Moxon Rectangle Notes

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Dedication

This volume of studies on the Moxon rectangle is dedicated to my wife, my friend, my supporter, and my colleague, all of whom are Jean. Her patience, understanding, and assistance gave me the confidence to retire early from academic life to undertake full-time the continued development of my website (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. Jean passed away Nov. 4, 2002, after a 13-month courageous struggle against cancer. Her final wish was only that all of the friends she knew should plant in their yards a tree or a shrub to support the songbirds that she so much loved and so ably rehabilitated.

Preface

A little over a decade ago, while investigating the properties of small beams, I encountered the Moxon rectangle and a number of kindred antenna designs. Since that day, the Moxon has become a personal favorite among antennas that I like to study, build, and test. I have written a fair number of articles on various incarnations of the Moxon for bands ranging from 80 meters to 900 MHz. Perhaps it is time to consolidate my many notes into a coherent volume.

There are simpler antennas and more complex antennas. There are antennas with much higher gain. So the very first question is what properties of the Moxon rectangle attracted my attention. The answer comes from a particular challenge facing many radio amateurs as they attempt to progress from a simple dipole or doublet into the realm of directional beams: space. The Moxon packs almost as much gain into a 2-element parasitic array as a full-size reflector-driver Yagi. However, the rectangle has a better front-to-back ratio, the potential for a 50-Ohm feedpoint impedance, and a broad operating bandwidth. All of these properties fit into an area that is only 3/4ths the side-to-side dimension of a full size 2-element Yagi. As we shall discover, the antenna also has a number of other very useful properties. The antenna is not a cure-all for every antenna need. But, it does offer enough special features to give it a more or less permanent place among the antennas used by radio amateurs and others.

Like every other antenna design, the Moxon rectangle has a history, and we shall begin there. I shall even reveal why I insist on crediting the antenna design to Les Moxon, G6XN, rather than trying to label it with my own name or call sign. Then we shall turn to the basic principles and properties of the rectangle, including its relationship to 2-element Yagis and 2-element phased arrays. We shall also pause to compare the rectangle with other shrunken and scrunched 2-element antenna designs.

Perhaps the most crucial chapter in this volume is the third. I discovered that the dimensions for a 50-Ohm rectangle derive from just two variables: the element diameter and the design frequency. Hence, to design a Moxon rectangle, we need only plug these two variables into a computer program and come up with successful dimensions for virtually any frequency from the AM broadcast band through 1 GHz. Moreover, we can set the program into almost any venue: a GW Basic utility, a spreadsheet, a stand-alone Windows program, or an antenna model within a program that permits modeling by equation.

The remainder of our work will focus upon methods of construction and applications. For the HF region, wire versions of the rectangle are very appropriate, not just for the lower region, but as well on 10, 6, and even 2 meters. For fixed installations, we shall explore some techniques for reversing the beam direction. For bands from 20-meters upward, rotatable Moxon rectangles are both feasible and straightforward to implement. We must contend with the fact the a 50-Ohm Moxon rectangle is a mono-band array that does not take well to nesting. However, that fact does not prevent us from incorporating the rectangle into a compact dual-band or tri-band beam of very usable performance.

As we move upward in frequency into the VHF and UHF regions, the Moxon rectangle reveals further interesting characteristics. While still useful as a modest-gain utility beam for horizontally polarized communications, orienting the antenna vertically gives us two special properties. One is a very deep and sharp rearward null, useful for direction-finding. The other is a broad beamwidth so that we need only 3 such antennas to cover the entire horizon. Horizontal and vertical orientations do not exhaust the directions for pointing a Moxon—or even a turnstiled pair of Moxons. Aimed straight up, the rectangle makes a good fixed-position satellite antenna.

We shall close our examination of the Moxon rectangle with a brief look at some of its cousins, mostly antennas that bend some or all of their element-ends toward each other in a Vee. However, perhaps the closure of the text will mark the beginning of your own further investigations. I have included some software. There are programs that permit you to calculate Moxon rectangle dimensions. As well, I have gathered a good number of EZNEC models of Moxons using thin and fat elements for bands ranging from 80 meters down to 33 centimeters.

1. A Short History of the Moxon Rectangle

The history of the Moxon rectangle is actually a history of rectangular antenna using parasitic principles—that is, feeding only one element of the two in the array. The designer folds the ends of each element so that they point at each other along the sides of the array. Since rectangles include squares, we may find that the origins of the Moxon rectangle do not date simply from the middle of the 20th century, but instead go back a few decades earlier.

Some antenna designers and analysts might be disturbed—even discouraged—by the discovery that their seemingly new offspring are intimately related to designs of the more distant past. I do not share that view. Instead, I happily pay homage to past work and grow in my appreciation of how well basic design principles were known 6 decades ago. The 1930s comprise a fertile decade for design thinking in antennas, with vast strides in pressing wire antennas to their limits.

It would take the 1980s and 1990s to yield new techniques of software to allow some of the older design principles to be implemented with assured performance. Moreover, new ground is being broken daily in antenna design. However, we should not let contemporary development rates lead to the impression that "they knew hardly anything back then." They knew a very great deal—and developed ingenious ways of making it work in the absence of the complex antenna analyzers and other test equipment we have at our disposal today.

It is no slur against current design and analysis efforts to suggest that they mostly carry out the details of principles long known. Those details are crucial to making antennas perform to the peaks that the principles promised but that older measurement and calculation limitations could not assure. (One might get a sense of the importance of recent developments by asking when the 1920s work of Yagi and Uda started yielding really good antenna designs instead of really good antenna claims.) Perfecting the implementation of basic principles is a worthy enterprise in any era.

At the same time, new principles and techniques are also emerging today. Someday, they will be the more distant past to which we look with admiration. But at just this moment, October, 1937, will do as a past worth at least my own appreciation.

More specifically, we shall refer to *QST* for October, 1937. In that issue is an article composed of 2 items, although we shall focus on the second only.

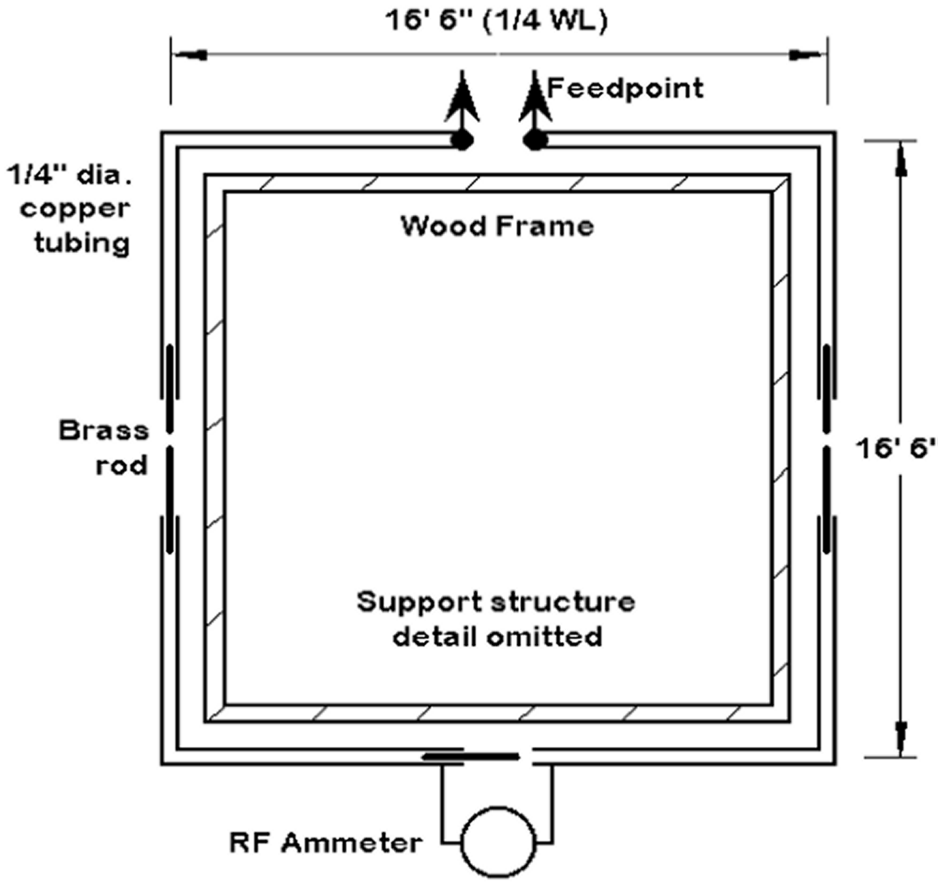
The composite article, called "Concentrated Directional Antennas for Transmission and Reception," (pp. 27-30), was put together because "Rhombics and multiple arrays of conventional form give high gains—but even for the 14-Mc band, they take considerably more yardage than most of us have available. Therefore, concentrated directional systems which are more readily fitted into the usual back yard have a distinct appeal. . .." It is interesting that the editor chose to call the small and possibly directional antennas "concentrated." The term conjures many images, although nothing clearly electronic. Such imagery—sometimes useful, sometimes misleading—was more common in the 1930s than it is today.

Conventionally, we have identified the predecessor of the Moxon rectangle in the square antennas built by VK2ABQ. Between the work of Fred Caton, VK2ABQ, and more recent developments employing its offspring, the (Les) Moxon (G6XN) rectangle, there is continuity. However, as Peter Dodd has pointed out in the 2nd edition of his *Antenna Experimenter's Guide* (pp. 99-100), there is a more distant predecessor, "A Square 'Signal Squirter' for 14 Mc." Dr. Burton T. Simpson, W8CPC credits John L. Reinartz, W1QP for the suggestions that led to his proto-VK2ABQ square. The basic suggestion was that most of the radiation from a standard 1/2 wavelength dipole emerges from the center half of the antenna wire. The lower current end portions might be bent back with little loss.

The expression "signal squirter" seems today to be almost baby talk. However, in the 1930s. new operators were often called "young squirts," not just because many were very young (which is incidentally true), but because they were new to the game of "squirting" RF around the world. Imagistically, the rig and antenna formed the world's most perfect atomizer, with a mist finer than any perfumery ever dared dream. Note how easy it is to get carried away by the everyday metaphors of 1930s amateur radio.

The Simpson electrical design is shown in **Fig. 1-1**. We can bypass the extensive reinforced and rotatable wooden square on which the antenna turned.

Simpson specifies a spacing of 16' 6" from front to back, and the wood frame he used, bristling with ceramic insulators to support 1/4" diameter copper tubing, suggests a similar distance side-to-side. What affect the many metal reinforcement plates had on antenna performance is impossible to tell at this distance.



The W8CPC Square **Fig. 1-1**

Like the VK2ABQ square, the W8CPC antenna separates two folded-back dipoles with a small end gap. The tubing ends were 18" apart, but each end had a brass rod insert to adjust the gap. Tuning up the antenna involved simultaneous adjustments to both the transmitter and antenna, using an RF ammeter across a temporary gap in the reflector. Again, the feedpoint gap was fairly large by current standards, allowing a variable length spread in the feeders as an aid to matching--where matching means maximum power transfer to the antenna. In this case, the transfer was measured in terms of reflector element current levels. When tune-up was complete, another brass rod closed the gap left by removing the RF meter.

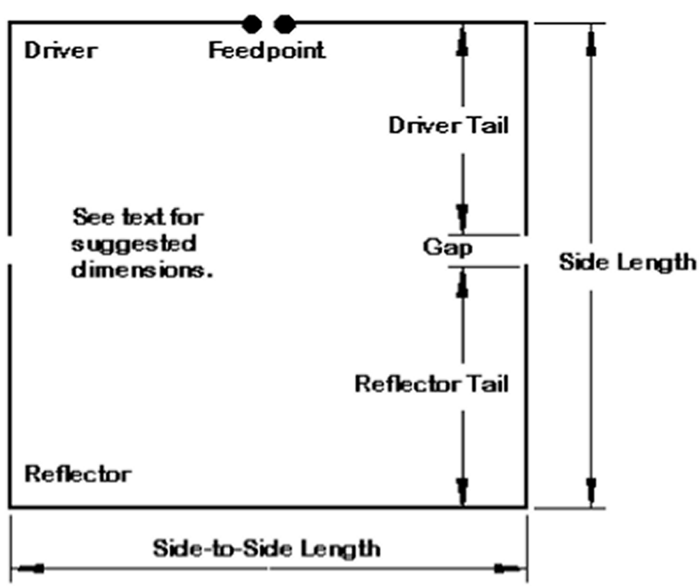
Having modeled a number of VK2ABQ designs, I am aware of the critical nature of the gap in the end of the two elements. There are actually two gap settings that provide forward gain and a front-to-back ratio. The narrower gap provides more gain but with what we would today consider mediocre front-to-back ratio. A much wider gap provides a current on the reflector that is nearly perfect in magnitude and phase to yield a maximum rear null (>30 dB), but at the cost of over a dB of gain. (Similar results accrue to the Moxon rectangle, but with considerably greater ease of finding the right dimensions to use with no post-assembly adjustment required.)

The gap required for a maximum front-to-back ratio exceeds by a wide margin the range of adjustment available in the W8CPC design. Hence, I have to conclude that he adjusted his antenna for a quite narrow gap, something close to 1". The trick is the position of the gap. Using a 16' 6" square, one can terminate the driver 4" forward of the side-to-side center-line. If the reflector is then brought within an inch of the driver, the loop can yield about 5.1-dB forward gain and about 5.0-dB front-to-back ratio. If the same gap size is transferred to the 8.5- and 7.5-inch positions, the gain drops to about 4.7 dB, but the front-to-back ratio exceeds 8.0 dB. This is about the maximum movement forward of the center-line within the +/-9" range of adjustment in the antenna. For both cases, the source impedance is less than 150 Ohms, considered low in those days, and both settings are within 18 Ohms reactance of resonance at the target frequency.

I cannot be certain that my models have captured the Simpson design exactly, especially in view of his claim of about a 7 S-unit difference in a DX report of his signal forward and reverse. However, they are indicative of the kind of performance that might be typically achieved by the antenna type. The numbers from these models are consistent with models of the 1" coat-button spaced wire antennas in the VK2ABQ collection. Clearly, the Simpson square is a close match to the VK2ABQ squares, apparently without direct lineal connection. And it follows that all contemporary variations on the square and the folded-back rectangle share a common root going back at least to 1937.

VK2ABQ Squares

VKs and Gs have long been familiar with a square antenna about one wavelength in circumference. The basic idea for the antenna is simple: take a single quad loop and tip it 90 degrees to put the wire in the horizontal plane. At the midpoints of the sides (calling the feedpoint wire the front and the parallel wire to it the rear), cut the loop and insulate the cut ends from each other while preserving the loop. It is reported that VK2ABQ, the antenna's sire, used coat buttons for insulators. The antenna now looks like a 2-element parasitic beam with a driven element and a reflector. It provides forward gain and a front-to-back differential. Folding the



The VK2ABQ Square Fig. 1-2

ends inward, relative to a Yagi in normal linear configuration, improves the front-to-back ratio at the loss of some theoretically possible forward gain. Moreover, loops for several bands (typically, 10, 15, and 20) can be laid out concentrically and fed from a single coaxial cable. **Fig. 1-2** shows the general layout of a mono-band square.

One problem that the builder faces in trying to replicate the antenna is finding the right dimensions. The problem is not a lack of dimensions, but too many sets. **Table 1-1** and its notes list several sets taken from a couple of British sources. See L. A. Moxon, *HF Antennas for All Locations* (R.S.G.B., 1982), p. 168; see also Pat Hawker, *Amateur Radio Techniques* (R.S.G.B., 1980), pp.315-316, p. 320, and p. 334. For a summary of work on the VK2ABQ square and the Moxon rectangle, see Erwin David, G4LQI, Ed., *HF Antenna Collection* (RSGB, 1991), pp. 23-28. Apparently, the antenna is somewhat sensitive both to the wires for the bands not in operation and to the method of construction. Different builders have used different amounts of metal in the hub and support spokes, leaving the new builder to play endlessly with wire lengths without much of a clue as to what the goal should be. Although I have only scanned the literature, it appears that until the 1990s, American builders largely ignored the design. In fact, no one seemed to have modeled the antenna to find out what it can theoretically do for amateur operation.

A Sampling of Recommended Dimensions for the VK2ABQ "Square" Beam

All dimension in feet and nearest inches.

Source	Moxon, p. 168	Hawker p. 334	Hawker, pp. 315-316	
Tail length	6' 2"	6' 0"	5' 9"	5' 11"
Perimeter length	34' 9"	33' 11"	32' 6"	33' 5"
Side length	8' 9"	8' 6"	8' 2"	8' 4"
Formula/side	248/f (MHz)	242/f (MHz)	232/f (MHz)	238/f (MHz)

Table 1-1. Dimensions for the VK2ABQ "Square" Beam.

Les Moxon, in his *HF Antennas for All Locations*, provides the essential clue to the idea behind the square. “The main benefit [of a beam] accrues from the reduction of interference during reception, though the 4 to 6 dB gain provided by typical amateur beams is an important bonus and probably the reason which carries the most weight with the majority of amateurs” (page 67). Here is a theory of beam operation quite un-American is style: instead of gain, Moxon strives for front-to-back ratio as the most crucial aid to ham operation. His statement is an affirmation of the “good ears” theory of operation. One can sacrifice gain if the overall front-to-

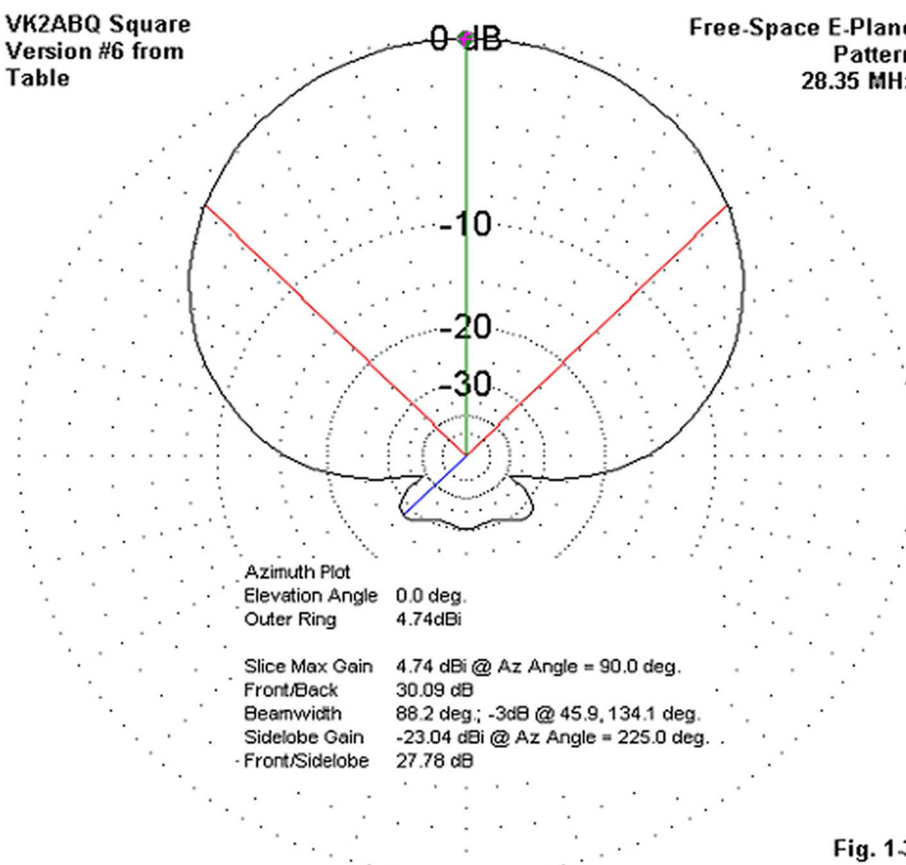


Fig. 1-3

rear-area ratio can be improved. Precisely here lies the inspiration behind Fred Caton's invention, the VK2ABQ square.

Using the original design, optimized for least reflector loading and least reactance at the feedpoint, but retaining the close-spaced element ends, early models achieved respectable performance. **Fig. 1-3** shows the E-plane (free-space azimuth) performance pattern of an optimized model, while **Table 1-2** supplies the dimensions and analysis figures of the models that led up to this performance. For those unused to trying to capture an antenna with a model, the process may prove instructive.

A Sampling from the Series of VK2ABQ "Square" Antennas Modeled

Antenna	Dimensions (feet)				Reflector	Gain	Front-to	Source Z
	X	Y	Gap	El. Length	Load (?X)	(dBi)	Back (dB)	(R ? X)
1.	8.8	8.8	0.2	17.4	0	4.2	16.3	133 + 23
2.	9.0	8.8	0.8	17.0	+45	4.5	22.4	103 - 14
3.	9.1	8.8	1.0	16.9	+60	4.3	22.2	94 - 28
4.	9.2	8.8	1.2	16.8	+60	4.6	30.6	94 - 19
5.	9.4	8.8	1.4	16.8	+60	4.7	34.2	91 - 24
6.	9.8	8.8	1.6	17.0	+47	4.8	30.1	91 - 7.3

Note: All performance values are calculated free space figures. All dimensions in feet. X = the side-to-side length. Y = the side length. See **Fig. 1-2**. Design frequency = 28.35 MHz. AWG #14 copper wire elements.

Table 1-2. A sampling from the series of VK2ABQ "square" antennas modeled.

The initial modeling for this series of beams used ELNEC, a version of MININEC that is not corrected for the known frequency "bias" or offset that increases with frequency. The initial design frequency for each model was 28.5 MHz. I have later transferred the models to NEC-4, which is frequency-accurate. Without changing dimensions, the actual design frequency turned out to be 28.35 MHz. This shift works to our advantage, because—as we shall see—the SWR curve and the front-to-back curve are steeper below the design frequency than above it. Hence, having a design frequency in the vicinity of 28.35 MHz works to equalize to some degree the band-edge values, if we define the operational band as 28.0 to 29.0 MHz.

Beginning with a model only slightly smaller than the largest encountered in British sources, I modeled antenna 1. Since all sources on the VK2ABQ recommended extremely close spacing of the driven element and reflector ends, I held this spacing at 0.2' or less. The resulting inductive reactance at the feedpoint showed that driven element was long. Moreover, the front-to-back ratio, while slightly better than a typical 2-element Yagi, was not up to expectations.

Tackling the second problem first, I began to increase the spacing between element ends. This move shortened the element lengths, since I held the front-to-back or side (Y) dimension constant. The front-to-back ratio began to improve dramatically, as models 2, 3, and 4 demonstrate. However, to achieve this calculated performance, it was necessary to insert an inductive load into the center of the reflector element, suggesting that the reflector was short for optimum performance. Note that in all models of the VK2ABQ, the elements are the same length, a design that is counterintuitive for someone familiar with Yagi configurations.

Model 5 achieves the best front-to-back performance, but at the cost of considerable inductive reactance at the feedpoint and the need for sizable reflector loading. Model 6 lengthened the element to bring down the feedpoint reactance successfully. However, it widens the gap between element ends beyond optimum and still requires reflector loading.

Model 6 represents the best performance achieved with the basic VK2ABQ square. We can see the extended array properties in performance graphs from 28.0 to 29.0 MHz. **Fig. 1-4** shows the gain and front-to-back values across the first MHz of 10 meters. As with any 2-element reflector-driver beam, the gain shows a nearly linear decline with increasing frequency. The 180-degree front-to-back curve peaks at 30.1 dB, although the worst-case front-to-back ratio—indicated on the graph by the front-to-side line—peaks at only 28.2 dB.

Fig. 1-5 shows the resistance, reactance, and SWR curves for antenna #6 from the list of squares. The feedpoint resistance changes by only 8 Ohms across the band, while the reactance varies by 12 Ohms. Hence, the resulting 75-Ohm SWR curve is extremely stable, with a peak value of 1.24:1. One might even use a

50-Ohm cable if SWR values from 1.7:1 to 1.9:1 are acceptable. However, it is useful to note that the SWR curve remains usable far beyond the frequency limits of acceptable performance in the forward gain and front-to-back ratio categories.

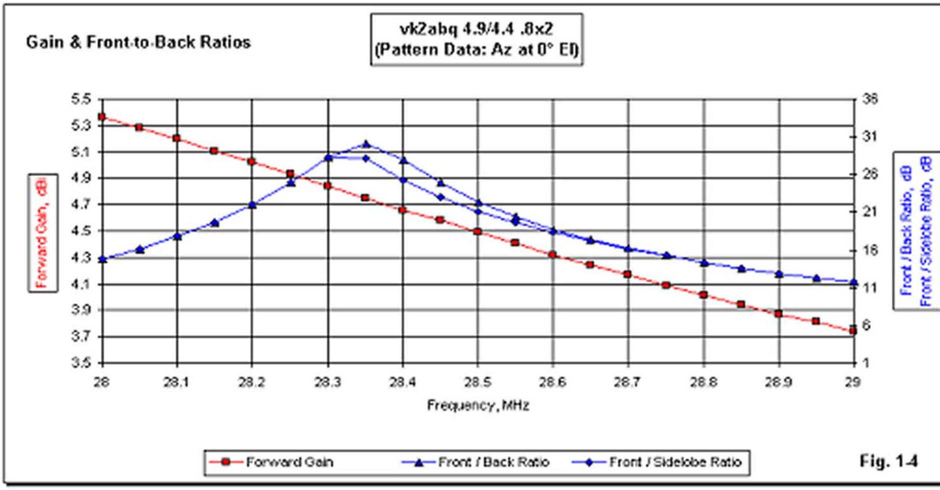


Fig. 1-4

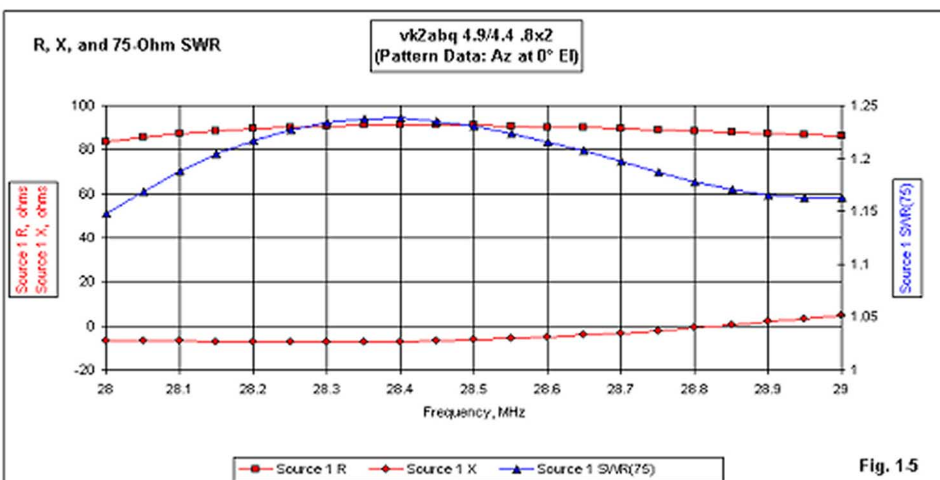


Fig. 1-5

Modeling ceased at this point because of several factors. First, the forward gain of the beam was not improving significantly. The best VK2ABQ, while providing exceptional front-to-back ratio, produced a forward gain only bit higher than that of a single quad loop mounted in the normal plane. Second, the model was departing from square to a degree that made the Moxon rectangle the next logical step in the work.

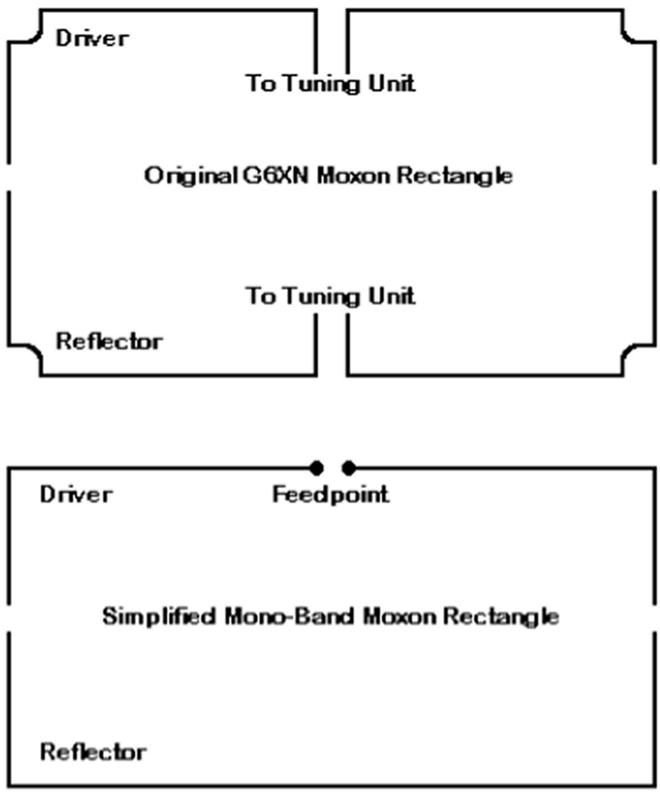
However, before departing the VK2ABQ, we should notice the general pattern in **Fig. 1-3** once more. Unlike a standard 2-element reflector-driver Yagi, the VK2ABQ puts all its power in the forward lobe, with a beam width that settles in around 88 to 90 degrees between -3 dB points. The main lobe extends around to the sides so that direct side rejection is only half the front-to-back ratio. In comparison, the dipole, the single quad loop, and the 2-element Yagi antennas have excellent front-to-side ratios. None of these antennas, however, can even approximate the VK2ABQ for the clean and empty wide rear quadrants. This feature may be useful in more than one application.

The Moxon Rectangle

To achieve better performance, Moxon lengthened the front and rear elements and shortened the side tails. The resulting rectangle requires very little more turning radius than the square, but improves the gain of the antenna considerably. Modeling Moxon's beam required some initial guesses at the actual 10-meter dimensions, since the builder created U-shaped insets at the corners to handle excess wire needed to make up the perimeter. Nonetheless, only two steps yielded a pretty good Moxon beam model. **Fig. 1-6** shows the general outline of the Moxon rectangle, while **Table 1-3** shows the progression of models and their results.

Once more, the initial modeling was done on a version of MININEC without a frequency drift correction, although the patterns shown here represent re-modeling the antenna using NEC-4. Like the VK2ABQ squares, the array used AWG #14 copper wire throughout. So, too, did the initial prototype of the final version of the antenna.

Moxon Rectangle Outlines Fig. 1-6



A Sampling from the Series of Moxon "Rectangular" Antennas Modeled

Antenna	Dimensions (feet)				Refl.	Gain	F-B	Source Z
	X	Y	Gap	El. Length	Ld (?X)	(dBi)	(dB)	(R+/-X)
1.	11.2	6.6	0.2	17.6	-20	5.3	22.5	115 + 86
2.	11.0	6.6	0.2	17.4	- 5	5.2	21.3	114 + 69
3.*	10.4	6.6	0.2	16.6 DE 17.0 Re	+30	5.3	18.7	103 + 5.1

4.	11.0	6.6	0.8	16.6 DE 17.0 Re	+35	5.5	37.0	80 - 3.6
5.	11.0	6.7	0.8	16.6 DE 17.0 Re	+25	5.5	35.0	81 - 4.2
6.	11.2	6.6	0.8	16.6 DE 17.4 Re	+18	5.6	34.3	80 - 0.1

Note: *Models from this point onward use unequal lengths for the driven element and the reflector. All performance values are calculated free space figures. All dimensions in feet. X = the side-to-side length. Y = the side length. See **Fig. 1-2** for designations. Design frequency = 28.35 MHz. AWG #14 copper wire elements.

Table 1-3. A sampling from the series of Moxon "rectangular" antennas modeled.

The initial models preserved the VK2ABQ close end spacing (although Moxon widened the gap). Model 2 is especially interesting, since it shows excessive driven element length in the inductively reactive source impedance. The reflector is about right for this configuration. However, the front-to-back ratio is not up to VK2ABQ standards. The next moves were a simultaneous increase of the gap between ends and an unbalancing of the forward and rear elements. Moxon prefered matched elements, tuning each of them to optimum performance remotely. That way, he could reverse the beam and do away with expensive and maintenance-intensive rotators. However, rotators are a way of life in the U.S. (a TV rotator will likely handle a Moxon beam), and there are many uses for portable beams that are hand-rotated or fixed in the field. Thus, I decided to continue the exercise in unequal element lengths.

In models 3, 4, and 5, we can see the approach to a model that would have a roughly resonant feedpoint and require no loading of the reflector. The last model, number 6, is considered optimum for these reasons. **Fig. 1-7** provides a free space azimuth pattern for comparison to other antennas. The modified Moxon rectangle is a close match to RG-11 or RG-59 coax for direct feed. The differentials of front-to-back ratio in models 4, 5, and 6 make little difference in practice, and the forward gains of the three models are the same.

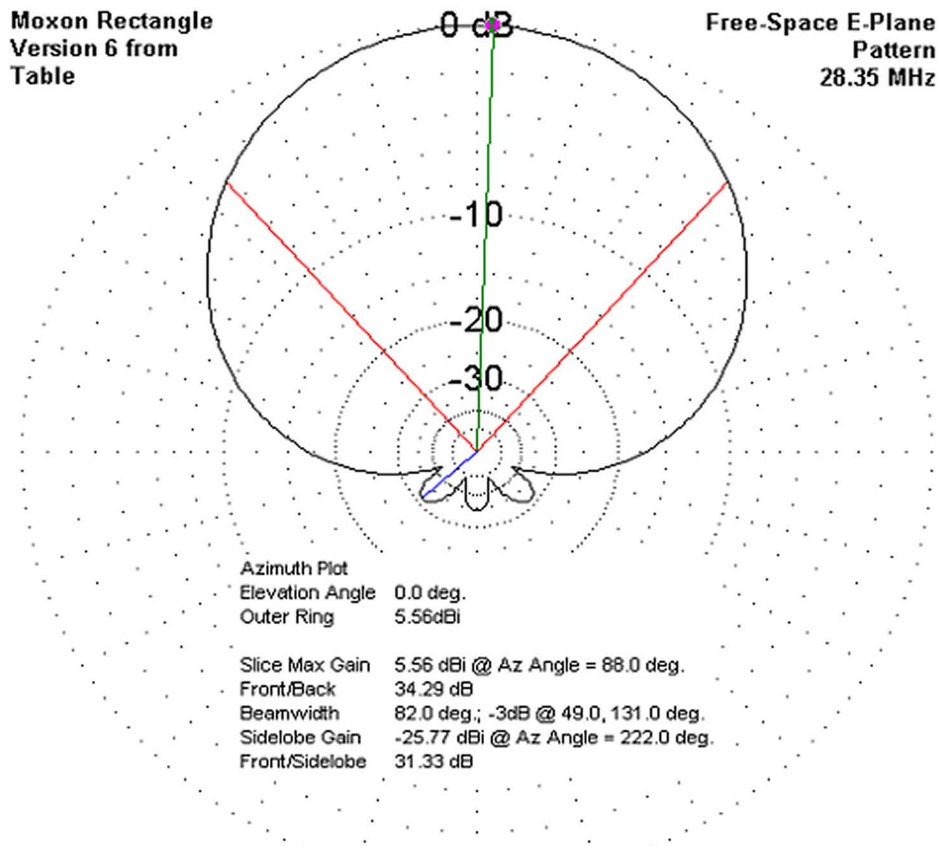


Fig. 1-7

Fig. 1-8 gives us a glimpse of the performance of the antenna across the first MHz of 10 meters. Note that the front-to-back ratio exhibits a sharp peak near the design frequency, whether we reference the 180-degree ratio or the worst-case ratio (again, represented by the front/sidelobe line in the graph. The free-space forward gain—like that of the VK2ABQ squares—shows the typical 2-element driver-reflector decline with increasing frequency, although the level at every frequency is significantly higher than for the squares. In fact, we shall achieve about another half-dB gain in designs developed since this initial test antenna, which should be considered as a virtual historical relic in the growth of the Moxon. Nonetheless, its properties showed sufficient promise to continue the process of development.

