Designing Multi-Band Parasitic Beams
Part 6: Small Yagi-Yagi Alternatives to the Moxon-Yagi 2-Band Beam

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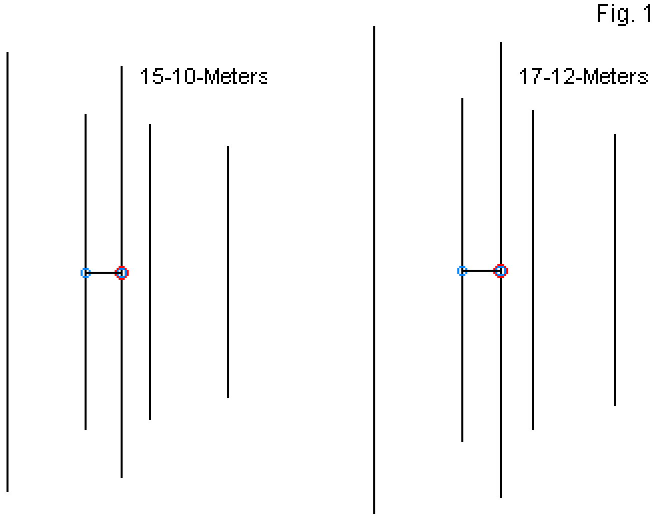
In the exercises exploring the design of 2-band beams, I employed a Moxon rectangle as the lower-band element set. For 15 and 10 meters, the Moxon rectangle presented some interesting challenges, since the 10-meter driver—positioned behind the 15-meter driver—had to be shortened to fit the space between the Moxon driver tails. One result was the need to use a 125-Ω connection line between the two drivers. Nevertheless, with 2 elements on 15 meters and 3 elements on 10 meters, we managed to develop a quite usable array.

Not everyone needs or prefers the compactness of the Moxon element structure. The requirement for element corners and mechanical (but non-conductive) alignment links between the tails engenders concerns, if for no other reason than that the array looks abnormal compared to standard Yagi configurations. So I re-designed the array for a more familiar Yagi-Yagi configuration. Since the Yagi reflector requires additional spacing behind its driver, thereby lengthening the boom, I moved the 10-meter directors forward to improve performance on that band by a small amount. The increases in the boom length do not materially affect the turn radius, since the longer low-band Yagi elements largely determine this value.

The resulting array proved to offer fewer challenges to the design effort while still showing all of the earmarks of the general principles set out in the preliminary discussion of designing multi-band beams. In fact, I ended up with 2 designs: one for 15 and 10 meters, the other for 17 and 12 meters. **Fig. 1** shows the general outlines of both beams and allows a general size comparison. Like the initial Moxon-Yagi design, the upper-band driver is behind the lower-band driver for each version of the array. The main feedline connection is to the lower-band driver. However, the connecting transmission line between drivers is 50 Ω.

Fig. 1

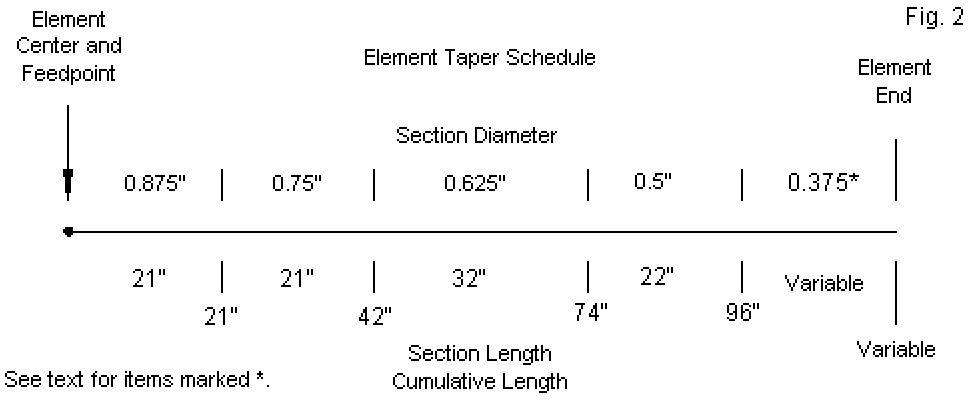


General Outlines: 5-Element Yagi-Yagi
Beams for 15-10-Meters and 17-12-Meters

Let's examine the two beams separately, beginning with the 15-10-meter version, which must cover wider amateur bands than its big brother.

A 5-Element Yagi-Yagi Array for 15 and 10 Meters

Like all of the arrays in this serial collection, the current designs emerge from NEC-4 software. Therefore, they presume that all elements are well insulated and isolated from any conductive boom. The 15-10-meter 5-element array uses a fairly light element diameter taper schedule and is likely to handle up to 50-60-mile-per-hour winds without ice loading. **Fig. 2** shows the progression of sections for the half-elements—with the missing half a mirror image to the sketch. The one exception to the sketch occurs with the most forward 10-meter director. Its required length eliminates the need for the 0.375” tip section in the sketch.



Element Taper Schedule for 15-10-Meter Array

Table 1 provides the dimensions of the array. For the inner element sections, the length values are the exposed tube length and presume a 2”-3” addition for insertion into the next larger tube size—except for the largest tubing size, of course. The tip length values, however, are the half-element cumulative values. Multiply by 2 for the total element length. Subtract 96” (for all but director 2 for 10 meters) to obtain the exposed tip length.

