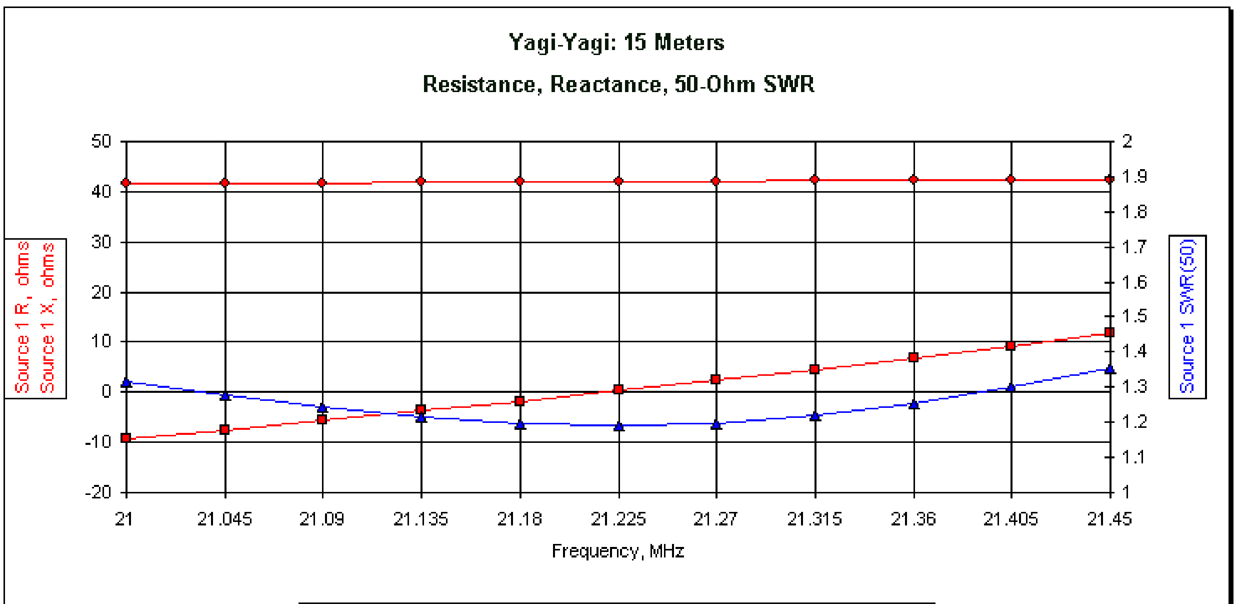


Fig. 6

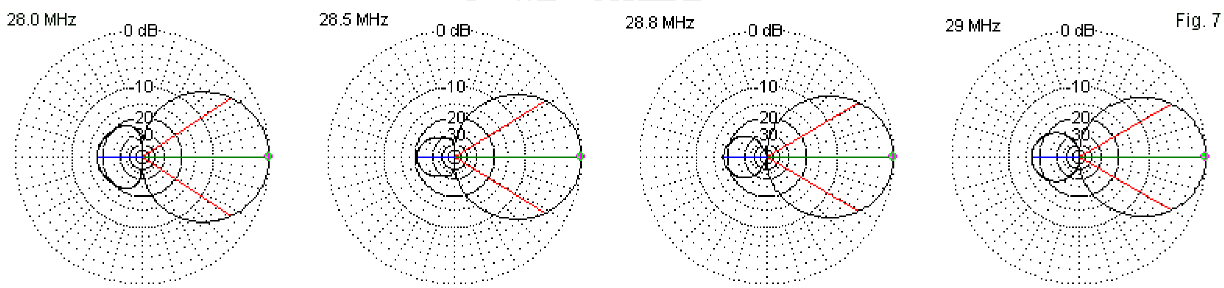
The 15-meter 3-element Yagi provides a basic framework into which we must interlace 10-meter elements positioned for adequate performance on the band.

10-Meter Performance

The 10-meter "section" of the 2-band beam consists of 4 elements: a reflector, a driven element, and 2 directors. After several trials, the driven element found its place behind the 15-meter driven elements, connected to the overall feedpoint by 9" of 125-Ω (VF=1) connecting transmission line. The reflector position is about mid way between the 15-meter reflector and the 10-meter driver. The two drivers mark the approximate center of mass of the array, creating a challenge for attaching the boom to the mast. The mast and its mounting hardware should not be tightly spaced to either driver or placed between them unless one is prepared for some serious redesign based on the degree to which the attachment affects the performance of these elements. See **Fig. 2** to gain a sense of this mechanical design situation.

The first director is far enough from the driver pair to function almost solely as a director and not to act like a secondary 10-meter driver. However, changes in the length and position of the first director on 10 meters do require adjustments to the length and position of the 10-meter driver to establish or re-establish a satisfactory feedpoint impedance (as transformed by the connecting line and in parallel with the off-band impedance of the 15-meter driver). The second and forward-most 10-meter director is ahead of the 15-meter director to re-establish control of the pattern and the feedpoint impedance. Without this final upper-band director, the 10-meter performance would deteriorate severely and the operating bandwidth—even with degraded performance—would narrow unacceptably. The second director, however, does not yield 10-meter performance that is on a full par with an independent monoband 4-element Yagi. Instead, the two 10-meter directs tend to provide 3-element Yagi performance enhanced somewhat by small additions that result from the activity on the 15-meter elements.

The initial design for 10 meters, shown in the **Table 1** dimension set, also contains a compromise. The element positions and lengths available within the 20' boom length and the selection of the number of elements for each band allow us to either maximize the front-to-back ratio or to cover the entire first MHz of 10 meters with an acceptable (<2:1) 50-Ω SWR, but not both. The dimensions shown opt for the best front-to-back ratio. For either option, the free-space E-plane patterns, given in **Fig. 7**, are well behaved. They have a single forward lobe and a single rearward lobe.