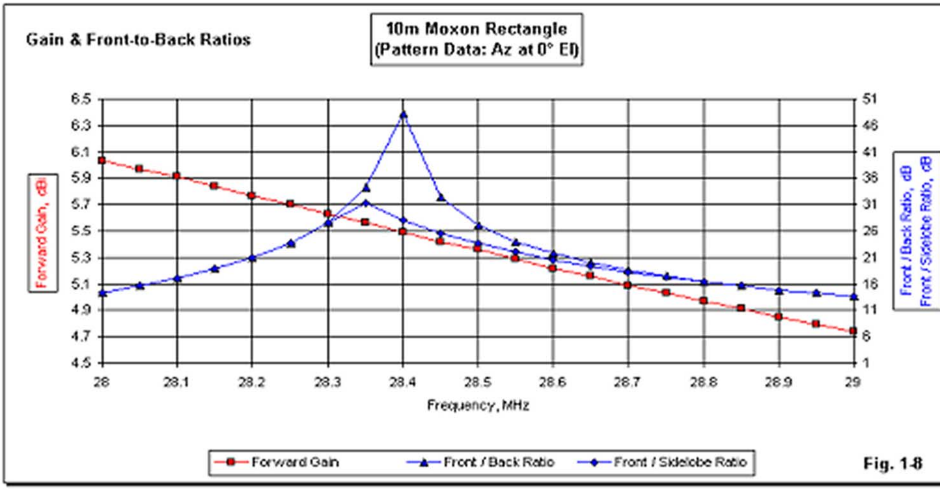


Fig. 1-8

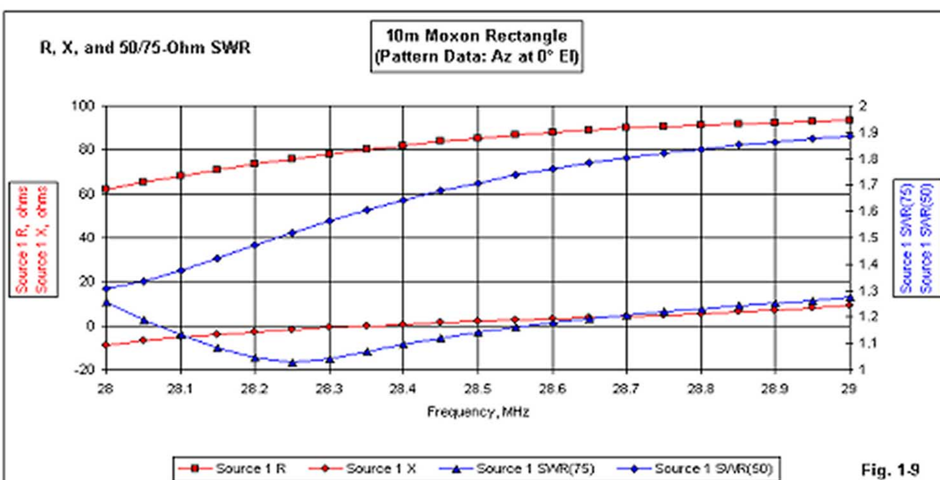


Fig. 1-9

In **Fig. 1-9**, we obtain a picture of the feedpoint performance of the test antenna. Across the lower end of 10 meters, the feedpoint resistance varies from 62 to 93 Ohms, a 31-Ohm range. The reactance shows a much smaller 18-Ohm range, varying from -9 Ohms to +9 Ohms. The reactance range is especially interesting, since standard 2-element Yagis show a much wider range of reactance change in the same frequency span, even when using tubular elements with much larger diameters than the AWG #18 wire of the test antenna.

One consequence of the small reactance change is a very shallow 75-Ohm SWR curve. As the graph reveals, the SWR never climbs above 1.27:1 at the band edges. However, like the front-to-back curve, the best values occur only about 0.2 to 0.3 of the way across the operating passband, with steeper curves below the design frequency than above it. Also notable is the fact that the 50-Ohm SWR curve is quite usable if one's equipment can tolerate SWR values as high as 1.9:1. Later designs of the Moxon rectangle would focus on achieving a 50-Ohm feedpoint impedance, since the required revisions also produced additional gain.

A Performance Comparison Among the VK2ABQ, the Moxon, and Some Reference Antennas

Antenna	Conditions	Refl. Load (?jX ohms)	Gain (dBi)	Front-Back (dB)	Feed-Z (R ? X)
VK2ABQ #6	Free Space	+47	4.7	26.6	88 - 8
(Table 1-2)	35' Ave Gnd*	+47	10.3	30.8	98 - 13
Moxon #6	Free Space	+ 5	5.5	33.6	80 - 3
(Table 3)		0	5.6	24.1	76 + 1
	20' Ave Gnd	- 5	11.1	20.4	81 - 6
		0	11.0	18.9	85 - 10
	35' Ave Gnd	+ 5	11.0	25.5	88 - 3
		0	11.1	21.9	83 + 1
2-element Yagi	Free Space	—	6.3	11.2	32 + 1
(DE + Refl.)	35' Ave Gnd	—	11.7	13.5	35 ?+ 0
Quad loop,	Free Space	—	3.2	—	127 + 4

#18 copper wire	35' Ave Gnd	—	8.5	—	125 - 6
Wire dipole,	Free Space	—	2.1	—	72 ? 0
#18 copper wire	35' Ave Gnd	—	7.7	—	86 - 8

*Average ground or earth: dielectric constant = 13, conductivity 5 mS/m

Table 1-4. A performance comparison among the VK2ABQ, the Moxon, and some reference antennas.

Free space is not a fully adequate indicator of the performance of the square and the rectangle over real ground. The potential for needing reflector loading was too great simply to build the free space model and hope it would work. **Table 1-4** presents some comparative figures. Compare free space figures only to other free space figures and over-ground figures only to other over-ground figures.

Without any reflector load at all, the Moxon-6 model promised adequate performance at both 20 feet (a typical portable height) and 35 feet (a typical home-installation height) above medium earth. The 20' Moxon exhibits a small wide swell in rear coverage, while the 35' Moxon demonstrates a more stepped appearance. Both front-to-back ratios are reasonable for the heights, although neither reaches the level of the tiny free space rear lobes.

The Moxon beam shows a gain midway between the VK2ABQ and the typical 2-element Yagi, which we may use as a reference standard against which to compare the Moxon rectangle. Why the Moxon rectangle's gain is less than that of a linear 2-element Yagi, despite the absence of power in the rear lobe, may raise some questions. However, such questions reveal 2-dimensional thinking. Antennas are three-dimensional devices. Besides forward and back, power may radiate up and down and anywhere between. Both the VK2ABQ and the Moxon rectangle radiate considerably more power to the sides and at high radiation angles relative to the horizontal than 2-element Yagis. Although these properties hold down forward gain, they may prove useful in other applications.

The Moxon rectangle's 3-dB gain over a dipole at the same elevation is useful, but the most significant Moxon feature is the reduction in all rear directions of potential QRM. At 6 dB per S-unit, the Moxon rectangle promised (at least, in model form) to reduce QRM by more than a full S-unit and perhaps as much as 2 S-units compared to a 2-element Yagi. Whether the beam could deliver on its model's promise required an exercise in building.

Building a Moxon Rectangle

Since the diversity of VK2ABQ dimensions in the literature suggests a sensitivity to the conductivity of the antenna structure, the prototype Moxon beam required a minimum of metal to test the model dimensions. Therefore, the beam I built was an exercise in plywood, PVC, and nylon cord. See **Fig. 1-10**. A center platform of well-varnished or fiber-glassed 3/8" plywood measured 22.5" by 13.5". These dimensions assured that the rectangular X-frame would have the proper angles. A pair of #10 1.5" stainless steel bolts (with washers and nuts) secured each of the four half-inch nominal thin-wall PVC arms. In place of the bolts nearest the corners of the platform, one may use 1/2" nominal PVC conduit clamps with #8 stainless

General Construction Outline: Test 10-Meter Moxon Rectangle

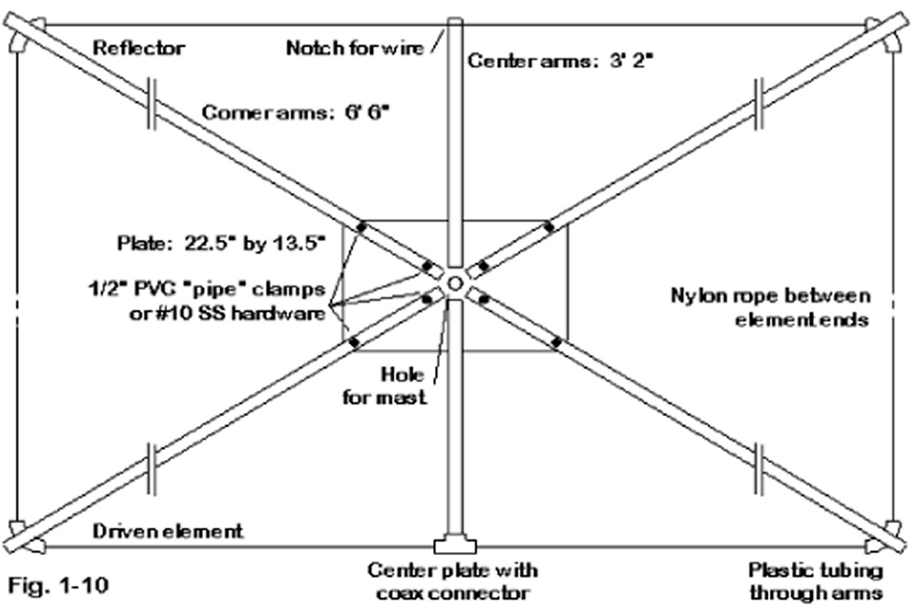
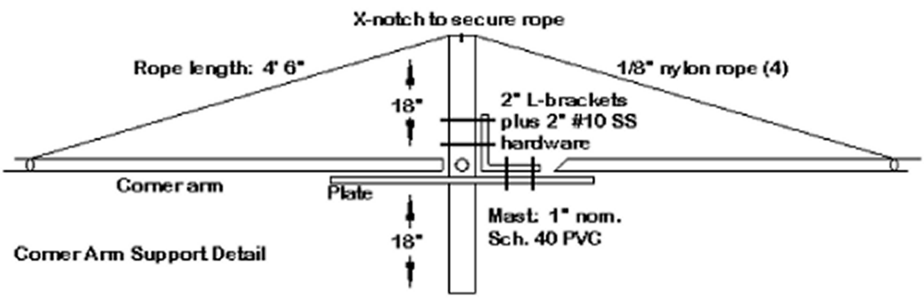


Fig. 1-10

steel hardware. Fifth and sixth arms project from the platform to the center of the driven element to support the feedline and to the center of the reflector element.

The platform has a center hole to pass a 3-foot length of 1" nominal schedule 40 PVC pipe. Two 2" corner brackets secure the platform to the pipe 18" down from the top. The brackets use bolts that pass through a bracket, the pipe, and the opposing bracket. Short #10 stainless steel hardware secures the brackets to the platform. Note that the brackets are above the platform, since it will rest on the 1.25" nominal PVC mast pipe, with a pair of bolts through the nested pipes to lock them together.

At the upper end of the platform pipe, an X-cut—enlarged and smoothed—provided a channel for eighth-inch nylon support cord. The cord ends pass through holes in opposing arms about 2/3rds the way out to the corner. Several wrappings of the cord before knotting reduce stress on this light guy. **Fig. 1-11** provides guidance for setting up the support guys.



Construction Details: Test 10-Meter Moxon Rectangle Fig. 1-11

Each arm was 6' 6" long. Mounted on the plate about 1" from the center point (to allow room for the pipe hole), the arms extended about an inch beyond the precise corner points. Quarter-inch holes through the arm in the plane of the wire permitted the insertion of plastic tubing to reduce stress on the element wires that pass through them. The result was a well-braced Moxon rectangle for use in up to moderate winds.

I used part of the driven element's excess wire to attach a simple dipole center insulator and coax fitting. I used a W2DU-type choke to reduce chances of RF traveling down the outside of the coax braid.

It is not necessary to make any of the initial adjustments and tests with the beam in the air. Lay the beam over a wooden prop so that the reflector is a few feet off the ground and the driven element points to the sky. With a low power signal, adjust the driven element lengths for the lowest SWR at the frequency of choice. Now erect the antenna in the normal plane at least 15 feet high. With a small signal source and a receiver, adjust the reflector for minimum signal off the rear. Try to keep the element ends about 9 to 10 inches apart. The SWR of the driven element should not be adversely affected. However, you may wish to lower the antenna and redo the driven element length one more time to finish the adjustment task. Only the most finicky operator should need to make further adjustments at height.

With minimal metallic mass in the mounting, the Moxon rectangle adjusts quite closely to the model dimensions. Although my test set-up did not permit test range figures, the antenna performed to expectations at a height of 20 feet. For signal strength, it does not quite match my 2-element beam at 35 feet, but the front-to-back ratio is much better, despite the height disadvantage

Point-to-point tests with local operators located 10 to 15 miles from the station confirmed the modeling exercises quite well. Using both received signals and reports of transmitted signals, the front-to-back ratio of the antenna averaged better than 4 S-units on a variety of transceivers, compared to a little over 2 S-units for my HF5B at 35 feet. The front-to-side ratio averaged between 1 and 2 S-units, but signals fell off rapidly as the beam was rotated past the side point to the rear. The relationship of S-units on a transceiver meter to dB of front-to-back ratio is too uncertain for quantitative comparison. However, for practical operation, the basic characteristics of the Moxon rectangle appeared to be satisfactorily confirmed.

Further Developments

The test Moxon rectangle appeared in *Communications Quarterly* nearly a decade ago. Since that time, the rectangle has undergone considerable development, mostly in three areas: refining the dimensions, experimenting with construction methods, and finding further applications. At the same time, Peter Dodd, G3LDO, was experimenting with an even more compact version of the Moxon rectangle. He dubbed his antenna the "double-D" with reference to its shape. His results have appeared in a number of articles and he provides one of the latest versions in the 2nd edition of his well-respected volume, *The Antenna Experimenter's Guide* (RSGB, 1996).

One direction of my own further development of the Moxon rectangle has been to try to establish reliable dimensions for the array. The work has had 2 goals. One is to arrive at dimensions that yield a feedpoint impedance very close to 50 Ohms to permit the user to directly connect the ubiquitous 50-Ohm coaxial cable feedline. The other goal has been to relate the dimensions to the minimum number of variables that permits the calculation of a reliable model over a frequency range from the AM broadcast band (MF) up to UHF frequencies. As we shall see in Chapter 3, the final result requires the potential builder to enter only 2 variables: the design frequency and the diameter of the elements to be used.

A second direction of effort has involved construction methods. The test-bed model that we described as a matter of history has limited utility, although I have learned of several variations on the scheme used. However, fixed wire version for lower HF use are also possible—along with bi-directional versions that we shall explore in Chapter 4. The array lends itself to upper HF use as an aluminum tubing rotating array, and we shall sample some techniques for this construction method in Chapter 5. VHF and UHF construction may use stiff wire or rods, and we shall examine a few variations in Chapter 6.

One of the most interesting lines of further develop has involved potential applications for the Moxon rectangle. Initial modeling and testing showed the utility of the array as a horizontally polarized beam having an excellent front-to-back ratio and a very broad forward lobe. However, later work at VHF and UHF frequencies using the antenna vertically polarized revealed two promising characteristics. When vertical, the array shows a very deep and sharp rearward null, useful for direction-finding. As well, the broad forward lobe combined with the very high front-to-back ratio offers potential in closely-spaced polling antenna applications.

Lest we fall back into 2-dimensional thinking, let's consider the antenna pointed straight up. From the beginning, the use of the Moxon rectangle as a simple fixed position satellite antenna seemed clear. However, lending the array circular polarization by developing turnstiled versions of the antenna took a while longer. Interestingly enough, this work has returned us to versions of the rectangle with higher feedpoint impedances.

None of these developments marks the end of the development line for the Moxon rectangle. Rather, the developments so far have simply established that the array has a place—indeed, a variety of places—within the spectrum of antennas used in the amateur community and elsewhere in radio work. This compilation of notes, then, marks only the beginning, with the future left to the ingenuity of others.

Some correspondents have asked me why I do not call the antenna "the Cebik (or W4RNL) Rectangle?" The answer is simple: because I did not develop it. I have only gone a bit of the way along the trail of isolating the properties that are inherent in the Moxon rectangle. That task has opened the door to some interesting applications within which the rectangle shows equality with or superiority over some other designs we have used in the past. Besides, Les Moxon, G6XN, has contributed so much to the study of amateur radio antennas that he certainly deserves to be remembered by the relatively permanent fixing of his name to an antenna design that he developed and that has moved into a wide variety of daily uses.

Lest we dwell too long on history, let's now move to phase 2 of our work: examining the fundamental properties of the Moxon rectangle in its 50-Ohm incarnations.

* * *

Appended models used in this chapter: vk2abq-6.ez, moxon-6.ez

2. Basic Principles and Properties

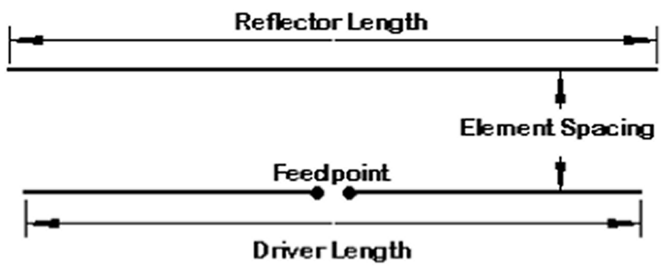
Our goals in this exercise are to understand how and why the Moxon rectangle works in the manner that it does. It has an uncommonly wide beamwidth and an uncommonly high front-to-back ratio relative to other 2-element parasitic arrays in more common use. It also shows some wide-band characteristics. Physically, it is unusual in that we turn the element ends toward each other, resulting in a full-performance beam that is only a little over 70% as wide as full size 2-element beams. These are indeed characteristics worth looking into if we are to master the potentials of the design.

Part of our work will be comparative. We shall open the chapter with some relevant comparisons with conventional 2-element Yagi-Uda parasitic arrays that also use a driver and reflector. In the middle, we shall look more closely at the some properties peculiar to the Moxon rectangle. Getting a handle on these properties will make it easier for us to design rectangles to do the specific jobs we have in mind. We shall close the chapter by looking at the Moxon rectangle radiation patterns with the antenna horizontal, vertical, and pointed straight upward.

The 2-Element Yagi as a Standard of Comparison

The 2-element driver-reflector Yagi-Uda parasitic array is one of the most common antennas used by amateurs, especially those who are making their first move from single wire dipoles and doublets up to the realm of directional antennas. Although we might try a driver-director array, we would find that it has a very narrow operating bandwidth and is most suited to narrow bands such as 30, 17, and 12 meters. As well, maximum gain for a driver-director Yagi occurs with the elements closely spaced, which results in fairly low feedpoint impedances. In contrast, we can create with fair ease a 2-element driver-reflector array with good gain (for a beam of its size), some front-to-back ratio, and a feedpoint impedance of about 35 Ohms. A simple gamma or beta match resolves the matching problem and still yields fairly wide-band characteristics. (With even wider spacing and slightly less performance, we can create a 2-element Yagi with a direct 50-Ohm feed.)

Fig. 2-1 shows us the essential dimensions of a 2-element Yagi. For any given element diameter, there will be a driver length, a reflector length, and a spacing between elements that will yield usable characteristics. For this exercise, let's design a Yagi for 28.4 MHz and use 1" diameter aluminum elements. If we make the reflector 17.4' (0.502 wavelength) long and the driver 15.86' (0.458) long, then a spacing of 4.27' (0.123) will produce a very reasonable Yagi. Note that in a driver-reflector Yagi, the reflector is normally only a bit above 1/2 wavelength, while the driver is significantly shorter than 1/2 wavelength. In fact, the driver—if extracted from the beam—would be short relative to a resonant dipole for the same frequency using the same element diameter.

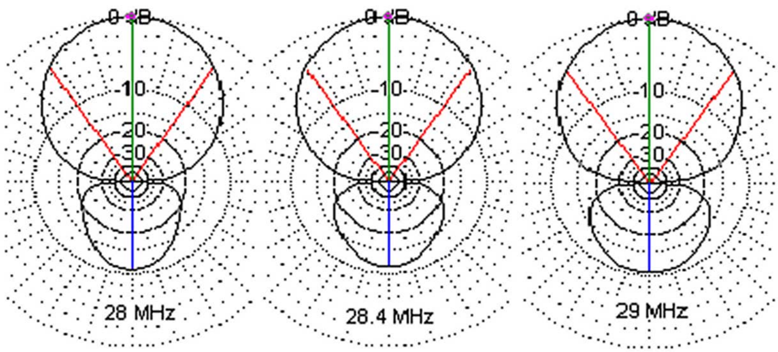


2-Element Driver-Reflector Yagi-Uda Array

Essential Dimensions Fig. 2-1

From a 2-element Yagi with a spacing of about 1/8 wavelength, we do not expect magic. However, the individual who has never experienced the benefits of reduced QRM and QRN from the rear of an antenna will often be amazed. Indeed, such an individual will often confuse the benefits of the front-to-back ratio with forward gain, since received signals will seem so much clearer. Nevertheless, the 2-element Yagi has a forward gain that is about 4 dB higher than a standard dipole in the same position, and that amount is under 1 S-unit. Any remaining signal clarity is due to the reduction in unwanted signals from the rear.

Fig. 2-2 provides free-space E-plane patterns (corresponding to azimuth patterns over ground) for the band edges and design frequency of our 2-element Yagi. Each pattern shows a front-to-back ratio of more than 10 dB but less than 12 dB. 12 dB corresponds to about 2 S-units of signal strength, although each receiver meter may vary somewhat—with further variations within the receiver from one band to the next. If we add the improvements in signal clarity together, we arrive at more than 3.5 S-units of improvement in signal reception clarity. These are very worthy improvements in performance. However, we must remember that in terms of transmitted signal, we only gain the 4-dB improvement over the dipole that we replaced. Hence, our signal reports from the other end of the communications circuit may not fully reflect the improvements in our ability to hear.



2-Element Driver-Reflector Yagi-Uda Parasitic Array
Free-Space E-Plane (Azimuth) Patterns

Fig. 2-2

The 2-element Yagi that we have just created for the first MHz of 10 meters is also useful in revealing some basic properties of this class of antennas. To understand these properties, we can productively use some modeled frequency sweeps of the design across the operating spectrum. We shall examine the gain and front-to-back ratio as a measure of performance. Then we shall look at the feedpoint conditions as a measure of the ease of using the antenna.

The free-space forward gain, shown in **Fig. 2-3**, shows the typical reflector-driver descending curve that is almost linear with increases in frequency. (A Yagi that uses one or more directors would normally show a gain curve that increases in strength with increasing frequency, even if the design also includes a reflector.) The forward-gain range is about 6.6 down to 5.8 dBi across the first MHz of 10 meters, using the 1" diameter elements. Because there are no forward sidelobes, the front/sidelobe curve shows the worst-case front-to-back ratio, which is coincident with the 180-degree front-to-back ratio. In this category of performance, we find only a small change across the band—less than 1 dB—with a peak value of about 11.2 dB. These performance values are all typical of 2-element Yagis of the design used.

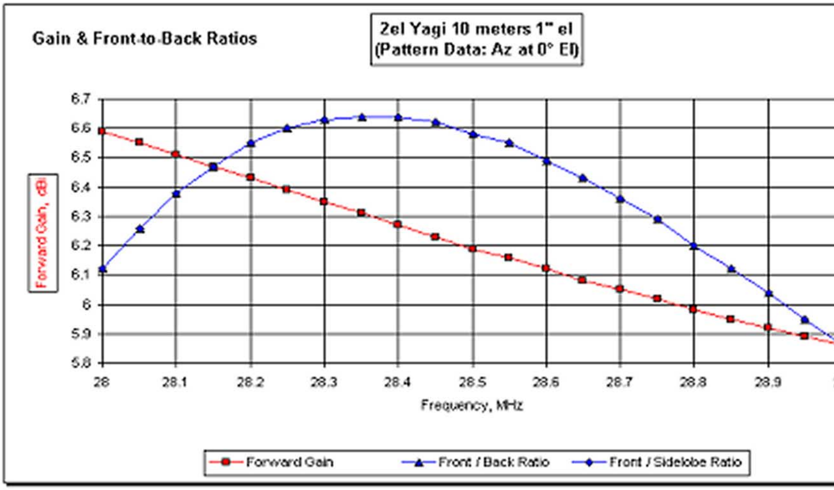


Fig. 2-3

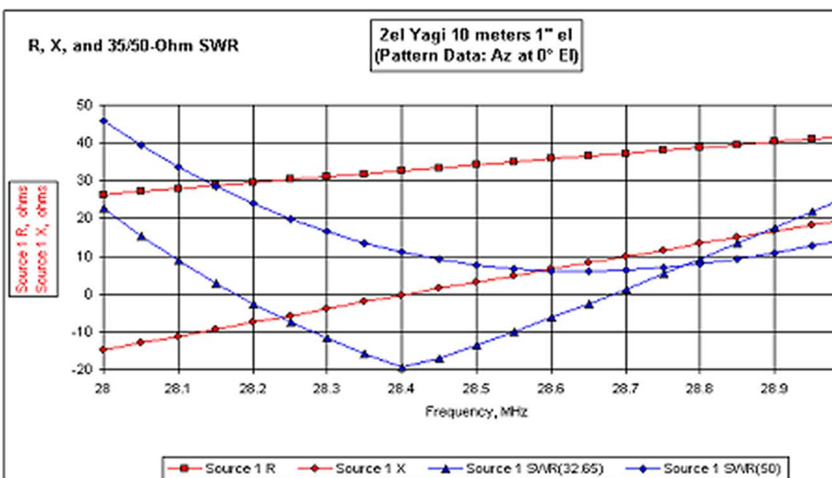


Fig. 2-4

The feedpoint values appear in **Fig. 2-4**. Relative to a resonant feedpoint impedance at the design frequency of 35 Ohms, the feedpoint resistance runs from 26 to 42 Ohms, or a range of 16 Ohms. The ratio of the change of resistance to the resonant resistance is about 0.5:1. However, the reactance ranges from -15 to + 20 Ohms, a 35 Ohms differential or a 1:1 ratio with the resonant impedance of the feedpoint. The result of the changes in both resistance and reactance is a 35-Ohm SWR peak of about 1.75:1 at the band edges. These values are generally acceptable for most equipment used on 10 meters and assure adequate SWR performance when we place a matching network at the feedpoint in order to employ a 50-Ohm coaxial cable feedline. Like the performance figures, the feedpoint values are typical for driver-reflector Yagis of similar proportions.

Although there is more that we should note about 2-element Yagis, the data presented serve to show what is typical of 2-element performance. However, to make best sense of the additional data on the Yagi standard of comparison, let's first examine the basic physical properties of the Moxon rectangle.

Basic Moxon Rectangle Properties

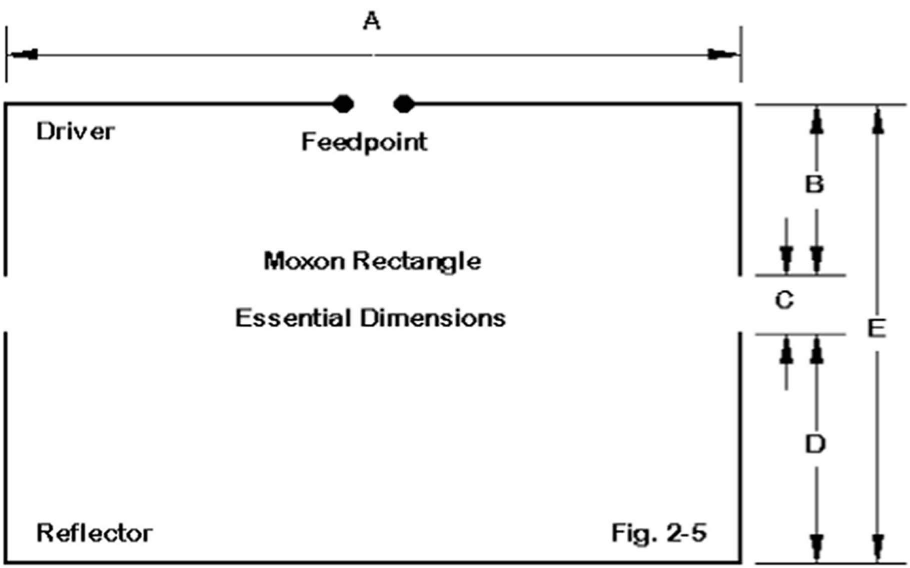


Fig. 2-5

Because the Moxon rectangle folds its elements back toward each other, the operating characteristics depend upon a larger set of physical variables. **Fig. 2-5** shows the shape and the key physical dimensions. The letter designations will be used throughout these notes to specify rectangle dimensions.

Dimension A specifies the side-to-side length of the array. Up to a point, increasing this dimension (while shrinking the front-to-back dimension) tends to lower the feedpoint impedance and increase gain. Normal design calls for a resonant feedpoint. Hence, the length of the driver tails, dimension B, is set for that condition. The total driver length is simply A plus twice B. In models of Moxon rectangles, the side-to-side dimension will be given as plus or minus 1/2A.

The reflector of a Moxon rectangle follows the pattern of any 2-element parasitic beam and is longer than the driver. Since dimension A is fixed, if we want a rectangle, the reflector tails, dimension D, will be longer than the driver tails, dimension B. Normally, we set the reflector to yield maximum front-to-back ratio at the same design frequency that we use for setting the driver to resonance.

For a 50-Ohm feedpoint impedance rectangle, the side-to-side length will be about 70% of the side-to-side length of a standard 2-element Yagi. The spacing between the driver and the reflector, given as dimension E, will be about 8% wider. Dimension E, however, is the sum of the tail lengths (B + D) and the gap between the element tail ends, given as dimension C. There is a balance between the element lengths, their spacing, and the gap that together determine the operating characteristics of the Moxon rectangle.

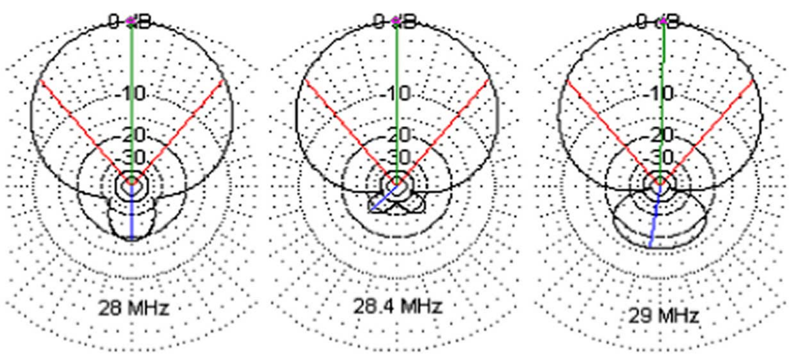
More than any other dimension of the Moxon, the gap distance is a function of the element diameter. The smaller the element diameter, the closer the tails must approach each other for the degree of coupling that yields the best possible performance from a given set of elements. Conversely, the larger the element diameter, the wider the spacing that we require for equivalent optimized performance. The following table gives the dimensions for a 10-meter Moxon designs for 28.4 MHz and covering the first MHz of the band. Like the 2-element Yagi, it uses 1" diameter aluminum elements.

Moxon Rectangle Dimensions for 28.4 MHz and 1" Elements

Dimension	Length (“)	Length (‘)	Length (Wavelengths)
A	149.22	12.435	0.359
B	19.49	1.624	0.047
C	7.24	0.603	0.017
D	28.75	2.396	0.069
E	55.48	4.623	0.133

These dimensions apply only to a Moxon rectangle designed for 28.4 MHz and using elements with a 1" diameter. Like the precise dimensions of a Yagi, we may scale the antenna only if we change every dimension, including the element diameter, by the ratio of the old and new wavelength (which is equal to the inverse of the ratio of the old and new frequency). If we change the element diameter alone, we shall need to calculate a new set of dimensions.

Fig. 2-6 gives us a view of the free-space E-plane patterns at the band edges and the design frequency for the antenna having the dimensions that we just determined.



Moxon Rectangle
Free-Space E-Plane (Azimuth) Patterns

Fig. 2-6

Although the patterns do not list the forward gain for each frequency, they do provide some valuable information, especially if we compare them with the corresponding patterns for the 2-element Yagi in **Fig. 2-2**. Clearly, the front-to-back ratio of the Moxon rectangle is far superior to that of the Yagi, even at the upper band edge, which is considerably removed from the design frequency. Second, the forward beamwidth is considerably wider, indeed up to about 10 degrees wider, than the beamwidth of the Yagi. As well, note the fact that the side-nulls do not occur at 90 degrees from the maximum forward gain direction, but more like 110-120 degrees from that bearing. The Moxon pattern is almost cardioidal.

Before we comment further on these traits of the Moxon, let's look at the overall performance figures across the spread from 28.0 to 29.0 MHz. **Fig. 2-7** graphs these characteristics. Across the band, the gain descends with increasing frequency, just as it did with the Yagi, showing the basic driver-reflector nature of a Moxon rectangle. The forward gain levels are just about 0.3 dB less than for the Yagi, ranging from 6.6 dBi at 28 MHz to 5.5 dBi at 29 MHz. Since the smallest audibly detectable change in signal strength is about 1 dB, the reduction in forward gain is not significant.

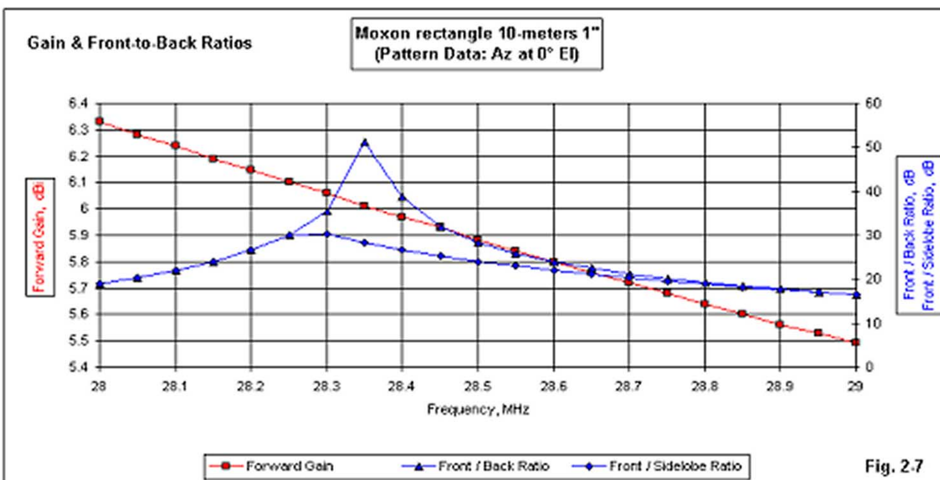


Fig. 2.7

However, the increase in the front-to-back ratio is significant, ranging from 16.5 dB at 29 MHz to a worst-case value of 30 dB near the design frequency. (The worst-case front-to-back value is often a better indicator of rearward performance than the 180-degree ratio.) The Moxon quiets noise and signals from the rear by 5 to 20 dB better than the Yagi across the operating passband.

As well, the Moxon shows broader bandwidth characteristics at the feedpoint than the Yagi, as illustrated by **Fig. 2-8**. The resonant impedance near the design frequency is about 52 Ohms. Across the passband, the feedpoint resistance runs from 40 to 67 Ohms, for a range of 27 Ohms or a ratio of 0.5:1 with the resonant impedance. The reactance varies from -14 to +9 Ohms, a range of 23 Ohms, again, a ratio of 0.5:1 relative to the resonant impedance. The reactance range is significantly smaller than the range that we encountered with the standard Yagi. Hence, we should expect a shallower SWR curve. Indeed, the curve shows a maximum value of less than 1.5:1 at the passband edges. Hence, the array is suitable for use even with sensitive equipment that may shut itself down when sensing reverse voltage values associated with 50-Ohm SWR values above 1.5:1. And, of course, the Moxon provides for a direct connection to a 50-Ohm feedline.

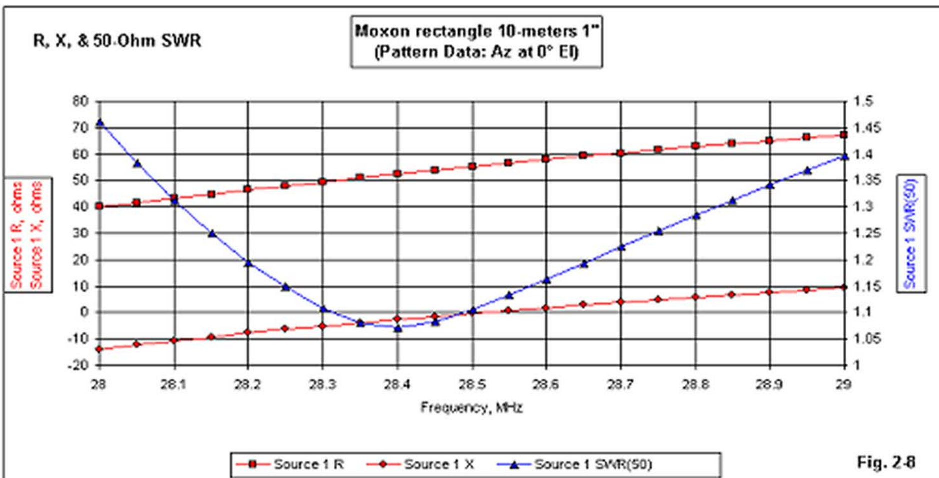


Fig. 2-8

Relative to the Yagi, then, the Moxon shows the following characteristics:

1. A forward gain only slightly less than that of the Yagi;
2. A broader beamwidth;
3. A far superior front-to-back ratio;
4. A feedpoint impedance directly compatible with a 50-Ohm feedline; and
5. A broader feedpoint impedance curve, as indicated by lower SWR values across the passband.

There are reasons for each of these characteristics, some obvious, others not. The broader beamwidth grows out of the folding of the elements. Although the current level in the tail portions of the elements is much less than at the center, the current level is still sufficient to provide some radiation to the “sides,” thus broadening the overall beamwidth. Since the wide-angle radiation must come from somewhere, given a fixed power level for the two antennas that we are comparing, the forward gain decreases slightly.