Table 1. 2-element 15-meter Yagi—3-element 10-meter Yagi dimensions

15-meter Yagi			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.875”	21”	Both	0.875”	21”
	0.75	21		0.75	21
	0.625	32		0.625	32
	0.5	22		0.5	22
Ref tip	0.375	146	Ref tip	0.375	105
DE tip	0.375	135.75	Dir 1 tip	0.375	97.5
			Dir 2 tip	0.5	83

Array Spacing	
15-m ref	0
10-m DE	51
15-m DE	75
10-m dir 1	93.5
10-m dir 2	145

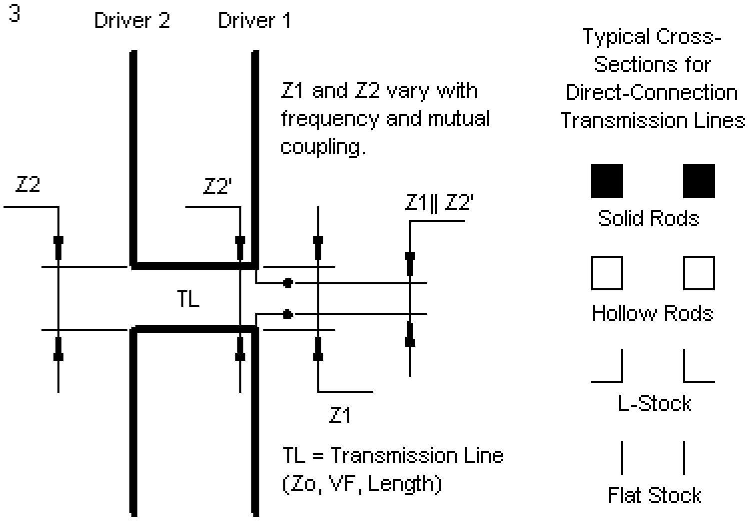
Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 1.
3. Spacing values progressive from rear element.
4. Driver-to-driver TL = 50 Ω, VF 1.0
5. Feedpoint: 15-meter DE
6. Boom length: 12’ 1”

As with all arrays—monoband or multi-band—that employ an element diameter taper schedule, the dimensions are specific to the schedule. The schedule presumes the use of 6063-T6 aluminum tubing or its equivalent. Changes in element diameter or even in the length of the individual sections of the elements will require careful re-design of the array to assure performance. Of course, like all multi-band arrays, expect to spend more than a few minutes with field adjustments.

Like the Moxon version of this small array, the 15-meter section is very stable and withstands extensive experimentation with 10-meter element placement without requiring any changes. The upper-band elements are somewhat more sensitive to changes. First, 10 meters is the wider band, and adjustments must assure adequate performance across the entire passband from 28.0 to 29.0 MHz. Second, the upper band elements for almost any multi-band array (except trap designs) tend to show performance curve compression and more rapid rates of change than a comparable beam in monoband form. As always, the final settings used in this design represent a compromise among conflicting trends in performance as one adjusts the upper-band element placement and length, so this design is not the only combination possible.

The feed system for the array uses directly coupled drivers. The main 50-Ω feedline connects to the lower-frequency driver (in this case, 15 meters). For the upper band, we use a parallel feedline the exact length of the distance between the drivers. As shown in **Fig. 3**, the upper-band driver (10 meters) connects to the feedline. As a result, the impedance in parallel with the 15-meter driver is a transformed value, with the exact transformation a function of the connecting-line characteristic impedance and the impedance of the upper band driver. The upper-band impedance depends in part upon the mutual coupling between driver elements, given the relatively close spacing (about 26” on this version).

Fig. 3



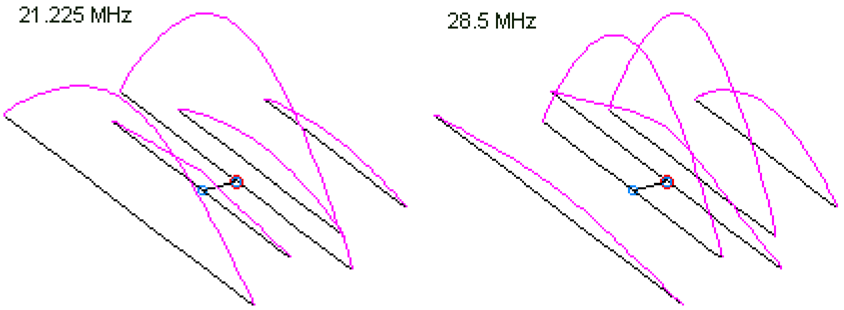
Feedpoint Considerations for Directly Connected Drivers

In the earlier Moxon-Yagi arrays, the upper-band driver impedance—when active—was not 50 Ω, largely due to the need to shorten the driver so that it did not contact the Moxon tailpieces. Freed from that constraint, the 10-meter driver is 105” per side, as long as the Moxon was wide. As a consequence, the 10-meter impedance on 10 meters is close to 50 Ω. Hence, a 50-Ω connecting line serves very well. Bare round conductors cannot form a 50-Ω line, since the wires begin to interpenetrate as the line impedance drops below 80 Ω. However, flat-faced materials, such as those suggested by the right side of **Fig. 3** can form a 50-Ω parallel line. With a face width of 0.25”, the required gap is a narrow 0.05”. As the width increases to

0.5”, the gap increases to about 0.10”. 0.75”-wide lines need a gap of 0.154”. It is likely that a prototype of this array (or the 17-12-meter version yet to come) should allow for gap adjustment as part of the field adjustment procedure.

