Preface to Multi-Band Beams

There is among some amateur radio beam designers a special art: the art, science, 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.

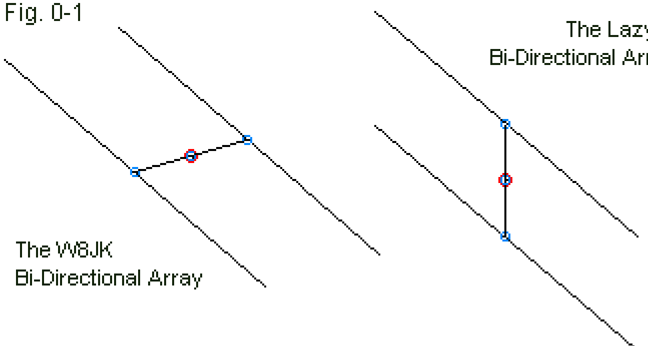
Fortunately, enough information as emerged over the last 20 years that we can begin to make some inroads into the task of designing an effective multi-band beam. Part of the information is subject to at least qualitative codification, although we are far from a clear systematic quantitative analysis. 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*).

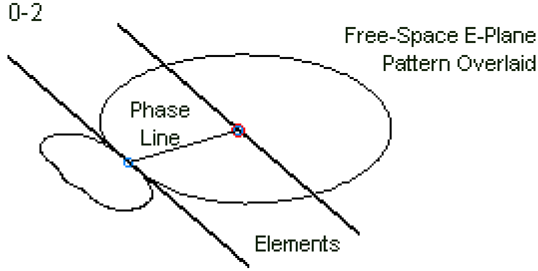
Fig. 0-1



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.

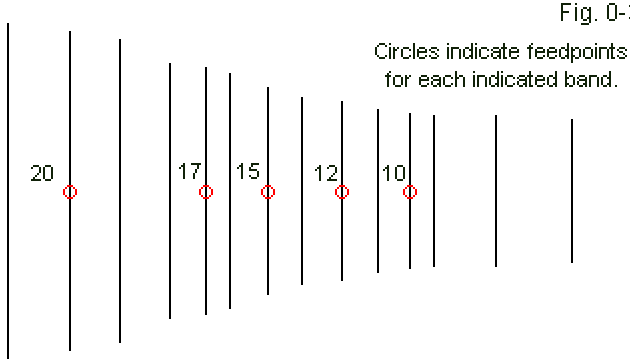
Fig. 0-2



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.

Fig. 0-3

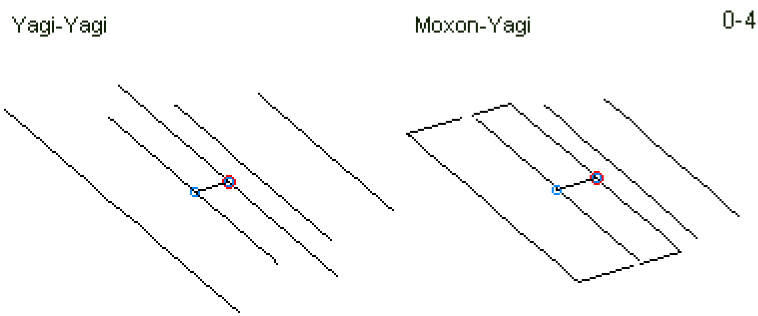


A 5-Band Pure Forward Stagger Beam by ON4ANT
with Separate Feedpoints for Each Band

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.

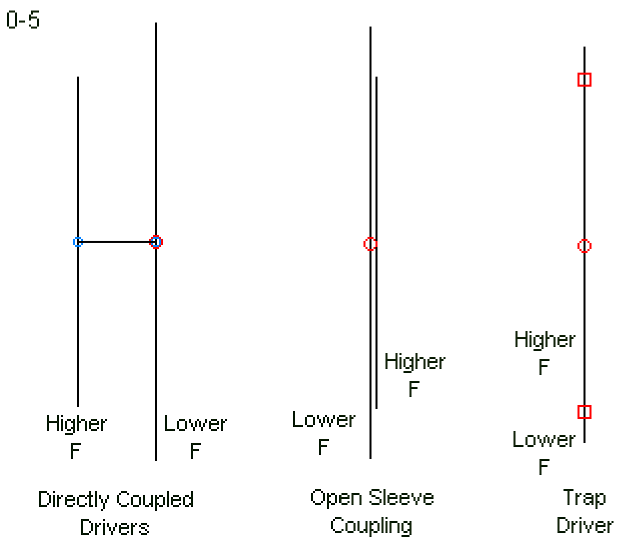
So far, I have not specified that the parasitic antennas interlaced in a multi-band array are Yagis. Indeed, as shown in **Fig. 0-4**, not all of the antennas need to be Yagis. The outline shows two very comparable 2-band beams. The one on the left interlaces a 2-element Yagi for the lower band with 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.

