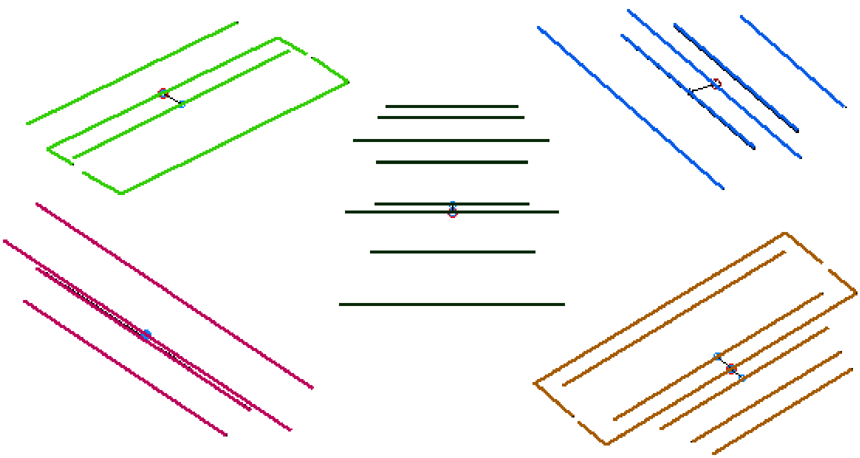
Some Basics of Multi-Band Beam Design



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Dedication

This volume of studies of antennas is dedicated to the memory of Jean, who was my wife, my friend, my supporter, and my colleague. Her patience, understanding, and assistance gave me the confidence to retire early from academic life to undertake full-time the continuing development of my personal web site (http://www.cebik.com). The site is devoted to providing, as best I can, information of use to radio amateurs and others–both beginning and experienced–on various antenna and related topics. This volume grew out of that work–and hence, shows Jean's help at every step.

Preface to Multi-Band Beams

There is among some amateur radio beam designers a special art: the art, since, and craft of designing multi-band parasitic beams. Sometimes the work of an individual, sometimes the work of a team, designing directional antennas that cover more than one amateur band is not as easy as it may seem on the surface. We cannot simply interlace a collection of monoband beams, since all of the off-band elements will be active, at least at a low level, on all bands. The interactions are sufficient to complicate the process of deriving on all bands adequate gain, respectable front-to-back ratios, clean radiation patterns, and an acceptable feedpoint impedance. As we shall discover, maneuvers (such as changing element length or spacing) often bring conflicting results. An increase in gain reduces the front-to-back ratio—or vice versa. Peaking the radiation performance play havoc with the SWR curve for one or more bands. The problems increase almost exponentially with the array boom length and the gain that we try to extract on all bands.

The process of designing multi-band beams has largely hidden beneath a veil of silence. Those who pursue this work very often have a proprietary interest in the designs. Some with a virtually intuitive knack for the process very often cannot clearly articulate what they do so well. So most amateur literature simply passes over the subject or presents a design without much theoretical commentary. We, the outsiders who look in on multi-band beam design, view it as a mystery, as a function of secret optimizing software, as esoteric knowledge to which the average amateur is denied access.

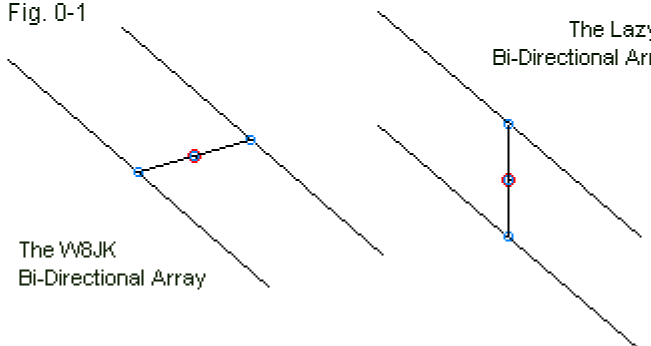
Fortunately, enough information as emerged over the last 20 years that we can begin to make some inroads into the task of designing an effective multi-band beam. Part of the information is subject to at least qualitative codification, although we are far from a clear systematic quantitative analysis. We have learned much about the interactions, at least to a level that makes it possible for someone versed in the use of antenna modeling software to begin designing at least rudimentary multi-band antennas. This volume simply presents what I have managed to learn about the process over the years. I have certainly not learned everything—just enough to get started and to realize the limits of what I know.

What is a Multi-Band Beam?

A *beam* is any directional antenna. In the broadest terms, then, a *multi-band beam* is any antenna that is directional on more than one amateur band. (Of course, we can make multi-band beams for other than amateur radio use, for example, for the old lower- and higher-frequency television broadcast channels.) We shall pare down our subject by first limiting ourselves to horizontal antennas, the type used in the upper HF and the VHF regions of the spectrum.

Our second limitation will be to work only with directional (meaning 1 direction) beams and to set aside bi-directional arrays, such as the two outlined in **Fig. 0-1**. Both arrays are highly competent performers that will provide good results over at least a 2:1 frequency span, but their operation falls outside our concerns in this context. For further information on these arrays, see the first two chapters of *2-Element Horizontal Beams, Volume 1, Phased Arrays* (available from *antenneX*).

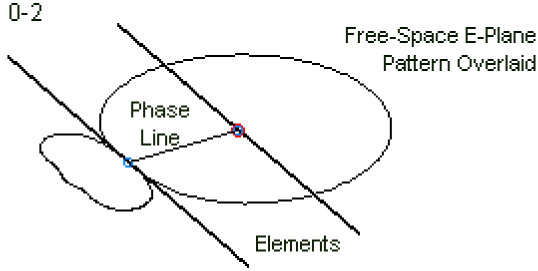
Fig. 0-1



Two Forms of Phased Bi-Directional Arrays

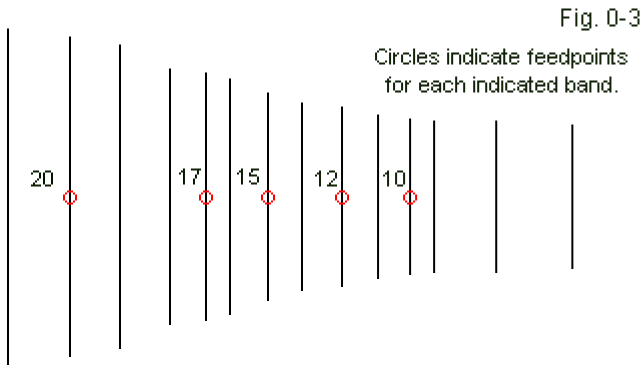
Both arrays use phase lines to establish the desired current magnitude and phase angle on each of the two elements. Phased arrays need not be bi-directional. **Fig. 0-2** shows the outline and an overlaid free-space E-plane pattern of a directional phased array. The line between elements indicates the phase line, while the little circle indicates the main feedpoint for the entire antenna. As the pattern indicates, the small version of a ZL-Special is a highly competent performer. However, we shall be working solely with parasitical arrays, that is, antennas with a single feedpoint per band. They obtain the desired current magnitude and phase on the remaining elements solely by mutual coupling.

Fig. 0-2



A Phased Directional Array

As well, we shall not work with all types of multi-band parasitic arrays. Some well-designed and very competent parasitic arrays use a separate feedpoint for each band. **Fig. 0-3** shows the outline of a very large antenna covering all of the upper HF amateur bands from 20 through 10 meters. Ostensibly, it uses 3 elements on each of the bands, except on 10 meters. On some bands, the next higher-band reflector is the director for the immediate lower band. In the transition from 20 to 17 meters, these are separate elements. However, the beam manages better than 3-element performance on each band because the seemingly inactive elements are actually contributing to the array gain, although in small ways per individual off-band element. We call the phenomenon *forward stagger*, and as the outline suggests, it works when the beam shows a progression of ever shorter elements in the direction of radiation. The rate of shortening cannot be too great, or the activity level forward of the most active elements on a given band will not be active enough to affect the forward gain. As well, the elements require proper spacing for their lengths to material contribute to the array's performance.

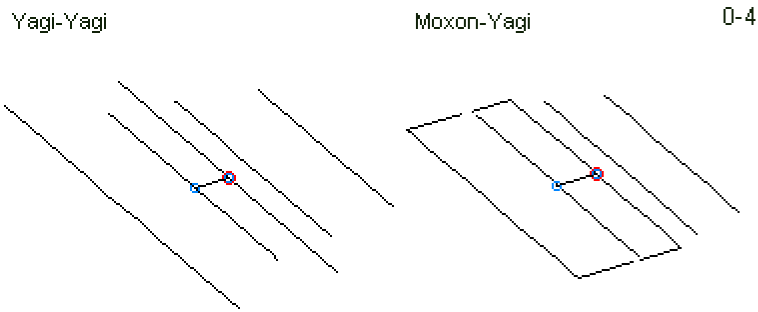


A 5-Band Pure Forward Stagger Beam by ON4ANT
with Separate Feedpoints for Each Band

What rules out these beams from our work is the use of separate feedpoints for each section of the beam. When we think of a multi-band beam, we usually envision interlaced elements with a common feedpoint and a single feedline serving the entire array. We shall focus on these interlaced parasitic antennas.

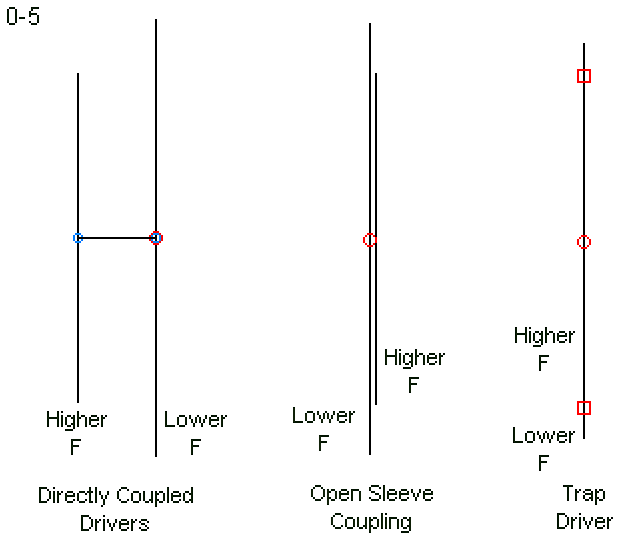
So far, I have not specified that the parasitic antennas interlaced in a multi-band array are Yagis. Indeed, as shown in **Fig. 0-4**, not all of the antennas need to be Yagis. The outline shows two very comparable 2-band beams. The one on the left interlaces a 2-element Yagi for the lower band with a 3-element Yagi for the upper band (ignoring forward stagger functions for the moment). The classic Yagi-Uda parasitic array derives the necessary current magnitude and phase angle on the non-driven elements via coupling between the parallel elements, sometimes called inductive coupling.

The array on the right uses a Yagi arrangement for the upper band, but employs a Moxon rectangle for the lower frequency. The Moxon rectangle is a parasitic beam with a driver and a reflector element, but it uses two forms of coupling. One form is the standard Yagi-type coupling between parallel sections of the elements. The other form is the coupling between the element tails across the gap between them, sometimes called capacitive coupling. This second form of coupling modifies the operating characteristics of the two elements relative to the performance that we derive from the correlative Yagi elements in the left sketch. Some of our subject antennas will use the Moxon rectangle for the lower frequency section, if only to save some space in the yard. The Moxon is a parasitic array, but not a true Yagi.



Outlines of Two Different 2-Band Parasitic Beams

The two sample outlines in **Fig. 0-4** shows upper- and lower-frequency driver pairs connected by a line. In fact, there are three generally used forms of coupling together the drivers for the bands covered so that the array as a whole requires only 1 feedline—usually a 50-Ω coaxial cable. **Fig. 0-5** shows the three systems, omitting all but the driver elements. On the left, we find the direct coupling technique. The main feedline connects to the element with the small circle. The other driver element uses a short length of parallel feedline for its connection to the feedline at the main element. On each band, the junction of the connecting line and the directly fed element shows an acceptable impedance. As well the off-band impedance will be very high so that the lower impedance of the active branch dominates the current distribution. Since the connecting line is a transmission line that can also transform the load impedance presented by the driver at its end, the driver may require significant adjustment relative to its place in a comparable monoband beam in order to obtain good beam functions. Because the shorter driver may be affected significantly by close coupling to the longer driver, we may encounter a further influence requiring adjustment of its position and length. However, there is no rule that says the line must run from the longer driver to the shorter. In some designs, we may find occasion to reverse the system.



Three Common Types of Multi-Band Beam Feeding

All three driver systems are for beams whose main direction of radiation is to the right. Again, there are no rules against placing the shorter, higher-frequency driver behind the longer, lower-frequency driver relative to the radiation direction. Placement often is a function of deriving the desired performance from a given limit to the boom length.

The middle system uses no physical connection between the two driver elements. We provide a direct feed to the longer, lower-frequency driver. The shorter driver derives its energy from its close spacing to the other driver. With the proper selection of spacing and element length, the shorter driver dominates at the higher frequency, and the main feedpoint shows an acceptable impedance on the band to which the longer driver is not tuned. One name used for this driving system—which has counterparts in vertical antennas—is *open-sleeve coupling*. The effect is not limited to multi-band driver elements. In some monoband Yagi designs, such as the optimized wide-band array (OWA) type, we find that the fed driver dominates performance at the low end of a band, while at the upper end of the band, a closely spaced and shorter first director actually becomes a form of secondary driver.

The final common feed system for multi-band interlaced parasitic arrays is the trap element. The sketch on the right in **Fig. 0-5** indicates the trap placement by the use of small squares. A trap is a parallel tuned circuit tuned at or just below the upper-frequency band. It presents a high impedance on the upper band, effectively cutting off the element so that it can function as a normal element on those frequencies. Note that the distance between the traps in the sketch is just about the same as the length of the upper-band drivers for the other two systems. The overall length of the element is shorter than the lower-band drivers in the other system, because on the lower frequency, the residual inductance of the non-resonant parallel tuned circuit loads the element. The effect is somewhat, but not exactly, like the effect of adding a loading coil to the element. Despite the shortening, the lower-band driver—using the element as a whole—becomes the lower band driver. A properly designed trap driver can present close to the same feedpoint impedance on each of the bands that it serves.

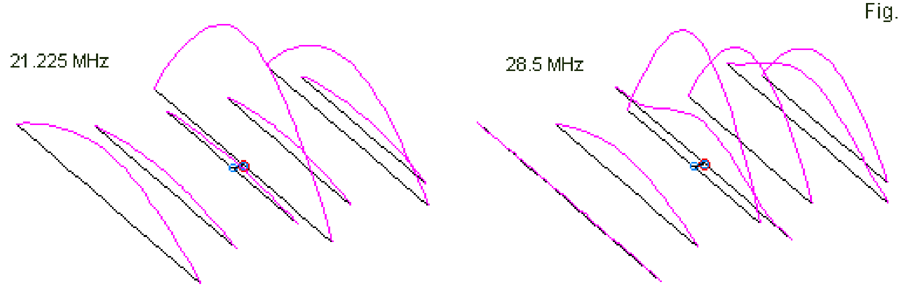
We shall have occasion to discuss each of these driver system in greater detail in the proper places. However, so consistency, we shall major on the use of directly connected drivers in the greater part of our examination of interlaced multi-band parasitic beams.

A Plan of Attack

The notes in this volume do not form a theoretical treatise on multi-band parasitic array design. Rather, we shall be quite practical, if for no other reason than the fact that so few equations exist that will do the amateur designer any good. We shall not even use any of those ubiquitous and quite misleading cutting formulas. Nor shall we engage any computer optimizer programs, since they will not improve our understanding of what goes on in multi-band beams. Instead, we shall set down some general principles and cautions and then go to work applying them on some interesting examples.

Chapter 1 attempts to lay out some of the principles that we may use to guide the design of at least basic 2-band beams. We shall encounter terms such as *forward stagger* and *control element*. These terms indicate the process of placing elements to maximize their off-band enhancement of performance and to control deleterious affects of off-band elements. We shall also learn why virtually every multi-band beam involves compromises among the performance categories in which we have the most interest, such as forward gain, front-to-back ratio, and operating bandwidth.

Fig. 0-6

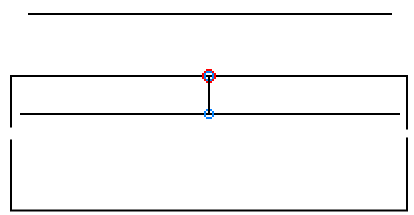


Current Distribution on a 2-Band Beam

We shall also lean how to develop reasonable expectations from multi-band beams and to use—as sampled in **Fig. 0-6**—current distribution among array elements as an indicator of performance. In the course of these introductory notes, we shall also examine some of the modeling and construction challenges that go into these antennas.

With Chapter 2, we embark on the only way that I know to show the meaning of the initial principles: designing some sample 2-band beams. We shall limit ourselves to 2-band arrays in order to keep the design principles as clear as possible. The initial discussion will cover a Moxon-Yagi array for 15 and 10 meters, sketched in **Fig. 0-7**. In the course of our examination, we shall explore alternatives to the directly coupled feedpoints and their implications for element dimensions and array performance.

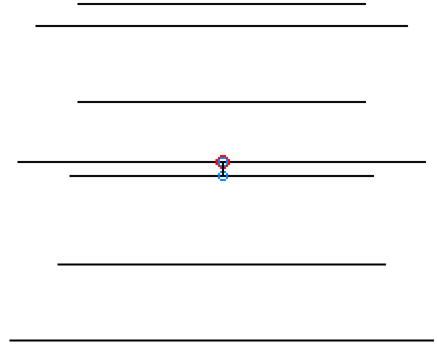
Fig. 0-7



Two-Band Moxon-Yagi

Next, we shall move to a more complex design involving 15- and 10-meter Yagis. The design will use at least three elements on each band, with a fourth for the upper band. **Fig. 0-8** outlines the most basic form of the array. Like to simpler Moxon-Yagi, it uses directly coupled drivers.

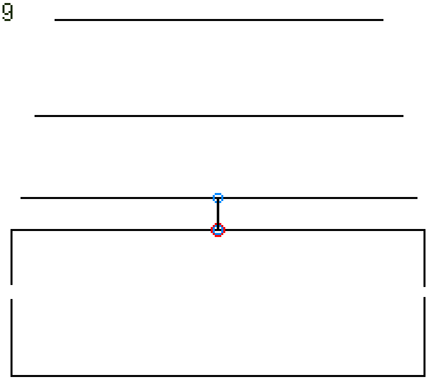
Fig. 0-8



Two-Band Yagi-Yagi

The growth in boom length and the number of elements per band does enhance performance. However, the important lesson will be to discover why we cannot likely attain full monoband performance on each band from the combined array. The term *compromise* will continue to increase its meaningfulness.

Fig. 0-9

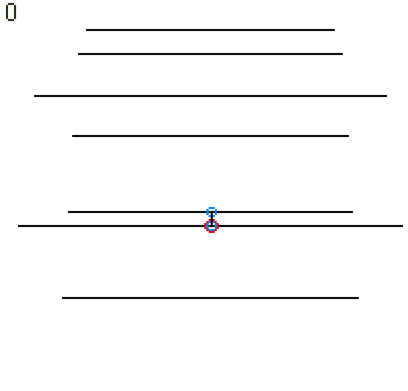


Alternative 2-Band Moxon-Yagi

Fig. 0-9 suggests that in Chapter 4 we shall regress to simpler designs. However, the sketch of an alternative Moxon-Yagi suggests that we need to look at further alternatives in multi-band design. The upper-band driver may be either fore or aft of the lower-band driver. As well, we may use either one or two directors in the upper-band section. Both moves have implications both for the size of the array and for its performance, and we need to explore these alternatives before settling on the best design for a given application.

Similar alternatives apply to the larger Yagi-Yagi design, as suggested in the sample sketch in **Fig. 0-10**. In Chapter 5, we shall explore the matrix of alternative driver placement and the addition of an extra director to discover two sorts of information. The first type of data is internal to the Yagi-Yagi design: what performance trends emerge from each alternative design on each band? The second sort of information concerns whether the Yagi-Yagi trends parallel those of the Moxon-Yagi design and thus become general principles or whether some trends are unique to each type of array. A continuing question will have a place in all of these initial discussions: where shall we place the boom-to-mast assembly—and with what affect?

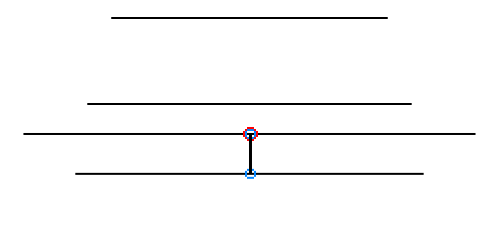
Fig. 0-10



Alternative 2-Band Yagi-Yagi

Some builders—even in simple 2-band arrays—do not prefer to work with the bent-element configuration of the Moxon rectangle. Linear elements, such as those shown in **Fig. 0-11** are preferable for their simpler construction.

Fig. 0-11

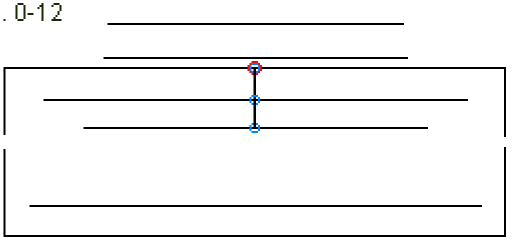


Replacing a Moxon Section with a Yagi Section

In Chapter 6, we shall examine the ease or difficulty in replacing the Moxon elements with standard driver-reflector Yagi elements. We shall look both at the performance implications of the revision and at the affect of the revision on total beam size. In fact, the beam design will turn out to be somewhat simple to implement—at this stage of our journey. Therefore, we shall create a version for our standard test bands of 15 and 10 meters and a second version for the narrower 17- and 12-meter bands, where simpler beams are more commonly used.

I could not engage in this safari into multi-band beams without exploring the properties of at least one 3-band beam for 20, 15, and 10 meters. As shown in **Fig. 0-12**, the design will combine a 20-meter Moxon rectangle with Yagi elements for the upper two bands. However, the idea of a single design—without increasing the level of array complexity—gives was to at least 4 different versions, depending upon the placement of the 10-meter driver and on which element we use for the connection with the main feedline. We shall also explore variations on the characteristic impedance of the line that directly connects the drivers. In virtually all forays into multi-band design, we shall discover that there is always more than one way to achieve a desired general goal. The design decisions then become a matter of giving weight to each factor that goes into a final pre-building decision.

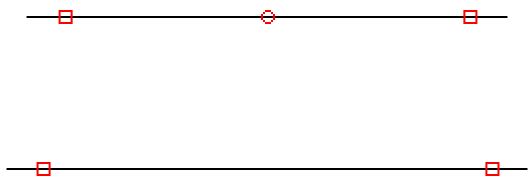
Fig. 0-12



A 3-Band Moxon-Yagi-Yagi

The chapters up to this point have focused on using sample multi-band beam designs to develop a sensitivity to the factors that go into interlacing elements to form a beam having the best possible operating characteristics on each of the selected bands. I know of no other way than this one, developed through many design exercises, of embodying the general principles shown in broad strokes in the first chapter. However, we have neglected some alternative forms of multi-band beam creation along the way.

Fig. 0-13

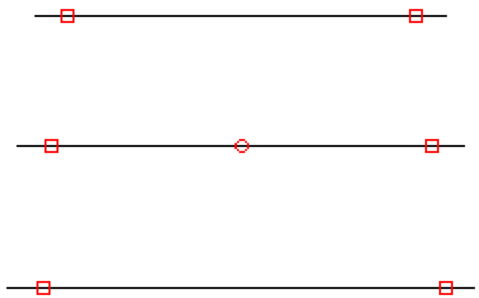


2-Band 2-Element Trap Beam

For example, the use of trap elements has been a large part of the history of multi-band beams. At the simplest level, we may take two elements, such as those sketched in **Fig. 0-13**, and design a 2-band beam with some ease. We shall look at the steps required to design a trap driver-reflector Yagi for 17 and 12 meters so that we obtain the best possible performance on both bands, relative to monoband Yagis of the same general design. Part of our effort will be to understand what traps do, why they are not lossy in the upper of the two bands, and the loss sources on the lower of the two bands. The last question will be especially significant due to some current hype that would automatically equate the expressions *trap* and *lossy trap*. We shall discover that the use of traps is not lossy on some bands and that the losses from trap use are not wholly confined to the resistive losses in the trap itself.

We rarely find traps for any band included in more than three elements of a multi-band array. There are reasons that go well beyond the trap itself for this limitation. In Chapter 9, we shall delve into the design of a 2-band 3-element Yagi for 17 and 12 meters to discover some of those reasons. **Fig. 0-14** outlines the final product of our efforts, but does not reveal from its shape the requisite design factors that both dictate the dimensions of the array and determine a significantly large differential in the performance on the two bands. 3-element Yagi design considerations—apart from the use of traps—will go a long way toward improving our understanding the design challenge that faces anyone planning a trap Yagi with more than 2 elements per band.

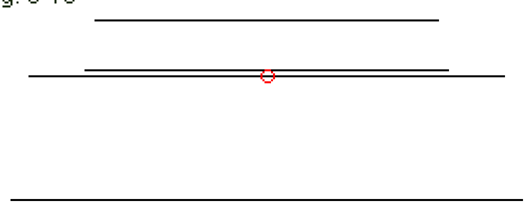
Fig. 0-14



2-Band 3-Element Trap Beam

Chapter 10 will be the final leg of our journey through the rudiments of multi-band beam design. In this chapter, we shall explore the nature and use of sleeve-coupled drivers and eventually wind up designing a 2-band beam for 17 and 12 meters with the general shape shown in **Fig. 0-15**. Note that there is no physical connection between the two very closely spaced driver elements in this combination of a driver-reflector and a driver-director design.

Fig. 0-15



2-Band Yagi-Yagi: Sleeve Coupling

Along the way we shall explore a bit of the history of the *sleeve* nomenclature and its multiple uses. For example, we shall use sleeve coupling to widen the operating bandwidth in all performance categories to produce a short-boom Yagi that covers all of 10 meters from 28.0 to 29.7 MHz with the performance we expect of a single-driver Yagi for only the first MHz of the band. We shall also examine some applications for which guidance equations provide little assistance, such as combining 17- and 12-meter arrays with different feedpoint impedance and different element diameters.

When we are done, we shall only have scratched the surface of all that the design of multi-band arrays may involve. The construction techniques suggested are useful only for beams laid out on a linear plane; the samples employ only about 1/3 of the elements of truly complex array, and most of the beams cover only 2 bands (with one exception, a tri-band model). See **Fig. 0-16** for a sample of what a truly complex multi-band array might become.

Fig. 0-16

The sample is a photograph of an Optibeam OB16-5: a 5-band 16-element Yagi for the upper HF region. Although we count this as 16 elements linearly along the boom, note that several parasitic elements are multiples, with elements for three bands stacked vertically. However, before we can reach the level of designing a beam so complex, we must master a number of fundamentals.

Many of the basic properties of interlaced elements presently only submit to qualitative description. Long experience that includes many frustrating and futile design exercises along with a number of successful ones remains the key to mastering the design of multi-band beams. At most, these notes are a start in the right direction.

These notes include in a separate directory the EZNEC and standard ASCII NEC files for the main beams discussed. The number per chapter is not great, since I did not include the frustrating failures. I have separated the models by chapter for easy identification. I recommend that you download them onto a hard drive to facilitate using them and saving your own improvements and modifications. NEC-2 with Leeson corrections is adequate to replicate the results for designs that use only linear elements. However, you may need NEC-4 to handle the Moxon-Yagi combinations. Alternatively, use the .NEC format files and import them into Antenna Model to handle the models within a MININEC framework.

Part I: Designing Multi-Band Parasitic Beams
1. General Design Considerations

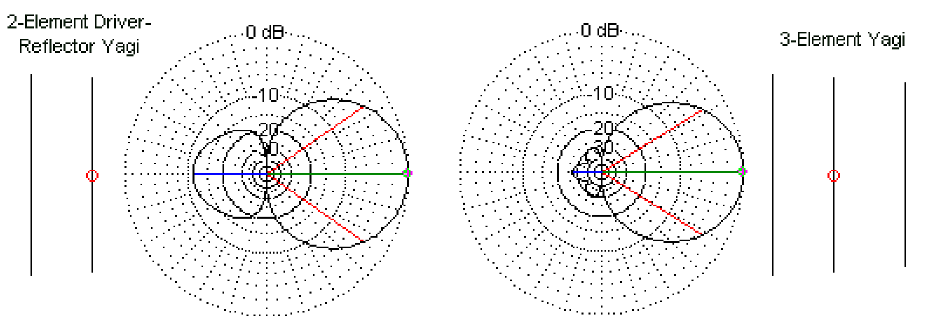
The design of a multi-band parasitic beam displays artistry, science, and craftsmanship that should engender admiration of the designers, whether a beam emerges from a team effort or from the labors of an individual. Modern designs have set aide traps in favor of larger collections of individual elements. We shall not here debate the relative merits of one design over another. Rather, these notes will try to encapsulate some of the considerations that go into effective multi-band beam design. We shall focus on design factors affecting beams with linear elements, since multi-band quad design raises quite different versions of the critical factors involved.

Too many adventuresome novices in the antenna arena try to slap together two monoband beams, interlacing them on the same boom. Then they wonder why neither beam performs as well as it did when on its dedicated boom. The task of creating a multi-band beam, especially one using a common feedpoint for all bands covered, is far different from just interlacing a set of elements. It requires an understanding of the consequences of placing elements for different bands in relatively close proximity. Even with that understanding, the development of an adequate design may still require considerable trial and error. Once, all of the adjustments to element length and position required the manipulation of physical elements on a range. Today, 95% of the adjustments occur using antenna modeling software, with the final 5% performed on the actual prototype to account for construction variables that models do not take into account. Whatever the savings in labor that computer modeling accrue, successful new designs do not emerge overnight.

Let's divide these notes into two efforts. In this section, we shall examine the background necessary for successful design of a relatively simple 2-band parasitic beam. There will be nothing completely new in these notes, but the compilation may be useful to those just beginning to give vent to the urge to design one's own multi-band beam. In parts 2, 3, and 4, we shall explore two different types of beams that cover 15 and 10 meters as examples of the principles in action. No part will cover exhaustively every option and possibility, but the points that we do cover will underlie most multi-band beams. You may have already noted that I have not yet used the term *Yagi* in this introduction. The void is intentional, since one of the examples in Part 2 will make use of a Moxon rectangle for one band. That type of antenna is a parasitic beam, but not a true Yagi.

Expectations

The first step in multi-band beam design consists of understanding monoband beam designs well enough to have reasonable expectations of the final product. The most common monoband parasitic beams used as the building blocks of a multi-band beam are the driver-reflector 2-element Yagi and the 3-element Yagi. These beams bring with them very different performance expectations. The outlines and patterns in **Fig. 1-1** only sample some of the differences.



Free-Space E-Plane Patterns: Typical Monoband Yagis

Fig. 1-1

One reason for use a driver and reflector in a 2-element array is that we achieve a greater operating bandwidth than we can obtain from a driver-director model. We may be able to design a driver-director Yagi with up to a full dB more gain and 5-8-dB higher front-to-back ratio, but that peak performance might cover only about ¼ to 1/3 of one of the wider upper HF bands. The other price that we pay for the added gain is a very low feedpoint impedance. Such designs are better suited to the narrower 30-, 17-, and 12-meter bands. In contrast, we can construct a wide-band driver-reflector 2-element Yagi with a 50-Ohm impedance and cover all of the first MHz of 10 meters with relatively equal gain and front-to-back ratio. However, the gain and front-to-back numbers will be modest, as shown by the curves for a sample version of the 2-element antenna in **Fig. 1-2**.

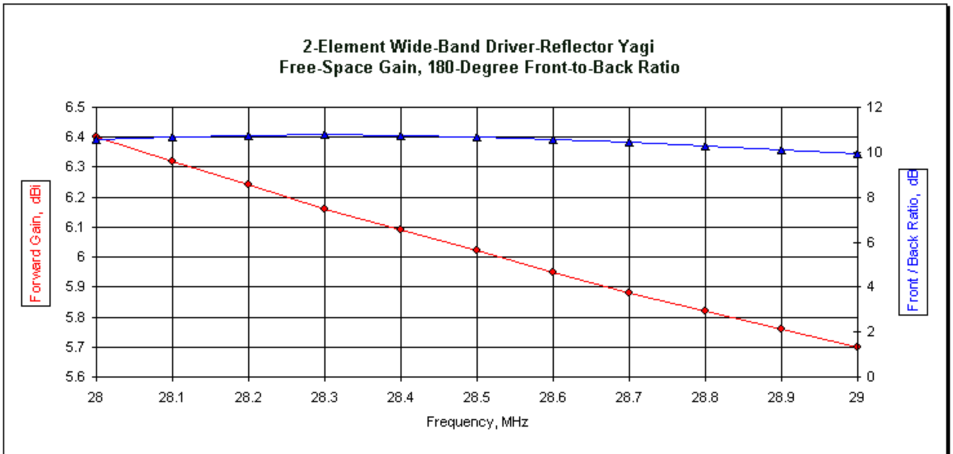


Fig. 1-2

Like all driver-reflector 2-element arrays, the Yagi shows a declining gain with increasing frequency. The front-to-back ratio is almost constant in this relatively wide-spaced version (about 0.15-λ). The ratio will increase if we close the spacing and reduce the feedpoint impedance. At about 0.125-λ spacing, the beam would have about 1-2-dB added front-to-back ratio, but the gain would not increase significantly. Despite these modest figures, the driver-reflector 2-element Yagi is highly serviceable.

Despite the fact that this sample does not place the minimum 50-Ω SWR at mid-band, the value rises only to about 1.6:1 at the upper end of the band, as shown in **Fig. 1-3**. The rates of change of both the feedpoint resistance and reactance are close to the same and quite modest. Therefore, the design is relatively uncritical of small construction variables.

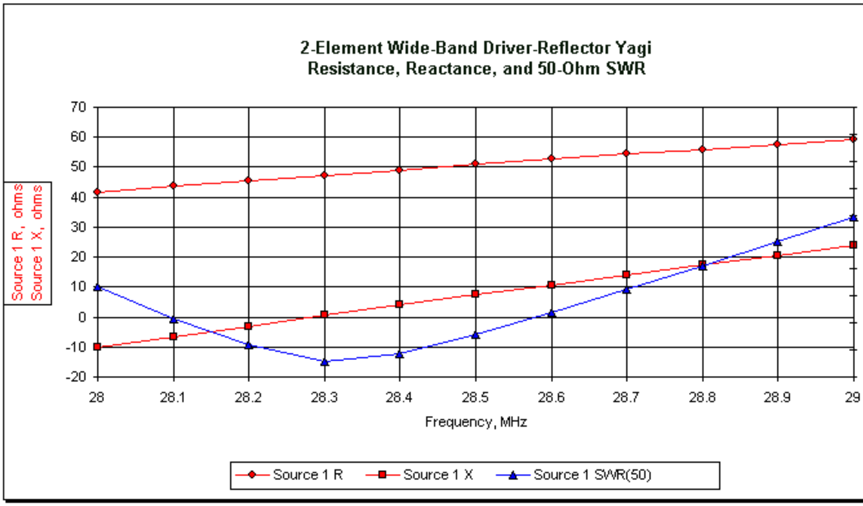


Fig. 1-3

A three element Yagi with both a reflector and a director has quite different characteristics. The presence of a director is the chief source of the differences. Not only does the director improve forward gain, but it also is largely responsible for the improved front-to-back figure, as evidenced in the initial pattern for this arrangement. Some arrays with multiple directors have dispensed with the reflector altogether with only a small loss of performance. The reflector length and spacing from the driver tends to set the feedpoint impedance and to broaden the operating bandwidth, especially at the lower end of the range. Most well designed 3-element Yagis will have free-space E-plane patterns like the sample, although the numbers that we attach to the patterns cover a very wide range.

If we are willing to accept a feedpoint impedance between 20 and 25 Ω, then the boom length will largely determine the gain. A total boom length of less than 0.25-λ (about 8’ on 10 meters) will yield a design frequency gain of just over 7 dBi in free space. As the boom length approaches 0.35-λ (about 12’ on 10 meters) the gain increases to about 8 dBi in free space. For either length and lengths in between, we can so structure the elements to achieve about 20 dB front-to-back ratio and have that figure hold over the first MHz of 10 meters and easily over the other wide upper HF bands.

If we desire a feedpoint impedance closer to 50 Ω, we must rearrange the elements, using a much wider driver-to-reflector spacing. For a boom length close to 0.35-λ, the array loses about 1 dB of gain relative to the lower impedance version of the same length, but the beam requires no matching network for connection to a 50-Ω source. The following curves in **Fig. 1-4** show the basic performance of the wide-band version of the 3-element Yagi.

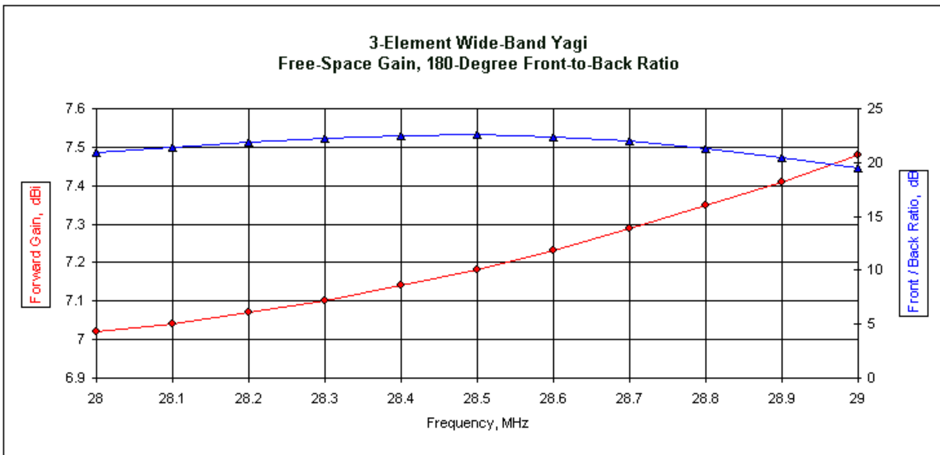


Fig. 1-4

As with any parasitic array with a director, the sample 3-element Yagi shows a rising gain values as the operating frequency increases. The front-to-back ratio is stable across the entire first MHz of 10 meters, dipping just below the 20-dB standard at the upper passband edge. Equally stable are the impedance and SWR curves. With a well-centered SWR curve (see **Fig. 1-5**), the maximum value at the band edges is only about 1.4:1, even though the resistive component is slightly under 50 Ω.

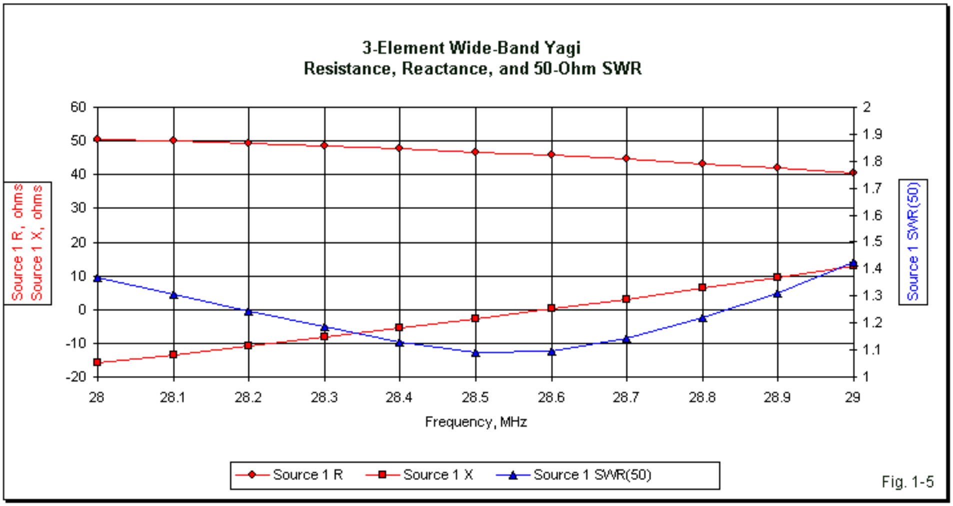


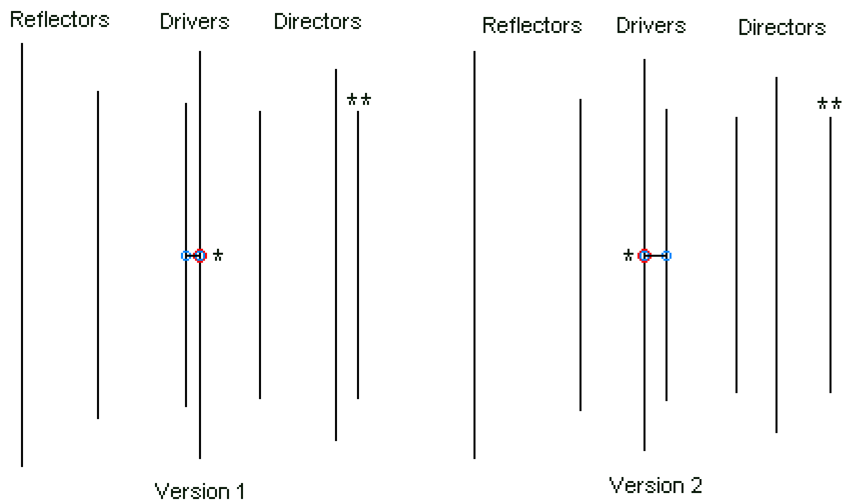
Fig. 1-5

The behavior of the wide-band 3-element Yagi with a wide space between the driver and the reflector suits the needs of a larger multi-band Yagi system. We often see such Yagis as the 20-meter foundation for the multi-band array. A few designs shrink the driver-to-reflector spacing to save boom length, but for a direct 50-Ω connection, the impedance of the raw 3-element Yagi rarely drops to 40 Ω.

This review of basic monoband beam performance provides us with a set of standards. When we incorporate such designs into a multi-band beam, we tend to expect a drop in performance on a given band relative to a monoband beam. This expectation does not always occur. Some facets of multi-band Yagi design can actually improve performance in one or another category, while others prove detrimental. Obviously, one fundamental principle of multi-band Yagi design is to maximize the improvements and minimize the detriments. However, learning how to do these two jobs requires that we understand what happens when we start combining elements for different bands.

Some Multi-Band Fundamentals

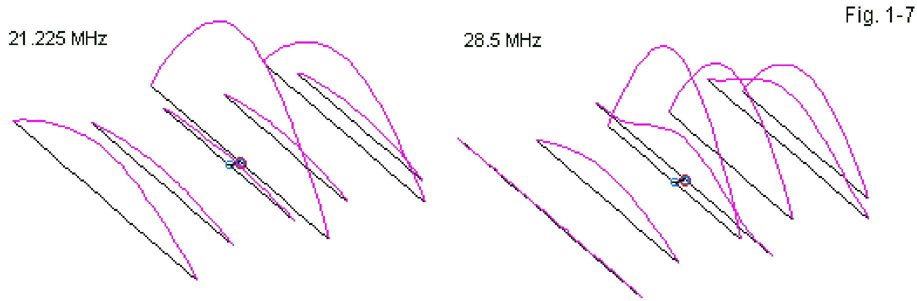
There is no single way to create a multi-band Yagi. **Fig. 1-6** shows two variations on a single theme: 3 elements for 15 meters and 4 elements for 10 meters.



Some Basic Multi-Band Parasitic Beam Considerations

Fig. 1-6

The design on the left places the 10-meter or higher-frequency driver behind or on the reflector side of the 15-meter or lower frequency driver. The design on the right reverses the process. Either system has been made to work. More significant initially is the fact that the lower frequency antenna shows the proportions suited to a wide-band 3-element Yagi. However, the elements for the high-frequency Yagi have quite different spacing proportions. The differences result from mutual coupling among the elements. The seemingly inactive elements for the band that is not in use are in fact quite active, even if at lower activity levels. If we use Version 1 of the multi-band Yagi outlines, we obtain different patterns of current magnitude on the various elements as we move from 15 meter to 10 meters and back again. See **Fig. 1-7**. The relative current magnitude values are indicators of the mutual coupling between elements, not only on the same band, but also on both bands.



Relative Current Magnitudes on the Elements of a Dual-Band Yagi at Different Frequencies

On 15 meters or the lowest band covered by the array, we may easily identify the current magnitudes associated with the 15-meter elements. The 10-meter reflector and directors show some activity, but at a low level. The activity is enough to require slight readjustments to the element lengths and spacing values on the lower band, but the changes are normally small. Hence, in most multi-band Yagi design exercises, we tend to freeze the low-band dimensions first.

When we set the higher-band elements in place, we obtain a very different situation. Although the low-band reflector is relatively inert, the low-band driver and director are very active. For both elements, note the change in the slope of the curve for the current toward the element ends. The two elements play a role in the performance on the upper band, but their greater length tends to push the performance curve into the lower portion of the upper band. Element placement and length can overcome this effect to a major degree, but the effects may limit the operating passband on the high frequencies.

The high activity of the 15-meter director also explains why most multi-band

Yagis have a high-band director forward of the forward-most low-band director, as noted in the initial sketches by the double star. The added director is not in place to increase gain so much as it serves to restore control of high-band performance to the high-band element set as a whole. In some highly complex multi-band arrays, we may find a high-band director on each side of and fairly close to a low band director that can disturb the gain or impedance curves for the antenna. In many tri-band beams, the forward-most directors for 10 meter and for 20 meters seem to need the same location. Under these conditions, a designer might introduce 10-meter traps to reduce the total element count.

The activity of the elements for the band that is not in use can affect performance. Rightly used, we may enhance performance (sometimes calling this “forward stagger”). For example, the very low level activity on the 10-meter elements while 15 meters is in use can increase gain on the lower band beyond our monoband expectations for a wide-band 3-element Yagi. On the upper band, we rarely obtain all of the performance that we might expect from a 4-element monoband Yagi. However, we may show some increase above the values for a 3-element Yagi. At the same time, the intrusive mutual coupling that creates relatively high activity on the higher band has additional effects. First, it tends to make the rate of gain change across the band greater than for a monoband beam. This factor tends to make the placement and length of the upper-band elements somewhat more finicky. Very small element changes (as little as 0.5” on 10 meters) may create significant performance changes. For example, a half-inch placement change might make the difference between SWR coverage to 29.0 MHz and only 28.8 MHz, while altering the front-to-back ratio by as much as 2 dB. Murphy’s law dictates that the improvement in one parameter results in a decay of the other.

Second, high activity on all elements while using the upper band may change the shape of the rearward lobes. The 15-meter director, for instance, may act to some degree like a reflector on 10 meters. The added outer director restores the forward gain, but it does not prevent an enlargement of the rearward sidelobes at some frequencies. Third, the activity of the 15-meter elements on 10 meters can create considerable change in the feedpoint impedance on the higher band.

The search for a set of element lengths and spacing values for the higher-band portion of the beam may sometimes require a revision of the lower band section to make room for elements or to change the mutual coupling between higher-band and lower-band elements. The changes may move the operating conditions of the lower-frequency portion from their most optimal monoband configuration. However, basic interactions have already modified the performance. Therefore, the goal is no longer to replicate monoband performance. Rather, the aim is for a set of operating conditions across the lower band that will be acceptable and that will allow equally acceptable performance of the upper-band elements. What counts as acceptable in the early 21st century tends to be considerably superior to performance levels of the 1970s and 1980s. Despite the efficiencies offered by computer modeling, the search for the final element settings remains a patient undertaking.

Feedpoint impedances can be a topic all unto itself. Some earlier trap-based tri-banders used network matching on 20 meters with element adjustments to arrive at adequate feedpoint impedances on higher bands. More recent trapless arrays have used one of two types of feedpoint system, both aimed at a direct connection to a 50-Ω source. One system, sometimes called open-sleeve coupling, makes a direct connection only to the driver element for the lowest band. It relies on tight mutual coupling between the fed or master driver and one or more slaved drivers for high frequency ranges. By a judicious selection of driver spacing and the length of the slaved driver, the master driver will show a 50-Ω impedance at the higher frequency, and the slaved driver will exhibit a current magnitude curve that is identical to one for a monoband driver at the same frequency. However, the position of the slaved driver relative to the array of elements will normally show a significant phase difference relative to the current at the source. Since all elements of the array will show a similar phase shift, the array operates normally. The significance of the phase shift lies in necessary steps the user must take if trying to stack beams of different types.

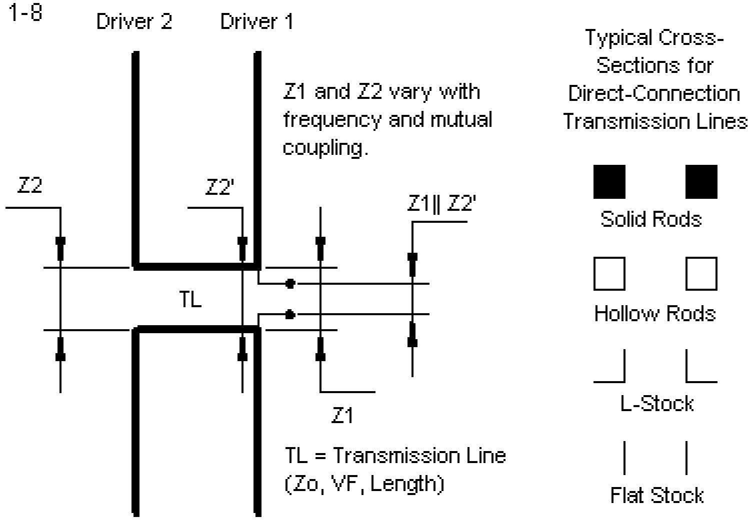
The second and more common feed system consists of making a direct connection between the low-band and the high-band drivers. The initial sketch of Version 1 and Version 2 of a 15-10-meter array placed a star at the feedpoints. In both cases, the direct connection to the source or feedline used the lower-frequency driver. A short parallel line connected the higher-frequency driver. Some designs reverse the connection point, running the feedline to the higher-frequency driver. It is all a matter of arriving at the correct impedance at the main feedpoint within each operating band.

Directly connected feedpoints are partially dependent upon mutual coupling between driver elements. Because directly connected drivers are usually farther apart than drivers using an open-sleeve coupling system, the coupling is weaker but still very significant. Therefore, the required length of the higher-frequency driver may differ considerably from the length of a monoband Yagi of similar design. In addition, in the higher frequency range, mutual coupling with the lower-frequency elements also results in changes in the feedpoint impedance of the higher-frequency driver. Very often, the impedance is considerably lower than the value that the higher-frequency elements would show in isolation. The goal of the feed system is to provide the feedpoint with an acceptable impedance relative to the source—something close to 50 Ω.

The sketch of a typical direct-feed system in **Fig. 1-8** shows one further complexity. The lower-frequency driver presents an impedance to the feedpoint in addition to the impedance provided by the higher-frequency driver. These impedances are in parallel. The net impedance must yield the desired 50-Ω value.

The direct connection lines themselves amount to a transmission line with a characteristic impedance (Zo), a velocity factor (VF), and a length. If the impedance designated as Z2 is 50 Ω and the line is 50 Ω, then Z2' will also be 50 Ω. (Similar results emerge from other matched systems for the connecting line and the associated driver.) Under these conditions, if the "other" driver shows a sufficiently high impedance, the parallel combination will be about 50 Ω. At the "other" frequency, the value of Z1 would normally be close to 50 Ω and the value of Z2' would be enough higher not to create a significant variation in that value.

Fig. 1-8



Feedpoint Considerations for Directly Connected Drivers

Some designs manage to achieve these goals. In such cases, they require short connecting transmission lines with very low impedances. The transmission-line impedance limit for round wires is about 80 Ω before the parallel wires touch each other. Therefore, most systems using direct connection employ square conductors. Although we call them square conductors, only the surfaces facing each other play a significant role in the transmission-line properties. Therefore, as shown in the sketch, we may use a variety of materials so long as the face areas are the same. Flat-face elements are capable of Zo values of 50 Ω or slightly lower in practical lines. Small solid rods are popular, since they are least susceptible to climate-induced shape and spacing changes.

Obtaining a Z2 value of 50 Ω when driver 2 is active is not necessary for the proper operation of a multi-band Yagi. Rather, the value of Z2' must be close to 50 Ω and should be considerably higher when driver 1 is active. The value of Z2' is a function of the impedance Z2 and its transformation along the length of the connecting line. The impedance transformation is a function of the line length and the relationship of Z2 to the Zo of the line. (Most such lines have a VF very close to 1.0.) One may experimentally try different values of Zo, as well as different relative positions of driver 2 and its length. (Ordinarily, once close to the desired combination, the designer can make minor adjustments to the length and position of the directors to refine the value. However, all such changes may also change the gain and front-to-back performance on the higher band.) As well, one may reverse the feedline connection point to determine if a better match occurs. In fact, with drivers sufficiently far enough apart, the designer can even try reversing the connections. For some (unknown) reason, custom has dictated that reversed lines are called *phased drivers* while un-reversed lines are simple called a directly fed system. However, the principles of operation are the same: only the current phase angles at the respective connection points change.