Free-Space E-Plane Patterns: Yagi-Yagi Combination: 10 Meters

The rearward lobe from about 28.0 to 28.5 MHz has an evolving shape that one might also expect from a monoband Yagi. However, once the front-to-back ratio reaches its maximum value, we tend to expect the rearward lobe to further evolve into an actual or incipient 3-lobe structure. See, for example, the progression of patterns for 15 meters in **Fig. 4**. However, the multi-band setting for the 10-meter elements yields a virtually circular rearward lobe over the upper half of the passband. This development is natural under the overall electrical conditions, but it is not the only possibility of what might emerge in a multi-band Yagi. An alternative, that is usually less desirable but sometimes unavoidable, is a pair of rearward sidelobes of considerable proportions, so that the 180° front-to-back ratio is higher than the worst-case front-to-back ratio by a significant amount. As the patterns show, in the present design, the 180° front-to-back ratio is also the worst-case ratio.

Table 3. Yagi-Yagi: 10-meter performance

Frequency	28.0	28.5	28.8	29.0
Free-space Gain dBi	7.15	8.02	8.56	8.87
Front-to-back ratio dB	17.62	20.79	18.54	16.89
Feedpoint Z (R +/- jX Ω)	40.2 – j13.8	43.6 + j14.5	46.6 + j33.3	50.8 + j43.9
50-Ω SWR	1.46	1.40	1.97	2.33

Table 3 samples the 10-meter performance. Like the patterns in **Fig. 7**, it contains an extra entry for 28.8 MHz. The SWR values show the reason for this entry: it marks the practical limit of the operating passband if we arrange the elements for peak front-to-back ratio values. Although the performance above 28.8 MHz is quite usable, the SWR exceeds normal recommended limits. The value might decreases at the equipment end of a lengthy feedline due to normal cable losses, but we shall not count on that phenomenon in this context.

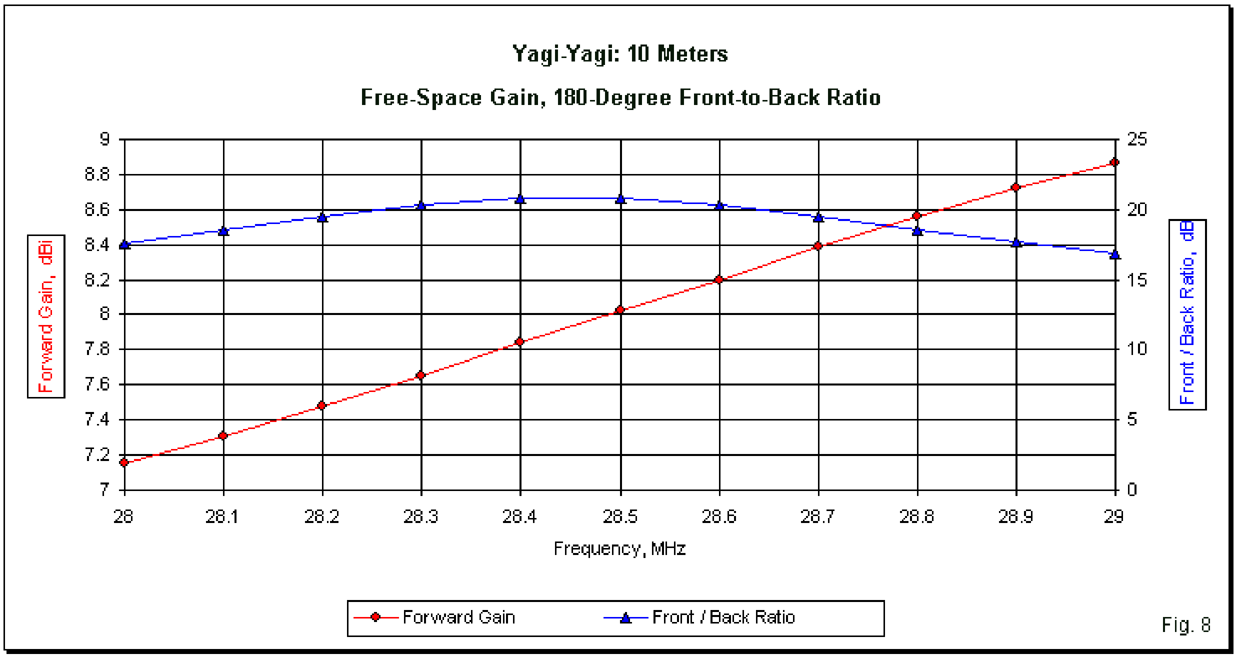


Fig. 8

Like virtually all upper-band sections of multi-band Yagis, the forward gain shows a more rapid rise than we would expect from a monoband 10-meter beam. The total differential for the 1-MHz spread is about 1.7 dB. The average gain is also the mid-band gain, since the curve is quite linear. 8 dBi free-space gain is what we might expect from a 3-element Yagi with a 12' boom. The need for the second director to control performance gives the 10-meter element a boom length of about 14.7' in this design.

The front-to-back ratio peaks above 20 dB in the center of the band, with band-edge values in the vicinity of 17 dB. These values are consistent with front-to-back values that we normally obtain from the best of commercial tri-band Yagis on 10 meters. The chief limiting factor with respect to the front-to-back ratio on 10 meters is the activity on the 15-meter director. At 10 meters, the element's excess length converts it into a reflector. The single director ahead of the 15-meter director re-establishes 10-meter control, but only to a limited extent.

The feedpoint data appear in **Fig. 9**. Across the entire passband, the resistance changes by only 10 Ω. However, the reactance undergoes nearly a 60-Ω swing, a situation that is consistent with the compression of the gain curve on 10 meters. The result is a more rapid change in the 50-Ω SWR. The low-end of the band shows that we have some leeway for re-design, but the commitment here to maximize the front-to-back ratio dictates that the minimum value appear at about 28.3 MHz. Hence, the SWR passes the 2:1 mark just above 28.8 MHz.