The higher feedpoint impedance, the superior front-to-back ratio, and the broad SWR curve are all less obvious. They all stem from the fact that the Moxon relies upon two forms of inter-element coupling rather than just one, as with the Yagi. What the Yagi and the Moxon share in common is the mutual coupling between the parallel portions of the elements. (Some folks refer to this as “inductive” coupling.) Since the spacing between elements in both arrays is similar, the level of mutual coupling will be similar. However, coupling between the element ends is negligible in the Yagi (although the end geometry does play a role in setting the beamwidth of any Yagi). In contrast, the Moxon makes use of coupling from one element tip to the other. (Some folks refer to this as “capacitive” coupling.) The required tip-to-tip coupling for optimal performance is fairly critical, although not so finicky as to make building a Moxon rectangle a difficult process. For any given design, we need to ensure 2 conditions: that the ends remain aligned and that the gap distance remains constant.

To a degree, the two forms of coupling operate in opposite directions. Hence, the array tends to show wider bandwidth properties than a Yagi with only one dominant form of inter-element coupling. As well, the shape of the rectangle together with the chosen gap permits the designer to set the feedpoint impedance at a desired level. In passing, we can note that within limits (say 40 to 100 Ohms or so), the higher the feedpoint impedance, the smoother the SWR curve. However, raising the feedpoint impedance requires that we “square” the rectangle to a greater degree. This required move results in a wider beamwidth and a lower forward gain. For horizontally polarized applications, a 50-Ohm feedpoint impedance results in a rectangle shape that tends to optimize forward gain, while retaining sufficient bandwidth for most operational needs. However, we shall encounter at least one application where the squaring of the rectangle does not adversely affect operation.

All of these aspects of Moxon performance do not yet explain the superior front-to-back ratio. To understand the difference in front-to-back performance between the

Yagi and the Moxon, we must look at the relative current magnitudes and phase angles on the driver and the reflector elements, as indicated by their values at the element centers. Let us assume that the driver feedpoint for both arrays shows a current magnitude of 1.0 at a phase angle of 0 degrees. Now the question is simply this: for each antenna, what is the current magnitude and phase angle at the center of the reflector? Of course, we shall also want to know what those values mean.

In a study of phased arrays, I examined the optimal reflector current magnitudes and phase angles for the reflectors of 2-element arrays. With modeling software, it is a simple matter to supply each element with separate sources. Setting the designated driver to a 1.0 magnitude and a 0.0-degree phase angle, I then sought the correct current magnitude and phase angle for the longer element so that the front-to-back ratio was maximum. Here, maximum meant greater than 50 dB or so. For a system that used elements not exactly the same as, but comparable to, the standard Yagi design, I obtained the following results.

Unequal-Length 2-Element Phased Array Performance
Maximum 180E Front-to-Back Configuration

Element Lengths: Front: 0.4772 WL Rear: 0.5010 WL
Frequency: 28.5 MHz Diameter: 0.001207 WL (0.5")

Space WL	Gain dBi	Front-to-Back Ratio dB	Rear I Magnitude	Rear I Phase
0.05	6.52	63.77	0.962	-16.9
0.075	6.52	61.79	0.974	-25.9
0.1	6.45	67.19	0.985	-35.1
0.125	6.35	62.79	0.992	-44.5
0.15	6.20	65.18	0.997	-54.1
0.175	6.01	65.28	0.998	-63.7
0.2	5.78	63.36	0.998	-73.3

If the rear element current magnitude or phase angle depart by very much from the listed values, then the front-to-back ratio drops quickly. Note that with element spacings greater than about 0.1 wavelength, the current magnitude approaches a constant level. What shows the most constant curve is the phase angle. As well, changes of element diameter and element lengths make only small changes in the required magnitude. For example, with the same elements reversed so that the front element (relative to the forward lobe of the pattern) is longer, the current magnitude on the rear element was an almost constant 1.18 for an element spacing that was greater than 0.1 wavelength. However, the phase-angle progression was almost identical to the values shown for the more conventional arrangement of elements.

For the element spacing values used by both the Yagi and the Moxon rectangle examples that we have been exploring, we should expect a relative current magnitude close to 1.0. The phase angle should be between -44 and -50 degrees for an element spacing between 0.12 and 0.14 wavelength. Models of the Yagi show a rear element current magnitude of 0.67 and a phase angle of -36 degrees. The Moxon, by way of contrast, shows a rear element current magnitude of 0.95 with a phase angle of -52 degrees. The Moxon obviously more closely approximates the ideal current and phase-angle values that favor a very high front-to-back ratio.

The single mode of coupling among elements employed by 2-element driver-reflector Yagi design is very limited in its ability to establish by parasitic coupling alone the optimal rear element conditions for maximum front-to-back performance. The Yagi has only a single fed element and relies upon mutual coupling between elements for its operating characteristics. (Driver-director arrays fare little better than driver-reflector arrays at the element spacing used here. However, they do show higher front-to-back ratios and more optimal current conditions with much closer spacing.) Since the Yagi array depends upon geometry alone to provide the current on the rear element and restricts that geometry to parallel linear elements, the resulting Yagi front-to-back ratio will necessarily be limited.

In contrast, the Moxon rectangle employs two forms of coupling between the elements. Hence, the proper balance among the dimensions, including the gap between the element tails, allows the designer to obtain a much more optimal rear element current magnitude and phase angle and hence a much high level of front-to-back performance. Although no single dimension works in isolation from the others, the gap between element tails is perhaps the key determiner for front-to-back performance.

In general, one designs a Moxon rectangle to place feedpoint resonance and maximum 180-degree front-to-back performance on the design frequency. Since both of these curves are steeper below the design frequency than above it, the design frequency is normally below the mid-band point for any given operating spectrum—except for relatively narrow bands. A design frequency ranging from 35% to 40% of the frequency distance from the lower edge of the passband to the upper edge normally results in relatively equal band-edge values for both the front-to-back curve and the SWR curve.

Materials Make a Difference

Thus far, we have worked with only a single Moxon rectangle in order to make some first-order comparisons with a comparable 2-element Yagi. Let's add a second Moxon rectangle to our list in order to investigate a few properties internal to the design of Moxon rectangles. Our second Moxon will consist of AWG #18 copper wire. The following table compares the dimensions of our initial 1" diameter version with the new wire version. All dimensions are in inches.

Moxon Rectangle Dimensions for 28.4 MHz

Length (“)	1" aluminum Dimension	AWG #18 copper Length (“)
A	149.22	151.47
B	19.49	23.05
C	7.24	3.87
D	28.75	28.17
E	55.48	55.09
Driver total	188.20	197.57
Reflector total	206.72	207.81

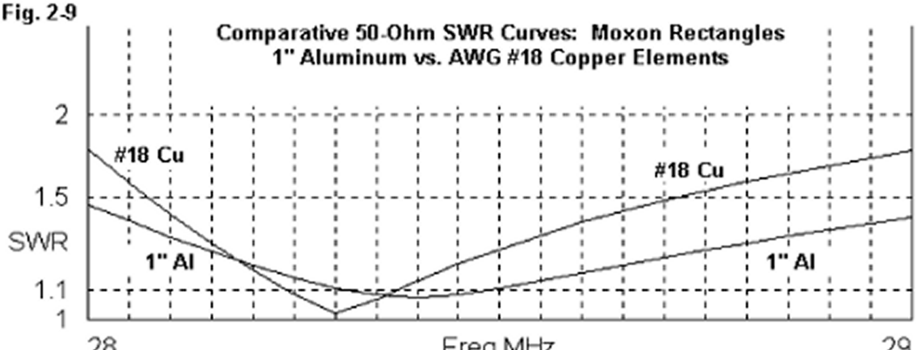
Both arrays produce rectangles that are approximately resonant at about 28.4 MHz. The 1" version has a feedpoint impedance of 52 Ohms, while the #18 version has a feedpoint impedance of 55 Ohms. The dimensional differences between the arrays are both interesting and important.

To achieve a 50-Ohm impedance with maximum gain and front-to-back performance, the wire array must be wider side-to-side and a bit thinner front-to-back. Indeed, the front-to-back narrowing is a function of the much smaller gap required by the thin elements—about half the distance required by the 1" elements. The driver tails are longer, resulting on an overall driver length that is also considerably longer than the 1" driver. For the most part, the longer thin-wire driver is a function of the element diameter, just as we would expect to see in contrasting thin and thick dipoles. However, the overall reflector lengths for the two arrays are more closely matched, with only an inch difference. With a slightly closer spacing to the driver, the thin-wire reflector does not need as much lengthening to achieve the required mutual coupling with the driver.

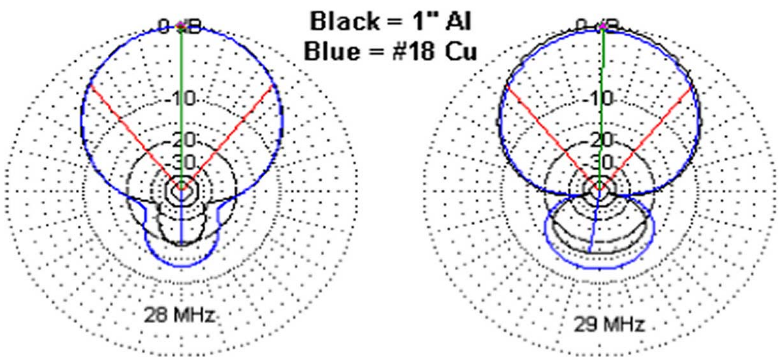
The tendencies that we have seen in the comparison of the two Moxon designs apply to every change of element diameter.

The performance of the two rectangles is similar, but with a few notable points. First, skin effect losses give the thin wire version a slightly lower gain. In fact, we might construct the 1" version from either copper or aluminum and arrive at the same free-space forward gain: 5.97 dBi. However, there is a sort of threshold effect so that for any given frequency, beyond a certain element diameter, differences of gain disappear. However, as we make the wire thinner, skin-effect losses show up as reduced forward gain. A copper version of the #18 Moxon has a design-frequency gain of 5.8 dBi, while an aluminum version drops the gain by 0.1 dB. Interestingly, the aluminum version has a front-to-back value that is 2 dB less than the copper version. The differences are not operationally significant at 10 meters, but may be significant at lower HF frequencies, where wire element diameters are a very tiny fraction of a wavelength. (The diameter of the 1" element is 0.0024 wavelength, while the diameter of the AWG #18 wire is 0.0403" or 0.00009 wavelength—a 26.67:1 diameter ratio.)

Fig. 2-9



Element diameter makes a much larger difference to the operating bandwidth of the rectangle. **Fig. 2-9** shows the comparative 50-Ohm SWR curves for the 1" and the #18 versions of the array, using aluminum for the fat elements and copper for the thin ones. Since the reactance of a Moxon array changes so slowly, the best 50-Ohm SWR point for the wire array occurs at about 28.3 MHz. However, the band-edge values are nearly the same: about 1.75:1. Although still very acceptable values in most circumstances, they are considerably higher than the values for the 1" version of the array.



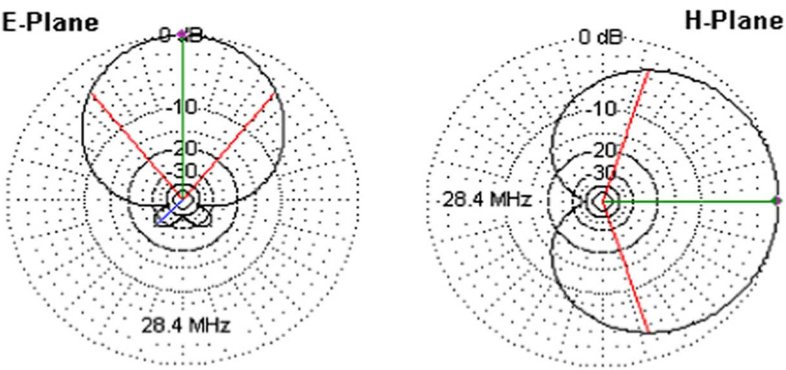
Band-Edge Free-Space E-Plane Patterns
1" Aluminum vs. AWG #18 Copper Elements **Fig. 2-10**

Fig. 2-10 shows a second aspect of the bandwidth question. The wire version of the array shows band-edge front-to-back ratios that are significantly poorer than the corresponding ratios for the 1"-element version. Although still quite usable, the wire values show that operating bandwidth is more than a question of SWR. One might also note in the 29-MHz patterns that the wire version of the array shows a more rapid decline in array gain than its fat-element cousin.

The design of a Moxon array always involves selecting the best materials for a job in light of the operating needs brought to the exercise. Materials do make a difference in performance.

What Antenna Patterns Tell Us

We can gather some further insights into the behavior of Moxon rectangles by examining the radiation patterns for the antenna under various conditions. In free space, the two key 2-dimensional patterns carry the names E-plane and H-plane patterns. For antenna arrays based upon the dipole—such as the Yagi or the Moxon rectangle—the E-plane is parallel to the plane created by the elements. The H-plane is at right angles to the E-plane. Since we can have 2 right-angle shifts, we select the one in which the main forward lobe (or lobes in a dipole) is the same as the one for the E-plane pattern.



Moxon Rectangle: Free-Space E-Plane and H-Plane Patterns

Fig. 2-11

Fig. 2-11 provides both E-plane and H-plane patterns for our 1" Moxon at 28.4 MHz, the design frequency. The E-plane pattern we have previously investigated, since it gives us a preview of the pattern we shall obtain for the antenna when we place it over the ground in a horizontal orientation—yielding horizontal polarization. A very large portion of Moxon applications in the HF region use this orientation. Hence, we have given it priority.

The H-plane pattern gives us a preview of the pattern we would obtain over ground if we orient the antenna vertically with the gaps above and below each other. Notable in this pattern are two important features relative to the E-plane pattern. One is the very deep and sharp rear null. We can make use of this null in some applications, especially in the VHF or UHF region, where it is practical to set the antenna vertical. Second is the much wider beamwidth—well over 120 degrees. Again, this feature can be useful for VHF and UHF applications where we might wish to cover the entire horizon with as few as 3 fixed-position arrays. We shall devote at least 2 chapters to potential applications of the Moxon at these upper frequencies.

The difference between the E-plane and H-plane patterns is to a large degree a function of geometry. The names “E-plane” and “H-plane” derive from the planes in which we find the near-field electrical and magnetic fields of the antenna. However, the types of patterns with which we are dealing are far-field patterns, composed virtually exclusively of electrical fields. Hence, the names themselves describe an orientation, but do not explain why the pattern shapes differ.

If we were to take free-space patterns of a simple dipole, the E-plane pattern would be the classical figure-8, while the H-plane pattern would form a perfect circle. At the center of the H-plane pattern, the antenna would appear as a dot, because we are viewing it on end. Note that the circular element has nothing to limit the pattern in any direction. However, the E-plane pattern would show the antenna as a line with the ends extending into the null regions of the pattern. The current distribution on the wire provides radiation broadside to the wire length.

Every directional array rearranges the energy patterns, suppressing energy in one direction and allowing it to add to energy in another. Both the Yagi and the Moxon E-plane patterns show a reduction of one side of the dipole figure-8 and an enlargement of the other. When we look at the H-plane pattern, we see a similar effect, but applied to a circle. One side of the circle is pinched inward and the other side expands.

When we place an antenna over a ground surface, the radiation patterns take on new names: azimuth and elevation. For a horizontally oriented Moxon, the azimuth pattern corresponds to the E-plane pattern and has a similar shape—depending upon the height of the antenna above ground. If we orient the antenna vertically, then the azimuth pattern will correspond to the H-plane pattern and have a shape similar to it.

Since the next few chapters of these notes will involve HF Moxons horizontally oriented, let’s investigate some radiation patterns for this arrangement. We shall be interested not only in azimuth patterns, but as well in elevation patterns. The latter type of patterns gives us a good idea of at what angle our signal emerges and at what strength. Since HF applications usually involve skip or the refraction of radiation in the ionosphere, the elevation plot can give us a sense of how successful we might be in communicating over paths of various lengths. Of course, our actual success also depends upon the propagation conditions at the time we operate. So radiation patterns only tell us part of the story, but a significant part.

We shall sample the azimuth and elevation patterns at various heights above ground. Heights will appear as fractions of a wavelength above ground. Although we shall use our 1" diameter element Moxon at 28.4 MHz as our modeling sample, the data will apply generally to any horizontal Moxon at any frequency that is the same fraction of a wavelength above ground. We shall begin very low—at 1/4 wavelength above average ground—since many field applications of the Moxon for the lower HF region have difficulty getting the antenna even this high. Unlike the situation with vertical antennas, where the quality of the ground can make sizable differences in antenna performance, horizontal antennas vary only slightly as we change the ground quality from very poor to very good. Hence, the use of average or good ground, with a conductivity of 0.005 s/m and a permittivity (relative dielectric constant) of 13 will serve as a median set of values.

We shall accompany each pattern sample with a set of data, listing the forward gain in dBi, the front-to-back ratio in dB, and the take-off angle. The take-off (TO) angle is the elevation angle of maximum radiation. We should never look at this figure in isolation, but always combine it with an examination of the pattern to determine the vertical beamwidth. Since we define beamwidth as the angle between those points where the power level is half its maximum value—or -3 dB points—the vertical beamwidth gives us a view of the range of elevation angles over which we have significant radiation—enough perhaps for successful use of a given propagation path. The horizontal beamwidth of 78-80 degrees will not change significantly as we change antenna height, so we shall omit that figure from the data. As well, we shall list the feedpoint impedance of the antenna in terms of the feedpoint resistance and reactance. This last figure will show us that the Moxon rectangle is rather stable, even at low antenna heights. Adjusting the antenna at a low height rarely requires us to make any further adjustments when elevating it to its final position.

Free-Space Data

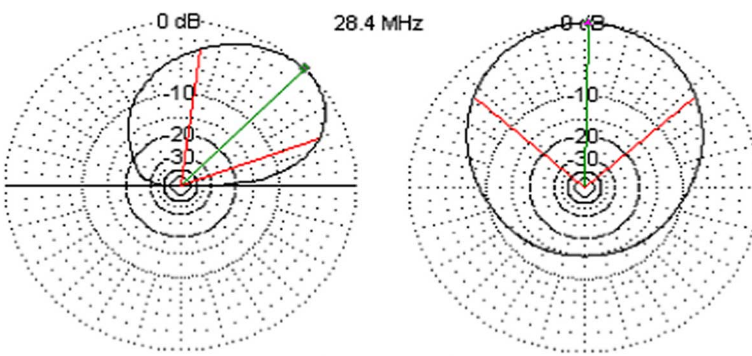
Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
5.97	38.68	———	143	52 - j 3

The free-space data gives us a point of reference for the information on antenna performance over ground at various heights. We shall expect a higher forward gain due to ground reflections that add to the gain. We shall also expect a much smaller vertical beamwidth for much the same reason. To explain other data changes, we shall refer to the antenna patterns themselves.

Data: 1/4-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
8.47	14.96	45	62	44 - j 0

The patterns in **Fig. 2-12** give sense to the data in the lines above. Due to the low antenna height, the antenna creates a single bulbous forward pattern, with significant rearward radiation—as indicated by the lower front-to-back value. However, the high-angle elevation pattern still has significant radiation at low angles, suggesting some utility for longer-range communications.



Elevation Azimuth

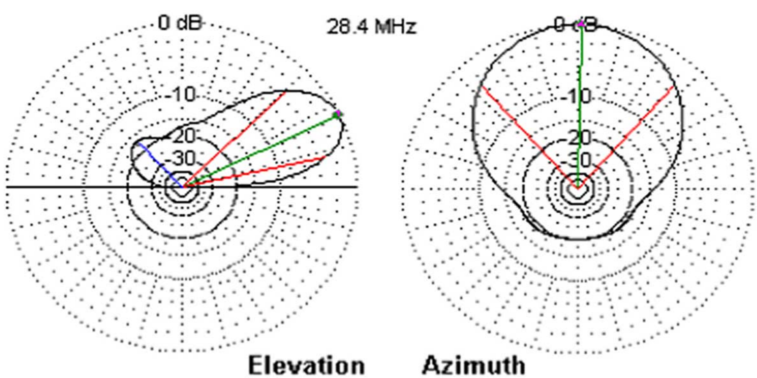
Moxon Height: 0.25 Wavelength Above Average Ground

Fig. 2-12

Data: 1/2-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
10.56	20.35	26	44	58 - j 1

By the time we elevate the antenna to a 1/2-wavelength height, we find a significant increase in gain, a lower TO angle, and a smaller vertical beamwidth. However, the antenna has only one main lobe, with very little wasted radiation in the vertical direction. See **Fig. 2-13**. In addition, we have regained a large part of the front-to-back ratio that was depressed at the lower (1/4-wavelength) height. Although the feedpoint impedances for both 1/4 and 1/2 wavelength are very usable without antenna modifications, we should expect to see fluctuations in the feedpoint impedances of horizontal antennas at heights below 1 wavelength. The pattern, as we shall see when we look at the 3/4-wavelength data, is not constant, but shows values both above and below the free-space values, depending upon the exact antenna height. For most home-station installations, 1/2-wavelength is a good minimum antenna height for which to strive, even if we cannot attain it in the lower HF region.



Moxon Height: 0.5 Wavelength Above Average Ground

Fig. 2-13

Data: 3/4-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	R+/-jX Ohms)
11.02	24.02	18	20	49 - j 3

The 3/4-wavelength data shows that as we increase the antenna height, we also increase the forward gain. However, the rate of increase slows with each new increment of height that we add. We also note the decreasing TO angle, and the fact that it, too, shows a slowing rate of decrease with each additional increment of antenna height. Note also that the vertical beamwidth is slowly approaching the value of the TO angle. By an antenna height of 1 wavelength, the two values will correspond very closely. As we continue increasing antenna height, the feedpoint resistance does not show an increase, but is actually lower than the value for 1/2 wavelength, illustrating the fluctuation noted earlier. However, perhaps the most vivid aspect of the information for this antenna height is the appearance in the elevation plot in **Fig. 2-14** of a secondary lobe. The lobe has a vertical development and is much weaker than the main lobe. Watch the development of this and other secondary lobes as we increase height further.

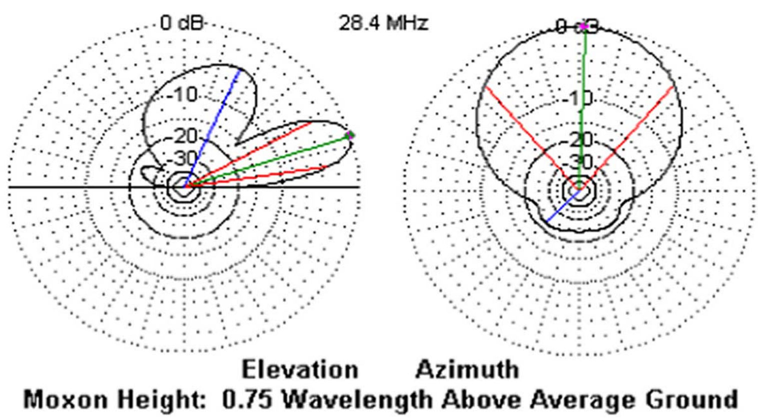
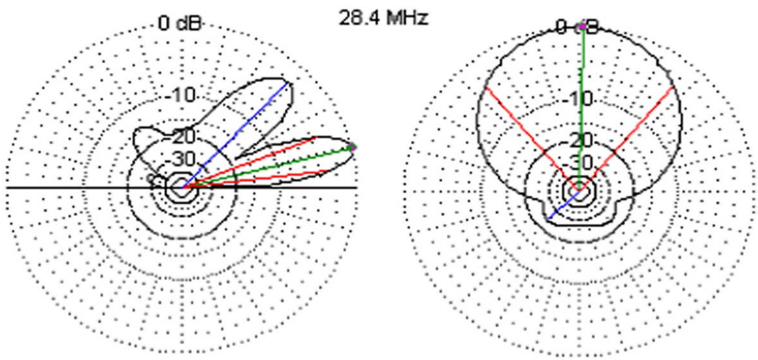


Fig. 2-14

Data: 1-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
11.34	27.51	14	15	55 - j 1

At a height of 1 wavelength, the array continues the progressions of increasing gain, increasing front-to-back ratio, decreasing TO angle, and decreasing vertical beamwidth. The narrowing of the lowest forward lobe concerns some users of this and other horizontal arrays (and the patterns are typical for most of them). However, the vertical signal spread from about 7 degrees through about 21 degrees tends to cover most of the useful propagation angles, except for those that are very low. As shown in **Fig. 2-15**, the high-angle secondary lobe has narrowed and moved forward, producing a lobe that is sometimes useful in the upper HF region for sporadic E skip communications. The development of this lobe and its counterpart rearward secondary lobe is a foreshadowing of the development of other lobes. Ground reflections yield highly complex although completely predictable lobe structures as we increase antenna height.



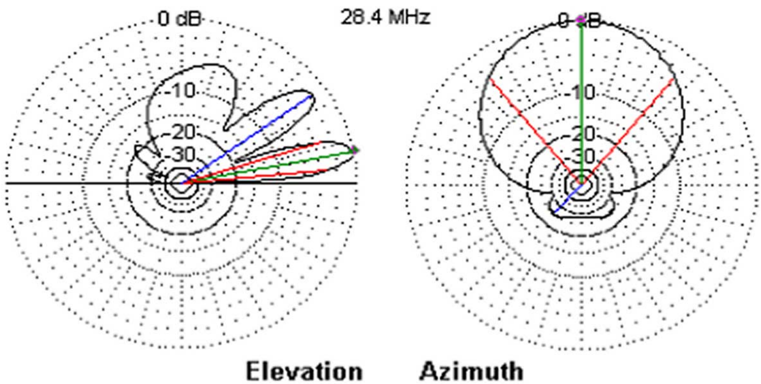
Moxon Height: 1.0 Wavelength Above Average Ground

Fig. 2-15

Data: 1-1/4-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
11.44	27.74	11	12	50 - j 3

All of the progressions that we have noted so far continue at the 1.25-wavelength mark. Perhaps the most significant feature of the data is the fact that the feedpoint impedance has become very stable, changing by an ever-decreasing amount from one height to the next. **Fig. 2-16** shows the development of a third elevation lobe, and the spreading and narrowing of the previous secondary lobes. Compare the new lobe at 1.25 wavelengths with the emerging secondary lobe in the 0.75-wavelength pattern. The similarity in shape is not accidental, since lobe development largely occurs at 1/2-wavelength intervals of increasing antenna height. Over perfect ground, the first of the secondary lobes may approach the lowest lobe in strength. However, over ordinary ground, the same lobe is usually 3 dB or more weaker than the lowest lobe in the elevation pattern. Finally note that the lower edge of the beamwidth marker is now at the 5-6-degree mark, thus enhancing very-low-angle skip communications for very long paths.



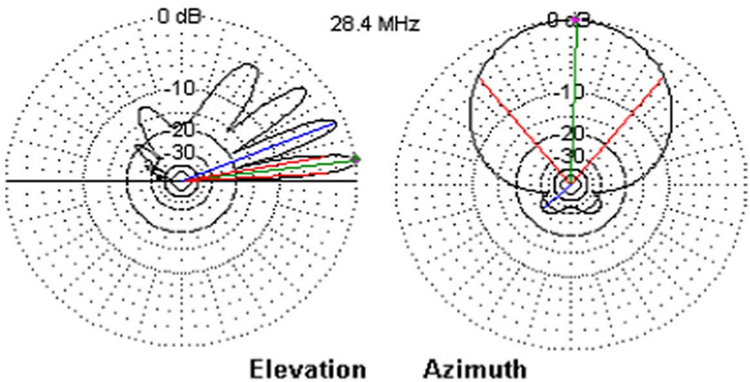
Moxon Height: 1.25 Wavelengths Above Average Ground

Fig. 2-16

Data: 2-Wavlength Height

Gain	F-B Ratio	TO Angle	V. B-W	Feed Impedance
dBi	dB	degrees	degrees	(R+/-jX Ohms)
11.68	34.53	7	7	54 - j 2

We have skipped some intervals to close our survey at the 2-wavelength mark. The rate of change of the data progressions between 1.25 and 2.0 wavelengths is too small to need detailed recording. By a height of 2 wavelengths—perhaps obtainable only in the upper HF and lower VHF region—we have re-acquired virtually all the free-space front-to-back ratio, including the general shape of the rear lobes. The lower edge marker for the vertical beamwidth in the elevation pattern in **Fig. 2-17** is now down to the 3-4-degree level. However, let's compare the structure of this elevation pattern with the one for 1 wavelength. In the region vertically above the antenna, we see a ver similar pattern of low gain. However, the 2-wavelength pattern has two more elevation lobes than the 1-wavelength pattern. As noted earlier, the emergence of elevation lobes tends to recur at 1/2-wavelength intervals of height increase. With this set of patterns, we may conclude our survey, since you can now predict the shapes, angles, and performance data for height antenna heights.



Moxon Height: 2.0 Wavelengths Above Average Ground

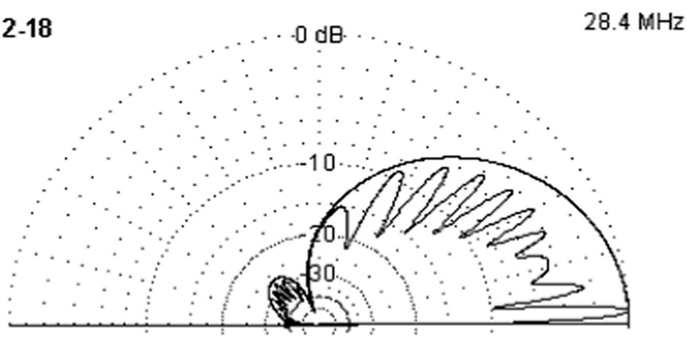
Fig. 2-17

Although this survey may be “old-hat” to some readers, most individuals investigating the Moxon rectangle and comparable small arrays are relatively new to antenna theory and practice. Hence, I have included the survey in order to develop a sense of proper expectations of antennas as we move them upward. The values for the Moxon rectangle are similar to those for a 2-element Yagi, although the Yagi would average about 0.3 dB higher gain but 15-20 dB lower front to back ratio. Even very large Yagis would follow the lobe development in the elevation plot portions of the figures.

The elevation plots for vertically polarized beams differ considerably from the plots of horizontally polarized arrays. We often have difficulty sorting out the elevation lobes, because some of them tend to overlap and combine, giving the illusion of a single, wide lobe rather than a pair of lobes. As well, many antenna enthusiasts are unfamiliar with the relationship between the free-space pattern and the elevation pattern when we orient the array vertically. Azimuth patterns are simple, since their shape shows a clear relationship to the corresponding free-space pattern. But the many lobes of the elevation pattern make its correspondence to free-space patterns more elusive.

Fig. 2-18 combines the smooth outline of one-half the E-plane pattern in free-space with the many-lobed elevation pattern for the same antenna when we place it in a vertical orientation and set it 5 wavelengths above average ground. This situation would be common for a vertically polarized VHF or UHF application of the Moxon rectangle. Note that the many lobes of the high-altitude antenna over ground fall wholly within the general outline of the free-space pattern. We can replicate this overlay with the elevation patterns of horizontal antennas and their corresponding H-plane free-space patterns. The ability to make such patterns shows us that there is nothing random or accidental about the lobe structure of an elevation pattern.

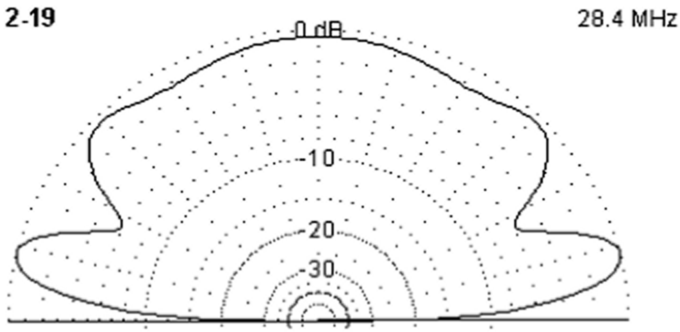
Fig 2-18



Free-Space H-Plane Pattern Overlaid in Elevation Pattern of 10-Meter Moxon Rectangle at 5 Wavelengths Above Ground

Finally, let's examine one more pattern. We have looked at the Moxon in both vertical and horizontal orientations, but we have omitted one important orientation: pointing the antenna straight upward. **Fig. 2-19** sets our standard 28.4-MHz 1" element rectangle 1 wavelength above ground at the reflector level, with the antenna directed toward the zenith. Although there are a pair of low-angle lobes and nulls, the main portion of the pattern forms a relatively smooth dome. This pattern may give us a few ideas about satellite applications to appear later on in a separate chapter.

Fig 2-19



Elevation Pattern of Moxon Rectangle Pointed Upward at a Height of 1 Wavelength Above Ground

We might go on indefinitely listing and illustrating properties of the Moxon rectangle (and antennas in general). However, we shall encounter further Moxon properties as we work with practical antennas in subsequent chapters. For now, I think we have enough properties in hand to decide whether we want to try to build one. However, we have only a few sample designs that may not meet our needs or desires. So the next question is this one: how do we determine the dimensions for any Moxon rectangle for (nearly) any frequency using (nearly) any size element? The answer is only a page away.

* * *

Appended models used in this chapter: yagi10-1al.ez, mox10-1al.ez, mox10-18cu.ez, mox10-1alv, mox10-1alu

3. Calculating Moxon Rectangle Dimensions

There is an urge among antenna builders to discover “magic formulas” for determining the element lengths of various antenna types. In most cases, tradition sets the form of these formulas in the following terms:

$$Length_{dim} = \frac{K}{f_{MHz}} \qquad \mathbf{1}$$

We seek the length in customary dimensional units (and “dim” may equal feet, inches, meters or millimeters) using some constant, K, and the frequency, f, in MHz.

Except for the simplest of antennas, we should wean ourselves from this urge. Antenna dimensions do not tend to scale in such simplistic terms. Even the simple 1/2 wavelength dipole resonant length varies with wire size and height above ground. Hence, using a cutting formula becomes a matter more of luck than of antenna knowledge.

More complex antennas tend to be less prone to performance variations created by antenna height, if the antenna is at least 1/2 wavelength high. The more closed the structure of the antenna, the more immune it becomes to variations in resonant element length by virtue of height above ground. However, almost all common types of antennas will vary according to the diameter of the element size.

In most cases, dimensional differences will be negligible between antennas built of materials with perfect conductivity and those using ordinary materials such as copper and aluminum. A difference is negligible if it falls within the margins of error that are inherent in standard construction practices. For home shop construction practices, a 1 to 2 percent dimensional error range is normal. Of course, the more elaborate the shop and the more experienced the builder, the smaller the potential error range.

In the end, then, we are left with the diameter of the element wire (or rod or tubing) as the key to determining the element length. One common warning that we give with respect to scaling antennas for other than the design frequency is also to scale the wire diameter. Only under this condition will the scaling play true. In addition, we must also attend to element length differences between uniform-diameter elements and those elements that are tapered in steps, normally from a large diameter at the element center to a small diameter at the tip. Likewise, different tapering schedules may result in different element lengths for the same frequency and materials.

A Procedure for Developing Sensible Design Equations

If we work initially with uniform-diameter elements, it is possible to develop design equations for many antenna types. The starting point will normally be the element diameter. Again, the equations should begin using perfectly conductive material, with any necessary adjustments for real materials made later. The question then becomes how we may develop such equations. To answer the question, we may turn to an example.

Fig. 3-1 is the outline of a Moxon rectangle, a two element array that combines mutual coupling between elements and coupling between the element tips to yield a

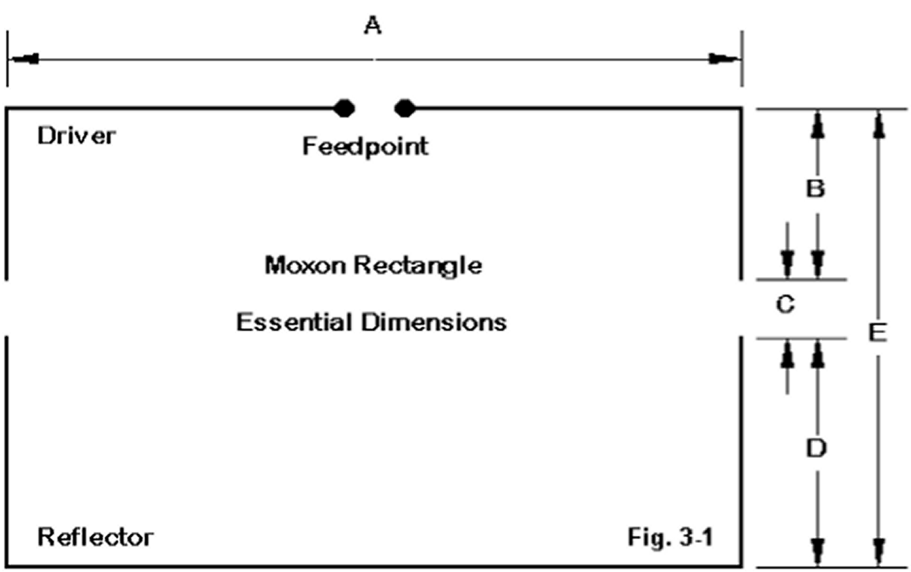


Fig. 3-1

broad forward lobe with nearly the strength of a 2-element driver-reflector Yagi. The pattern is almost cardioidal so that minimum radiation does not occur 90 degrees off the main lobe, but closer to 120 degrees away. The antenna at its design frequency is capable of better than 30 dB front-to-back ratio, with better than 20 dB front-to-back ratio across most HF amateur bands. Because the side-to-side dimension of the antenna is only about 70% of the width of a full-size 2-element Yagi, the antenna has found interest among those with limited space. Further interest has arisen among those who can put the antenna pattern to good use. An additional advantage of the design is the 50-Ohm feedpoint impedance, which simplifies matching requirements. A considerable bibliography on the antenna is available from British, American, and Australian sources, as well as at my web-site (http://www.cebik.com).