The feedline meets a parallel connection when it joins the 15-meter driver. The off-band impedance should be considerably higher than the active-band impedance to allow the parallel combination to show essentially the impedance of the active driver. One way to check the interaction of the drivers is to measure the impedance on each band. Another indicator is the graph of relative current magnitude distribution along the elements on each band. **Fig. 4** provides graphs for both bands. The lines indicate relative current magnitude rather than absolute values. As well the lines do not indicate the relative phase angle of the currents.

Fig. 4



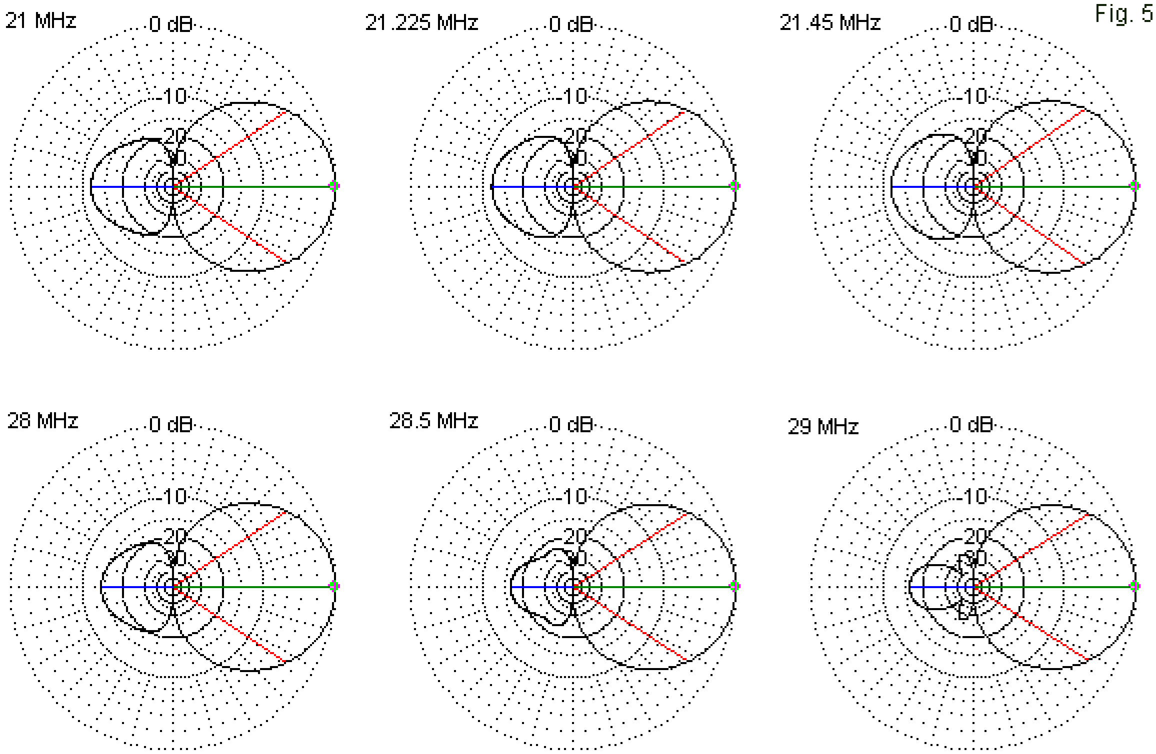
Relative Current Magnitude Distribution: 5-Element 2-Band Array

For both bands, the current levels on the ostensibly inactive elements are very low. On 15 meters, the 10-meter directors provide only a tiny forward stagger “boost” to the forward gain. The 10-meter driver current is relatively negligible when we use the beam on 15. When we use the beam on 10 meters, the 15-meter reflector shows a low current level and does not materially affect 10-meter performance. The 15-meter driver shows higher current. However (although hard to discern) the current curve on the band shows a small knee toward each end, just about where the 15-meter driver ends. The relatively low activity on the 15-meter elements when operating on 10 meters tends to broaden the bandwidth of the upper band. As well, the higher the relative isolation of the two sets of interlaced elements, the cleaner will be the patterns that we can obtain from the antenna.

Fig. 5 provides us with a gallery of sample free-space E-plane patterns for both 15 and 10 meters as derived from the design model. The 15-meter patterns are typical for a 2-element driver-reflector Yagi, widely spaced to yield close to 50-Ω as the feedpoint impedance. On 15 meters the reflector-to-driver spacing is just above 0.14 λ. For a monoband 2-element Yagi of the same design, the forward gain would be about 6.0 dBi, with a front-to-back ratio of between 10 and 11 dB. The forward stagger effect provides a gain boost of about 0.2 dB, with a 1-dB improvement in the front-to-back value. Both increases have no operational significance at all.

On 10 meters, the forward pattern is clean, while the rearward pattern undergoes considerable reshaping across the 1-MHz passband. The rearward patterns are typical of those we find with a short-boom 3-element Yagi. However, the rearward lobes are larger than for a monoband Yagi. The stronger rearward radiation results partially from the fact that the forward-most director serves mostly to control the operating passband and only secondarily helps shape the pattern. Indeed, position and length maneuvers that we can perform on the 10-meter directors, especially for the front element, tend to work at odds with each other. Moves that increase gain tend to reduce the front-to-back ratio, and vice versa. The dimensions selected represent a personal compromise decision between these two value sets and obtaining a broad SWR curve to cover the entire passband.