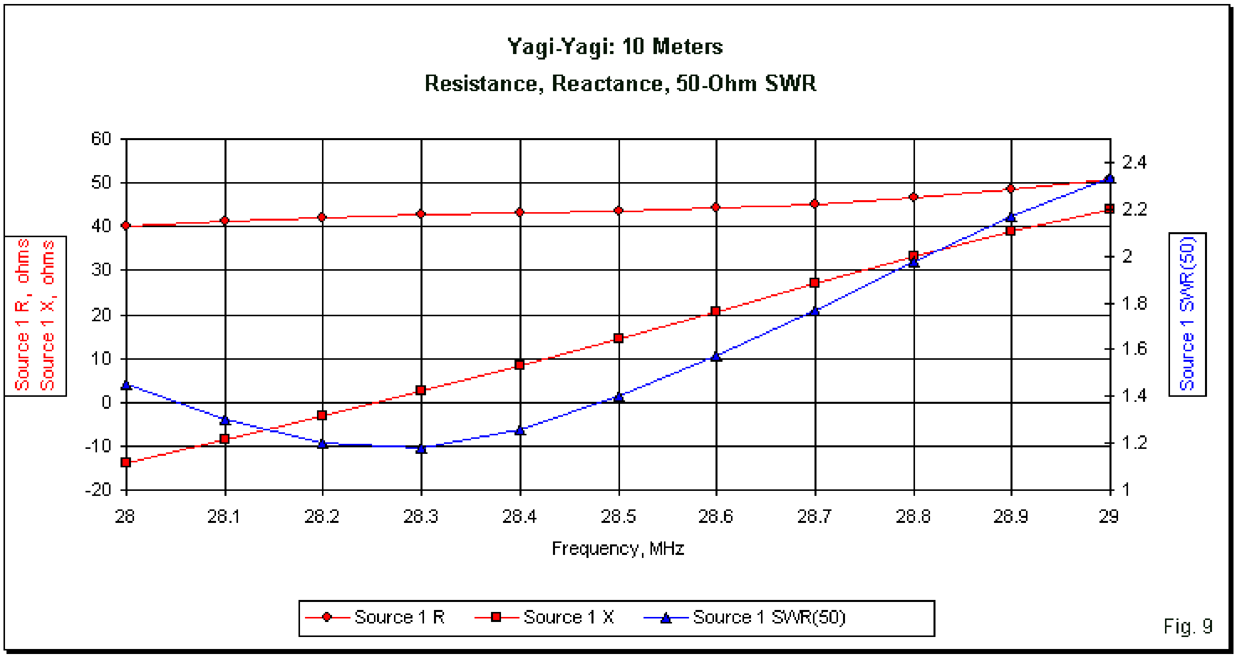


Fig. 9

Despite the limitation to the 10-meter passband, the 10-meter performance of the 2-band array is very good for antennas of this type. Except for the SWR at the high end of 10 meters, a user would have difficulty differentiating the 15- and the 10-meter performance.

The overall array feedpoint appears on the 15-meter driver. The transmission line from the array feedpoint to the 10-meter driver feedpoint consists of a 125-Ω line with a velocity factor of 1.0, indicating a fabricated line for the purpose. It is possible to construct a 125-Ω transmission line from 2 round wires. The lower impedance limit for round wires is around 80 Ω, depending upon the exact wire diameter, before the wires touch. At the desired impedance, square wires permit a gap or face-to-face spacing that is about 1.45 times the gap between round wires. With face widths of about 0.25", the required spacing is 0.22". For 0.5" faces, the spacing is 0.43", and for 0.75" materials, the spacing increases to 0.65".

A Design Variation for Expanded 10-Meter Coverage

The initial design opted for maximizing the front-to-back ratio on 10 meters. With a few small design variations solely to the positions and lengths of the 10-meter elements, it is possible to increase the operating passband, but at a cost to the front-to-back ratio on that band. The number of adjustments a few and the amount is small. Exploring this design variation provides us with a feel for how sensitive 10-meter dimensions are relative to the very stable lower-band dimension. **Table 4** provides the full set of dimensions for the revised beam for comparison with those in **Table 1**. I have highlighted the changes necessary to obtain the new 10-meter performance curves.

Table 4. 3-element 15-meter Yagi—4-element 10-meter Yagi dimensions: modification

15-meter Yagi				10-meter Yagi		
Element	Diameter	Length		Element	Diameter	Length
Both	0.875”	30”		Both	0.75”	24”
	0.75	66			0.625	42
	0.625	84		Ref tip	0.5	110
Ref tip	0.5	143		DE tip	0.5	102
DE tip	0.5	137		Dir 1 tip	0.5	96.5
Dir tip	0.5	125		Dir 2 tip	0.5	*97*

Array Spacing	
15-m ref	0
10-m ref	*51.5*
10-m DE	*112*
15-m DE	120
10-m dir 1	*160*
15-m dir	212
10-m dir 2	*227.5*

Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 1.
3. Spacing values progressive from rear element.
4. Driver-to-driver TL = 125 Ω, VF 1.0
5. Feedpoint: 15-meter (Moxon) DE

The only change in length is to the second director: it is 0.5” longer on each end or a total of 1” longer overall. The reflector moves forward by a half inch, while the 10-meter driven element is 1” closer to the 15-meter driver. The first director moves back (toward the 15-meter driver) by 1”, while the second director moves forward by a half-inch. In a monoband Yagi design, the element spacing values in the upper HF range are rarely so exacting. However, upper-band Yagi elements are quite sensitive due to the compression of the performance curves in the multi-band setting.