Our interest in the antenna stems from the designations of the element dimensions, listed as A through E in **Fig. 3-1**. By judicious modeling in NEC (version 2, 3, or 4), one can develop fairly precise models to create a base-line data set for the development of some design equations. However, the data set must meet standards for use as the basis for this development. For the Moxon rectangle, I set the following standards for each model in the data set.

Free-Space Gain Range:		5.95-6.05 dBi
180-Degree Front-to-Back Ratio:		>35 dB
Source Impedance:	Resistance:	50-54 Ohms
	Reactance:	<+/-1 Ohm

The next step is to decide upon the wire diameters to use for development purposes. Several factors enter into this decision. Common antenna building materials include AWG wire sizes (in the U.S.) and aluminum tubing and rods ranging from 1/8" to over 1" in diameter. For reference, the following table lists commonly used AWG wires sizes and their diameters in various units of measure.

AWG Size	Dia. Inches	Dia. Feet	Dia. mm
18	.0403	0.003358	1.0236
16	.0508	0.004233	1.2903
14	.0641	0.005342	1.6281
12	.0808	0.006733	2.0523
10	.1019	0.008492	2.5883

As useful as these conversions may be, they will not satisfy the needs of developing design equations. The wire size used must be given in terms of a fraction of a wavelength, and this number will vary with frequency for any given physical wire size. To provide a sense of the range of wire sizes, when given in terms of wavelengths, the following table presents some materials that have been used in published antenna projects, with the element diameter given in wavelengths for various frequencies.

Wire		Frequency (MHz)				
Size	Dia.(“)	1.8	7	28	50	144
#18	0.0403	6.146E-6	2.390E-5	9.560E-5	1.707E-4	4.917E-4
#14	0.0641	9.775E-6	3.802E-5	1.521E-4	2.715E-4	7.820E-4
#10	0.1019	1.554E-5	6.043E-5	2.417E-4	4.317E-4	1.243E-3
1/4"	0.25	3.813E-5	1.483E-4	5.931E-4	1.159E-3	3.050E-3
1/2"	0.50	7.625E-5	2.965E-4	1.186E-3	2.118E-3	6.100E-3
1"	1.00	1.523E-4	5.931E-4	2.372E-3	4.236E-3	1.220E-2

In practical terms, the range of wire sizes—given in terms of a fraction of a wavelength—runs between about 1E-5 and 1E-2. Extending the range to thinner wires presents no problems, although it is not especially useful. However, at the upper limit, there is a potential modeling problem. The Moxon “tails” (dimensions B and D in **Fig. 3-1**) require proportional segmentation to the parallel wires (dimension A). For good convergence, I chose to set B at 5 segments and D at 7 segments, with A using 35 segments. As the wire diameter approaches 0.01 wavelength, the wire diameter begins to exceed the segment length. Ideally, the segment length should be considerably greater than the wire diameter. Hence, the modeled results become less reliable with the fattest wires in the set. (A model with only linear elements would not present this difficulty, and a lower level of segmentation might well be used with excellent reliability.)

The next step is to decide what wire-size steps to use in developing the baseline data set. In most cases, antenna dimensions tend to show changes that relate to the logarithm of the wire size rather than to linear steps in wire size. For the range of wire sizes shown, we can conveniently take the common log of wires sizes from 1E-5 through 1E-2 to get a progression of logarithms from -5 to -2 in integral steps. However, the data set would be very small. To keep the log steps linear, we may take intermediate wire sizes from 3.162E-5 through 3.162E-3 to obtain values for the common logs -4.5 through -2.5. How much finer one might wish to go depends very much on the rate of variation of values and the anticipated complexity of the resultant curves. For this project, the seven data sets provided a sufficiently large basis for the development of design equations.

The following table lists the results of the modeling exercise, showing the free-space gain, 180-degree front-to-back ratio, feedpoint impedance, and dimensions A-E (in wavelengths) for the models.

1. Performance Parameters

Wire Size (wl)	Log (base 10)	Gain (dBi)	Front-to-Back Ratio (dB)	Feedpoint Z (R+/-jX Ohms)
1E-5	-5	6.04	48.1	52.5 + j 0.4
3.162E-5	-4.5	6.06	39.2	51.5 + j 1.0
1E-4	-4	6.03	41.8	52.5 - j 0.8
3.162E-4	-3.5	6.01	36.1	52.5 + j 0.6
1E-3	-3	6.00	41.7	53.0 - j 0.7
3.162E-3	-2.5	5.95	35.4	53.3 - j 0.8
1E-2	-2	5.95	35.0	53.9 + j 0.8

2. Dimensions (See **Fig. 3-1**)

Wire Size	Dimensions in Wavelengths				
	A	B	C	D	E
1E-5	0.366	0.057	0.007	0.067	0.131
3.162E-5	0.366	0.056	0.009	0.067	0.132
1E-4	0.364	0.055	0.010	0.068	0.133
3.162E-4	0.364	0.053	0.012	0.068	0.133
1E-3	0.360	0.051	0.013	0.069	0.133
3.162E-3	0.358	0.046	0.018	0.069	0.133
1E-2	0.356	0.040	0.024	0.070	0.134

The front-to-back ratios of the base-line models seem to vary considerably. However, the peak 180-degree front-to-back ratio—which may reach 50 dB in models—is a very narrow-band phenomenon. Hence, values between 35 dB and 45 dB may be only a few kHz apart.

Dimension A is the full length of the side-to-side dimension. Models conventionally set with one of the axes bisecting this dimension will show +1/2A in one direction and -1/2A in the other direction away from the axis line. The dimension also includes the gap for the feedline connection in the driver element. The gap is not critical within reason, and small variations in the gap size do not affect performance. Gaps for HF models might range from 0.25" to 1.0". At VHF, gaps up to about 1/2" or so are acceptable with no difficulties. Obviously, we should strive to have the smallest feedpoint gap in the driver element that we can manage for a given method of construction.

In order to maintain a feedpoint impedance close to 50 Ohms, the side-to-side dimension (A) must decrease as the wire size increases. One expected result would be an increase in the driver tail length (B). However, the increasing wire diameter overrides this increase and results in a shortening of the tails as well as the side-to-side dimension. The reflector is less affected by the changes in wire diameter and shows an increase in tail length (D) with the shortening of A.

Most evident and rapid is the increase in dimension C, the gap between the tips of the driver and reflector tails. As the wire size increases, the degree of coupling between tips also increases. To sustain roughly equivalent performance across the base-line set of models, the gap must be increased in an ascending curve. The greatest increases in the table do occur where the models begin to show reduced reliability. However, the general trend holds true. Note that the overall front-to-back dimension (E) does not change much over the entire range of wire sizes.

Step-wise (rather than smooth) variations occur in the tabulated results because the increments of dimensional change were limited to 0.001 wavelength. For almost identical performance, there is a small range of values for the gap. (If there were not, the antenna would be difficult to reproduce.) Centering the gap value within its range would have yielded smoother curves for all of the dimensions. However, this degree of precision would have been superfluous to the effort.

From Data to Equations

The data set generated by the base-line models is sufficient to develop design equations. The easiest way to develop usable equations is to subject the data to regression analysis, which is available in many mathematical software packages, either in stand-alone form (such as DataFit) or in larger suites of functions. Although a significant description of regression techniques is well beyond the scope of these notes, we can indicate the process and its output.

For any data set—especially where the plotted data has a linear X-axis scale—regression analysis can develop polynomial equations that best fit the data. The routines can produce any order of polynomial. For example, the form most used in the following discussion is a 2nd order polynomial of the form

$$y = a\,x^2 + b\,x + c \qquad \textbf{2}$$

where a, b, and c are coefficients generated by the regression analysis, (for our case) x is the common log of the wire diameter, and y is the dimension under analysis. Dimensions A, B, and C require second-order polynomials, while dimension D can be satisfied with a first order equation.

In any such exercise in regression analysis, it is important to understand that the equations developed have no inherent physical meaning relative to antenna theory or practice. The results are simple curve-fitting exercises within the upper and lower limits of the values for X and the data supplied. However, the results are usable in practice with some care. Foremost is the need to determine when a generated equation is adequate to a given task. Although in complex cases, the test routines report important information by which to evaluate the equations, simply plotting the equations against the data points can—in simpler cases—provide enough information to decide which level of polynomial will satisfy the needs of a project. For the present data set, one significant factor is that the equations should not result in extreme departures from the modeled data at the limits of the values for x. For A through C, 2nd-order equations sufficed, and for D, a first order equation (ax + b) proved sufficient. (In other cases, I have used up to 4th-order polynomials.)

To establish the adequacy of the data fits, the following graphs of dimensions A though D may be useful.

Fig. 3-2 shows a comparison of modeled and calculated values for dimension A. Within any normal building tolerances, this curve is a very tight fit. The step in the initial model data results from carrying out the dimension to only 3 decimal places.

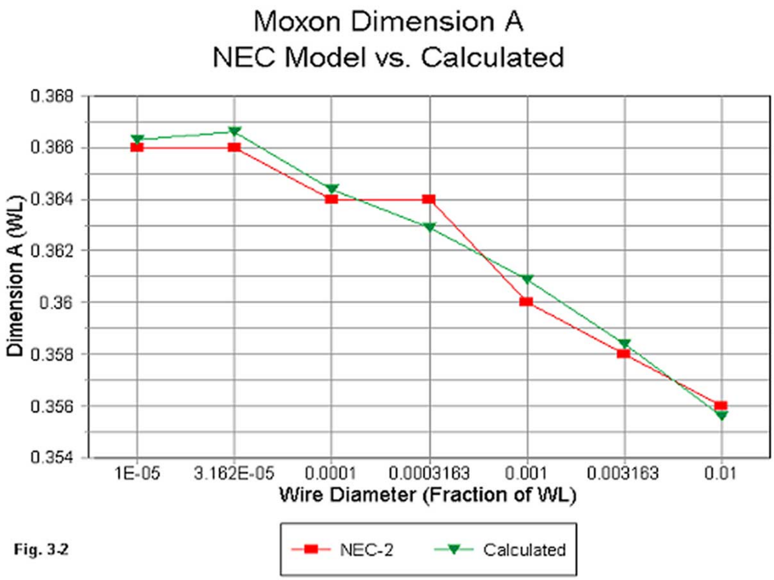

Moxon Dimension A
NEC Model vs. Calculated
Dimension A (WL)
0.368
0.366
0.364
0.362
0.36
0.358
0.356
0.354
1E-05
3.162E-05
0.0001
0.0003163
0.001
0.003163
0.01
Wire Diameter (Fraction of WL)
NEC-2
Calculated

Fig. 3.2

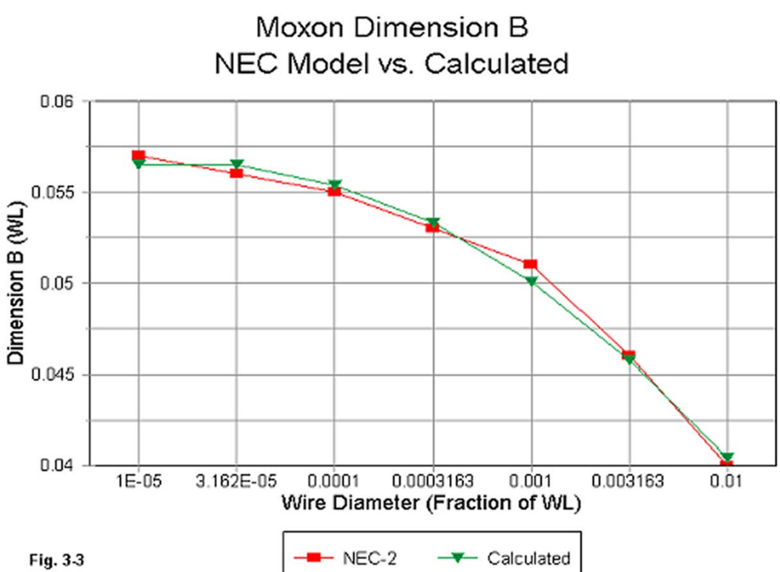

Moxon Dimension B
NEC Model vs. Calculated
Dimension B (WL)
0.06
0.055
0.05
0.045
0.04
1E-05
3.162E-05
0.0001
0.0003163
0.001
0.003163
0.01
Wire Diameter (Fraction of WL)
NEC-2
Calculated

Fig. 3.3

A comparison of modeled and calculated values for dimension B (the driver tail) appears in **Fig. 3-3**. This curve is an even tighter fit than for dimension A. Changes of materials (for example, from copper to aluminum) will result in greater changes in the feedpoint values than the differences between the modeled and the calculated dimensions.

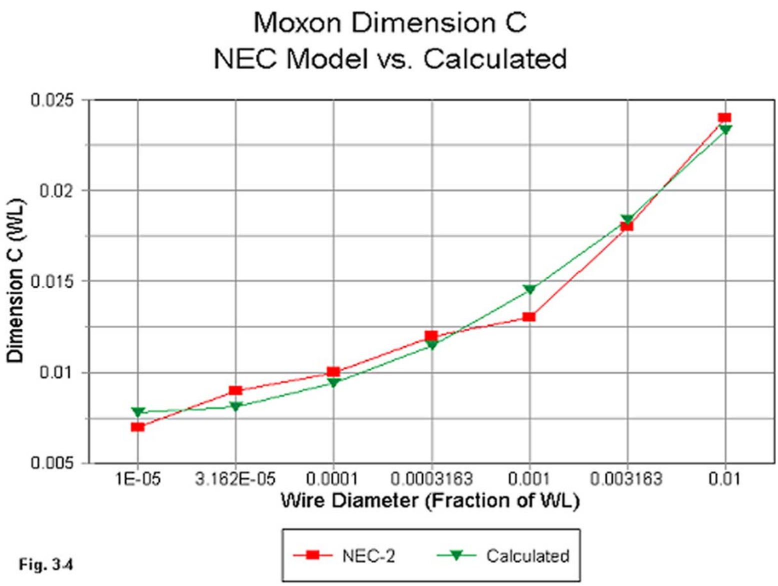


Fig. 3-4

Fig. 3-4 shows a comparison of modeled and calculated values for dimension C, the gap between element tips. The modeled (NEC-2) values do not have enough significant digits for a smooth curve. Nevertheless, since a Moxon rectangle is not completely finicky, even in its most critical gap dimension (C), there is always room for slight design variations without perceptible differences in performance. Hence, for practical purposes of actual antenna design, the curves fit together perfectly well.

A comparison of modeled and calculated values for dimension D (the reflector tail) appears in **Fig. 3-5**. The sharpness of turns in both curves is due to the very small change overall on dimension D.

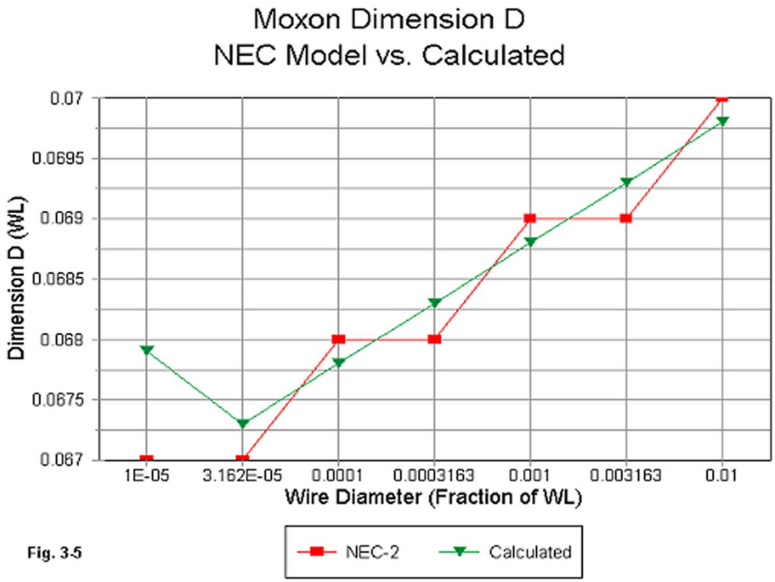


Fig. 3-5

I have not yet shown the values for the coefficients, because they will appear shortly within each of the two methods I have selected for packaging the results. However, it should be apparent that all of the curves fit the data reasonably well, given the increment of change within which the models were developed. I cannot stress enough two key points. 1. The equations have no direct theoretical meaning within antenna theory. 2. We must exercise care to ensure that the equations are neither more complex than they need to be for a task nor too simple to capture the essential data within the limits of the defined range of values.

Packaging the Design Equations

There are innumerable ways to package the design equations in order to make them usable and convenient. We shall look at only three here.

1. *A Basic (or other language) utility program*: The following listing provides a small utility program for calculating Moxon dimensions from an input of the wire diameter and the design frequency. The wire diameter may be input in inches, millimeters, or

wavelengths. The output is given in wavelengths, feet, and inches. The simple addition of a few lines converting the English output into metric units (0.3048 * feet) would complete the program.

```
10 CLS:PRINT “Program to calculate the dimensions of a Moxon Rectangle.”
20 PRINT “All equations correlated to NEC antenna modeling software for wire diameters”
30 PRINT “     from 1E-5 to 1E-2 wavelengths.”
40 PRINT “L. B. Cebik, W4RNL”
50 INPUT “Enter Desired Frequency in MHz:”;F
60 PRINT “Select Units for Wire Diameter in 1. Inches, 2. Millimeters, 3. Wavelengths”
70 INPUT “Choose 1. or 2. or 3.”;U
80 IF U>3 THEN 60
90 INPUT “Enter Wire Diameter in your Selected Units”;WD
100 IF U=1 THEN WLI=11802.71/F:DW=WD/WLI
110 IF U=2 THEN WLI=299792.5/F:DW=WD/WLI
120 IF U=3 THEN DW=WD
130 PRINT “Wire Diameter in Wavelengths:”;DW
140 D1=.4342945*LOG(DW)
150 IF D1<-6 THEN 160 ELSE 170
160 PRINT “Wire diameter less than 1E-6 wavelengths:  results uncertain.”
170 IF D1>-2 THEN 180 ELSE 190
180 PRINT “Wire diameter greater than 1E-2 wavelengths:  results uncertain.”
190 AA=-.0008571428571#:AB=-.009571428571#:AC=.3398571429#
200 A=(AA*(D1^2))+(AB*D1)+AC
210 BA=-.002142857143#:BB=-.02035714286#:BC=.008285714286#
220 B=(BA*(D1^2))+(BB*D1)+BC
230 CA=.001809523381#:CB=.01780952381#:CC=.05164285714#
240 C=(CA*(D1^2))+(CB*D1)+CC
241 DA=.001:DB=.07178571429#
242 D=(DA*D1)+DB
243 E=(B+C)+D
250 PRINT “Moxon Dimensions in Wavelengths:”
260 PRINT “A = “;A
270 PRINT “B = “;B
280 PRINT “C = “;C
```

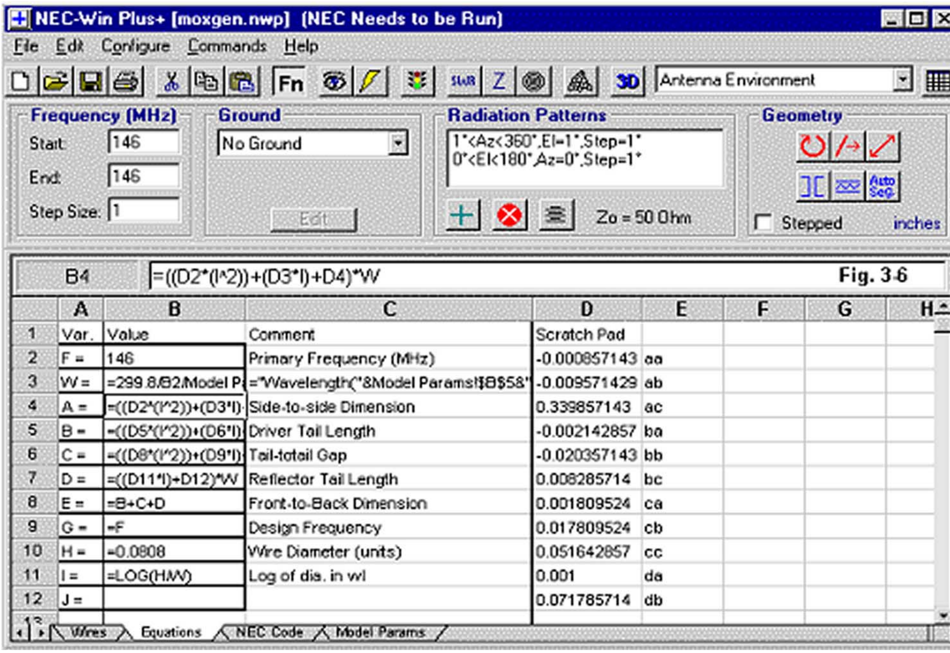
```
290 PRINT "D = ";D
295 PRINT "E = ";E
299 WF=983.5592/F:WFI=WF*12:PRINT "Wavelength: =";WF;"Feet or ";WFI;"Inches
300 PRINT "Dimensions in Feet and Inches"
301 PRINT "A = ";A*WF;"Feet or ";A*WFI;"Inches"
302 PRINT "B = ";B*WF;"Feet or ";B*WFI;"Inches"
303 PRINT "C = ";C*WF;"Feet or ";C*WFI;"Inches"
304 PRINT "D = ";D*WF;"Feet or ";D*WFI;"Inches"
305 PRINT "E = ";E*WF;"Feet or ";E*WFI;"Inches"
350 INPUT "Another Value = 1, Stop = 2: ";P
360 IF P=1 THEN 10 ELSE 370
370 END
```

Lines 190 through 243 contain the design equations and coefficients derived from the regression analysis. The variable names AA through DB should be self-explanatory. Note that the calculations use the common log of the wire diameter in wavelengths, and not the wire diameter itself. In GW Basic, the "log" entry always means a natural logarithm (conventionally designated ln). Therefore, line 140 contains a multiplier to convert the natural log value into a common log value. Should you convert this program to a spreadsheet, you may drop the multiplier (.4342945), since all modern spreadsheets know the difference between ln and log.

Dimension E is the simple sum of B, C, and D. It serves as a check on the fittingness of the other calculated dimensions by comparing it with the corresponding modeled value. Additionally, I have expressed the coefficients and other constants to fully calculated values, rather than using truncated values based on the least significant digits of any entry. You can easily trim the resulting output values to any sensible level of significance.

With the calculated dimensions in hand, one can create a model of the Moxon as a check, as a basis for optimization in models, or as a guide to building. The side-to-side dimension will require halving in order to place the front-to-back axis along the center-line of the antenna in any NEC model.

2. *A NEC-Win Plus NEC Model Using Equations*: The equations can also be entered directly into a NEC program that has the facility to accept design-by-equation. As an example, **Fig. 3-6** shows the equations screen for a NEC-Win Plus model.



Only one of the equations appears fully in the upper entry line, but it suffices to show the parallel to the Basic program. The spreadsheet does know the difference between natural and common logarithms, so the calculation of the log of the wire diameter in wavelengths (variable I) has a different meaning of "LOG" from its meaning in Basic. (Common GW Basic uses only natural logs and hence requires a conversion factor to yield common logs.)

The list of coefficients is entered in column D. As the sample equation for box B4 indicates, the equations of the dimension variables call upon the locations of the coefficients to employ their values in the calculation. Column E contains the identification of each coefficient, using the same labels as in the Basic listing.

The advantage of entering the equations directly into a modeling program is that one can then design a Moxon for any reasonable frequency with any reasonable wire diameter and evaluate the model—all in one operation. One of the variable entries equates the design frequency with the current frequency. However, you can lock in a set of dimensions by simply entering a design frequency. This is useful for frequency sweeps and other activities that will optimize the design.

How Good Are the Results?

The easiest way to find out how adequate the equations are is to design a few Moxon rectangles and then test their modeled performance. So that you can correlate the dimensions to the model description, **Fig. 3-7** provides the variables entry version of the wires page. Note the calculated values for all X entries and the calculated values for the driver tails. In the examples, I shall show only the values version of the wires page, and you can extrapolate back to the equations page values for A through E. All dimensional values will be in inches.

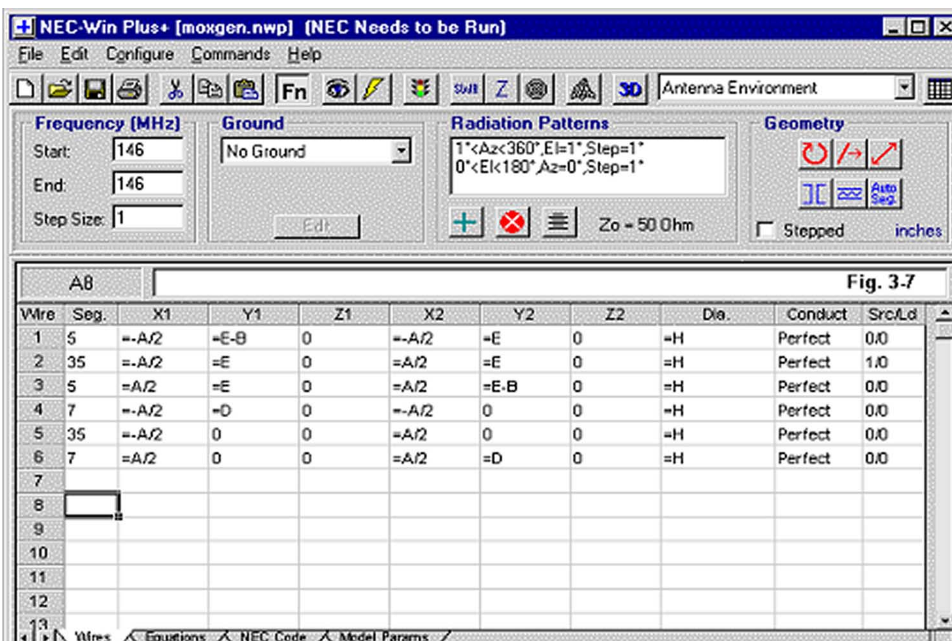
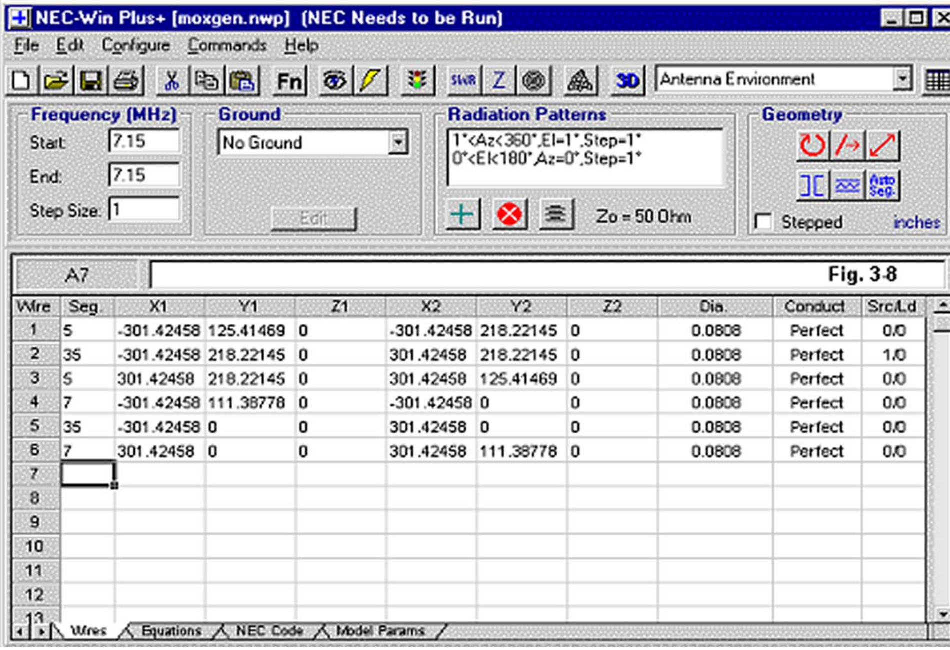


Fig. 3-7

1. *A 7.15 MHz #12 wire version*: The wires page for this antenna appears in **Fig. 3-8.**



The following table gives the modeled performance for both perfect wire and for copper wire.

Frequency MHz	Version	Gain dBi	Front-to-Back Ratio dB	Feedpoint Z R+/-jX Ohms
7.15	Perfect	6.01	39.07	53.9 + j 4.6
	Copper	5.80	31.29	55.9 + j 4.4

For reference, **Fig. 3-9** shows the typical free-space azimuth pattern for a Moxon rectangle, based on this particular model. Of course, one convenience of modeling by equation is that we can run a pattern and obtain other data with every change we make without intervening steps in the process.

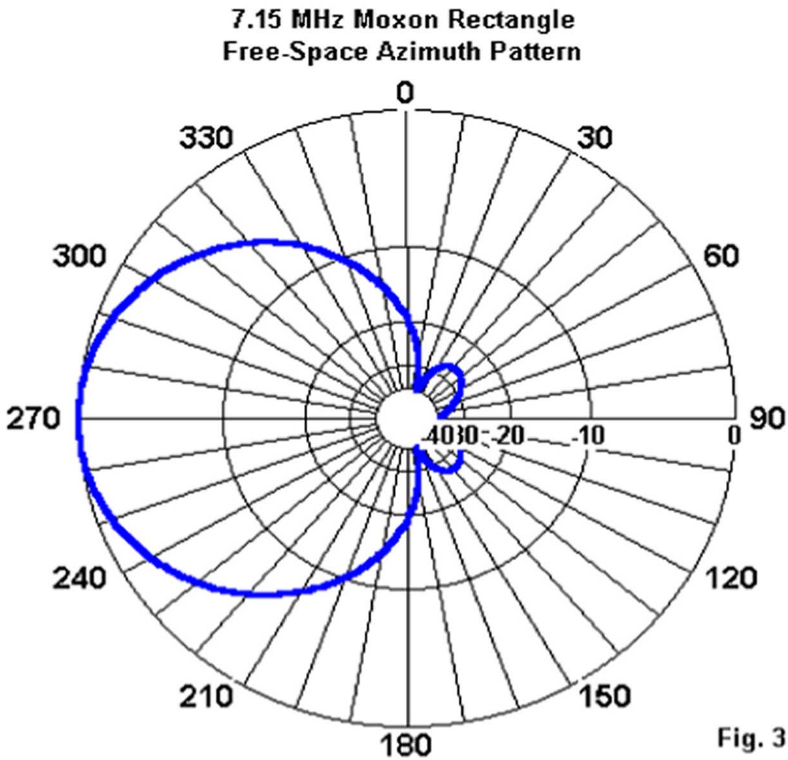
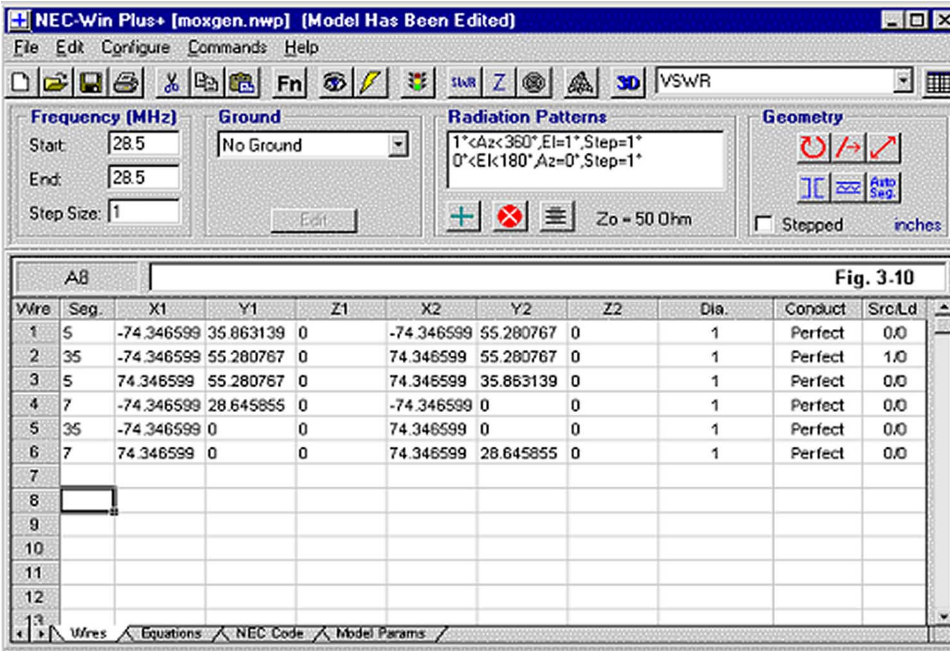


Fig. 3-9

Because AWG #12 wire is only 0.0808" in diameter, the efficiency of this antenna drops to 96.1% as we move from perfect wire to copper wire. The losses not only show up in the additional 2 Ohms in the feedpoint impedance, but as well in decreased gain and front-to-back ratio values.

Despite these facts about the wire Moxon rectangle, the calculations yield a design that is within original modeling limits set for this exercise, with a remnant reactance of only about 4.6 Ohms.



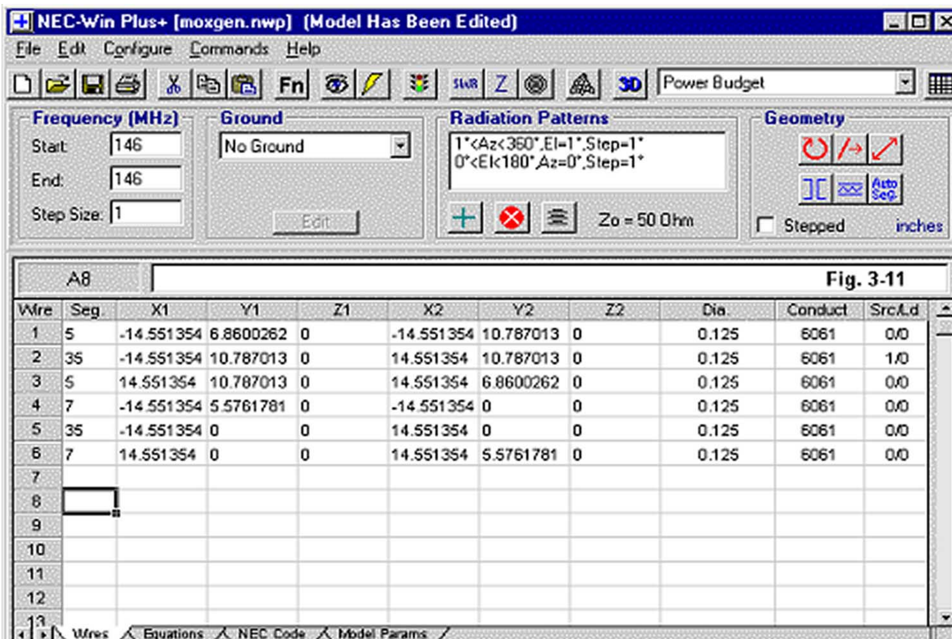
2. *A 28.5 MHz 1" tubing version*: **Fig. 3-10** contains the wires page dimensional values for the calculated model. The following table lists the performance using perfect wire and aluminum tubing:

Frequency MHz	Version	Gain dBi	Front-to-Back Ratio dB	Feedpoint Z R+/-jX Ohms
28.5	Perfect	5.97	36.89	52.9 - j 2.5
	Aluminum	5.96	36.43	53.0 - j 2.5

Despite the greater losses of aluminum relative to copper, the larger surface area of the 1" material and the higher frequency (which makes the diameter a larger fraction of a wavelength) yield a very high efficiency: 99.97%. Hence, the differential between perfect wire and large aluminum tubing is negligible. Once more, the calculated dimensions of the antenna come very close to matching the modeling limits, with only a 2.5-Ohm remnant reactance.

3. *A 146 MHz 0.125" rod version*: **Fig. 3-11** shows the relevant wires page for this model. The following table lists the performance using perfect wire and aluminum rod:

Frequency MHz	Version	Gain dBi	Front-to-Back Ratio dB	Feedpoint Z R+/-jX Ohms
146	Perfect	6.01	43.50	51.8 - j 3.4
	Aluminum	5.96	39.68	52.3 - j 3.5



The aluminum version of the antenna has a 99.1% efficiency. Although the frequency is roughly 5 times higher than the 10-meter model, the rod is only 1/8 the diameter of the 10-meter material: hence, the slightly lower efficiency. Once more, the calculated model fallies well within the requirements for the goal of producing a design that can be translated directly into a constructed antenna.