Fig. 5



Free-Space E-Plane Patterns: 15-10-Meter 5-Element Array

Table 2 and **Table 3** provide the modeled free-space performance data.

Table 2. 2-element 15-meter Yagi—3-element 10-meter Yagi: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.58	6.36	6.18
Front-to-back ratio dB	11.81	11.96	11.67
Feedpoint Z (R +/- jX Ω)	39.7 – j8.8	51.3 – j5.9	64.0 – j5.2
50-Ω SWR	1.36	1.13	1.30

Table 3. 2-element 15-meter Yagi—3-element 10-meter Yagi: 10-meter performance

Frequency	28.0	28.5	29.0
Free-space Gain dBi	6.77	7.13	7.53
Front-to-back ratio dB	14.06	16.41	16.01
Feedpoint Z (R +/- jX Ω)	40.3 – j2.6	43.9 + j7.9	46.5 + j26.6
50-Ω SWR	1.25	1.24	1.73

Relative to the Moxon-Yagi combination, the 15-meter Yagi section of the array provides slightly more gain, but considerably less by way of a front-to-back ratio. On 10 meters, the 3 active elements provide more gain (by about a half-dB) than the Moxon-Yagi array. As well, the front-to-back ratio is up, but only by about 1 dB. From the standpoint of operation, the differences are to small to make a difference in obtaining successful communications. The choice between 2-band beam designs must rest on other grounds.