The changes to the 10-meter elements result in virtually no change in the 15-meter performance, as shown by the modeled free-space values in **Table 5**. Compare these numbers with the corresponding set of values in **Table 2**.

Table 5. Yagi-Yagi: 15-meter performance: modification

Frequency	21.0	21.225	21.45
Free-space Gain dBi	7.82	7.92	8.06
Front-to-back ratio dB	21.48	21.33	18.04
Feedpoint Z (R +/- jX Ω)	41.6 – j9.1	42.0 + j0.6	42.2 + j12.0
50-Ω SWR			

Although the new set of dimensions does not alter 15-meter performance, it does make a difference to the performance on 10 meters. **Table 6** provides sample numbers for comparison with those in **Table 3**.

Table 6. Yagi-Yagi: 10-meter performance: modification

Frequency	28.0	28.5	28.8	29.0
Free-space Gain dBi	7.31	8.20	8.73	9.02
Front-to-back ratio dB	17.82	18.67	16.40	15.02
Feedpoint Z (R +/- jX Ω)	36.6 – j21.5	44.4 + j10.6	51.7 + j28.5	58.9 + j34.1
50-Ω SWR	1.79	1.29	1.74	1.89

In general, gain rises a little over 0.1-dB, too little to be more than numerically notable. The average front-to-back ratio decrease is about 1.5-dB. For this cost, we obtain full coverage of the first MHz of 10 meters with a 50-Ω SWR of less than 2:1. If the cost is not too great and if one needs performance above 28.8 MHz, then the revised design is likely the more preferable one.

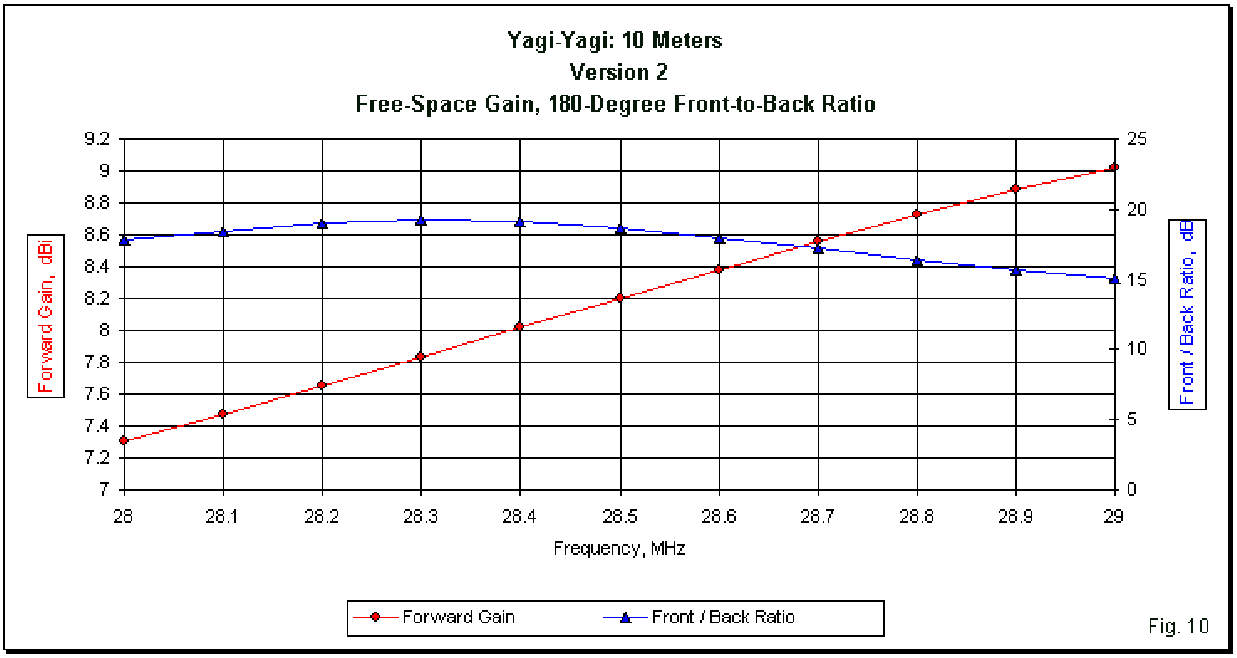


Fig. 10

Fig. 10 shows the consequences of the redesign for 10-meter gain and front-to-back performance. The 180° front-to-back curve essentially slides lower in frequency and does not obtain the peak value obtained by the initial design. Otherwise, little changes, including the pattern shapes. Since the patterns are so similar to those in **Fig. 7**, we do not need a new set here.