Fig. 3-12 illustrates the simple way in which we may obtain further data from our model without altering the equation values. The only difference between this set-up and the one in **Fig. 3-11** is in the upper left corner, where we specify the frequency. We have now specified a frequency sweep from 144 to 148 MHz in 0.25-MHz steps. This specification is independent of the design frequency that we entered on the equations page as variable G (in place of using the preset variable F for its value in **Fig. 3-6**).

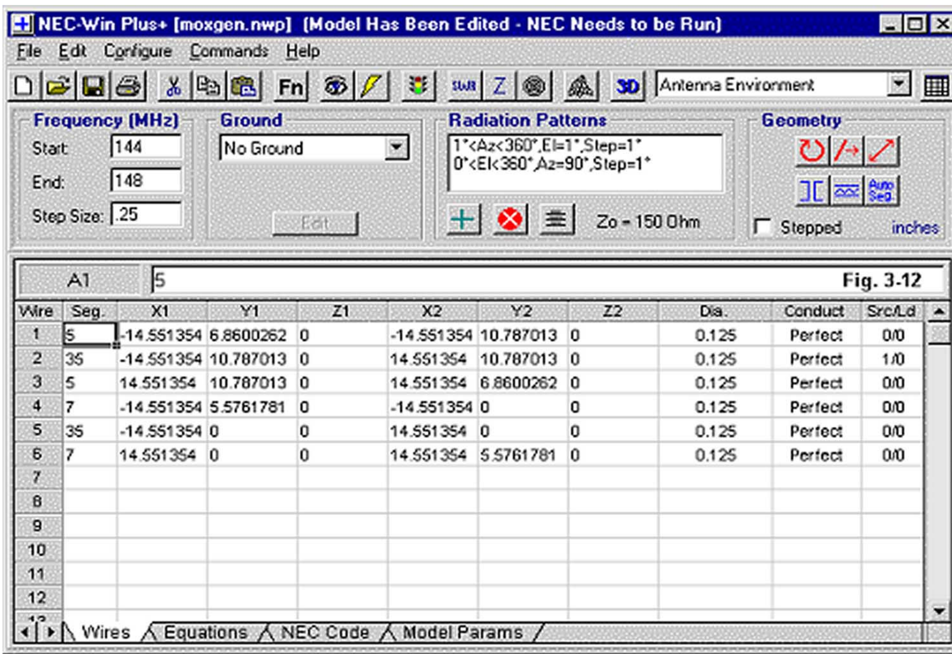


Fig. 3-13 shows one type of data that we can instantly receive from sweeping the model. The 50-Ohm SWR curve reveals the anticipated steeper climb below the design frequency than above it. If we intend to use the antenna vertically, say, for repeater use on the 2-meter band, then our operating span would stretch from 145-148 MHz. The operating-band edge SWR values are roughly equal, suggesting that the design frequency is a good choice for this use. However, if we plan to use the antenna over the full 2-meter band, perhaps we might best choose a slightly

lower frequency as the design frequency, one that is about 1/3 the way from the bottom of the operating spectrum.

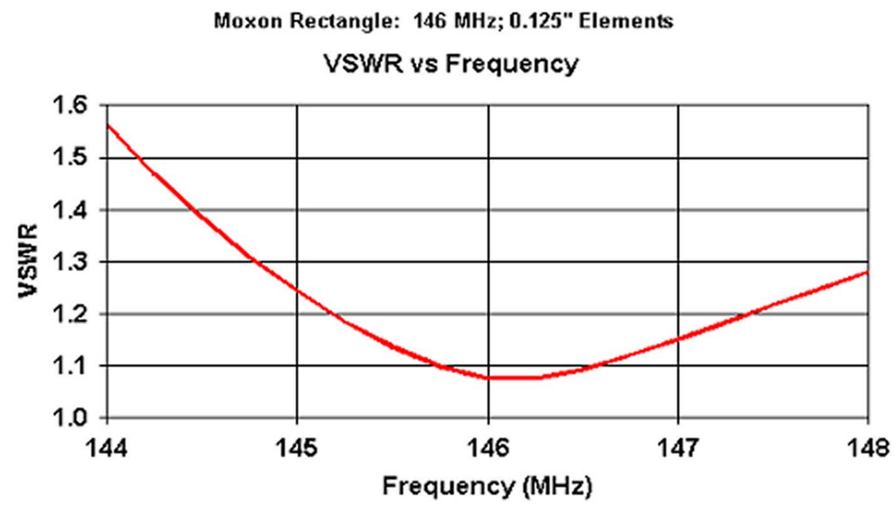


Fig. 3-13

Fig. 3-14 shows another data set that we can easily obtain: the ranges of feedpoint resistance and reactance across the band. As well, we can easily call up radiation patterns and overlay them for appropriate comparisons of potential performance.

3. *A Stand-Alone Windows Program*: At my suggestion, crack programmer Dan Maquire, AC6LA, converted the design equations into a stand-alone windows program. The program is available free from his website and is included (along with the NEC-Win Plus model and the GW Basic program) in the collection of models and programs that accompany this volume. All have the same filename: MOXGEN. However, each has a distinctive extension: .BAS for basic, .NWP for the NEC-Win Plus model, and .ZIP for the pre-installation version of the stand-alone program.

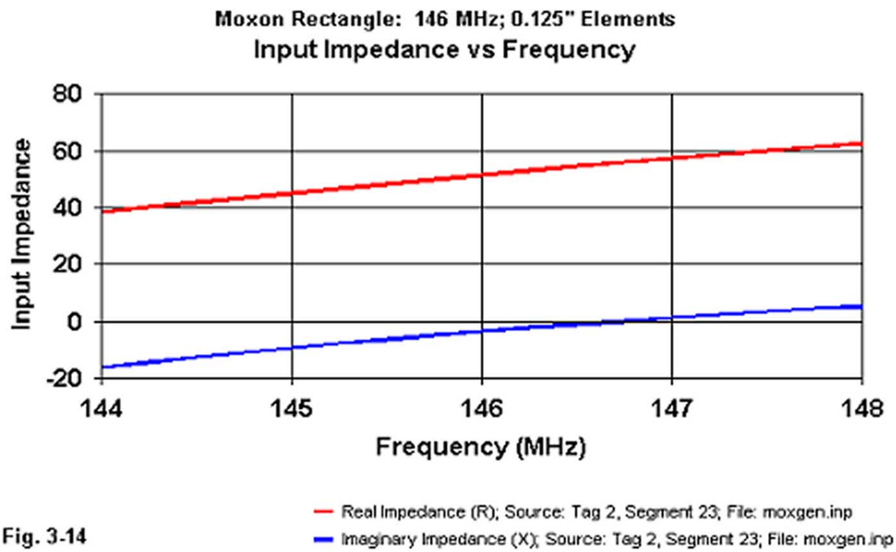
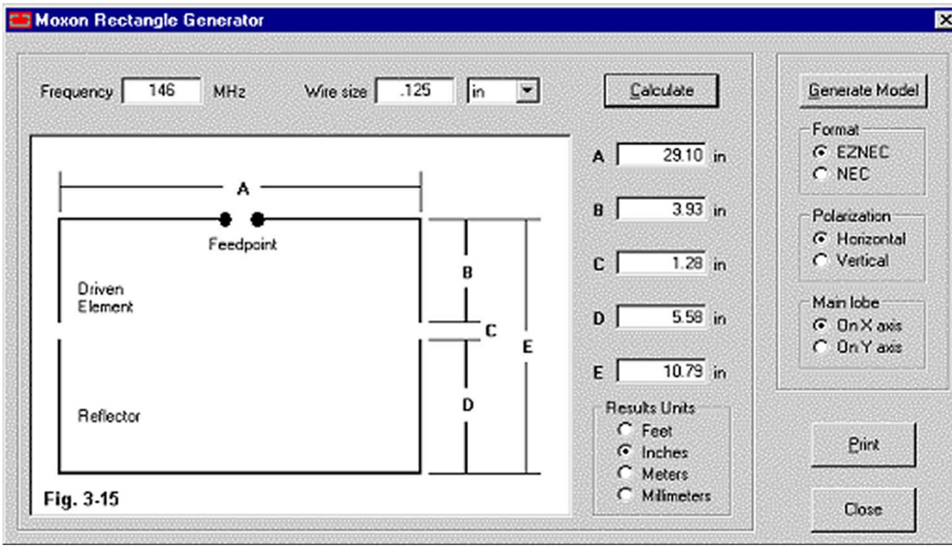


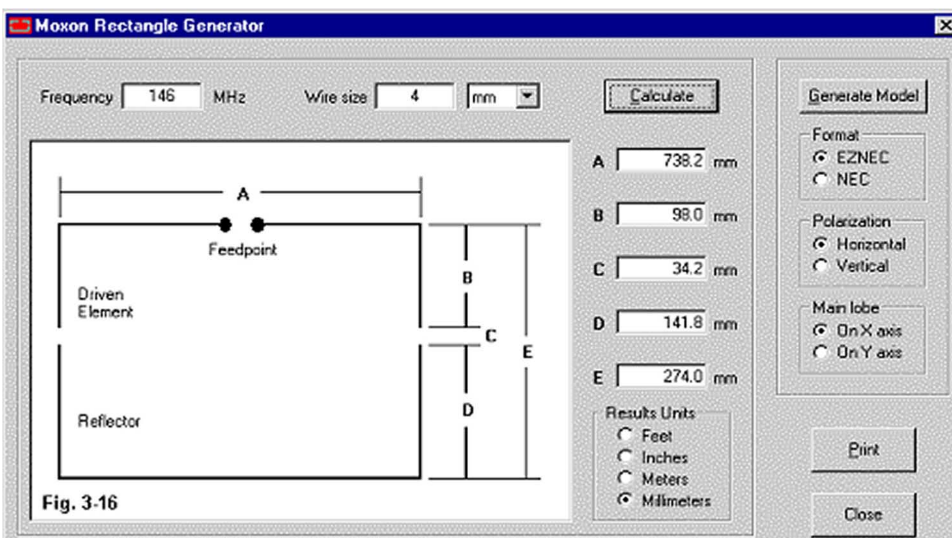
Fig. 3-14

The program uses the same regression algorithms to calculate Moxon dimensions A through E that I used in both the GW Baic utility and the NEC-Win Plus model. In fact, you may wish to compare the screen-grab of the AC6LA program in **Fig. 3-15** with the same 146-MHz, 0.125" element Moxon rectangle in **Fig. 3-11**. The dimensions—within decimal limits—are identical.

In the NEC-Win Plus model, we can simply change units for the model to develop metric rectangles. In the stand-alone program, the move is simply a matter of clicking either the “meters” or the “millimeters” option for the results and the appropriate input unit selection.

As an experiment, let’s note that 4-mm rod is a popular European antenna material for VHF and UHF arrays. So we may enter the value as our diameter and change the diameter unit to millimeters. Following that step. We may request the results in millimeters. The final result will be the dimensions shown in **Fig. 3-16**.





Like the NEC-Win Plus version of the calculation mechanism, we may enter wire sizes as AWG values. Since #12 copper wire antennas are common on 2 meters, let's convert our 0.125" elements into #12 elements (0.0808" diameter). **Fig 3-17** shows the results. Compare them with the values in **Fig. 3-15**. The overall front-to-back dimension and the reflector tail dimension have hardly changed. However, the #12 gap is significantly smaller and its corresponding driver tail is significantly longer, given that a tenth of an inch is significant at 2 meters.

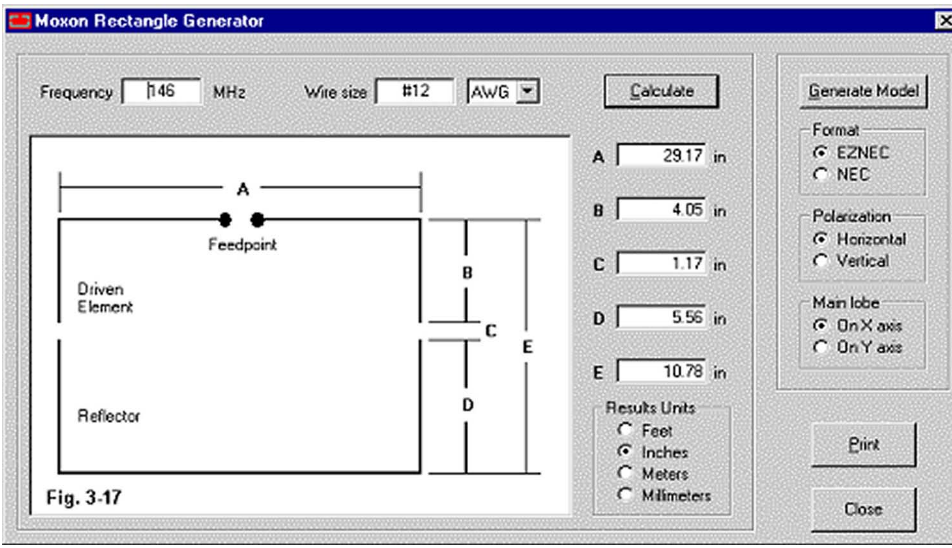


Fig. 3-17

The stand-alone program is especially useful for two sorts of builders. Those without access to an antenna-modeling program may use it with confidence. As well, modelers who use EZNEC may generate EZNEC models that point along either the X- or Y-axis and that are either horizontal or vertical. Users may also generate standard ASCII-based .NEC models for use in programs like NEC-Win Pro, GNEC, or independent developments around the public-domain NEC-2 core. As well, the program now allows either a comma or a dot as the decimal separator to conform to either European or U.S. conventions.

Conclusion

The goal of the exercise was to develop a series of equations that one might use to design Moxon rectangles for any reasonable frequency using any reasonable wire diameter. The equations make use of the common log of the wire diameter and the design frequency to determine the dimensions for the antenna, based upon a base-line data set of models optimized for maximum front-to-back ratio and about 50 Ohms feedpoint impedance at the design frequency. However, the equations apply only to uniform-diameter elements. The use of stepped-diameter elements would require optimization within NEC-4. Since the elements are not linear, the Leeson corrections built into some commercial implementations of NEC-2 will not operate. A version of MININEC might also be used if (for the public domain version) the elements are length-tapered toward the 4 corners of the array.

Regression analysis proves to be a very usable technique of developing working equations for the design exercise, although the equations themselves have no theoretical significance other than fitting curves to a data set within the limits of that set. The equations can be packaged in utility programs—such as the little exercise in Basic—or they can be applied directly to a NEC model within a program capable of modeling by equation, or they are amenable to a stand-alone program in Windows.

For those interested in modeling by equation, the model shown here is also available in .NWP format at the Nittany-Scientific web site, along with some other models using equations featured in the monthly "Antenna Modeling" column in *antenneX*. The URL is http://www.nittany-scientific.com. Updates for the AC6LA stand-alone Windows program are available from http://www.qsl.net/ac6la.

The quest for magic formulas for cutting antennas only futilely chases after super-simple equations using only a single constant and the operating frequency. Most antenna types answer better to collections of equations based on both wire size and operating frequency. Although the equations themselves may not be simple, one can put them into packages that are simple to use. However, easy generation of building dimensions is no substitute for understanding the fundamentals of how such antennas work.

* * *

Appended models and programs used in this chapter:
moxgen.bas, moxgen.nwp, moxgen.zip

4. Wire Moxon Rectangles

For the HF bands, especially the lower regions from 80 through 20 meters, radio amateurs have often improved performance by constructing fixed wire beams. Compared to aluminum tubing, wire is cheap. As well, fixed beams save the cost of a tower and rotator (plus allied cabling), since we can often use available trees, poles, and other structures to support them. Even on the upper HF bands from 15 through 10 meters, the budget-conscious ham often turns to a wire beam.

Wire beams and arrays have one significant limitation: we cannot rotate them. Therefore, we must resort to carefully planned aiming during installation. Still, we can only cover so much of the area across the country or the world with the beamwidth available from most wire arrays with gain. The dreamers will always wonder if they could have garnered a few more contacts lost to the deep front-to-side ratio offered by most 2-element Yagi designs.

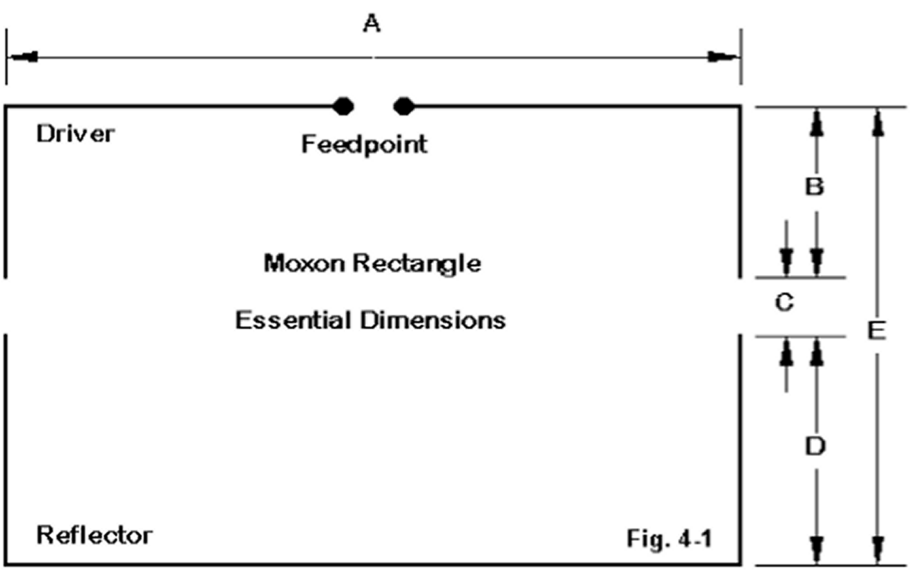


Fig. 4-1

Let's explore an alternative to the 2-element wire Yagi, one that is only about 70% as wide, side-to-side, and which offers some other benefits as well: the wire Moxon rectangle.

In its most fully developed monoband form, the Moxon rectangle looks in outline form like the sketch in **Fig. 4-1**. The dimensions are conventionally designated by the indicated letters. A is the side-to-side length of the parallel driver and reflector wires. B is the length of the driver tails, while D is the length of the reflector tails. C is the distance between the tips of the two sets of tails. If any dimension of the Moxon rectangle is critical, it is C. E, the total front-to-back length of the array, is simply the sum of B, C, and D. Although this figure is by now familiar to us, I repeat it here since most of the tables in this chapter will refer to it.

The Moxon rectangle has 3 properties that recommend it for applications calling for a wire beam. These applications include both home station installations and temporary field uses.

1. It is not as wide as an equivalent wire Yagi, due to the folding of the two elements toward each other.

2. It offers—with the right dimensions—a 50-Ohm feedpoint impedance so that we require no matching system (although a choke to suppress common mode currents is always desirable).

3. It presents a very useful pattern, with a wide beamwidth, good gain, and a very high front-to-back ratio.

Fig. 4-2 overlays the pattern for a typical 2-element Yagi (reflector-driver design) and the Moxon rectangle. The pattern may appear odd since it uses a linear dB scale (rather than the more usual log dB scale) to enhance the detail at the pattern center. Although the Yagi has slightly more gain, the Moxon's deficit will not be noticeable in operation. Most apparent is the front-to-back ratio advantage that accrues to the Moxon. In practical terms, the Moxon effectively squelches QRM to the rear. Of equal importance is the broader beamwidth of the Moxon. The azimuth pattern does not show deep nulls off the ends of the beam elements. Instead, the deep nulls are about 15 to 20 degrees further back. Signals off the beam sides may be 15 dB stronger than for a corresponding Yagi, even though the rear quadrants themselves will be that much quieter than the Yagi. The result is that the Moxon provides useful signal strength from one side to the other—as if it had good peripheral vision.

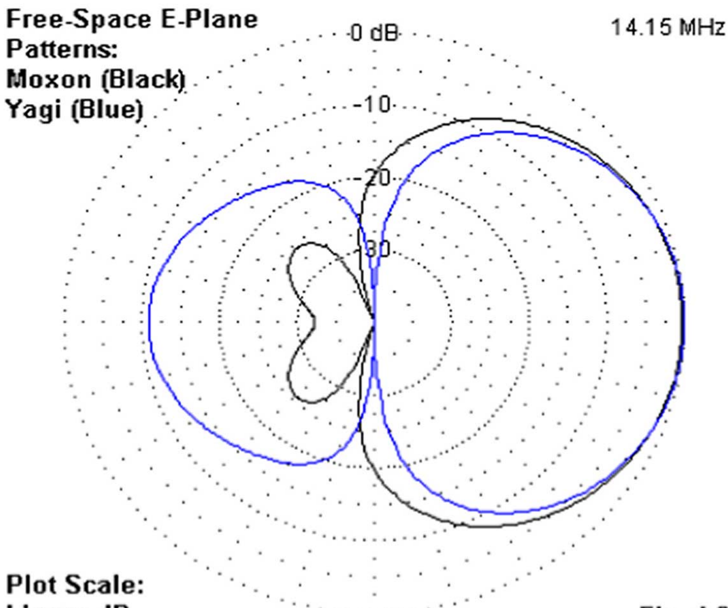


Fig. 4-2

Let's assume that we are participating in a portable operation, such as the annual Field Day exercise sponsored by the American Radio Relay League (ARRL). For a station located near one of the country's borders (or in Canada), a single Moxon rectangle aimed in the general direction of the greatest number of potential Field Day contacts will generally gather in signals from a broader sector of the horizon than most other antennas—with the bonus of good QRM suppression from the rear. For those stations located inland and needing coverage in all directions, we shall have a solution a bit further on. But first, let's design a Moxon rectangle.

Designing a Moxon Rectangle

The objectives in designing a Moxon rectangle are to produce a set of dimensions for the wire diameter to be used that will yield the maximum front-to-back ratio, maximum gain, and 50-Ohm feedpoint impedance at the design frequency that we choose. For this exercise, I have chosen #14 bare copper wire as perhaps the most popular Field Day antenna material. I have also aligned the maximum front-to-back and 50-Ohm resonant feedpoint frequencies. Gain will vary across the band, as it does with any 2-element parasitic array.

Dimensions of Wire Moxon Rectangles for 80-10 Meters

All dimensions refer to designations in **Fig. 4-1.** They are in feet and apply to #14 AWG bare wire antennas.

Band	Frequency	A	B	C	D	E
80	3.6 MHz	99.98	15.47	2.16	18.33	36.96
75	3.9	92.28	14.28	2.00	16.92	33.20
40	7.10	50.62	7.81	1.15	9.33	18.29
30	10.125	35.46	5.45	0.84	6.56	12.85
20	14.15	25.35	3.88	0.63	4.70	9.21
17	18.118	19.79	3.01	0.51	3.68	7.20
15	21.20	16.90	2.56	0.44	3.15	6.15
12	24.94	14.36	2.17	0.39	2.68	5.24
10	28.3	12.65	1.90	0.35	2.36	4.61

Due to bandwidth vs. wire size considerations, 40-, 20-, 15- and 10-meter design frequencies are below the mid-band points to obtain less than 2:1 50-Ohm SWR over as much of the band as possible. See the text for alternative strategies.

Table 4-1. Dimensions of wire Moxon Rectangles for 80-10 meters.

With these design criteria, **Table 4-1**, includes the dimensions of Moxon rectangles for 80, 75, 40, 20, 15, and 10 meters—all potential Field Day bands of operation. The design frequencies are listed with the band of operation. Because 40 and 10 meters are wide bands relative to the wire size used, I have moved their design frequencies below the mid-band point in order to obtain low-end coverage at under a 2:1 SWR ratio. Should you wish to use other wire sizes (including center-supported versions made from aluminum tubing in diameters up to well over an inch in diameter), Chapter 3 discusses programs that will ease the design work. The output will be accurate to within under 0.5% relative to the NEC-4 models used to derive the algorithms.

The Moxon rectangle functions by virtue of both the mutual coupling between parallel element segments and the coupling between the facing element tips. Hence, the "gap" between element tips (dimension C in **Fig. 4-1**) is the most critical dimension. Measure the gap accurately and ensure that the spacing does not change over time. The other dimensions follow from setting the gap in order to obtain the desired performance characteristics.

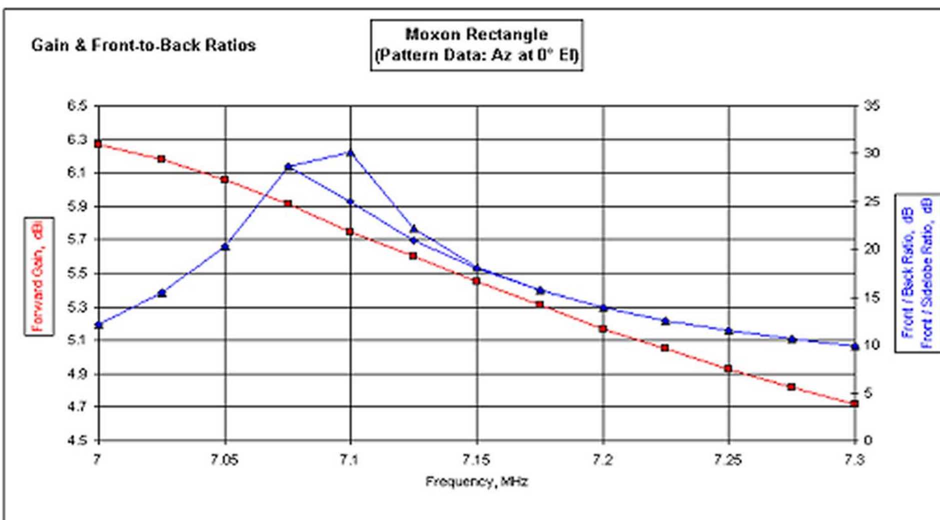


Fig. 4-3

Fig. 4-3 shows the gain and front-to-back curves for a 40-meter version of the #14-wire Moxon rectangle, designed for 7.1 MHz. I chose 40 meters because it is a tricky band to cover with a wire beam. Although the band is only 300 kHz in the U.S. allocation, the #14 wire we are using for the elements is a very tiny fraction of a wavelength. The thinner the wire, the narrower the operating bandwidth: hence, the effective size of the band relative to common antenna materials is greater than the kiloHertz count. We need to be very careful in our designs and in our field adjustments of any 40-meter array.

Note that the gain curve is nearly linear across the band. The free-space forward gain ranges from a high of 6.27 dBi at 7.0 MHz to a low of 4.72 dBi at 7.3 MHz. These values are slightly lower than we might obtain at 10 meters using 1" diameter elements. The 180-degree front-to-back ratio peaks near the design frequency and tapers off—more rapidly below the design frequency than above it. The worst-case front-to-back ratio peaks slightly below the 180-degree peak, but the two curves are coincident except in the region where the ratio is the highest.

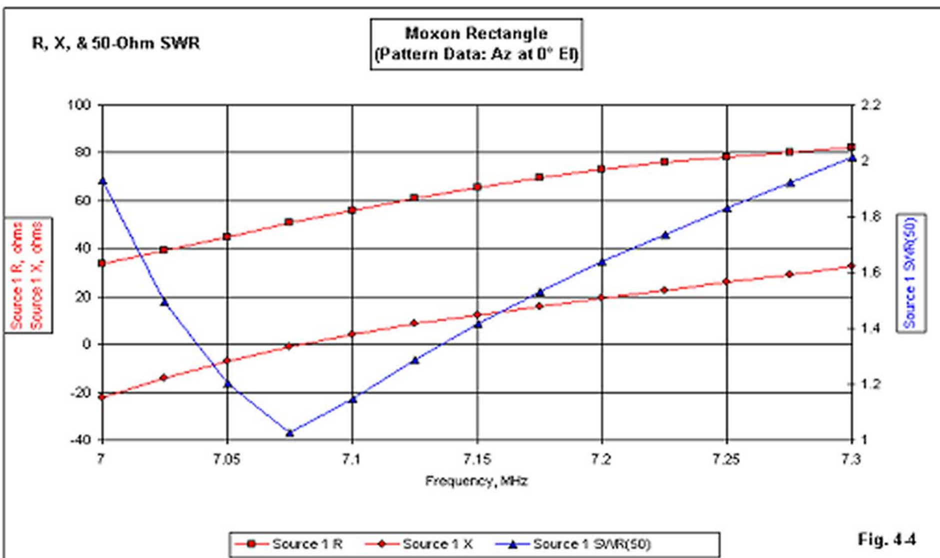
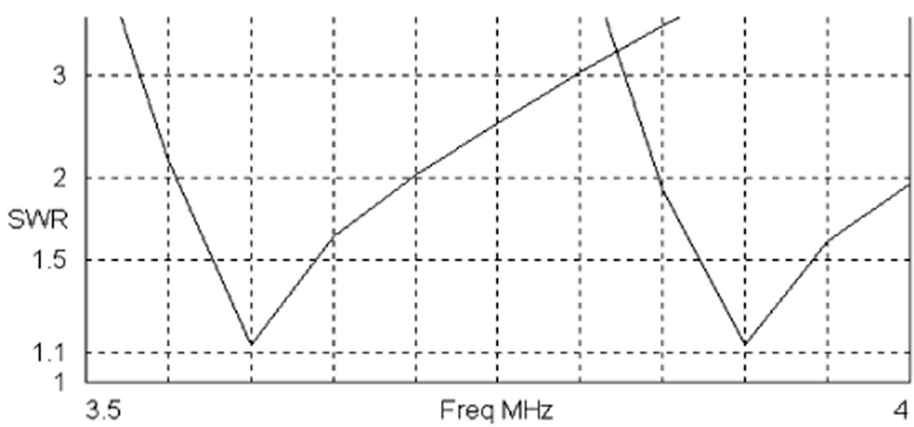


Fig. 4-4

Fig. 4-4 shows a similar curve for the 50-Ohm VSWR, with the rate of increase more rapid below the design frequency than above it. The feedpoint resistance ranges from 34 to 82 Ohms, a wider spread than with our early 10-meter fat-element design in an earlier chapter. Indeed, the thin wire is not the sole source of this range. At resonance, a perfect or lossless wire would show a resistance of 53 Ohms. However, even with the high conductivity of copper, the use of thin wire relative to a wavelength raises the feedpoint resistance by 3 Ohms—or nearly 6%. The feedpoint reactance varies from -22 to +33 Ohms. Hence, the 50-Ohm SWR curve barely meets the 2:1 limit that we ordinarily use as a stand for antennas fed with coaxial cables.

If we move the Moxon down to the 80-75-meter region, our #14 wire becomes half as thin—relative to a wavelength—as it was at 40 meters. Consequently, we should expect a further narrowing of the operating bandwidth. **Fig. 4-5** overlays modeled SWR curves for the 80-meter and the 75-meter versions of the antenna. The curves demonstrate that not even a pair of Moxon rectangles is adequate to cover the 500 kHz of this lowest HF ham band. Additionally, these Moxon designs that are optimized for a 50-Ohm feed system do not nest well. Hence, if one wishes to cover all of 80 and 75 meters with a single array (or array of arrays), the Moxon rectangle may not be the best choice. However, for covering a specific segment of the band, the antenna will provide wider bandwidths than many other options in 2-element design.

Fig. 4-5 50-Ohm SWR Curves for AWG #14 Copper Wire Moxon Rectangles for 3.6 MHz and 3.9 MHz



Customizing a Moxon Rectangle Design

There is no absolute need to align the maximum front-to-back frequency with the resonant 50-Ohm feedpoint. We can move one or both of them by small adjustments in the antenna dimensions. (Large moves will benefit by a new starting recalculation from one of the programs listed in the preceding chapter.) To sample the rates of change in performance parameters relative to small changes in dimensions, I altered some dimensions of a 20-meter version of the antenna by 1 inch. (1" at 20 meters is, of course, approximately equivalent to changes of 4" on 80, 2" on 40, and a half-inch on 10 meters.) In all cases, the gap (dimension C) is held constant.

1. Decreasing or increasing the side-to-side dimension (A in **Fig. 4-1**), raises or lowers both the maximum front-to-back and the resonant feedpoint frequencies by about 40 kHz on 20 meters. For small changes in dimension A, the resonant feedpoint impedance does not change.

2. Increasing or decreasing only the length of the driver tails (dimension B) by 1" lowers or raises the resonant frequency of the driver by about 70 kHz on 20 meters. The new resonant feedpoint impedance will be a few Ohms lower (for an increase in driver length) than before the change. The frequency of maximum front-to-back ratio will not change significantly.

3. Increasing or decreasing only the length of the reflector tails (dimension D) by 1" lowers or raises the peak front-to-back ratio frequency by about 70 kHz on 20 meters. The driver's resonant frequency will not significantly change, but the impedance will be higher (for an increase in reflector length) than before the change.

With these guidelines, you can tailor a basic Moxon rectangle design to suit what you decide is best for your operation.

Antenna Height Above Ground

One of the realities of a wire array is that you will not operate your antenna in free space. The actual antenna heights over real ground may range from 1/4 wavelength to over a wavelength up, depending on the band and the available supports. To sample the operation of the Moxon rectangle at various heights, I modeled a 40-

meter version of the antenna at various heights, listed in **Table 4-2** in terms of fractions of a wavelength. The performance of versions for other bands will not materially differ for equivalent heights.

Note that as the antenna height increases, the "take-off" angle (or the elevation angle of maximum radiation) decreases, as do the vertical and horizontal beamwidths between half-power points. These properties are in line with those of any horizontally polarized array. Hence, the gain increases slightly with increases in height. **Fig. 4-6** overlays the azimuth patterns for all of the heights in the table to demonstrate the small differences among them. Moreover, the feedpoint impedance of the antenna undergoes only small changes with changes in heights. Indeed, the excellent front-to-back performance at the low height of 1/4 wavelength holds promise for 40-meter and lower frequency installations. The semi-closed design configuration of the Moxon rectangle tends to yield fewer interactions with surrounding structures than antennas with linear elements, an added advantage for installations using a low height. The upshot of this exercise is that a Moxon rectangle falls in the class of

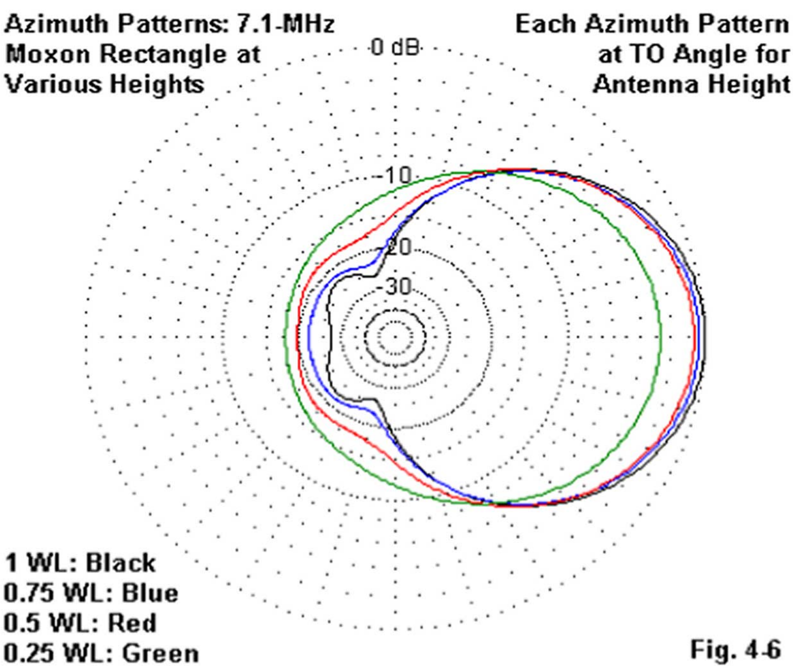


Fig. 4-6

"well-behaved" antennas, requiring no finicky field adjustments once the basic design is set and tested.

Relative Performance of a Wire Moxon Rectangle at Different Heights Above Ground

Height wavelengths	TO angle degrees	Gain dBi	F-B Ratio dB	VBW deg.	HBW deg.	Feedpoint Z R+/-jX Ohms
Free-space	—	5.8	30.2	—	78	56 + j 4
0.25	44	8.6	15.1	61	96	47 + j 8
0.5	27	10.7	19.2	31	83	63 + j 5
0.75	18	11.0	21.6	20	79	52 + j 4
1.0	14	11.3	27.2	15	78	59 + j 4

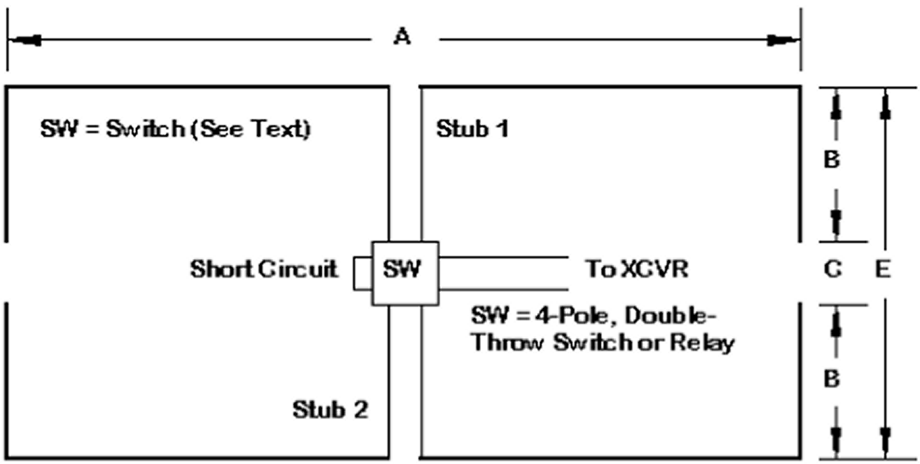
Modeled antenna is a 40-meter #14 AWG wire Moxon rectangle at 7.1 MHz. TO ("take-off") angle refers to the elevation angle of maximum radiation. The 180-degree front-to-back ratio is used in this table. Vertical bandwidth (VBW) and horizontal bandwidth (HBW) refer to the beamwidth between points at which power is down -3 dB relative to the maximum power. The feedpoint impedance (Z) is given in conventional "resistance +/- reactance" terms. See **Fig. 4-6** for comparative azimuth patterns.