Theoretically, we may have occasion to use any connection-line Zo value. However, most direct connection systems employ lower values. 100 to 150 Ω is a practical upper value for such systems. If the higher-frequency system has a low impedance—commonly the case—then a very high value of Zo may narrow the operating range of the antenna as the value of Z2 undergoes its change across the passband. The mutual coupling between lower-frequency and higher-frequency elements often creates faster rates of change in operating parameters than we would find in essentially the same high-frequency beam under monoband conditions. As well, every change in the value of Zo may require a change in the length of driver 2, which in turn will change the value of Z2. For some array designs, there may be no usable combination of values. At that point, the designer must revise at least the upper-band design to see if a usable combination evolves.

Some Mechanical Considerations

Some mechanical details of the proposed multi-band beam construction are arbitrary in the sense that they do not interact with the design itself. However, other facets of construction do have a direct bearing on the design. Some of these aspects of beam mechanics deserve at least brief attention.

Perhaps the most significant mechanical detail of an HF beam is the element taper schedule for each band. Rather than using long lengths of uniform-diameter tubing, virtually all HF beam elements use a series of tubes with the largest diameter at the element center and successively smaller diameter tubes farther out. The beam designer has two major responsibilities. First, he must ensure that the element can withstand a desired level of wind and ice loading. Second, he must take the element taper schedule into account in the design process.

An element that tapers from the center outward will be longer for resonance on any given frequency than one that is a uniform diameter, even if the uniform diameter is below the average diameter of the tapered element. Associated with the element taper are a number of modeling issues that we shall note separately. In this section, we need to note that every variation in the taper schedule will result in required element length changes. Even elements that use the same set of tubing diameters will yield different element lengths if the lengths of the individual subsections of the element differ. See Chapter 8 of the *Physical Design of Yagi Antennas* by David Leeson, W6NL, for a detailed analysis of tapered elements and their uniform-diameter equivalents.

In general, the beam designer should choose an element taper in advance based on the desired wind-load survivability that he wishes to assign to the antenna. In part, this decision rests on the materials selected for the array. In Europe, where metric aluminum tubing sizes are available, most designers use aluminum with thicker walls than we commonly use in the U.S. The resultant beams, like European oaks, tend to be heavier assemblies, but may be close to indestructible. In contrast, some U.S. makers have used thinner-wall materials. With proper selection, the elements are just as capable of withstanding heavy winds and ice loading, but they tend to flex like the branches of willows.

In the middle is the U.S. standard tubing material: 6062-T832 aluminum with a standard wall thickness of about 0.056" (sometimes given as 0.058"). The hard aluminum material is available in 0.125" increments. The difference between the seemingly ideal wall thickness of 0.0625" and 0.056" allows for manufacturing tolerances while still providing a smooth but close fit between tubing sizes. By properly selecting the lengths of the fatter sections, we can arrive at a very strong element for any upper HF band.

We may approach the element-tapering schedule in two different ways. The most fundamental method is to use a program like *YagiStress* to design the element from scratch. Equally effective is to use tapering schedules that have already undergone such design work. For example, Dean Straw, N6BV designed both the physical and electrical properties of the monoband Yagis shown in Chapter 11 any recent edition of *The ARRL Antenna Book*. For our exercises that involve 15-meter and 10-meter elements, we might replicate one of the two schedules that he uses. **Fig. 1-9** shows the relevant dimensions of the heavy-duty schedule that can withstand winds well above 100 miles per hours, with appropriate de-rating for ice loads.

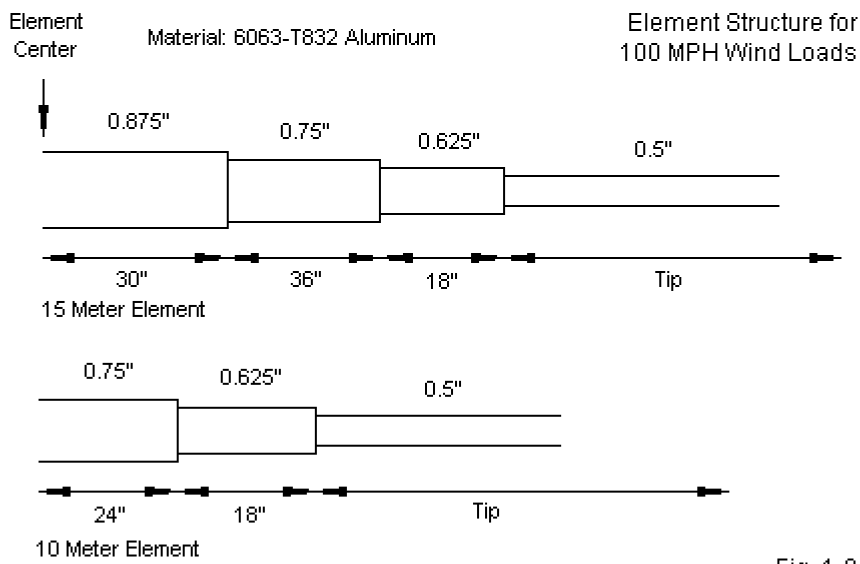


Fig. 1-9

The sketches show half elements. The 0.5” diameter tip sections are open ended, since the length of that section will vary from one element to the next. However, the tip section can be any reasonable length for an element on the selected band and still maintain the wind-load rating. Each section shows the exposed length of tubing. An overlap of from 2 to 3 additional inches is normally sufficient to ensure good section-to-section electrical contact and a secure connection using common fasteners, such as stainless steel sheet-metal screws.

The design dimensions will also depend to some degree on the construction method to be used, especially with respect to the element-to-boom mounting technique. The direct-connection feedpoint system that we have discussed requires that the driver elements be well insulated and isolated from any conductive boom material. The parasitic elements may use a similar mounting system or be directly connected to the boom. Directly connected elements will require a length adjustment—usually longer—than elements that emerge from computer software such as NEC.

For uniformity, I personally tend to prefer the use of isolated elements, although that preference is by no means universal. **Fig. 1-10** shows the details of the element-to-boom assembly that I have used on several monoband and multi-band beams.

The keys to the element in the sketch follow:

A Polycarbonate element-to-boom mounting plate
B Boom
C Boom stainless-steel U-bolts and saddles
D Driven element tube
E Driven element gap insulating rod or tube
F Element stainless-steel U-bolts and saddles
G Stainless-steel nuts/bolts/washers/soldering lugs
H Reflector or director element tubes
I Inner linking conductive tube
J L-stock coax connector mounting plate
K Through-chassis coax connector
L Stainless-steel sheet-metal screws

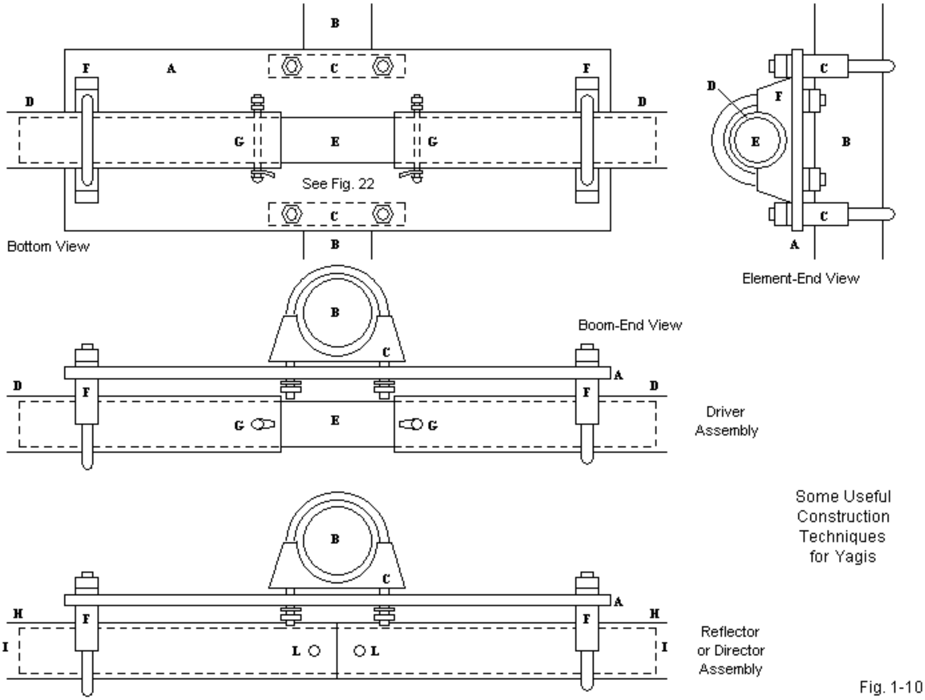


Fig. 1-10

The elements require a linking piece at the center. The parasitic elements (reflectors or directors) require a scrap of conductive tubing (I), while the driven element requires an insulating material, such a fiberglass rod (E). The linking pieces extend just beyond the outer U-bolts to allow element alignment with only two U-bolt fasteners. The driver gap size is not especially critical in the upper HF region, but should be as small as good electrical separation and easy connection assembly permit. The gap is a part of the overall element length, not an addition to it.

All hardware should be stainless steel. This requirement applies to U-bolts (C and F), nut-bolt-washer combinations (G), and sheet metal screws (L). Stainless steel serves two purposes. First, it resists corrosion across the range of weather conditions we are likely to experience in the U.S. Second, it is not subject to electrolysis, which can occur when dissimilar metals join. Therefore, use washers liberally at the connection of copper conductors to the aluminum driven element. The U-bolts show solid aluminum saddles, which are less subject to element compression than double-edge muffler-clamp types of saddles. I do not recommend U-bolts without saddles. I do recommend flat washers between U-bolt lock washers and the mounting plates to avoid gouging the plate and loosening the connection.

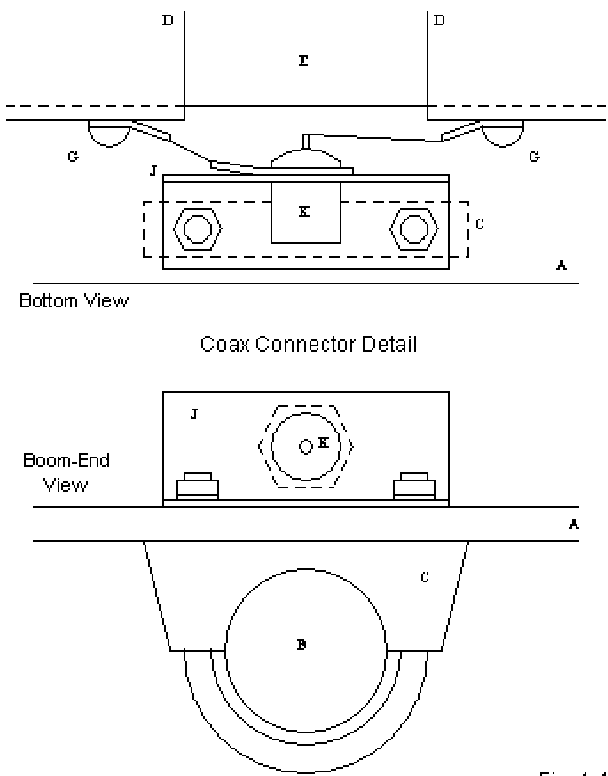


Fig. 1-11

Fig. 1-11 shows one way to install a coax connector (K) to the driven element. The through-chassis connector will fit neatly in the space provided by aluminum L-stock with 1" wide walls and 1/16" thickness. The mounting plate L-stock (J) can extend between two boom U-bolt ends for secure fastening. The connector end of the coax fixture should face the mast position along the boom.

The basic plates that I prefer are polycarbonate, sold under the trade name Lexan in some places. The plate size will vary with the amateur band, which generally determines element size and weight. ¼" thick material generally satisfies most upper HF requirements. The material should be UV-protected. Like Plexiglas, it cuts and drills like wood, in contrast to the acrylic materials available in many home centers. In conjunction with the non-conductive polycarbonate plates, the U-bolt saddles insure satisfactory separation between the element and the boom to attenuate potential interactions to a negligible level.

Many alternative construction techniques are available and can be equally satisfactory. The techniques shown simply coincide with the design decision to use elements that are universally insulated and isolated from the boom. This decision also coincides with the principal design techniques, which involve the use of NEC or MININEC software.

Modeling Considerations

We have already seen some of the fruits of using NEC software as a design tool for creating multi-band beams. Although the graphic portrayals of radiation patterns and performance curves have resulted from EZNEC Pro/4, similar outputs are available from other implementations of NEC. However, not all NEC cores are equal.

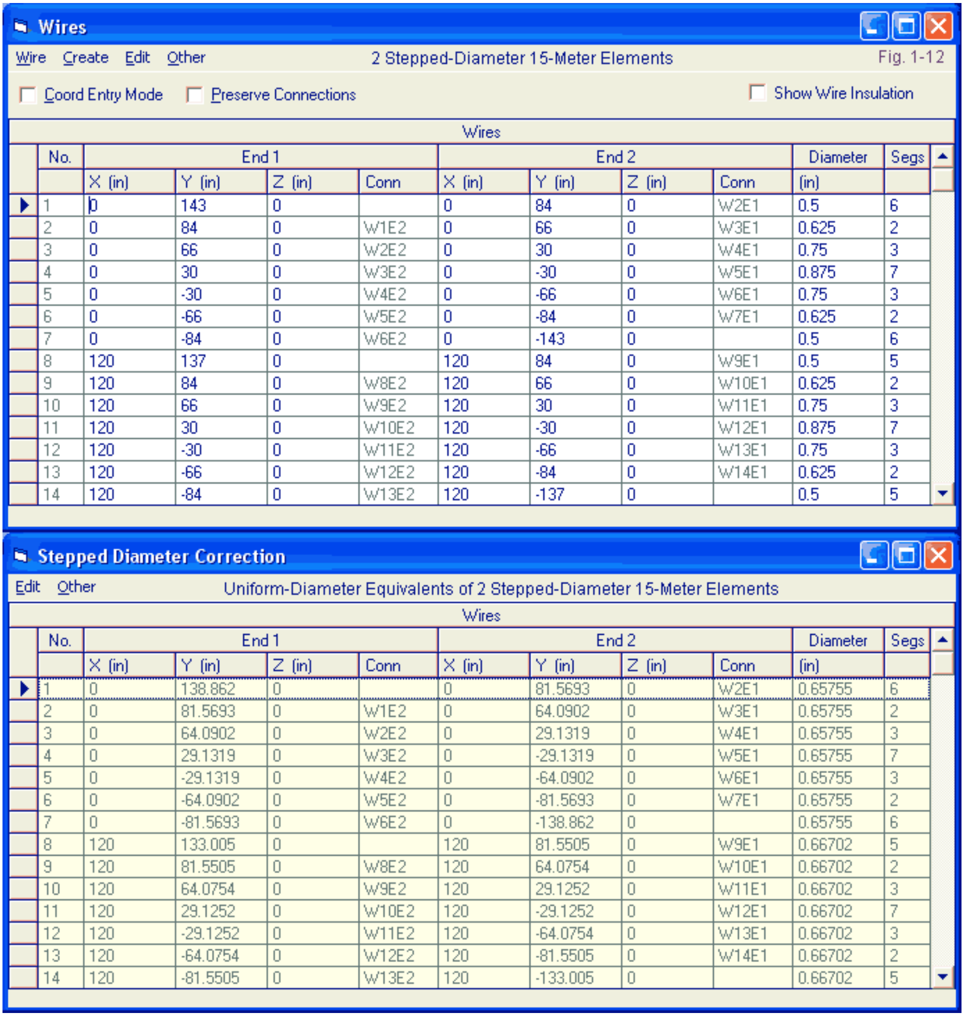
The public domain version of NEC (-2) cannot model linear elements with stepped-diameter elements without significant error, due to the simplified current algorithm used by that early (1980) core. In NEC-4, program developers increased the complexity of the current calculations and improved the accuracy of the core relative to linear elements having a variable diameter. However, even NEC-4's accuracy suffers if the steps between element diameters are too great.

The normal 0.125" increments used in standard U.S. element construction does not stress the program limits in this regard.

NEC-2 is usable for multi-band (or monoband) Yagi design and analysis in the upper HF region if the implementation provides the Leeson corrections. As earlier noted, Leeson used the work of Schelkunoff to develop calculations for creating a uniform-diameter substitute element that had the same properties as a specified stepped-diameter element. NEC programs that allow this correction perform calculations using the substitute element and not the original element structure specified by the user in the wire entry portion of the program. Empirical tests have shown the corrections to be highly accurate when used within their limitations. The corrections are applicable only within a frequency range of about +/-15% of the frequency at which the substitute element is ½-λ long. As well, the element must have no loads to disturb the normal current distribution along the length.

Fig. 1-12 shows two 15-meter elements from one test array, along with the Leeson re-calculations. The substitute uniform-diameter elements are both significantly shorter than the specified tapered-diameter element with the same performance. In addition, both sample elements use the same element taper schedule and differ only in the tip length. Note that as the overall length of the element grows shorter under these conditions, the re-calculated uniform diameter grows fatter. The substitute element as a NEC model consists of the same number of individual wires per element, and each substitute wire has the same number of segments as the original section that it replaces.

Just as it is possible to press NEC-4 toward inaccuracy by making the diameter steps too large, we may also stress the accuracy of substitute elements by failing to attend closely to the segmentation. NEC is most accurate when all segments in a simple or complex wire are the same length. The need for this measure is greatest in the high-current region of the element, that is, at the element center region for standard Yagi designs. Violation of this recommendation tends to yield plausible results that simply do not set the operating parameters on the desired frequency in a physical implementation of the antenna.



No.	End 1 X (in)	End 1 Y (in)	End 1 Z (in)	End 1 Conn	End 2 X (in)	End 2 Y (in)	End 2 Z (in)	End 2 Conn	Diameter (in)	Segs
1	0	143	0		0	84	0	W2E1	0.5	6
2	0	84	0	W1E2	0	66	0	W3E1	0.625	2
3	0	66	0	W2E2	0	30	0	W4E1	0.75	3
4	0	30	0	W3E2	0	-30	0	W5E1	0.875	7
5	0	-30	0	W4E2	0	-66	0	W6E1	0.75	3
6	0	-66	0	W5E2	0	-84	0	W7E1	0.625	2
7	0	-84	0	W6E2	0	-143	0		0.5	6
8	120	137	0		120	84	0	W9E1	0.5	5
9	120	84	0	W8E2	120	66	0	W10E1	0.625	2
10	120	66	0	W9E2	120	30	0	W11E1	0.75	3
11	120	30	0	W10E2	120	-30	0	W12E1	0.875	7
12	120	-30	0	W11E2	120	-66	0	W13E1	0.75	3
13	120	-66	0	W12E2	120	-84	0	W14E1	0.625	2
14	120	-84	0	W13E2	120	-137	0		0.5	5

No.	End 1 X (in)	End 1 Y (in)	End 1 Z (in)	End 1 Conn	End 2 X (in)	End 2 Y (in)	End 2 Z (in)	End 2 Conn	Diameter (in)	Segs
1	0	138.862	0		0	81.5693	0	W2E1	0.65755	6
2	0	81.5693	0	W1E2	0	64.0902	0	W3E1	0.65755	2
3	0	64.0902	0	W2E2	0	29.1319	0	W4E1	0.65755	3
4	0	29.1319	0	W3E2	0	-29.1319	0	W5E1	0.65755	7
5	0	-29.1319	0	W4E2	0	-64.0902	0	W6E1	0.65755	3
6	0	-64.0902	0	W5E2	0	-81.5693	0	W7E1	0.65755	2
7	0	-81.5693	0	W6E2	0	-138.862	0		0.65755	6
8	120	133.005	0		120	81.5505	0	W9E1	0.66702	5
9	120	81.5505	0	W8E2	120	64.0754	0	W10E1	0.66702	2
10	120	64.0754	0	W9E2	120	29.1252	0	W11E1	0.66702	3
11	120	29.1252	0	W10E2	120	-29.1252	0	W12E1	0.66702	7
12	120	-29.1252	0	W11E2	120	-64.0754	0	W13E1	0.66702	3
13	120	-64.0754	0	W12E2	120	-81.5505	0	W14E1	0.66702	2
14	120	-81.5505	0	W13E2	120	-133.005	0		0.66702	5

NEC's calculations involve only axial currents, that is, currents along the length of a wire. The program does not calculate transverse currents. For elements that are well insulated and isolated from a conductive boom, this limitation presents no difficulties. However, for elements connected to a conductive boom, the program does not take into account the effects of the boom on the required element length for a given set of performance specifications, such as self-resonance. One effective modeling technique to compensate for this situation is the insertion of a very short but very fat element section at the center of the element. For the element taper shown, when intended for direct contact with the boom, one might insert a 6" section of 3.0" diameter wire on 15 meters and a similar section of 2.8" wire on the 10-meter element. The technique carries with it a difficulty. For parasitic elements, the length of the inserted section, if 1 segment long, determines the length of all other segments in the element. A multi-band beam with many elements can easily grow quite large in terms of the total segment count. More significantly, if the segment lengths are not as equal as the model permits, the calculations based on the Leeson substitute elements may also become less accurate.

An alternative that does not require Leeson corrections or NEC-4 is to use an adequate form of MININEC for the modeling. MININEC calculates the current along an element by an alternative algorithm that places the center of current at a *pulse*, which occurs at a segment junction (rather than on a segment itself, as in NEC). One consequence of the difference is that MININEC yields high accuracy with element that use a tapered-diameter schedule.

However, not all implementations of public domain MININEC (3.13) are equal. Raw MININEC has a variety of limitations that can create calculation errors. For example, unless one uses a very high segment count, the corners of Moxon elements will result in errors. Some implementations of MININEC have introduced correctives that overcome some of the limitations. However, the only version that matches the accuracy of NEC-4 in virtually all benchmark tests is Antenna Model (by Teri Software). As well, the package has also welded the NEC Sommerfeld-Norton high-accuracy ground calculation system to the MININEC core. (The standard simplified MININEC ground shows growing errors as a horizontal wire comes close to the ground.) Finally, the package can import and transform standard NEC files to the Antenna Model format if the commands used in the NEC file fall within the range that fit the more limited MININEC command set. Since all of the models that we shall examine use free space as the environment and construct elements from individual straight wires, importation of the models will not challenge the software.

Conclusion

These notes have tried to coalesce the main lines of challenges facing anyone who may wish to design a multi-band Yagi. The individual challenges included developing reasonable expectations, accounting for the many forms of element interaction, deciding upon the element structure, and using design software within its limitations. Reasonable expectations emerge from examining the performance of relevantly similar monoband Yagis to the forms used in a multi-band array. In the course of our further work with sample 2-band arrays, we shall give definite form to the element interactions that we enumerated under the general principles. However, we shall not come close to exhausting the possibilities.

Although we showed some construction possibilities that coincide with the inability of round-wire modeling software to account for interactions when connected to a conductive boom, these suggestions are equally non-exhaustive. They show a way, not the way, to construct beams in a home workshop. In addition, as we noted in the discussion, the NEC-4 models used to formulate our samples leave open other avenues of antenna modeling.

All of these factors interact in the design process. As a result, there can be no final comprehensive treatment of the process. As much as an understanding of the principles of antenna element interaction undergirds the process of creating an effective multi-band Yagi, there remains an element of artistry that deserves admiration, especially in the creation of high-performance complex beams for 3 or more bands. Such arrays go well beyond the limits that we shall use to illustrate the basic principles.

In Chapter 2, we shall put some of the considerations explored here to the test. We shall look at a small beam for 15 and 10 meters. It will be relatively simple, involving only 2 elements per band. However, the 15-meter parasitic beam will not be a true Yagi, but instead a Moxon rectangle. In later sections, we shall examine a more complex Yagi combination that will use 3-elements on 15 meters and at least 4 elements on 10 meters to form a relatively high performance 2-band Yagi. Both types of beams will reveal how we may use element interactions to enhance performance, as well as the decisions we might face in accepting one or another limitation.

2. A Small 15-10-Meter Design Example

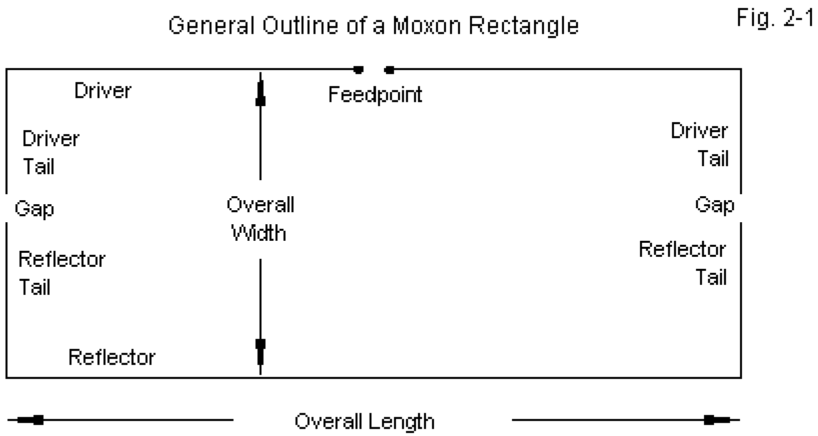
The design considerations for a multi-band parasitic beam antenna have many applications, ranging from very modest arrays to very long-boom complex antennas. In these notes, we shall design a very small beam for 15 and 10 meters, using 2 elements on each band. The total boom length will be less than 10'. However, the design will purposely make use of some variations on the basic ideas that we explored in order to show how the beam design must adapt them to a given design project.

The basic premise will be that someone who wishes to develop a short-boom array for 15 and 10 meters is likely also to be short on installation area. Therefore, the 35' spread of element lengths for the lower band may press the property lines. One option we might consider is loading the 15-meter elements to shorten them and to accept the reduce performance on that band. However, we have another option: to use for 15 meters a Moxon rectangle, which provides wide-band full driver-reflector performance with elements only about 70% of the length of linear 15-meter elements. Since 10-meter elements are considerable shorter, we can use a Yagi design for that band.

At least one of the Yagi elements must fit inside the outline crated by the Moxon rectangle. If we were design the array for 20 and 15 meters, the situation would create no challenges, since the frequency ratio between bands is about 1.5:1. However, the frequency ratio between 15 and 10 meters is only about 1.3:1. We may encounter a tight squeeze, but the existence of these notes suggests that we may successfully meet the challenge.

Expectations

Chapter 1 of this series provided us with reasonable expectations for monoband 2-element Yagi performance in the upper HF range. However, we do not yet have at hand any performance expectations of a Moxon rectangle. We should begin by becoming familiar with the structure and operation of this interesting parasitic beam. **Fig. 2-1** shows the rectangle's outline.



The Moxon rectangle, which owes its origins to Les Moxon, G6XN (now SK), consists of two parallel elements, a driver and a reflector. The parallel portions of the elements exhibit the standard sort of mutual coupling that we obtain from the linear elements of a Yagi. However, the Moxon bends the outer end of each element toward the other element, as shown in the sketch. The driver tails and the reflector tails form a line, but leave a critical gap between the ends. The gap, in conjunction with the element diameter at those points, determines the coupling between the element ends. Hence, the Moxon rectangle makes use of two forms of coupling to obtain some unique radiation patterns. The overall length, the overall width, the tail lengths, and the gap together allow the designer to create a wide-band driver-reflector beam with a 50-Ω feedpoint impedance and generally desirable performance characteristics.

If we were using uniform-diameter elements, we might simply refer to some design algorithms that I developed several years ago to create the antenna structure. However, our Moxon rectangle (and the associated 10-meter Yagi) will use tapered diameter elements with standard U.S aluminum tubing sizes. To lighten the overall structure, I have modified the heavy-duty antenna element structure shown in Chapter 1. **Fig. 2-2** shows the structure employed not only in the design of the independent Moxon, but as well in the eventual multi-band beam.

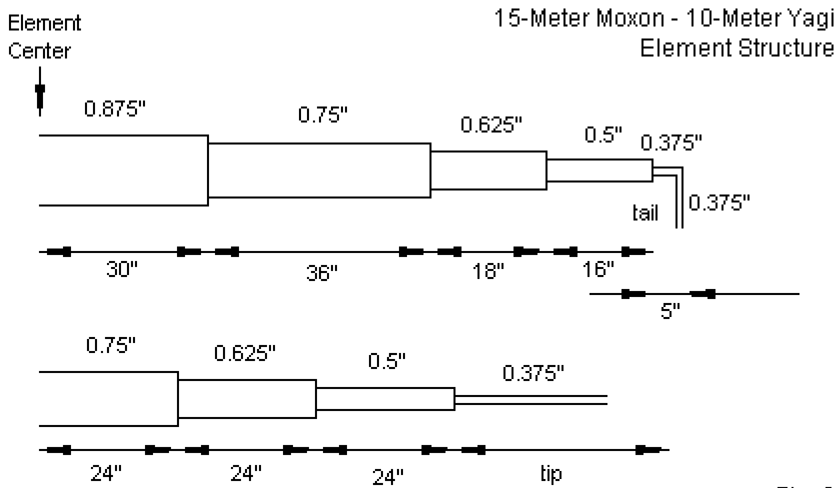


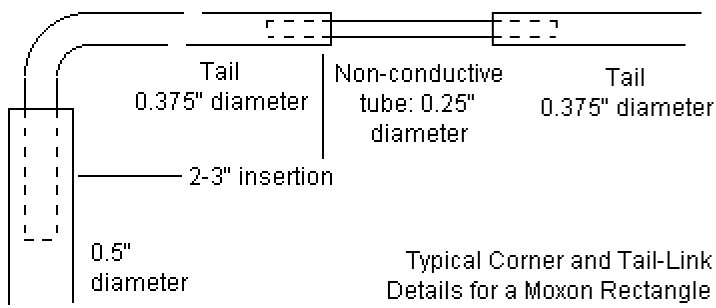
Fig. 2-2

Because the Moxon elements have a corner bend and since both antennas make use of 0.375" end sections, the wind-load will be reduced relative to the larger structure in Chapter 1. However, the resulting antennas should easily handle winds of about 75 miles per hour, with appropriate de-rating under significant ice loads.

Two structural aspects of the Moxon rectangle deserve special attention. First, the corners require a 90° bend. The radius of the bend should be small enough to preserve the antenna's dimensional integrity but large enough to prevent cracks from forming at the corner. Warming the tubing and bending around a form in a slow progression of effort generally succeeds in creating good corners.

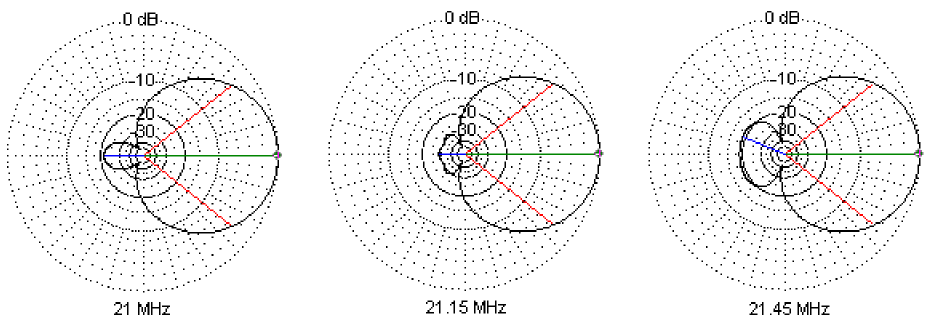
Fig. 2-3 shows the corner structure, including the required insertion overlap for the corner and tail sections. The sketch also shows one way to keep the gap well aligned. A section of 0.25” plastic rod (polycarbonate works well) provides a rigid link that generally does not disturb the overall flexibility of the antenna structure. One may use small stainless steel sheet metal screws as fasteners, but small hitch-pin clips provide an equally secure attachment with smaller holes. The center sections of the elements are amenable to the treatment shown in Chapter 1.

Fig. 2-3



Settling on the element taper schedule is important, since a Moxon rectangle requires significant modification to operate successfully relative to the dimensions we would use for uniform-diameter elements. In general, the overall length from side-to-side will increase, and the front-to-back overall width will decrease for a given feedpoint impedance. In fact, the dimension of the Moxon rectangle will not change as we adapt the antenna to multi-band design, because the rectangle forms the lower-frequency antenna for the beam. We shall examine those dimensions in more detail later. At this point, we need to develop a set of reasonable performance expectations from the antenna.

Fig. 2-4 shows three representative free-space E-plane patterns for an independent Moxon rectangle. The center pattern does not occur at the center of the band, because the design strategy for a Moxon rectangle calls for the design frequency to be about 1/3 the way up the operating passband. This procedure tends to ensure roughly equal values of 180° front-to-back ratio and 50-Ω SWR at both band edges. The forward gain of the Moxon rectangle is within about 0.2-dB of a standard driver-reflector Yagi with the same element spacing, but the beamwidth is considerably greater and the front-to-back ratio averages over 10-dB higher. The performance improvement results from using two forms of coupling between elements, which gives the reflector a current magnitude and phase angle that is close to ideal for maximizing the front-to-back ratio. **Table 2-1** provides modeled performance figures at the band edges and the band center for later comparison with what we obtain on 15 meters when we use the Moxon in the multi-band beam.



15-Meter Moxon Rectangle: Free-Space E-Plane Patterns

Fig. 2-4

Table 2-1. Moxon Rectangle: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.32	6.02	5.74
Front-to-back ratio dB	21.42	26.90	18.43
Feedpoint Z (R +/- jX Ω)	42.9 – j6.6	52.6 + j3.1	61.0 + j10.9
50-Ω SWR	1.23	1.08	1.32

Fig. 2-5 shows the sweep graph of the gain and the front-to-back ratio. Above the design frequency, the rearward lobes are stronger off axis, so the line labeled “Front/Sidelobe Ratio” shows the worst-case front-to-back ratio. Note

that both values do not fall below 20 dB until the very upper limit of the 15-meter band. Like all driver-reflector parasitic beams, the forward gain decreases as the operating frequency in the passband increases. The gain change is less than about 0.6-dB across the entire band.

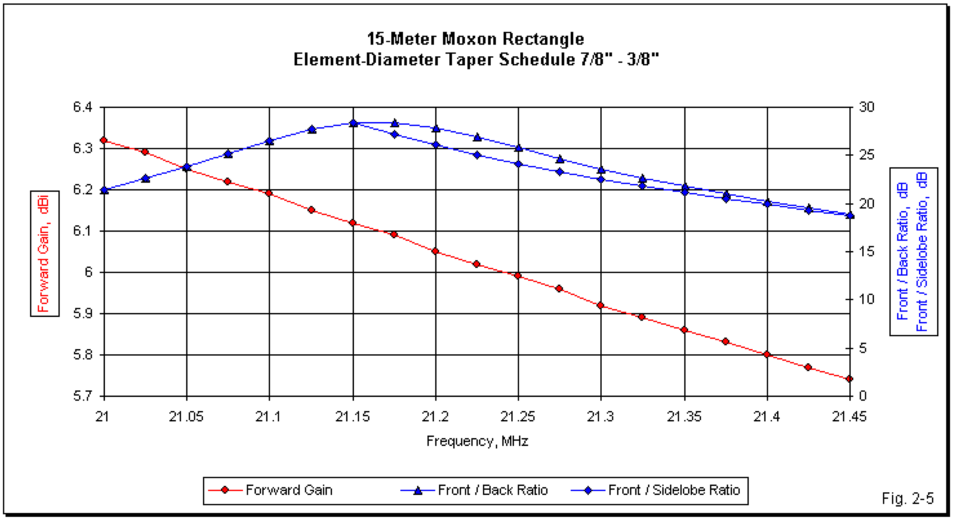


Fig. 2-5

The peak in the front-to-back ratio at the design frequency (about 21.15 MHz) reappears as a null in the 50-Ω SWR curve at about the same frequency. **Fig. 2-6** provides curves for the feedpoint resistance and reactance, as well as the 50-Ω SWR for the monoband version of the Moxon rectangle. The peak SWR value is only about 1.3:1, largely due to the very small changes in the feedpoint resistance and reactance from one band edge to the other. In fact, both values change by only 18 Ω in 450 kHz.

The net result of the monoband design work is a beam with relatively good performance values for a 2-element antenna and only modest performance changes over the 15-meter band. With close attention to the gap distance—the most critical design factor—the antenna becomes relatively forgiving of most other construction variables that occur between versions. It adheres to the suggestion made in Chapter 1 that the lower-band antenna should have wide-band characteristics. With a wide-band lower-frequency antenna, the designer can often focus on the elements for the upper band without having to revise the lower-band dimensions.

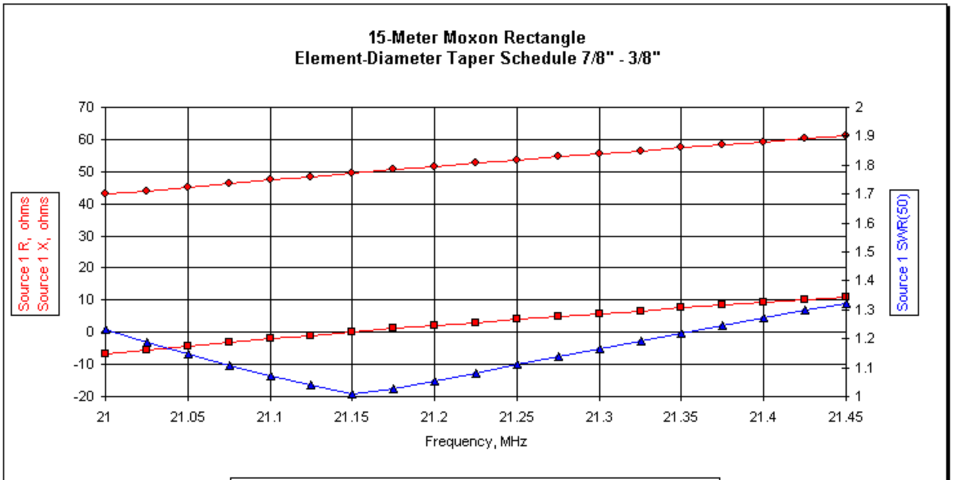


Fig. 2-6

The Electrical Design of a 15-Meter Moxon—10-Meter Yagi Combination

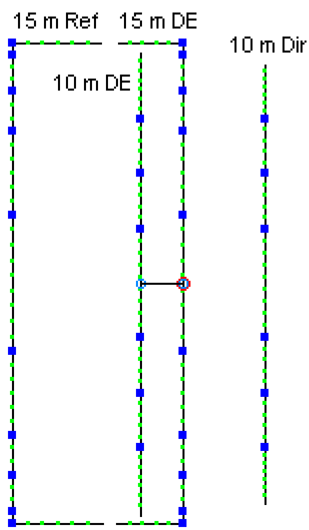
If we use a Moxon rectangle for 15 meters, we cannot easily try to nest another Moxon within the same area for use on 10 meters. Essentially, the gap coupling between the elements on each band—especially on the upper band—decay beyond retrieving. As well, the wide-band characteristics also decay. I have developed some nested Moxons for 12 and 17 meters, but they work only because these bands are so narrow. Even the first MHz of the 10-meter band gives us the widest of the upper HF bands. Hence, achieving a wide-band array is essential.

Using a Yagi structure for 10 meters presents its own challenges. Reflector elements for 2-element 10-meter Yagis are about 110” on each side of center.

This dimension exceeds the Moxon width by about 5". If we wish to keep all of the elements on the same plane, we might have to replace the usual driver-reflector Yagi with a driver-director version.

We tend to think of driver-director Yagis as narrow band antennas. Hence, we might write them off too easily in the present context. Driver-director 2-element Yagis obtain high performance (superior gain and excellent front-to-back ratios) by using close element spacing. However, if we increase the element spacing and accept somewhat lesser performance, we can broaden the operating bandwidth. At the same time, we may increase the monoband feedpoint impedance. Finally, we might even be able to place the driver inside the Moxon rectangle.

Fig. 2-7



General Outline: 15-Meter Moxon Rectangle
and 10-Meter Yagi Combination

The importance of placing the driver behind the 15-meter Moxon driver arises from a desire to keep the boom length as short as possible. A boom length of 10' or less is one project goal in order to form the most compact beam possible while maintaining adequate performance. The Moxon rectangle itself will be just over 6' from back to front. We shall need at least 5' as the element spacing on 10 meters to obtain coverage of the entire band. To keep the entire package within the target 10' boom limit, the 10-meter driver must rest inside the Moxon rectangle and yet be short enough that the element tips do not touch the Moxon driver tails. **Fig. 2-7** shows the outline of the semi-final design. (No multi-band design is ever absolutely finished.) The outline shows with blue dots the element sections, while the green dots indicate the segmentation of each wire in the design model.

Table 2-2 provides the dimensional data for the array.

Table 2-2. 15-meter Moxon—10-meter Yagi dimensions

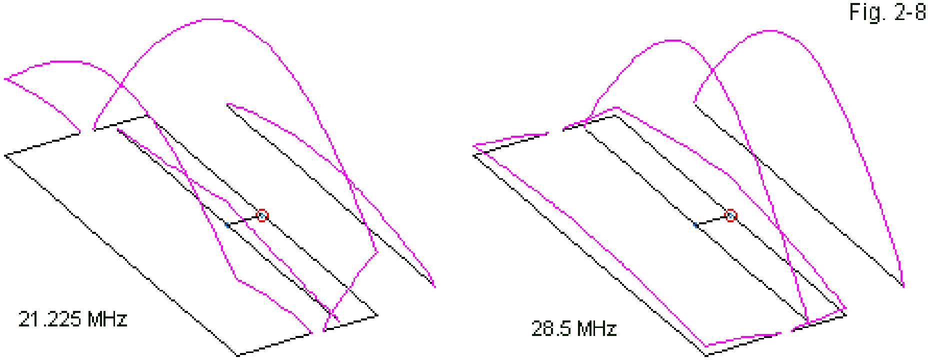
15-meter Moxon Rectangle			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.865"	30"	Both	0.75"	24"
	0.75	66		0.625	48
	0.625	84		0.5	72
	0.5	100	DE tip	0.375	101
	0.375	105	Dir tip	0.375	96
Ref tail	0.375	39.5			
DE tail	0.375	28.5			
Gap		6			
Total width		74			

Array	Spacing	Notes:
15-m ref	0"	1. Length values progressive from element center.
10-m DE	56	2. Reference Moxon dimensions to Fig. 2-1.
15-m DE	74	3. Spacing values references to parallel elements.
10-m Dir	110	4. Driver-to-driver TL = 125 Ω, VF 1.0
		5. Feedpoint: 15-meter (Moxon) DE

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 wire 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".

The dimensions of the 15-meter Moxon rectangle do not change between its monoband use and it presence in the 2-band array. However, the elements of the 10-meter portion of the beam require careful placement to achieve a collection of goals that do not always move in the same direction. We need to arrive at a driver placement (along with the director) that will allow the 15-meter impedance to be relatively undisturbed relative to its monoband values but also produce an acceptable or 50-Ω-compatible impedance from 28.0 to 29.0 MHz. As well, the driver (as indicated in the dimensions) must be short enough to fit between the driver tails without significantly detuning them. Finally, the director must have a length and position that provide acceptable 10-meter performance while allowing the desired feedpoint impedance.

Fig. 2-8



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

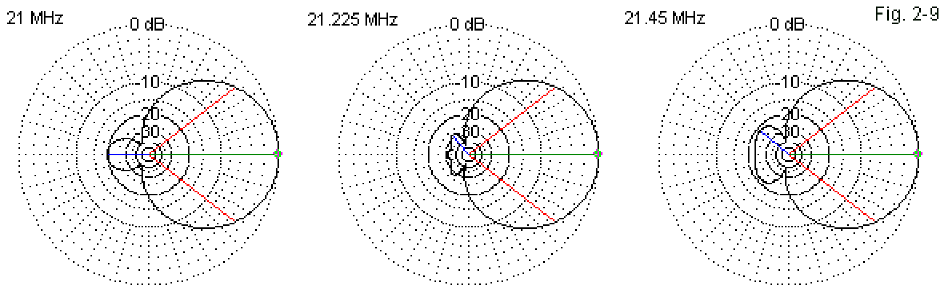
As shown in **Fig. 2-8**, the two bands do interact, but not severely. On 15 meters, we find a small current magnitude on the 10-meter driver, but generally less than 1/10 the peak value on the 15-meter driver. The current on the 10-meter director actually aids the forward gain of the Moxon, but not so much as to be operationally significant. On 10 meters, the 15-meter driver shows some activity. Its chief function is to require adjustment of the 10-meter driver length to compensate, since we now have a pair of roughly (if not crudely) phased driver elements. The 10-meter elements show the highest activity. The low current magnitude on the 15-meter reflector indicates why the array does not have a 10-meter reflector. Such a reflector element would show no higher current magnitude and hence not significantly affect the array performance. As we shall see, the off-band activity level is not so high as to make the dimensions of the array excessively finicky, although in any multi-band parasitic array, one must use far greater care with construction than one needs to employ with a monoband beam.

15-Meter Performance: On 15 meters, we obtain essentially the same performance that we would accrue from a monoband version of the Moxon rectangle. **Table 2-3** samples the performance numbers, while **Fig. 2-9** supplies the associated free-space E-plane patterns.

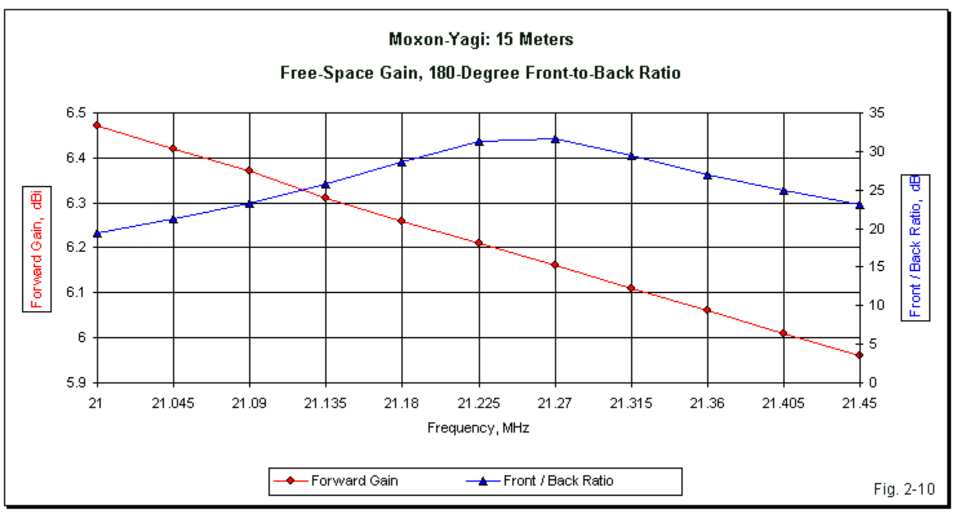
Table 2-3. Moxon-Yagi: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.47	6.21	5.96
Front-to-back ratio dB	19.45	31.36	23.19
Feedpoint Z (R +/- jX Ω)	46.5 – j11.5	59.4 – j8.0	70.6 – j6.8
50-Ω SWR	1.28	1.25	1.44

There is virtually no difference between the radiation patterns in **Fig. 2-9** and those in **Fig. 2-4**. The gain entries show a slight improvement, although it amounts to an undetectable 0.2 dB or less. The gain differential across the band remains at about 0.6-dB. The gain and front-to-back curves in **Fig. 2-10** go some distance toward showing the difference between monoband and multi-band 15-meter front-to-back values. The peak front-to-back value has moved upward in the band by about 100 kHz. As a result, the dip below the 20-dB level now occurs at the low end of the band rather than the upper end.



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



The main feedpoint on the 15-meter driver now contains a parallel combination of the impedances of the 15-meter driver and the transformed off-band impedance of the 10-meter element. As a consequence, the impedance values shift downward, but not so far as to disable the Moxon from use with a 50-

Ω cable or even enough to require adjustment of the Moxon driver elements. The SWR nowhere rises to 1.5:1, as shown in the modeled resistance, reactance, and SWR curves in **Fig. 2-11**. The resistance across the band changes by about 24 Ω, an increase over the differential for the monoband Moxon. However, The reactance change drops to about 5 Ω, thereby reducing the effect of the resistance change on the SWR across the band. However, the overall shift due to the presence of the 10-meter driver and the transmission line is a small displacement of the SWR lower in frequency by about 50 kHz.

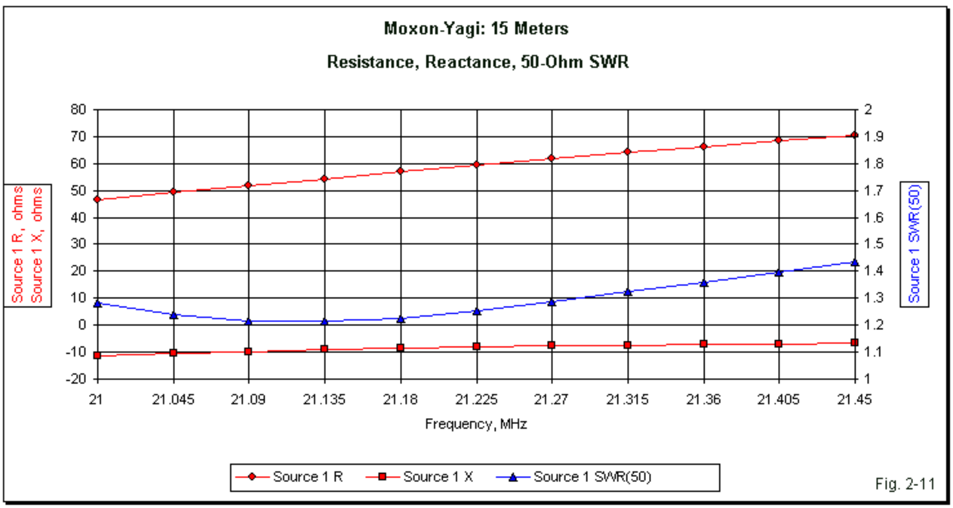
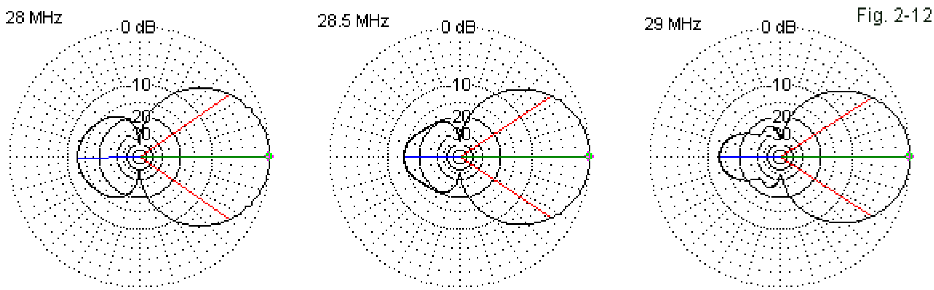


Fig. 2-11

Virtually all of the performance changes created by the presence of the 10-meter elements fall within the normal construction variations for a monoband version of the lower-band antenna. Therefore, modifying the 15-meter dimensions to better center the values loses any justification.

10-Meter Performance: 2-element Yagi performance on 10 meters does not have as rigorous a comparator as the Moxon performance did on 15 meters. The performance goal included finding a director placement and length that would achieve at least the performance level of the 10-meter 2-element Yagi sampled in

Chapter 1. That beam showed a free-space gain range from about 6.4 dBi at 28.0 MHz down to about 5.7 dBi at 29.0 MHz. The front-to-back level averaged about 11 dB with very little change across the band.



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

The free-space plots in **Fig. 2-12** suggest that the multi-band array achieves a set of well-behaved radiation patterns, with a suggestion of some improvement to the front-to-back levels. The numbers in **Table 2-4** confirm the impression. The front-to-back levels average 2-3 dB improvement over a standard driver-reflector Yagi.

Table 2-4. Moxon-Yagi: 10-meter performance

Frequency	28.0	28.5	29.0
Free-space Gain dBi	6.19	6.65	7.18
Front-to-back ratio dB	12.68	14.47	13.11
Feedpoint Z (R +/- jX Ω)	39.9 – j7.7	39.2 + j5.7	35.1 + j23.6
50-Ω SWR	1.33	1.32	1.92

The gain values, as shown in **Fig. 2-13**, show a considerable difference from the values for a driver-reflector array. Because the multi-band 10-meter section uses a director, the gain values increase with a rising operating frequency. The use of the director provides a gain improvement of about 0.5-dB over a monoband driver-reflector Yagi, although the gain change across the band is close to 1-dB. To what degree the gain values result from the director alone and to what degree the 15-meter reflector activity plays a role is impossible to determine, since without the reflector, the array is seriously detuned. Nevertheless, in most beams, the director has a far greater influence on array gain than the reflector, whose role is significantly diminished.