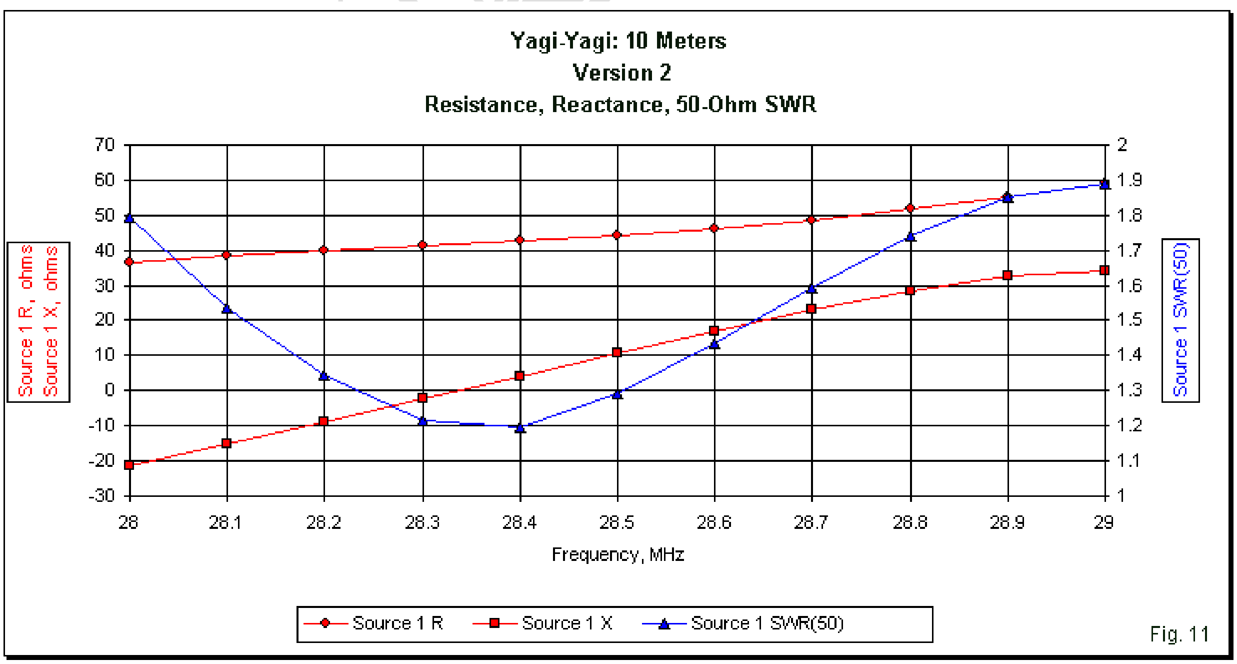


Fig. 11

Fig 11 shows the consequence of the design changes for the feedpoint values. The resistance curve changes very little, but the reactance curve tends to gradually flatten at the upper end of the band. As a result, the SWR minimum value only needs to increase its frequency by about 100 kHz to obtain less than 1.9:1 50-Ω SWR at the upper band edge.

We need not belabor the question of which design is intrinsically superior, since the selection would depend upon one's operating needs and desires. In terms of our overall goal of using design examples to show some of the dimensions of multi-band Yagi design, having both versions of the beam is useful. This is especially true in terms of understanding how sensitive upper-band dimensions are compared to the very stable baseline offered by a reasonable lower-band element set. For an individual who needs (or who has room for) a beam covering 15 and 10 meters, either version would compete well with any commercial array on the market.

The Second 10-Meter Director: Is it Really Necessary?

I have noted in numerous places that the second 10-meter director is necessary as a control element for upper-band performance. We might introduce here a small demonstration. We shall return to the initial design, the dimensions for which appear in **Table 1**. However, we shall also modify this beam to remove the second 10-meter director. A comparison of the results may prove instructive.

Table 7 repeats the 10-meter performance values for the initial design and adds a new set of sample values—those without the second director.

Table 7. Yagi-Yagi: 10-meter performance

With second director

Frequency	28.0	28.5	28.8	29.0
Free-space Gain dBi	7.15	8.02	8.56	8.87
Front-to-back ratio dB	17.62	20.79	18.54	16.89
Feedpoint Z (R +/- jX Ω)	40.2 – j13.8	43.6 + j14.5	46.6 + j33.3	50.8 + j43.9
50-Ω SWR	1.46	1.40	1.97	2.33

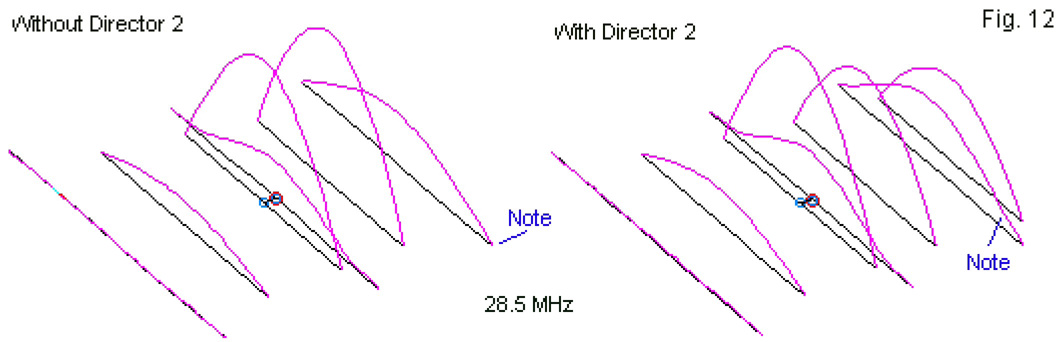
Without second director

Frequency	28.0	28.5	28.8	29.0
Free-space Gain dBi	5.28	5.85	6.39	6.85
Front-to-back ratio dB	10.35	13.13	14.90	14.66
Feedpoint Z (R +/- jX Ω)	49.6 – j28.5	35.9 – j9.0	25.6 + j12.3	19.8 + j29.5
50-Ω SWR	1.76	1.48	2.11	3.51

The sample numbers establish several general trends. First, the absence of the second director severely reduces the forward gain. The reduction is almost 1.5 dB, enough to raise the question of using the larger beam at all, compared to the 10-meter performance of the smaller array in Part 2 of this series. The question becomes even more relevant when we examine the second trend, the reduction in the front-to-back ratio values, which are lower by an average of 5 dB relative to the beam version with the second director in place.

The third trend shows up in both the front-to-back ratio and the SWR data. Without the second director, both sets of values show compression, that is, a higher rate of change across the band. The usable passband shrinks. As well the peak front-to-back ratio occurs within the band, but the lower-end value is more distance from the peak value than we find in the range of values with the second director in place.

We may gather a feel for the performance depression when we do not use the second 10-meter director by comparing the current magnitude on the elements both with and without that director. **Fig. 12** provides relative curves for 28.5 MHz for both versions of the array.