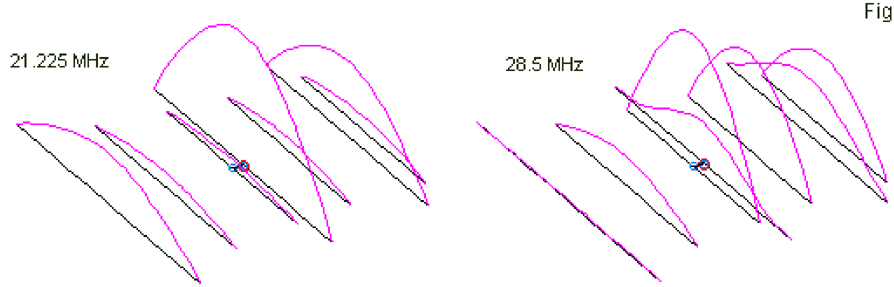
We shall have occasion to discuss each of these driver system in greater detail in the proper places. However, so consistency, we shall major on the use of directly connected drivers in the greater part of our examination of interlaced multi-band parasitic beams.

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

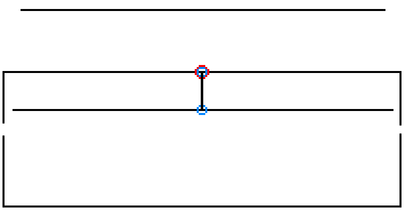


Current Distribution on a 2-Band Beam

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.

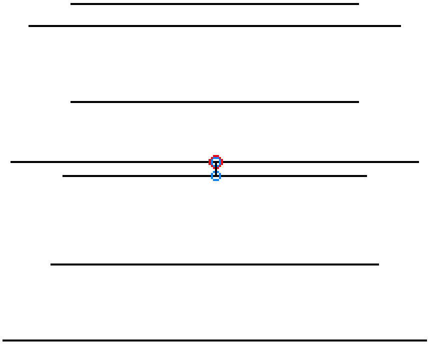
Fig. 0-7



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.

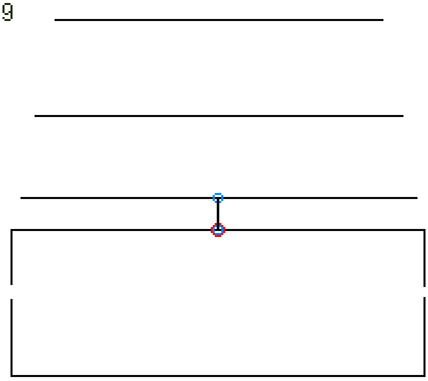
Fig. 0-8



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

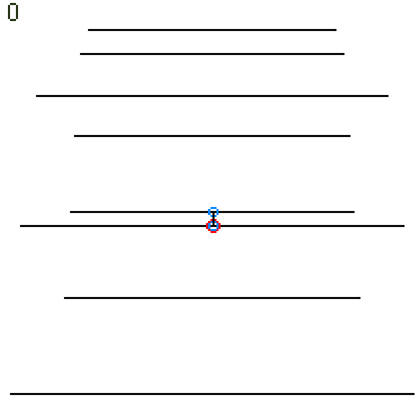


Alternative 2-Band Moxon-Yagi

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?

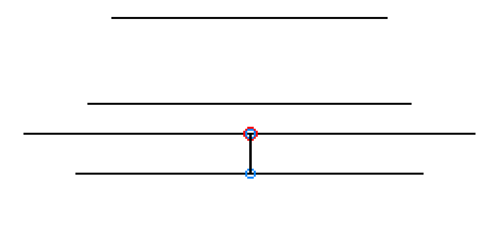
Fig. 0-10



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

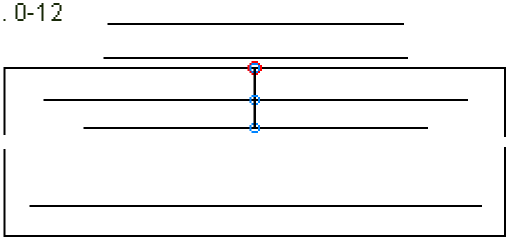


Replacing a Moxon Section with a Yagi Section

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.

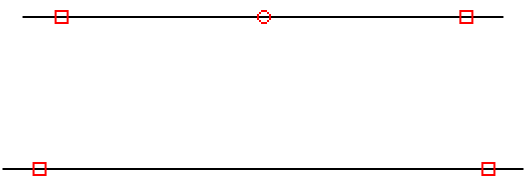
Fig. 0-12



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

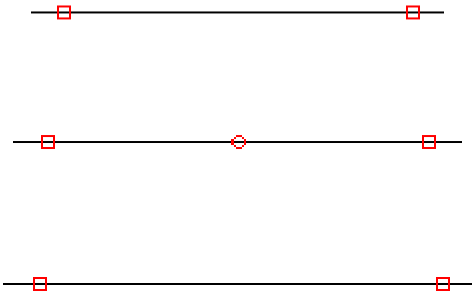


2-Band 2-Element Trap Beam

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.

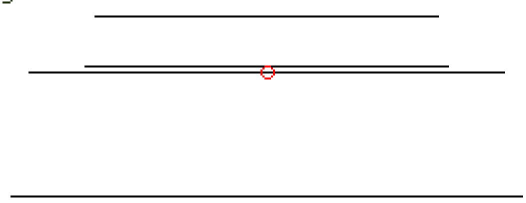
Fig. 0-14



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.