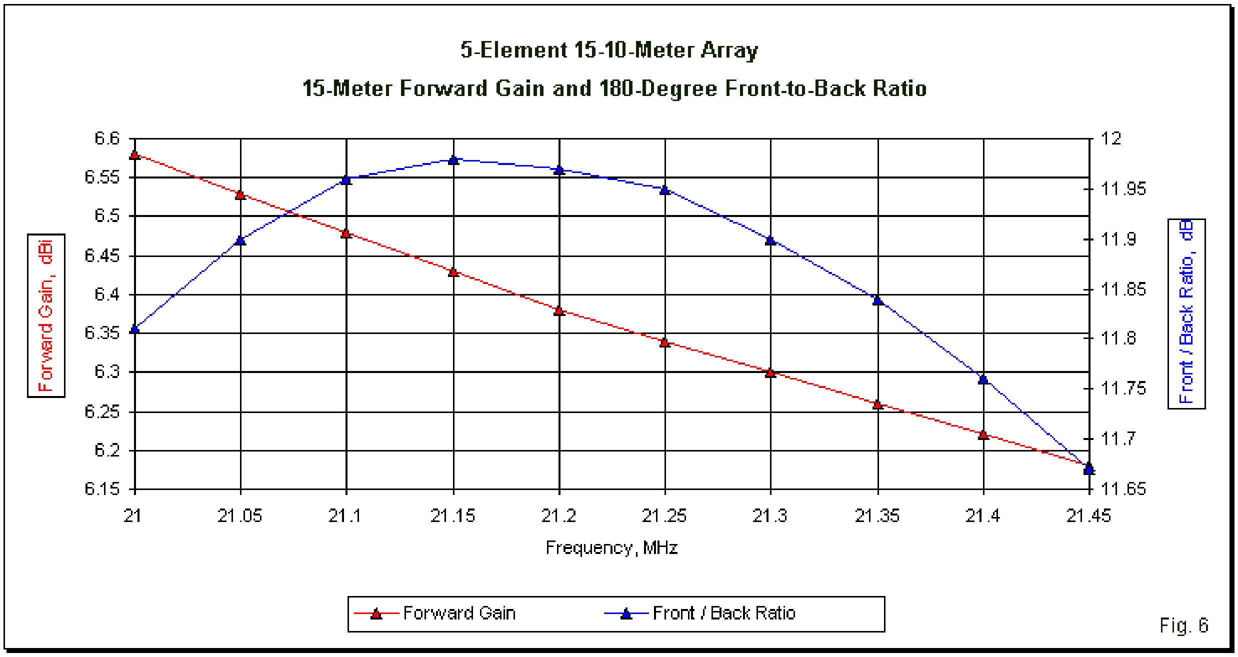


Fig. 6

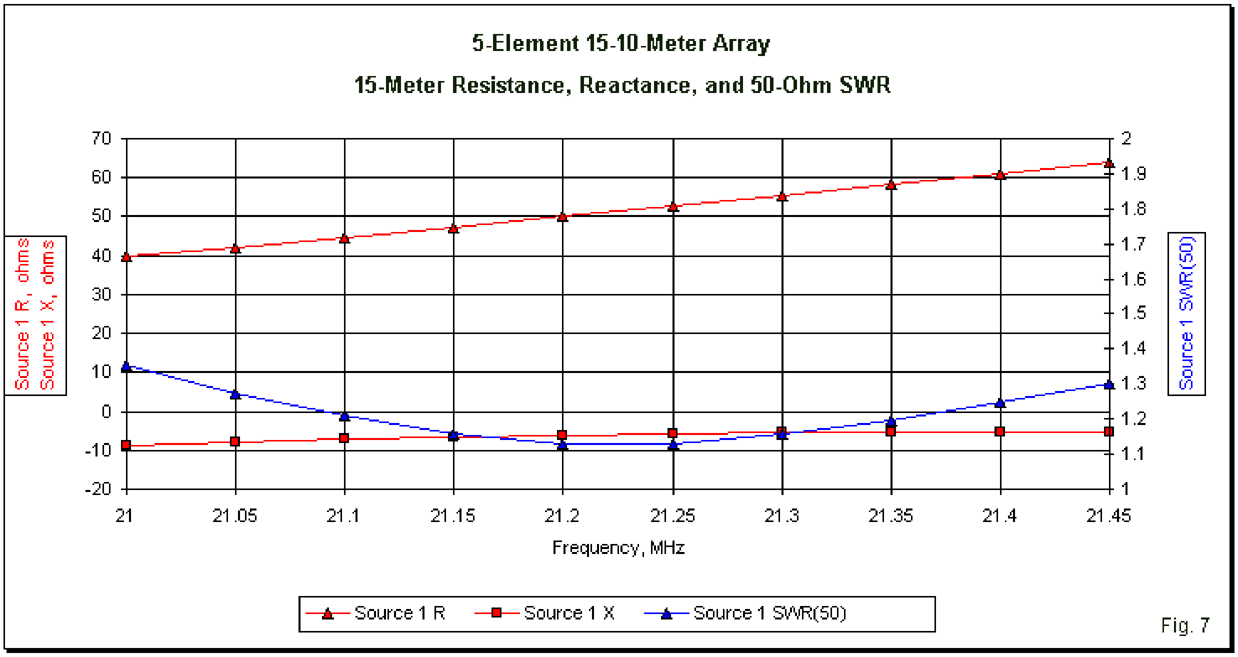


Fig. 7

Fig. 6 and **Fig. 7** provide frequency sweeps for the design models across 15 meters. Although some curves appear to be somewhat steep, that illusion results from the small increments of change used along each Y-axis. The gain changes by only about 0.4 dB across the band, while the front-to-back change is equally small. The relatively tame SWR curve is not directly a function of a low change in feedpoint resistance across the band: that Δ value is about

24 Ω. Rather, the reactance across the band changes by less than 4 Ω and the shallower SWR curve follows.