Table 4-2. Relative performance of a wire Moxon Rectangle at different heights above ground.

Bi-Directional Moxon Rectangles

If you live somewhere within the vast central region of the country, you may be interested in signals from both sides of the Moxon rectangle. If you live on either the east or west coasts, you may be interested in foreign as well as domestic communications The antenna can accommodate you with fair ease. Following the design lead of Carrol Allen, AA2NN, we can design the Moxon rectangle for bi-directional use. (See Carrol Allen, AA2NN, "Two-Element 40-Meter Switched Beam," *The ARRL Antenna Compendium*, Vol. 6 (ARRL, 1999), pp. 23-25. Note especially Carrol's improved method of stub construction.) **Fig. 4-7** shows the outline. Essentially, we create two resonant drivers using the same dimensions as for the basic antenna.

Then we load the one we select as the reflector so that it becomes electrically long enough to perform as a reflector. Our technique of loading will be a length of shorted 50-Ohm cable. By bringing equal length stubs to a central point, we can switch them. The one we short becomes part of the reflector. The other one is connected to the main feedline and simply becomes part of the overall system coax.



Bi-Directional Moxon Rectangle

Fig. 4-7

One switching caution: use a 4-pole double throw switch so that you switch both the center conductor and the braid of the coax lines used as stubs. When in use as a shorted stub, the line should not be electrically connected to the main feedline at all. **Fig. 4-8** shows some of the details of a typical switching scheme. A plastic box to insulate the coax fittings from each other makes a good switch mount. Permanent installations using remotely controlled relays, of course, will have to pay careful attention to weather-proofing the components.

Table 4-3 lists the suggested dimensions for bi-directional Moxon rectangles for 80 through 10 meters. Because we are using 2 drivers, with their shorter tails, the overall front-to-back dimension (E) of the antenna is smaller than for one-way versions. The shorter front-to-back dimensions lower the feedpoint impedance by 5 to 7 Ohms into the mid-40s, still a very good match for a coax feedline.

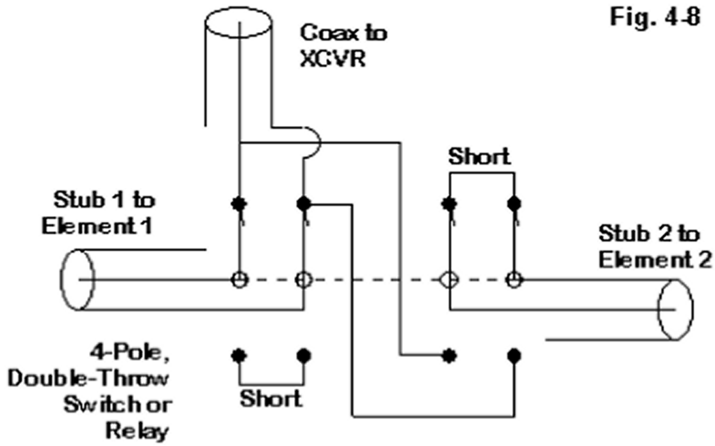


Fig. 4-8

Bi-Directional Moxon Rectangle Switching

The table also lists 2 stub lengths. The shorter one is the basic length of a shorted 50-Ohm stub to achieve the required reflector loading. All of the designs required just about 65 Ohms inductive reactance to electrically lengthen the reflector so that the maximum front-to-back frequency aligns with the driver resonant point. Hence, the basic stub length for the shorted stub will be about 52.4 electrical degrees. Since you have a choice between cables with solid and foam dielectric materials, you must multiply the listed length by the actual velocity factor of your stub cable. In general, solid dielectric 50-Ohm cables tend to have velocity factors of 0.66 to 0.67, while foam cables tend toward a velocity factor of about 0.78. However, I have found significant departures from the listed values, so measuring the velocity factor of your line is a good practice. Otherwise, expect to cut and try lengths until you hit the right one.

Dimensions of Bi-Directional Wire Moxon Rectangles for 80-10 meters

All dimensions refer to designations in **Fig. 4-7**. They are in feet and apply to #14 AWG bare wire antennas.

Band	Freq.	A	B	C	E	Stub Simple	+.5 WL
80	3.6 MHz	99.98	15.47	2.16	33.10	39.78	176.39
75	3.9	92.27	14.28	2.00	30.56	36.72	162.82
40	7.10	50.62	7.81	1.15	16.77	20.17	89.44
30	10.125	35.46	5.45	0.84	11.74	14.14	63.34
20	14.15	25.35	3.88	0.63	8.39	10.12	44.88
17	18.118	19.79	3.01	0.51	6.53	7.90	35.05
15	21.20	16.90	2.56	0.44	5.56	6.76	29.95
12	24.94	14.36	2.17	0.39	4.73	5.74	25.46
10	28.3	12.65	1.90	0.35	4.15	5.06	22.44

Stub lengths are based on an inductively reactive load of 65 Ohms for the reflector element at the design frequency. Listed stub lengths are for 50-Ohm cable with a 1.0 velocity factor. Multiply listed lengths times the actual velocity factor of the line to obtain the final length.

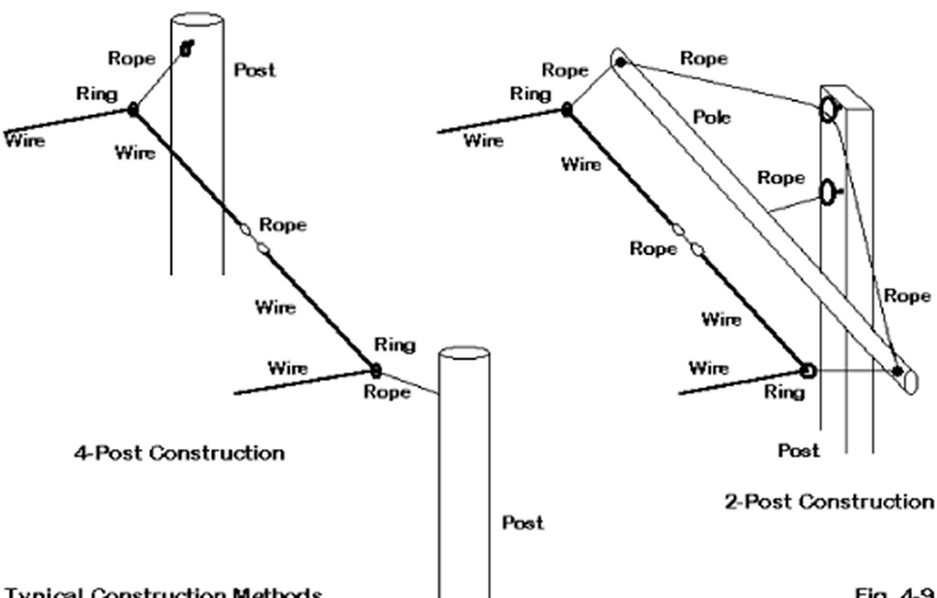
Table 4-3. Dimensions of bi-directional wire Moxon Rectangles for 80-10 meters.

Since the shorter length of the stub for some bands may leave them hanging high in the air, I have also listed the lengths of stubs that add a half wavelength of line to them. The loading effect will be the same as for the shorter stub, but the lines may now reach a more convenient level for switching, especially in field conditions. It is wise to keep the lines suspended in the air, with the switch box hanging from a tree limb or tied to a post or stump. Again, multiply the listed values of longer lines by the velocity factor of the line you are actually using. Finally, be aware that coax stubs are not lossless and thus may slightly alter the performance of the array relative to the perfect lines used in models. In most cases, the differences will not be noticeable in practice.

The principles of reflector loading apply not only to Moxon rectangles, but as well to wire Yagis, deltas, quads, and a host of other 2-element parasitic arrays. With good preplanning, they yield simple enough antennas to be manageable in the field. At the same time, the operator gains the benefits of a directional pattern that may nearly double one's score. In non-scoring terms, a bi-directional array means more effective communication under almost all conditions.

Construction of a Moxon Rectangle

Despite their simplicity and low cost, wire beams can be ungainly. Hence, you should survey the installation site in advance. For field operations, if possible, practice raising and lowering the antennas. For the Moxon rectangle, we shall need to look for or plan for suitable supports to stretch the antenna at its corners. Of course, the higher the support, the better. Since the Moxon rectangle is only about 70% the side-to-side width of a comparable 2-element Yagi, its space requirements are relatively modest, allowing the site designer somewhat greater flexibility.



Typical Construction Methods Fig. 4-9

Fig. 4-9 outlines two types of systems for supporting the Moxon rectangle. Consider them to be only the barest starting point for a real system. The 4-post system at the left is suitable for any band. The posts can be trees, guyed masts, or building corners. The rope terminating at the post can be tied off there, if the "ring" point is accessible. Or, we can run the rope over a limb or through an eye-bolt so that we can easily raise and lower the corner.

The ring at the end of the corner rope through which the wire passes can be a simple loop in the rope or even a plastic bottle-neck used to reduce mutual abrasion of the wire and rope. Since the shape of the Moxon rectangle is important, the corner bends should be locked. A short piece of wire that runs from main wire to tail, but which goes around the corner ring, can effectively keep the corner in place. A permanent installation might solder the ends of the locking wire to the antenna elements, but a short-term field installation can usually do well with just a few twists of the locking wire on the element.

The 2-post construction method is more apt to the upper HF bands. It uses a long pole, PVC tube, or similar non-metallic structure to anchor the corner ropes. The corner rope can be terminated at the pole or passed through it and run to the post. The sketch shows a 2-anchor mounting for the pole. The upper support ropes aligns the pole horizontally. Thus, the rope should be locked to the ring or other support to keep everything horizontal. Alternatively, we can brace the pole directly to the support post, tree, or mast so that it remains horizontal. The remaining attachment mechanisms are the same as for the 4-post method of support.

The rope that separates the driver and reflector tails should not stretch. Its job is to maintain the tail gap spacing as securely as possible. In addition, since the degree of coupling between tails is a function of the wire diameter, the wire foldback to make an attachment loop in the element tails should be as tight and flat as possible without weakening the antenna wire. For added strain relief and dimensional precision for upper HF versions of the Moxon rectangle, it is possible to place the non-metallic pole at or inside the perimeter of the antenna. With some judicious use of electrical tape where the elements end along the pole, you can omit the tail-to-tail rope altogether. For larger, lower HF band version of the antenna, you can use a rope that runs from each front ring to the corresponding rear ring and tape the driver and reflector tails wires to it.

For the upper HF regions, we can use some variation of the system shown initially in Chapter 1 and repeated in outline form in **Fig. 4-10**. A plate at a central hub for the mast supports 4 to 6 non-conductive arms. If we add 1/8" diameter rope trusses from a mast extension to positions about 2/3 of the way out the corner arms, we can use some of the thinner-wall version of PVC as the arm material. Any non-conductive arm material should be resistant to ultra-violet radiation. Common PVC materials may vary from one part of the country (or world) to another in their UV-resistance.

General Construction Outline: Upper HF Wire Moxon Rectangle

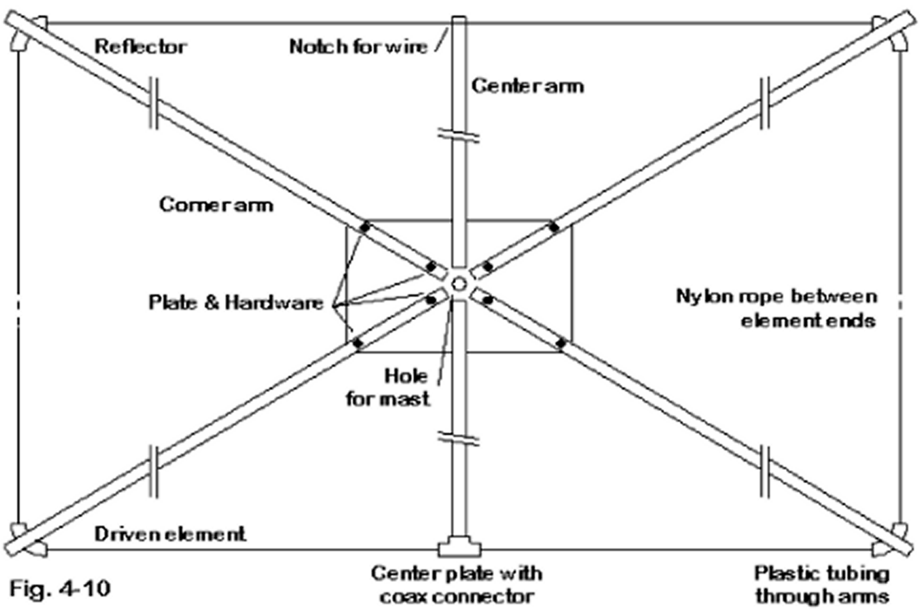


Fig. 4-10

The wires pass through the ends of the support arms, with some form of abrasion reduction. The feedpoint position, gap, and connector fastening is largely a matter of using the best local materials that match one's building skills. A rope makes a good material to maintain the gap between tails and to keep them aligned. Tying the rope to the front-and back corners of the arm assembly let's you simply tape the tails to the line rather than forming loops and thereby altering the coupling between tail ends.

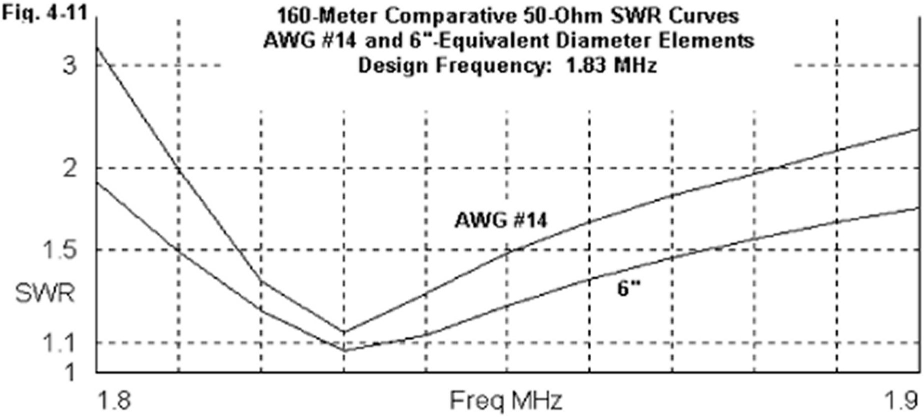
For field use, light-weight coax line is often useful to reduce the stress on the driven element(s) at the feedpoint. RG-8X is often a very useful field line for 50-Ohm applications. However, where conditions permit, support of the element centers is advisable. In fact, slightly Vee-ing the elements will normally produce no adverse affects in performance. However, if you contemplate a shallow inverted-Vee form of the antenna, pre-test the assembly to assure that everything will work as planned.

Wire array construction is a primary exercise in adapting easily obtainable materials to particular site configurations. Hence, it is not possible to provide universal guidance for every situation. However, these notes should get you started. Do not forget to survey your local home center for possible fixtures and non-metallic connectors that may prove useful for a wire array. You may find them anywhere in the store. The plumbing and electrical departments are good starting places to find adaptable PVC fittings.

We have not included 160-meters in this survey of wire Moxons for 2 reasons. First, #14 AWG wire is not mechanically suitable for that band, given the length of the elements. Even #14 copperweld is marginal. Second, the wire is too thin to provide adequate operating bandwidth.

Fig. 4-11 compares the 50-Ohm SWR curves for #14 and a 6-inch-equivalent element. With a design frequency of 1.83 MHz, the thin-wire version of the array covers only a small portion of the first 100 kHz of the band. The fat-wire version covers the band segment with ease. The differences in the SWR curves also indicate differentials in the front-to-back curves and in the rate of change of forward gain across the operating passband. Unless one has a need to operate only within a narrow window, one must plan on developing cage-wire elements having an effective diameter of 4" or more. A cage of 4 AWG #8 wires with about 8" on each side is roughly equivalent to a solid 6" element, although wire losses will be slightly higher. A 6-wire cage slightly larger in diameter than 6" will approximate the 6" solid wire used in the model, if the individual wires are large enough (AWG #8 or #10). However, every extra wire in a cage adds very considerably to the overall element weight.

Fig. 4-11



As the following short table shows, the differential in wire size makes a big difference in the required Moxon dimensions.

Dimensions of Wire Moxon Rectangles for 160 Meters

All letters refer to designations in **Fig. 4-1** with 1.83 MHz as the design frequency.

Diameter	A	B	C	D	E
AWG #14 (0.0641")	196.87	30.37	4.21	35.90	70.48
6" (or equivalent)	194.02	27.04	7.68	36.95	71.67

Table 4-4. Some 160-meter Moxon rectangle dimensions.

Perhaps the biggest challenge may lie in setting the gap. Most cages come to a point at their end junction. This structure may require experimentation to find the best gap separation for optimal tail-end coupling.

We have not finished the subject of wire Moxons, but instead have only begun it. We shall return to some wire cousins of these arrays in Chapter 8. However, we should spend a little time with aluminum tubing for the upper HF region. Some folks will wish to rotate a Moxon rectangle.

* * *

Much of the material in this chapter originally appeared in “Having a Field Day with the Moxon Rectangle,” *QST*, June, 2000, pp. 38-42. I am indebted to the ARRL, 225 Main Street, Newington, CT 06111, for permission to use this material.

* * *

Appended models used in this chapter:
mox160-14.ez, mox80-14.ez, mox40-14, mox30-14.ez, mox20-14.ez, mox17-14.ez, mox15-14.ez, mox12-14,ez, mox10-14.ez, mox160-6.ez

5. Rotatable Moxon Rectangles

The use of aluminum tubing for Moxon rectangles offers the potential for an easily rotated array with modest dimensions compared to 2-element reflector-driver Yagis. Hence, the antenna is suitable for the small yard or rooftop. It may also be a good field beam, since it may be light enough for hand-rotation.

Still, we have a few questions to pose:

1. How do we build an antenna with corners?

2. How do we design an antenna with corners using modeling software?

3. Is there any mechanical difference between a permanent and a field version of an aluminum Moxon rectangle.

To give definitive answers to these questions would require a survey of almost every beam builder alive. In this chapter, we shall only suggest some directions of effort, using two main examples. The first will be a 10-meter Moxon for permanent installation. The second will be a 20-meter Moxon for field use. The similarities and the differences between the two arrays will at least alert the prospective builder to the special parts of a rectangle that require a bit of extra care. But in the end, the building challenge does not differ much from what a comparable Yagi requires. The key differences will lie in the corners and the alignment of the element tails.

An Aluminum Moxon Rectangle for 10-Meters

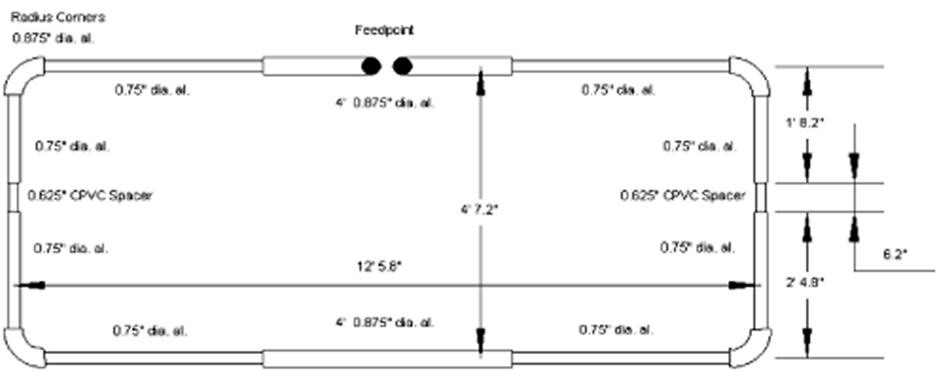
I occasionally receive inquiries from folks who cannot quite support the width of a 10-meter Yagi (either 2 or 3 elements) because obstructions give them less than the necessary 16.5' side-to-side space. Is there an antenna with decent performance that will fit in a space about 12-13' wide? If it can be home built to save money and require no complex tuning or matching system, so much the better.

In fact, there is an antenna that fits this category almost perfectly. Imagine an antenna with the gain (over real ground) of a 2-element Yagi (11+ dBi), nearly the front-to-back ratio of a 3-element Yagi (>20 dB from 28.3 to 28.5 MHz), and an SWR of below 2:1 from one end of 10 to the other. Also imagine that the antenna has better than 15 dB front-to-back ratio all the way down to 28 MHz and still has about 12 dB front-to-back ratio at 29.7 MHz.

Imagine also that the antenna can be directly connected to 50-ohm coax with no matching system whatsoever (even though I always recommend a 1:1 choke or bead balun). Now imagine that you can make it yourself from hardware store materials, that it will weigh about 10 pounds including the boom (under 5 pounds without the boom), and that you can make it in your garage with no special tools. Finally, imagine that when it is done, you will still have change from a $50 bill.

The antenna is the Moxon rectangle. Les Moxon, G6XN, derived the original design from VK2ABQ squares. He tunes both elements of his wire version to form a 2-way fixed-mount beam. However, we can optimize the dimensions to form an aluminum beam that is easy to rotate.

Fig. 5-1 shows a sketch, with fairly complete dimensions, of the version of the antenna that appeared in *The ARRL Antenna Compendium*, Vol. 6, pp. 10-13. (I am grateful to the American Radio Relay League for granting permission to use material from this article in the present chapter.) It uses hardware depot 7/8" and 3/4" diameter aluminum tubing to form the main elements, with 3/4" tubing for the side elements. The corners can use radius-bent tubing or be squared by making some



General Outline: 10-Meter Aluminum Moxon Rectangle

Notes: 1. CPVC = 1/2" nominal

2. Boom and boom-plates at builder's discretion

Fig. 5.1

corner supports from L-stock. Cut the straight tubing at 45-degree end angles and use 1/16" thick L-stick to fashion over and under supports. About 1-2" lengths of support each way around the corner, using stainless steel sheet metal screws or pop rivets, will solidify the corners with minimal weight. I even tried 1/2 inside conduit Ls, but had to ream out the ends to accept the 3/4" tubing.

Let's pause a moment to think about the dimensions. I modeled the antenna design on NEC-4, using the actual planned element diameters. NEC-2 tends to begin to go astray with stepped diameter elements, even if we use only two closely related sizes. If we wish to calculate the dimensions using one of the programs or models appended to this volume, we shall not arrive at exactly the same dimensions. Let's split the difference between 7/8" and 3/4" tubing and calculate for 0.8125" diameter elements for 28.4 MHz, the design frequency.

Version	A	B	C	D	E
Fig. 5-1	149.8"	20.2"	6.2"	28.8"	55.2"
Calculated	149.4"	19.8"	6.9"	28.7	55.5"

The differences are actually rather slight. The reflector tails (D) and the overall width (E) are very close. The slightly smaller gap (C) results partly from the use of 0.75" tubing rather than the 0.8125" tubing specified for calculations. The driver (both A and B) is actually within 0.3% wavelength of the calculated value. The bottom line is not to convert precision into a fetish for differences that do not make a difference. The most critical dimension remains the gap between element tails.

The corners I used were 7/8 aluminum radius-bent sections. You can bend your own by filling the aluminum tube with sand (or cat litter in a pinch) and bending around a 6" or larger wheel or pulley. Work slowly. Keep the sand well packed in the tube to prevent pinch bends. Alternatively, you may discover usable pre-bent aluminum tubing almost anywhere. Versions of the array have used corners from the legs of aluminum lawn chairs headed for the scrap pile.

The combination of 7/8" and 3/4" aluminum tubing lets you telescope the ends into the center for a precise fit or a center frequency adjustment. A similar advantage accrues from using 1" and 7/8" hardware store aluminum tubing.

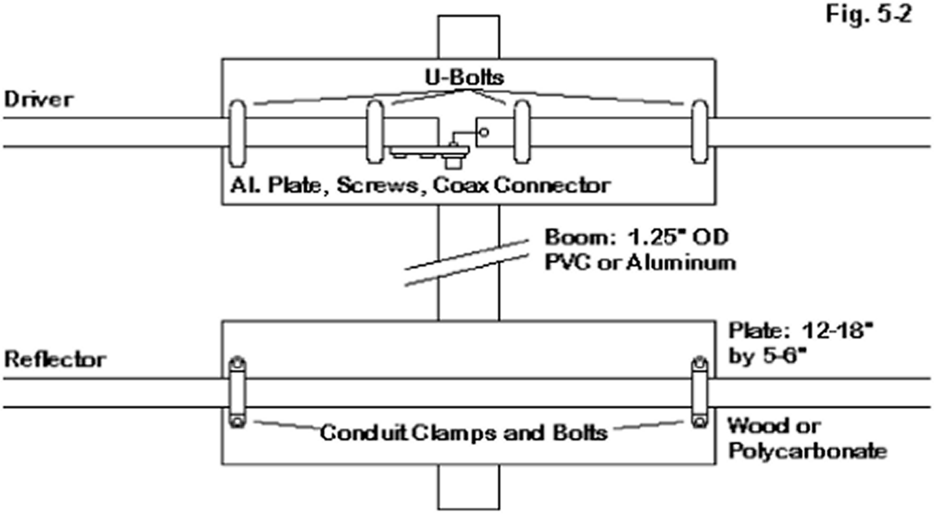
The side-to-side length is the key to centering the SWR curve for lowest reading at about 28.4 to 28.5 MHz. The center frequency changes about 150 kHz for every 2" of length adjustment. Hence, using the U-shaped outer ends as trombone slides will let you center the antenna anywhere in the 10-meter band. If you use slightly larger stock, say 1" and 7/8" hardware store aluminum tubing, performance will change very little. With 7/8" tubing for the outer main elements and the sides, you can weld or otherwise fasten (with Penetrox or another bi-metal conductor/protector between metals) 3/4" copper plumbing pipe Ls as the corners.

Since the end spacing and alignment is somewhat critical to the antenna's full performance, you can slide a piece of CPVC or similar lightweight, durable tubing either inside the ends or over the ends and lock them in place with sheet metal screws. The rigid spacer is also a good idea to limit the twisting force placed on the curved or right-angle corners. Sheet metal screws also connect the 3/4" and 7/8" tubing together. Be sure that all hardware screws are stainless steel. "Pop" rivets will also do well, if you use the sturdiest kind.

Simplified details of the element-to-boom mounting system appear in **Fig. 5-2**. The sketch shows two methods of holding elements to the plates: standard small U-bolts and PVC electrical conduit clamps and #8 stainless steel hardware. Either system will work. As well, the plates can be either treated and sealed plywood or polycarbonate. You may also trim the corners at shallow angles from the boom to the element, so long as you do not significantly weaken the plate.

The feedpoint assembly uses a very simple system. I cut one side of the driven element tubing 1" short at the feedpoint. I then cut a 2" section of 1/16" thick L-stock (shown in **Fig. 5-2** as a simple plate for ease of reading the figure), and cut a 5/8" diameter hole at one end. A chassis-mounting female coax connector (with a lock washer) fits into the hole, with the plug-side pointed at the mast. Stainless steel sheet metal screws attach the "extra-inch" side of the L-stock to the cut-off tube. A #14 copper wire (tinned the entire length) goes from the center pin to the other side of the feedpoint, where it is fastened under another sheet metal screw. You can devise your own more durable set of feedpoint connections. After testing, but before committing the antenna to permanent installation, be sure to waterproof the rear of the coax connector as well as the coax plugs.

Fig. 5-2



Simplified Mounting Dertails With 2 Forms of Element-to-Plate Hardware

My test model used 1/2" PVC electrical conduit U-straps fastened in place with #8 stainless steel hardware. Since 7/8" tubing stresses these straps a bit too much, I placed an extra washer between the U-strap and the plywood plate. The object is a very firm grip, but not a broken strap. Two straps hold the reflector center tube in place, but the driven element requires two on each side of the feedpoint. You may reduce the number of driver element clamps to 2 if you place a short length of fiberglass rod or tube inside the aluminum tubes at the feedpoint. The fiberglass tube should be as long as the plates. The feedpoint hardware will hold the fiberglass in place, although you may have to slightly redesign the position of the coax connector to move it above the fiberglass separator.

As with all good antenna structures, let the elements hang under the boom. What boom? Well, almost anything, from 1-1/4" nominal diameter PVC (which I had on hand) to a good grade of aluminum tubing (thicker-wall than the usual 0.55" hardware store variety—or two pieces nested) to a 5' length of spar varnished 1.25" diameter closet rod. Make up a boom-to-mast plate similar to the boom-to-element plates, only a bit more square, and you are in business. PVC is the heaviest; aluminum the lightest, but at a 5' length, the boom weight is not a significant issue.

The dimensions of the antenna in the drawing are too fussy, being direct translations of the computer model used to generate the antenna. Just try to keep the dimensions within about 1/4" of the drawing, and no one will be able to tell any difference in performance. Squaring the corners or missing the dimensions by a half inch will shift the performance centers by about 100 kHz at most. In most cases, you will not be aware of any difference at all. To assure that the assembly is neatly squared and close to the prescribed dimensions, you can draw the outer dimensions and centerline on the shop/garage/basement floor with a marker pen and then assemble the pieces within those boundaries. As shop experts always say, measure twice, cut and assemble once.

Note that the antenna is just about 12'-6" wide and under 5' front-to-back, for a turning radius of about 6'-8" or so. Strapped up on the side of the house, the antenna is unlikely to overhang the neighbor's yard line. The antenna is light enough for hand rotating, but an old TV rotator might come in handy. Because of the antenna's characteristics, you may not need to rotate it much.

A Performance Review

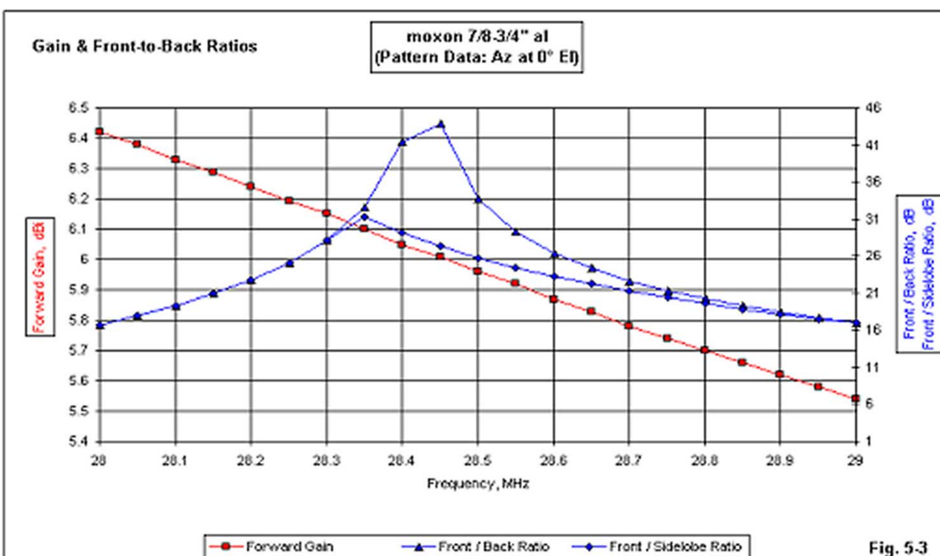


Fig. 5-3

In lieu of free-space azimuth patterns, we can review the basic performance of the antenna across the first MHz of 10 meters by way of graph (**Fig. 5-3**).

As with all Moxons, the free-space gain decreases with rising frequency, ranging from 6.4 down to 5.5 dBi. The 180-degree front-to-back ratio peaks at 28.45 MHz, but the worst-case front-to-back ratio peaks at 28.35 MHz. The peaks bracket the design frequency. However, note that the front-to-back ratio is about the same at the band edges—close to 16 dB.

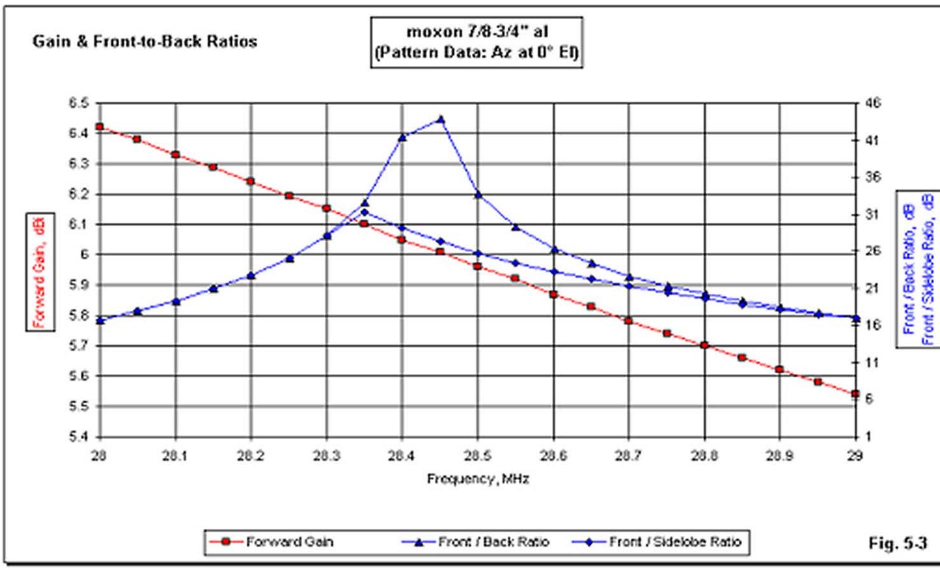


Fig. 5-3

The 50-Ohm SWR curve is not quite as equal at the band edges, with the low end of the band showing just above 1.5:1. The resistance varies from 38 to 67 Ohms across the band, while the reactance changes from -15 Ohms to +11 Ohms in the same range. In short, as **Fig. 5-4** shows, the antenna is very well behaved.

But what about performance at real heights above ground?

Even at a mere 20' up, a typical portable antenna height at 10 meters, the antenna continues to display excellent front-to-back characteristics with the gain of a typical driver-reflector 2-element Yagi, and the front-to-back ratio of a 3-element Yagi. See **Fig. 5-5**. The elevation angle of maximum radiation is about 23 degrees at the 5/8-wavelength height.

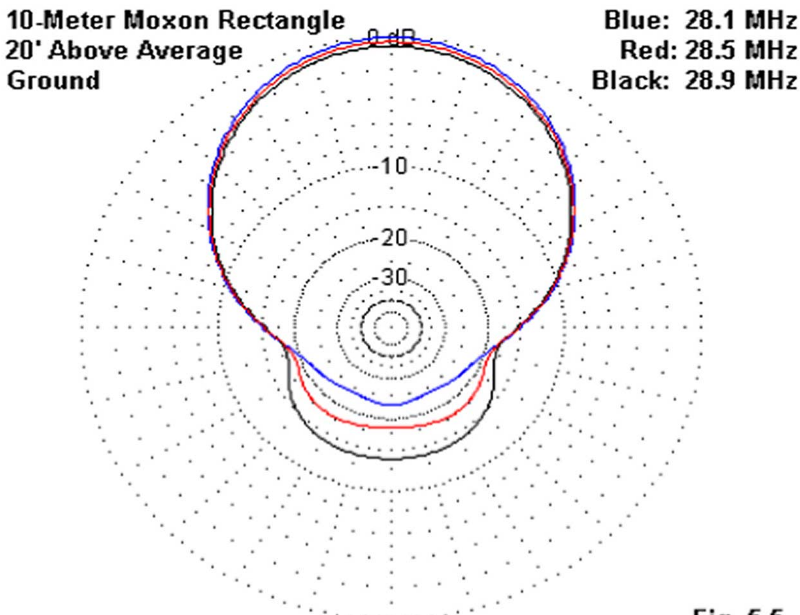


Fig. 5-5

My own initial procedure was to fasten the antenna to a 20' mast propped up by a sturdy tripod. The reflector was no more than 5' above ground. I then adjusted the side-to-side length to minimize SWR at 28.45 MHz, using the trombone-slide end sections. After fastening down the sections and raising the antenna, there was no detectable difference in SWR performance from the adjustment position pointing at the sky.

On-the-air tests with Moxon rectangles verify that the antenna shows less than 2:1 SWR across the entire 10-meter band when the design center frequency is about 28.4 MHz. The gain and front-to-back ratio continue to decrease as the frequency increases, but some directionality and gain persist even at the upper end of 10 meters. Local contacts confirmed that the front-to-back ratio within the first MHz of 10 meters is far superior to that of a comparable driven element-reflector 2-element Yagi. Gain was not measurable, but there appeared to be no detectable difference between the Moxon and a 2-element Yagi at my station.

At 35' up, about 1 wavelength, the antenna provides most of its free space performance across the band, as shown in **Fig 5-6**. At higher mounting levels, the performance moves closer to free-space patterning. The elevation angle at 35' for maximum gain is 13-14 degrees, similar to that of almost any horizontal array.