Relative Current Magnitudes on the Elements of a 2-Band 15-10-Meter Yagi With and Without the 10-Meter Second Director

Without the second director, it appears that the first director on 10 meters has a higher relative current magnitude than when the second director is present. As well, the current on the 15-meter director might be slightly lower when it is the terminal element. The current magnitude curves might be accordingly ambiguous if we did not note the difference in the shape of the current magnitude curves on the two versions of the 15-meter director. Without the second 10-meter director, the curve has a normal nearly sinusoidal shape. Under these conditions, the element operates as a long element on 10 meters, largely functioning as a reflector. Hence, it manages to reduce forward gain and increase rearward gain. The result is not only the degraded performance, but as well a disruption of the feedpoint impedance curve.

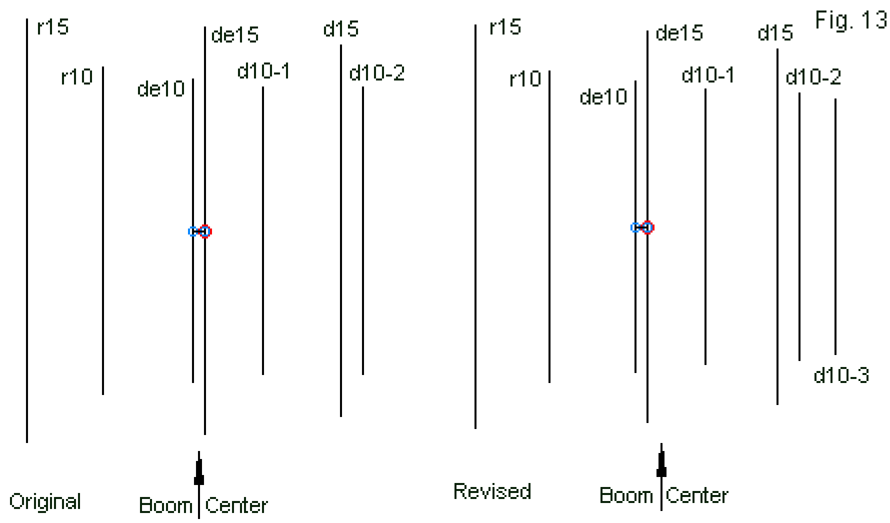
The presence of the second 10-meter director alters the shape of the current distribution curve on the 15-meter director. It slopes more rapidly toward zero until it passes the limit of the 10-meter director. Since the current cannot go to zero until the element ends, the electrical reshaping of the current distribution cannot be complete. As a result, we cannot fully defeat the effects of the 15-meter elements as a reflector by the use of the controlling second 10-meter director. However, the control director goes a long way toward providing acceptable 10-meter performance, including adequate front-to-back and SWR-passband values.

In more complex cases, the lower-band element may need upper-band control elements on both sides.

Do We Need a Third 10-Meter Director?

Although we have noted a peculiar mechanical problem, we have not fully addressed it in these notes. Multi-band parasitic beam designs often wind up with the center of the boom or the center of element mass falling directly or almost directly on or between the driver elements. If we include mounting hardware and plates in the boom assembly, the boom wants to fall in the middle of 2 drivers connected by a transmission-line section. Our dual-band Yagi combination with 3 15-meter elements and 4 10-meter elements is no exception, as shown on the left in **Fig.**

13. We may offset the boom and compensate for the greater weight on either the forward or rearward end. However, many multi-band beam designers abhor simply adding mass without also adding useful electrical work in the process.



Adding a 10-Meter Director for SWR Control and Boom Placement

On the right in **Fig. 13** we find one typical avenue of solution. Instead of adding mere weight, we add a new 10-meter director. The revised 2-band Yagi now has 5 elements on 10 meters, a somewhat longer boom, and a few electrical improvements. However, since everything about the upper band (or bands) of a multi-band Yagi is somewhat of a compromise, we also pay a small cost. Many commercial beam makers either disguise the cost or simply do not mention it. Since we are presenting full design data on our work here, the cost will become as evident as the improvements.

The added director requires careful placement and selection of length, to do its mechanical job, and to restore, if not improve, 10-meter performance. However, as the dimensions in **Table 8** show, the 15-meter values do not change. I have shortened the 15-meter reflector and director by 1" at each end to re-center the 15-meter performance curves within the band. However, the performance would have remained entirely satisfactory without those changes—just slightly offset to the lower part of the band.

The primary changes on 10 meters occur with the lengthening of the boom from 18.9' to 21', with the usual added length to support mounting plates or hardware. In many circles, we tend to count aluminum in 10' sections. Hence, the shorter Yagi is preferable from that perspective—assuming one can resolve the mast placement challenge in other ways than moving it to an unoccupied part of the boom. However, the new boom is only about 2' longer than the old boom, and we shall assume for the sake of argument that the new length is not excessively forbidding.

The other major changes involve the lengths that we assign to both the second and third directors. If we compare the second director in the new configuration to previous versions of the array, we discover that it is about 3.5" shorter on each end than the earlier directors. The new (third) director is even shorter.

Table 7. 3-element 15-meter Yagi—5-element 10-meter Yagi dimensions

15-meter Yagi

Element	Diameter	Length
Both	0.875"	30"
	0.75	66
	0.625	84
Ref tip	0.5	142
DE tip	0.5	137
Dir tip	0.5	124