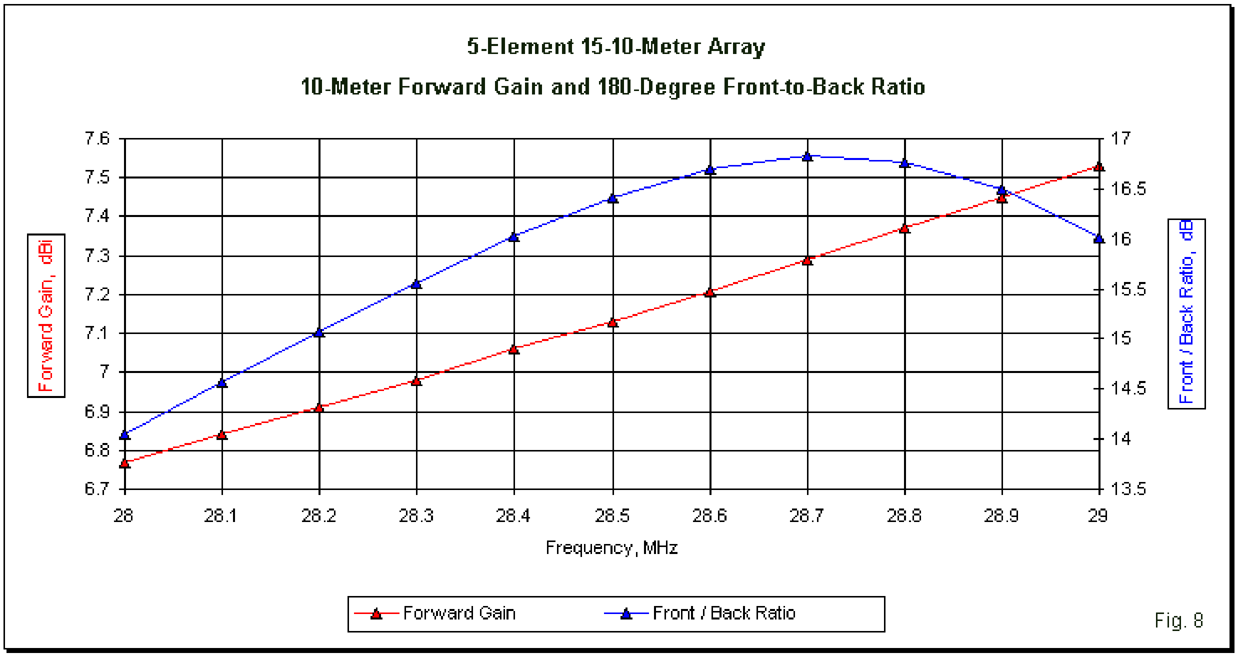


Fig. 8

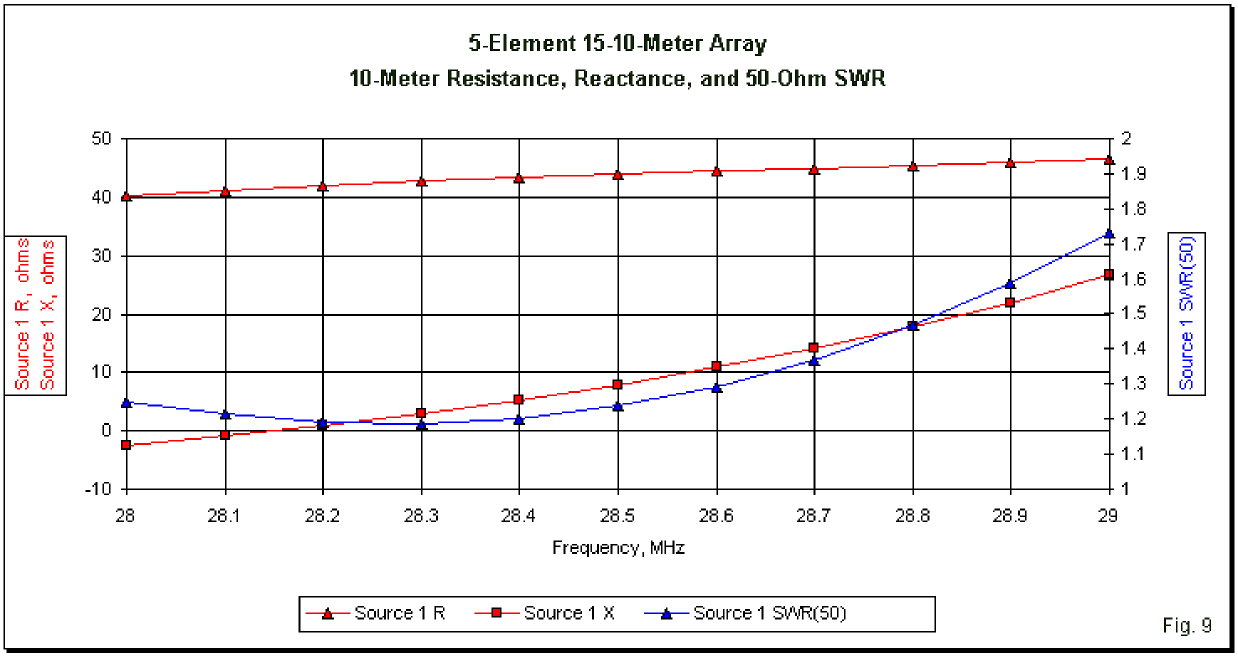


Fig. 9

When we sweep the wider 10-meter band, we instantly notice the reverse slope of the gain curve as a function of having at least one director on that band. See **Fig. 8**. The rise of about 0.75-dB is a function of both the wider passband and the compression of curves that we expect for upper bands on a multi-band array of this design type. The front-to-back ratio changes by a little less than 5 dB across the band, with values that are considered good for a 2-element beam but modest for a 3-element beam. In fact, they are roughly typical of multi-band arrays, few of which achieve a 20-dB front-to-back ratio except as a peak value somewhere within a band.

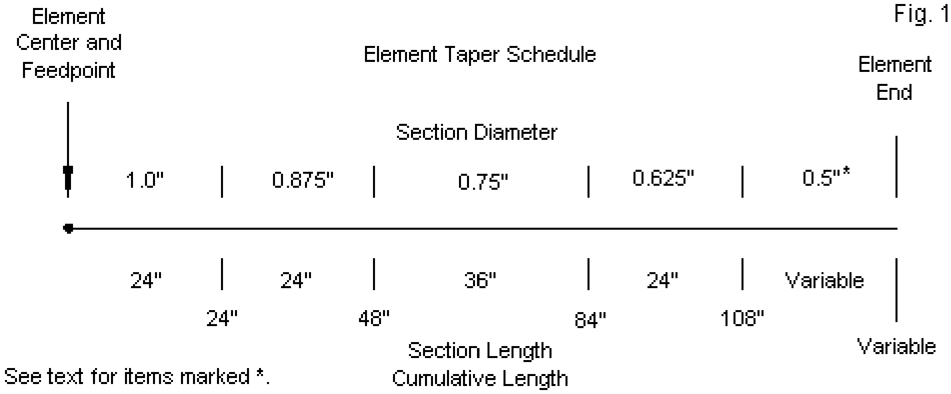
The feedpoint behavior of the 10-meter section shows the reverse trends that we observed in the 15-meter feedpoint values. On 10, the feedpoint resistance is quite stable, changing by only 6 Ω. However, the reactance changes by about 29 Ω, resulting in the curve that appears in **Fig. 9**. Trying to center the curve around 28.5 MHz would yield a lower SWR value at the upper end of the band, but at the cost of either gain or front-to-back performance—or both. Since the present curve shows a value of less than 1.5:1 at 28.8 MHz, I decided to retain the performance rather than seek equal SWR values at both ends of the passband.

The 5-element Yagi-Yagi 2-band array for 15 and 10 meters offers relatively good performance for its size. It does not match the gain numbers shown by the considerably larger and more complex Yagi-Yagi design shown as part of our exploration of beam design. However, that beam used 7 elements on a 19’ boom rather than 5 elements on a 12’ boom. The present design allows some variation in the structure without undue harm to performance. For example, a driver-connection transmission line with a velocity factor of 0.8 creates virtually no change in performance with the other dimensions shown.