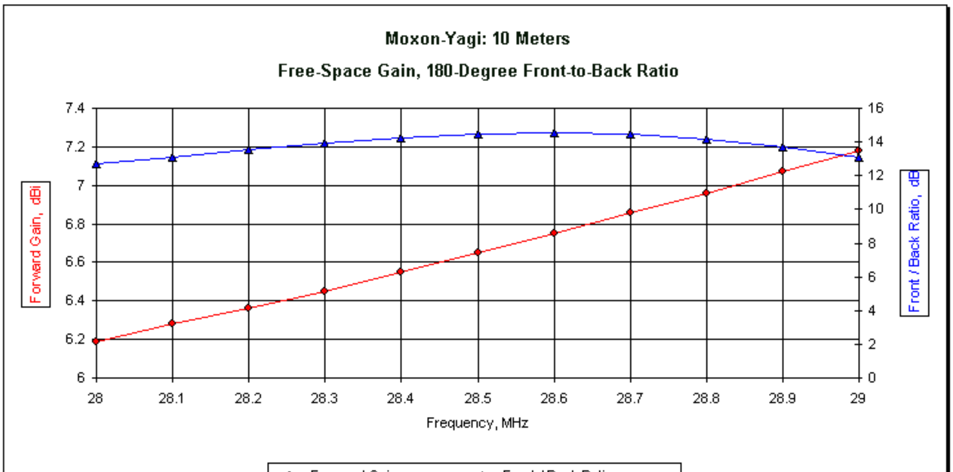


Fig. 2-13

The higher band in any multi-band Yagi tends to show a narrower operating passband and more rapid changes in gain than a corresponding monoband beam. The gain differential across 10 meters is one indicator of this phenomenon. The other indicator is the feedpoint properties, where we use the single parallel feedpoint position to take our readings. This feedpoint has as one parallel component the off-band impedance of the 15-meter Moxon driver. The other component is the transformed impedance of the 10-meter driver. With the connection line shown, the net impedance at the feedpoint remains well within limits for effective 10-meter operation.

Fig. 2-14 provides the curves of the resistance, reactance, and 50-Ω SWR across 10 meters. The SWR value reaches its lowest level at about 28.3 MHz.

Although the SWR never drops to a 1:1 value, it remains below about 1.6:1 through 28.8 MHz and is below 2:1 at the upper end of the passband. The resistive component is quite stable and changes by only 4 Ω across the band. However, the reactance changes by about 30 Ω from the bottom to the top of the passband. Its nearly linear rise across the band results in the slope of the SWR curve.

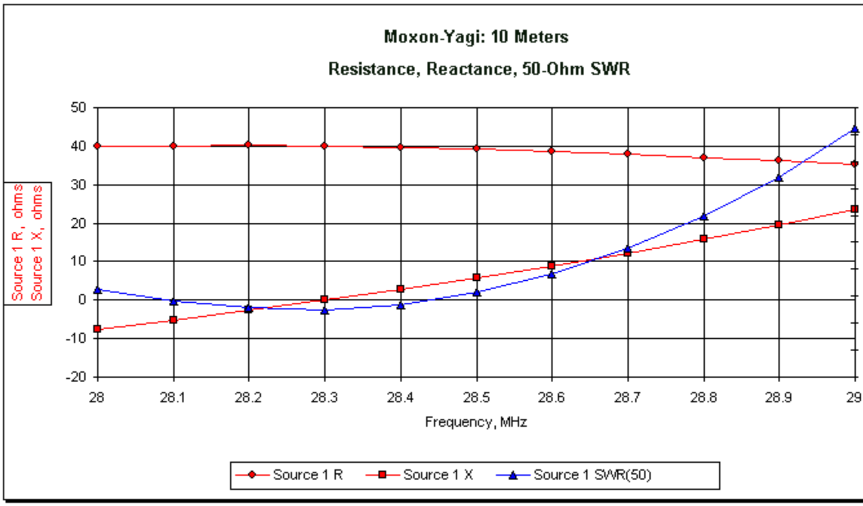


Fig. 2-14

The final combined product is a multi-band 15-10-meter parasitic beam that does not differ in principle from various commercial products, although the latter generally try to cover 3 bands. However, adding a third band to the array would have obscured the application of the design principles in Chapter 1 to the sample beam.

The array that we have been examining has a final challenge for a builder. The physical center of the antenna in the front-to-back dimensions is just behind the 10-meter driver. The center of mass is closer to the 15-meter Moxon driver. Standard boom-to-mast mounting systems tend to use a plate and U-bolts to strap the beam to the mast. However, that system would be ill advised in this case, since the mast and plate would fall directly in the region of the transmission-line that connects the two drivers. Good mounting techniques might include a top-mounting Tee system or an offset system. Alternatively, one might insert enough short sections of tubing into the rear of the boom to move the center of mass back far enough to allow a standard mount behind the 10-meter driver. Since the overall beam weight is not great, one might use a polycarbonate plate rather than the usual aluminum material.

A Modification to and Test of the Array Design

The patterns of current magnitude shown in **Fig. 2-8** suggested that the 10-meter and 15-meter sections of the overall beam were relatively but by no means completely independent of each other. The degree to which the sections are independent shows up also in the degree to which we may make changes without totally disrupting performance on either band. For example, dropping the connecting-line characteristic impedance to 100 Ω does center the 50-Ω SWR minimum at the middle of the passband, resulting in a small increase in the SWR at the lower end of the band but a maximum value of 1.8:1 at 29.0 MHz. The price for the change is an average drop in the front-to-back ratio of about 0.5 dB. The basic design retains the 125-Ω line for two reasons. First, the wider spacing between transmission-line conductors allows for slightly easier construction. Second, we might replace the parallel 125-Ω Line with a length of RG-63 coaxial cable (with the broad not grounded). RG-63 has a characteristic impedance of 125 Ω nominal with a velocity factor of 0.8.

The revision of the transmission-line properties does require small revisions in the dimensions of the array. **Table 2-5** lists the complete dimensions for the array as modified, with the changes highlighted. The revisions require no changes to the element lengths. However, both 10-meter elements move back (toward the Moxon elements) by 3”. The change in the 10-meter element positions increases the physical length of the transmission line from 18” to 21”. Although the velocity factor increases the electrical length of the line even more (to nearly 27”), the change in the 10-meter element positions—especially the driver—has also changed the impedance at the driver feedpoint. Therefore, the required transformation for an acceptable composite feedpoint impedance has also changed.

Table 2-5. 15-meter Moxon—10-meter Yagi dimensions: modification

15-meter Moxon Rectangle			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.865”	30”	Both	0.75”	24”
	0.75	66		0.625	48
	0.625	84		0.5	72
	0.5	100	DE tip	0.375	101
	0.375	105	Dir tip	0.375	96
Ref tail	0.375	39.5			
DE tail	0.375	28.5			
Gap		6			
Total width		74			

Array	Spacing
15-m ref	0”
10-m DE	*53*
15-m DE	74
10-m Dir	*107*

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig. 2-1.
3. Spacing values references to parallel elements.
4. Driver-to-driver TL = *125 Ω, VF 0.8*
5. Feedpoint: 15-meter (Moxon) DE

We do not need further graphs and patterns, since the revisions have virtually no effect upon the 15-meter performance of the array. Compare the modeled values in **Table 2-6** with those in **Table 2-3** to confirmed to what degree the 15-meter Moxon is unaffected by the modifications.

Table 2-6. Moxon-Yagi: 15-meter performance: modification

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.47	6.21	5.97
Front-to-back ratio dB	19.50	31.42	23.30
Feedpoint Z (R +/- jX Ω)	45.2 – j13.1	58.1 – j11.1	69.4 – j11.4
50-Ω SWR	1.34	1.29	1.46

On 10 meters, the performance differences are numerically more evident but operationally of equal insignificance. Compare **Table 2-7** with **Table 2-4** for some relevant details. The 10-meter gain decreases by about 0.2-dB, but the front-to-back ratio increases slightly, especially at the upper end of the band. The 50-Ω SWR curve shows its lowest value at the lower end of the band, but the 29.0-MHz value is the same with both direct-connection lines.

Table 2-7. Moxon-Yagi: 10-meter performance: modification

Frequency	28.0	28.5	29.0
Free-space Gain dBi	6.01	6.47	7.02
Front-to-back ratio dB	12.72	15.35	15.13
Feedpoint Z (R +/- jX Ω)	45.3 + j0.8	43.8 + j11.3	39.2 + j27.4
50-Ω SWR	1.11	1.32	1.92

In the end, no operational difference emerges between the two methods of making the direct connection between the driver elements. In either form, the Moxon-Yagi combination for 15 and 10 meters is a modest but highly serviceable 2-band parasitic array. With significant care in construction (as befits any multi-band array), the antenna should be reproducible in the average amateur home shop.

Conclusion

The essential purpose of these notes is not to create a building project so much as it is to illustrate the principles of multi-band parasitic beam design on a small scale. The small scale of our sample array has allowed us to examine a number of facets of the design process in detail while keeping the text to a reasonable size. If the exercise results in a usable antenna for those whose situations call for compact size, so much the better. With a modest (10’) boom and short Moxon elements, the array that we have used as a focal point may in fact fulfill a need.

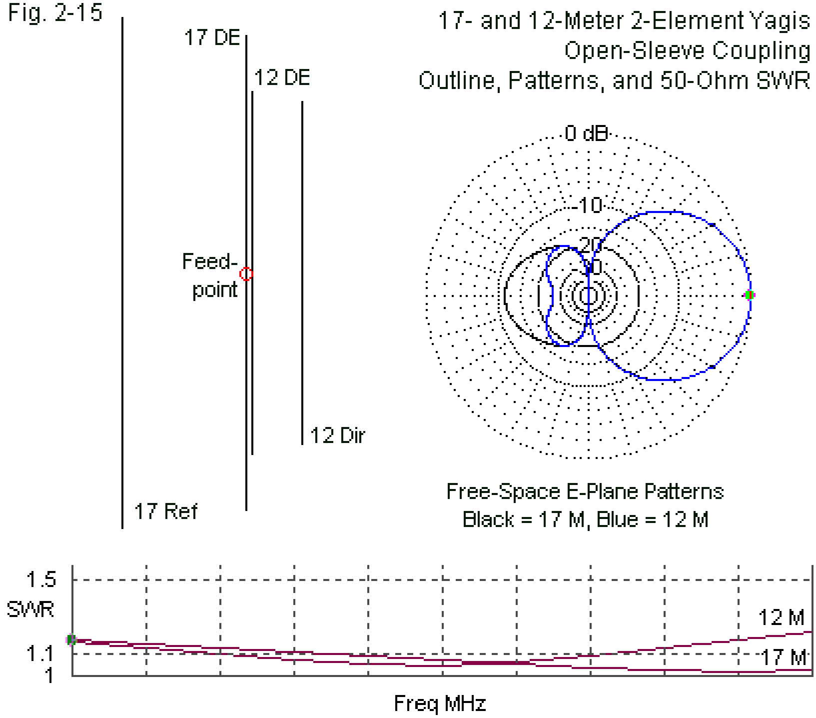
The reasons for using 15 and 10 meters as the test bands for the simple design and others still to come involve both bandwidth and frequency separation. Because the ratio of frequencies is only about 1.3:1, the bands created a physical challenge for our Moxon-Yagi design, one that the final element dimensions overcame. A 20-15-meter combination would have been easier to physically set up, with good clearance between the 15-meter Yagi driver and the 20-meter Moxon tails.

In addition, the 15-10-meter combination uses a stable design on the lower band with a narrower bandwidth (about 2.1%) with a less stable upper-band elements set that had to cover a greater operating bandwidth (about 3.5%). The bandwidth difficulties would have been less daunting had we used a 20-15-meter combination, where the bandwidth would decrease from 2.5% to 2.1% as we moved from the lower to the upper band.

Because the sets of elements are fairly well isolated or free of interactions (except for the drivers, of course), the array has only hinted at some of the principles that we explored in Chapter 1. For example, the effects of “forward stagger” only managed to increase gain by less than 0.2-dB, a value that is less than convincing that forward stagger is the source. Entire beams, such as the monumental 5-band array by ON4ANT, have used forward stagger exclusively—with separate feedlines on drivers for each band—to achieve excellent results. (For further information on the very long but highly proficient ON4ANT array, see http://www.cebik.com/yagi/on4ant.html, “Three Forward-Stagger 5-Band Yagis from ON4ANT.”)

In addition, we have designed the 2-band Moxon-Yagi combination using direct-feed techniques. We originally noted that open-sleeve coupling techniques tended to show narrower operating bandwidth properties on upper bands than direct-feed or closed-sleeve methods. However, for the home antenna builder, these techniques have application, especially on beams designed for the narrower amateur bands, such as 30, 17, and 12 meters. (For some applications of open-sleeve coupling, see http://www.cebik.com/yagi/bb.html, “Director/Driven Element 2-Element Yagis: Some Ideas for 12 and 17 Meters.” See also “Basic Beams for 12 and 17 Meters,” *QST* (August, 2000), pp. 57-62.) **Fig. 2-15** shows the outline, patterns, and SWR curves of a driver-reflector Yagi for 17 meters open-sleeve coupled to a driver-director Yagi for 12-meters. We shall do a rapid survey of sleeve-coupled drivers and some application in Chapter 10. However, we shall discover that beyond general principles, some of the quantitative theory behind the driver system will have to give way to both design and field experimentation. The use of stepped-diameter element tapers and differences in the impedances at each operating frequency will modify basic formulations in ways that make trial and error software modeling more efficient than extensive pre-calculation.

Fig. 2-15



The listed references provide some potential construction details of this array. What the graphic cannot show is the need for careful field adjustment of the 12-meter driver position and length to obtain an acceptable 50-Ω SWR value for the upper band. Nevertheless, once one has found correct dimensions anywhere within 12 meters, the settings are good for the entire band. Although there are successful commercial beams available for the wider bands in the upper HF region, I would recommend that use of the open-sleeve coupling technique for multi-band amateur beams be left to the commercial antenna makers, who have the facilities, test equipment, and experience to make the adjustment phase of the effort routine. On the other hand, the technique is more readily adaptable to beam combinations for the narrower amateur bands where one may set aside concerns for widely separated band-edge SWR values and focus on a single test frequency when making adjustments.

All of the beams that we have considered in the part of our work are fairly simple, when considered on a band-by-band basis. The 2 lower band elements form a wide-band parasitic beam that is both broadband and stable. Adjustments to the upper-band elements had little if any effect on the lower-band elements. In general, this principle is applicable to multi-band beams of any complexity level, although the need to make small adjustments may rise with the number of elements per band and the number of bands covered by the array. Even the open-sleeve sample in **Fig. 2-15** uses a wide-band design for 17 meters that provides both a 50-Ω feedpoint and stability in the presence of the 12-meter elements.

The next step in multi-band array complexity is to increase the element count from 2 to at least 3 elements per band, again using 15 and 10 meters as the operating bands. There will be a 4^{th} element for 10 meters that is not optional. However, it will force us to make some design decisions along the way.

3. A 3-Element 15-Meter, 4-Element 10-Meter Design Example

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.

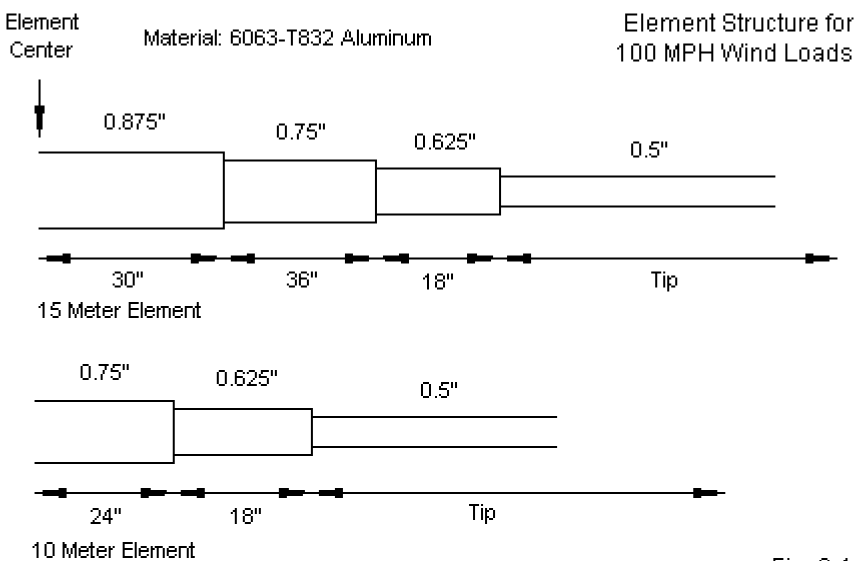


Fig. 3-1

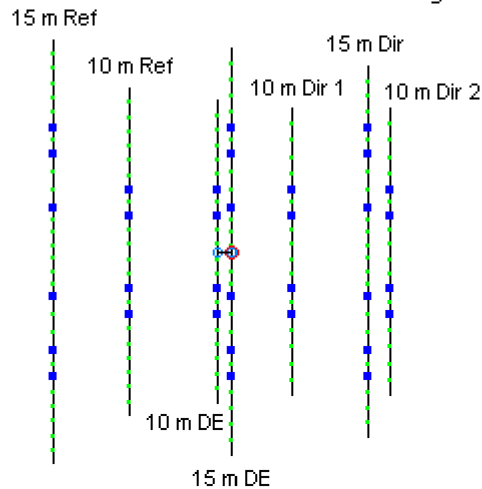
Among the preliminary decisions that we must make is the element taper schedule. **Fig. 3-1** replicates the sketch from Chapter 1 showing a taper schedule that will withstand 100 mile-per-hour winds, with appropriate de-rating for significant ice loads. The 6063-T832 aluminum tubing in standard 0.125" 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.

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. 3-2** shows the overall array outline, with the elements functionally identified. **Table 3-1** gives the dimensions for our initial design.

Fig. 3-2



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

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

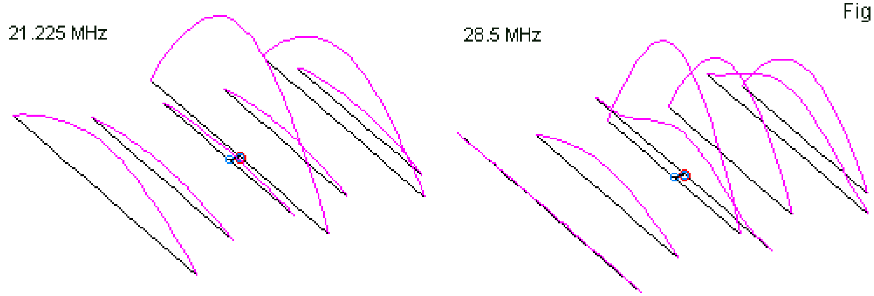
15-meter Yagi			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.875”	30”	Both	0.75”	24”
	0.75	66		0.625	42
	0.625	84	Ref tip	0.5	110
Ref tip	0.5	143	DE tip	0.5	102
DE tip	0.5	137	Dir 1 tip	0.5	96.5
Dir tip	0.5	125	Dir 2 tip	0.5	96.5

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. 3-2.
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 Chapter 2, the larger 2-band Yagi shows extensive element interaction. **Fig. 3-3** shows the relative current magnitude on each element for frequencies at the center of each passband.

Fig. 3-3



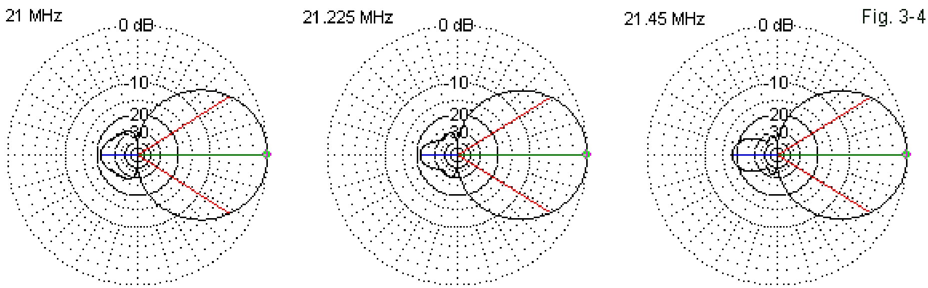
Relative Current Magnitudes on the Elements of a 2-Band Multi-Element Yagi on 15 and 10 Meters

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. 3-4**. 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 3-2**, 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 3-2. 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. 3-5 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.

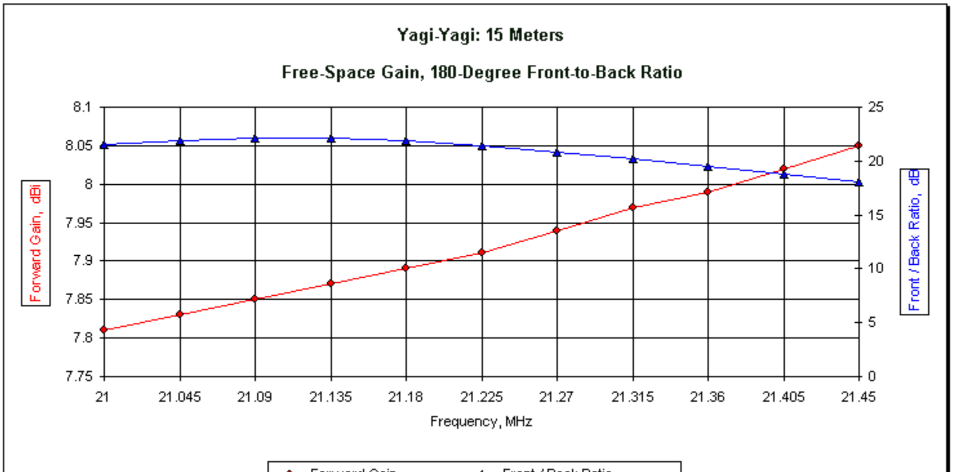


Fig. 3-5

The feedpoint behavior of the beam on 15 meters is equally tame, as shown by the curves in **Fig. 3-6**. 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.

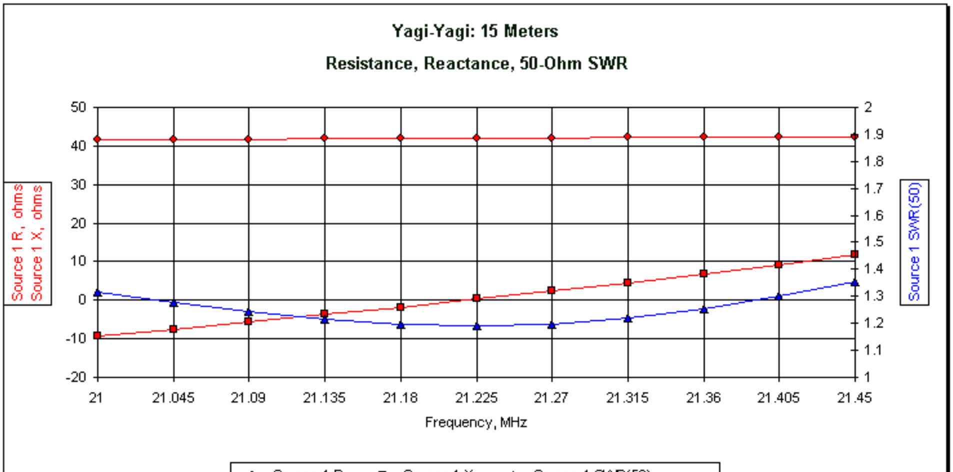


Fig. 3-6

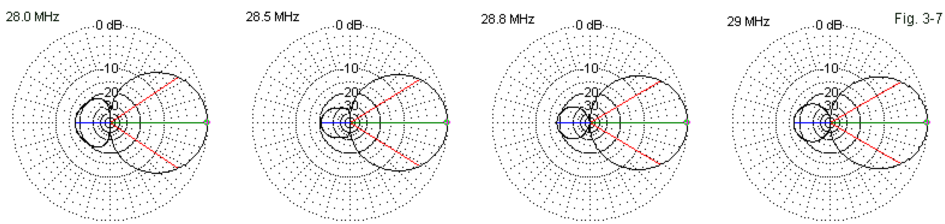
The 15-meter 3-element Yagi provides a basic framework into which we must interlace 10-meter elements positioned for adequate performance on the band.

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. 3-2** 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 3-1** 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. 3-7**, are well behaved. They have a single forward lobe and a single rearward lobe.



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

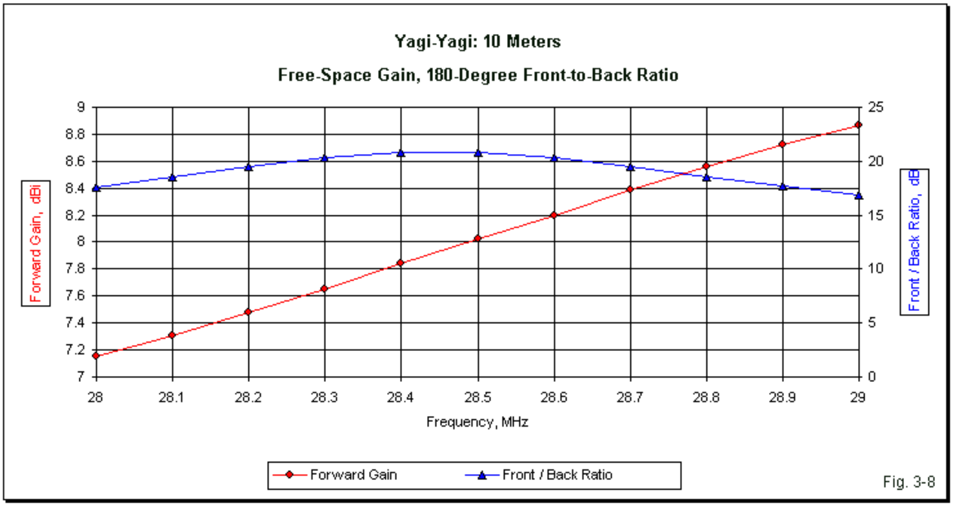
The rearward lobe from about 28.0 to 28.5 MHz has an evolving shape that one might also expect from a monoband Yagi. However, once the front-to-back ratio reaches its maximum value, we tend to expect the rearward lobe to further evolve into an actual or incipient 3-lobe structure. See, for example, the progression of patterns for 15 meters in **Fig. 3-4**. 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 3-3. 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 3-3 samples the 10-meter performance. Like the patterns in **Fig. 3-7**, 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.

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. See **Fig. 3-8**. 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. 3-9**. 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.

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.

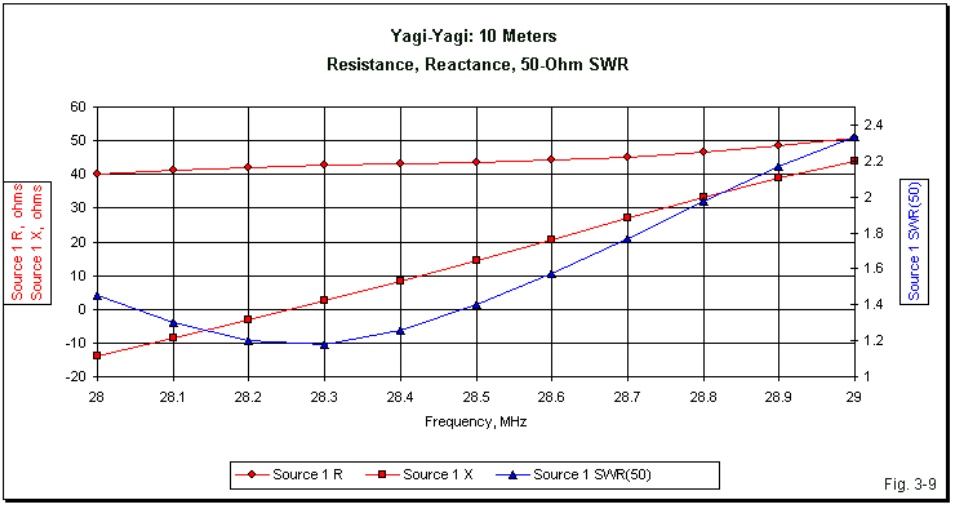


Fig. 3-9

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 3-4** provides the full set of dimensions for the revised beam for comparison with those in **Table 3-1**. I have highlighted the changes necessary to obtain the new 10-meter performance curves.

Table 3-4. 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. 3-2.
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 3-5**. Compare these numbers with the corresponding set of values in **Table 3-2**.

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 O)	41.6 - j9.1	42.0 + j0.6	42.2 + j12.0
50-Ω SWR	1.31	1.19	1.36

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

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. 3-10 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. 3-7**, we do not need a new set here.

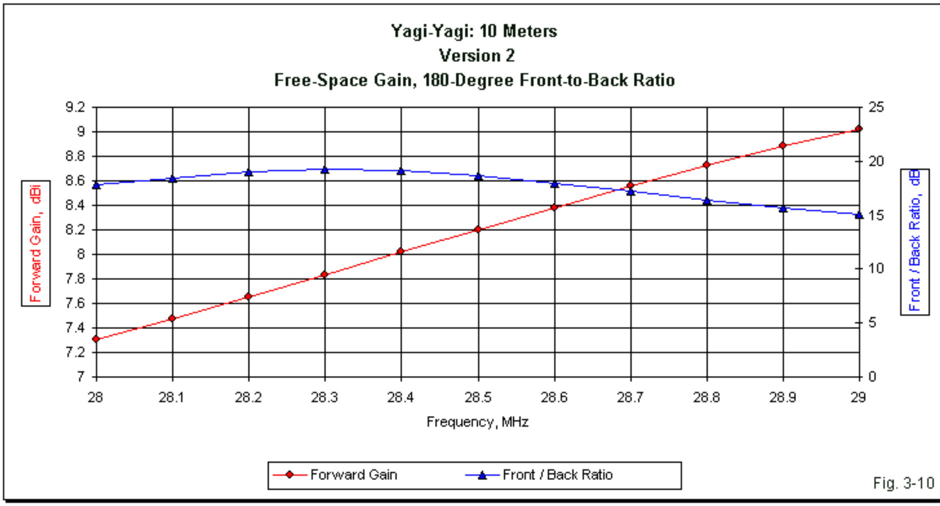


Fig. 3-10

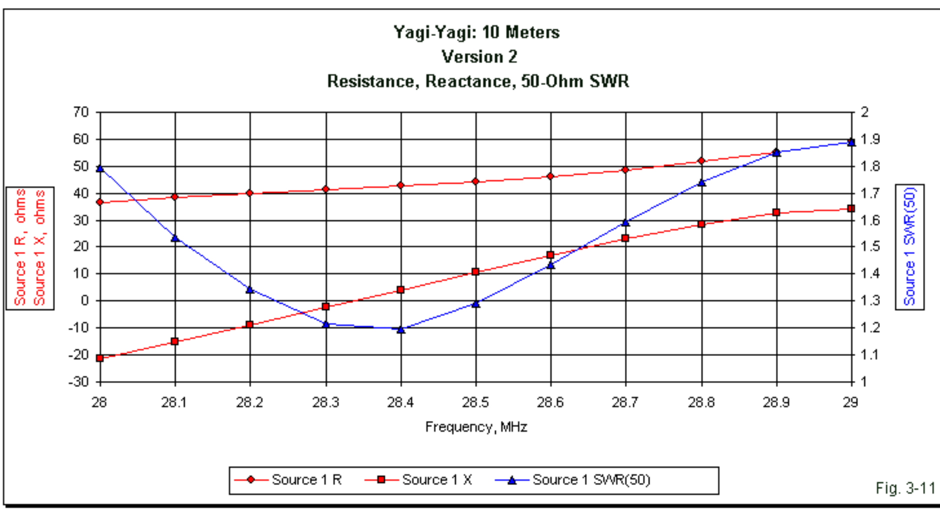


Fig. 3-11

Fig 3-11 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 3-1**. However, we shall also modify this beam to remove the second 10-meter director. A comparison of the results may prove instructive.

Table 3-7 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

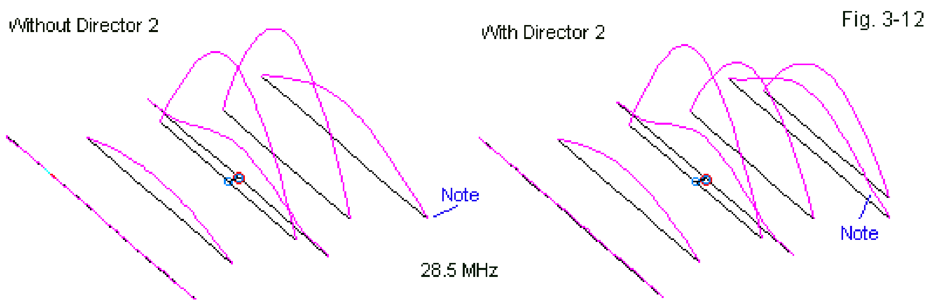
Frequency	28.0	28.5	28.8	29.0
Free-space Gain dBi	7.15	8.02	8.56	8.87
Front-to-back ratio dB	17.62	20.79	18.54	16.89
Feedpoint Z (R +/- jX Ω)	40.2 – j13.8	43.6 + j14.5	46.6 + j33.3	50.8 + j43.9
50-Ω SWR	1.46	1.40	1.97	2.33

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 Chapter 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.



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

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. 3-12** provides relative curves for 28.5 MHz for both versions of the array.

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.

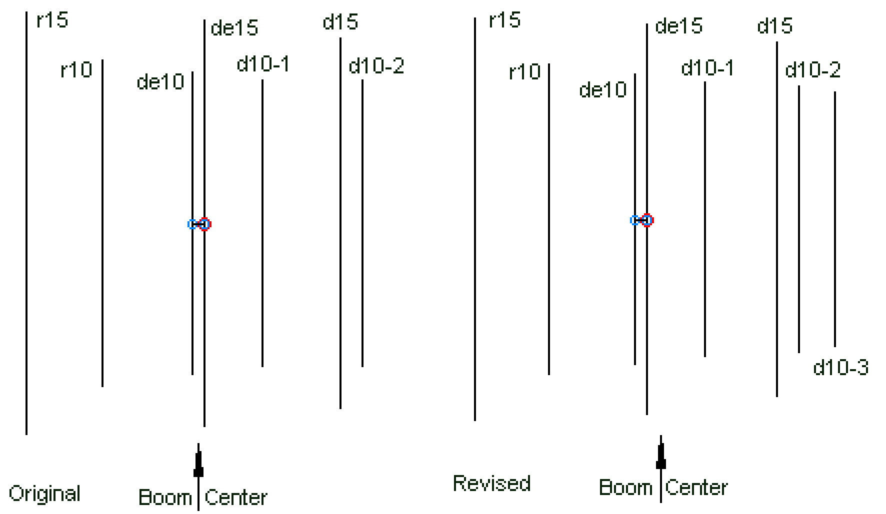
The presence of the second 10-meter director alters the shape of the current distribution curve on the 15-meter director. It slopes more rapidly toward zero until it passes the limit of the 10-meter director. Since the current cannot go to zero until the element ends, the electrical reshaping of the 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—or vertically stacked director elements.

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. 3-13**. 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.

Fig. 3-13



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

On the right in **Fig. 3-13** 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 3-8** 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 third director is even shorter.

Table 3-8. 3-element 15-meter Yagi—5-element 10-meter Yagi dimensions

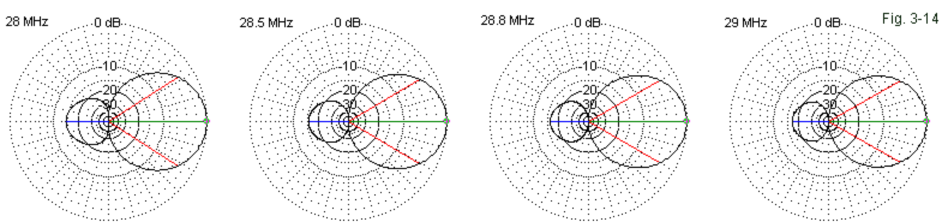
15-meter Yagi			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.875"	30"	Both	0.75"	24"
	0.75	66		0.625	42
	0.625	84	Ref tip	0.5	109
Ref tip	0.5	142	DE tip	0.5	102
DE tip	0.5	137	Dir 1 tip	0.5	96.5
Dir tip	0.5	124	Dir 2 tip	0.5	92.5
			Dir 3 Tip	0.5	89.5

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. 3-2.
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. 3-14** 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 3-9** 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 3-9. 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 3-10**. 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 3-10. 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	

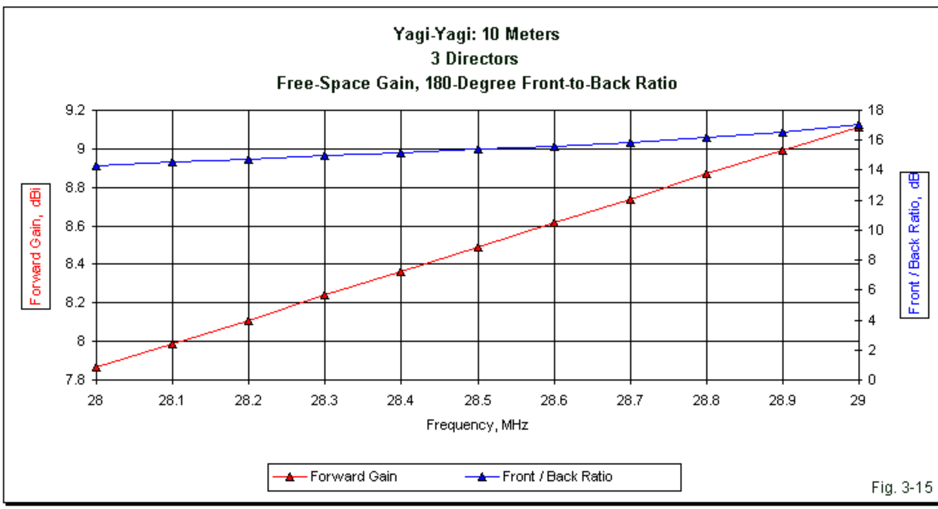


Fig. 3-15

The full set of values for the free-space forward gain and the 180° front-to-back ratio appear in **Fig. 3-15**. 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. 3-10**.) 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.

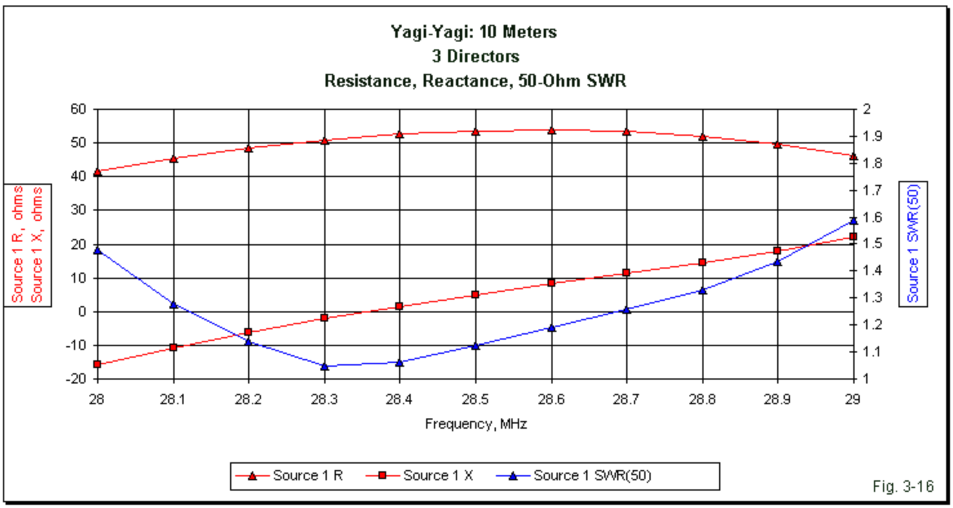


Fig. 3-16

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. 3-16** shows the complete sweep of values. Compare this graph to **Fig. 3-11**. 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.

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. 3-13**. 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 Chapter 2. For example, we found—in a very limited and operationally insignificant way—the phenomenon of forward stagger. We may also be getting a sense that any activity on off-band reflectors is relatively insignificant for performance. Instead, the activity on off-band directors tends to play a more important role in determining the performance on a given band. In addition to forward stagger, we obtained a bit more experience in the performance compromises that we must make within a fixed boom-length limit, we since were unable to achieve all of the desirable performance goals with the same element dimensions.

We also saw the importance of placing an upper-band director ahead of the forward-most lower-band director in order to control the current distribution on the lower-band director. Adding a further director, if closely spaced, provides a control function of smoothing gain performance across the band. A full-size director at a greater distance from the 4th upper-band element might improve gain, but like all Yagis, the 10-meter section of the present array grows longer faster than it increases gain. As well, increasing the gain on 10 meters would through the performance levels of the two array sections further out of balance. As a consequence, the addition of the third upper-band director should likely play the role shown—controlling performance across the passband—rather than function as a means of improving performance on one band only.

Appearances are that we may well have covered all of the available territory in developing modest but capable 2-band arrays. However, the very last sample voided our commitment to a fixed boom-length limit. 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 next two chapters, we shall create 10-meter beam sections with additional 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. Chapter 4 will examine what happens to the Moxon-Yagi array with a forward driver. Chapter 5 will return to the Yagi-Yagi combination. Throughout the process, we shall be looking for trends in the performance of each variation. Then we shall compare the trends for the Moxon-Yagi set with those for the Yagi-Yagi set to see which ones, if any, have generality that we can carry to other arrays that we might imagine and someday design.

4. Alternative 15-Meter Moxon, 10-Meter Yagi Design Examples

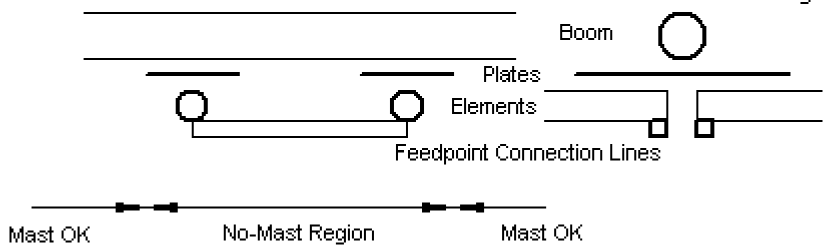
When I initially struck an outline for these notes on multi-band parasitic beam design, I thought that I might need only two episodes. One would, as does Chapter 1, set forth the general principles and limitations of designing such beams. The second section would illustrate those principles by using two 15-10-meter arrays as examples: a simple beam and a more complex beam. There is nothing like a good example to reveal uncovered details in the expression of the general principles, gaps that require further exploration. Therefore, the relatively small Moxon Yagi combination required a full section, as did the more complex Yagi-Yagi affair. It turns out that we are still not quite done with our work.

We left behind a number of unanswered questions. As well, in the course of developing notes on these subjects, other questions arose. Here is a brief list of what still remains undone.

1. *The Boom-to-Mast Question*: In previous episodes, I have noted that some designs manage to place their driven elements at the boom center. Although the linear center of the boom is not usually the exact center of array mass, it is close enough to give us a guide to the problems involved. Remember that all of our designs make use of a 125-Ω (VF 1.0) transmission line to connect the 10-meter driver to the 15-meter drive that also serves as the connection point for the main feedline. **Fig. 4-1** illustrates the mechanical problem facing the multi-band beam designer.

The sketch shows the driver assembly elements from two perspectives. The array side view, looking down the element tubes, is perhaps the more helpful of the two, since it defines a region that I have called the “no-mast” zone. If we hang the elements beneath the boom, as is common upper HF practice, we cannot attach a mast within the region occupied by the elements or the transmission line, as shown on the right. The mast and its plate or other assembly cannot touch either an element or one of the two conductors making up the connecting line. Indeed, a mast needs sufficient spacing to avoid unbalancing the connecting transmission line. The alternative is to find a means to place the mast either ahead of or behind the pair of drivers without (if possible) seriously unbalancing the array or adding deadweight to one or the other end of the boom.

Fig. 4-1

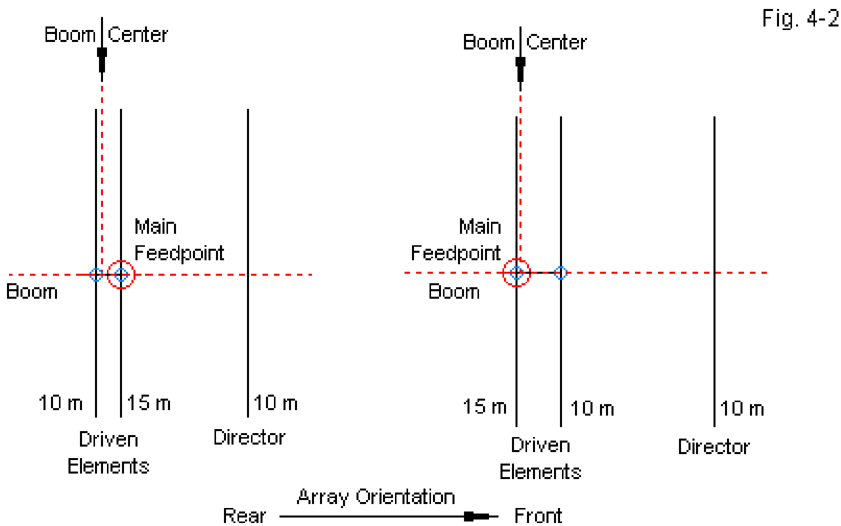


The Mechanical Question: Boom-to-Mast Connection Position

One way to manage the array balance might be to add another 10-meter director. By adding the new element, we violate or original intention of keeping the beams as short as feasible. Still, the additional element and boom length might shift the center point enough to allow a clean mast-to-boom junction without resorting to Tee fittings and other non-standard mounting systems.

2. *The Driven-Element Placement Question*: In our quest for short boom lengths, we automatically placed the secondary 10-meter driver behind the 15-meter driven element. However, without the boom-length restriction, we might as easily have chosen the place the 10-meter driver forward of the 15-meter driven element and still have used the lower-band driver as the connecting point for the main feedline. **Fig. 4-2** illustrates our alternatives.

The sketches of hypothetical structures are not far off the boom centers that we shall encounter. The option on the right does not resolve the mechanical problem, but it does inform us that we shall automatically require longer booms—as much as 3' to 4' longer—than the option on the left. In return, the upper-band-forward position is suggestive of an additional opportunity to make use of forward stagger by placing two 15-meter elements behind the rearmost 10-meter elements. The design question then becomes whether we gain anything significant enough to warrant the forward position for the 10-meter driver.



The Driver-Position Question: 15-10 or 10-15?

3. *The General Compromise Question*: Every multi-band beam is a mass of compromises required by limitations that we impose—sometimes just by wanting a beam to cover more than one band with a single feedline and boom. Our initial boom-length restriction was about 10’ for the smaller array and 20’ for the larger. We have already seen that some of our new options will require longer booms. A second restriction emerges from tying together the feedpoints of the driven elements for both bands. This limitation would occur whether we used traps, direct connections, or open-sleeve coupling. The required proximity of the drivers and the need for an acceptable 50-Ω SWR limits the potential positions available to the drivers. This factor interacts with the positions of the elements for each band. As a consequence, we face a new set of limitations. The element positions and lengths required for the best impedance curve do not coincide with

those for the best front-to-back ratio curve, and neither set coincides with the positions and lengths needed to maximize gain. As we begin to remove some limitations, such as the length of the boom, we enter less certain ground in terms of reaching a decision about what set of dimensions is "best." For example, we need to obtain full passband coverage with less than 2:1 50-Ohm SWR in most amateur arrays. In some cases, but not all, we can obtain excellent SWR curves, but at the cost of other performance categories. If we peak one or another performance category, such as the front-to-back ratio, the SWR curve may narrow, skew, or simply rise too high.

The result is that every design set to paper (and into a prototype) is not the only set of array dimensions that will yield performance that is acceptable to someone. The designs that we shall review in this final set of notes will all show signs of compromise. However, it will be much harder to specify just why I chose the compromises used in the designs. Nonetheless, the effort to articulate those reasons may give insight into both the process of design and the potential range of variation that one may expect from personal adjustments to the listed designs.

In working with these questions, we need a rough plan. Therefore, we shall work first with the Moxon-Yagi combination and later with the Yagi-Yagi combination. Each basic array will have 4 versions, all of which use the same direction-connection feed system with its 125-Ω transmission line. We shall look at two designs with the 10-meter driver behind the 15-meter driver and two with the 10-meter driver ahead of the 15-meter driven element. The differentiation between designs for each driver placement will be in the addition of an extra director to determine if it provides assistance with the mechanical question and with overall upper-band performance.

For both exercises, we shall use set 15-meter element groupings that will not vary. This restriction allows us to see more clearly the nature of the compromises involved in the design process. Still, it does restrict our flexibility below the level that a serious beam designer might have in adjusting element positions. On the other hand, the 10-meter elements will have so little affect on the 15-meter elements that the performance on the lower-band is relatively immune to whatever we do to the upper-band elements

For each variation on the design themes, we shall initially provide tabular results of the NEC-4 modeling. As in past episodes, there will be tables of dimensions, and all beams will use the same element taper schedules used in earlier sections. As well, each beam variation will have free-space performance tables for both 10 and 15 meters. In general, we shall reserve most of our comments for follow-up summaries using a number of frequency-sweep curves on both bands. Let's begin with the smaller Moxon-Yagi combinations.

15-Meter 2-Element Moxons Rectangles Combined with 3- and 4-Element 10-Meter Yagis

The 15-meter tapered-element Moxon rectangle that we introduced in Chapter 2 remains the stable core of all of the variations in this portion of our work. Whatever, the 10-meter driver placement or the number of new 10-meter directors, the performance of this portion of the array remains almost constant. Among all of the beams that we shall analyze, the Moxon forward gain varies by under 0.2-dB, with an average front-to-back variation across the band of only about 2 dB. (The front-to-back average is skewed by the fact that its value rises to a very high peak value near but not on the mid-band frequency.) Equally tame are the SWR curves with a maximum variation of less than 0.2 across the 15-meter band. Although one might wish to tweak the design slightly to place resonance at the band center in any final design, this move is wholly unnecessary to obtain excellent Moxon performance across the band with all variations.

Version C1 of the array—where C simply means compromise—places the 10-meter driver behind the 15-meter driver. As well it uses a single 10-meter director forward of the Moxon rectangle for 15. **Fig. 4-3** outlines the design and also shows the approximate position of the boom center. It is likely that one might be able to connect the boom to a support mast slightly behind the center point an avoid interactions with the driver while still providing a strong support.

The dimensions and performance values for this array appear in **Tables 4-1**, 4-**2**, and 4-**3**. The values are very similar to those appearing in Chapter 2 of this series.

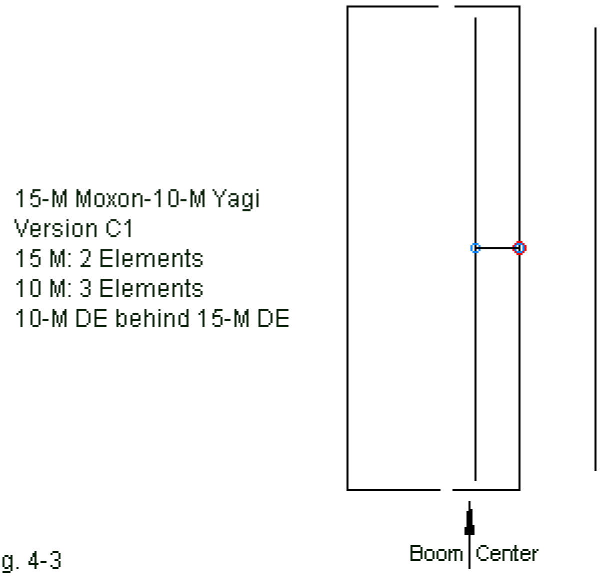


Fig. 4-3

Table 4-1. 15-meter Moxon—10-meter Yagi C1 dimensions

15-meter Moxon Rectangle

Element	Diameter	Length
Both	0.865”	30”
	0.75	66
	0.625	84
	0.5	100
	0.375	105
Ref tail	0.375	39.5
DE tail	0.375	28.5
Gap		6
Total width		74

10-meter Yagi

Element	Diameter	Length
Both	0.75”	24”
	0.625	48
	0.5	72
DE tip	0.375	101
Dir tip	0.375	96

Boom length: 8.92’ plus ends

Array	Spacing	Notes:
15-m ref	0”	1. Length values progressive from element center.
10-m DE	55	2. Reference Moxon dimensions to Fig. 4-3.
15-m DE	74	3. Spacing values references to parallel elements.
10-m Dir	107	4. Driver-to-driver TL = 125 Ω, VF 1.0
		5. Feedpoint: 15-meter (Moxon) DE

Table 4-2. Moxon-Yagi C1: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.47	6.20	5.96
Front-to-back ratio dB	19.48	31.13	23.04
Feedpoint Z (R +/- jX Ω)	46.4 – j11.6	59.3 – j8.3	70.7 – j7.3
50-Ω SWR	1.29	1.26	1.44

Table 4-3. Moxon-Yagi C1: 10-meter performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.07	6.52	7.05	0.98
Front-to-back ratio dB	12.72	15.25	14.88	2.53
Feedpoint Z (R +/- jX Ω)	41.3 – j8.2	40.2 + j3.7	35.6 + j19.9	5.7 + j28.1
50-Ω SWR	1.30	1.26	1.77	

This version of the simple 2-band beam is the smallest in terms of boom length. A 10’ length of tubing would provide more than enough room for the elements and any mounting plates used, with a bit of room for end caps to keep the boom from whistling in the wind. See Chapters 1 and 2 of this series for additional construction ideas.