10-meter Yagi

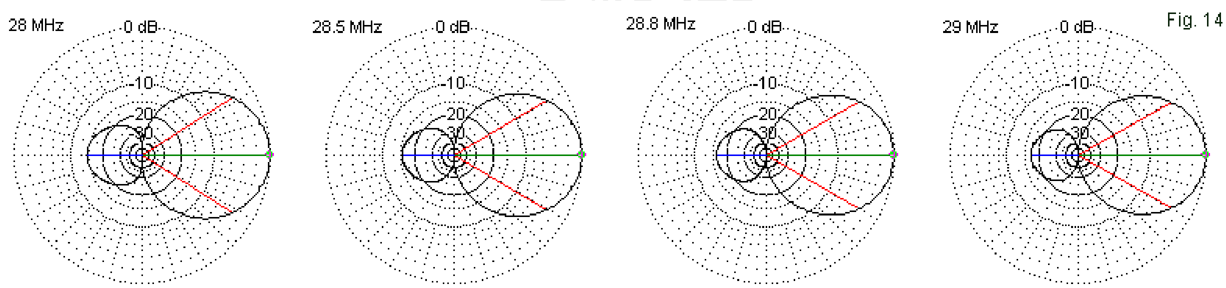
Element	Diameter	Length
Both	0.75"	24"
	0.625	42
Ref tip	0.5	109
DE tip	0.5	102
Dir 1 tip	0.5	96.5
Dir 2 tip	0.5	92.5
Dir 3 Tip	0.5	89.5

Array Spacing	
15-m ref	0
10-m ref	51.5
10-m DE	112
15-m DE	120
10-m dir 1	161
15-m dir	212
10-m dir 2	227
10-m dir 3	252

Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 2.
3. Spacing values progressive from rear element.
4. Driver-to-driver TL = 125 Ω, VF 1.0
5. Feedpoint: 15-meter (Moxon) DE

Boom Length: 21.00' plus ends

As a 5-element beam for 10 meters, the new array does not reach the territory of showing forward sidelobes. **Fig. 14** provides patterns that you may compare directly with those in earlier pattern galleries. The figure shows only 10-meter patterns, since the 15-meter plots have not changed shape. The upper-band patterns are all quite well behaved, with a single forward lobe and a single very round rearward lobe.



Free-Space E-Plane Patterns: Enhanced Yagi-Yagi Combination: 10 Meters

To confirm the continuing sound performance of the 15-meter portion of the array, **Table 9** provides sample values from the free-space model at the band edges and the band center. The table also presents some figures for the total change in value across the band for several categories of data. The stability of the lower-band performance has its evidence in the very low values in the Δ column of the table.

Table 9. 3-element 15-meter Yagi—5-element 10-meter Yagi: 15-M Performance

Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	7.92	8.00	8.11	0.19
Front-to-back ratio dB	19.41	20.76	18.68	2.08
Feedpoint Z (R +/- jX Ω)	41.7 – j6.6	43.0 + j2.9	43.9 + j13.8	2.2 + j20.4
50-Ω SWR	1.26	1.18	1.38	

The corresponding data for 10 meters appears in **Table 10**. The table omits the data for 28.8 MHz, since the added element in the 10-meter section of the array frees us from concerns about a limited 10-meter SWR bandwidth.

Table 6. 3-element 15-meter Yagi—5-element 10-meter Yagi: 10-M Performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	7.87	8.49	9.11	1.24
Front-to-back ratio dB	14.33	15.39	17.05	2.72
Feedpoint Z (R +/- jX Ω)	41.7 – j15.9	53.7 + j4.9	46.2 + j22.1	12.0 + j38.0
50-Ω SWR	1.48	1.13	1.59	

The full set of values for the free-space forward gain and the 180° front-to-back ratio appear in **Fig. 15**. Interestingly, the peak gain at the upper end of the passband is not very different from the value we obtained with one less director. (See **Fig. 10**.) However, the major improvement occurs lower in the band. The gain at 28.0 MHz has increased by nearly 0.6-dB. The operational significance of this value does not lie in the gain itself, but in the increased smoothness of the gain value across the band. The gain differential has decreased by about 60%. In exchange, we come to the cost of the added director: an average reduction of about 1 dB in the front-to-back ratio, with most of the loss in the lower portion of the 10-meter passband.