A 5-Element Yagi-Yagi Array for 17 and 12 Meters

One of the interesting potentials for the design is the ability to adapt it to the 17- and 12-meter bands almost (but not quite) by scaling everything upward. The first measure of scaling occurs in the element diameter taper schedule for the physically larger array. **Fig. 10** shows the taper schedule used in the design of this array.

Fig. 10



Element Taper Schedule for 17-12-Meter Array

The center of each element uses a 1” diameter tube and progresses down to 0.5”. Once more, there is an exception. The forward-most 12-meter director is not long enough to need the half-inch tip section. The wind-load capability of the elements should be in excess of 75 miles per hour—before ice-load de-rating.

We need not repeat the theory of operation for the 17-12-meter version of the antenna, because it is identical to operation on 15 and 10 meters. On the narrower bands, some of the concerns about rates of change in curves disappear, since over each 100-kHz band, values do not change enough to develop true curves. Therefore, we may proceed directly to the dimensions of the 2-band array, shown in **Table 4**. The same rules for reading **Table** 1 also apply to this table.

Table 4. 2-element 17-meter Yagi—3-element 12-meter Yagi dimensions

17-meter Yagi			12-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	1.0”	24”	Both	1.0”	24”
	0.875	24		0.875	24
	0.75	36		0.75	36
	0.625	24		0.625	24
Ref tip	0.5	169	Ref tip	0.5	119.5
DE tip	0.5	158	Dir 1 tip	0.5	110.5
			Dir 2 tip	0.5	94.5

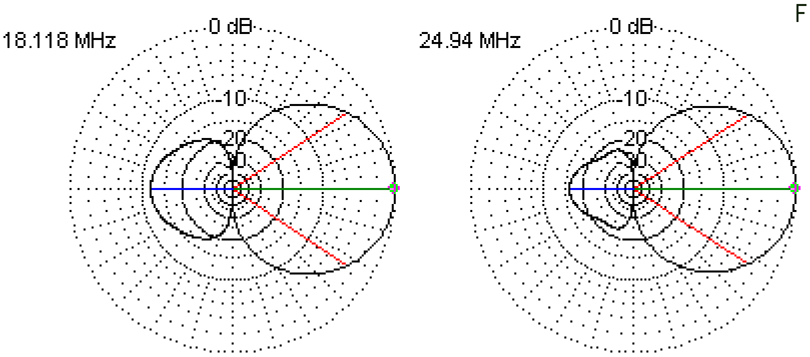
Array Spacing	
17-m ref	0
12-m DE	60.7
17-m DE	87
12-m dir 1	109.1
12-m dir 2	165.6

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 = 50 Ω, VF 1.0
5. Feedpoint: 17-meter DE
6. Boom length: 13’ 10”

The required boom is slightly less than 14’, about the same length as might be required by a 3-element trap beam for the band. However, the elements are each lighter and have less wind resistance with the absence of the bulge created by trap assemblies. The feedpoint connecting line is identical to—although somewhat longer than—the one used in the 15-10-meter array.

We may expect the antenna to yield patterns as clean as those for the smaller version. **Fig. 11** shows free-space E-plane patterns at the center of each band. Because the bands are not wide enough to show any pattern shape changes, we may omit the band-edge patterns. If the upper-band pattern closely resembles the 28.5-MHz pattern in **Fig. 5**, it is no accident. Although the relationship between the two bands in this array is not quite the same as the relationship between 15 and 10 meters, the frequency ratio is close enough not to create a major challenge in bringing the larger array under control on both bands

Fig. 11



Free-Space E-Plane Patterns: 17-12-Meter 5-Element Array

In evaluating the performance of the 5-element antenna on the two narrow bands, we can also dispense with sweep curves. A large set of essentially straight lines tends not to create anything interesting. However, we can tabulate performance numbers for each band. **Table 5** and **Table 6** provide the relevant data.

Table 5. 2-element 17-meter Yagi—3-element 12-meter Yagi: 17-meter performance

Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.50	6.44	6.39	0.11
Front-to-back ratio dB	11.76	11.81	11.83	0.07
Feedpoint Z (R +/- jX Ω)	45.9 – j2.7	49.2 – j1.7	52.6 – j0.8	6.7 + j1.9
50-Ω SWR	1.11	1.04	1.06	

Table 6. 2-element 17-meter Yagi—3-element 12-meter Yagi: 12-meter performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	7.04	7.09	7.13	0.09
Front-to-back ratio dB	15.87	16.09	16.27	0.40
Feedpoint Z (R +/- jX Ω)	46.3 + j7.1	46.7 + j8.6	47.2 + j10.2	0.9 + j3.1
50-Ω SWR	1.18	1.21	1.24	

I have included Δ-values to illustrate just how little that performance changes across 17 and 12 meters, even for an array that some might consider to be narrow-banded. Relative to operating bandwidths, the changes in both gain and front-to-back ratio are roughly proportional to those that we encountered in the wider-band version for 15 and 10 meters. If you compare the 12-meter performance values with those for the earlier antenna, you will see a very small (and operationally insignificant) trade-off of gain for front-to-back ratio in the present design. The 10-meter values should come from the 28.5-MHz values in **Table 3**. The trade was possible by designing the 12-meter section of this array on the upward slope of the SWR curve while still holding the maximum value to less than 1.25:1.