The 15-meter performance data is typical of Moxon rectangles, and the 15-meter patterns shown in Chapter 2 are adequate to portray the azimuth patterns that we can expect. The 10-meter data is more interesting because it reveals an SWR curve that seems to be shifted to favor the lower end of the band. At the same time, the front-to-back ratio data appears to favor the upper end of the band. The contrast in the data lines reveals one of those conflicts calling for a compromise set of element positions and lengths. If we had set the dimensions for the best SWR curve, we would have obtained the data in **Table 4-3a**.

Table 4-3a. Moxon-Yagi C1: 10-meter performance: best SWR curve

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	5.47	5.84	6.31	0.84
Front-to-back ratio dB	10.58	13.24	17.99	7.41
Feedpoint Z (R +/- jX Ω)	50.4 – j6.7	49.0 – j1.5	43.6 + j7.6	6.8 + j14.3
50-Ω SWR	1.14	1.04	1.24	

The 50-Ω SWR curve for the alternative dimensions is outstanding—and does not affect the 15-meter performance of the Moxon. To obtain this excellent SWR performance, we lost two other facets of the compromise performance values. First, the forward gain level dropped considerably—by more than 0.6-dB. In addition, the front-to-back curve shows an extreme amount of variation, rising from a very poor level at the low end of the passband to a very good value that occurs only at the upper end of the passband.

In contrast, we might also design the array for better overall front-to-back values. We can improve the average value by about a full dB relative to the values in **Table 4-3**, but in the process the SWR curve drifts even further off center and reaches a value of 2:1 at the upper end of the passband. Although we might present such a design, we must always allow for construction variables and leave room for variations between the computer design and a prototype. Pressing a design to the limit on paper is one very good way of ensuring that a prototype will pass over the limit.

Version C2 of the array retains the 10-meter driver position behind the Moxon driver. But it adds an additional director ahead of the existing director. In fact, both directors require custom positions and lengths to reach the relevant compromise performance. **Fig. 4-4** provides the outline of the revised array. Although the new director lengthens the boom, it does not resolve the mechanical problem of the mast connection point. In fact, one might judge that the new director only makes matters worse.

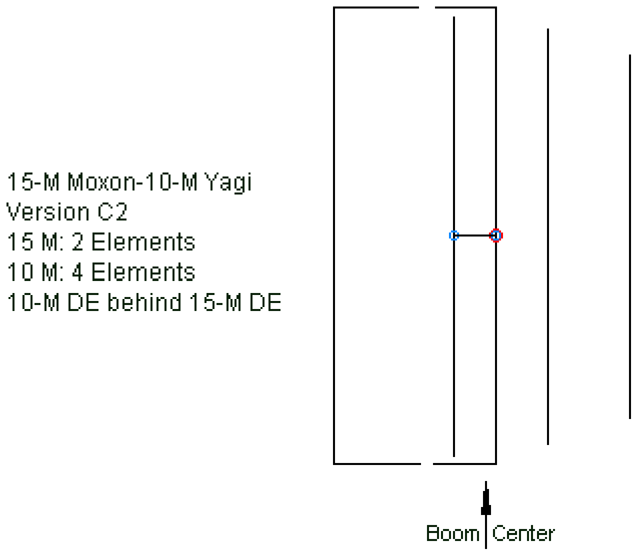


Fig. 4-4

The dimensions for the revised array appear in **Table 4-4**. Note the changes in the position and length of the first director relative to version C1. The revised design would require a 12' boom to handle the elements and their mounting assemblies to keep them well insulated and isolated from the boom.

Despite the extensive changes to the 10-meter elements, the net result for 15-meter operation is a set of tiny changes that we could not operationally detect. **Table 4-5** shows the performance in free-space terms. The patterns of Chapter 2 remain valid for this implementation of the Moxon rectangle—and indeed, for all of the versions of the Moxon-based 2-band antenna. At most we find a slight shift in the operating point for the lower-band array, but well within the likely construction variables that any prototype would reveal.

Table 4-4. 15-meter Moxon—10-meter Yagi C2 dimensions

15-meter Moxon Rectangle			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.865”	30”	Both	0.75”	24”
	0.75	66		0.625	48
	0.625	84		0.5	72
	0.5	100	DE tip	0.375	101
	0.375	105	Dir 1 tip	0.375	95.5
Ref tail	0.375	39.5	Dir 2 tip	0.375	83.5
DE tail	0.375	28.5			
Gap		6			
Total width		74	Boom length: 11.33’ plus ends		

Array	Spacing
15-m ref	0”
10-m DE	55
15-m DE	74
10-m Dir 1	98
10-m Dir 2	136

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

Table 4-5. Moxon-Yagi C2: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.55	6.30	6.07
Front-to-back ratio dB	18.97	31.61	25.52
Feedpoint Z (R +/- jX Ω)	48.5 – j14.2	61.3 – j12.4	71.9 – j12.8
50-Ω SWR	1.34	1.35	1.52

Table4- 6. Moxon-Yagi C2: 10-meter performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.36	6.69	7.07	0.71
Front-to-back ratio dB	12.60	14.25	14.87	2.27
Feedpoint Z (R +/- jX Ω)	38.6 – j7.6	39.9 + j3.4	38.6 + j16.2	1.3 + j23.8
50-Ω SWR	1.36	1.27	1.57	

The 10-meter sample performance numbers in **Table 4-6** show many of the same traits as the values for the single-director model (C1). The SWR curve is slightly skewed toward the lower end of the band while the front-to-back values favor the high end of the band. Note that the added director increases gain only at the lower end of the band while broadening the SWR curve somewhat, mostly due to a reduction in the total range of feedpoint reactance. However, as we shall see for many cases of adding an extra director, the average front-to-back value across the band is slightly lower than for the initial array.

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Version of the antenna marked CC place the 10-meter driver ahead of the 15-meter driver. Model CC1 uses a single director and therefore roughly corresponds to model C1, but with a longer boom. CC1's outline appears in **Fig. 4-5**.

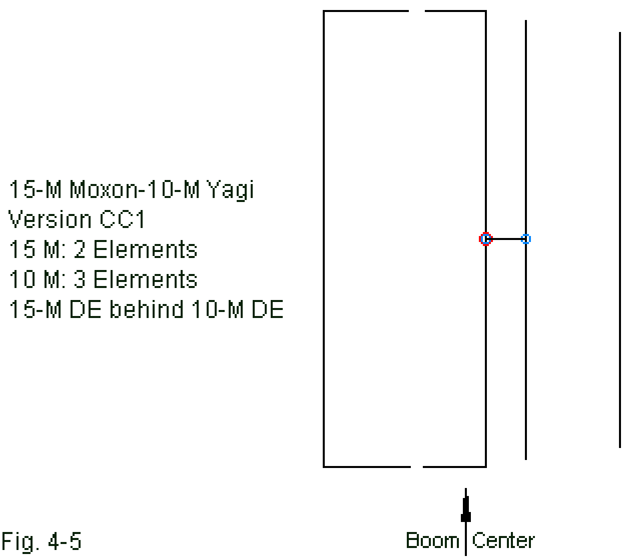


Fig. 4-5

As the dimensions in **Table 4-7** reveal, the single-director, forward driver array requires the same boom length (just under 12') as the double-director, rearward driver model. The repositioning of the 10-meter elements changes the driver length by a total of only 1" and the director length does not change at all. However, the compromise director position is closer to the driver than in model C1, although there is no partially active 15-meter element between the 10-meter elements.

Table 4-7. 15-meter Moxon—10-meter Yagi CC1 dimensions

15-meter Moxon Rectangle			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.865"	30"	Both	0.75"	24"
	0.75	66		0.625	48
	0.625	84		0.5	72
	0.5	100	DE tip	0.375	101.5
	0.375	105	Dir tip	0.375	96
Ref tail	0.375	39.5			
DE tail	0.375	28.5			
Gap		6			
Total width		74	Boom length: 11.33' plus ends		

Array	Spacing	Notes:
15-m ref	0"	1. Length values progressive from element center.
15-m DE	74	2. Reference Moxon dimensions to Fig. 4-5.
10-m DE	93	3. Spacing values references to parallel elements.
10-m Dir	136	4. Driver-to-driver TL = 125 Ω, VF 1.0
		5. Feedpoint: 15-meter (Moxon) DE

The performance tables may prove surprising—not in the 15-meter table (**4-8**), but the 10-meter table (**4-9**). We might have expected performance improvements, but they prove to be scant.

Table 4-8. Moxon-Yagi CC1: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.53	6.26	6.01
Front-to-back ratio dB	18.28	28.65	23.84
Feedpoint Z (R +/- jX Ω)	46.2 – j8.2	57.6 – j5.0	67.2 – j3.7
50-Ω SWR	1.21	1.18	1.35

Table 4-9. Moxon-Yagi CC1: 10-meter performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	5.83	6.39	7.07	1.24
Front-to-back ratio dB	13.80	18.73	18.33	4.93
Feedpoint Z (R +/- jX Ω)	37.9 – j18.5	37.8 + j0.2	34.4 + j23.6	3.5 + j42.1
50-Ω SWR	1.65	1.32	1.95	

Although we do obtain some apparent improvement in the front-to-back curve (which peaks at about 28.8 MHz), we find a decline in gain at the low end of the passband. As well, the SWR curve is sharper than we found with either C1 or C2. From our work with models C1 and C2, we can recognize that the settings of the dimensions represent a compromise, but one that seems to teeter at the edge of multiple facets of performance. Perhaps the one major factor favoring this design is that the boom center falls well behind the 15-meter driver and is not far from the center of mass for the array.

If we add a second director to the array, we lose the convenient position for the mast, as shown in the outline for model CC2 in **Fig. 4-6**. The dimensions appear in **Table 4-10**. The boom length increases to over 15'. After examining the values for the element positions and lengths, we shall be interested in seeing if we obtain any added performance, especially relative to the original model, C1

Table 4-10. 15-meter Moxon—10-meter Yagi CC2 dimensions

15-meter Moxon Rectangle			10-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.865"	30"	Both	0.75"	24"
	0.75	66		0.625	48
	0.625	84		0.5	72
	0.5	100	DE tip	0.375	101.5
	0.375	105	Dir 1 tip	0.375	93.75
Ref tail	0.375	39.5	Dir 2 tip	0.375	83.75
DE tail	0.375	28.5			
Gap		6			
Total width		74	Boom length: 15.08' plus ends		

Array	Spacing
15-m ref	0”
15-m DE	74
10-m DE	90
10-m Dir 1	132
10-m Dir 2	181

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig. 4-6.
3. Spacing values references to parallel elements.
4. Driver-to-driver TL = 125 Ω, VF 1.0
5. Feedpoint: 15-meter (Moxon) DE

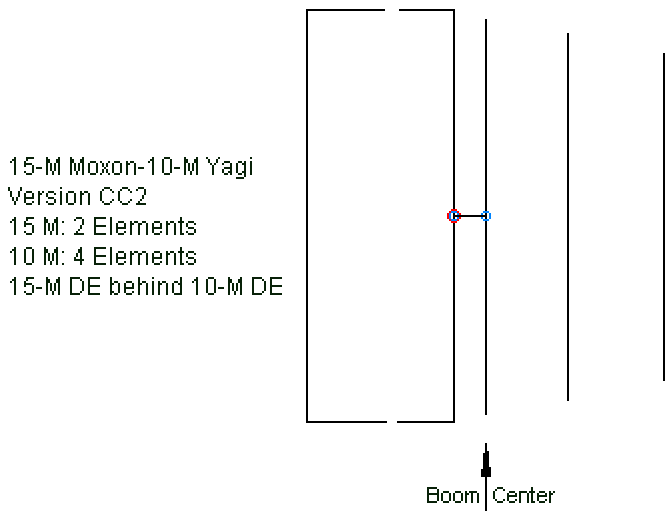


Fig. 4-6

Table 4-11. Moxon-Yagi CC2: 15-meter performance

Frequency	21.0	21.225	21.45
Free-space Gain dBi	6.65	6.40	6.17
Front-to-back ratio dB	18.90	33.04	25.49
Feedpoint Z (R +/- jX Ω)	46.6 – j10.4	57.2 – j7.2	65.9 – j5.5
50-Ω SWR	1.25	1.21	1.34

As shown in **Table 4-11**, the 15-meter performance remains very stable. The values are consistent with all other tables for this array in the dual-band array. More interesting are the 10-meter values shown in **Table 4-12**. In fact, the numbers are in line with those for model C2 on a shorter boom and not very much better than those for the original array.

Table 4-12. Moxon-Yagi CC2: 10-meter performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.33	6.73	7.16	0.83
Front-to-back ratio dB	12.88	13.64	13.38	0.76
Feedpoint Z (R +/- jX Ω)	38.2 – j18.6	44.6 + j3.2	49.0 + j25.2	10.8 + j43.8
50-Ω SWR	1.65	1.14	1.66	

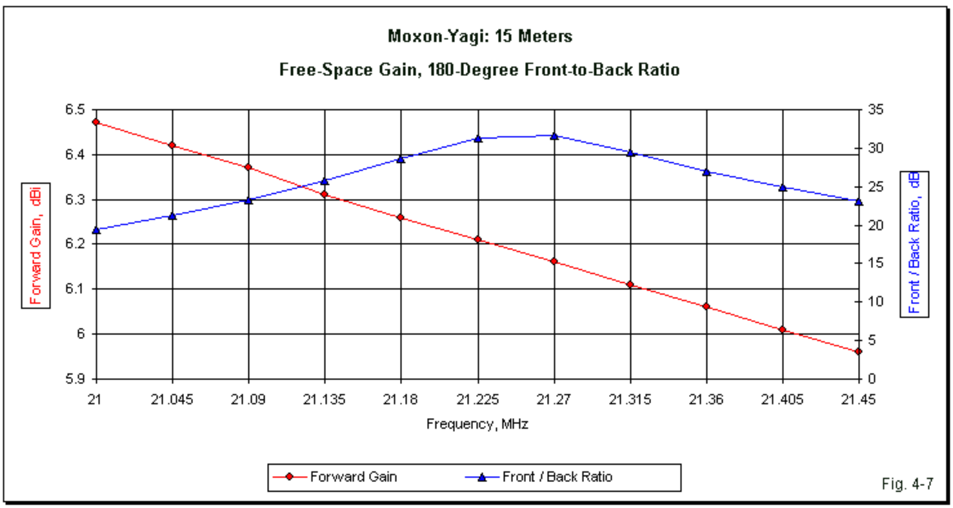


Fig. 4-7

One way—but certainly not always the best way, to evaluate the performance of a multi-band array is to see if the performance values for the two bands are comparable. (There are a number of larger tri-band arrays in which the 10-meter performance is much better on average than the performance on the lower two bands. There are significant reasons for this situation, one of which is the requirement for using control directors for 10 meters that bracket the lower-band elements, especially the 20-meter elements, which can control the frequency range of the 10-meter passband.) Therefore, it may be useful to graph the 15-meter performance of the Moxon rectangle. Since the performance numbers are so tightly grouped, we may use a frequency sweep for model C1 to stand in for the entire set of models on the lower band. **Fig. 4-7** provides a sweep of the free-space forward gain and the 180° front-to-back ratio. As we noted in Chapter 2, the Moxon rectangle shows a gain curve typical of driver-reflector parasitic arrays, with declining gain as the operating frequency rises. Between 21.225 and 21.27 MHz, we would find a relatively sharp peak in the front-to-back ratio. However, even without final tweaking, the lowest front-to-back value on 15 meters is above 18 dB, a high value for a driver-reflector parasitic array.

Fig. 4-8 reviews the feedpoint conditions across the 15-meter band. The graph shows the feedpoint resistance, reactance, and 50-Ω SWR value. The reactance values are all capacitive, suggesting that the array driver is a bit short. However, the SWR curve is at odds with the front-to-back curve, which places its peak above the center of the band.

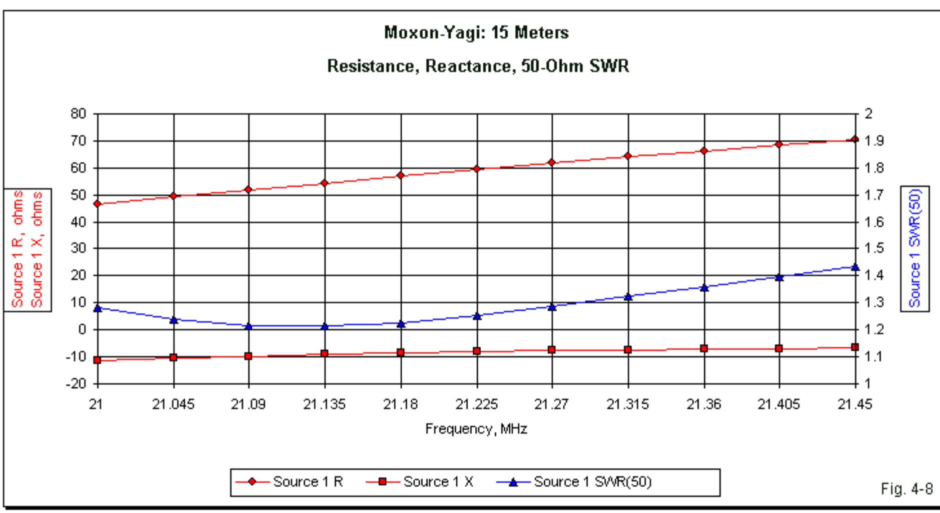


Fig. 4-8

If we look only at the gain figures for all four models on 10 meters, we can simultaneously compare them to each other and to the 15-meter gain values. **Fig. 4-9** provides the data, with indications of which model belongs with which line. Note that the gain values tend to converge at the upper end of the first MHz of 10 meters and show their greatest divergence at the lower end of the band. Given the requirements for compromise element positions and lengths, the models with the driver forward of the Moxon element show both the highest and lowest gain values. The two models with an extra director show the highest gain values, with the original model (C1) having intermediate values.

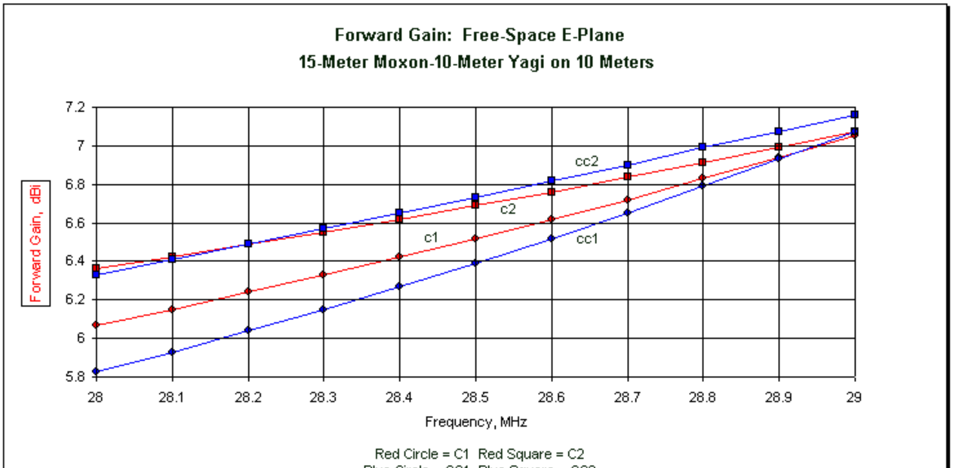


Fig. 4-9

The greatest range in gain is only about a half-dB, and it occurs only at the lower end of the operating passband. Otherwise, the range of gain values is consistent with the values that we can derive from the Moxon rectangle, despite the fact that each element set favors opposite ends of its band. The graph suggests that gain would not be a significant reason for choosing among the possible designs.

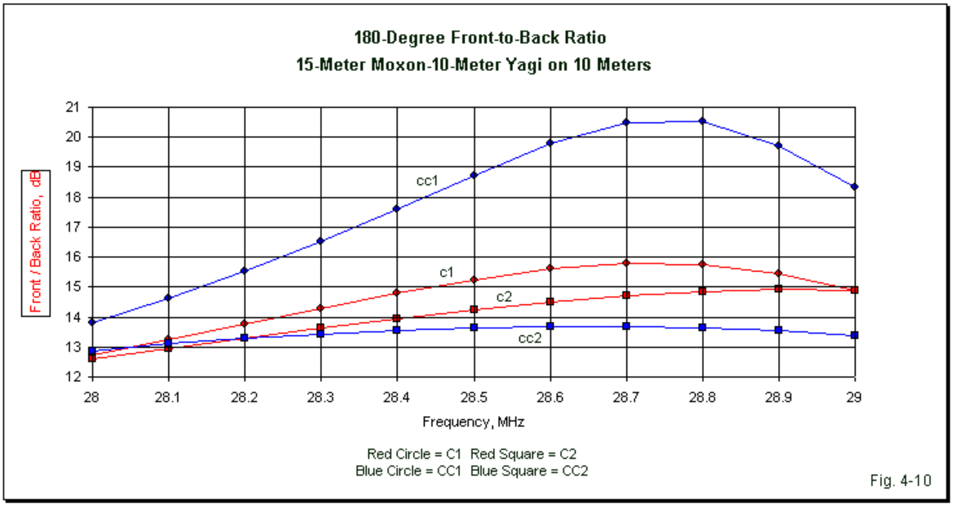


Fig. 4-10 provides a similar graph of the front-to-back ratio values for all four versions of the 10-meter elements. The sweep shows a clearly superior model in this category, CC1, the 1-director forward-driver model that requires a 12' boom. The performance level, especially in the middle and upper regions of the passband, is more consistent with the superior front-to-back performance on 15 meters. In addition, model CC1 showed a boom center that appeared to be the most ideal of all of the models in this set. Despite these advantages, model CC1 also showed the lowest gain levels of all of the models in the set.

In contrast, model C1, the original model with a single 10-meter director and the driver behind the Moxon driver, holds an intermediate position in the gain and the front-to-back graphs. C1's front-to-back ratio is better than we find with a driver-reflector Yagi and has a wider bandwidth than we might find with a driver-director Yagi. Unlike the troublesome boom center of the 2-director models, the position on C1—while not optimal—appears adaptable for an adequate mast mounting point.

Before we settle the issues at hand, let's also examine the 50-Ω SWR curves for all four arrays. **Fig. 4-11** provides the data lines. The curves immediately show two facets of the design work. Both models with forward 10-meter drivers have sharper SWR curves than the two curves for models with rearward 10-meter drivers. In general, broader curves allow the most room for construction variables while still assuring acceptable performance below the SWR limits (in this case, 2:1).

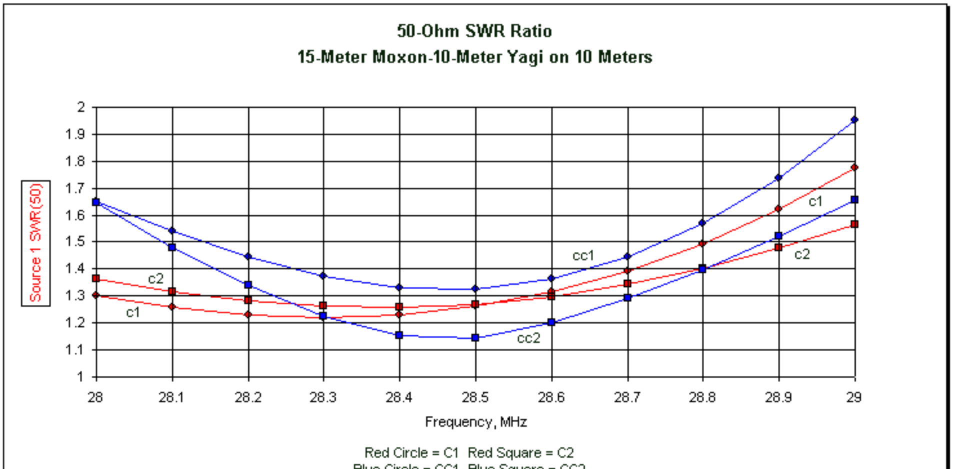


Fig. 4-11

Both curves for models with multiple directors (C2 and CC2) show broader and less skewed curves than their respective single-director counterparts. Despite the lower minimum SWR value for CC2, model C2 with its rearward 10-meter driver shows better SWR values at both ends of the 10-meter passband. In general, only the curves for model CC1 shows an upper-end value about which one might have some concern. The concern is not that we cannot adjust the elements to keep the SWR curve below the 2:1 limit. Instead, the concern is that in adjusting the position or the length of one or more elements to achieve this goal, we may degrade the array's performance in some other category. For example, model C1 cannot afford any further losses in gain at the low end of the 10-meter band.

The final decision will rest largely on the set of requirements that one brings to the design exercise—assuming that it occurs in preparation for a subsequent building exercise. In general, there appears to be nothing that favors the addition of a second director in this array. The gain does not go up significantly, and the front-to-back ratio actually decreases, given the requirements for a usable set of 50-Ω SWR values across the entire first MHz of 10 meters.

If a 12' boom is acceptable, model CC1 with its forward-position 10-meter driver offers the best front-to-back ratio and the easiest challenge for mast connection. However, its SWR and gain curves are less than stellar. In contrast, model C1, with a rearward 10-meter driver, offers the shortest boom with slightly better gain values and lesser front-to-back numbers. As well, the mounting position behind the 10-meter driver may still require some mass compensation to place the center of mass at the mast connection point. How one weights the various factors in making a decision is a measure of both site restrictions and operating needs.

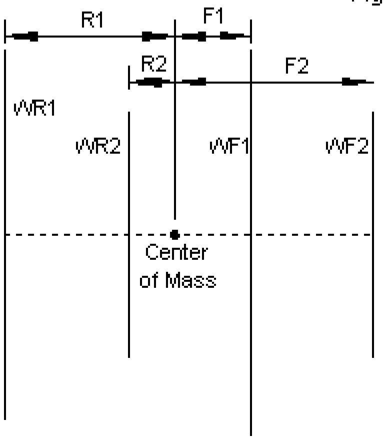
Of course, one may also create variations of any of these four designs. As I noted during the discussion, other dimensions are possible and they will result in changes to the operating curves over the passband. As well, one may also re-design any of the arrays to focus on a narrower passband. In multi-band beam design, there is no single final answer, but only designs that are better and worse for some specified set of limitations of passband, SWR, boom length, mast mounting, site area, and numerous other variables that we bring to the design table.

Boom Center vs. the Center of Mass

In these notes, we have used the center of the boom length as a stand-in for the array center of mass. Ultimately, the balance point for a multi-element array is the center of mass, which may or may not coincide with the boom center. When the array has an odd number of elements, the two positions hardly ever match.

The most precise way to determine the center of mass is to build a prototype and then to find the balance point along the boom. In many design exercises, you may need to estimate that position before making all of the final decisions that determine the exact masses involved. There is a fairly straightforward method that, with a little trial and error, can result in a reasonable approximation of the center of mass. **Fig. 4-12** provides a guide.

Fig. 4-12



Estimating the Center of Mass

If the designated point is the center of mass (CM), then the sum of the rearward weights (WR1 and WR2) times the rearward distances (R1 and R2) will equal the sum of forward weights (WF1 and WF2) times the forward distances (F1 and F2). That is,

WR1*R1 + WR2*R2 = WF1*F1 + WF2*F2

The values of the distances will vary with the boom length and the trial positions that we might use to zero in on an effective value for CM. The units of measure do not matter so long as we use the same units throughout. Indeed, in the absence of specific weight information on the proposed elements, we can use relative values based on the element lengths and diameters. For example, for the Yagi elements specified in these models, setting the 10-meter elements at 1 and the 15-meter elements at 1.5 is a usable approximation for initial purposes. Later, we can replace those values with others based on the weight of the tubing and center assemblies. In the end, the final determination must await the prototype.

Conclusion

I had hoped to cover both the simple Moxon-Yagi combination and the more complex Yagi-Yagi combination in this episode. However, each of the 4 Moxon-Yagi combinations has required enough compromises to extend the discussion into a full chapter. If we wish to perform a similar comparison among the more complex Yagi-Yagi combination for 15 and 10 meters, we shall need one more session.

It is important that we give the Yagi-Yagi combination due space. We have found some interesting trends associate with the Moxon-Yagi array. For example, the addition of an extra director appears to broaden the SWR curve, but lower the average front-to-back ratio. As well, the gain improvements wrought by an added director appear small and serve mostly to smooth gain performance across a specified passband. In addition, placing the 10-meter driver ahead of the Moxon 15-meter driver resulted in sharper SWR curves. What we cannot tell from using only the present dual-band antenna models is whether these are general trends or unique to the combination of Yagi upper-band elements and lower-band Moxon rectangle elements.

So we still have a bit of work to do.

5. Alternative 15-Meter-10-Meter Yagi Design Examples

As we experimented with the 10-meter driver placement and the use of an additional director, we found some interesting trends associate with the Moxon-Yagi array. For example, the addition of an extra director appears to broaden the SWR curve, but also to lower the average front-to-back ratio. As well, the gain improvements wrought by an added director appear small and serve mostly to smooth gain performance across a specified passband. In addition, placing the 10-meter driver ahead of the Moxon 15-meter driver resulted in sharper SWR curves. What we cannot tell from using only the Moxon-Yagi dual-band antenna models is whether these are general trends or unique to the combination of Yagi upper-band elements and lower-band Moxon rectangle elements.

Therefore, we need to apply the same general exercise to the more complex Yagi-Yagi array composed of a 3-element wide-band Yagi for 15 meters and a comparable set of Yagi elements for 10 meters. Our initial designs used 4 elements on 10 meters, but the terms of the present work require us to try both 4- and 5-element 10-meter Yagis.

We shall keep in mind the same fundamental questions that we asked at the beginning of Chapter 4. First, there is the boom-to-mast mounting position question. A design that requires that we place the mast between the two driver elements is generally undesirable, if not completely unacceptable. The potential for contacting or disrupting the 125-Ω transmission line that connects the two drivers is too great. As well, we wish to avoid adjusting the array center of mass by the use of dead weight inserted into one or the other end of the boom.

Second, we wish to know the relative merits, if any, of placing the 10-meter driver behind or ahead of the 15-meter driver, to which we attach the main 50-Ω feedline. The question acquires additional significance in light of the Moxon-Yagi results that yielded sharper SWR curves for the same number of elements with the 10-meter driver in front. Essentially, we do not know if the difference in the

SWR curves relative to 10-meter driver placement is a consequence solely of the placement or whether the close proximity of the 10-meter driver ends to the Moxon driver tails had a bearing on the broader SWR curves with the rearward placement scheme.

10-meter driver placement and the addition of an extra director had a major affect on the Moxon-Yagi small array. For example, forward driver placement and an extra director increased the boom length from about 9' to just over 15'. In our initial design work with the Yagi-Yagi combination, we tried to keep the boom length less than 20'. We know in advance that we shall exceed 20' in some designs to come, but the total degree of boom lengthening will be less important. The smallest boom will be about 19' long (plus ends to support the mounting plates), while the longest will be less than 22'. Unless the difference is critical to some construction limitations, the degree of lengthening is almost too small to have any significance.

Finally, we shall again explore—although in a somewhat cursory way—the general situation of using compromise element positions and lengths as these matters affect the more complex structure of the Yagi-Yagi combination. Undoubtedly, we shall uncover seemingly incompatible trends in the performance curves with some adjustment, and the available adjustments will not allow us to peak all performance values simultaneously. Chapter of what we wish to learn is whether the compromises that we need to make result in acceptable performance curves across the 10-meter band.

The Moxon-Yagi combination and the Yagi-Yagi combination share a significant common trait. Both begin with a wide-band 15-meter element set. The 3-element 15-meter Yagi, described in both Chapter 1 and Chapter 3 of this series provides very acceptable performance relative to a monoband version of the antenna and other monoband 15-meter Yagis that we might design. We sacrificed a minimum of gain while still obtaining a wide-band 50-Ohm SWR curve compared to monoband designs that require a matching network on the same boom length. The front-to-back ratio is nearly 20 dB across the 15-meter band. Even more significant for our design work is the fact that the 15-meter Yagi proves to be very stable in the presence of 10-meter elements. As a result, the

15-meter dimensions require either no change across the range of experiments with 10-meter elements or at most a change of only 1" at the ends of the parasitic elements to re-center the operating passband. In addition, the 10-meter elements provide sufficient forward stagger gain to bring the 15-meter performance to a par with the best of monoband 15-meter beams with the same boom length.

The use of a stable 15-meter lower-band array provides us with both an advantage and a limitation relative to these experiments. The advantage is that we shall not need to change any 15-meter element position or length in the course of making adjustments to the 10-meter elements. In terms of the general compromise question, this procedure is also a limitation. We are limited to making the 10-meter elements fit with fixed 15-meter elements. Hence, in the very large picture of compromise settings, we shall not know if giving up a small amount of 15-meter performance might allow us to make a sizable improvement in one or another category of 10-meter performance. Our reasons (or excuses) are two. First, holding the 15-meter array in a fixed condition allows us to see more clearly the trends that we create by adjusting the 10-meter elements. We do not need to face the ambiguity of which adjustment—the one to a 15-meter element or the corresponding one to a 10-meter element—is the source of the performance change. Second, the designs that we shall explore are not finished or final products. Some one or more of them may be suitable for construction, but our goal is mainly an appreciation and understanding of the parameters that surround the design of multi-band upper HF parasitic arrays.

All of the 15-10-meter Yagi combinations in this episode will use the same element taper schedule shown in Chapters 1 and 3. This schedule ensures a sturdy beam, should one wish to build one. As well, the use of an unchanging taper schedule allows a direct comparison among all of the Yagi-Yagi designs in this series. Since NEC-4 will be our design vehicle, we shall presume that all elements are well insulated and isolated from any conductive boom material. As a result, the construction methods must be comparable to those shown in Chapter 1. Connecting any parasitic element directly to a conductive boom will require suitable adjustments to the element's length, although its position on the boom will normally not require change.

We shall use the same plan of attack that we employed with the Moxon-Yagi combination. We shall divide the antenna designs into two groups, those with the 10-meter driver behind the 15-meter driver (designated C) and those with the 10-meter driver forward of the 15-meter driver (designated CC). For each case, we shall begin with a single director ahead of the 15-meter director (designated 1) and then add a second forward director (designated 2). The result is a matrix of 4 compromise designs, although we shall introduce one variation to illustrate the trends and effects of selecting a different compromise among possible element dimensions.

15-Meter 3-Element Yagis Combined with 4- and 5-Element 10-Meter Yagis

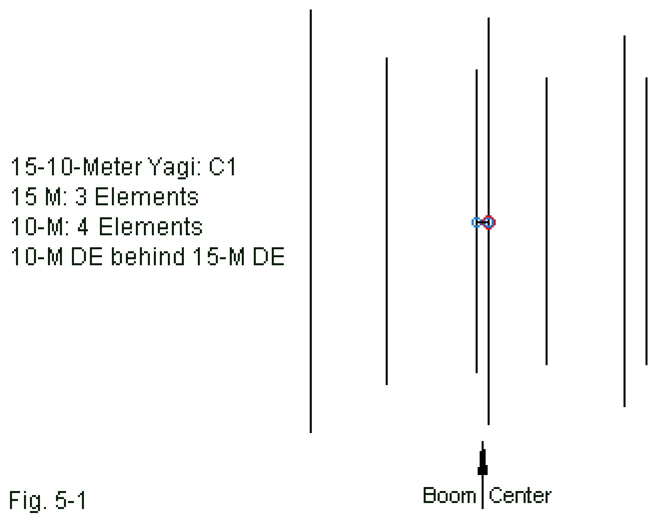


Fig. 5-1

The first of our comparative models (C1) uses 4 elements on 10 meters with the 10-meter driver to the rear of the 15-meter driven element. **Fig. 5-1** outlines the array, while **Table 5-1** provides the dimensional details. The array is a replication of the one that we discussed in Chapter 3 of this series. Of the 4 versions under discussion, it requires the shortest boom at just under 19’. The first director is nearly centered between the 15-meter elements, while the forward

10-meter director is quite close to the 15-meter director. The element taper schedule is rated for better than 100 mile-per-hour wind loads without ice on the elements and less depending upon the winter build-up. Note that in this design, the boom center occurs between the two driver elements—just where we would prefer that it not be.

Table 5-1. 15Y3-10y4-C1: 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	97

Array	Spacing	Notes:
15-m ref	0	1. Length values progressive from element center.
10-m ref	51.5	2. Reference dimensions to Fig. 5-1.
10-m DE	112	3. Spacing values progressive from rear element.
15-m DE	120	4. Driver-to-driver TL = 125 Ω, VF 1.0
10-m dir 1	160	5. Feedpoint: 15-meter (Moxon) DE
15-m dir	212	
10-m dir 2	227.5	Boom Length: 18.96’ plus ends

Table 5-2 and **Table 5-3** provide the modeled free-space performance information for the array on 15 meters and on 10 meters, respectively. The 15-meter numbers will be very similar for each band, with a total gain variation among versions of only about 0.2-dB. The gain curves will be smooth with a band-edge-to-band-edge variation in the 0.2 to 0.25 dB range. The SWR curve is very shallow, as indicated by the very modest change in both the source resistance and the source reactance across the band.

Table 5-2. 15Y3-10y4-C1: 15-M Performance

Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	7.82	7.92	8.06	0.24
Front-to-back ratio dB	21.48	21.33	18.04	3.44
Feedpoint Z (R +/- jX Ω)	41.6 – j9.1	42.0 + j0.6	42.2 + j12.0	0.6 + j21.1
50-Ω SWR	1.31	1.19	1.36	

Table 5-3. 15Y3-10y4-C1: 10-M Performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	7.31	8.20	9.02	1.71
Front-to-back ratio dB	17.82	18.67	15.02	3.65
Feedpoint Z (R +/- jX Ω)	36.6 – j21.5	44.4 + j10.6	58.9 + j34.1	22.3 + j55.6
50-Ω SWR	1.79	1.29	1.89	

The C1 model on 10 meters exhibits a considerable change in gain across the band, the penalty for selecting dimensions that enhance the front-to-back ratio. The settings do not yield the maximum ratios possible, since gain tends to decrease as the front-to-back ratio increases. As well, the settings yield a reasonably well-centered SWR curve. Compare the change in the source resistance and reactance across the band in comparison to values for 15 meters. Even halving the values to compensate for the different width of each band still yields a sharper 10-meter curve, a situation that is usually—but not universally—true of upper-band elements on a multi-band beam. Nevertheless, the gain performance on average exceeds the values for 15 meters, while the front-to-back performance is weaker but normal for upper-band performance.

If we add a second director to model C1, we obtain model C2, as outlined in **Fig. 5-2**. The second director moves the boom center forward of the 15-meter driver, and the center of mass is not far from the boom center. As shown in **Table 5-4**, the dimensions for both directors that are forward of the 15-meter director differ considerably from the length of the single forward director in model C1. The required boom is just about 21' long.

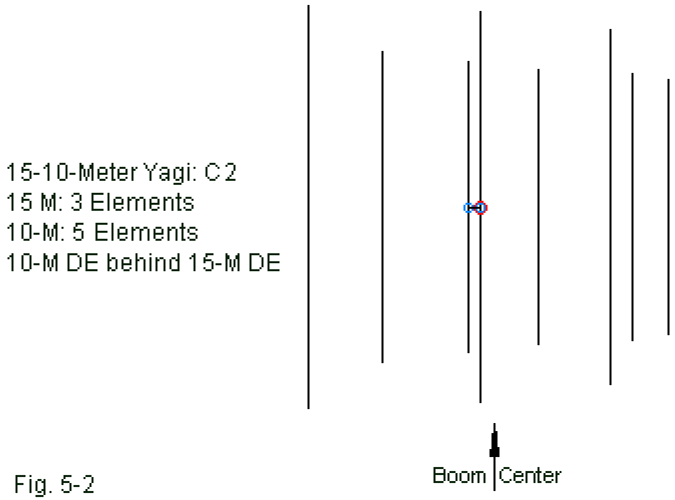


Fig. 5-2

Table 5-4. 15Y3-10y5-C2: 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. 5-2.
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

The performance values for the revised array appear in **Table 5-5** and in **Table 5-6** for each band. A user could not in operation distinguish the performance report for 15 meters for either model so far.

Table 5-5. 15Y3-10y5-C2: 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	

Table 5-6. 15Y3-10y5-C2: 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	

On 10 meters, we may note several interesting comparisons between models C1 and C2. First, the gain at the lower end of 10 meters increases, although the high-end gain remains nearly constant. The front-to-back ratio values decrease slightly and show a bias toward the upper end of the band. Like the Moxon-Yagi combinations, the added director appears to improve the SWR curve for the same type of driver positioning. The source resistance and reactance change are only about 2/3 as great as those for the C1 model.

Unlike the Moxon-Yagi combinations that placed the boom center in the "no-mast" zone, adding a director to the Yagi-Yagi assembly not only positions the boom center in a generally good region, but the smoother gain values across the band (or the improvement in low-end gain) and the broader SWR curve may be reason enough to select this version, despite the slightly lower front-to-back values and the longer boom. However, user needs will dictate the final comparative assessment.

Model CC1 moves the 10-meter driver forward of the 15-meter driver, as shown in the **Fig. 5-3** outline sketch. The initial version of this array uses a single director ahead of the 15-meter director, with the unfortunate result of moving the boom center to the region between drivers. The required boom is just over 20' long, as shown in **Table 5-7**.

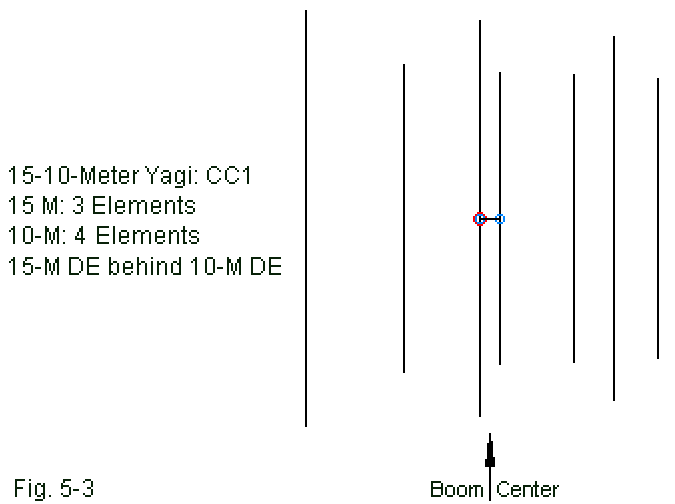


Fig. 5-3

Table 5-7. 15Y3-10y4-CC1: 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	106
Ref tip	0.5	143	DE tip	0.5	100.5
DE tip	0.5	137	Dir 1 tip	0.5	98.75
Dir tip	0.5	125	Dir 2 tip	0.5	96.4

Array	Spacing
15-m ref	0
10-m ref	67
150-m DE	120
105-m DE	134
10-m dir 1	184
15-m dir	212
10-m dir 2	242

Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 5-3.
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: 20.17’ plus ends

Table 5-8. 15Y3-10y4-CC1: 15-M Performance

Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	7.92	8.03	8.18	0.26
Front-to-back ratio dB	21.27	20.30	17.11	4.16
Feedpoint Z (R +/- jX Ω)	40.2 – j8.8	41.3 + j1.4	42.5 + j13.7	2.3 + j22.5
50-Ω SWR	1.34	1.21	1.40	

Table 5-9. 15Y3-10y4-CC1: 10-M Performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	8.39	8.97	9.12	0.73
Front-to-back ratio dB	17.76	15.93	15.49	2.27
Feedpoint Z (R +/- jX Ω)	44.5 – j3.7	49.4 + j17.7	36.0 + j24.5	13.4 + j28.2
50-Ω SWR	1.14	1.43	1.92	

The movement in the 10-meter driver position also results in a revision of the spacing between 10-meter elements and in their lengths, compared to the elements in model C1 with the rearward 10-meter driver. However, the revised 10-meter driver position requires no change to the 15-meter elements. The modeled performance values appear in **Table 5-8** and in **Table 5-9**. The 15-meter performance numbers remain virtually unchanged from those derived from models C1 and C2. Because the 10-meter elements forward of the driver yield slightly higher forward stagger consequences, we find a slight increase in 15-meter gain as we compare C1 and CC1. However, the amount is only about 0.1-dB.

Moving the 10-meter driver to a forward position allows us to find dimensions that enhance the gain at the low end of the band. The gain change across 10 meters is less than half the value for model C1 and only 2/3 the value of model C2. However, some of the improvement derives from the selection of dimensions from the ones that are possibly usable. The evidence for this fact shows up in the front-to-back values, which favor the low end of the band. The SWR curve also favors the low end of the band, with a somewhat marginal value at 29 MHz. However, with the forward 10-meter driver position, the change in reactance across the band is lower than for either model using a rearward 10-meter driver position.

The final model in our sequence is CC2, shown in **Fig. 5-4**, which uses the forward 10-meter driver position and an extra director. With a 21.6' (plus end allowance) boom, it is the longest of the designs. The boom center is just forward of the 10-meter driver, which would allow a safe boom-to-mast connection. As well, with 4 elements on each side of the indicated position, the center of mass is likely to be reasonably close. Like model C2, model CC2 uses the added director effectively to yield a less challenging mounting situation. **Table 5-10** provides the full details of the arrays dimensions. Note especially the progression of 10-meter directors with respect to both length and inter-element spacing.

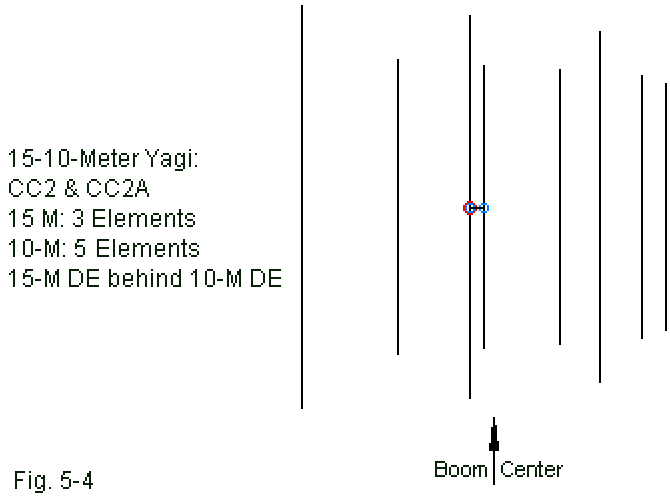


Fig. 5-4

Table 5-10. 15Y3-10y5-CC2: Dimensions

15-meter Yagi

Element	Diameter	Length
Both	0.875”	30”
	0.75	66
	0.625	84
Ref tip	0.5	143
DE tip	0.5	137
Dir tip	0.5	125

10-meter Yagi

Element	Diameter	Length
Both	0.75”	24”
	0.625	42
Ref tip	0.5	105.5
DE tip	0.5	100.5
Dir 1 tip	0.5	98.3
Dir 2 tip	0.5	94
Dir 3 Tip	0.5	87.5

Array	Spacing	Notes:	
15-m ref	0		1. Length values progressive from element center.
10-m ref	68		2. Reference dimensions to Fig. 5-4.
15-m DE	120		3. Spacing values progressive from rear element.
10-m DE	130		4. Driver-to-driver TL = 125 Ω, VF 1.0
10-m dir 1	184		5. Feedpoint: 15-meter (Moxon) DE
15-m dir	212		
10-m dir 2	242		
10-m dir 3	259		Boom Length: 21.58' plus ends

The performance values derived from the array model appear in **Table 5-11** and in **Table 5-12**. The 15-meter values show their anticipated stability. The added director increase the average gain by about 0.1-dB, while the forward 10-meter driver position also increases gain by about 0.1-dB. Hence, with respect to our initial model (C1), the gain is up about 0.2 dB at the center of 15 meters. However, without some slight adjustment to the 15-meter reflector and director, the beam shows a front-to-back ratio bias in favor of the low end of the band. Trimming about 1" from the ends of each parasitic element would bring the array back into a well-centered condition without affect the 10-meter performance.

Table 5-11. 15Y3-10y5-CC2: 15-M Performance

Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	8.03	8.14	8.27	0.24
Front-to-back ratio dB	20.62	19.24	16.35	4.27
Feedpoint Z (R +/- jX Ω)	39.9 – j6.2	41.0 + j4.2	41.9 + j16.5	2.0 + j22.7
50-Ω SWR	1.30	1.25	1.49	

Table 5-12. 15Y3-10y5-CC2: 10-M Performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	8.72	9.09	9.28	0.56
Front-to-back ratio dB	15.36	14.75	16.31	1.56
Feedpoint Z (R +/- jX Ω)	37.9 – j19.2	51.7 + j3.5	35.5 + j15.6	16.2 + j34.8
50-Ω SWR	1.67	1.08	1.65	

The added director of model CC2 does the same general work as it did for model C2 relative to its shorter version. It allows a smoother gain curve with only about a half-dB difference between the band-edge values. As well, it allows a well-center SWR curve that is comparable to the one for model C2, but with a very low mid-band value. Indeed, this model shows the highest gain at 28 MHz of any of the four models that we are examining. Although the front-to-back ratio values are about 5-dB down from the amateur standard for monoband Yagis, the differential in the value across the band is very low.

Model CC2 has enough plus-side merits that it deserves use to illustrate how small changes in the element dimensions can alter the performance in significant ways. Model CC2A has the same outline, but makes changes that are indicated in the dimension set in **Table 5-13**.

Table 5-13. 15Y3-10y5-CC2A: (Alternative to CC2) 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	105.5
Ref tip	0.5	143	DE tip	0.5	100.5
DE tip	0.5	137	Dir 1 tip	0.5	98.3
Dir tip	0.5	125	Dir 2 tip	0.5	94
			Dir 3 Tip	0.5	*86.25*

Array	Spacing	Notes:
15-m ref	0	1. Length values progressive from element center.
10-m ref	68	2. Reference dimensions to Fig. 5-4.
15-m DE	120	3. Spacing values progressive from rear element.
10-m DE	130	4. Driver-to-driver TL = 125 Ω, VF 1.0
10-m dir 1	184	5. Feedpoint: 15-meter (Moxon) DE
15-m dir	212	
10-m dir 2	242	
10-m dir 3	*256*	Boom Length: *21.33’* plus ends

By altering only the position and length of the most forward 10-meter director, we can modify the performance curves. The changes are small. The variation moves the most forward director back by 3” and shortens its length by 1.25” on each end. The performance results appear in **Table 5-14** and **Table 5-15**.

Table 5-14. 15Y3-10y5-CC2A: 15-M Performance

Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	8.01	8.12	8.25	0.24
Front-to-back ratio dB	20.77	19.44	16.50	4.27
Feedpoint Z (R +/- jX Ω)	40.0 – j6.6	41.8 + j3.9	41.8 + j16.1	1.8 + j22.7
50-Ω SWR	1.31	1.24	1.48	

Table 5-15. 15Y3-10y5-CC2A: 10-M Performance

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	8.58	8.99	9.23	0.65
Front-to-back ratio dB	16.11	15.66	16.49	0.83
Feedpoint Z (R +/- jX Ω)	37.4 – j21.4	47.6 + j3.4	36.4 + j19.8	11.2 + j41.2
50-Ω SWR	1.76	1.09	1.74	

As we would expect, the 15-meter numbers change only by enough to prove that they are not simple copies of the last set. The closer position and shorter length of the most forward driver is enough to reduce the 10-meter gain by a numerically more noticeable amount, but an amount that would be operationally undetectable. The maneuver also raises the minimum SWR value at the band center and sharpens the curve relative to the initial settings for CC2. What we gain for these small costs is an even smoother front-to-back ratio curve with a nearly constant value across the wide span of 10 meters. Again, which performance categories receive precedence depends mostly on the requirements that we bring to the design exercise. However, the variation between models CC2 and CC2A demonstrates once more that with certain fixed design elements, such as the 15-meter elements, many adjustment trends will oppose each other. The designer has to select the most acceptable ones for a given set of communications and construction goals.

We may best compare some of the properties that we have noted, along with others, by exploring some relevant frequency sweep graphs of relevant performance values. As a review, the 15-meter 3-element values for gain and front-to-back ratio appear **Fig. 5-5**. The graph uses model C1, but the values for the other models are too close to require multiple lines.