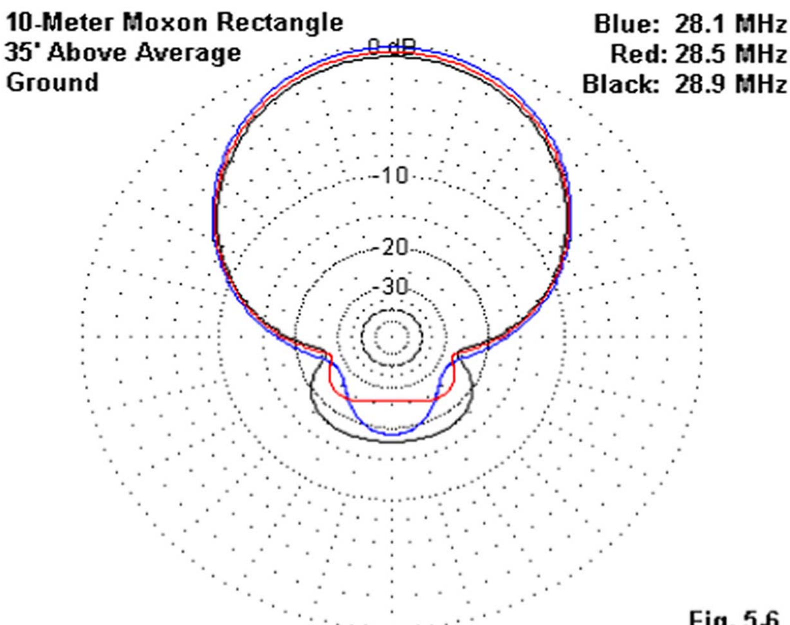


Fig. 5-6

The test model of the 10-meter all-aluminum Moxon is still in service 5 years after its completion. It still serves as a handy portable antenna for manual rotation.

A Truly Portable Moxon Rectangle for Nearly No-Tool Field Assembly

Since I began development of the Moxon rectangle as a 2-element monoband directional beam with a superior front-to-back ratio and a direct 50-Ohm feed, I have had numerous exchanges with various hams on making the antenna truly portable. Various ideas have filtered through discussions, including the use of a fiberglass support frame—alternatively stressed and unstressed—with wire elements. However, tubular elements offer a wider bandwidth for all the main operating characteristics. So I have focused in this direction.

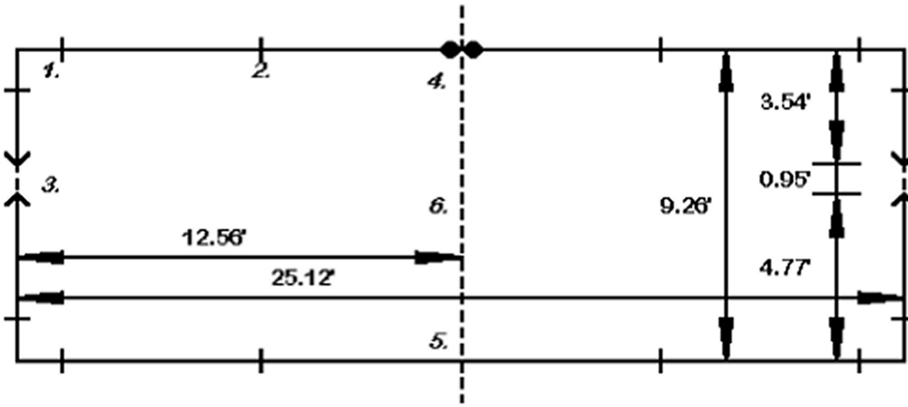
The tubing that I selected for a series of portable rectangles is 5/8" (0.626") diameter 6063-T832 aluminum, available from such sources as Texas Towers (http://www.texastowers.com) in convenient 6' lengths. Based on the use of this material, we may plug the element diameter and the design frequency into any of the Moxon design programs to derive dimensions. For 20 and 15 meters, a design frequency about 40% up from the bottom of the band provides whole band coverage. Therefore, 14.150 and 21.200 MHz are the design frequencies. On 10 meters, a frequency of 28.350 seems best for covering the entire first MHz of the band. The following chart provides the dimensions in feet.

Moxon Rectangle Dimensions: 0.625" Diameter Elements

Dimension	20 Meters	15 Meters	10 Meters
A	25.12'	16.73'	12.49'
B	3.54'	2.31'	1.69'
C	0.95'	0.69'	0.55'
D	4.77'	3.19'	2.39'
E	9.26'	6.19	4.63'

E, of course, is the simple sum of B, C, and D to give the overall front-to-back dimension. The constant diameter material means that the diameter as a fraction of a wavelength increases with frequency. Hence, the gap (C) at 10 meters is more than half the gap at 20 meters.

In the notes that follow, I shall focus on the most difficult of the versions to make truly portable—the 20-meter rectangle. You may adapt the idea for construction with greater ease to smaller versions than you can when trying to scale up construction. **Fig. 5-7** shows the 20-meter rectangle with dimensions and several kinds of markings that will be of significance in construction.



20-Meter Aluminum Portable Moxon Rectangle

Detail References (italics):

1. *Corner Assembly, including fold and lock parts*
2. *Element Segment Junction, including 0.625" and 0.5" tubing*
3. *Tail Alignment Assembly, including non-conductive separator*
4. *Driver Feedpoint and Element-to-Boom Assembly, including plate*
5. *Reflector Element-to-Boom Assembly, including plate*
6. *Boom-to-Mast Assembly, including plate and hardware*

Fig. 5-7

The decision to attempt construction of a truly portable Moxon depends in part on the antenna performance. **Fig. 5-8** shows free-space azimuth patterns for the 20-meter band edges and center for the array. The very high front-to-back ratio diminishes to about 18 dB at the band edges, while the gain decreases in a typical 2-element reflector-driver parasitic array curve.

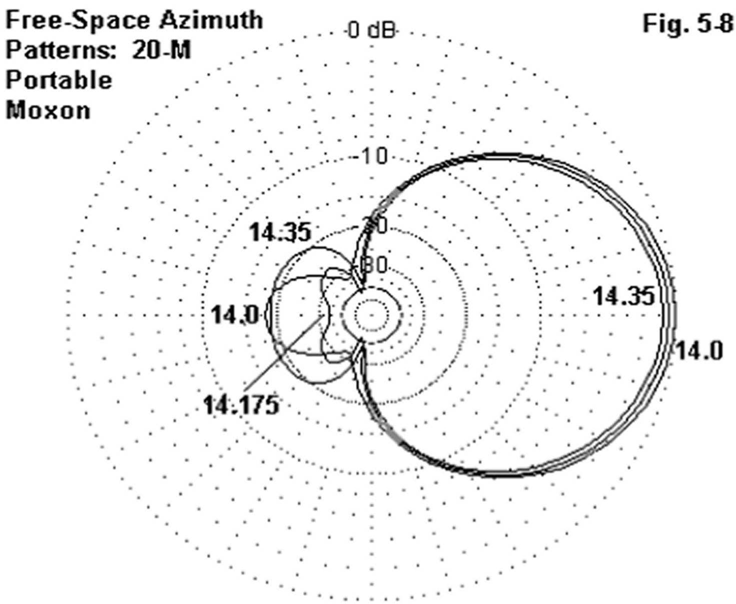


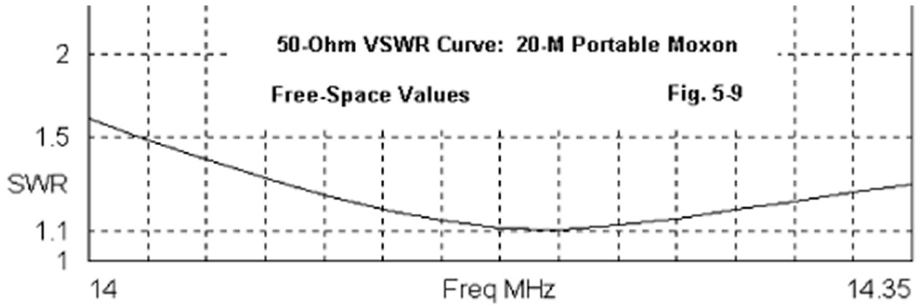
Fig. 5-8

The anticipated performance figures—which will be similar for all 3 wide upper HF bands—appear in the following table.

20-Meter Moxon Performance in Free Space

Frequency MHz	Gain dBi	Front-to-Back Ratio dB	Feed Impedance R +/- jX Ohms	50-Ohm VSWR
14.0	6.36	18.0	39.3 - j 18.0	1.60
14.05	6.25	21.7	43.1 - j 13.7	1.39
14.10	6.14	27.6	46.9 - j 9.9	1.24
14.15	6.02	38.0	50.6 - j 6.5	1.14
14.20	5.91	29.0	54.1 - j 3.5	1.11
14.25	5.80	23.5	57.4 - j 0.7	1.15
14.30	5.69	20.3	60.5 + j 1.9	1.21
14.35	5.59	18.1	63.3 + j 4.4	1.28

The gain drops about 3/4 dB across the 20-meter band. As **Fig. 5-9** shows, the SWR curve is steeper below the design frequency than above it. This curve parallels the front-to-back ratio curve, and together, the two curves dictate a design frequency of maximum front-to-back ratio that is a bit below the mid-band point.



For the average radio amateur without high towers and the finances to put a high performance set of beams into the air, the Moxon performance offers a chance for effective communications. The azimuth patterns suggest that the beam has two principal offerings. First, it is very quiet to the rear, enhancing signals from the forward direction. Second, the forward lobe is very wide, which requires less precision in aiming the antenna.

For Field Day and similar operations, the antenna can be very effective, whether constructed of wire or tubing. In this set of notes, we shall concentrate on making the tubular Moxon truly portable.

The Requirements for Portable Operation: A truly portable beam must meet several requirements:

The array must form a compact package for storage and transport.
The array must go together using the minimum number of tools.
The array must come apart in a simple reversal of the assembly order.
The pieces must go together and come apart many times.
The array must be reasonable sturdy in light winds.

The ideas that following meet all of the criteria. However, the structure must not be used for either permanent installation or for winds that are brisk or better. 15 knots represents the highest recommended wind load for the antenna.

The key to the ideas sketched in these notes is to assemble in the shop those pieces that form permanent subassemblies. Shop construction will require stainless steel hardware (bolts, sheet-metal screws, or clamps) for any junction of metals. In the field, a freshly made junction will provide electrical continuity for the duration of an operating session. Therefore, the only task for hardware will be to securely hold in place the junctions created in the field. Screws, clamps, and bolts are unnecessary for this purpose.

The only hardware needed for field junctions is the hitch pin clip (otherwise knows as the hitch pin, the hairpin cotter pin, or the spring retainer). (See **Fig. 5-10**.) When properly sized, these pins will more than suffice to keep the pieces of a portable Moxon in place. Hitch pins are available in many sizes. Although stainless steel pins are the most durable, they cost twice as much for half the number of zinc-

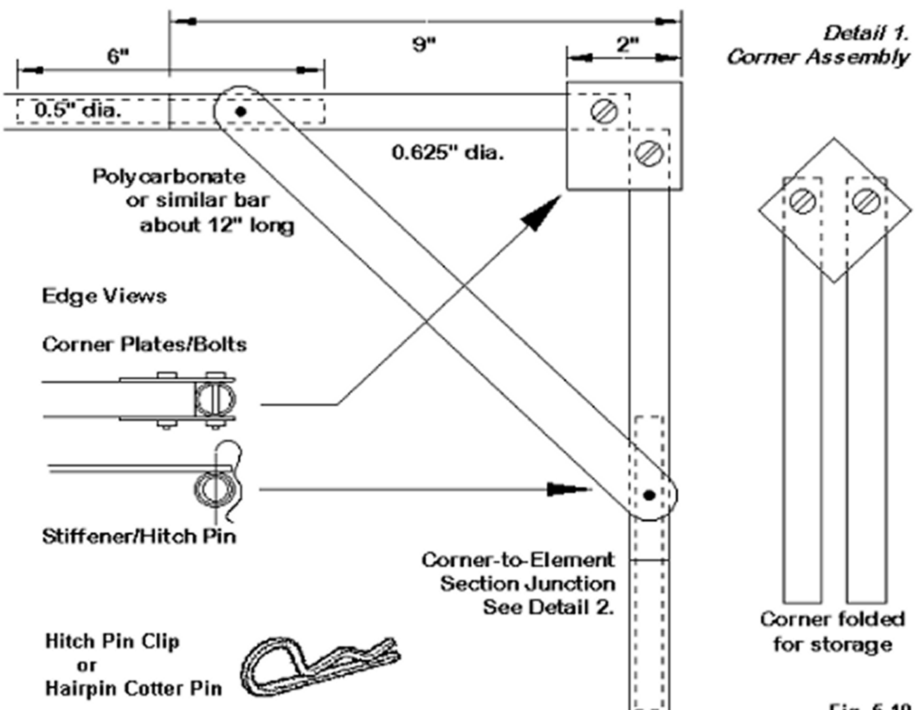


Fig. 5-10

plated steel version, according to McMaster-Carr catalog pages (page 2971 of the on-line catalog at http://www.mcmaster.com.

Effective use of the hitch pin requires careful shop work. Drill the junction pieces of tubing together with the junction tightly in place. Use a hole size just barely large enough for the straight side of the pin. The tighter the fit, the more durable the junction. However, if a pin hole becomes loose and sloppy after a few uses, then a redrill at a nearby location will fix the problem.

Hitch pins come in many sizes. For 5/8" diameter tubing, the pin rated from 1/2" to 3/4" service is suitable. The pin wire diameter is 1/8" (0.125"), which dictates the shop drilling bit size. Unless you have a precision shop, it is unlikely that similar pieces will be interchangeable at junctions. Therefore, it is wise to use tape on both side of a junction with a coding that allows you to join the correct pieces in the field.

Hitch pins are one of those items most likely to become lost in the grass. Therefore, be sure to obtain and store with the antenna parts a sufficient over-supply. As well, you might obtain brightly colored tape and add a tab through the top ring of each pin. These cautions fall under the basic principle that the more worst-case thinking you do in the shop, the fewer worst-case events will occur in the field.

Making a portable Moxon rectangle for 20-meters is our goal. The design effort begins by breaking the antenna into many sub-assemblies. The dimensions for these assemblies emerged from the dimensional requirements, shown in **Fig. 5-7** and the available materials. Tubing comes in 6' lengths from many mail-order sources in order to fit with the UPS limits above which special shipping charges apply. Since the 20-meter version of the antenna is 12.56' (150.7") each side of the center line, we can use two sections between 5' 9" (69") and 6.0' (72") for each element's long portion. (A 10-meter version would require only one section per element per side of centerline, and a 15-meter version might use two shorter sections.) The corner assembly will make up the remaining few inches. The tail- pieces are well under 6', so they can be independent parts. The junctions consist of 0.5" tubing inside the main 0.625" tubes.

The array for 20 meters will need about 70' of tubing, which weighs less than 7.5 pounds in the 0.58" wall size. The boom and other hardware, if carefully chosen and constructed will about double to total weight, for a 15-pound package. Because the hardware needs—including the boom, boom-to-element mounts, and boom-to-mast mount—will not substantially change for the smaller versions of the antenna, expect a 10-pound 10-meter Moxon and a 12-pound 15-meter version.

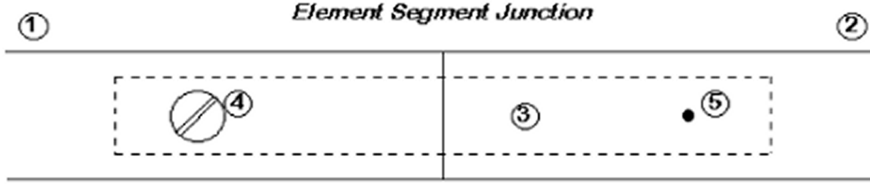
The first stop along our examination of details consists of the corner assemblies in **Fig. 5-10**. The 9" lengths of tubing will be variable according to the exact lengths of the tubing from the center-line (boom) to the element end. A 6" 0.5" diameter tube is permanently attached with stainless steel hardware to the linear section of the element—both to the long element and to the tail-piece. Hitch pins position the junctions and also lock down a length of non-conductive strap or bar that holds the corner square during use. Two small plates make up the corner hinge that allows the piece to fold for storage and transport. The folding corner's chief advantage is storage compactness.

The drawback of the folding corner is the need for tools to tighten the corner. You might well replace the type of corner shown with a section of bent 0.5" diameter aluminum. If you choose this route, be certain that the straight and curved sections of each element add up to the correct overall element length shown in the chart of dimensions. The total driver length is A + (2 x B), while the total reflector length is A + (2 x D). Bending aluminum tubing to 90 degrees requires some care. Fill a piece that is longer than the final dimensions with play sand, the finer the better. Many benders warm the aluminum and sand to the point where they can just handle the piece with gloves. Make up a form (or use a suitable solid circular piece among the "found-objects" in the shop). Pin down on end of the tube. Bend slowly in small increments until the piece reaches a slightly tighter angle than the 90 degrees. It is easier to slightly unbend the cooled piece than to add to the curve later on.

The bent corner requires no brace. Hitch pine holes aligned with the inserted junction pieces are the final step in shop work—except for the labeling. Four corners with hitch pin holes of slightly different alignments can become a frustrating field exercise if not labeled for easy selection.

Detail 2 in **Fig. 5-11** shows the general junction scheme used throughout the portable design. 0.5" diameter tubing forms each junction piece. The inward sections of the long element portions and the tail pieces use appropriate hardware for permanent connection. The more outward tubing or the corner section gets a hitch-pin hole. Create the hitch-pin holes by first ensuring a tight butt joint at the ends of the 5/8" tubing section to be joined. Then drill carefully through both the inner and outer tubing all the way through the “top” and “bottom” of the junction. If the drill bit will pass though both holes, the hitch pin straight side will also fit.

Detail 2.
Element Segment Junction



(1) Section of 0.625" dia. tubing: long element sections: 5' 9" long driver tail section: 2' 9.5" long; reflector tail section: 4' 0" long Inner tube fastend to indicated section with nut-bolt or sheet metal screw ("permanent")

(2) Section of 0.625" dia. tubing for outer section of long elements or the corner assembly tube: fasten with tight-fitting hitch pin

(3) Junction section of 0.5" diameter tube: for junctions with the corner assembly, tube is 6" long; for junctions within the long-element sections, tube is 12" long

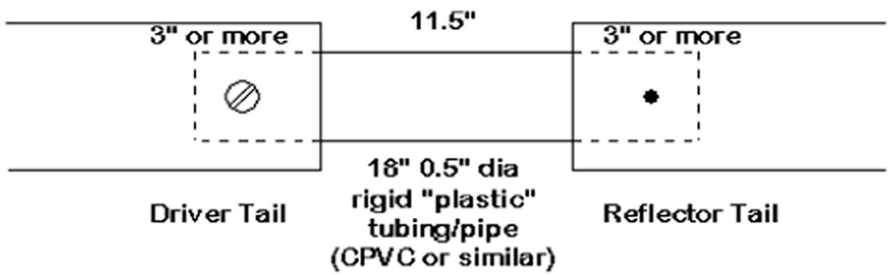
(4) #8 or #10 stainless-steel hardware (bolt or sheet metal screw)

(5) Stainless steel hitch pin; use tight fit

Fig. 5-11

Detail 3 in **Fig. 5-12** shows the tail assemble, although not to scale. For the 20-meter Moxon, obtain about 36" of rigid or nearly rigid tubing with a true outside diameter of 0.5". (Measure any tubing that lists its dimensions as “nominal,” since such materials tend to use pipe dimensions and only a measuring device will show the true outside diameter.) 18" per tail will hold the ends of the 20-meter Moxon tails the correct distance apart while maintaining alignment. Since the driver tail will be shorter, the permanent hardware goes on that side, with the hitch pin applied to the reflector tail portion. Because you need a similar assembly on each side of the array, good labeling is important.

Detail 3. Tail Alignment Assembly

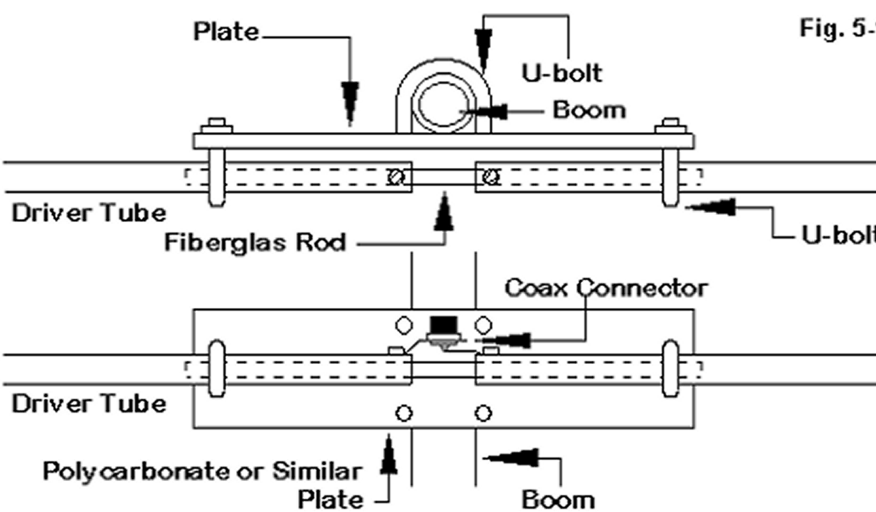


Note: For storage and transport, the nonconductive tube mounts to the shorter driver tail with stainless steel hardware. A hitch pin attaches the non-conductive tube to the longer reflector tail during use.

Fig. 5-12

Detail 4 in **Fig. 5-13** reveals that the Moxon requires a split feed mount that insulates and isolates the elements from the boom. A 1/4" thick polycarbonate plate provides the strongest plate for this service. It can be any length and width that will

Fig. 5-13

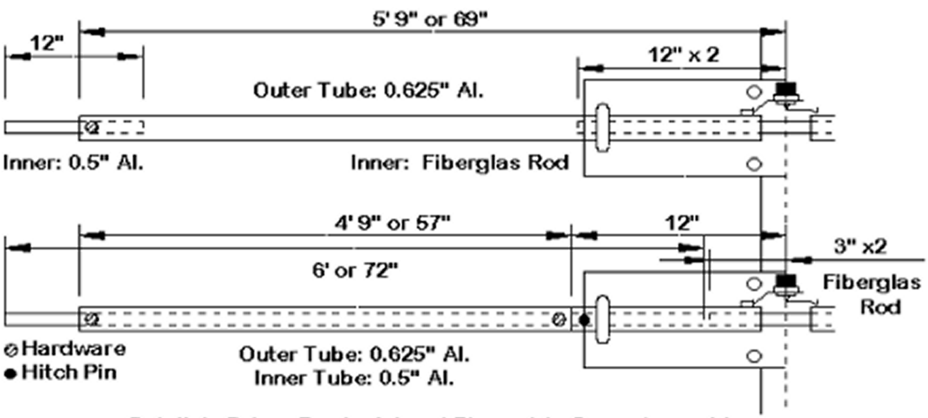


Detail 4. Driver Feedpoint and Element-to-Boom Assembly

fit the need. For the feedpoint plate, be sure there is room for a small aluminum bent pieces to hold a coax connector and leads to the tubing on each side of the plate.

Since the plate shown uses U-bolts, obtain a polycarbonate or fiberglass rod to fit within the driver tubes. Such a rod keeps the tubes aligned, thus reducing the number of U-bolts required. It also prevents the tubing from collapsing under the pressure of tightened U-bolts.

For storage, the system shown in Detail 4 and repeated in the alternative figure (**Fig. 5-14**) has a disadvantage. It requires tools to loosen at least one side of the assembly so that you can disassemble one of the 69" element sections. (Remember that 69" is approximate and depends on how you apportion the subsections of the parallel element portions.) The alternative construction shown in the lower portion of the figure uses a shorter length of non-conductive rod. Its function is to align the tubing ends and to provide a base for hardware that allows connection to the coax receptacle.



Detail 4. Driver Feedpoint and Element-to-Boom Assembly
Assembly Options

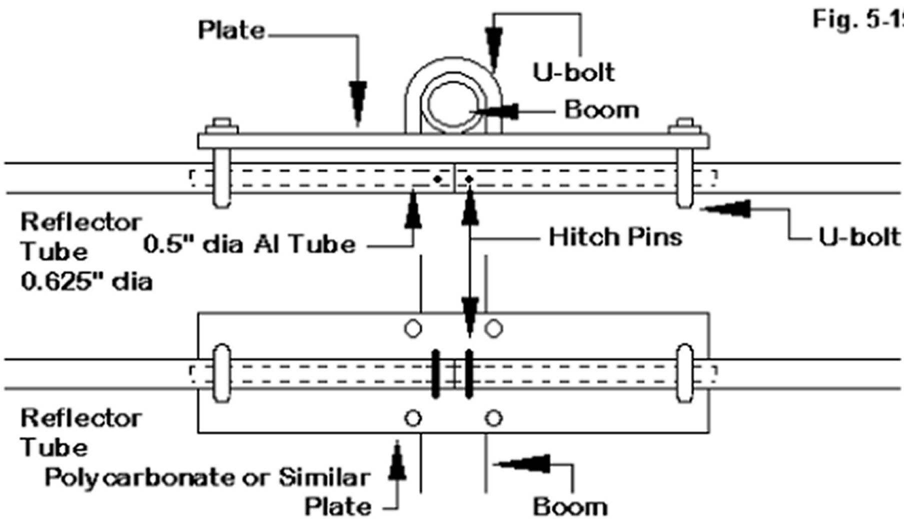
Fig. 5-14

The alternative center mount uses portions of the first long-element section with a cut-off just beyond the feedpoint plate. To strengthen the inner portion of the 20 meter elements, a full 6' length of 0.5" tubing runs the entire length of the element and forms the junction inside the feedpoint assemble as well as the junction with the next outward section of tubing. The long tube holds the permanent hardware, with hitch pins on the other side of each junction. The sketch shows the positions of the pins, but not their orientation. The hitch pin at the feedpoint plate should be parallel to the face of the plate.

Although somewhat more complex to construct, the alternative feedpoint plate assembly can now remain fully constructed with no need for tools at the field site. Hitch pins do the work.

Detail 5 in **Fig. 5-15** shows the corresponding reflector plate. As shown, the plate will require tools to loosen one of the element U-bolts. For a no-tool assembly job at the field site, revise the sketch to resemble the alternative feedpoint plate, but with a 0.5" junction tube instead of the fiberglass or polycarbonate rod. Of course, the coax connector is irrelevant to the reflector.

Fig. 5-15



Detail 5. Reflector Element-to-Boom Assembly

The final detail (6 in **Fig. 5-16**) concerns the boom and the boom-to-mast mount. I recommend nested sections of 1.25" and 1.125" aluminum if the wall is 0.58" thick. Single thickness tubing might work, but is subject to distortion under the pressure of U-bolts. For 20 meters, we need 9.5 to 10 feet of boom. To create such a boom, use a 6' length of each size tubing and a shorter (3.5' to 4') length. Alternate their placement and position with hitch pins. The pins allow disassembly for storage as lengths no more than 6' long—roughly that same as the longest element pieces. The boom-to-mast plate can be either 1/8" thick aluminum or 1/4" polycarbonate. U-bolts should be stainless steel. Saddles are useful in preventing slippage and tubing distortion.

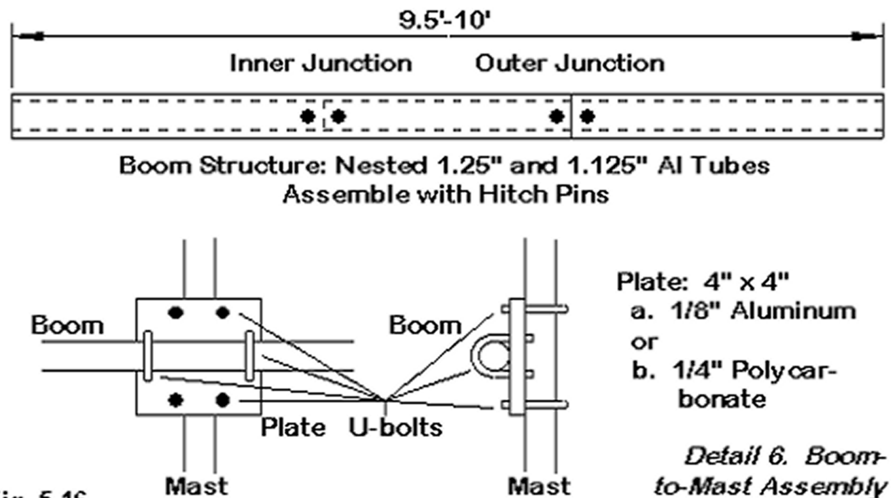


Fig. 5-16

Storage, Transport, and Use: There is nothing magical in the suggested construction of the portable Moxon rectangle. Feel free to adapt and revise as you wish—and you may well have ideas to improve the techniques suggested here. The two key goals are these:

1. Keep to an absolute minimum the number of tools needed at the field site to assemble and disassemble the antenna. Murphy's Law dictates that you will forget

to bring the one key tool you need to complete the assembly. Keep Murphy at bay by developing the antenna so that it needs no tools at all—or only a small steel rod (sometimes called a screwdriver) to free the hitch pins after use.

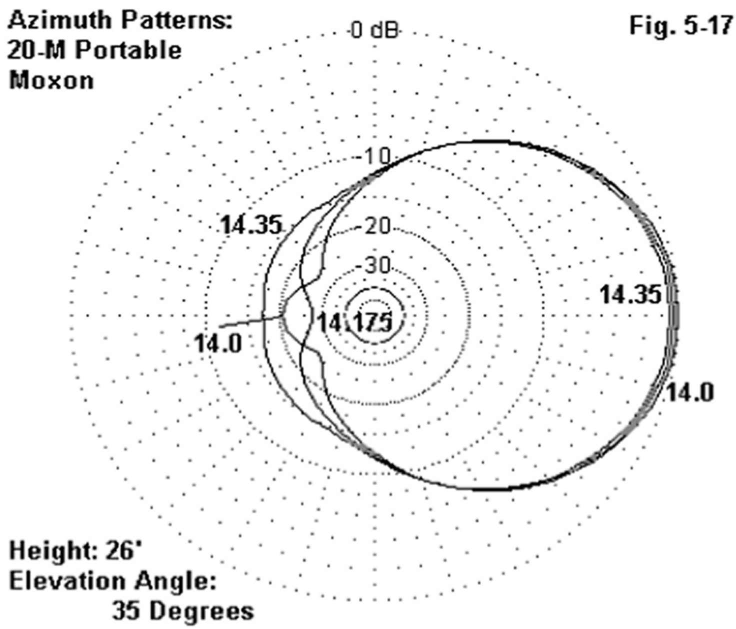
2. Keep the storage package as short and small of girth as possible. The 6' tubing lengths, plus fixed extensions for junctions dictates one dimension. The stack of well-labeled tubes has a certain girth when bound together. The folding corners add least to the girth of a round stack, but bent tubes might well be accommodated with a flatter storage scheme.

Develop some sort of storage container. Canvass or similar material works well. Be certain that the hardware fits in a well-marked and hard-to-lose bag or box—with extra pins. If your assembly needs a few tools, purchase a few inexpensive tools especially for the antenna and store them with the aluminum and hitch pins.

I have made no comments on the mast assembly, since the options are too many and often are site-specific. However, try to raise the Moxon rectangle as high as safely feasible. For 20 meters, the approximate minimum recommended height is about 3/8 wavelength or 26' above ground. At this height and above, the SWR curve will be very stable.

Fig. 5-17 shows the band-edge and band-center azimuth pattern at the take-off angle for the array at a height of 26' on 20 meters. At 3/8 wavelength, the TO angle is 35 degrees, but drops to about 26 degrees when the antenna is 1/2 wavelength up. The lower height, however, is often satisfactory for field use, since the vertical lobe of the far-field pattern is very broad, with usable radiation down to 10 to 15 degrees elevation. As well, at 3/8 wavelength height, as the figure shows, the front-to-back ratio is excellent for a two-element array.

These notes are only a set of ideas on the construction of a truly portable Moxon array for 20 through 10 meters. The hitch pin is a much overlooked fastener that can simplify field assembly and disassembly. However, it requires the tubing itself to make the electrical contact at the junctions. If you clean the tubing (with a plastic abrasive pad, not steel wool or other scarring materials) before each use, electrical contact should pose no problems.



For permanent installations involving long term exposure to weather and the chemical soup called the atmosphere, use other connection methods and a stronger basic design.

However, for short-term field operations, the construction ideas shown here and supplemented by your own knowledge of materials and hardware can produce a truly portable Moxon rectangle—or almost any other type of array you wish to carry into the field.

Contrary to claims made for the VK2ABQ squares, these antennas do not like to be nested for a multi-band array. Stacking requires a minimum of 10' or more between 10- and 15-meter models. However, you might consider back-to-back 10 and 15-meter antennas. Computer studies suggest that a 13' boom would hold both antennas, reflector-to-reflector with minimal interaction.

The Moxon rectangle will not overpower competition. However, it does provide wide-band gain with very good directional performance and a good match with common coax for the upper-HF operator with limited space and budget. Construction is straightforward using local materials. These may be enough good features to earn the antenna a place among useful ham antennas.

* * *

Appended models used in this chapter: mox10-78.ez, mox20-58p

6. Moxon Rectangles and Multi-Band Beams

The optimized Moxon rectangles that we have been exploring do not nest well. That is, I have to this time been unable to find a satisfactory way to combine Moxon rectangles into a multi-band beam that preserves all of the major characteristics of the individual arrays. These characteristics include forward gain, front-to-back ratio, feedpoint impedance, and the relatively wide operating bandwidth.

Performance deteriorates mostly for the inner Moxons in the assembly. The rectangle for the lowest band—the outer Moxon of the group—has the least difficulty. In fact, it tends to be relatively immune to disturbance from higher-band antennas very near to it. Since there is more than one way to create a multi-band array, we should likely capitalize on this fact and see if we can create something other than a pure Moxon multi-band array. Let's aim instead for an array with a Moxon rectangle at its core.

Moxon-Modifying the C3-Type Tribander

The Force 12 C3 tri-band Yagi has become a very popular compact beam for the general operator. Nevertheless, its 35' wing-spread has prevented some would-be owners from purchasing the antenna because their available space is not sufficient for full-size 20-meter elements. I have over the years received a number of inquiries as to whether the 20-meter elements could be shortened by various types of loading.

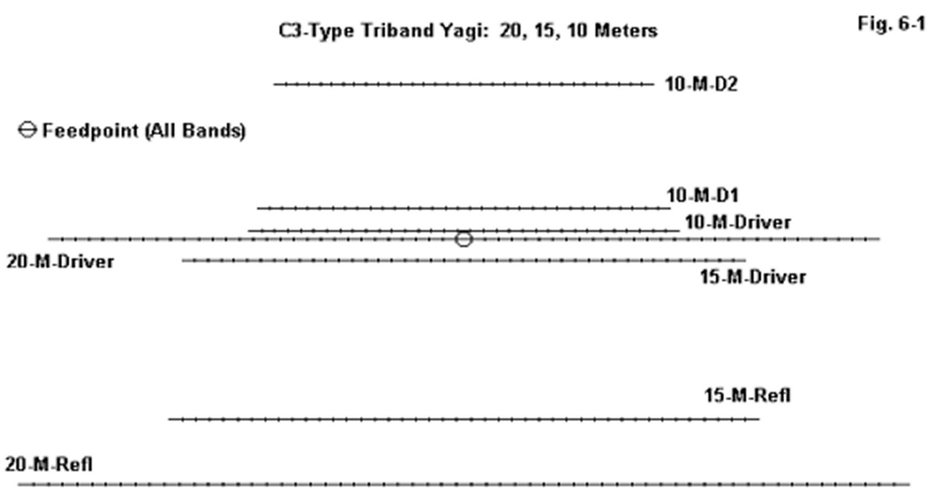
In general, but not absolutely, the answer has been negative. Most forms of loading—except element-end loading—disrupt the current phase relationships between the fed driver and the slaved drivers, destroying the feed system.

However, the 2-element 20-meter portion of the array can in principle be replaced by a Moxon rectangle without disturbing the other elements of the array. The result is not only a beam with only a 25' side-to-side spread, but as well a boom length nearly 2' shorter than the original.

The following notes are designed only as a feasibility study to validate the replacement in principle. Our first step is to understand something of how the C3 is designed. For that purpose, I shall not present a detailed model of the Force 12 C3. To obtain a computer model of the antenna, one should contact the company directly. My model makes use of uniform-diameter elements and hence represents only a C3-type antenna, not the actual commercial version.

As well, many facets of the actual C3 are protected by patents and other proprietary considerations, for example, the open-sleeve feed system. Therefore, these notes are intended only as a design study for individual use and not for any commercial purpose whatsoever.