The Δ-values also demonstrate the complete parallel in designs within the entries for the feedpoint resistance and reactance. In both versions of the beam, the lower band showed a larger change in resistance and a smaller change in reactance, while the upper band trends are just the reverse. Although the total change across 17 and 12 meters is small, it is sufficient to reveal the trends.

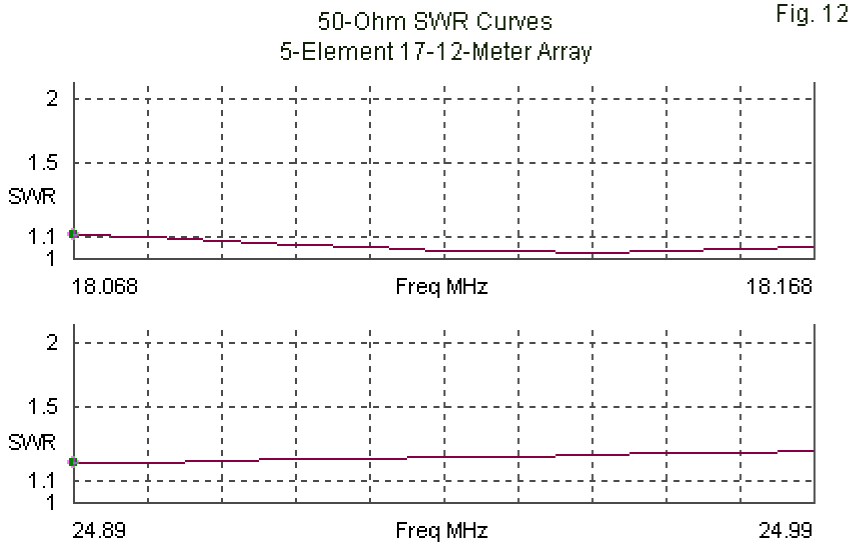


Fig. 12 provides the obligatory 50-Ω SWR sweeps across each band, and both curves are suitably flat. Field adjustment of the array is simplified—relative to the task on 15 and 10

meters—by the fact that a satisfactory impedance value set anywhere within each band will satisfy the need for the entire band.

17 and 12 meters rarely require (or economically justify) large arrays. The lower population on these bands also tends to reduce the level of QRM that is often the chief reason for needing a very high front-to-back ratio. Therefore, an array like the present design may satisfy communications needs on these bands on a single 14' boom.

Conclusion

The 2-band Yagi-Yagi design that we have been examining is an alternative to the Moxon-Yagi design that we explored in the past. The linear elements may prove easier to construct for some builders, although for any given band, the side-to-side dimension will be about 1.4 times the side-to-side dimension of a Moxon rectangle. Both designs are roughly equivalent in performance. As well, both design are adaptable to covering any two upper-HF amateur bands with a skip of one band between the larger and the smaller section. For example, we can set either design to cover 20 and 15 meters as well as to cover 17 and 12 or to cover 15 and 10, (Trying to cover adjacent upper-HF bands in a design can run into some very sensitive dimensions that may complicate someone's efforts to replicate a design.) As you scale up an array such as this one for a lower band, such as 20 meters, do not forget also to scale up the element diameter taper schedule. The requirements for element strength for a given wind load become more stringent as the element grows longer.

We have in past articles reviewed some construction techniques that are applicable to 2-band arrays. As well, we have covered the procedures most likely to result in successful field adjustments to bring a prototype into operation. There is little to add here on those subjects. Moreover, the basic concepts underlying the design of the two variants of the Yagi-Yagi are not new. For example, Optibeam of Germany produces a 4-element beam for use on 12 and 17 meters that operates using essentially the same principles. Indeed, most Optibeam designs use direct driver connections with 50-Ω square connecting transmission lines. The designs that we have reviewed here are not copies of their work. Rather, once the basic design decisions are made—for example, the upper-band driver placement behind the lower-band driver and the use of directly connected drivers—most of the results will reach rough coincidence. I have noted along the way some places where there is room for variation in the designs shown here. On the other hand, there is only so much room for such variations and the final results of two independent designs using the same general techniques will ultimately resemble each other without cloning each other. Perhaps the greatest difference between designs is economic. The commercial beam will cost over $500 plus shipping from Europe. A homebrew version should cost less than $200 including the best stainless steel hardware available. On the other hand, a commercial beam has already undergone full testing and tweaking and should only need assembly according to a complete instruction set. Building your own beam from scratch requires structural as well as electrical decision, some shop equipment and skills, and sufficient experience and test gear to assure operation to specification.

Our goal has been to explore the multi-band beam design process, not to provide a beam for automatic or semi-automatic replication. Therefore, I cannot recommend the construction of these designs or any others that have emerged from the exercises. If you decide to undertake a construction project of this magnitude, be prepared and patient while developing the structure and performing the field adjustments. Even monoband beams will show some differences between NEC models and the final product, although NEC-4 has a very good track record of going from computer to aluminum with minimal variation in the process, at least within the upper

HF region. Multi-band arrays have more sensitive dimensions, especially on the band or bands showing higher-than-monoband rates of performance change within a given passband. Dimensional and structural differences that make no difference at all in a monoband beam may prove significant in a multi-band array.

Since you will need to expend considerable time performing final adjustments to any prototype, you should also feel free to develop your own designs, even if they are simple variations of the designs that we have explored or others that you derive from a study of commercially available antennas. The full challenge of making a beam begins with understanding its operation well enough to set your own design.