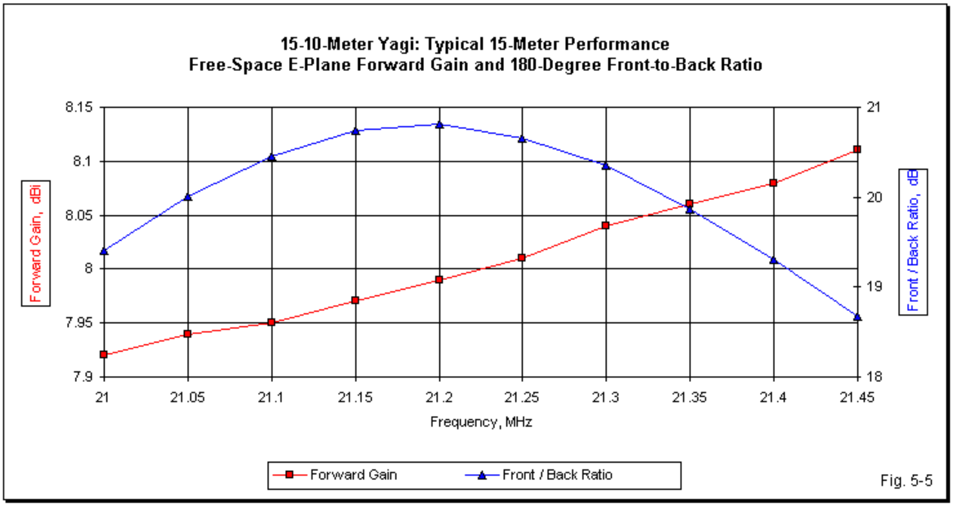


Fig. 5-5

The free-space forward gain curve has the expect rise in value with increases in the operating frequency within the passband. (At a point above the upper end of the passband, the forward gain will rapidly fall, pass through zero, and show up as gain in the reverse direction. At this point, the former reflector is too long to play almost any role in determining performance, and the former director will be long enough to function as a reflector for a 2-element Yagi.)

The curve for the front-to-back ratio shows a slight downward drift in the peak frequency relative to the same antenna used as a monoband Yagi. To re-center the curve and produce almost equal front-to-back values at both band edges, one may trim the parasitic elements by a small amount. For C1, the trimming will be less than an inch per element end. Since the sample numerical values in the tables suggest further drift for the most complex versions of the array, an additional half-inch trim may be necessary. In terms of deriving satisfactory operational performance from the 15-meter elements in any version of the beam, the trimming is optional.

Fig. 5-6 provides data on the resistance, reactance, and 50-Ω SWR at the feedpoint on 15 meters. Note that the SWR minimum value is lower than the mid-band frequency and that the driver reactance is inductive for at least 2/3 of the band. It is possible to trim the 15-meter driver, but you should take this step only after setting the parasitic elements for the best sweep curves. In many instances, the parasitic trimming will yield small changes in the driver impedance sweep so that you will not need to trim the driver at all.

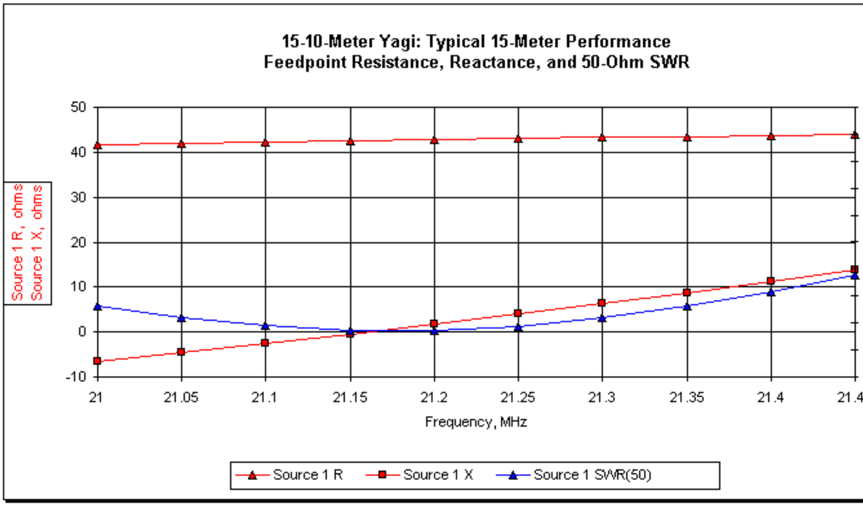


Fig. 5-6

The greatest differences appear in comparative graphs of performance values for the 10-meter section of the array. **Fig. 5-7** provides the free-space forward gain curves for all of the variations that we have discussed, including both CC2 and CC2A. Unlike the 10-meter Yagi elements associated with the Moxon rectangle, the Yagi-Yagi combination produces a small but distinct improvement in forward gain when we add the new director to the array using either 10-meter driven element position.

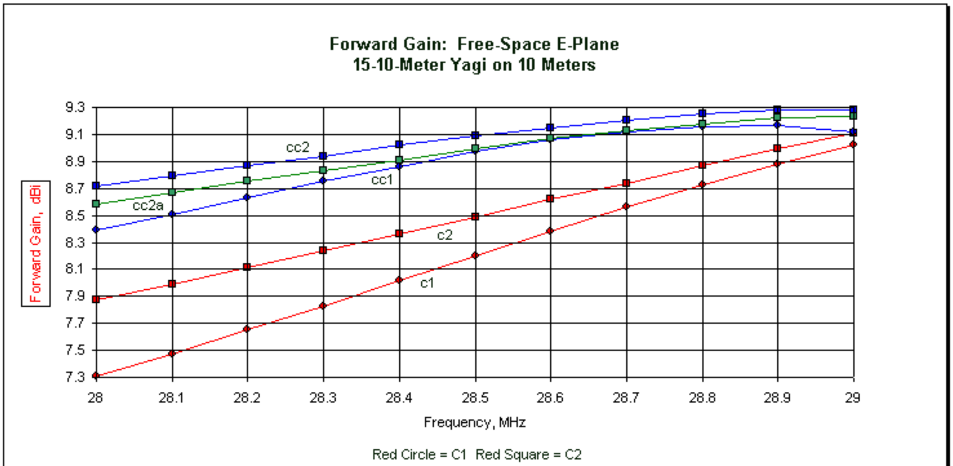


Fig. 5-7

The comparable graph of Moxon-Yagi options suggested that we would obtain no significant gain improvements using either a rearward or a forward 10-meter driver position. This trend does not hold for the Yagi-Yagi combination that we have been exploring. C1 and C2, the two arrays with a rearward 10-meter driver position, show significantly lower gain potential than even the shorter of the arrays with a forward driver position. From the perspective of forward gain, a forward position for the 10-meter driver is desirable. The forward position for the 10-meter driver also shows another desirable trait: the beams reach their peak gain value within (just barely) the 10-meter passband.

The gain curves also establish a likeness between the simpler array and the present design collection. One useful function of the added director is to raise the gain at the lower end of the band to yield more even performance across the wide 10-meter passband. The director cannot eliminate the upward gain curve, but it can reduce its slope.

When we turn to the 180° front-to-back curves in **Fig. 5-8**, we discover an exercise in abstract art amid the flow of the lines. The differentials among designs do not rest on the relatively simple parameters that we found for the less complex Moxon-Yagi combinations. Model C1, with a rearward 10-meter driver and only one forward director shows the highest peak front-to-back value, but at the upper end of the band, the value rapidly decreases to arrive at the lowest value on the graph. Model C2, with an extra forward director, centers the SWR curve, but at the expense of shifting the front-to-back curve to peak beyond the upper limit of the passband.

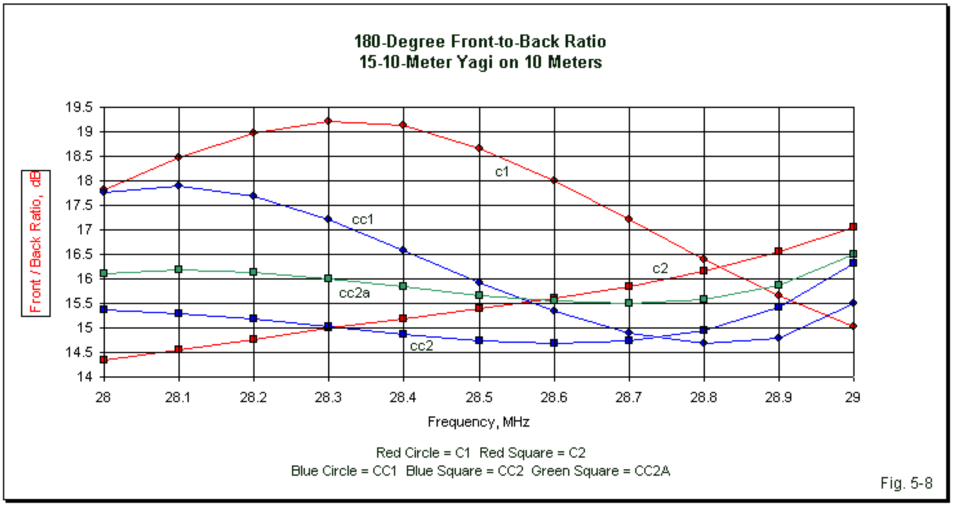


Fig. 5-8

Model CC1, with a single forward director and a forward 10-meter driver, has a somewhat skewed front-to-back curve that favors the low end of the band. That curve places the peak front-to-back value near the low end of 10 meters. The curve also passes through a minimum value and begins to rise again before reaching the upper limit of the passband. Models CC2 and CC2A show relatively level and parallel curves. Although the average values seem modest, they manage to exceed the values of the other models over at least a small portion of the band. At this point, we may compare the gain and the front-to-back curves for models CC2 and CC2A. The latter improves the front-to-back ratio over the former by a more significant amount than we find in its decreased forward gain values.

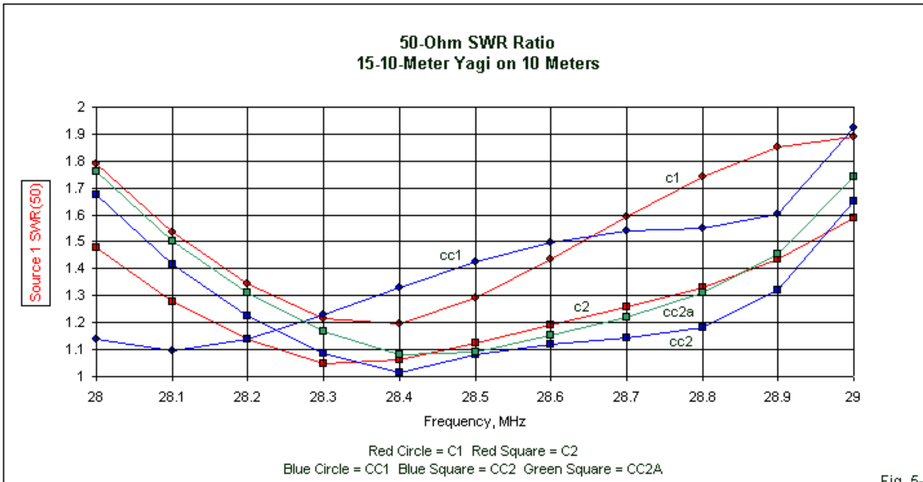


Fig. 5-9

The 50-Ω SWR curves in **Fig. 5-9** all meet the standard maximum value limit of 2:1. C2 has perhaps the broadest curve, although CC2 and CC2A show well-formed curves with only moderate peak values at the band edges. The two models with only a single director forward of the 15-meter director provide the most aberrant curves, indicating lesser control over the feedpoint impedance than we obtain by adding a further director. In contrast to the Moxon-Yagi arrays, the forward position for the 10-meter driver does not show a distinct sharpening of the SWR curves in the Yagi-Yagi combinations. It is therefore likely that the difference that we saw in Chapter 4 resulted from the presence or absence of coupling between the 10-meter driver ends and the 15-meter driver tails.

Unlike the Moxon-Yagi combinations, the Yagi-Yagi arrays show distinct advantages to using a forward position for the 10-meter driver. The forward position yields adequate impedance characteristics. With an added director ahead of the 15-meter director, the front-to-back ratio is more even across the band, even though the average value may be less due to the absence of distinct peaks. In addition, the forward driver position yields higher and more level forward gain values across the 10-meter passband. In the final decision-making process, one is likely to debate the differences between models CC2 and CC2A. Both models appear to allow a boom-to-mast mounting position just forward of the 10-meter driver. The difference lies mostly in whether we prefer the most perfect SWR curve possible or the slightly better front-to-back ratio performance.

Some of the Moxon-Yagi trends reappeared in the Yagi-Yagi exercise, while others did not. Because the Yagi-Yagi combinations use additional elements, including added 15-meter and 10-meter directors, we would be hasty in ascribing all differences to the Moxon rectangle geometry. Nevertheless, the differences and similarities of the trends are instructive and become part of the accumulated experience that makes up the art, craft, and science of designing multi-band parasitic arrays.

Conclusion

This small series of notes has aimed to develop an appreciation and—to whatever degree possible—an understanding of some of the elements that go into the design of multi-band parasitic beams. In Chapter 1, we developed in a broad way the general principles (including pitfalls) involved in both the mechanical; and electrical aspects of the design process. Perhaps the two most significant points involve stability and the most forward element. The lower-frequency element set will be the most stable and undergo the least modification as the overall multi-band design emerges. The stability, including broadband behavior, is much lower on an upper band, where we find a compression of the gain and impedance curves relative to monoband beams of similar arrangement. Upper-band elements are far more sensitive to small changes in position and length than are lower-band elements. Unfortunately, the top band for most upper-HF multi-band arrays coincides with the widest band covered. Moreover, lower band elements normally show greater activity on upper bands than upper-band elements show when one uses a lower band.

To some degree, the activity of lower-band elements at higher frequencies is usable to enhance at least some aspects of performance, such as forward gain.

However, in most cases, a forward lower-band element will act as a reflector to reduce upper-band performance unless the upper band has a director at the front of the overall array. The forward-most upper-band director generally acts less to enhance basic performance than it does to restore control of the upper-band elements over the performance properties in terms of gain, front-to-back ratio, and to some degree impedance bandwidth. As our final two episodes showed, the addition of a second forward director can sometimes enhance performance, if only to smooth out the upper-band performance across its passband. Nevertheless, design revisions showed us that with some elements fixed—such as those for the lower band—revisions that improve performance in one category may result in degraded performance in others.

The smaller and larger sample designs that we showed served to illustrate some of these basic principles in action. For clarity, we used only two bands for the designs. As well, we used direct feeder interconnection via a 125-Ω transmission line between the drivers, with the lower-band driver as the main feedpoint location. As noted, other schemes are not only possible, but in some cases preferable.

6. Small Yagi-Yagi Alternatives to the Moxon-Yagi

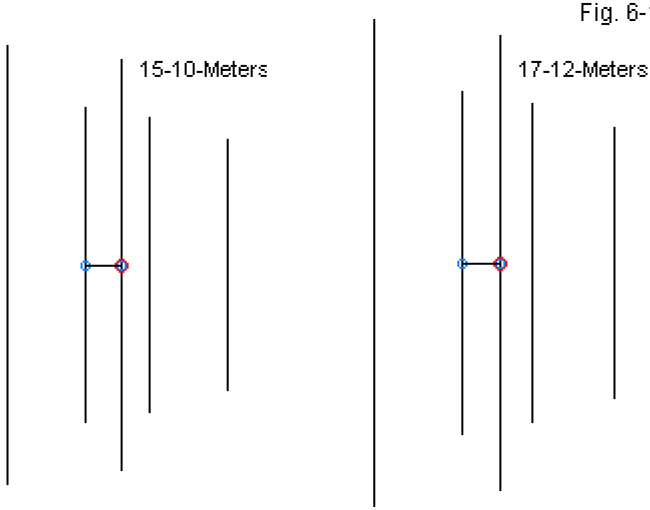
In the exercises exploring the design of 2-band beams, I employed a Moxon rectangle as the lower-band element set. For 15 and 10 meters, the Moxon rectangle presented some interesting challenges, since the 10-meter driver—positioned behind the 15-meter driver—had to be shortened to fit the space between 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. 6-1** 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.

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

Fig. 6-1

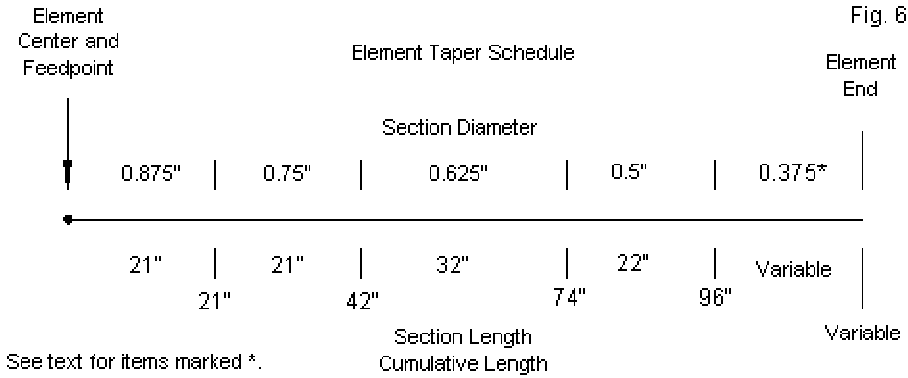


General Outlines: 5-Element Yagi-Yagi
Beams for 15-10-Meters and 17-12-Meters

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. 6-2** 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.

Fig. 6-2



Element Taper Schedule for 15-10-Meter Array

Table 6-1. 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	Notes:
15-m ref	0	1. Length values progressive from element center.
10-m DE	51	2. Reference dimensions to Fig. 6-1.
15-m DE	75	3. Spacing values progressive from rear element.
10-m dir 1	93.5	4. Driver-to-driver TL = 50 Ω, VF 1.0
10-m dir 2	145	5. Feedpoint: 15-meter DE
		6. Boom length: 12’ 1”

Table 6-1 provides the dimensions of the array. For the inner element sections, the length values are the exposed tube length and presume a 2”-3”

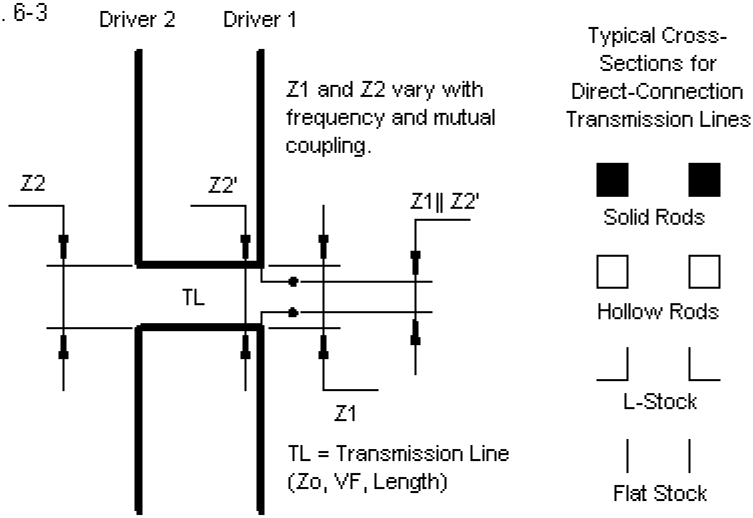
addition for insertion into the next larger tube size—except for the largest tubing size, of course. The tip length values, however, are the half-element cumulative values. Multiply by 2 for the total element length. Subtract 96” (for all but director 2 for 10 meters) to obtain the exposed tip length.

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. 6-3**, 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. 6-3



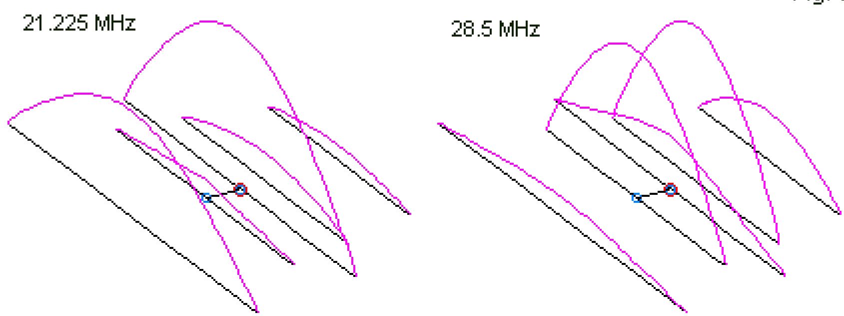
Feedpoint Considerations for Directly Connected Drivers

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. 6-3** 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. 6-4** 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. 6-4



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. 6-5 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.

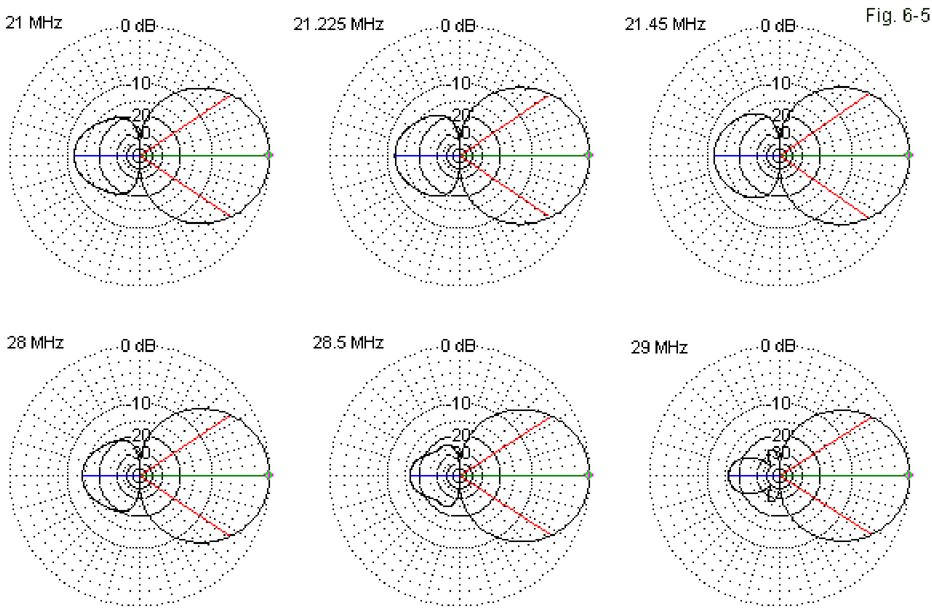


Fig. 6-5

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

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.

Table 6-2 and **Table 6-3** provide the modeled free-space performance data.

Table 6-2. 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 6-3. 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.

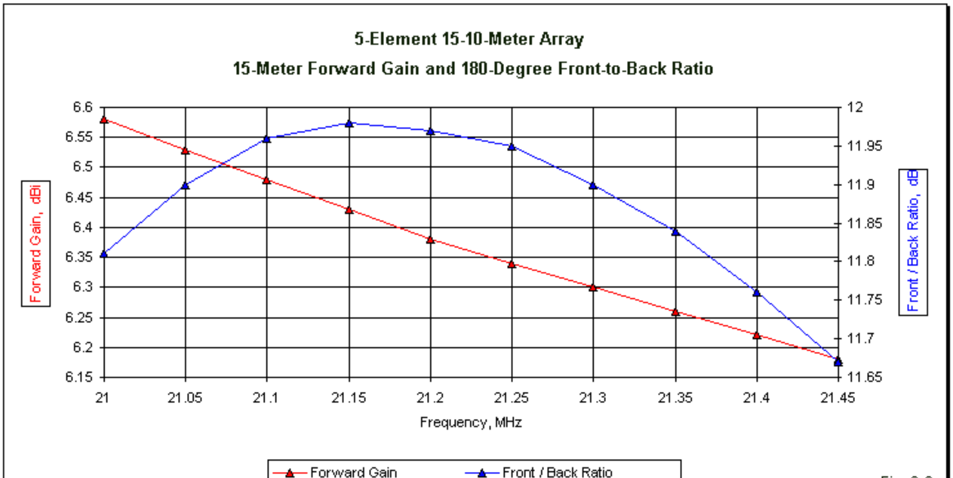


Fig. 6-6

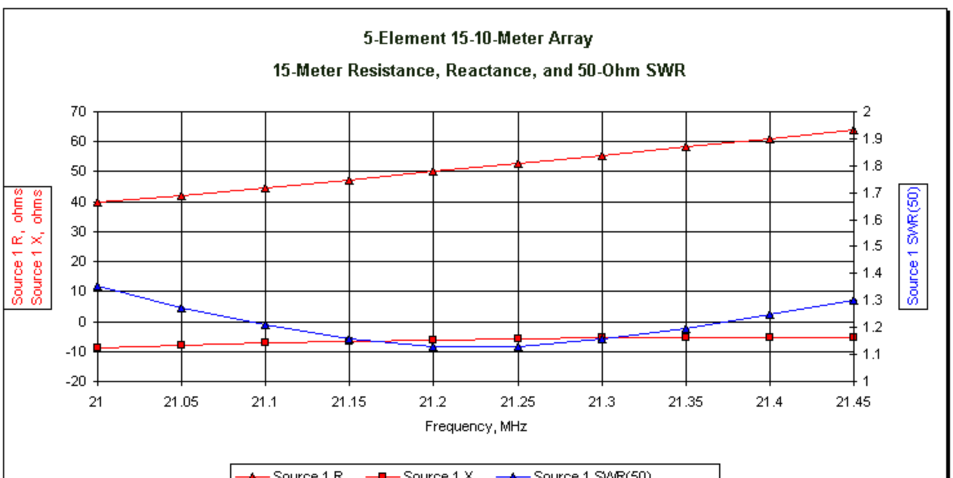
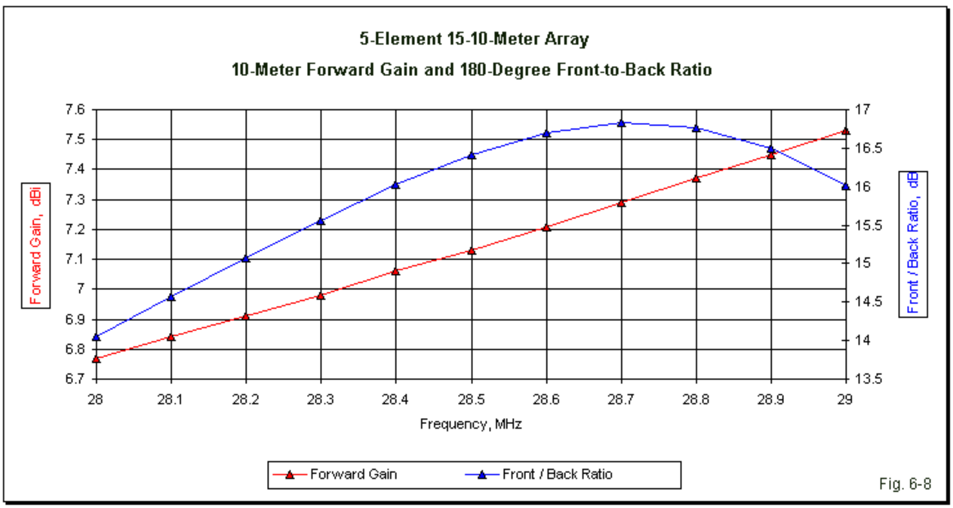


Fig. 6-7

Fig. 6-6 and **Fig. 6-7** provides 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.



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. 6-8**. 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.

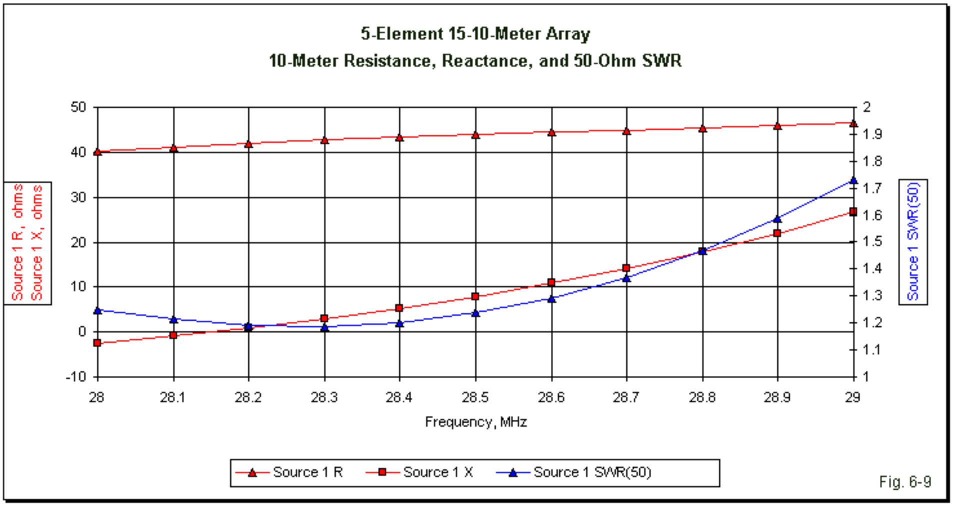


Fig. 6-9

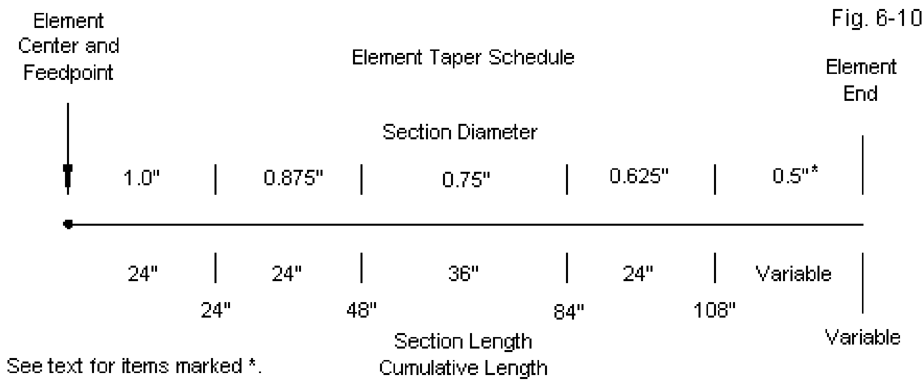
The feedpoint behavior of the 10-meter section shows the reverse trends that we observed in the 15-meter feedpoint values. On 10, the feedpoint resistance is quite stable, changing by only 6 Ω. However, the reactance changes by about 29 Ω, resulting in the curve that appears in **Fig. 6-9**. Trying to 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. 6-10** shows the taper schedule used in the design of this array.

Fig. 6-10



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 6-4**. The same rules for reading **Table 6-1** also apply to this table.

Table 6-4. 2-element 17-meter Yagi—3-element 12-meter Yagi dimensions

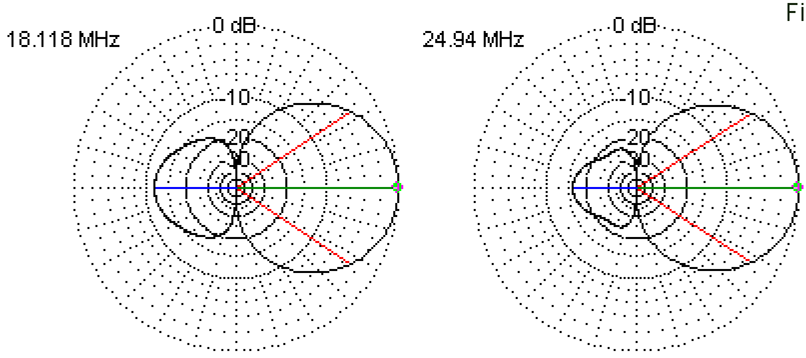
17-meter Yagi			12-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	1.0”	24”	Both	1.0”	24”
	0.875	24		0.875	24
	0.75	36		0.75	36
	0.625	24		0.625	24
Ref tip	0.5	169	Ref tip	0.5	119.5
DE tip	0.5	158	Dir 1 tip	0.5	110.5
			Dir 2 tip	0.5	94.5

Array	Spacing	Notes:
17-m ref	0	1. Length values progressive from element center.
12-m DE	60.7	2. Reference dimensions to Fig. 6-1.
17-m DE	87	3. Spacing values progressive from rear element.
12-m dir 1	109.1	4. Driver-to-driver TL = 50 Ω, VF 1.0
12-m dir 2	165.6	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. 6-11** 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. 6-5**, 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. 6-11



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 6-5** and **Table 6-6** provide the relevant data.

Table 6-5. 2-element 17-meter Yagi—3-element 12-meter Yagi: 17-meter performance

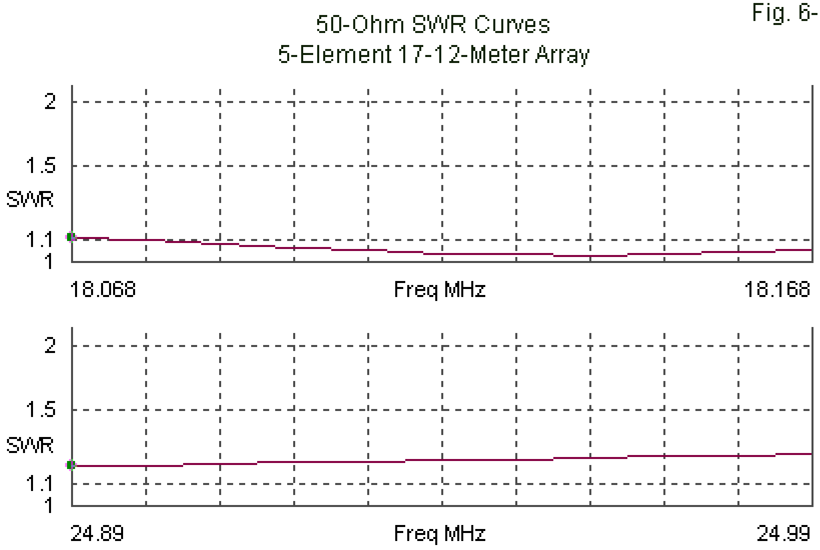
Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.50	6.44	6.39	0.11
Front-to-back ratio dB	11.76	11.81	11.83	0.07
Feedpoint Z (R +/- jX Ω)	45.9 – j2.7	49.2 – j1.7	52.6 – j0.8	6.7 + j1.9
50-Ω SWR	1.11	1.04	1.06	

Table 6-6. 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 6-3**. 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.

Fig. 6-12



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. 6-12 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 needs 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 chapters 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.

Part II: Other Designs
7. MYY-TRI: A Tri-Band Beam

"MYY-Tri" stands for a Moxon rectangle-Yagi-Yagi tri-band array for 20, 15, and 10 meters. We may pronounce the label as "My Try." In effect, the antenna that we shall examine in these notes is a design exercise aimed at seeing if I could apply some of the principles recorded and illustrated in the first 6 chapters of this volume of notes and ideas. Those chapters focused on 2-band beams in order to keep the principles as clear as circumstances permitted. However, most amateurs wish to cover at least three bands with their directional arrays. So I started working on a tri-band beam using a Moxon rectangle for 20 meters, with linear Yagi elements for the two upper bands. The result turned out to be two designs rather than just one, and there are at least 5 notable variations in all.

Be advised from the beginning that these notes cover only the design phase of the process of developing a multi-band beam. There are two facets to this caution. First, although many good monoband Yagis and Moxon rectangles can move directly from a NEC-based design to a working prototype with little or no further field adjustment, multi-band beams tend to require some working of the prototype to set the physical antenna to the performance parameters shown in the design. The close spacing of elements for different bands creates interactions that the models do not always register with precision. In addition, the boom-to-mast assembly is usually near the driven elements, which often creates some interactions that are not within the model at all. Second, the nature of these designs puts NEC at a disadvantage. NEC (either –2 or –4) is most accurate when using the Leeson corrections for HF elements with a stepped diameter structure. Unless, the taper schedule is extremely gentle, even NEC-4 will show slight differences between direct models and models using substitute uniform-diameter elements. However, because the Moxon rectangle used for 20 meters has non-linear elements, the correction system is unavailable. Therefore, the design work used NEC-4 alone. For these reasons, and because my facilities are not adequate to manage a physical prototype of the beam, we must stop at the end of the design work. See Part 1 of the original series on multi-band designs some basic construction suggestions.

Background

The basic tri-bander that we shall discuss provides essentially 2-element Yagi performance on each of the three bands. I shall use 7 elements and benefit to a small degree from the forward stagger effect to place the out-of-band elements—to the degree feasible—at the service of the band in use.

Such beams already exist on the commercial market. Some years ago, I developed the design for a *Moxonized* version of the well-known Force12 C3 antenna. (For further information, see "Moxon-Modifying the C3-Type Tri-bander" at http://www.cebik.com/moxon/c3m.html.) The 7-element beam used a 16' boom. Some time after that design, Optibeam of Germany developed their OB6-3M beam using 6 elements on a 10' boom. The outlines of both beams appear in **Fig. 7-1**, along with the outlines of the designs that we shall explore. The present designs differ in several respects from either previous design. For example, the design based loosely (but not authoritatively) on the C3 retains the Force 12 open-sleeve coupling. Both present designs use direct feedpoint connecting transmission lines. In that regard, they tend to resemble the Optibeam tri-band antenna.

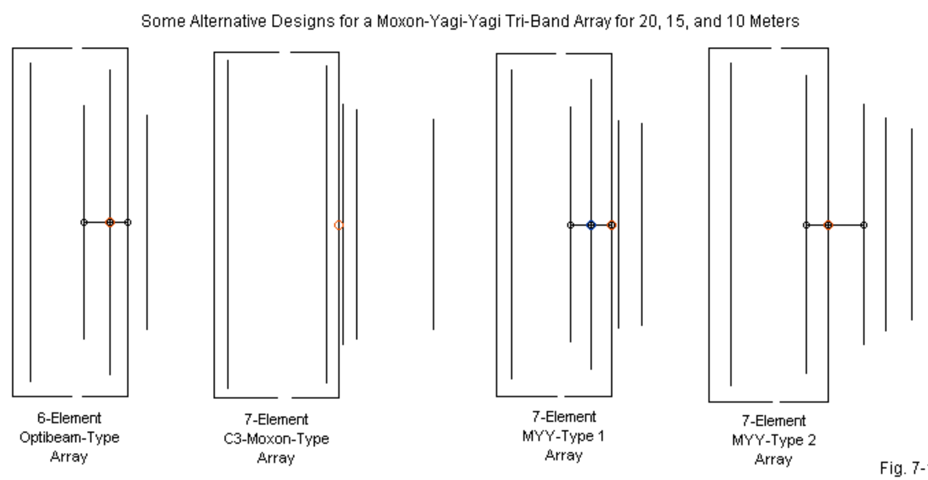


Fig. 7-1

However, the Optibeam design uses 6 elements with the single 10-meter director being a full-size element. Even the version (Type1) of the MYY that uses a similar driver placement has 7 elements, with relatively close spacing and a very significant taper to the lengths of the 10-meter directors. The Type-2 MYY uses a 10-meter driver position that is forward of the Moxon. As well, the tubing used in the present designs is U.S.-standard 6063-T832 tubing that is available in 0.125" diameter increments.

Inevitably, all four designs will use some principles in common, beginning with the Moxon rectangle for 20 meters. In the earlier design work with open-sleeve coupling, I used uniform-diameter Moxon elements for modeling convenience. That work was only to prove the principle. The present design uses a set of tapered-diameter elements applied in the past to the 20-meter design in "Stepped-Diameter Moxon Rectangles for 20 through 10 Meters" (see http://www.cebik.com/moxon/moxstep.html.) The dimensions have been slightly adjusted to compensate for the influence of two other off-band drivers. The Moxon driver (like the 20-meter Yagi driver in the C3) marks a dividing point in arrays designed for good 2-element performance, a division that more complex beams often cannot enjoy. The 15-meter elements nest inside the two 20-meter elements, with some pattern enhancement by lower-level activity on the forward 10-meter element or elements. Most and sometimes all of the 10-meter elements are forward of the 20-meter driver, eliminating to a large degree the potential for the higher-band elements to act as reflectors, a condition that reduces performance unless the designer applies further compensation.

Since I do not have an authoritative model of the Optibeam array and since the modified C3 array was also based on approximation, I shall not try to present any performance numbers for the commercial arrays. Needless to say, the original (linear-element) C3 beam has been highly successful, and the Optibeam Moxon-Yagi design is well worth consideration for a reduction in side-to-side element length without a loss of performance. The German beam is a paradigm of sturdy construction designed to survive European winters, and its only drawback for some U.S. users is its weight.

Feeding and Modeling

In all of the variations on the basic tri-band design, the Moxon rectangle remains fixed. After initial variations from the monoband dimensions, I made no further adjustments, although in some variations of each type, further small changes are justified to raise the feedpoint impedance from its monoband value. However, the amount of these changes is likely to fall within the same range as the changes required in converting the designs to a physical antenna. As well, I limited the increment of element length change to 0.25” per half element. A commercial design might use increments as small as 0.1”.

The performance of the Moxon rectangle does not vary from its monoband values by an operationally significant amount. The peak front-to-back ratio and the monoband resonant impedance occur about 1/3 the frequency span from the low to the high end of 20 meters. In a monoband rectangle, the front-to-back ratio and the SWR values are about equal at the band edges. Because the composite feedpoint impedance of the entire array is more complex, the SWR curves will not reflect this design decision. However, the front-to-back ratio remains reasonably well centered in the band. For 15 meters, the 2 linear elements form a driver-reflector Yagi, again, affected in small ways by the surrounding elements. As with virtually all multi-band beams, the rates of change in performance are higher than we would find in a monoband version of a 15-meter Yagi. On 10 meters, we have a 3-element Yagi with no reflector. The two directors provide performance that is able to cover all of 10 meters. The 2-director system used in these designs uses moderately close spacing. The forward-most director is shorter than one might usually expect. Its function is less to increase gain than it is to control the operating bandwidth of the array with respect both to the pattern shape and the feedpoint impedance. Hence, mid-band 10-meter performance remains under 7 dBi in free space.

Feeding the array relies on low-impedance direct transmission lines from the main feedpoint (to which we connect the feed cable) and the adjacent driver elements. Connecting-line characteristic impedances may range from about 50 Ω to 70 Ω, and we shall look at both values in the detailed sections on the beam variations. Since the lower limit for the characteristic impedance of lines using round bare conductors is about 80 Ω, the connecting lines must use flat-face conductors composed of square stock, L-stock, or even flat stock. **Table 7-1** lists some calculated values for the required gap between conductors with common stock face widths.

Table 1. Required gap between flat faces of transmission lines for 50 and 70 Ω

Width of flat face	0.25”	0.5”	0.75”
Impedance		Gap	
50	0.051”	0.102”	0.154”
70	0.083”	0.166”	0.249”

The larger gap needed for the higher impedance suggests that it might be easier to construct. However, it is more likely that any physical prototype should allow for some gap adjustment to arrive at the best SWR curves on each band above 20 meters.

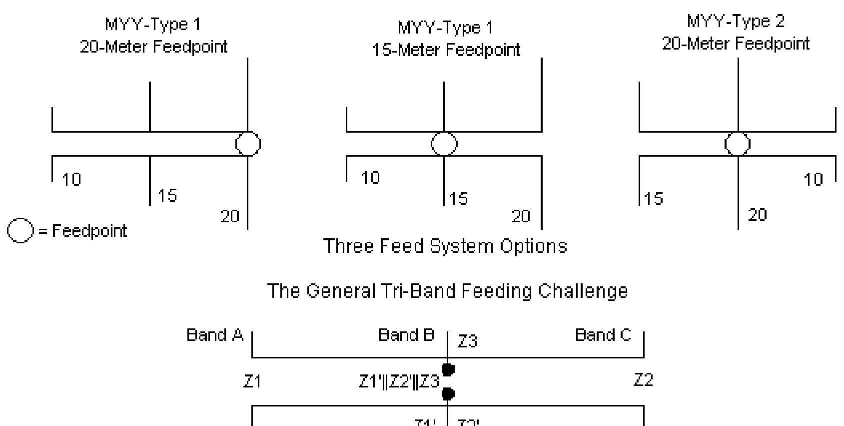


Fig. 7-2

In addition to the variation in the connecting-line characteristic impedance, the two types of tri-band designs offer different connection systems among the elements. If the main cable goes to the 20-meter driver in a Type-1 array, then the lines form a daisy chain to the 15-meter driver and finally the 10-meter driver. The left sketch in **Fig. 7-2** shows this arrangement. For a similar driver configuration, Optibeam runs the main cable to the 15-meter driver, with a line to the driver on each side, as shown in the center sketch. We shall explore this option using the 7 elements of the MYY-Tri design to see what differences (if any) that this arrangement makes. On the right in the figure, we can see the Type-2 array feed system. By running the cable to the 20-meter driver, we automatically have a "centered" feedpoint with lines to the aft 15-meter driver and to the fore 10-meter driver.

The lower portion of the figure shows one of the reasons why a tri-band array becomes somewhat more difficult to design than a 2-band beam. The impedance at the junction with the feedline is a parallel value composed of the impedance of the beam on the active band and the transformed impedances of the off-band drivers (where "off-band" means a band other than the one being used). In theory, if we use a low-impedance line and drivers with low impedances when active, then the higher impedances that they show when another band is in use will also appear at the parallel junction of the lines. It is possible to design a tri-band beam using higher line impedances, but they tend to reduce the predictability of the impedances of the off bands at the parallel junction. As well, the impedance transformations may result in narrower SWR bandwidths on some bands. Therefore, a low-impedance system tends to provide the widest operating range for each band along with relative ease in design.

Nevertheless, the parallel junction of three drivers tends to reduce the net impedance. For example, the Moxon rectangle in monoband service would show a virtual 1:1 50-Ω SWR between 1/3 and ½ the span between the low and high end of 20 meters. The parallel combination of drivers does not permit this ideal condition. The resistive component of the impedance will be a bit less than 50 Ω, while the reactive component will nowhere pass through zero.

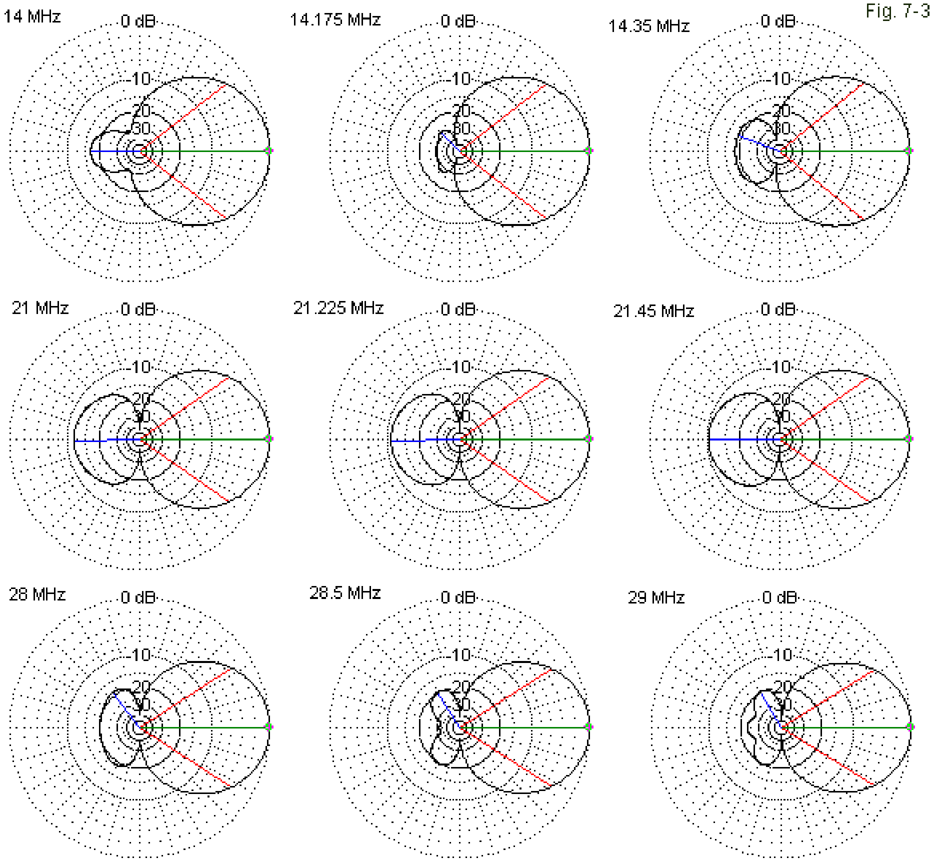
Since the exercise presumes the use of NEC-4 as the pre-prototype design vehicle, the element taper schedule shown in the dimension tables to come determines to a large degree the final length and spacing values. NEC-2 is not adequate, since the Leeson corrections are not available for the bent Moxon elements. The feed system also adds a constraint. To assure the correct combination of transformed impedances at the main junction of the connecting lines, all driven elements in the model must use the same geometry convention, moving either from left to right or from right to left in concert. Mixing driver orientations will result in errors relative to a physical antenna, errors that we cannot correct by simply reversing one or more of the connecting transmission lines.

The design challenges, of course, include all of the phenomena that we recorded for the 2-band designs. The final dimensions represent a compromise among the main performance parameters of gain, front-to-back ratio, SWR bandwidth, and the rates of change of each value across each band. Hence, variations are always possible, even using the elements employed in this exercise. As well, as suggested in the last episode in that series, one may wish to replace the Moxon 20-meter elements with linear Yagi elements, with a small increase in the spacing between the driver and reflector elements for that band.

Type-1 MYY-Tri Designs

All variations of the Type-1 MYY-Tri design, with the 10-meter driver to the rear of the 15-meter and 20-meter drivers, yield very similar patterns. **Fig. 7-3** provides a gallery of typical patterns at the edges and the center of each band. Variations in the driver system may change some of the performance values slightly, but not the pattern shapes.

The 20-meter patterns are typical for any Moxon rectangle set for that band. The forward gain is within about 0.2-dB of 2-element Yagi performance, while the front-to-back ratio runs 5 to 15 dB higher. **Fig. 7-4** shows a typical gain and front-to-back sweep curve set for the Moxon portion of the array. As a driver-reflector parasitic beam, the array's gain curve decreases with rising frequency. The peak front-to-back ratio occurs between 14.15 and 14.20 MHz and so does not show up as a spike using the sweep increments of the graph.



Selected Free-Space E-Plane Patterns: Type-1 Tri-Band Array
10-Meter Driver Rearward, 50-Ohm Feedpoint Connection Line, Cable to 20-Meter Element

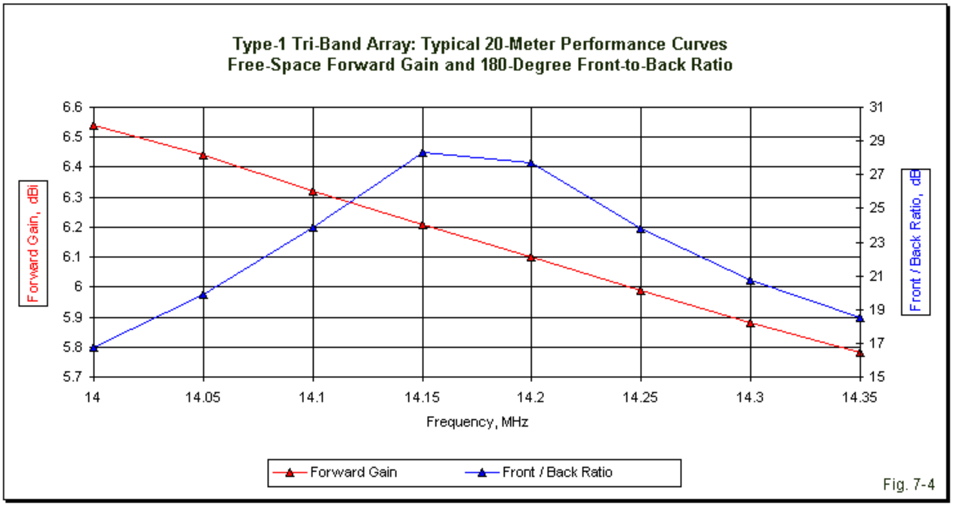


Fig. 7-4

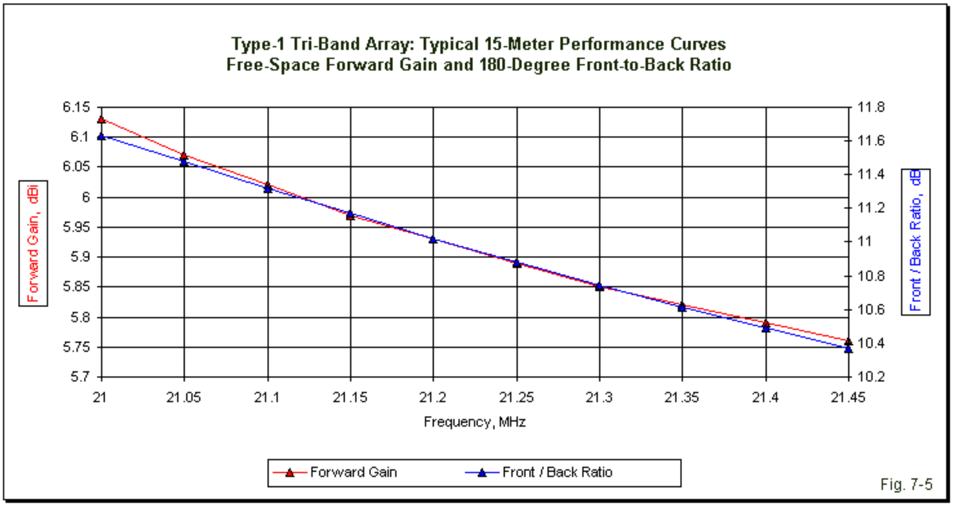


Fig. 7-5

The 15-meter patterns show the typical range for a driver-reflector Yagi, with a modest 10-12-dB range of the front-to-back ratio. **Fig. 7-5** provides the relevant frequency sweep curves for gain and front-to-back ratio. Both curves show very small decreases across the band. The gain curve is a function of the driver-reflector design of the 15-meter section of the array. The front-to-back curve emerges from necessary compromises between performance and SWR bandwidth concerns. Hence, the apparent congruence of the curves is both accidental—since one might peak the front-to-back ratio within the passband—and necessary—in terms of overall array performance.