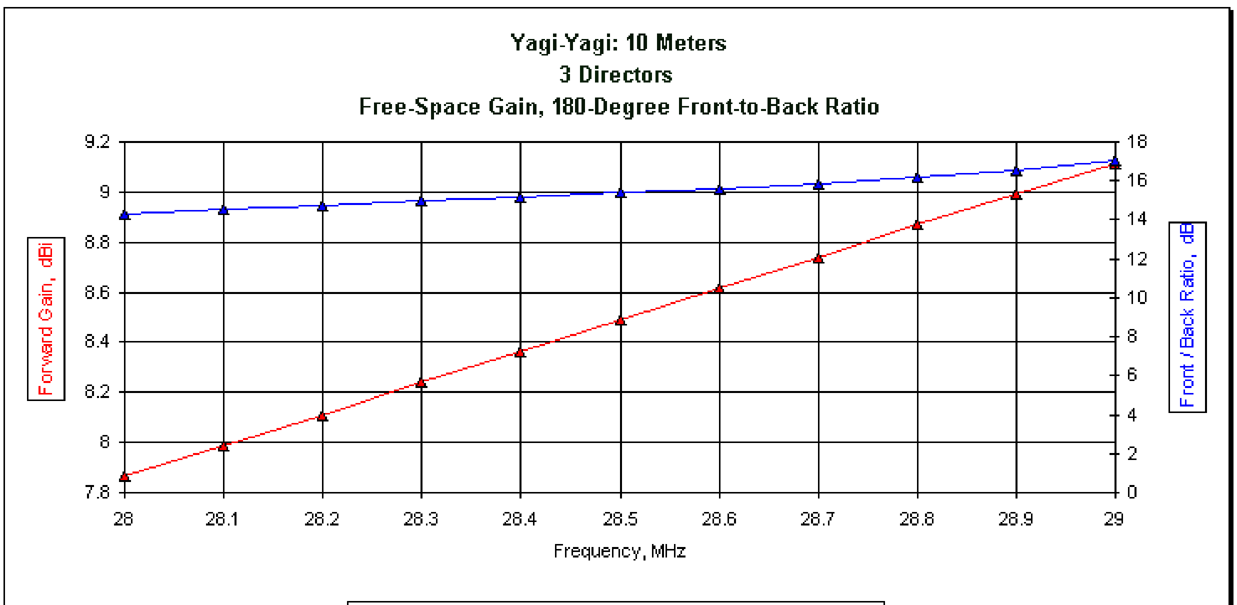


Fig. 15

In addition to the stabilization of gain across 10 meters, the added director provides another electrical benefit. It yields a more stable set of feedpoint resistance and reactance values, with the result being a broadening of the 10-meter SWR curve. **Fig. 16** shows the complete sweep of values. Compare this graph to **Fig. 11**. The peak 50-Ω SWR value for the smaller array was 1.90:1. As we noted in the discussion, including the entire first MHz of 10 meters within the 2:1 SWR limit that we normally use as a standard in amateur radio design work required some fairly sensitive adjustments to the parasitic elements positions and length values. The SWR curve for the design that uses an added director show a maximum 50-Ω SWR of about 1.6:1. The broadness of the curve reduces the sensitivity of the design to construction variables that inevitably occur.

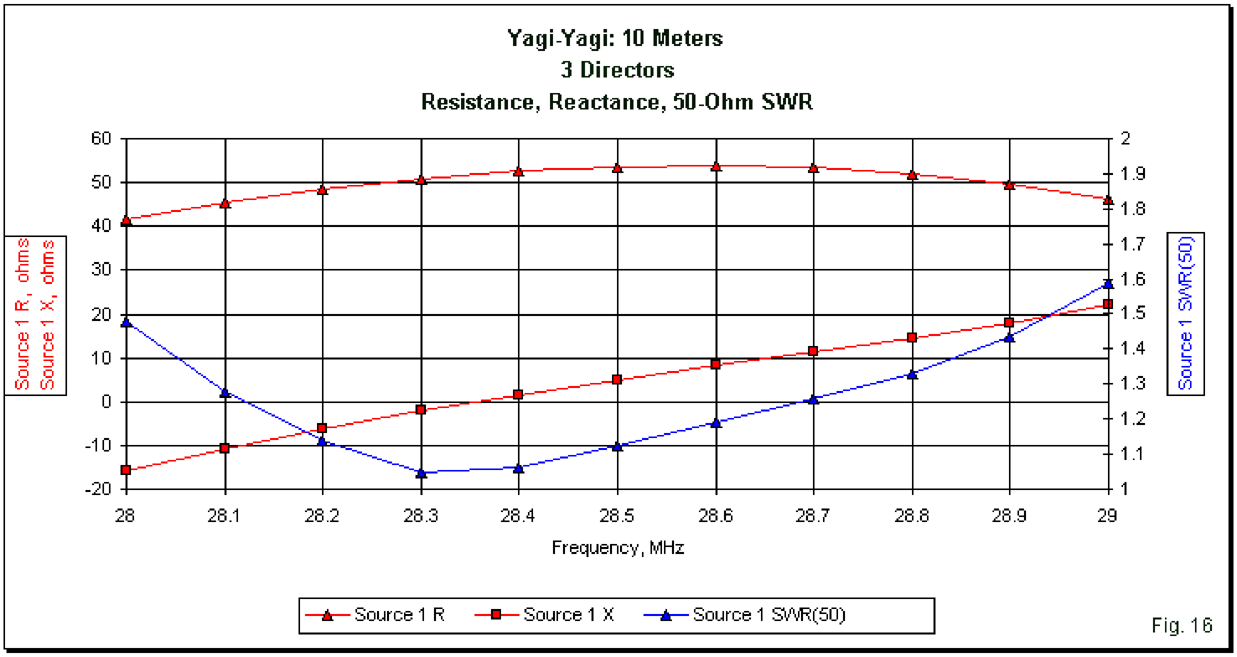


Fig. 16

To the list of advantages that we accrue from adding the third director to the 10-meter portion of the beam we must go back to **Fig. 13**. There we find the boom center forward of the 15-meter driven element. If we minimize the metal mass that we employ in mounting the boom to the mast, the assembly at that point should not significantly alter the operation of the array beyond the normal requirements of field adjusting a prototype of any array.

The final performance score then is 3 improvements vs. 1 reduction. Not only does the added element smooth out gain across 10 meters, it also provides greater control of the feedpoint values for a broader SWR curve. Finally, the added element removes the problem of where and how to mount the array to a mast. For those advantages, we lose a small amount of front-to-back ratio. We may rationalize away the significance of that loss, but when we employ the usual amateur radio monoband beam standard of 20 dB, the multi-band Yagi is deficient in that regard on the upper band. This loss is common to almost all multi-band Yagis that I have encountered. That fact does not mean that superior front-to-back performance is not possible. Rather, it simply means that I have not yet found a way to bring a high ratio into concert with appropriate gain curves and a broad SWR curve. In a monoband beam, there are ways of achieving this goal. However, the upper-band of a multi-band beam always contends with the compression of both the gain and front-to-back curves, so that expanding one of the two tends to result in lower values for the other.

Conclusion

In this episode, we have exemplified most of the principles that we exampled in general terms as part of the first set of notes. As well, we have extended the discussion beyond the limits displayed in the very simple designs in Part 2. Appearances are that we may well have covered all of the available territory. However, our willingness to extend the boom beyond the initial desire to keep it at or under 20' opens an interesting option that we have so far not discussed.

All of the arrays that we have sampled have placed the 10-meter driven element behind the 15-meter driven element. As long as we are extending the boom to lengths greater than 20', we should see what happens if we move the 10-meter driver. Let's place it ahead of the 15-meter driven element and compare the results with some of the designs that we have so far introduced. In the final section of notes, we shall create 10-meter beam section with 4 and with 5 elements, but with the driver in the forward position. Along the way, we shall compare the results with those we just obtained in this section of the notes.