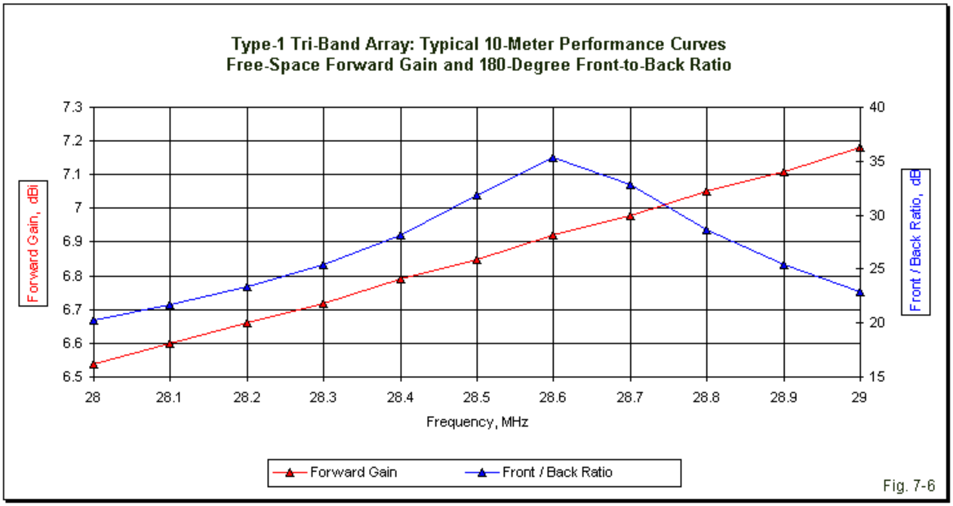


Fig. 7-6

On 10 meters, we find a wider range of rearward pattern changes, partly due to the wider band and partly due to the more rapid change in pattern shape for any Yagi that uses directors. Since the design uses directors, the gain rises with increasing frequency within the passband. The average gain is higher than the values that we obtain for the two lower bands, but shy of what we might obtain in a full-size monoband 3-element Yagi. In all of the MYY-Tri design variations, the goal has been to place the highest 180° front-to-back ratio near the center of the band to equalize as well as feasible the overall front-to-back ratio values at the band edges. The array version used for the sweeps, shown in **Fig. 7-6**, shows the peak value at 28.6 MHz. The value may drift up to 100 kHz in other variations of the design.

We shall examine three variations of the Type-1 MYY-Tri, with the rearward 10-meter driver position. Since the progression of sweep values will not significantly change, we may rely largely on tabular data to see whatever differences arise from varying the feedpoint position and the connecting-line characteristic impedance.

Type 1: 20-Meter Element Feedpoint with a 50-Ω Connecting Line: The dimensions of the basic 7-element MYY design appear in **Table 7-2**. The table lists the element taper schedule for the 20-, 15-, and 10-meter elements by showing the progressive length of each element. All section lengths assume an additional 2” to 3” for insertion into the next larger size tube—except, of course, for the center section. The dimensions are for half elements, with the half not shown being a mirror image of the values listed. The tip sections show the ultimate half-length of each element, with special notations for the unchanging Moxon rectangle. Double the tip value to obtain the total element length. Subtract the sum of the interior half-element section from the tip value to obtain the exposed length of the tip section.

Table 7-2. MYY-Tri Type 1: 20-meter feedpoint, 50-Ω line: dimensions

10-meter Moxon Rectangle			15-meter Yagi			10-Meter Yagi		
Element	Dia.	Length	Element	Dia.	Length	Element	Dia.	Length
Both	1.0”	30”	Both	0.75”	24”	Both	0.625”	36”
	0.875	66		0.625	60	DE tip	0.5	109
	0.75	96	Ref tip	0.5	144	Dir 1 tip	0.5	97.5
	0.625	120	DE tip	0.5	135.25	Dir 2 tip	0.5	94
	0.5	152						
	0.375	159						
Ref tail	0.375	57						
DE tail	0.375	42.75						
Gap		7.25						
Total width		107						

Array	Spacing
20-m ref	0”
15-m ref	19
10-m DE	69
15-m DE	87.5
20-m DE	107
10-m Dir 1	114
10-m Dir 2	136

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig. 7-1.
3. Spacing values reference to parallel elements.
4. 20-m-to-15-m TL = 50 Ω normal.
5. 15-m-to-10-m TL = 50 Ω normal.
5. Feedpoint: 20-meter (Moxon) DE
6. Boom length: 11.33’ plus ends.

The sweep curves used this version of the Type-1 array. You may glean the performance values from those graphs or refer to **Table 7-3**.

Table 7-3. MYY-Tri Type 1: 20-meter feedpoint, 50-Ω line: performance

20 Meters				
Frequency	14.0	14.175	14.35	Δ
Free-space Gain dBi	6.54	6.15	5.78	0.76
Front-to-back ratio dB	16.76	28.99	18.52	12.23
Feedpoint Z (R +/- jX Ω)	31.1 – j14.4	47.6 – j13.5	61.3 – j18.5	30.2 + j5.0
50-Ω SWR	1.81	1.32	1.48	
15 Meters				
Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	6.13	5.91	5.76	0.37
Front-to-back ratio dB	11.63	10.95	10.37	1.26
Feedpoint Z (R +/- jX Ω)	28.5 + j3.2	52.2 + j7.9	79.7 – j2.4	51.2 + j10.3
50-Ω SWR	1.83	1.28	1.55	
10 Meters				
Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.54	6.85	7.18	0.64
Front-to-back ratio dB	20.29	31.92	22.88	11.63
Feedpoint Z (R +/- jX Ω)	45.8 – j21.4	52.8 – j13.8	70.6 – j7.9	24.8 + j13.5
50-Ω SWR	1.30	1.26	1.77	

The Δ column provides a rough measure of the rates of change of performance values across each band. The 20-meter and 10-meter Δ values may be misleading to the degree that they record the 180° front-to-back values.

Therefore, correlate all front-to-back values with the pattern gallery in **Fig. 7-3**. The values are just where we might expect them to fall, given the structure of each band's elements. The contributions of forward stagger effects might be numerically detectable, but would be operationally insignificant. Overall, the band-edge performance values and the relatively low rates of gain change across each band are hallmarks of a competent array.

Modeled 50-Ohm SWR Curves at Feedline Junction Fig. 7-7
Type-1 Tri-Band Array
10-Meter Driver Rearward, 50-Ohm Feedpoint Connection Line,
Cable to 20-Meter Element

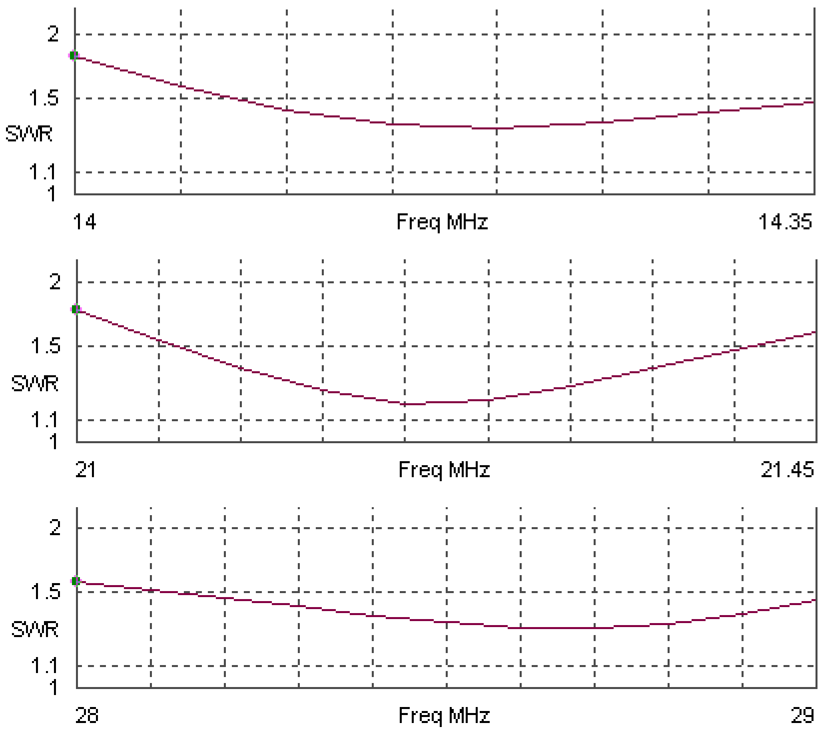


Fig. 7-7 shows the modeled free-space SWR curves for the three bands. All curves fall well within the normal 2:1 SWR standard used for amateur-band antennas. Changing the characteristic impedance of the connecting line among drivers to 70 Ω creates such small changes that I shall bypass this option in these notes. Nevertheless, one might wish to lower the minimum value of the 20-meter Moxon curve and perhaps improve the general values in the 10-meter curve. Therefore, it is useful to check the use of the 15-meter driver as the main feedline connection point and avoid the daisy chain of lines to the 10-meter driver. Optibeam uses this system for its own design that employs only a single 10-meter director. The technique is worth examination.

Type 1: 15-Meter Element Feedpoint with a 50-Ω Connecting Line: Placing the feedline cable on the 15-meter element requires some small changes in the tip lengths of the elements (excluding the constant 20-meter Moxon elements). **Table 7-4** provides a complete dimension set that uses the same rules of reading that applied to **Table 7-2**. The use of a complete dimension table allows one to extract the dimensions as a whole rather than having to gather together pieces from multiple tables to have an experimental set of design dimensions. Comparing dimensions sets will require examination of 15- and 10-meter tips lengths and the element spacing values. In general, all of the required dimensional changes affect the 15-meter element positions and lengths. The 10-meter element set requires no changes, while the 20-meter elements remain fixed as an initial design decision.

Table 7-4. MYY-Tri Type 1: 15-meter feedpoint, 50-Ω line: dimensions

10-meter Moxon Rectangle			15-meter Yagi			10-Meter Yagi		
Element	Dia.	Length	Element	Dia.	Length	Element	Dia.	Length
Both	1.0”	30”	Both	0.75”	24”	Both	0.625”	36”
	0.875	66		0.625	60	DE tip	0.5	109
	0.75	96	Ref tip	0.5	143.5	Dir 1 tip	0.5	97.5
	0.625	120	DE tip	0.5	136	Dir 2 tip	0.5	94
	0.5	152						
	0.375	159						

Ref tail	0.375	57
DE tail	0.375	42.75
Gap		7.25
Total width		107

Array	Spacing
20-m ref	0"
15-m ref	17.5
10-m DE	69
15-m DE	87.5
20-m DE	107
10-m Dir 1	114
10-m Dir 2	136

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig. 7-1.
3. Spacing values reference to parallel elements.
4. 15-m-to-20-m TL = 70 Ω normal.
5. 15-m-to-10-m TL = 70 Ω normal.
5. Feedpoint: 15-meter (Moxon) DE
6. Boom length: 11.33' plus ends.

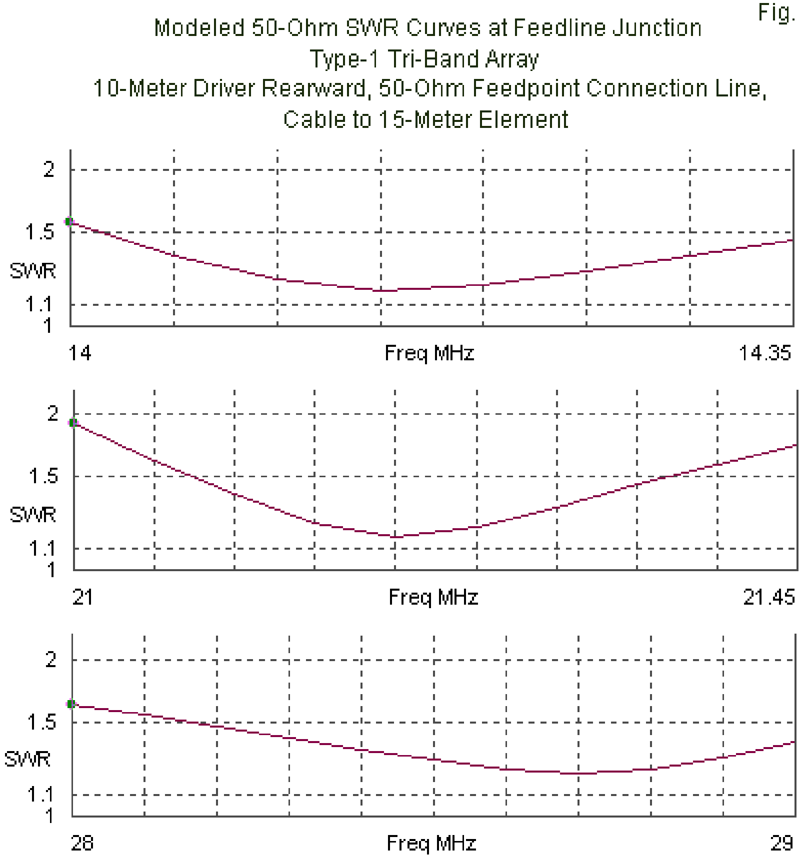
Table 7-5 shows the performance that goes with the revised main feedpoint.

Table 7-5. MYY-Tri Type 1: 15-meter feedpoint, 50-Ω line: performance

20 Meters				
Frequency	14.0	14.175	14.35	Δ
Free-space Gain dBi	6.55	6.16	5.79	0.76
Front-to-back ratio dB	16.66	28.98	18.69	12.32
Feedpoint Z (R +/- jX Ω)	33.8 – j9.0	51.9 – j7.7	67.2 – j12.9	33.4 + j5.2
50-Ω SWR	1.57	1.17	1.44	
15 Meters				
Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	6.25	6.01	5.84	0.41
Front-to-back ratio dB	11.96	11.35	10.74	1.22
Feedpoint Z (R +/- jX Ω)	27.4 – j9.3	51.9 – j7.5	75.7 – j22.6	48.3 + j15.1
50-Ω SWR	1.92	1.16	1.73	
10 Meters				
Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.67	6.94	7.21	0.54
Front-to-back ratio dB	23.90	40.40	20.85	19.55
Feedpoint Z (R +/- jX Ω)	41.3 – j20.4	49.2 – j11.9	68.2 – j4.4	26.9 + j16.0
50-Ω SWR	1.62	1.27	1.38	

The data make clear that from an operational standpoint, the revision of the main feedpoint location has made only numerical differences in performance. Operationally, we could not distinguish between either of the Type-1 arrays that we have so far examined. Perhaps the largest changes occur with respect to the shape of the 50-Ω SWR curves when we measure those values at the main feedpoint to which we attach the cable. **Fig. 7-8** provides the curves for comparison with those in **Fig. 7-7**.

Fig. 7-8



The most notable improvement occurs in the 20-meter SWR sweep, with lower values across the band. The 10-meter curve has simply shifted its frequency of lowest value. Had we chosen to make slight changes in the 10-meter dimensions, we might have better centered that curve, but such changes would not have improved performance on that band. In contrast, the 15-meter curve has become steeper, with a higher average band-edge value. Unless the SWR values on one band are more important than on some other band, there is little to choose in shifting the feedpoint position using a 50-Ω connecting line.

Type 1: 15-Meter Element Feedpoint with a 70-Ω Connecting Line: The transition to a 70-Ω connecting line among feedpoints while using the 15-meter driver as the junction with the main feedline involves no changes in dimensions. The only required change is to revise the characteristic impedance of the connecting lines to 70 Ω. We encountered the same general situation when applying 70-Ω lines to the initial version of MYY-Tri with the daisy chain feed for 10 meters. The changes in performance were not significant enough to show, and the SWR curves merely shifted position a bit. In the case of using 70-Ω lines with the 15-meter element main feedpoint, the performance values have enough differences to justify a new record in **Table 7-6**. The key differences will lie in the impedance lines.

Table 7-6. MYY-Tri Type 1: 15-meter feedpoint, 70-Ω line: performance

20 Meters				
Frequency	14.0	14.175	14.35	Δ
Free-space Gain dBi	6.55	6.16	5.79	0.76
Front-to-back ratio dB	16.67	28.99	18.70	12.32
Feedpoint Z (R +/- jX Ω)	35.8 – j5.0	54.6 – j0.9	71.7 – j3.0	35.9 + j4.1
50-Ω SWR	1.43	1.10	1.44	
15 Meters				
Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	6.26	6.01	5.85	0.41
Front-to-back ratio dB	11.99	11.37	10.78	1.21
Feedpoint Z (R +/- jX Ω)	29.6 – j7.3	54.2 – j1.1	82.6 – j9.0	53.0 + j7.9
50-Ω SWR	1.74	1.09	1.68	

10 Meters

Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.66	6.93	7.20	0.54
Front-to-back ratio dB	24.13	39.80	20.79	19.01
Feedpoint Z (R +/- jX Ω)	47.1 – j14.7	52.8 – j2.4	68.1 + j12.8	21.0 + j27.5
50-Ω SWR	1.36	1.07	1.46	

Fig. 7-9

Modeled 50-Ohm SWR Curves at Feedline Junction
Type-1 Tri-Band Array
10-Meter Driver Rearward, 70-Ohm Feedpoint Connection Line,
Cable to 15-Meter Element

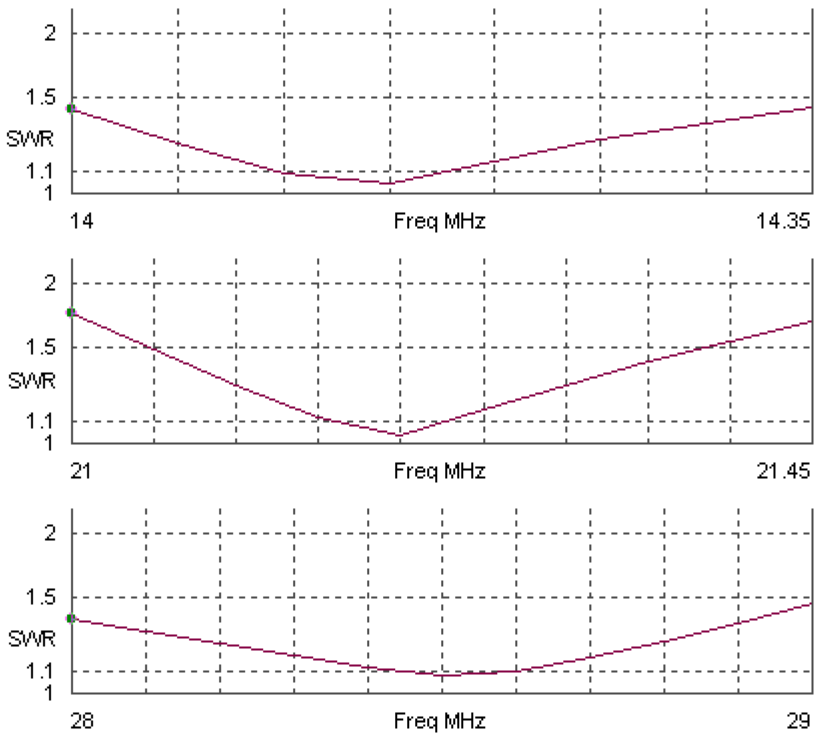


Fig. 7-9 provides the relevant set of SWR curves. With a 70-Ω connecting line, all three SWR curves improve in the sense of more closely approaching a 1:1 value somewhere within the passband. Only the 15-meter curve has values that rise above 1.5:1 at the band edges. On the other hand, the values for gain and front-to-back ratio do not change—in some cases, not even numerically, let alone operationally. Therefore, the situation leaves us with two questions.

First, how worthwhile are the seeming improvements of using a 70-Ω line with the main feedline connected to the 15-meter element? Unless one is operating with an amplifier that limits the SWR to 1.5:1 before shutting down, the differences among the three sets of SWR curves are operationally meaningless in terms of received and transmitted signal strength. (If a sensitive amplifier is in use, then it is likely that the station should be using monoband beams with SWR values that do not rise above about 1.3:1 anywhere in the passband.)

Second, how achievable are the lower SWR curves within a physical prototype that one may construct? The answer here depends on many variables, most of which concern the physical implementation of the array. I have already recommended that the connecting lines have some variability of gap spacing to allow for adjustment to the best compromise among curves for all three bands. Line construction, connectors, and a host of small influences may affect the actual characteristic impedance of the connecting lines. As well, the support mast and its hardware may (and likely will) be close to at least one of the drivers and its connecting line. The presence of the metal mass can detune the line slightly.

In the end, the design models can provide guidelines for construction. However, final tuning for the best set of SWR curves will require extensive field adjustment. The goal of these notes has been to provide a set of usable dimensions and feedlines specifications that provide a range of values within which most physical implementations can work. But the design notes cannot eliminate the need for testing, measurement, and adjustment.

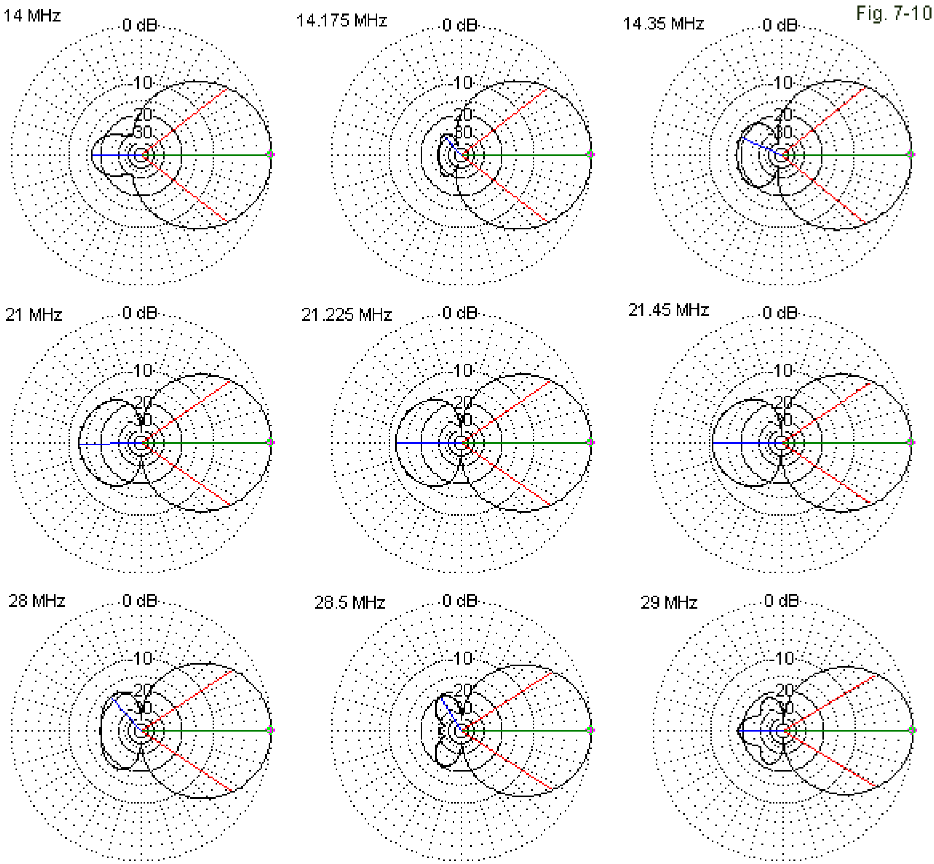
Type-2 MYY-Tri Designs

The general outline for Type-2 MYY-Tri arrays appears in **Fig. 7-1** on the far right. The basic design difference is the movement of the 10-meter driver forward of the 20-meter driver. Moving the 10-meter driver also forces a forward movement of the 10-meter directors. One consequence of this move is to lengthen the boom from just over 11' to about 15.5'. A second consequence is that we shall only view two variations on the scheme, one using a 50-Ω connecting line set, the other using a 70-Ω set of lines. With the main feedline connected to the 20-meter element, we now have automatic freedom from any daisy chaining of the connecting lines.

Relative to the Type-1 design, the Moxon rectangle for 20 meters will not undergo any revision. Whether this portion of the array should receiving final tweaking may be a function of the results that we obtain with the original configuration. However, we shall see some differences in the dimensions for 15 and 10 meters, mostly in terms of the length of the elements as we shift the impedance of the connecting lines.

Perhaps the bottom-line question involves whether we obtain anything useful for the beam revision. If we place the boom–to-mast assembly just behind the 15-meter driver, we might still be a bit off with respect to the array's center of mass, but we might thereby minimize unwanted influences on the connecting lines. However, we may relevantly ask whether we achieve any useful performance improvements over the versions with the shorter boom. The answer to this question emerges from the performance notes to follow.

Fig. 7-10 provides us with a gallery of patterns for the Type-2 design. Without careful scrutiny and comparison, we would be hard-pressed to notice any differences from the Type-1 patterns in **Fig. 7-3**. Since the gallery does not show values for maximum gain, we can only evaluate the general acceptability of the patterns. The 20-meter patterns are typical Moxon rectangle free-space plots, so their acceptability rests on the acceptance of the Moxon rectangle as the low-band radiator set. On 15 meters, we have typical deriver-reflector Yagi patterns, while on 10 meters, we see equally typical 3-element Yagi patterns.



Selected Free-Space E-Plane Patterns: Type-2 Tri-Band Array
10-Meter Driver Forward, 50-Ohm Feedpoint Connection Line, Cable to 20-Meter Element

Not only are the patterns similar between Type-1 and Type-2 array designs, but so too are the sweep curves of free-space forward gain and 180° front-to-back ratio. **Fig. 7-11** provides a sweep graph for the 20-meter operation of the Type-2 version of the beam. Compare the values and the curve slopes with those in **Fig. 7-4**. Virtually any detected difference will be operationally incidental. For example, the invisible peak front-to-back ratio still occurs between 14.15 and 14.20 MHz.

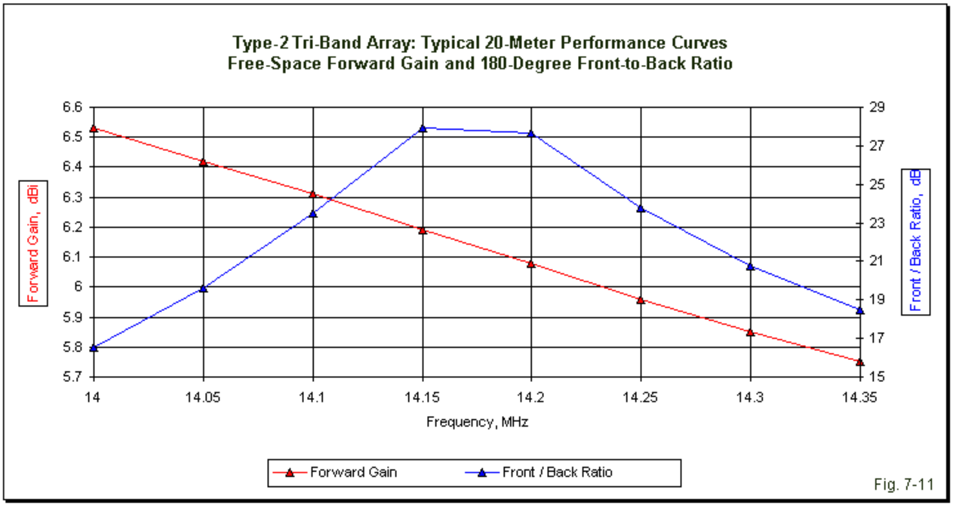


Fig. 7-11

The 15-meter curves, in **Fig. 7-12**, result in almost parallel lines, very similar to those for the Type-1 array in **Fig. 7-5**. The Y-axes do not use the same increments, so the absence of overlap between the two lines does not itself create a meaningful difference in performance. For the 10-meter sweep in **Fig. 7-13**, the relevant graph to compare is **Fig. 7-6**. In both cases, the design goal was to set the peak 180° front-to-back value at mid-band. As well, both graphs show a rising gain value with increasing frequency within the pass band. To determine whether the longer boom is worthwhile, we shall have to examine the modeled performance values for each band.

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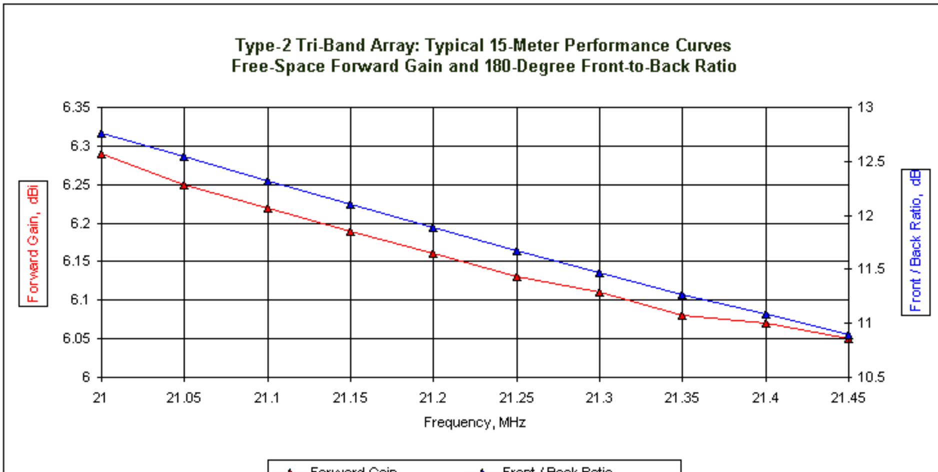


Fig. 7-12

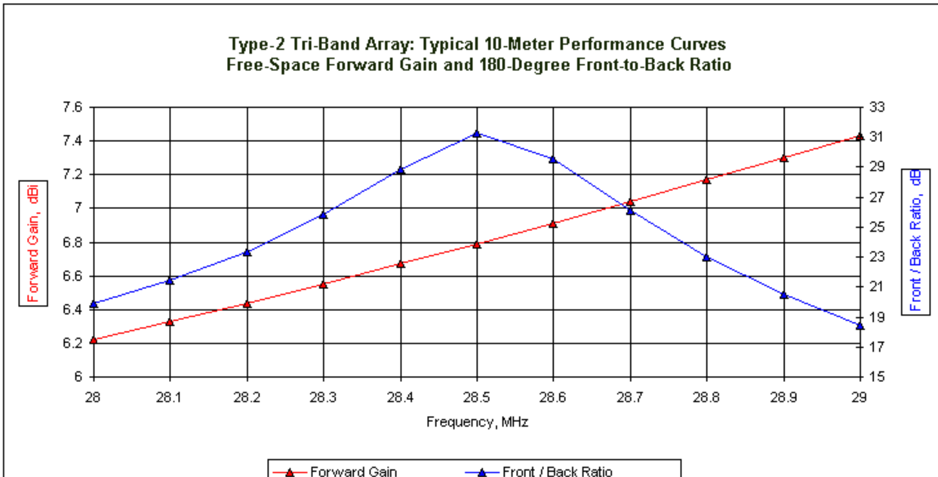


Fig. 7-13

Type 2: 20-Meter Element Feedpoint with a 50-Ω Connecting Line: The initial version of the Type-2 array uses 50-Ω connecting lines from the lower-band driver to each of the upper-band drivers. The move from Type-1 to Type-2 arrays does not change the element taper schedule used by any of the elements. The dimensions appear in **Table 7-7**, and they use the same reading rules that we set for reading both **Table 7-2** and for **Table 7-4**.

Table 7-7. MYY-Tri Type 2: 20-meter feedpoint, 50-Ω line: dimensions

10-meter Moxon Rectangle			15-meter Yagi			10-Meter Yagi		
Element	Dia.	Length	Element	Dia.	Length	Element	Dia.	Length
Both	1.0”	30”	Both	0.75”	24”	Both	0.625”	36”
	0.875	66		0.625	60	DE tip	0.5	108
	0.75	96	Ref tip	0.5	144.5	Dir 1 tip	0.5	96.25
	0.625	120	DE tip	0.5	135	Dir 2 tip	0.5	86.5
	0.5	152						
	0.375	159						
Ref tail	0.375	57						
DE tail	0.375	42.75						
Gap		7.25						
Total width		107						

Array	Spacing
20-m ref	0”
15-m ref	20
15-m DE	87.5
20-m DE	107
10-m DE	139
10-m Dir 1	161
10-m Dir 2	186

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig. 7-1.
3. Spacing values reference to parallel elements.
4. 20-m-to-15-m TL = 50 Ω normal.
5. 20-m-to-10-m TL = 50 Ω normal.
5. Feedpoint: 20-meter (Moxon) DE
6. Boom length: 15.5’ plus ends.

Except for the revised element spacing occasioned by setting the entire 10-meter section forward of the Moxon rectangle, the linear element length changes are small. Nevertheless, they are critical to obtaining acceptable performance. Comparing the element lengths to those for the Type-1 array may give a feel for the sensitivity of upper band element lengths within a multi-band beam.

The modeled free-space performance values for our first Type-2 array appear in **Table 7-8**. Compare these numbers relevantly with any of the Type-1 arrays whose numbers appear in **Tables 7-3**, **7-5**, and **7-6**.

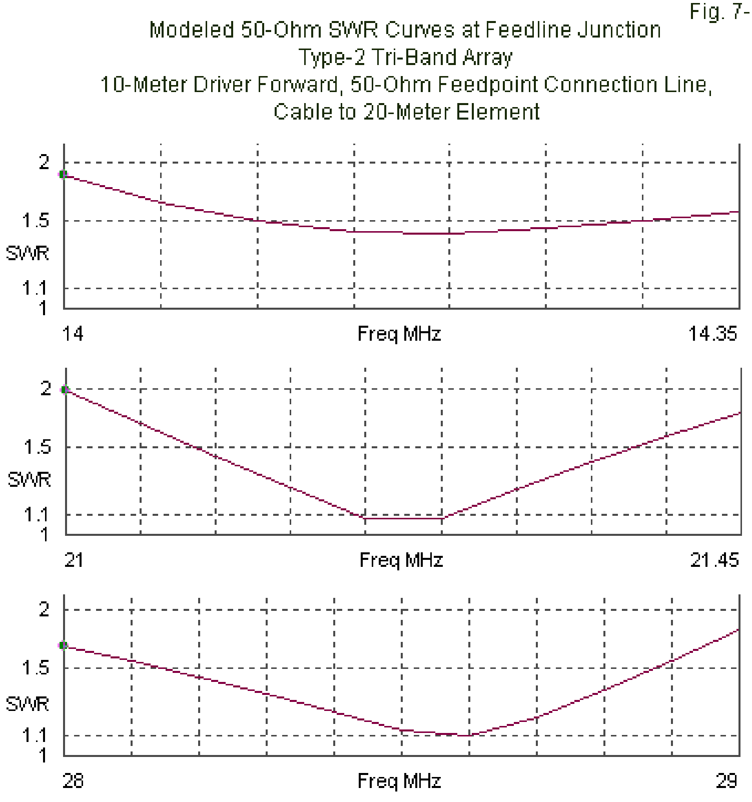
Table 7-8. MYY-Tri Type 2: 20-meter feedpoint, 50-Ω line: performance

20 Meters				
Frequency	14.0	14.175	14.35	Δ
Free-space Gain dBi	6.53	6.13	5.75	0.78
Front-to-back ratio dB	16.56	28.72	18.49	12.16
Feedpoint Z (R +/- jX Ω)	30.5 – j15.2	46.0 – j16.3	57.7 – j23.0	27.2 + j7.8
50-Ω SWR	1.87	1.42	1.56	
15 Meters				
Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	6.29	6.14	6.05	0.21
Front-to-back ratio dB	12.76	11.77	10.90	1.81
Feedpoint Z (R +/- jX Ω)	25.8 – j6.7	50.1 – j1.6	83.0 – j17.3	57.2 + j15.7
50-Ω SWR	1.96	1.03	1.77	
10 Meters				
Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.22	6.79	7.43	1.21
Front-to-back ratio dB	19.87	31.26	18.42	12.84
Feedpoint Z (R +/- jX Ω)	34.5 – j14.8	48.6 – j5.6	90.7 + j1.9	56.2 + j16.7
50-Ω SWR	1.67	1.12	1.82	

With 50-Ω connecting lines, the Type-2 array shows only marginal improvements, for example, in the 15-meter gain values. However, it shows some disturbing trends in other areas. The disturbances are not sufficiently great to disable the beam, but they are worth noticing. For example, the 10-meter front-to-back ratio falls below 20 dB at the band edges as a result of the greater rate of performance value change across the passband when compared to a Type-1 array. The phenomenon also shows up in the higher Δ value for the gain across the band. On 15 meters, we find that the gain changes hardly at all across that bad, but the front-to-back ratio changes considerably more than a counterpart Type-1 array.

Whether or not the numbers themselves draw any operational concern, the rapid changes in value have a consequence for replicating a design like the Type-2 beam with 50-Ω connecting lines. Faster rates of performance change signal a higher sensitivity to small changes in dimension, especially when making field adjustments in preparation for operation. The higher the rate of performance change per increment of frequency or for an equivalent change in an element's length, the easier it will be for the builder to set the beam dimensions at a point that seems to defy adjustment into proper operation.

Fig. 7-14



The rapid changes in performance across the bands also carry a penalty into the SWR curves, which appear in **Fig. 7-14**. Although both the 10-meter and the 15-meter curves reach very low values within the passbands, the band-edge values tend to be higher when taken together than they do in corresponding curves for the Type-1 arrays. In addition, the 20-meter SWR curve suggests a need for some significant re-design of the Moxon rectangle. With the drive arrangement shown in the dimensions, the 20-meter SWR curve has uniformly high values (although not outside a basic acceptable range). The culprit is a relatively high capacitive reactance across the band that results from the off-band impedance values of the other drivers, as transformed by the connecting lines.

Type 2: 20-Meter Element Feedpoint with a 70-Ω Connecting Line: We may achieve some improvement in the performance curves of the Type-2 array by replacing the 50-Ω connecting lines by 70-Ω lines. The required changes to dimensions, shown in **Table 7-9**, involve the element lengths for 15 and 10 meters.

Table 7-9. MYY-Tri Type 2: 20-meter feedpoint, 70-Ω line: dimensions

10-meter Moxon Rectangle			15-meter Yagi			10-Meter Yagi		
Element	Dia.	Length	Element	Dia.	Length	Element	Dia.	Length
Both	1.0”	30”	Both	0.75”	24”	Both	0.625	36”
	0.875	66		0.625	60	DE tip	0.5	108
	0.75	96	Ref tip	0.5	144.25	Dir 1 tip	0.5	96.
	0.625	120	DE tip	0.5	134.5	Dir 2 tip	0.5	86
	0.5	152						
	0.375	159						
Ref tail	0.375	57						
DE tail	0.375	42.75						
Gap		7.25						
Total width		107						

Array	Spacing
20-m ref	0”
15-m ref	20
15-m DE	87.5
20-m DE	107
10-m DE	139
10-m Dir 1	161
10-m Dir 2	186

Notes:
1. Length values progressive from element center.
2. Reference Moxon dimensions to Fig.7-1.
3. Spacing values reference to parallel elements.
4. 20-m-to-15-m TL = 70 Ω normal.
5. 20-m-to-10-m TL = 70 Ω normal.
5. Feedpoint: 20-meter (Moxon) DE
6. Boom length: 15.5’ plus ends.

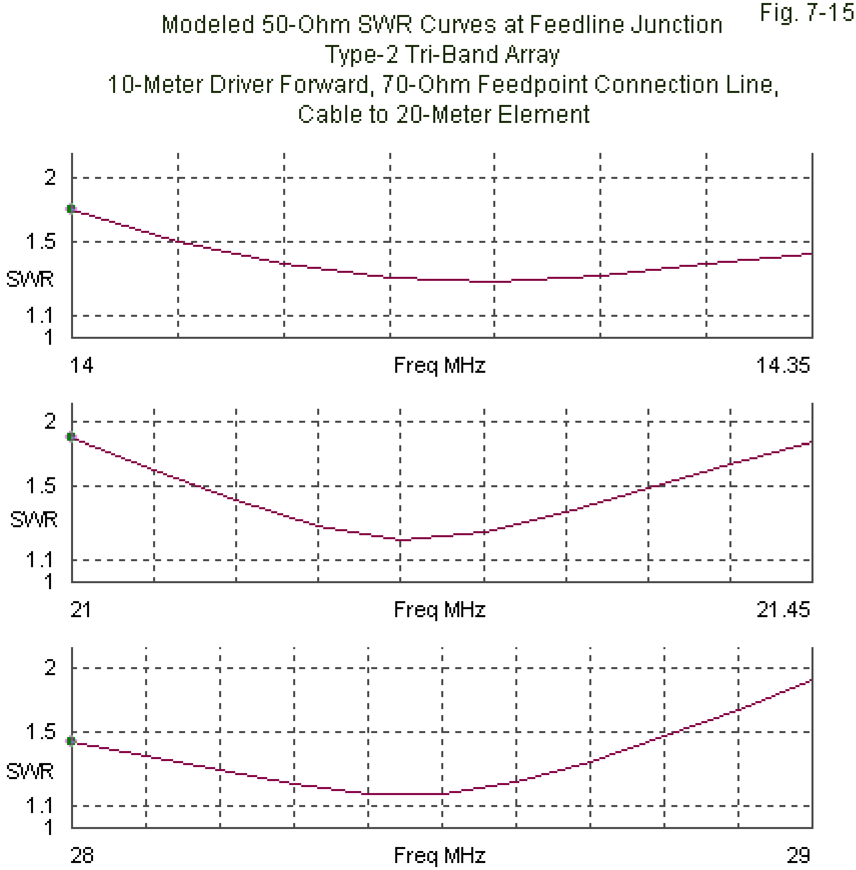
The performance values that result from the changes appear in **Table 7-10**.

Table 7-10. MYY-Tri Type 2: 20-meter feedpoint, 70-Ω line: performance

20 Meters				
Frequency	14.0	14.175	14.35	Δ
Free-space Gain dBi	6.53	6.13	5.75	0.78
Front-to-back ratio dB	16.55	28.72	18.50	12.17
Feedpoint Z (R +/- jX Ω)	32.4 – j13.4	48.9 – j11.7	63.0 – j15.4	30.6 + j3.7
50-Ω SWR	1.72	1.27	1.43	
15 Meters				
Frequency	21.0	21.225	21.45	Δ
Free-space Gain dBi	6.32	6.16	6.06	0.26
Front-to-back ratio dB	12.81	11.83	10.95	1.86
Feedpoint Z (R +/- jX Ω)	27.0 – j2.7	50.6 + j9.3	89.6 + j9.6	62.6 + j12.3
50-Ω SWR	1.86	1.20	1.82	
10 Meters				
Frequency	28.0	28.5	29.0	Δ
Free-space Gain dBi	6.16	6.72	7.37	1.21
Front-to-back ratio dB	19.08	30.19	19.49	11.11
Feedpoint Z (R +/- jX Ω)	37.0 – j8.8	46.0 + j5.5	68.4 + j32.9	31.4 + j41.7
50-Ω SWR	1.44	1.15	1.88	

Although we can find small numerical changes in the various performance entries for the forward gain and the front-to-back ratio, they do not add up to anything that we could detect in operation. The value changes across the 3 passbands also do not change significantly. The move from 50-Ω to 70-Ω connecting lines creates virtually no change in the current distribution among the elements in the array at any frequency.

Fig. 7-15



Even though the higher characteristic impedance of the new set of lines does not change performance, it does change the impedance values that appear at the main feedpoint on all of the bands. For example, on 20 meters, the capacitive reactance is considerably reduced, thereby lowering the SWR values across the band (since the resistive component did not materially change). In contrast, on 10 meters, the range of feedpoint resistance values has decreased, while the range of reactance values has increased. The changes result in lower SWR values in the lower half of the band. On 15 meters, we see only modest changes in the ranges of the two impedance components, but the SWR value at the low end of the band is somewhat better.

The sum of the changes is a set of somewhat flatter SWR curves, as shown in **Fig. 7-15**. Despite the improvement and the fact that all of the curves fit well within standards for amateur-band beam operation with a 50-Ω feedline, the curves are not as promising as some of the sets that we viewed in connection with the Type-1 arrays.

Conclusion

The design exercise has established that we can indeed reach workable 7-element tri-band array dimensions with acceptable performance specifications using directly connected drivers in a variety of configurations. The use of connecting lines with characteristic impedance values between 50 Ω and 70 Ω is most promising for a successful array. In all cases, however, we must be aware of the sensitivity of upper-band element dimensions, especially during field adjustment. As well, we should be prepared to alter the connecting-line gap as part of the adjustment process.

In general, the Type-2 array does not offer enough advantages to overcome its tendency toward increased rates of performance change across the upper bands, the increased sharpness of some of the SWR curves, or the additional 3.5’ of required boom length. In the end, one of the Type-1 arrays might serve better, even if only marginally so. As well, one may replace the Moxon rectangle with linear Yagi elements with only a small cost in additional boom length. Once you are comfortable with the way in which elements interact when interlaced, the possibilities for variations become endless—and so do the missteps that give the design process both enduring interest and constant frustration.

8. A Trap 2-Band 2-Element Beam for 17 and 12 Meters

Over the last 2 decades, we have seen a crossroad between older and newer multi-band beam designs. Older multi-band beams tended to make heavy use of traps to achieve 2-band and 3-band performance from a minimum number of elements. Newer beam designs gave up the trap and let each element serve only one primary band, whether the element was a driver or a parasitic element. Initial feed systems, pioneered by Force12, used open-sleeve driver coupling, although later makers have tended toward forms of direct driver coupling. In the market place today, trap and non-trap beams are available both in short and simple and in long and complex designs.

In the series of articles on the rudiments of multi-band beam design, I used forms of direct coupling among the drivers. Although I made passing reference to both trap and open-sleeve designs, I did not linger on them. The time to linger has come. In these notes, we shall examine a 2-element trap beam design for 17 and 12 meters. My band selection is not accidental. Many amateurs already have commercial tri-band arrays for the wider upper HF bands. They need a 2-band beam for 17 and 12 meters, two of the younger and narrower amateur bands. Very often, they wish to use a somewhat smaller array, since the activity level on these no-contest bands seems to merit a lesser investment. In addition, the project seems more fitting to home design and construction.

The 17-12-meter combination is a good place to experiment. Materials are readily available, and the pieces are macro rather than mini or micro. Standard hardware (stainless steel, of course) works well for most tasks. If the project takes longer than anticipated, it does not disturb more regular operations on the wider bands. Therefore, let’s design a 2-element beam for the 17- and12-meter bands.

Traps and Trap Beams

The newer Yagi technology created a phrase: the *lossy trap*. Seemingly, this phrase was synonymous with the simpler word *trap*. As a result, any antenna application for traps became almost forbidden on pain of losing most of one's signal inside the trap assembly. One consequence has been our loss of understanding of how traps work, along with how well they work.

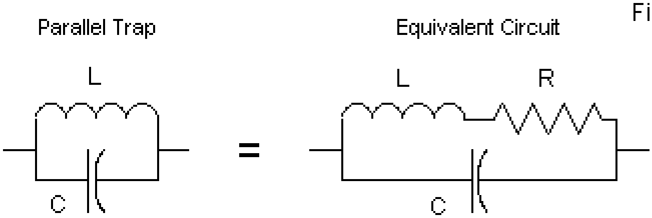
In fact, most of the hype about lossy traps emerged from the inadequate performance of parasitic beams that used them. Indeed, some designs dating back to the 1970s and 1980s showed very little gain and only had directivity as a recommendation for use. In most cases, traps were far less culpable for poor performance than were matters of general design in the effort to reduce the number of elements to an absolute minimum. Poor beam performance resulted largely from unacceptable compromises in element spacing on each band. Consider a 3-element, 3-band trap Yagi. Each band uses traps for the upper two bands on each of the elements. At the same time, the beam had to cover with an adequate SWR value as much as possible of the 20-, 15-, and 10-meter bands. Even with zero-loss traps, the project cannot succeed and still provide standard levels of 3-element monoband performance on all 3 bands. First, the element spacing will be optimal on only one of the three bands, relative to of obtaining maximum gain and a usable feedpoint impedance. Second, on all bands below the highest covered by the beam, the elements will be shorter than normal due to residual inductive loading by one or more traps. Shortening elements inherently reduces gain relative to a full-size element. In the end, these somewhat primitive designs did not need traps to yield lower performance levels than we can easily attain today in multi-band beams. Still, rather than fully analyzing the earlier designs, almost everyone blamed the poor trap. Even today, some makers of non-trap verticals try to give competing trap vertical monopoles a bad name, simply because they use traps.

Are traps lossless? Not by a long shot. Are they as bad as much current literature tries to make us believe? Not by an equally long shot. Indeed, traps have a perfectly usable place in the array of beams that we use on the upper amateur bands, so long as our needs are suitably modest. For example, we may design a 17-12-meter driver-reflector beam that has a relatively short boom and only two elements total. Its performance will be operationally indistinguishable from monoband 2-element designs that we might put in its place using 2 separate booms and a total of 4 elements. Before we take that step, let's review some basics of traps and their use.

Traps

A trap is neither more nor less than a parallel circuit composed of inductance and capacitance. **Fig. 8-1** shows the basic trap circuit and its equivalent if we consider—and we must—the series RF resistance of the inductor.

Fig. 8-1



The Basic Antenna Trap for Multi-Band Elements

A parallel tuned circuit resonated on any given frequency has a very high impedance on that frequency. If we insert the circuit in an antenna element and try to operate the element on the frequency to which we have tuned the trap, the active element length is restricted to the part from the feedpoint up to and including the trap. The current beyond the trap on that frequency will be very low and not contribute significantly to the radiation from the element. In general, the total length of the element should not exceed a length of about 3 times the length up to the trap or the element may act like a collinear array, a situation not especially good for use in most applications.

Trap builders are always concerned with the series RF resistance of the inductance. Commercial trap coils have Qs (the ratio of inductive reactance to RF resistance at the self-resonant frequency) of perhaps 220 to 300. Numerous alternative designs have emerged trying to raise the trap Q, some by using coaxial cables to form the coil and the capacitance together. However, for our work, we may stick with standard designs using discrete coils and capacitors.

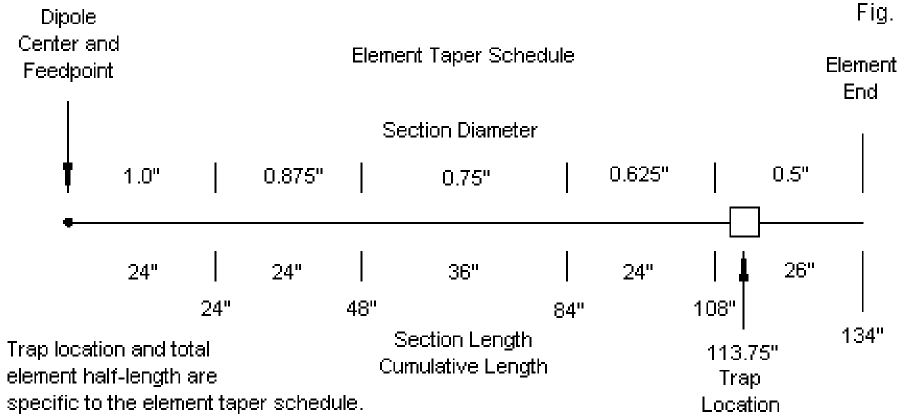
For our work on 17 and 12 meters, we shall create a 12-meter trap consisting of a 2.8-μH coil in parallel with a 15-pF capacitor. I have somewhat arbitrarily assigned a series resistance of 1.5 Ω to the coil, yielding a Q just below 300.

These values show a self-resonant frequency of about 24.55 MHz. (For reference, the resonant frequency for any combination of inductance (in μH) and capacitance (in pF) is equal to the square root of 25330 divided by the product of inductance and capacitance.) A half-century of experience has taught builders that a trap should be self-resonant on a frequency at the bottom or just below the band to which it applies. Since the 12-meter band runs from 24.89 to 24.99 MHz, our self-resonant point coincides with experience.

A trap terminates significant current flow on an element at a length suitable for resonating the element on a desired operating frequency—the upper frequency of elements intended for 2-band operation. On the lower frequency, it serves as an inductive loading coil in the element at its location. However, the residual inductive loading is not solely a function of the inductor in the parallel combination. Rather, it is a function of the complex combination of inductive and capacitive reactance yielded by the trap components when both are distant from resonance. As well, the Q of the combination is not the same as the Q of the coil alone within the trap at resonance. For further information on calculating the parameters of trap operation, see the notes in "Systematic Trap Modeling" (http://www.cebik.com/model/trapg.html"). Among the "load" options in EZNEC is a trap selection that uses its own methods to pre-calculate traps parameters for each frequency in a sweep in a manner that fits NEC requirements. The design models that we shall employ in these notes make use of this facility.

We may begin with a simple trap dipole for both bands. The sample will use the dimensions prescribed in **Fig. 8-2**. The diagram specifies an element diameter taper schedule consisting both of section diameters and section lengths. The trap position and the total element length are partial functions of the taper schedule and any changes will require redesign of the trap position and the tip length. The diagram shows only half the element, since the other half is a mirror image. The material is aluminum.

Fig. 8-2



One-Half of a Trap Dipole for 17 and 12 Meters

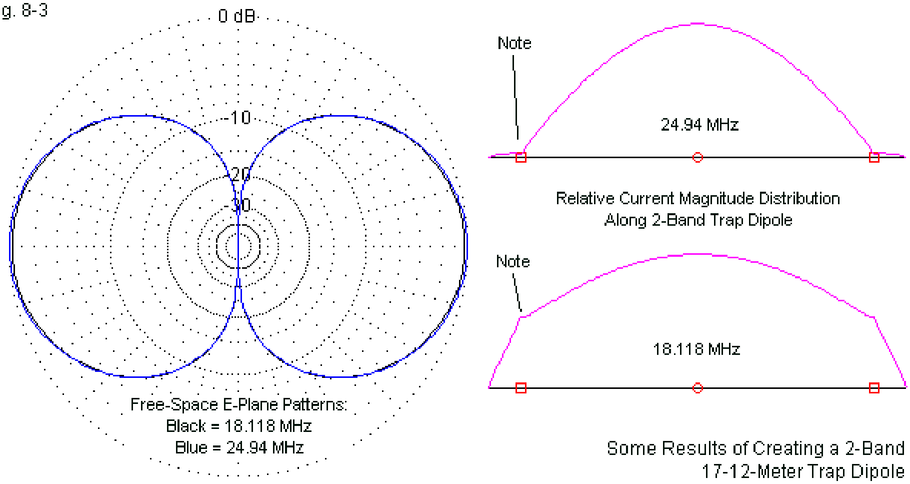
Table 8-1 provides us with the free-space performance of the dipole on both bands, using our trap design placed as specified.

Table 8-1. Mid-band performance of a 17-12-meter trap dipole in free space

Frequency	Gain	Feedpoint Impedance
18.118 MHz	1.93 dBi	70.9 + j4.1 Ω
24.94	2.13	73.4 – j5.0

The difference between the gain numbers for the 2 bands (0.2 dB) may lead us to some hasty conclusions. Therefore, let's examine the situation a few steps further. **Fig. 8-3** can assist us in this effort. It presents the overlaid E-plane free-space patterns of the 2-band performance, and also shows the distribution of current magnitude along the element on both bands. We need all of this information to reach even preliminary conclusions.

Fig. 8-3

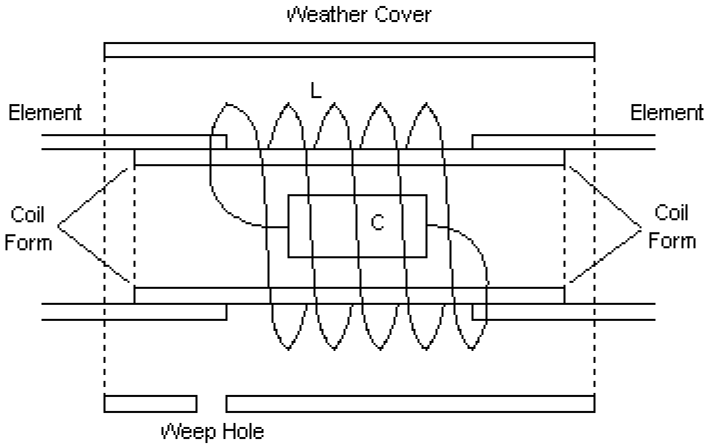


Perhaps the first thing that should strike us is the difficulty of discerning the 0.2-dB difference in free-space gain between the two E-plane patterns. The lower band (17 meters) has the weaker of the two patterns, but the deficit in gain is not wholly due to the trap. The element on 17 meters is only 134” per side (256” overall). A full-length 17-meter element—without the traps either side of center) requires 160” per side (320” overall) for resonance, and such a dipole yields 2.13 dBi free-space gain. If we shorten the trapless element to the smaller size, a reduction of over 16%, then the gain drops to 2.03 dBi. Fully half the gain decrease in the trap dipole is due to element shortening, and only half due to trap losses.

The right side of **Fig. 8-3** goes some distance in both explaining and evaluating the performance of the dipole. At 12 meters, the trap resonance is below the lower end of the band. However, the current distribution curve in the upper right suggests that the trap is highly effective. Relative to peak current along the element, the current magnitude beyond the traps is quite negligible. On 17 meters, we may note the “corners” in the current curve. Beyond the trap assembly, the current drops very rapidly, indicating the missing section of element relative to a full-size dipole with its nearly sinusoidal distribution. The corner also indicates a limitation of the method by which NEC models RLC loads. They do not have a physical dimension. Hence, in the load, we do not have the normal mixture of inductive and wire-length phenomena. Inductors distant from a peak current feedpoint do not encounter equal current levels on both ends of the coil. Hence, in an antenna, they do not act at those positions as pure inductors. Their inductive effects extend only so far as we have equal current magnitudes on both ends of the solenoid. To the degree that there is a current differential, the coil wire acts like antenna wire, but arranged so that it does not radiate significantly. The chief consequence of the difference between pure (mathematical) NEC inductors and physical inductors at a distance from the feedpoint is that the model will fall short of precision with respect to both the required trap position and the component values required in the trap. In most cases, the component values will be close enough to allow effective trap operation, but the position may require careful adjustment to arrive at upper band resonance. Since every small change of position of the trap will also affect the lower band by the revised placement of the residual reactance, the tip length must also change. Therefore, in creating any trap element, the builder must be prepared for careful field adjustment before declaring the element ready for operation.

We should combine these structural notes with a review of **Fig. 8-2**, noting that the position of the trap is on the 0.5"-diameter section of the element. One reason for using the element taper schedule shown is to provide sufficient support for the trap assembly, which is considerably heavier than a simple length of tubing filling the space. Suppose that we determine to give the trap inductor a 0.75" diameter. The needed 2.8-μH inductor requires just over 27 turns of AWG #14 wire using 8 turns per inch for adequate spacing. The total coil is about 3.4" long. Of course, there is inter-turn capacitance, which may reduce the required parallel capacitance to about 13.5 pF for resonance on about 24.55 MHz. As well, any necessary leads contribute further inductance. Therefore, the builder must resonate traps independently of their placement in the element to ensure their adequacy to the trapping task.

Fig. 8-4



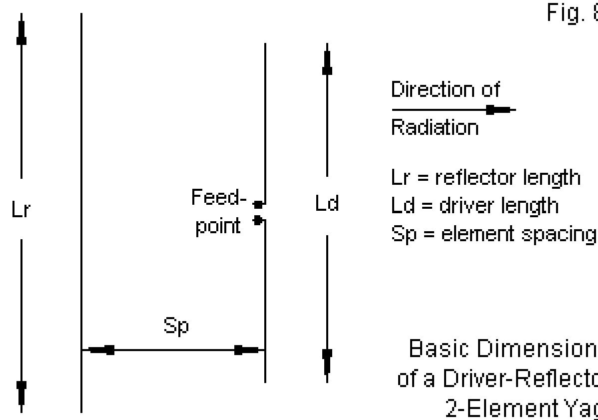
General Construction Features of a Standard
Antenna Trap Using Discrete Components

Fig. 8-4 shows some—but not all—of the construction details of a typical trap using discrete components. The sketch assumes the use of stainless steel hardware to firmly hold the assembly together and to the cut element in which we insert it. A weather cover is normally necessary to keep out both moisture and nesting small bugs. (Inspect and clean traps annually for continued effective performance.) Use wire large enough to handle the current levels on both bands. As well, the capacitor should be able to handle both the current and the voltage levels involved. In addition to the details suggested directly by the sketch, both sides of the trap should be adjustable. The trap position is movable for 12-meter tuning by changing the insertion distance of the half-inch tubing into the next 5/8" section. To adjust the tip length for resonance on 17 meters, one might replace some of the outermost end section of the element with a moveable length of 3/8" tubing. Of course, once you have located the exactly proper positions for each band, be sure to secure the sections for durable operation.

The Driver-Reflector Yagi for 2-Band Operation

Before we design a trap 2-band driver-reflector beam, we should fully understand a monoband beam of this design. In these notes, we shall not review all of the material in *2-Element Horizontal Beams, Volume 2, Parasitic Arrays* (available from *antenneX*), but the volume is available for anyone who wishes to develop a more thorough grounding in the subject. Here, we need to cover some basics and to avoid some misunderstandings. **Fig. 8-5** provides us with a sketch of the basic antenna.

Fig. 8-5



Basic Dimensions
of a Driver-Reflector
2-Element Yagi

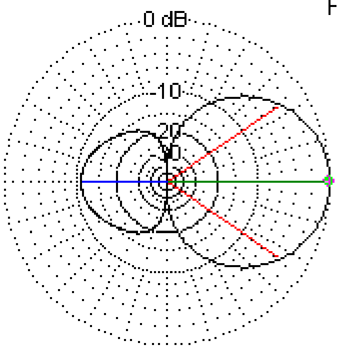
The three critical dimensions are the reflector length (Lr), the driver length (Ld), and the element spacing (Sp). We shall develop our sample for 17 meters (18.118 MHz), but the performance will not vary significantly for any band with appropriate element adjustments. If we use the same element taper schedule that we assigned to the trap dipole, then we need a driver that is 156” each side of center and a reflector that is 169” each side of center. These dimensions will be longer than a uniform-diameter element set due to the tapering of the element from the center outward. Different taper schedules using other element diameters or even individual section lengths will call for other total half-element lengths to achieve the same performance.

The element spacing for the sample is 81.6", a figure based on 0.125 λ at the operating frequency. Driver-reflector performance reaches a peak at this distance. In addition, the feedpoint impedance will be in the low-30-Ω range, which allows the builder to use either a matching section or a direct connection to 50-Ω coaxial cable. The 1.5:1 SWR is not a problem over such a narrow operating bandwidth (100 kHz). With these constraints, we may derive from NEC-4 the free-space performance reports shown in **Table 8-2**. NEC software presumes that the elements are well insulated and isolated from any conductive support boom.

Table 8-2. 17-meter 2-element driver-reflector Yagi performance

Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.39	6.27	6.25	0.14
Front-to-back ratio dB	10.99	10.99	10.96	0.03
Feedpoint Z (R +/- jX Ω)	33.2 – j0.7	34.6 + j2.5	36.0 + j5.6	2.8 + j6.4
50-Ω SWR	1.51	1.45	1.42	

Fig. 8-6



Free-Space E-Plane Pattern
2-Element Driver-Reflector
Yagi for 18.118 MHz

Over the narrow bandwidth of 17 meters (0.55%), the changes in values across the band—shown in the column marked "Δ"—make no operating difference at all. However, we shall use them as rough standards to better understand the operation of a trap 2-band Yagi. In addition, the radiation pattern does not change noticeably across 17 meters. **Fig. 6** shows a single free-space E-plane pattern, which suffices for the entire band. The rearward lobe shape is typical of the driver-reflector type of Yagi.

More significant than the data so far shown are some other aspects of the antenna, including some common misconceptions. One common bad idea for designing a 2-element Yagi is to start with a dipole and then make a reflector about 5% longer. In fact, the Yagi driver is shorter than a resonant dipole to yield a resonant beam. The reflector for this version is 8% longer than the driver. The precise measures depend on the element taper schedule, among other design considerations.

The sample model uses a spacing of 0.125 λ for peak performance. However, by lengthening the spacing to values between 0.145 λ and 0.165 λ, we can increase the feedpoint impedance from the low-30-Ω range to values closer to 50 Ω. The increase in both the spacing and the resonant feedpoint resistance costs us about 0.1 dB in forward gain and about 0.25 dB in front-to-back ratio. I know of no operator who could detect such differences, although these facts will assist us in designing a trap 2-band Yagi.

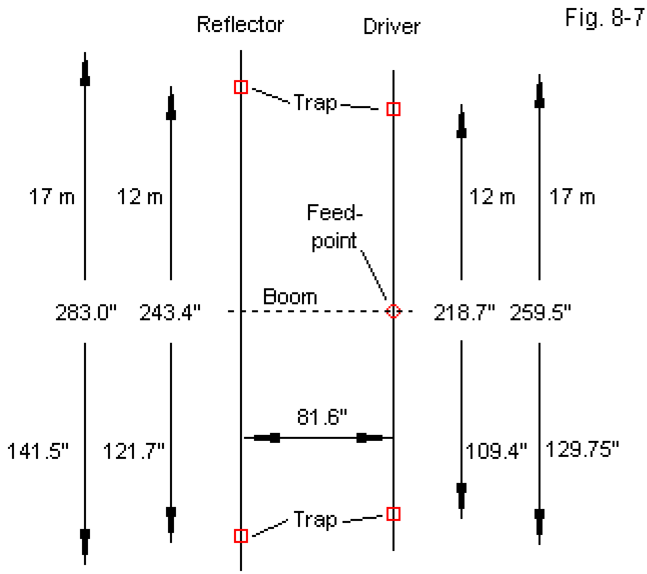
As we increase the spacing, we shall also need to change the element lengths to restore both peak performance and antenna resonance. Both the resistance and the reactance at the feedpoint will rise, so we shall need to shorten the driver, but only by a small amount. Adjusting the reflector length will yield conflicting results relative to gain and the front-to-back ratio. Lengthening the reflector will tend to reduce gain but increase the front-to-back ratio, while shortening the reflector will have the opposite effects. Since we have only two elements, adjustments to the reflector may require a further small adjustment to the driver, depending on the perfection of feedpoint impedance that we demand at the design frequency. A shorter reflector tends to yield lower feedpoint resistance values and more capacitive reactance, while a longer reflector raises the feedpoint resistance and tends to add inductive reactance. Understanding these trends can speed the work of making field adjustments when translating a 2-element Yagi design into a physical antenna.

The development of a reference 2-element Yagi for 17 meters is not an idle exercise. Rather, it is an important step in the development of our 2-band trap Yagi. Not only did we develop some performance standards against which to measure the more complex antenna, we also developed a methodology of design. For example, if we can accept the feedpoint impedance for the 0.125-λ spacing at 17 meters, even though we shall use a direct connection to a 50-Ω feedline, then we can use the same spacing for 12 meters. On that band, the spacing (81.6”) will be about 0.17 λ. We should be fairly close to 50 Ω at 24.94 MHz once we add traps to the assembly. In addition, we can simply use the trap that we designed for the dipole. In fact, all that we need to do is to place the traps correctly and adjust the tip lengths to arrive at our final (or at least semi-final) beam.

A 2-Band Trap 2-Element Yagi

The 2-band trap 2-element Yagi for 17 and 12 meters simply combines all that we have learned along the way into one antenna. **Fig. 8-7** shows the outline of the array. The individual elements use the same element taper schedule that we used on both simpler antennas. The traps are identical to those used in the initial sample trap dipole, with only position adjustments for the Yagi context.

The arrowed dimensions show the total element lengths from tip to tip. The half-lengths—from the center to a single tip—appear lower down. The spacing remains at 81.6”, which is about 0.125 λ on 17 meters and 0.17 λ on 12 meters. The smaller dimension for each element is the distance between the traps, essentially the lengths of the elements on 12 meters. The outer or larger dimensions for the elements amount to the 17-meter element lengths, taking into account two factors. One factor is the residual inductive reactance of the trap assembly at the lower frequency. The other factor is the decreased element spacing on 17 meters when measured in terms of a wavelength. The different spacing values require different proportions between the driver and reflector element lengths for each band. Therefore, the ratio of inner (trap-to-trap) dimension to outer (tip-to-tip) dimension for each element differs naturally.



Outer Dimensions of a 2-Band Trap 2-Element Yagi for 17 and 12 Meters

The performance of the array on each of the two bands is very close to the values that one might obtain from a monoband beam for each band. The date in **Table 8-3** shows the 17-meter values, while **Table 8-4** presents the 12-meter information. In both cases, the forward gain is down a bit from the values we derived for **Table 8-2**. However, at less than a half-dB maximum, the difference is not operationally detectable, since a 1-dB difference in signal strength is the least value a human operator can notice.

Table 8-3. 2-band trap 2-element Yagi: 17-meter performance

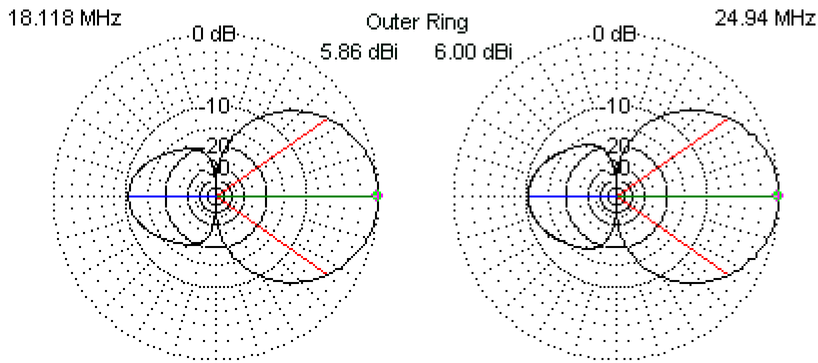
Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	5.99	5.86	5.72	0.27
Front-to-back ratio dB	9.86	10.67	11.05	1.19
Feedpoint Z (R +/- jX Ω)	29.0 – j6.4	33.4 + j1.9	36.0 + j10.2	7.0 + j16.6
50-Ω SWR	1.77	1.55	1.50	

Table 8-4. 2-band trap 2-element Yagi: 12-meter performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	6.05	6.00	5.95	0.10
Front-to-back ratio dB	10.50	10.52	10.52	0.02
Feedpoint Z (R +/- jX Ω)	50.0 – j10.2	51.6 – j7.3	53.1 – j4.4	3.1 + j5.8
50-Ω SWR	1.23	1.16	1.11	

The reduction in gain that we find when comparing the 12-meter values with the reference values results primarily from the increased spacing between the elements. Otherwise, 12-meter operation is quite normal, including smaller values of Δ in every catalog category. As predicted, the increased boom length as a fraction of a wavelength results in at 50-Ω feedpoint impedance with a very smooth—if modest—front-to-back ratio across the band.

In past notes on non-trap multi-band beams, we noticed compressed curves for the upper of the 2 bands covered due to a greater rate of change in virtually every performance area. Due largely to the shortening of the elements, a trap array exhibits the compression on the lower band. Compare the amount of change in values in the trap beam on 17 compared to the reference antenna. Nevertheless, the average gain and front-to-back values are down by less than a half-dB in each area. The decrease is also consistent with the gain drop for a single trap dipole on the lower band, which we roughly divided in two, half of the decrease belonging to the shortened elements and half due to losses in the trap assemblies acting as a loading inductive reactance. The SWR values—while less than ideal—still fall within acceptable limits for virtually all amateur applications.



Free-Space E-Plane Patterns: 2-Band Trap
2-Element Yagi for 17 and 12 Meters

Fig. 8-8

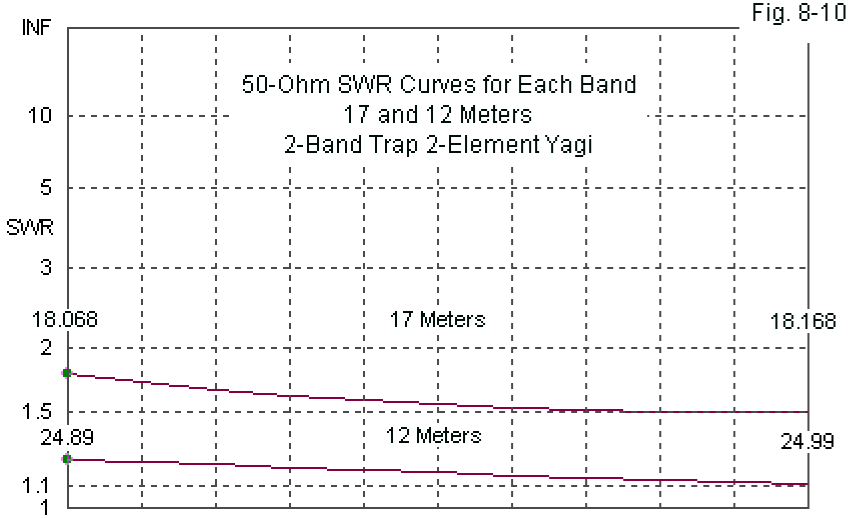
Fig. 8-8 provides a sample E-plane free-space pattern for each band. The 17-meter pattern is indistinguishable in shape from the pattern in **Fig. 8-6** for the reference 2-element Yagi, despite the slight difference in forward gain. The 12-meter pattern is very similar, but shows a slightly wider rearward lobe beamwidth, a natural function of the longer boom length.

Evidence for normal operation of the array shows up perhaps most clearly in **Fig. 8-9**, a pair of current distribution curves for the array, one for each band. In both cases, the ratio of peak driver current magnitude to peak reflector current magnitude is similar, with a slightly lower reflector current level on 12 meters, where the boom is longer. Both elements of the 12-meter curves show the effect of the traps to limit current beyond them to virtually negligible levels. On 17 meters, both elements show the "corners" in the current magnitude curves, with a rapid decrease in current from the trap (as an inductively reactive load) to the element tips.

Fig. 8-9

Current Magnitude Distribution on 17 and 12 Meters
2-Band Trap 2-Element Yagi

Fig. 8-10



Perhaps no description of a beam is complete without the obligatory SWR curve set. **Fig. 8-10** satisfies this requirement. It is possible by judiciously small adjustments in the driver length to obtain curves better centered in the passbands, and to do so without disrupting overall beam performance on wither band. However, that step takes us to a final set of reminders about multi-band trap beams.

From Model to Physical Reality

The beam as designed provides as good an approximation of monoband driver-reflector Yagi performance on both bands as we can expect from a trap design. Losses are far from excessive. Indeed, on 12 meters, the performance reaches monoband levels within the traps. On 17, where elements are shortened and loaded, we find a small drop in performance, but one that we might be hard pressed to detect in operation.

The design dimensions for the beam result from NEC-4 models and other calculation aids. In earlier sections, we enumerated some of the limitations of the design process that make field adjustment an expectation. First, as noted, the trap design, with a self-resonant frequency of about 24.55 MHz, does not account for inter-turn capacitance. Therefore, each trap needs to be resonated before installation in its element. The precise resonant frequency is not especially critical, and values up to the lower edge of the 12-meter band are usable. However, each trap should resonate at the same frequency to reduce the number of variables to think about during adjustment.

Second, each trap position, along with its lower-band tip section, needs to be initially adjustable, since the NEC models of trap loads vary slightly from physical reality when such loads are distant from the feedpoint. The model values are only starting points for the adjustment. For the average amateur, who usually lacks sophisticated measuring instruments and a good antenna range, the process comes down to establishing an acceptable SWR value. In physical reality, there may be many trap and tip settings that may yield good SWR values and poor performance.

Fortunately, the models provide a second form of guidance in the relative proportions of the inner and outer sections of the elements. When making adjustments, begin with the modeled dimensions. Start the adjustments on 12 meters. The goal—if only impedance measurements are possible—is to arrive at values very close to the modeled values with each element having the same proportions to the other as in the model. If the proportions drift excessively out of line with the model, then one may need to go back and start the process again. Once the 12-meter work is initially done, the 17-meter tips call for final adjustment, aiming both for the modeled impedance region and for final tip-to-tip lengths proportional to the model. Normally, this procedure will not call for a revision in the 12-meter adjustments beyond a fractional change in the inner driver length. Of course, the use of local assistance to confirm a reasonable front-to-back ratio (relative to the type of beam in question) is an invaluable aid to moving from the field adjustment phase to the operating phase of the beam's life.

Conclusion

We began this exercise with a review of trap structure and its consequences for a 2-band dipole element. The exercise showed that we may divide loses due to the use of traps into two parts, both of which apply to the lower of the two frequencies covered by the dipole. With a well-designed trap and good materials, we find no losses on the upper band relative to a trapless dipole cut to the same frequency. On the lower band, we found that about half the loss results from the resistive component of the residual trap impedance and about half from the necessary element shortening at the dipole outer ends. In a dipole, we could not operationally detect the performance difference in the most careful comparative test with a full size dipole for the lower band.

A 2-band trap Yagi is a viable alternative to other designs for these bands in terms of having modest but solid 2-element performance. Since the entire array uses only 2 physical elements, the boom length is just under 7' (or perhaps just over 7', depending upon the methods used to secure the elements to the boom). The element structure for beams using traps should be somewhat robust to ensure both strength and minimum sag from the weight of the traps. The structure that the design uses is rated for over 100 mile-per-hour winds, but requires de-rating in this application. Not only do the traps add weight near the element ends, they also increase the element wind loading due to their larger diameter.

The potential performance that we may obtain from the trap array should lay to rest the simplistic equation of *trap* with *lossy trap*. One may in fact design a very lossy trap, but that is an option (or an accident) and not inherent to standard trap design. Traps are not lossless, but may be nearly lossless on the upper band where they serve as traps. On a lower band, where they serve as inductive loads in the element, they inevitably show some loss. However, as the design samples have shown, much of the gain loss also stems from the resultant shortening of the elements. In terms of radiated energy relative to supplied energy, the array on 17 meter shows a NEC report of 85% efficiency. Compared to the upper-band efficiency of about 98%, where almost all of the loss is due to material resistance, it might seem that we should experience a greater loss of gain than we actually find in the trap beam. However, that sort of conclusion does not reckon with the designer's ability to adjust the outer element lengths to peak the performance curves within the operating passband. When designing directional beams, raw efficiency is not the only determinant of the array's forward gain.

Much of the excessively low gain shown by some past Yagis using traps is due to the use of unacceptable design compromises, not to losses in the traps. The present design, for all of its modest goals, makes use of established design principles on both bands to achieve reasonable performance on both bands. The results might well have been quite different had I chosen to design a three-element Yagi for both bands with traps in each of the elements. Three-element designs generally call for different spacing values on each band for each pair of elements. Such a design might be possible, but its advantage over a 2-element design might be debatable. We shall explore 3-element trap design in the next chapter.

The reason that a 2-element trap design, such as the one discussed here, is suitable for 17 and 12 meters is that for many amateurs, smaller beams are more acceptable and even desirable on these bands. Despite the challenges that it presents, the trap design is perhaps one of the most compact possible and uses the fewest physical elements for the performance level that it attains on both bands.

9. A Trap 2-Band 3-Element Beam for 17 and 12 Meters

In our exploration of 2-element trap 2-band Yagis, we began a process of sorting out losses due to trap resistance from losses on the lower band due to element shortening. The design exercise also developed a beam, which provided very reasonable performance on a relatively short boom. We measured what counted as reasonable performance by reference both to a sample monoband 2-element driver-reflector Yagi and to relatively well-known trends in this type of Yagi based on long experience and considerable literature. For example, we know that a driver-reflector Yagi reaches its peak value of front-to-back ratio with the elements about 0.125 λ apart. As well, we know that further separation of the elements increases the feedpoint resistance at only very small costs in gain and front-to-back ratio. On this basis, we were able to develop a trap Yagi that allows a direct connection to a 50-Ω transmission line and still performs like a 2-element Yagi.

The early part of the exercise began with a trap dipole in which we found a total loss of gain of about 0.2 dB on the lower band and none on the upper band. Models suggested that the losses were due in equal parts to the residual trap loading on the lower band and to the required shortening of the element on that band. There is no magic to the 0.2-dB per element figure—it is more of a guideline for expectations than a rigorous mathematical rule. However, the lower band of our eventual trap Yagi design showed a reduction in gain on 17 meters that is compatible with the basic finding, while the 12-meter gain was consistent with the wider element spacing when measured as a fraction of a wavelength.

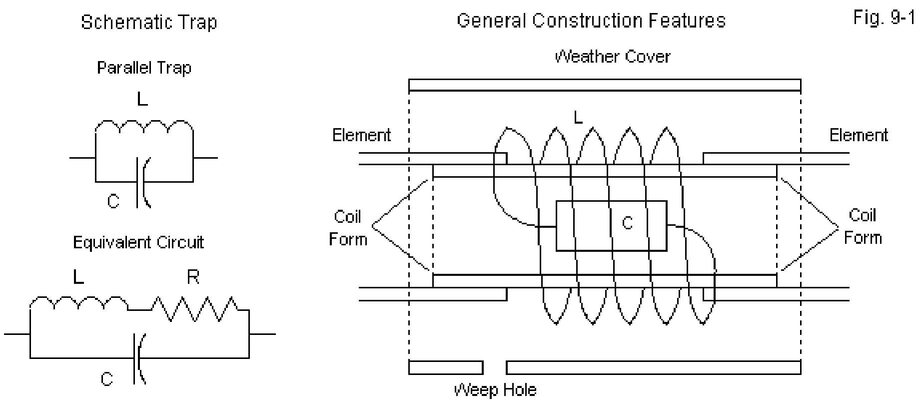
The net result was a better understanding of how reasonably well-designed traps affect Yagi performance—not to mention the hope that we may someday see an end to the hyperbole surrounding so-called *lossy traps*. Traps do have losses, most notably on the bands below the band for which they are traps. However, much of the excessive denunciation of traps stems from that fact that many Yagi designs in which they once were used were inherently deficient in gain.

We left the discussion with an intriguing question (at least for me): is it possible to develop a 2-band 3-element trap Yagi with reasonable performance? The question has two dimensions. First comes the design challenge of coming up with a design that works on both bands. Unlike 2-element driver-reflector Yagis, a 3-element Yagi has a far more complex set of interactions that determine both its gain potential and its feedpoint impedance. The challenge contains a limitation carried over from the 2-element foray: the feedpoint impedance must be compatible with a direct connection to a 50-Ω transmission line. A perfect 1:1 match is not required, since the 17- and 12-meter bands are so narrow, but it must be well below the usual amateur limit of 2:1. Not all combinations of elements can achieve this goal on one band, let alone two.

The second dimension of the question involves our understanding of what counts as reasonable in the domain of 3-element Yagis. The history of Yagi beams is both long and replete with unreasonable expectations borne of sound bites and simple imagination. Even the more modest claims that have emerged since the spread of software for antenna modeling as a dominant mode of Yagi design and analysis has yet to unravel the antique lore from the tapestry of reasonable expectations. Although we seldom commit the blatant errors of past generations, we tend to remain unfamiliar with what level of expectation goes with what kind of 3-element Yagi design. If we are to evaluate our design efforts, we must first set some standards for what counts as reasonable.

What We Retain from the 2-Element Work

We need not re-invent all aspects of the work with trap beams. The trap design with which we worked has nothing that will prevent us from re-using it in the 3-element designs. **Fig. 9-1** shows the circuitry and the physical structure of a typical trap assembly. The parallel circuit that we insert into the antenna element as a high impedance on the upper band consists of an inductance and a capacitance. To place the self-resonant frequency below the lower edge of the upper band, I used a 15-pF capacitor with a 2.8-μH inductor to resonate at about 24.55 MHz.

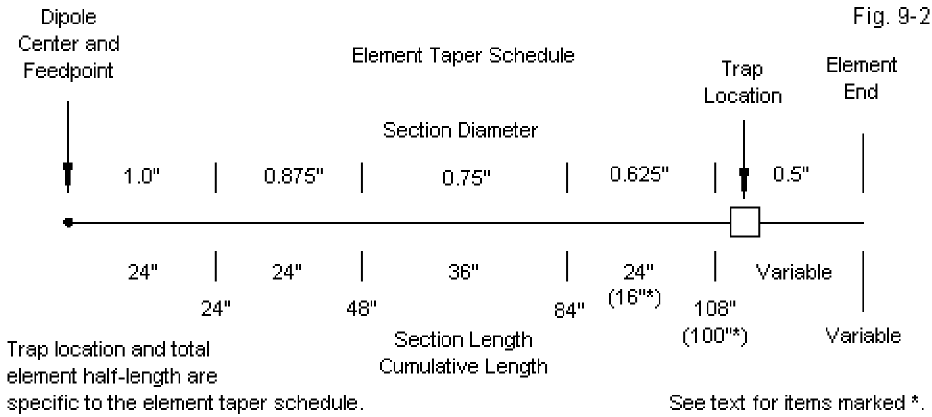


The Circuit and Structure of a Typical Antenna Trap

As the equivalent circuit shows, the inductor has an inherent series resistance to set its Q. A 1.5-Ω resistance gives the inductor a Q just below 300. The figure is only a bit higher than some popular traps of the past but lower than some of the newer traps composed of coaxial cables. For a detailed account of the elements of the typical traps structure—and the precautions we must take to ensure element integrity and trap weather protection—see the previous set of notes in Chapter 8.

A second item that we shall retain from the work with 2-element Yagis is the element diameter taper schedule. **Fig. 9-2** re-traces the element from its center to its outer end. The trap placement, of course, will vary on each element. The element uses a heavy-duty structure that—without a trap—would survive winds greater than 100 miles per hour. With a trap in place, we must de-rate the element's wind survivability due to both the trap weight and its increased surface. The heavier element construction does provide a more secure mounting for the trap than we would normally find with lighter elements

The element taper schedule has two starred items and alternative values in parentheses. As we shall discover when immersing ourselves in the actual design process, the director element of our Yagi will be somewhat shorter than we usually encounter. Therefore, the trap requires a position closer to the element center. To accommodate the trap, I found it necessary to shorten the 0.625" section of the element to 16". The move allows some flexibility to adjust the final trap position while keeping it on the 0.5"-diameter section of the element. This maneuver is required only on the director. The driver and reflector retain their original dimensions.



Element Taper Schedule for All Trap Designs in These Notes

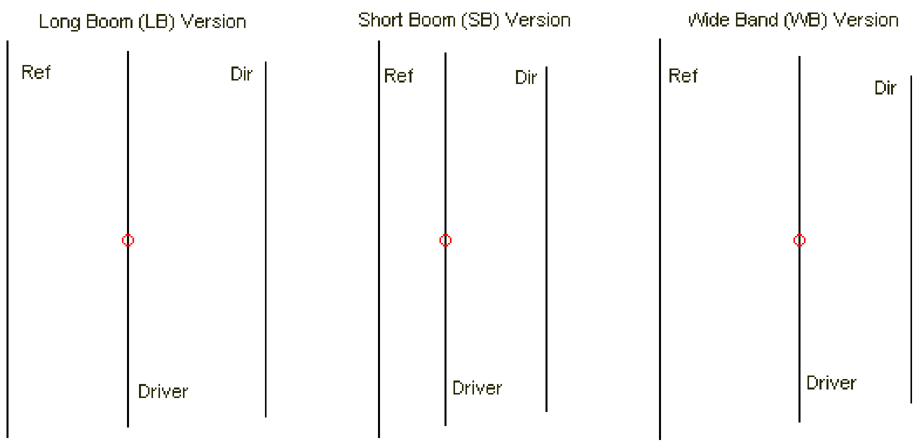
We shall examine the exact role played by the element structure revision further on in our journey. Before we can settle upon a design, we must first reach an accord on what we might expect from it.

Reasonable Monoband 3-Element Yagi Expectations

Since Jim Lawson's classic work on Yagi performance, we have known that for a given number of elements, gain increases with boom length. Indeed, a misleading reduction of this principle often leads us to say without qualification that, in principle, 3-element and 4-element Yagis (both with directors) with the same boom length would have about the same forward gain. Although we can prove the idea with models, we have to neglect a large number of other properties that an amateur beam must take into account before declaring a design successful. Except for the computer-readjusted SteppIR Yagi, amateur beams must cover a significant passband with fixed element length and spacing values. The gain must undergo the least possible change across the passband. Ideally, the front-to-back ratio should be at least 20 dB at the band edges. Whatever the raw impedance of the design, when transformed to 50 Ohms, it should provide less than a 2:1 50-Ω ratio across the passband without readjustment, and the network should introduce minimal, if not negligible, losses. In addition, the forward and rear patterns should be clean and free of unwanted sidelobes. Obtaining these results has been a challenge to monoband Yagi designers and an even bigger challenge to those attempting to design multi-band beams.

The requirements for an amateur-band Yagi limit the boom length that we can sensibly use and therefore the raw forward gain that we can obtain. For a 3-element Yagi on 17 meters, 18’ may be about the longest boom that is practical. However, numerous designers prefer shorter booms and accept lesser forward gain, while preserving the other standards that apply to Yagis in general. The Yagi designs in *The ARRL Antenna Book* for the last few editions are samples of this preference at work. A number of designers, such as Bill Orr, W6SAI, preferred wide-band Yagis. Having wide performance curves, even on such narrow bands as 17 and 12 meters, tends to ensure building success by the home constructor in spite of the variables that creep into the physical antenna as a result of differences in skills and materials. We might increase the list of alternative Yagi design philosophies, but these three are perhaps enough to set some standards.

Fig. 9-3 shows the outlines of 3 different Yagis from my collection: a long-boom, a short-boom, and a wide-band version. Note that the long-boom and the wide-band versions have about the same distance between the reflector and the director. However, the driver position and the rate of element length taper differ widely between these Yagis. In the middle is the short-boom Yagi, only about 2/3 the length of the surrounding designs. However, its performance may prove surprising, as suggested in **Table 9-1**.



Three Types of 3-Element Monoband Yagi Beams

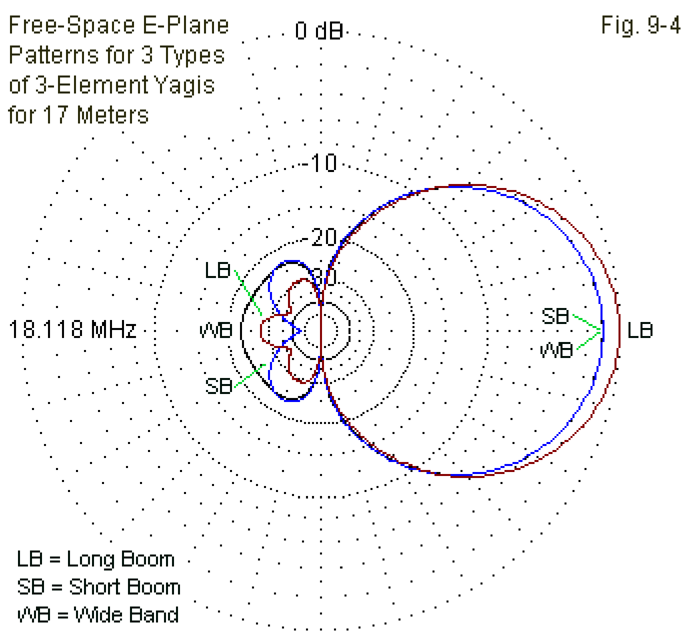
Fig. 9-3

Table 9-1. 17-meter 3-element monoband Yagis: performance at 18.118 MHz

Version	Boom Length	Gain	Front-to-Back Ratio	Feedpoint Impedance
Long Boom	17.6’	8.11 dBi	27.24 dB	25.7 – j0.9 Ω
Short Boom	11.8’	7.15	44.62	29.2 – j0.5
Wide Band	17.8’	7.11	21.60	47.1 + j1.0

Fig. 9-4 overlays the free-space E-plane patterns for the same beams and helps us to explain some of the differences in the number sets. For example, the front-to-back ratio is the 180° value, which shows a deep null in the short-boom version. However, the quartering rear sidelobes are as large as those of the wide-band version. If we were to average the rearward values for all three versions, the long-boom design would show the best value. However, all three designs easily exceed the 20-dB standard that we apply to amateur 3-element Yagis.

More significant are the remaining categories of performance recorded in the table. The forward gain of the short-boom and the wide-band versions are indistinguishable, although the wide-band version is 50% longer. In a monoband beam, we might automatically opt for the shorter boom, especially for the narrow band like 17 and 12 meters. However, operating bandwidth is not the only factor that forces the longer boom on the wide-band model. In addition to slow rates of gain and front-to-back change, the wide-band model is the only version that achieves a very good match to a 50-Ω feedline. Part of the technique used to obtain the impedance necessary to avoid a matching network is an increase in spacing between the reflector and the driver. Indeed, the reflector's chief role in any Yagi with directors is to control the feedpoint resistance value. (The reflector has other roles, especially in controlling the operating bandwidth toward the lower end of the passband.)



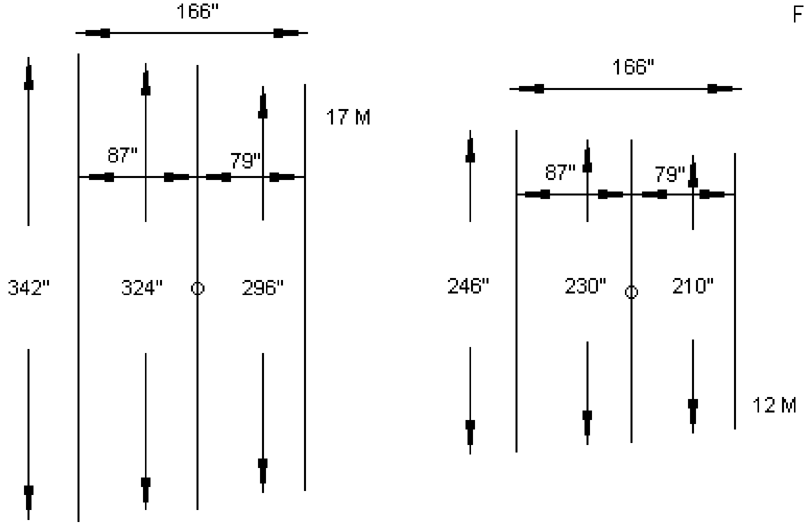
In a trap 3-element Yagi for 2 bands, we should not bring the long-boom performance to bear as the standard of judgment. First, our design must adequately (if imperfectly) match coaxial cable and thus needs wider spacing between the reflector and the driver. Second, with fixed element spacing, the reflector-to-driver distance will be different on each band as a function of a wavelength at each operating frequency. Relative to our current project, we might have called the wide-band design the "high-impedance" design. In fact, the wide-band version of the antenna should set our expectations on the performance that we derive from our trap exercise. Still, the exact design for each band will differ from the wide-band version of the monoband Yagi as a consequence of the compromises we must reach to work on both bands.

The Monoband Basis for the Trap Yagi Design

The special requirements for a trap beam covering two bands does not allow us to begin the design with one of the standard monoband configurations. Traps beams use fixed element positions when we measure them in physical units (feet, inches, meters, etc.) Therefore, the spacing between elements will have very different values on each of the two bands when we measure them in terms of wavelengths. If we wish to develop monoband 3-element Yagis to use as the basis for the eventual coalescing into a trap beam, we must find a set of element spacing values that will allow us to develop acceptable performance curves on each band. The task carries us into relatively uncodified areas of 3-element Yagi design.

Besides having acceptable values for forward gain and front-to-back ratio, each beam must also present a feedpoint impedance that is compatible with a direct connection to a 50Ω transmission line. We do not need to design exactly to 50 Ω, but the impedance must yield impedance values as far below a 2:1 SWR as possible. The result will be a compromise on each band between matching needs and performance optimization. In this effort—largely a software trial-and-error procedure—it pays to have a fairly large stock of potentially useful models as starting points. The designs selected, as shown in the outline sketches in **Fig. 9-5**, provide the basis for the trap model. However, they also reveal one of the significant limitations of a two-band trap 3-element beam, a limitation that rests on one of the basic principles of 3-element Yagi design. For a given number of elements, forward gain—even when constrained by the needs of impedance matching—depends upon boom length.

Fig. 9-5



General Outlines and Dimensions: Monoband Yagis for 17 and 12 Meters Using the Same Element Placement

The dimensions shown in the diagrams use the same element diameter taper schedule shown in **Fig. 9-2**. However, the 12-meter design uses a director that is shorter than the limiting end of the 0.625" tube (half-length: 108"). In preparation for the trap version of the design, I shortened the 0.625" section to 16" or a cumulative length of 100", adding a 5" section of 0.5"-diameter tubing at the tip. The total boom length is 166". With a small surplus to hold mounting plates and hardware, a 14' boom will contain the elements. This boom length will also serve the trap version of the array. Note that with respect to the monoband arrays that we examined, the boom is considerably shorter than either the long-boom or the wide-band Yagi designs.

Table 9-2. 17-meter 3-element monoband Yagi performance

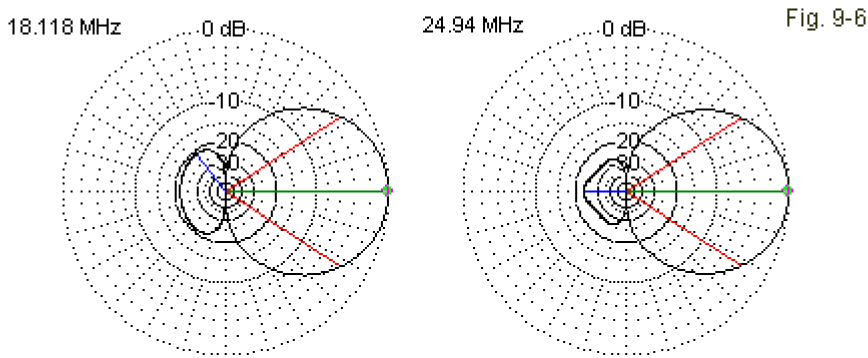
Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	7.09	7.10	7.11	0.02
Front-to-back ratio dB	20.86	21.89	23.05	2.19
Feedpoint Z (R +/- jX Ω)	46.5 – j1.7	46.0 – j0.2	45.4 + j1.3	1.1 + j3.0
50-Ω SWR	1.09	1.09	1.11	

Table 9-3. 12-meter 3-element monoband Yagi performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	7.62	7.64	7.66	0.04
Front-to-back ratio dB	23.31	23.26	23.05	0.26
Feedpoint Z (R +/- jX Ω)	41.5 – j2.0	41.2 – j0.4	41.0 + j1.3	0.5 + j3.3
50-Ω SWR	1.21	1.21	1.22	

Table 9-2 and **Table 9-3** show the modeled performance values for the two monoband beams with identical spacing values between elements. Each design—at least over the narrow confines of 17 and 12 meters—is a paradigm of stability, as the very small values in the Δ column clearly indicate. Both beams have very acceptable performance considering the total boom length on each of the two bands. As well, both beams have very good SWR curves for a 50-Ω matching situation. The free-space E-plane patterns shown in **Fig. 9-6** also tell us that each beam design yields a very clean pattern, both fore and aft.

The limitation that we face when combining these monoband beams into a trap combination shows up in the gain lines of the table. The boom length on 17 meters is about 0.25 λ, while on 12 meters, the length is about 0.35 λ. Because the 12-meter boom is longer, the gain on that band is higher, relative to the boom length and gain on 17 meters. When we combine the two beams into a trap version, we do not expect radical shifts in performance on 12 meters. However, we expect the gain on 17 meters to decrease due to the combination of element shortening and residual element loading by the trap and its finite Q. Hence, we can only expect the gain differential between the two bands to increase.



Free-Space E-Plane Patterns
3-Element Monoband Yagis for 17 and 12 Meters

A Trap 3-Band 2-Element Beam for 17 and 12 Meters

Combining two acceptable 3-element monoband beams with identical element spacing into a single array using traps is a straightforward process. In fact, the preliminary step of developing the pair of monoband beams saves considerable design and modeling time, since it provides upper band dimensions and performance expectations for both bands. The first step is to approximate the outer tip dimensions based on past experience. In the 2-element trap Yagis, the 17-meter elements were approximately 84% of the length of 17-meter monoband elements. Next, we may place the 6 traps on the element 0.5" tip sections, remembering to shorten the director 0.625" sections to 16" (cumulative half-length 100"). Once we have achieved the closest approximation that we can get to 12-meter monoband performance, we can adjust the lengths of the outer ends of the 17-meter elements to restore the best possible performance on that band.

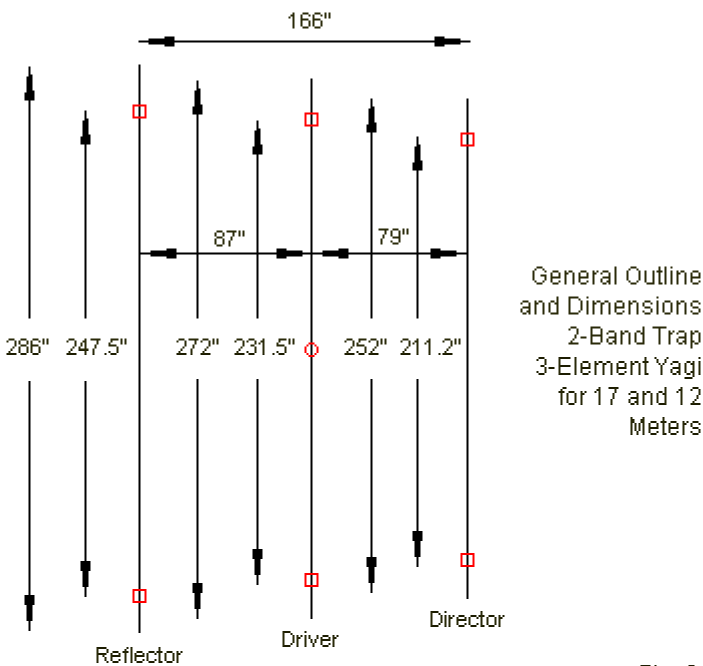
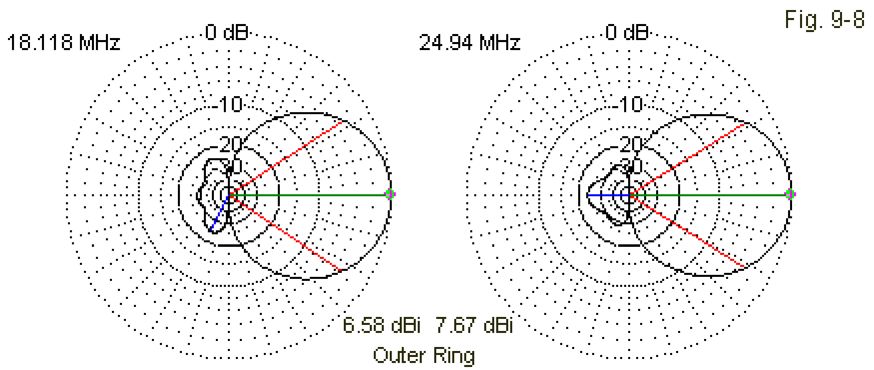


Fig. 9-7

Fig. 9-7 shows the outline of the final design, with the understanding that each element uses the prescribed element taper schedule and the prescribed trap design. Other element taper schedules or other trap components may result in a need to adjust any or all of the dimensions shown in the diagram. Of special note are the spacing values between traps for each element. The values are very close to the values of the element lengths for the monoband 12-meter beam. In fact, moving traps from one segment to another on the 0.5" tip element section provides only step movements of the traps. Hence, closer approximations to the monoband beam are not feasible if we use a single 0.5"-diameter wire for the modeled tip section. We might have subdivided the tip wire for each element into two wires, placing the trap on the last segment of the inner part of the subdivided section. This procedure is unnecessary, since the model is already limited in accuracy by placement of the RLC load at a considerable distance from the element center. Hence, the load accuracy is somewhat limited. As was the case for the 2-element trap beam, final placement of the trap and final adjustment of the 17-meter element lengths is necessarily a task for field adjustment of the physical prototype for the antenna. Nevertheless, the model should be quite close to reality.



Free-Space E-Plane Patterns
2-Band Trap 3-Element Yagi for 17 and 12 Meters

The use of traps in the 3-element beam does not disturb the shape of the monoband patterns, as shown in **Fig. 9-8**. The 12-meter pattern is virtually identical to the patterns for its monoband counterpart in **Fig. 9-6**. The 17-meter pattern shows a reduction in the rearward radiation relative to its monoband origins. The most likely source of the improved front-to-back performance is the loading of the reflector, as well as the altered overall E-plane outline of the antenna.

As we expected, the 12-meter portion of the antenna provides performance almost indistinguishable from the monoband beam. However, the 17-meter performance shows the anticipated gain decrease that results from both element shortening and element loading, combined with the shorter boom length as measured in wavelengths. Between monoband beams, we saw a gain differential of about 0.55 dB. In the trap version, the differential is about 1.1 dB. The gain deficit on 17 meters resulting from the traps and the required element shortening is therefore just over 0.5 dB, a value consistent with what we found in the 2-element trap Yagis and with our rule of thumb (about 0.2 dB per trap element). **Table 9-4** and **Table 9-5** provide a more detailed look at the performance values across each of the two bands.

Table 9-4. 17-meter 3-element trap Yagi performance

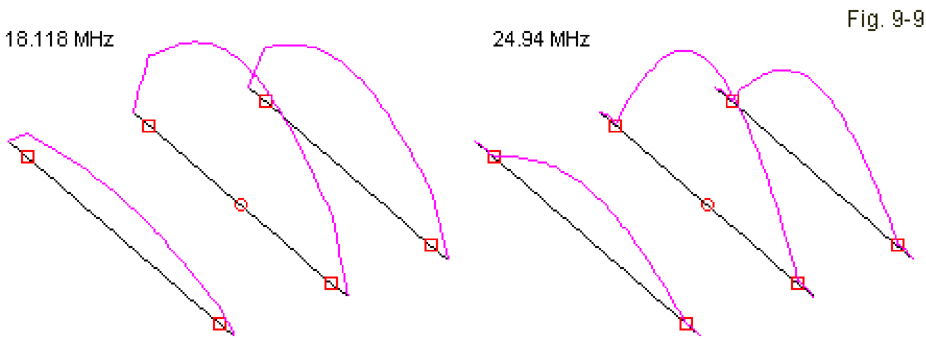
Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.60	6.58	6.55	0.05
Front-to-back ratio dB	34.92	27.96	21.53	13.39*
Feedpoint Z (R +/- jX Ω)	36.1 – j5.6	33.6 + j0.1	30.6 + j7.0	5.5 + j12.6
50-Ω SWR	1.42	1.49	1.68	

Table 9-5. 12-meter 3-element trap Yagi performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	7.63	7.67	7.72	0.09
Front-to-back ratio dB	23.78	23.46	22.65	1.13
Feedpoint Z (R +/- jX Ω)	40.4 + j6.8	39.8 + j9.6	39.1 + j12.5	1.3 + j5.7
50-Ω SWR	1.30	1.37	1.45	

The performance figures for 12 meters are virtually indistinguishable from those of its monoband basis beam. Although not quite a perfectly stable as the original, the values in the Δ column are tiny by any method of accounting. Since the trap positions are limited to stepping from one segment to the next, field adjustment would allow the centering of the SWR curve that is slightly offset in the model.

Although the 17-12-meter 2-element trap beam showed considerable curve compression on the lower band, with higher rates of value change per unit of frequency, the 17-meter performance of the 3-element trap Yagi shows more modest value changes for the gain and the impedance values. The rates are higher than for the monoband beam (**Table 9-2**), but still low compared to the 2-element trap beam. The one exception to this trend is the front-to-back ratio. The combination of element loading and shortening has moved the peak front-to-back ratio to the lower end of the 17-meter band. Under these conditions, we can discard the Δ for this parameter and note that the value remains well above 20 dB across the band.

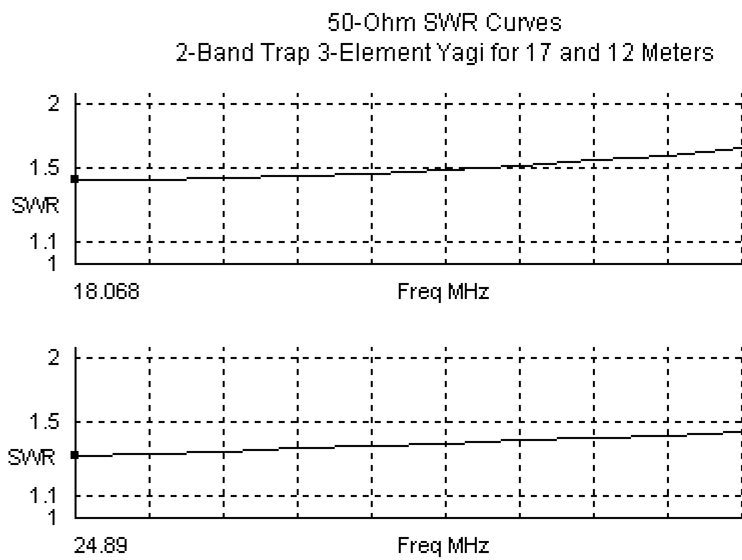


Current Magnitude Distribution Curves
2-Band Trap 3-Element Yagi for 17 and 12 Meters

Fig. 9-9 provides curves for the relative current magnitude on each element on each band. The peak values at the center of each element are comparable for the two bands and indicate typical 3-element Yagi performance. The 12-meter curves essentially terminate at the traps, with only negligible current magnitude beyond that point. The 17-meter curves show the "corner" effect at the trap locations, with a rapid decrease in current magnitude beyond that point, a typical effect of placing loading inductances in an element to shorten its physical length. In all respects, the current magnitude curves show very normal operation of a 2-band trap beam fully optimized for the circumstances.

As with the 2-element trap beam in the preceding episode, the feedpoint resistance values show a small decrease relative to the monoband models, even on 12 meters. As a result, the SWR curves are not quite as perfect, as evidenced in **Fig. 9-10**. Nevertheless, the 12-meter SWR never rises to 1.5:1 across that band. The element loading and shortening yields a greater increase in the 17-meter SWR as a result of the reduction in the feedpoint resistance. Nevertheless, the beam is capable of acceptable operation on that band—at least with respect to matching a 50-Ω main feedline.

Fig. 9-10



Evaluation and Conclusion

As indicated along the way, the design that we have developed requires either the use of the specified element taper schedule and the given trap values, or it the will require significant redesign. Under either condition, limitations of the modeling process will require extensive field adjustment before placing the beam into operation. As well, the traps will require pre-final-assembly resonating to bring each one as close as feasible to the same resonant frequency (nominally 24.55 MHz). These are simply the conditions of translating a trap beam design into a physical antenna. See the Chapter 8 for further details of this process.

Assuming that the design successfully translates into a physical antenna, it still leaves us with the quandary of whether it is a worthy alternative to more modern designs that employ separate elements for each band. The use of traps may reach its useful limit with the 3-element Yagi (if it has not already passed beyond those limits). Unlike a 2-element driver-reflector Yagi, a 3-element Yagi increases its gain as we lengthen the boom as a function of a wavelength. Inherently, then, the upper band will exhibit a higher gain than the lower band. In addition, the lower-band element loading and shortening will yield a further gain reduction that increases the differential between the gain values for each band. With our 17-12-meter combination, 2 elements produced a differential below the level of operational detection. The 3-element beam differential is about 1.1 dB, a value that just falls within the detectable range for a human operator. Adding elements to the Yagi design would only increase the gain differential between bands. As a consequence, we are unlikely to find trap beams any larger than 3 elements. Indeed, in terms of performance, a 3-element trap Yagi design appears to fall on the edge—acceptable by some and not by others.

In addition to performance questions, we also encounter physical quandaries. To more graphically illustrate them, I developed a 2-band non-trap Yagi-Yagi design using a boom length of 166”, essentially the same as the one used with the 3-element 2-band trap beam. **Fig. 9-11** shows—to scale—the outlines of both beams. The non-trap beam uses the same element taper schedule as the trap model. The shorter director omits the 0.5” end sections. The 5-element array uses a 50-Ω direction connection transmission line between the rearward 12-meter driver and the 17-meter driver to which we attach the main feedline. The modeled performance data appears in **Table 9-6** and **Table 9-7** for 17 and 12 meters, respectively.

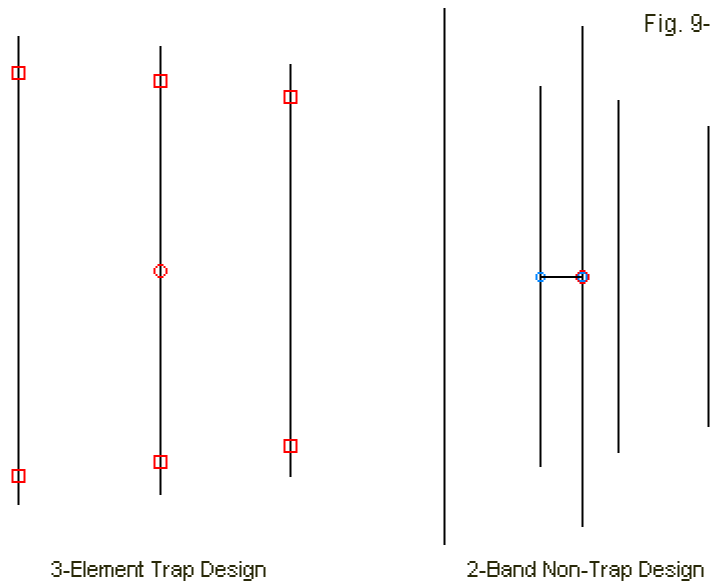
Table 9-6. 17-meter 5-element non-trap Yagi performance

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 9-7. 12-meter 5-element non-trap Yagi 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	

Fig. 9-11



Physical Differences Between Trap and Non-Trap Beam Designs

The morass of information is typical of what one might encounter between the specification sheets for competing beam designs on the market, although the information in the tables is far more complete than usually provided by manufacturers. Let's begin with the physical proportions of the antennas. The non-trap antenna requires 2 more elements than the trap model, and the 17-meter elements are longer, requiring a larger turning radius than needed for the trap beam. None of the elements carries the trap weight near the element end. Although the weight and wind load potential for each beam may be roughly the same, the trap elements require periodic maintenance to ensure clean, debris-free traps. The non-trap beam also requires (but seldom receives) periodic maintenance, but the task is usually simpler.

With respect to performance, the 5-element non-trap array achieves within about 0.1-dB of the gain produced on 17 meters by the 3 trap elements. The 2-element 17-meter section benefits from forward stagger effects due to activity on the 12-meter forward elements. On 12-meters, the non-trap antenna averages about 0.6-dB less forward gain than the trap model. In addition, the non-trap model shows 5 to 10 dB lower front-to-back ratio values than the trap antenna, depending upon the band. (It is possible to revise the non-trap beam for a higher front-to-back ratio on 12 meters, but at the cost of forward gain.) Offsetting this advantage for the trap beam are the excellent 50-Ohm SWR curves of the non-trap beam.

We cannot declare a distinct winner in the abstract. Which design one considers to be superior depends upon the weight one gives to each of the enumerated factors. In any final evaluation, the physical factors of construction ease and maintenance difficulty may play as large a role in some evaluations as the differences in performance.

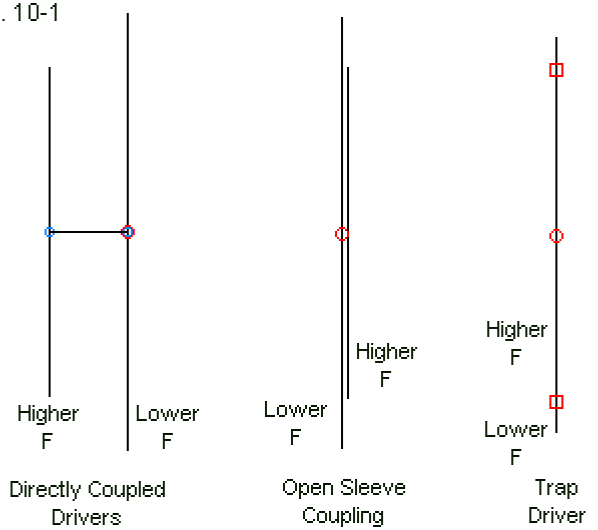
The design exercise, so far as we have taken it, does show that a 2-band 3-element trap Yagi remains a viable alternative to comparably sized non-trap beam designs. Well-designed and fabricated traps are not necessarily a hindrance to the performance that we may obtain from a given boom length, since both trap and non-trap Yagi arrays must inevitably show compromises in the design process. However, the growing differential in the gain potential between the two bands in trap beams does set 3-elements as the practical limit for such designs. In the end, these notes have not settled or even aimed to settle the question of whether to trap or not to trap. The journey through the wilderness of trap Yagis has aimed mostly to provide a more reasonable set of expectations of trap antennas by better understanding their effects on Yagi performance.

Before we close the covers on this collection of notes on some basic factors in multi-band beam design, we must plug up one gap in the coverage. Along the way, we have noted the possibility for using sleeve-coupled drivers rather than either traps or directly coupled drivers. In appearance, sleeve-coupled driver beams seem simpler than their counterparts, since they do not require either the circuitry of traps or the transmission-line connection between drivers. Appearances will prove deceiving, since sleeve-coupled drivers are a bit more complex electrically and may prove somewhat difficult to tame in the field—at least for the average antenna builder with a modest shop and test arrangement. Nevertheless, these drivers offer some interesting potentials that other systems do not share. Hence, we must give them their due before ending our journey.

10. Some Open-Sleeve Designs for 17 and 12 Meters

In the long course of our journey through rudimentary multi-band beams, we have looked very extensively at 2 of the three types of feed systems commonly used. **Fig. 10-1** provides a reminder of the three major feed systems: directly coupled drivers, trap driver elements, and open-sleeve coupled drivers.

Fig. 10-1



Three Common Types of Multi-Band Beam Feeding

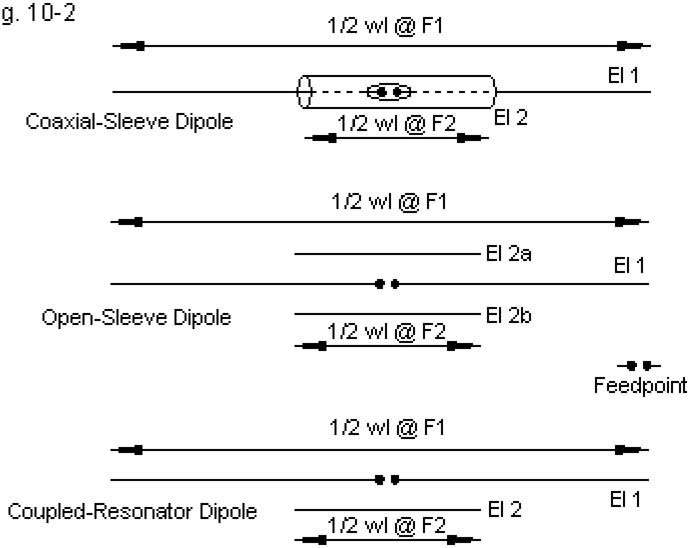
With directly coupled drivers, we employed a relatively low-impedance connection line between the drivers, and the main feedline connected only to one of them. Depending upon the multi-band design, the higher-=frequency driver may go ahead of or behind the lower frequency driver. As well, there are circumstances that may require a connection of the feedline to the higher-frequency (shorter) driver rather than the more usual lower-frequency (longer) driver. The connecting line is a short section of transmission line. Except when the secondary driver has a feedpoint impedance that exactly matches the line impedance, the secondary driver impedance will undergo a small but noticeable transformation along the line. The usual consequence is that upper-band SWR bandwidths on 2-band beams will be narrower than for the same element configuration in a monoband beam. In addition, the drivers are spaced close enough together to interact strongly. Therefore, the length of the upper-band driver may not coincide with the length of a driver on a monoband beam for the same band.

Trap drivers employ high-impedance parallel tuned circuits to effectively terminate the element at the trap locations on the upper band. On the lower band, the residual inductive reactance of the tuned circuit requires element shortening for resonance on the lower band, relative to a non-trap element fulfilling the same function. The shortening of the element and the losses in traps with a finite Q to the inductor result in lower band losses, although the upper band may show full performance.

The third type of feed system carries the general name of open-sleeve coupling. We connect the main feedline to the lower-band driver, sometimes called the master driver. A properly spaced driver element for the upper band (sometimes called the slaved driver) does not need a physical connection to the master driver to perform its function. When correctly set, the slaved driver controls the current distribution along both its length and the master driver's length, and at the upper band design frequency, the master driver provides a low-SWR match to the main feedline.

Open-sleeve coupling in general has a history that dates to the 1940s. As well, a collection of more specific names has attached itself to the variations upon a general theme of master and slaved driver systems. Chapter 7 of recent editions of *The ARRL Antenna Book* devotes several pages to the general theory of master and slaved drivers. **Fig. 10-2** covers some of the territory of the system's history, including showing how the name "sleeve coupling" arose. At the top, the earliest version of the feed system shows a coaxial sleeve that surrounds the master driver, with the sleeve forming the slaved driver. The ½-λ designations in the sketches mean a resonant length relative to the feedpoint impedance at the master driver on each of the 2 frequencies.

Fig. 10-2

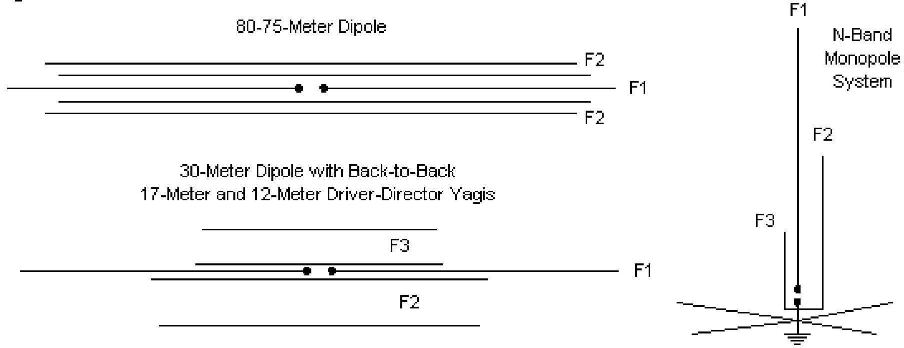


Forms of "Sleeve" Coupling

A later development recognized that a full coaxial or closed sleeve was not necessary to achieve the master-slaved-driver phenomenon. As few as 2 wires might achieve the same goal. Further on in the evolutionary cycle, K9AY realized that we only needed a single wire, and he dubbed this version “coupled resonators.” The multiplication of names is unnecessary, since later applications have shown that there are no sharp dividing lines between the forms. Hence, the most popular name, open-sleeve coupling—will do for all of them.

For ordinary dipole and monopole elements with uniform and equal diameters, K9AY established a basic relationship between the element spacing and the element diameter: $[\log_{10} d / \log_{10} (D/4)] = 0.54$, where d is the spacing of the conductors and D is the conductor diameter, when we measure both in wavelengths at the frequency of the slaved driver. While the relationship holds fairly reliably for simple dipoles and monopoles, especially when both require the same feedpoint impedance, the use of tapered-diameter elements and the presences of a complex set of interacting elements tend to modify the relationship. Hence, the most common methods presently used to design amateur open-sleeve systems is antenna modeling, followed by considerable field adjustment to overcome modeling limitations. Master and slaved drivers use very close spacing, which presses the limits of software such as NEC.

Fig. 10-3



Some Applications of "Sleeve" Coupling

Fig. 10-3 shows a few applications in which builders have employed open-sleeve coupling. The top left sketch represents a partial drawing of a dipole for the very wide 80-75-meter band. The bandwidth is over 13% from 3.5 to 4 MHz. At least one builder has used a master 80-meter driver surrounded by a cage of 6 to 8 75-meter slaved elements for operation across the band. The array illustrates two important points. First, we need not restrict open-sleeve coupling to operation on distinct bands. We may use the system to broaden the bandwidth of an antenna or array to cover a range of frequencies that a single driver cannot handle with reasonable performance and SWR levels. Second, the wire cage is neither a fully closed coaxial sleeve nor a fully open sleeve. It blurs the dividing lines among the plethora of labels.

The sketch to the right shows a collection of monopoles with a single master driver and a single radial system. Up to five monopoles have been driven successfully by a single driver. The advantage of this system lies in the relative independence from each other of all of the slaved drivers. The builder can tuned the length and spacing of each slaved monopole independently. In a simple monopole system, the tuning is simplified to obtaining a low SWR on the new frequency as measured at the feedpoint of the master driver.

The third sketch at the lower left in **Fig. 10-3** brings us closer to our fundamental interest in this volume: using open sleeve coupling as a method for feeding a multi-band horizontal array. The sketch shows a 30-meter dipole centered between drivers for 17 and for 12 meters. Each upper-band pair of elements forms a driver-director Yagi that is suitable for use on the narrow amateur allocations. Indeed, open-sleeve coupling tends to yield narrower operating bandwidths for the slaved drivers than we might obtain from a directly driven element. Hence, for multi-band use, their best home might well be the narrower upper HF amateur bands. The specimen shown places the 17- and 12-meter elements back-to-back, thus minimizing interactions and more easily assuring performance to the level of any driver-director Yagi with the same spacing between the driver and its director. Therefore, the key field adjustment becomes finding the correct spacing and driver length—for the element taper schedule used—that provides a usable SWR value. Driver-reflector Yagis with good forward gain and excellent front-to-back ratios generally have low feedpoint impedance values when fed as monoband beams. By making the driver a slaved element to a master driver, the builder can set the driver to obtain a 50-Ω impedance at the main feedpoint without otherwise disturbing the driver-director performance.

A 4-Element Very-Wide-Band Array for 10 Meters

Although our chapter title specifies designs for 17 and 12 meters, neither band is satisfactory for illustrating the fact that the master-slave driver system is usable within a parasitic array as well as within a simple dipole if our goal is to increase the coverage while maintaining performance across the band. Therefore, we may pause to explore 10 meters. We often consider even a monoband beam to have a wide operating bandwidth if it can cover the first MHz of the band with adequate performance. A short-boom (8') 3-element Yagi may do the job with an average gain of about 7.2 dBi and a 180° front-to-back ratio of about 20 dB or better. However, the feedpoint impedance will be between 20 Ω and 25 Ω, and so we shall need a matching network to handle the standard 50-Ω coaxial feedline.

Suppose that we retain the boom length, add a slaved driver, sustain the performance numbers, and have a 50-Ω impedance level without a matching network. Suppose further that the array can cover not only the first MHz of 10 meters, but instead the entire band from 28.0 to 29.7 MHz, close to a 6% bandwidth. The resulting array might look like the sketch in **Fig. 10-4.**

Outline of a Wide-Band 10-Meter Beam Using Sleeve-Coupled Drivers

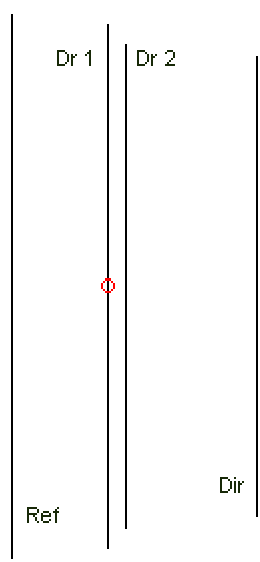


Fig. 10-4

The design model and prototype consisted of simple stepped-diameter elements. The inner section used +/-54" sections of 0.625" aluminum. **Table 10-1** shows the exposed length of the 0.5" tip sections (with the usual 2"-3" extension into the larger tubing) plus the total element length and the cumulative element spacing from the reflector.

Table 10-1. Dimensions of the 4-element wide-band Yagi using sleeve-coupled drivers

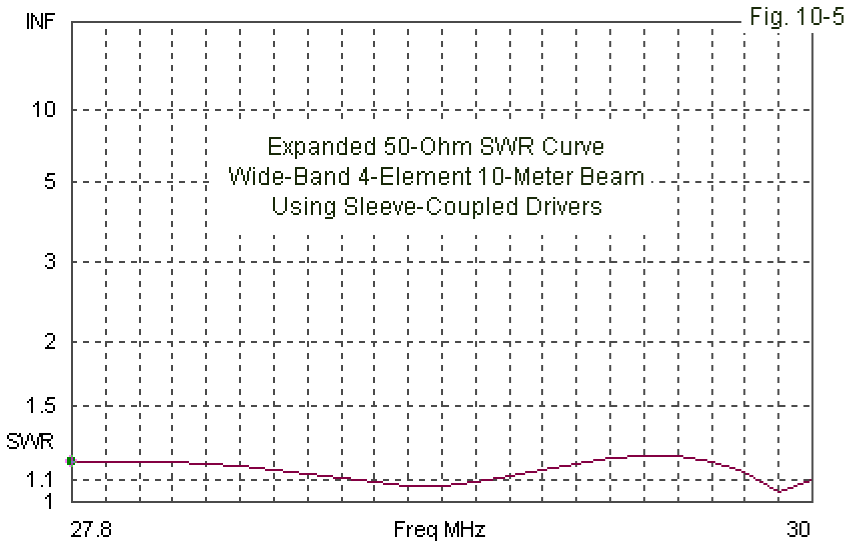
Section	Dia.	Length exposed	Total Length tip-to-tip	Spacing cumulative	Spacing from preceding
Inner	0.625	54"			
Reflector	0.5	53.25	214.5	---	---
Driver 1	0.5	49.6	207.2	37.5	37.5
Driver 2	0.5	41.9	191.8	45.0	7.5
Director	0.5	37.3	182.6	96.0	51.0

The 8' boom length in the table requires, of course, small additions to support the element-to-boom hardware. To sample the performance potential of the array, **Table 10-2** shows the key free-space performance values from the design model at the band edges and at the center of the expanded passband.

Table 10-1. 4-element wide-band Yagi with sleeve-coupled drivers: performance

Frequency	28.0	28.85	29.7	Δ
Free-space Gain dBi	7.04	7.13	7.55	0.51
Front-to-back ratio dB	19.21	33.05	18.02	15.03
Feedpoint Z (R +/- jX Ω)	49.4 – j8.2	47.0 – j0.6	51.6 + j8.4	4.6 + j16.6
50-Ω SWR	1.18	1.07	1.18	

The 50-Ω SWR curve for the array should show 2 dips, one for each driver. In multi-band uses of open-sleeve coupling, these dips occur at widely different frequencies. In some designs, such as the optimized wide-band antenna (OWA) versions of the Yagi, the dips may occur within the operating passband. For the present design, we must extend the SWR curve well outside the limits of the 10-meter band to find both minimum values. The SWR sweep in **Fig. 10-5** covers 27.7 to 30 MHz in order to provide a glimpse at the SWR capabilities of open-sleeve coupling to provide excellent values.



The peak 50-Ω SWR value within the sweep is about 1.22:1. The curve has a typical open-sleeve sharp dip at the resonance created by the slaved driver. SWR values tend to rise rapidly beyond this dip as the resistive component of the impedance falls rapidly. At the lower end of the passband, the SWR remains stable for a considerable frequency range below the passband edge. Indeed, for designs of this order, the SWR is not the limiting factor in wide-band performance.

Fig. 10-6 provides a sweep of the free-space forward gain and the front-to-back ratios (both 180° and worst case). The Y-axis label calls the worst-case ratio the front-to-sidelobe ratio, since the rearward lobe or lobes are the pattern sidelobes. Note that the forward gain shows a minor dip within the passband (down to 7.02 dBi), with the upward value swing carrying on below the lower passband limit. The key performance limitation is the front-to-back ratio, which declines steadily outside both the upper and lower passband limits. At the same time, the worst-case ratio remains very stable within the passband.

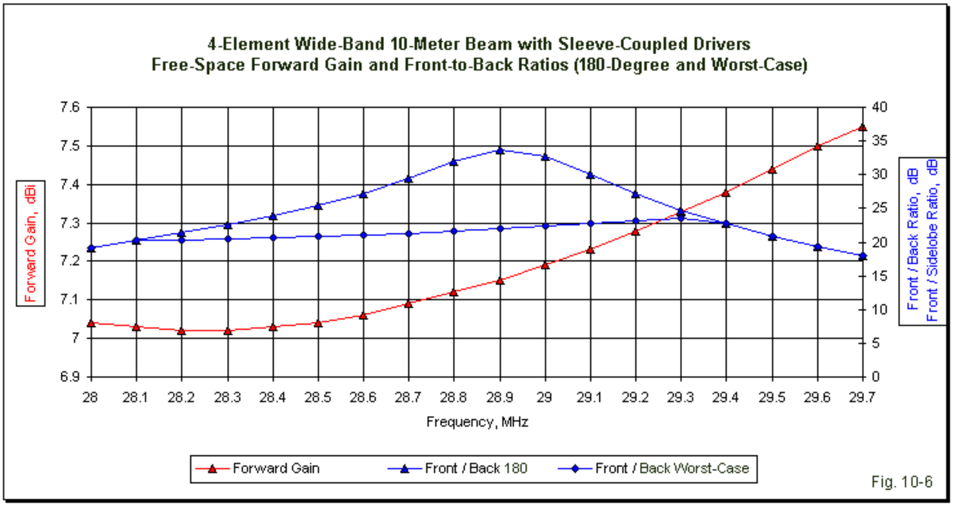


Fig. 10-6

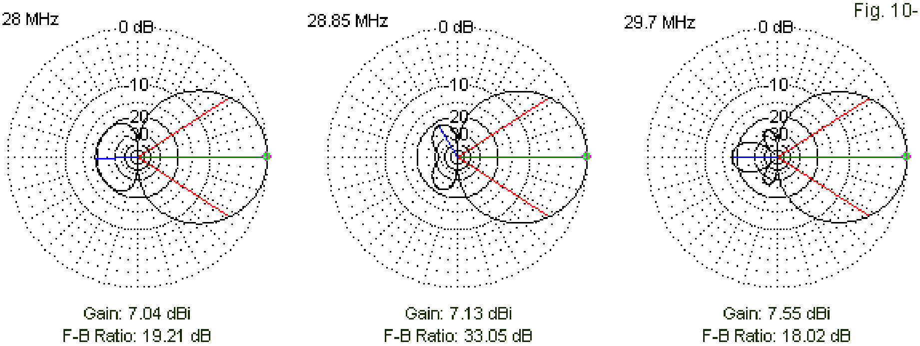


Fig. 10-7

Free-Space E-Plane Patterns and Performance Data
4-Element Wide-Band 10-Meter Beam with Sleeve-Coupled Drivers

The gallery of sample free-space E-plane patterns provides evidence that the evolution of the radiation patterns across the 10-meter band has many of the traits of such patterns for only the first MHz of the band when we use only a single driver. The gain changes by only about a half-dB across the band, while the worst-case front-to-back ratio has a range of only about 5 dB with an 18-dB minimum value. The design thus achieves it main design goal of providing monoband-Yagi performance for the given boom length over nearly double the bandwidth. In addition, whereas monoband Yagis would normally require a matching network to convert low feedpoint impedance values to 50 Ω, the 4-element array provide a direct 50-Ω match.

The sleeve-coupled driver pair thus provide means of not only widening the operating passband, but also of controlling the feedpoint impedance. The close coupling of the elements modifies the natural dipole impedance, even within the context of a parasitic array. (This is another reason why the guidance equation for coupled resonators provides only a starting point for design, but not fails to show all that we can do with such driver pairs.) The relationship between the drivers is complex, but in general, the main driver controls the lower end of the band, while the slaved driver dominates performance at the upper end of the band. **Table 10-3** provides the relative current magnitude on the slaved driver at 0.2-MHz intervals of the array passband. The relative current on the main driver is a constant 1.0. Note the point in the sweep where the slaved-driver current exceeds the main driver value.

Table 10-3. Slaved driver relative current magnitude (relative to 1.0)

Frequency	Magnitude	Frequency	Magnitude
28.0	0.737	29.0	0.975
28.2	0.786	29.2	1.057
28.4	0.829	29.4	1.182
28.6	0.871	29.6	1.375
28.8	0.916	29.8	1.653

The rapid rise in the slaved-driver current magnitude at the higher end of the band corresponds with the ultimate rapid rise in SWR beyond the upper end of the passband. Equally, the much slower rate of change at the low end of the passband corresponds to the flatness of the SWR curve as it passes beyond the lower passband limit. Interestingly, the exact length of the reflector tends to be most useful in setting the performance values at the low end of the band, while the director is most effective in controlling the performance at the passband's upper limit.

The wide-band 10-meter Yagi design not only provides us with information about the band-widening capabilities of sleeve-coupled drivers in the context of a parasitic beam, it also is a harbinger of expectations for multi-band array performance. Since the slaved driver will control the performance curves on the upper band in a 2-band array, we should expect a narrower passband at the higher frequency. To some degree, we can expand that passband by the judicious placement of additional directors. However, for simple arrays with no more than 2-elements per band, open-sleeve driver coupling may not be as effective for wider upper bands than the direct coupling methods that we examined in preceding chapters. However, the narrower amateur bands, such as 12 and 17 meters, do not challenge the bandwidth capabilities of open-sleeve coupled drivers.

A 4-Element Back-to-Back Array for 17 and 12 Meters

On the narrow 17- and 12-meter bands, the driver-director array becomes attractive for providing better gain and front-to-back ratio values that its driver-reflector counterpart. As well, we can achieve these values using a shorter boom—something in the 0.7-λ to 0.8-λ range for feedpoint impedances between 20 Ω and 25 Ω, a relatively easy match to a 50-Ω main feedline. The narrower passband for the driver-director arrangement presents no significant problems on 17 and 12 meters, although that feature requires more careful field adjustment of the antenna at any design frequency.

Difficulties do arise when we attempt to interlace driver-director arrays for more than one band. One way to overcome the problem of difficult element interactions is to place 17- and 12-meter driver-director Yagis back-to-back on the same boom. We may feed only the 17-meter driver, using a beta match or something equivalent. We may then place the 12-meter driver behind the 17-meter driver. The shorter driver acts as a coupled resonator and drives its own director in the opposite direction. The disadvantage lies in having to turn the array by 180° when changing bands but aiming to the same target communications area. The advantages may outweigh the disadvantage. First, we need only a single main feedline for the two bands. Second, the boom length is less than 7' for all 4 elements. **Fig. 10-8** provides an outline of the back-to-back array.

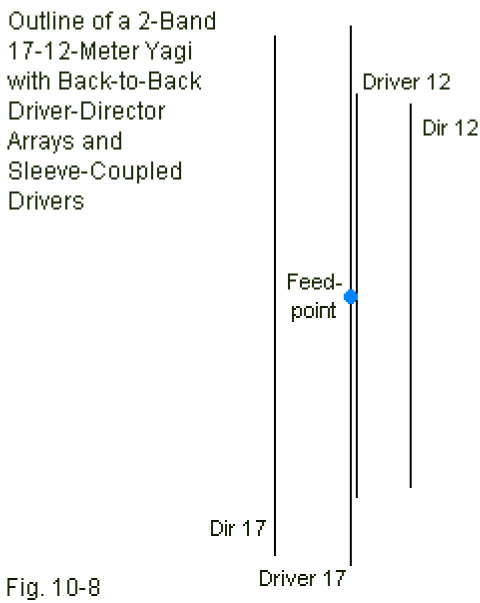


Fig. 10-8

Because the driver-director arrays individually have excellent front-to-back ratio values that exceed 20 dB, the close spacing of the arrays creates no harmful interactions. As the sketch shows, the two drivers are in very close proximity, partly as a function of the different pre-matched feedpoint impedance values. The 17-meter driver has an impedance of about 16 Ω (with a capacitive reactance) before adding the beta match. The beta match is also operative when the operating frequency is in the 12-meter band. Therefore, if a builder chooses some other type of matching system, significant re-design of the array may be in order, especially with respect to the driver lengths and spacing values. **Table 10-**

3 shows the dimensions and element taper schedule used in this array. The element dimensions show progressive values from the element center outward. Subtract one length value from the preceding value to obtain the exposed length of tubing. Then add 2” to 3” for insertion into the larger tubing. The tip lengths are half-element lengths. Double these values to obtain the total element length.

Table 4. 4-element back-to-back 17-12-meter array dimensions

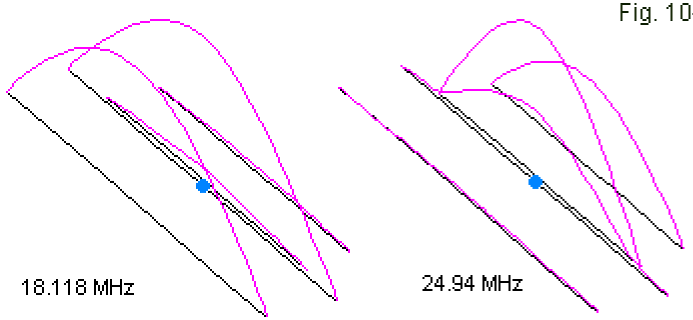
17-meter Yagi			12-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.875”	18”	Both	0.75”	12”
	0.75	42		0.625	30
	0.625	108		0.5	78
Dr 1 (m) tip	0.5	161.4	Dr 2 (s) tip	0.375	120.72
Dir tip	0.5	156.0	Dir tip	0.375	114.84

Array Spacing		Notes:
17-m dir	0	1. Length values progressive from element center.
17-m Dr 1	45.41	2. Reference dimensions to Fig. 10-8.
12-m Dr 2	48.89	3. Spacing values progressive from 17-meter director
12-m dir	81.89	4. Driver 1 uses a shorted beta stub TL = 600 Ω, 6”
		5. Feedpoint: 17-meter Dr 1
		6. Boom length: 6’ 10”

The dimension chart counts the spacing values starting with the 17-meter director. The two drivers are 3.48” apart, and the 12-meter director is 33.0” from its driver. The beta stub can be composed of any transmission line stub having the same reactance, about 34.75 Ω at 18.118 MHz. For example, a 63.5” length of 50-Ω line with a velocity factor of 1.0 will do the same job. However, adjust the physical line length for the velocity factor of the cable used. Indeed, be prepared to field adjust the beta section, whatever it composition, for the best SWR curves on both bands. Various factors, such as the presence of the boom, may affect the working velocity factor of a bare-wire beta hairpin. Of course, a beta inductor is equally usable in this application.

The back-to-back array provides us with a chance to see the relative current magnitudes on the various elements on each band. **Fig. 10-9** supplies the graphs for 17 and 12 meters. Note that on 17 meters, the 12-meter elements show only negligible activity due largely to the relatively high front-to-back ratio of the driver-director arrays.

Fig. 10-9



4-Element Back-to-Back Driver-Director Yagis
for 17 and 12 Meters with Sleeve-Coupled Drivers
Relative Current Magnitude Distribution

On 12 meters, we find the higher driver current on the 12-meter element. Although the main or 17-meter driver also shows significant current, the magnitude drops almost to zero at points close to the ends of the 12-meter driver. The 17-meter director is almost inert when operating the array on 12 meters.

Because the two bands are so narrow, we may glean the relevant modeled free-space performance data from tables. **Table 10-5** provides the 17-meter information, while **Table 10-6** supplies parallel material for 12 meters.

Table 10-5. 4-element back-to-back 17-12-meter array: 17-meter performance

Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.19	6.37	6.55	0.36
Front-to-back ratio dB	20.77	24.40	24.16	3.63
Feedpoint Z (R +/- jX Ω)	59.3 + j10.2	51.1 – j0.1	40.2 – j5.6	19.1 + j15.8
50-Ω SWR	1.29	1.02	1.29	

Table 10-6. 4-element back-to-back 17-12-meter array: 12-meter performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	6.38	6.44	6.50	0.12
Front-to-back ratio dB	24.74	23.57	21.42	3.32
Feedpoint Z (R +/- jX Ω)	55.0 + j14.7	48.8 + j1.6	36.5 – j6.2	18.5 + j20.9
50-Ω SWR	1.34	1.04	1.41	

In terms of basic information, the comparable back-to-back driver-director beams provide almost identical performance numbers. One slight difference is significant. The 17-meter band is about 35% wider as a function of its center frequency than the 12-meter band. However, the 12-meter band-edge SWR values are higher than those on 17-meters. Although not operationally significant in this case, the difference is continuing evidence that slaved-driver portions of a sleeve-coupled array have narrower bandwidths than comparable master-driver portions.

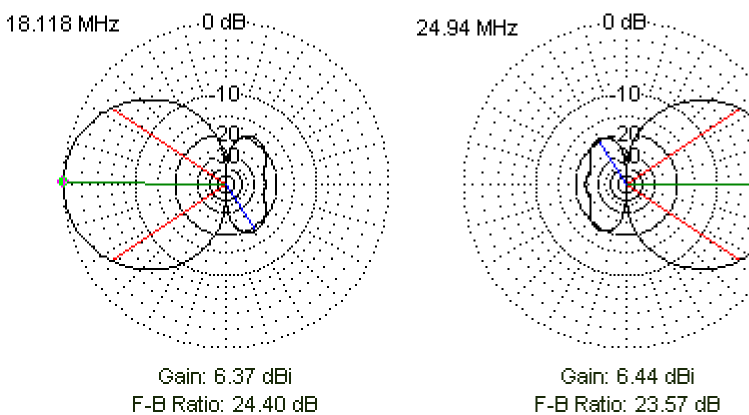


Fig. 10-10

Free-Space E-Plane Patterns and Performance Data: 4-Element Back-to-Back Driver-Director Yagis for 17 and 12 Meters with Sleeve-Coupled Drivers

Fig. 10-10 provides modeled free-space E-plane patterns for the center of the back-to-back bands. Except for their opposing directions, the two patterns are virtually indistinguishable.

A 4-Element Driver-Reflector Yagi for 17 Meters with a Sleeve-Coupled Driver-Director Yagi for 12 Meters

We can align the directions of the forward lobes in a 4-element 2-band sleeve-coupled beam if we are willing to sacrifice some of the lower-band front-to-back ratio—in fact, about half. If we make the 17-meter elements a driver-reflector Yagi, we may place the 12-meter driver-director Yagi ahead of it with almost no unwanted interactions. **Fig. 10-11** shows the general outline of such a beam. Photos of the prototype for this array appeared in “Basic Beams for 12 and 17 Meters,” *QST* (August, 2000), pp. 57-62. **Table 10-7** provides dimensions for this 2-band beam.

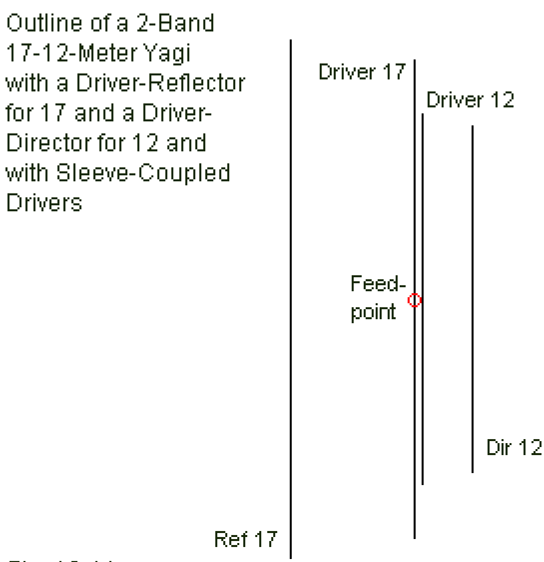


Fig. 10-11

Table 7. 4-element 17-12-meter array dimensions

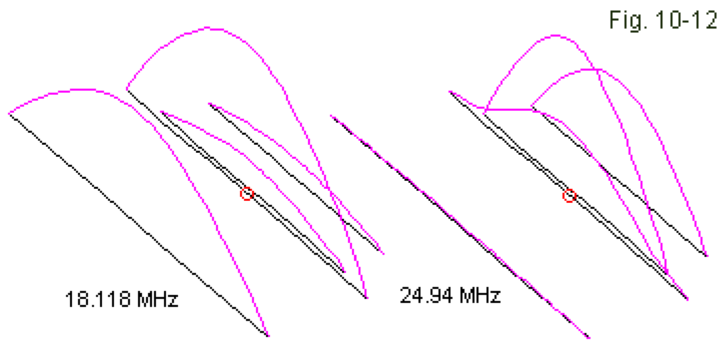
17-meter Yagi			12-meter Yagi		
Element	Diameter	Length	Element	Diameter	Length
Both	0.75”	48”	Both	0.75”	12”
	0.625	81		0.625	30
	0.5	114		0.5	78
Ref tip	0.375	169.2	Dr 2 (s) tip	0.375	120.84
Dr1 (m) tip	0.375	157.2	Dir tip	0.375	114.00

Array Spacing	
17-m ref	0
17-m Dr 1	81.6
12-m Dr 2	86.16
12-m dir	119.16

Notes:
1. Length values progressive from element center.
2. Reference dimensions to Fig. 10-11.
3. Spacing values progressive from 17-meter reflector
4. Driver 1 uses no matching network.
5. Feedpoint: 17-meter Dr 1
6. Boom length: 9’ 11”

The prototype for this array used light-duty construction, since its aim was to prove the principles involved. The overall width is about the same as the back-to-back array, but the boom is longer—about 10’. Much of the difference arises from the wide spacing between the 17-meter elements to yield a direct 50-Ω driver impedance without need for a matching network. Closer spacing is possible, but the addition of a matching network on the 17-meter master driver will change the required spacing and length of the 12-meter slaved driver. The distance between drivers for the present array is just under 4.6”, while the 12-meter driver-to-director spacing is 33”. Essentially, the 12-meter section of this 2-band Yagi is the same as the comparable section in the back-to-back array.

The current activity on the elements is also very similar to the activity in the earlier antenna, as shown by the relative current magnitude curves for each band in **Fig. 10-12**. On 17 meters, activity on the upper-band elements is just great enough to raise the lower-band gain by about 0.2 dB from monoband values. The front-to-back values are marginally higher as well. On 12 meters, the 17-meter reflector is almost completely inert. The driver and director for the upper band dominate. The 17-meter driver also shows very significant current levels, but the curve on the master driver almost terminates at the limits of the 12-meter driver.



Driver-Reflector and Driver-Director Yagis
for 17 and 12 Meters with Sleeve-Coupled Drivers
Relative Current Magnitude Distribution

The modeled free-space performance values for the dual-band Yagi appear in **Table 10-8** (for 17 meters) and in **Table 10-9** (for 12 meters).

Table 10-8. 4-element 17-12-meter array: 17-meter performance

Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.41	6.34	6.27	0.14
Front-to-back ratio dB	11.28	11.36	11.38	0.10
Feedpoint Z (R +/- jX Ω)	44.4 – j4.2	47.1 – j1.4	49.9 + j1.3	5.5 + j5.5
50-Ω SWR	1.16	1.07	1.03	

Table 10-9. 4-element 17-12-meter array: 12-meter performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	6.33	6.39	6.46	0.13
Front-to-back ratio dB	24.62	26.33	26.97	2.35
Feedpoint Z (R +/- jX Ω)	56.9 – j2.7	49.3 – j2.0	41.5 + j0.1	15.4 + j2.8
50-Ω SWR	1.15	1.04	1.21	

The wider SWR bandwidth of the 17-meter driver-reflector section is evident in the band-edge SWR values. The absence of a matching network shows up in the lower band-edge SWR values for 12-meters. In general, this form of an array requires less time to field adjust to an operating condition than the back-to-back array needs. The cost of having both arrays face in the same direction does not show up in the gain values. Allowing for the descending gain curve for the lower band that results from using a reflector element alone, the gain matches the values we obtain for 12 meters due to a small forward stagger effect on the lower band. The deficit on the lower band belongs almost solely to the 180° front-to-back ratio values, which are more than 10-dB lower than the 12-meter values. The difference shows up clearly in the free-space E-plane patterns for the two bands in **Fig. 10-13**.

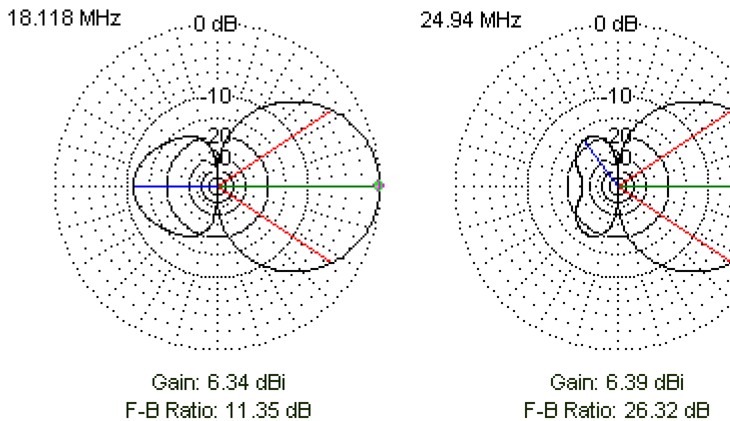


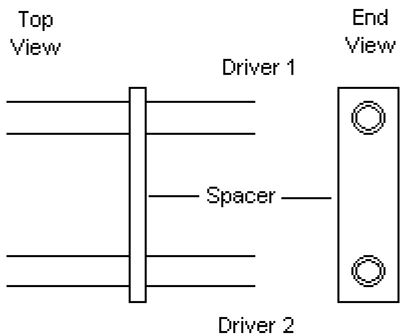
Fig. 10-13

Free-Space E=Plane Patterns and Performance Data: Driver-Reflector and Driver-Director Yagis for 17 and 12 Meters with Sleeve-Coupled Drivers

In exchange for the reduced lower-band front-to-back performance, we obtain a good balance in the band-to-band forward gain. As well, both patterns go in the same direction, simplifying band changes during operation. However, this 17-12-metr array requires a longer boom than the back-to-back version.

The construction of prototypes for these arrays used the same techniques shown in Chapter 1 of this collection of notes. There is one addition. The two drivers for all of the beams in this chapter have very close spacing. The 12-17-meter beams use drivers with very different lengths. The differences between driver structures show up in breezes, which sway the drivers at different rates. Because the spacing between drivers is critical to a stable SWR value, the drivers require a spacer piece to lock the drivers together. **Fig. 10-14** shows one possible form.

Fig. 10-14



Recommended Driver Spacer
for Sleeve-Coupled Elements

The position of the spacer pieces is not critical. However, a position about halfway out from the center of the shorter driver is close to ideal. A small piece of Plexiglas or polycarbonate is ideal for the task if the material has UV protection. If the spacer is wide enough, you may use setscrews to secure its position. Alternatively, you may use cable ties to prevent spacer movement along the elements.

When making field adjustments to the physical implementation of design models for any of the beams that we have examined, observe a special caution. Let any wag in the elements settle down before taking any readings. As well, the close coupling between the slaved driver and the master driver may call for a reversal of expectations, especially with respect to the slaved driver. The slaved driver current is normally about 160° out of phase with the master driver current. In some cases, the required adjustments to arrive at a low reactance may be the reverse of normal expectations. To make the upper band element more inductively reactive at the main feedpoint, we may need to shorten it—and vice versa. Therefore, you should make all adjustment in small increments until you get a feel for the directions required to move everything toward your goals.

Conclusion

The 17-12-meter arrays that we have used as samples of sleeve-coupled multi-band arrays are as close as possible to ideal starting points for experimenting with the technique. Nevertheless, they do not represent the only possible configurations or the maximum possible complexity in a beam with sleeve-coupled drivers. The now-classic Force12 C3 is a tri-band Yagi for 20, 15, and 10 meters using this technique for coupling the drivers. Our sample 2-band beams have simplified the process by maintaining the maximum degree of isolation between bands that we could obtain. As we add more elements for more bands, the isolation disappears and we encounter many of the challenges that we faced with the tri-band beam that used directly connected drivers.

We shall not pursue more complex beams using sleeve-coupled drivers because, quite frankly, directly connected drivers tend to yield wider operating bandwidths on the higher frequencies. One consequence of that fact is that finding setting for the elements that provide the best possible performance is somewhat easier with directly coupled drivers. As well, once the driver situation is settled, the performance of arrays using each type of feed system is almost indistinguishable at the design frequency using very similar parasitic element structures. Once we recognize that performance on each band—especially the upper band or bands—is a compromise involving decisions by the designer, much of the frustration of designing at least basic multi-band beams disappears. We must bring to the design session a set of scaled standards in which we decide in advance whether the SWR curve outweighs the front-to-back ratio—or the reverse—and whether raw gain is more important than very high directivity—

or the reverse. In the end, the designer must know two facts. One is what he wishes to get out of the beam. The second is the realization that he cannot get everything obtainable from a monoband beam.

Much remains beyond these basics of multi-band beam design. As boom grows longer and designs grow more complex, the designer must acquire experience that guides the placement both of gain improving and of control directors. In some advanced commercial beams, element placement has yielded vertical element stacking to overcome the tendency of certain elements of each band seeming to want the same boom position. When designs using such techniques become one of a kind, our hopes for codifying the methods into generalizations like those appearing in the first chapter of these notes grow dim.

Indeed, nothing can substitute for experience in complex multi-band beam design. Those who track the development of modern Yagi design should be impressed by and appreciation of the artistry involved in the increasing complex and capable designs emerging especially from the Force12 and Optibeam drawing boards. Their work served as the reason for putting together these notes, however basic the treatment that we could pack into the principles and especially the sample designs. At most, this volume is an homage paid from the freshman level to the heights of mastery that we find in some of the latest and best of today's multi-band beams.

Other Publications

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