The C3-Type Tri-Band Antenna: The C3-type tribander consists of three antennas: a 20-meter 2-element driver-reflector Yagi, a 15-meter 2-element driver-reflector Yagi, and a 3-element driver-director Yagi. The general arrangement is sketched in outline in **Fig. 6-1**. The following model description from EZNEC provides details of the element lengths and spacings.



```
C-3-Type 20-10-m tribander                    Frequency = 14  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1          -138.50, 34.000,  0.000       138.500, 34.000,  0.000 7.50E-01  43
2          -132.35,119.000,  0.000       132.350,119.000,  0.000 7.50E-01  43
3          -101.00,134.500,  0.000       101.000,134.500,  0.000 5.00E-01  33
4          -97.000,146.500,  0.000        97.000,146.500,  0.000 5.00E-01  33
5          -89.000,212.500,  0.000        89.000,212.500,  0.000 5.00E-01  33
6          -195.00,130.250,  0.000       195.000,130.250,  0.000 1.00E+00  61
7          -209.00,  0.000,  0.000       209.000,  0.000,  0.000 1.00E+00  61

              -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1          31     6 / 50.00   (  6 / 50.00)      1.000       0.000       I
```

The elements are organized in the order 15 meters, 10 meters, 20 meters. My placement of the 20-meter elements at the end results from the fact that we shall eventually replace them with a Moxon rectangle. Note also that I have used 1" diameter elements for 20 meters, 0.75" for 15, and 0.5" for 10 meters.

The most central feature of the C3-type multi-band Yagi is the drive system. It makes use of open-sleeve coupling such that only the 20-meter element is driven, whatever the band in use. The 15-meter driver is slaved to the 20-meter element on the side of the fed-driver closer to the corresponding reflector. Likewise, the 10-meter slaved driver is on the side of the fed driver closer to the 10-meter directors.

I should note that the spacing and lengths of the slaved drivers relative to the fed driver may differ from the actual dimensions used in a C3. Both NEC-2 and NEC-4 have some limitations when wires of different lengths and diameters are brought into close proximity. Even with great care in aligning segment junctions among the elements, the close the spacing, the higher the potential for error in the model. Hence, the actual required slaved driver lengths and spacings may be different from those used in the model. However, the model is sufficiently accurate to establish the principles involved in the operation of a C3-type antenna.

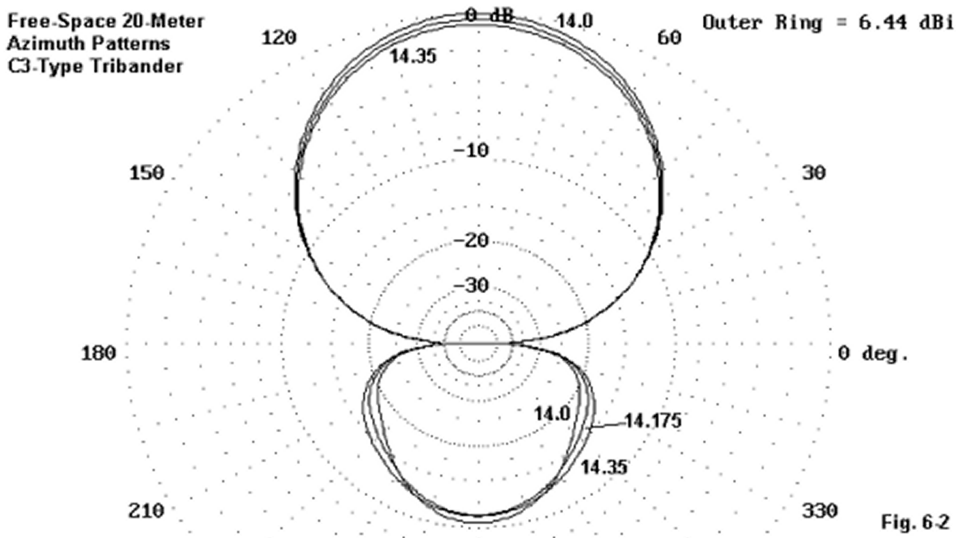


Fig. 6-2

The 20-meters driver and reflector together form a 2-element beam of relatively standard design and performance. **Fig. 6-2** shows the free-space azimuth patterns of the NEC-4 model at the ends and center of 20 meters. The following table summarizes 20-meter modeled performance.

Freq.	F-S Gain	F-B Ratio	Beamwidth	Feed Impedance	50-Ohm
MHz	dBi	dB	Degrees	R +/- jX Ohms	SWR
14.0	6.44	10.48	68.8	44.7 - j 4.4	1.16
14.175	6.13	10.90	69.6	55.4 + j 6.8	1.18
14.35	5.84	10.51	70.2	65.9 + j16.6	1.49

As the table shows, the performance is everywhere normal for a 2-element Yagi. The gain descends as frequency increases. The element spacing to achieve a 50-Ohm match reduces the front-to-back ratio slightly relative to that obtainable with closer spacing and a lower feedpoint impedance. However, the SWR curve for a direct feed system is outstanding.

Placing the 15-meter driver and reflector between the corresponding 20-meter elements results in close to optimal coupling, something that is more difficult to obtain had the 15-meter slaved driver been placed forward of the fed driver. However, a slaved driver generally has a narrower operating passband with respect to impedance than a directly driven element. The narrowing tends not to show up in terms of pattern shape, as evidenced by **Fig. 6-3**. However, the <2:1 SWR passband on 15 meters is only about 360 kHz, somewhat less than the whole band. However, the peak SWR of about 2.8:1 is well within the range of antenna tuners built into modern transceivers. As well, the SWR curve will be noticeably shallower at the shack end of any common coaxial cable if the cable is over a wavelength long. The following table shows the modeled performance of the subject antenna on 15 meters.

Freq. MHz	F-S Gain dBi	F-B Ratio dB	Beamwidth Degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
21.0	6.55	10.78	67.2	52.9 - j36.0	1.99
21.225	6.20	11.19	68.6	44.1 + j 4.9	1.18
21.36	5.99	10.92	69.6	39.3 + j28.5	1.96
21.45	5.84	10.59	70.4	36.2 + j44.2	2.83

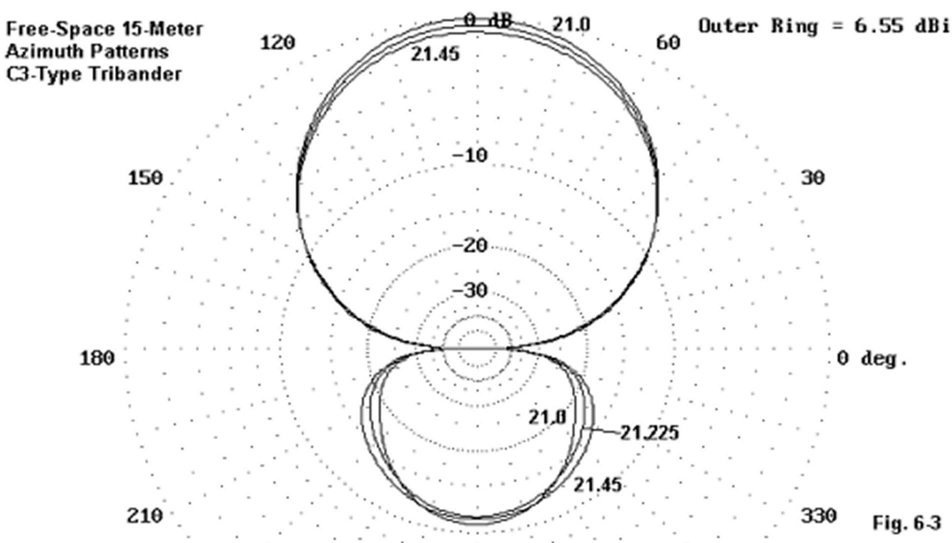


Fig. 6-3

The band-edge patterns of the 20-meter and 15-meter sections of the antenna are quite similar, as is the front-to-back level. Only the SWR curve reveals the presence of the open-sleeve coupling system, and it is still a highly workable set of values.

The 10-meter section of the antenna differs considerably from the 20-meter and 15 meter sections. Beginning with a slaved driver forward of the fed driver, there are two directors. Although there is no tuned 10-meter reflector, the 15-meter elements (especially) fulfill part of that function in a system known as forward-stagger design.

Note that the first director is quite closely spaced to the slaved driver. Although this director does not lose all of its gain-enhancing function, its chief role is in setting the impedance and the operating passband of the 10-meter section. It bears more than a small resemblance to the spacing that would be used in OWA designs. The result is a 900 kHz SWR passband with usable patterns above 29 MHz. **Fig. 6-4** shows the 28, 28.5, and 29 MHz free-space azimuth patterns for the modeled array.

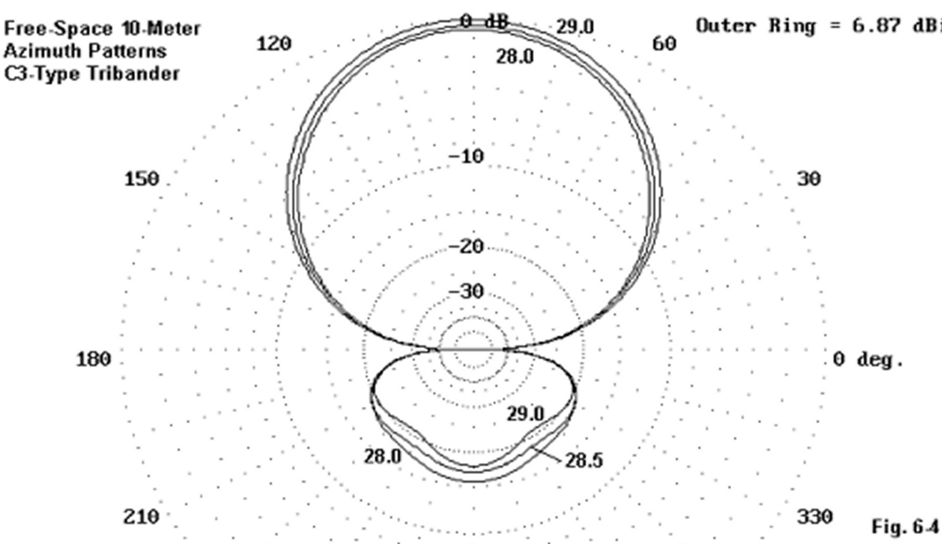


Fig. 6-4

The following tables shows the reported properties of the 10-meter section across the first MHz of the 10-meter band.

Freq. MHz	F-S Gain dBi	F-B Ratio dB	Beamwidth Degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
28.0	6.34	15.12	66.8	55.7 - j35.1	1.94
28.5	6.55	16.65	68.8	45.0 + j 0.2	1.09
28.9	6.80	17.68	70.4	36.0 + j26.6	2.00
29.0	6.87	17.86	70.8	32.7 + j33.0	2.44

Once more, the SWR curve at the shack end of a coaxial cable will likely be shallower than the one at the feedpoint terminals, and any remnant SWR in excess of 2:1 is easily handled by a built-in ATU in the transceiver. More significantly, the performance curve reflects a typical Yagi with directors, as the gain increases with increasing frequency. The use of two directors provides a bit higher gain across the operating passband than the driver-reflector sections used on 20 and 15 meters.

Replacing the 20-Meter Section with a Moxon Rectangle: If we replace the 20-meter elements with a Moxon Rectangle, we obtain an array with a smaller footprint: 10' narrower and almost 2' shorter. **Fig. 6-5** shows the outlines of such an array.

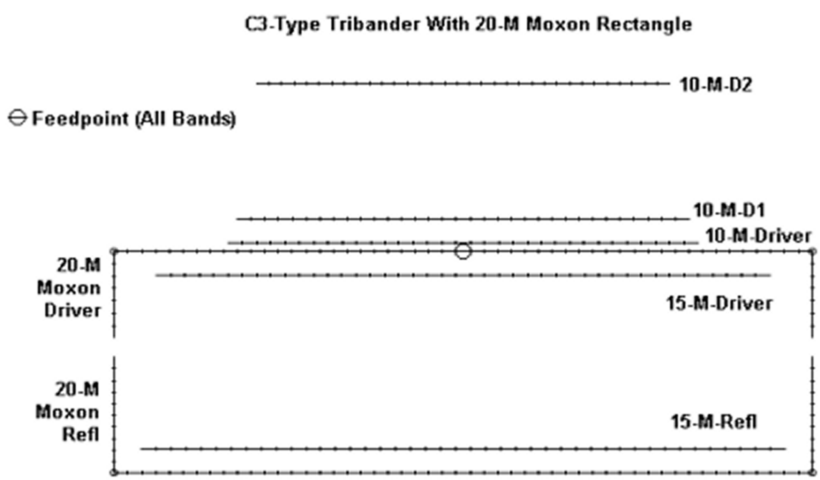


Fig. 6-5

The following model description permits a direct comparison of element length and spacing between the Moxon-ized version of the C3-type antenna and the basic model just examined.

```
Moxon-C3-type tribander                          Frequency = 14  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

               --------------- WIRES ---------------

Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs

1          -138.50, 34.000,  0.000       138.500, 34.000,  0.000 7.50E-01  43
2          -131.90,119.000,  0.000       131.900,119.000,  0.000 7.50E-01  43
3          -101.00,134.500,  0.000       101.000,134.500,  0.000 5.00E-01  33
4          -97.000,146.500,  0.000        97.000,146.500,  0.000 5.00E-01  33
5          -89.000,212.500,  0.000        89.000,212.500,  0.000 5.00E-01  33
6          -150.00, 88.250,  0.000  W7E1 -150.00,130.250,  0.000 1.00E+00   7
7     W6E2 -150.00,130.250,  0.000  W8E1 150.000,130.250,  0.000 1.00E+00  51
8     W7E2 150.000,130.250,  0.000       150.000, 88.250,  0.000 1.00E+00   7
9          -150.00, 78.650,  0.000 W10E1 -150.00, 22.250,  0.000 1.00E+00  10
10    W9E2 -150.00, 22.250,  0.000 W11E1 150.000, 22.250,  0.000 1.00E+00  51
11   W10E2 150.000, 22.250,  0.000       150.000, 78.650,  0.000 1.00E+00  10

               -------------- SOURCES --------------

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1          26     7 / 50.00   (  7 / 50.00)      1.000       0.000       I
```

If you examine wires 1-5, you will notice that the only change is to the 15-meter driver length—a slight adjustment needed to bring all of the SWR passbands back into alignment. I have left these elements at their original “boom” marks to facilitate the comparison. However, the Moxon reflector is 22.25" forward of the position of the former Yagi reflector.

Perhaps the most significant change in performance occurs on 20 meters, as the typical Moxon pattern replaces the 2-element driver-reflector pattern of the original array. **Fig. 6-6** shows the increased beamwidth, increased front-to-back ratio, and slight decrease in forward gain. The numbers associated with these patterns appear in the following table.

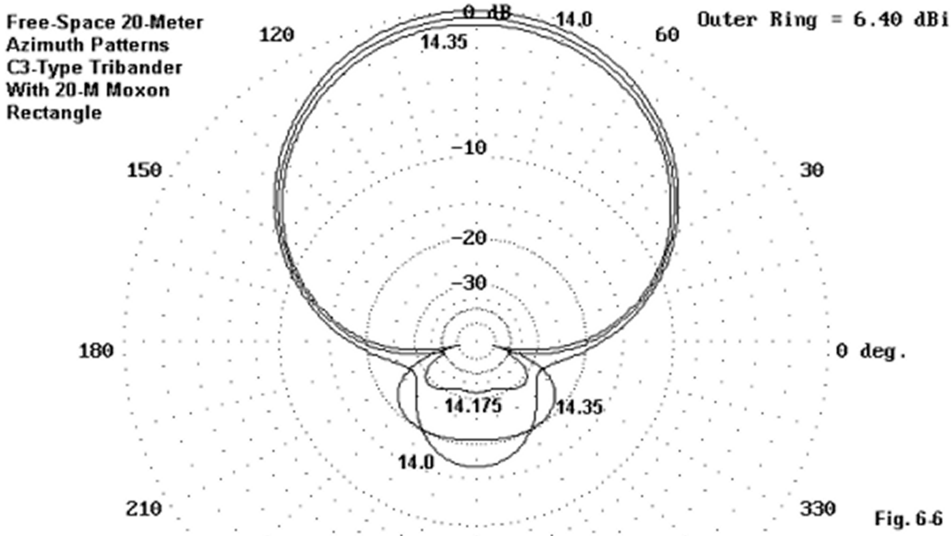


Fig. 6-6

Freq. MHz	F-S Gain dBi	F-B Ratio dB	Beamwidth Degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
14.0	6.40	16.56	77.2	43.0 - j11.4	1.33
14.175	6.03	31.51	77.8	60.9 - j 3.3	1.23
14.35	5.67	19.94	78.4	75.6 - j 1.1	1.51

While the gain differential is unlikely to be detectable in operation, the increased front-to-back ratio will be readily noticed. The 10-degree wider beamwidth may or may not be useful, depending upon the type of operation. In a contest, it reduces the need for re-aiming the beam so often. The key benefit of using the Moxon is the reduction in the side-to-side dimension of the array. However, every benefit is usually accompanied by a challenge. In this case, the difficulty lies in building element corners and a means of keeping the element ends in alignment. As well, unless good construction is used, the forward and rear elements may react to winds in differing rhythms, thus stressing the element tail assemblies. In short, Moxon rectangle construction for 20 meters may require a bit more careful planning than the usual 2-element Yagi.

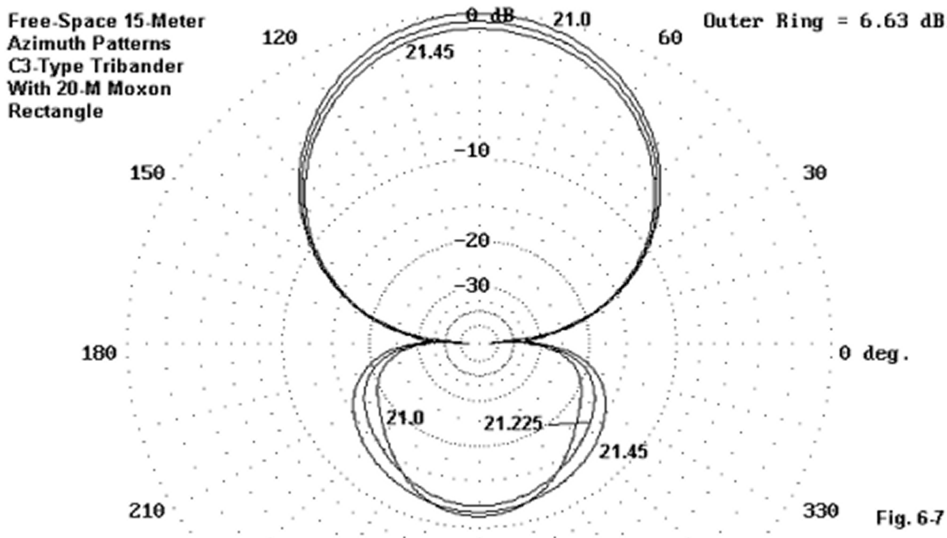


Fig. 6-7

On 15 meters, the chief feature to notice is that there is no significant change in performance compared to the basic array from which this one is derived. The **Fig. 6-7** free-space azimuth patterns are virtually identical to those for the basic array, and the following table of modeled values confirms the appearance of the patterns.

Freq. MHz	F-S Gain dBi	F-B Ratio dB	Beamwidth Degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
21.0	6.63	11.08	67.0	61.9 - j37.3	1.99
21.225	6.22	11.75	67.8	50.1 + j 8.4	1.18
21.36	5.99	11.25	68.2	44.0 + j33.2	2.01
21.45	5.84	10.74	68.4	40.3 + j49.4	2.91

Gain values, where they differ at all, do so only in the meaningless hundredths column. All of the other values are mere smidgens apart from the numbers reported for the basic array. In short, confining the 15-meter elements within the Moxon rectangle results in no significant interactions in addition to those one might find when the elements are between Yagi elements for 20 meters.

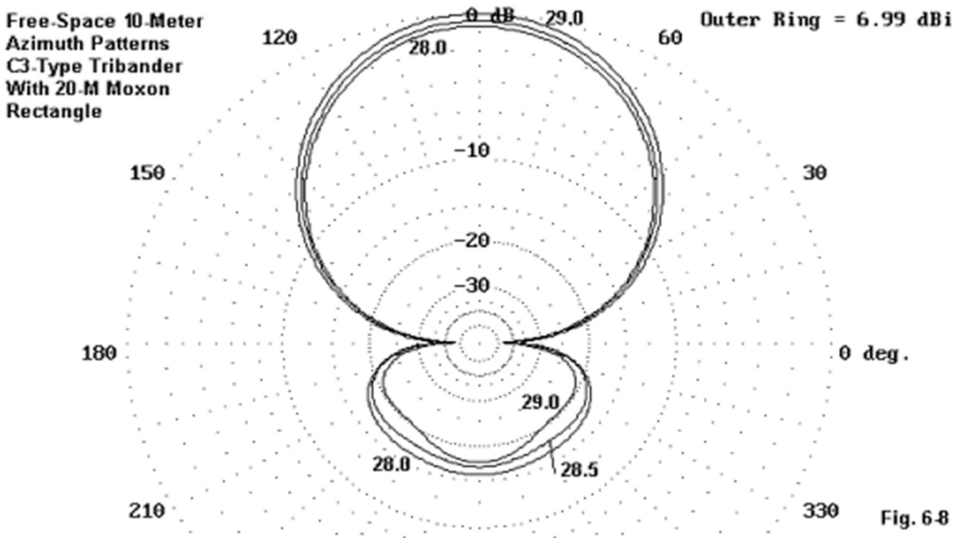


Fig. 6-8

In similar fashion, the 10-meter performance—as sampled in the free-space azimuth patterns of **Fig. 6-8**—also replicates closely the performance on 10 meters by the original array. The following table, when compared with the corresponding table for the original antenna, confirms how closely the two perform.

Freq. MHz	F-S Gain dBi	F-B Ratio dB	Beamwidth Degrees	Feed Impedance R +/- jX Ohms	50-Ohm SWR
28.0	6.32	15.14	67.0	57.4 - j34.7	1.92
28.5	6.61	16.51	67.4	46.8 + j 0.7	1.07
28.9	6.90	17.38	68.0	36.5 + j26.8	1.99
29.0	6.99	17.51	68.2	33.0 + j33.2	2.43

In principle, then, it is possible to replace the 20-meter elements in a C3-type antenna with Moxon rectangle elements with no loss of performance and only a change in the nature of the 20-meter patterns that reflect the differences between a 2-element Yagi and a Moxon rectangle. In principle, one obtains a smaller array that might fit in spaces in which a full-size C3-type antenna might not fit.

The Differences Between Principles and Practice: The design exercise has established a principle, but there may be numerous problems to overcome in translating the principle into practice. Although I have mentioned a few along the way, let's review what they might be in one place.

1. *Modeling limitations*: I have called attention to the fact that NEC-2 and NEC-4 have limitations associated with closely spaced wires having different lengths and diameters, even when one is careful to set up those wires so that the segment junctions align as closely as possible. The closeness of the slaved drivers to the fed driver, especially on 10 meters, suggests that the element dimensions and spacing are only starting points. They will require considerable adjustment in practice. For the 10-meter slaved driver forward of the fed driver, here is the guideline.

A. Increasing the element length decreases the feedpoint resistance and makes the reactance more inductive (or less capacitive). Decreasing the element length does just the opposite, increasing the feedpoint resistance and making the reactance more capacitive (or less inductive).

B. Closing the spacing decreases the feedpoint resistance and makes the reactance more capacitive (or less inductive. Opening the spacing increases the resistance and makes the reactance more inductive (or less capacitive).

If this is your first open-sleeve coupled beam, be extra patient. It is easy to forget the guidelines and adjust the wrong parameter. If that happens and the feedpoint values appear to be going awry, return the slaved element to its original length and spacing and start the procedure again. Make very small changes between feedpoint measurements until you get a good feel for how much each increment of change affects the feedpoint impedance.

2. *Element diameter taper and other construction points*: The models use uniform-diameter elements, which is normally impractical on the HF bands. For a practical antenna, one must first reconstruct the model using the element taper schedule that reflects proposed construction. The linear elements can be re-sized using Leeson correction factors. However, these corrections only apply to linear elements. Hence, the Moxon elements may require either the use of NEC-4 to obtain a reasonably reliable model or considerable experimentation during construction.

However, all is not thrown into a murky bog by this limitation. The Moxon elements can be built and tested independently. Once established, the remaining elements have almost no effect upon them. (Similarly, the 20-meter elements of the original array are almost wholly unaffected by the addition of the elements for 15 and 10 meters.)

There have been many techniques used for the construction of Moxon corners. One can bend aluminum around various forms by first filling the tubing with sand and then—if possible—warming it. However, numerous Moxon builders have found pre-bent sections of aluminum in many places. Among the most original was the use of leg-sections from lawn chairs that had been placed on a pile of discarded items. CPVC (thin-wall PVC) makes a cheap and reasonably rigid separator for the element ends. Polycarbonate tubing would be superior from a UV and RF perspective, but CPVC is quire serviceable.

Finally, it is wise to develop a simple bracket to keep the fed driver and the two slave drivers well aligned. Sheets of acrylic, plexiglass, or polycarbonate placed about 6-7 feet outward from the boom and "trapping" all three drivers will reduce SWR excursions created by winds that wave the elements out of step with each other.

This design exercise is, in the end, only a proof of principle and an invitation to those who wish to experiment further. However, for those with too little space for the original, the Moxon version may—with considerable construction care—prove to be a feasible alternative.

The OptiBeam OB6-3M: Since developing the models for the modified C-3-type antenna, I have encountered a new beam that resembles on the surface the C-3. OptiBeam of Germany makes a line of multi-band Yagis that differ from the Force 12 line in 2 respects: the OptiBeams use a method of directly feeding all drivers and the beams themselves are somewhat heavier in construction.

I suggested to the makers indirectly that they might consider Moxon-izing their smallest model, and they have done so. Thier OB6-3M is a 6 element, 3-band beam using a Moxon rectangle for 20 meters. Relative to the C3-type antenna, the Opti-Beam small model uses only 2 elements on 10 meters, placing the driver behind the 20-meter element with only 1 director. The makers claim a wider operating bandwidth for this arrangement. Since I do not have a version of the antenna on hand, I cannot vouchsafe for the claimed specifications, but they are quite similar to those noted in the study above.

Reality sometimes does catch up with antenna modeling.

The Possibility of a 2-Band Moxon

Since I began investigating the Moxon rectangle design, I have received numerous inquires about whether it is feasible to nest 2 or more of these antenna in the same plane. It is certainly possible to create a “Christmas tree” of Moxon rectangles, each with its own feedline. However, nesting 2 or more Moxons in the same plane presents some difficulties. G6XN did so with his wire multi-band array. However, this array used remote (antenna tuner) tuning for each element, as well as some decoupling arrangements. Although this system can be quite effective, it adds complexity to the operation of the antenna. The design goal for this effort is an antenna that requires no tuning and that can be fed with a single 50-Ohm coax transmission line.

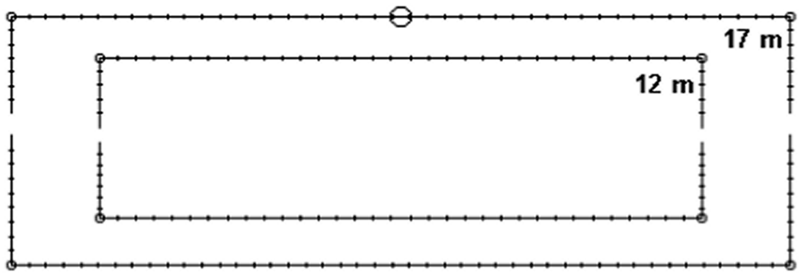
For the harmonically related ham bands, I have modeled pairs of nested Moxons using open-sleeve coupling. However, I have never recommended the designs. The high-band antenna within the lower band array displays very narrow bandwidth, both with respect to the resulting feedpoint impedance and with respect to the gain and front-to-back ratio characteristics. Hence, the designs would not have been satisfactory for these wider ham bands.

However, the WARC bands are inherently narrow, covering no more than 100 kHz maximum. Thus, the possibility for a dual-band WARC Moxon became a live possibility. **Fig. 6-9** shows the outlines of the final model.

At first sight, it would appear that the dual Moxon is a distinct possibility for home construction. With a boom just over 7' long, it would seem to make a nearly ideal compact antenna for 17 and 12. Unfortunately, I cannot recommend the array.

The main reason for not recommending the array is the exceptional finnickiness of the required adjustments. If we compare the rate of change for both the gain and front-to-back ratio for the two bands, we discover a major difference: on 12 meters, the rate of change is over twice as fast as on 17. The consequence of this fact is that any slight variation in construction from the model could result in very large changes in performance.

Outline of a 17-12-Meter Dual Moxon Rectangle **Fig. 6-9**



Remember, too, that any open-sleeve coupled element pair requires careful adjustment on its own. When combined with rapidly changing performance characteristics for tiny changes in dimensions, arriving at a usable match and having good performance may prove to be beyond reasonable construction methods.

An additional aspect of the difficulty is the fact that the two Moxons force on each other changes in dimensions relative to the dimensions needed for independent use. In short, the two Moxons are essentially too tightly coupled throughout their structure to make the task of finding exactly the right configuration feasible, let alone easy.

However, since the antenna is just under 20' wide (slightly narrower than a 15-meter Yagi, even though the frequency is lower), we might be willing to try a 10' boom. At this length, we may be able to develop a 17-12 combination far more easy to adjust.

A Moxon-Yagi Combination: It is much more convenient to combine the Moxon for 17 meters with a 12-meter Yagi. Unfortunately, placing a driver-reflector Yagi inside the Moxon does not work, since the required length of the reflector would overrun the side arms of the 17-meter Moxon. However, we can place a director-drive combination ahead of the Moxon.

In commercial antennas, the highest band (10 meters) usually requires several elements to achieve a combination of good operating bandwidth and gain. The WARC bands do not have significant bandwidth requirements. Hence, we can use a simple director-driver combination to achieve results that are compatible with the basic performance of the Moxon for 17 meters. **Fig. 6-10** shows the outline of the resulting design.

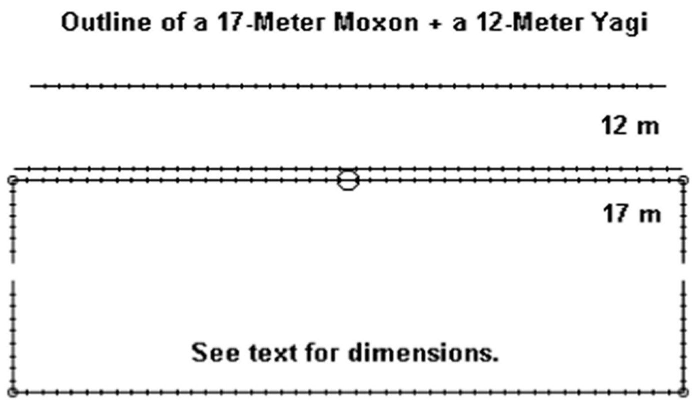


Fig. 6-10

The basic design uses 0.75" elements for 17 meters and 0.5" elements for 12 meters. Changes in element diameter will require adjustment relative to the following table of dimensions. For the Yagi portion of the design, "Space" refers to the distance from the Moxon driver to the 12-meter element in question.

Band	Dimension	Length (feet)
17-meter Moxon	(all elements use 0.75" diameter aluminum tubing)	
Moxon	A	19.56'
	B	2.74'
	C	0.625'
	D	3.68'
	E	7.04'
12-meter Yagi (all elements use 0.5" diameter aluminum tubing)		
Driver	Length	19.40'

	Space	0.35'
Director	Length	18.50'
	Space	3.08'

Perhaps the first thing to notice is the set of dimensions for the 17-meter Moxon. These dimensions are unchanged from those for a design optimized for independent use. The presence of the Yagi elements ahead of the Moxon does not affect the Moxon itself to any significant degree—that is, to a degree requiring redesign. The following performance table provides the data to show this even more clearly.

Frequency MHz	Gain dBi	Front-to-Back Ratio dB	Feedpoint Z R+/-jX Ohms	50-Ohm VSWR
18.068	6.41	20.0	62.9 - j 7.9	1.31
18.118	6.34	22.6	67.2 - j 7.3	1.38
18.168	6.27	25.8	71.4 - j 7.1	1.46
24.89	6.78	29.2	58.7 + j 9.3	1.26
24.94	6.86	30.2	52.1 + j 7.4	1.16
24.99	6.94	28.2	44.4 + j 7.0	1.21

The performance of the Moxon is altered by a small amount, as shown in **Fig. 6-11**. The presence of the 12-meter elements creates a slight "director" effect on

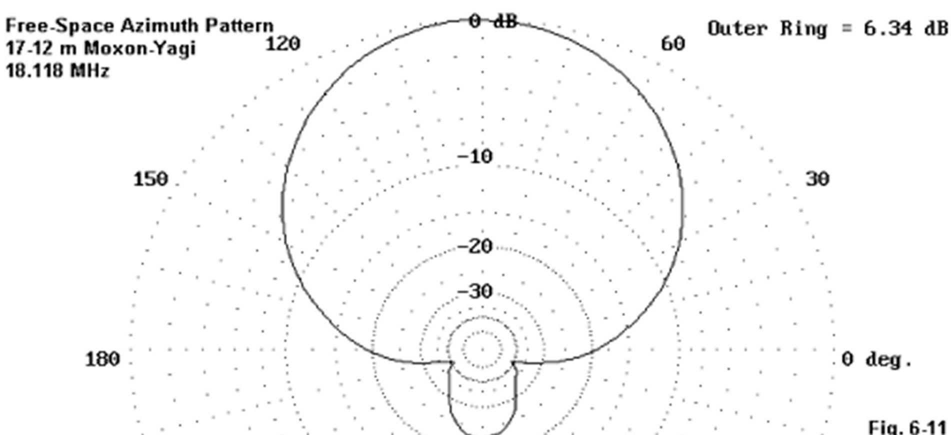


Fig. 6-11

the Moxon, which lowers the front-to-back ratio a small amount and which raises the feedpoint impedance somewhat from the 50-Ohm design specification for the antenna when used independently. The amount was considered too small to require design revision. In exchange for the slightly reduced front-to-back ratio—still at least 20 dB across the 17-meter band—the director effect gives a small boost to gain—about 0.3 dB. This will be too small to notice operationally, but every little bit helps.

On 12 meters, the director-driver combination exhibits a standard Yagi pattern, as shown in **Fig. 6-12**. The gain of the array on 12 meters is greater than the 2 12-meter elements would normally provide. The "forward-stagger" effect provides a small increase, since the Moxon elements provide a bit of a reflector effect. The 180-degree front-to-back ratio for 12 meters can mislead the user a bit, as **Fig. 6-12** also shows. Although the pattern has a fine dimple directly to the rear, the rear quartering lobes are down by only about 18 dB, for an average front-to-rear ratio in the 22 dB neighborhood. In fact, the 17 meter front-to-rear performance is superior overall, despite the lower 180-degree front-to-back ratio.

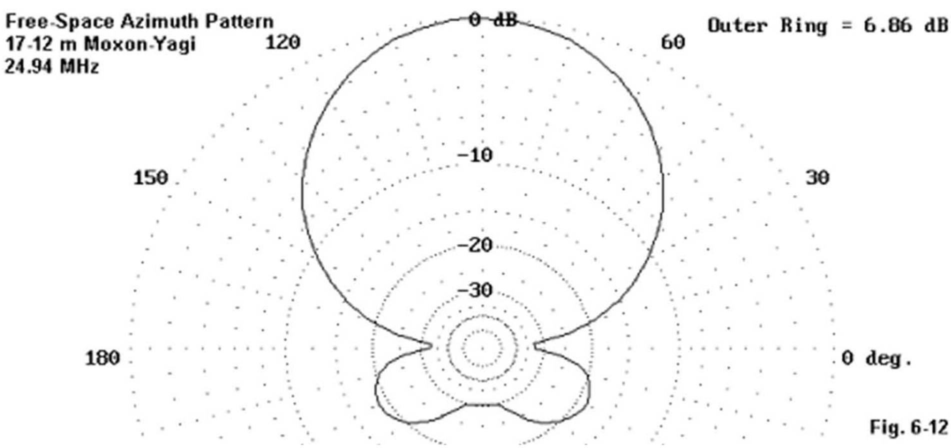


Fig. 6-12

The feedpoint impedance figures for 17 meters might be improved by a very small shortening of the side-to-side length (dimension A)—perhaps an inch or so. However, the reflector arms (D) should be lengthened by an equally small amount to restore and possibly center the front-to-back peak value within the operating passband on 17 meters. Indeed, it would be wise to make the reflector adjustment first to see the effect on the feedpoint impedance before adjusting the Moxon driver.

The key adjustment will be the placement and length of the 12-meter driver. Models of open-sleeve coupled elements always require subsequent field adjustment (a gentle way of saying “cut and try”). If the change of spacing relative to the given design is very small, then no further movement of the director will be required. If the change is more than a couple of inches, then readjust the director spacing closer to the value specified in the dimensional table in order to ensure that the array gives a satisfactory pattern. The juggling for 12-meters will have no significant effect on the 17-meter portion of the array.

The multi-band beam with a Moxon for the lowest band and slave-driven Yagi elements for upper bands is likely the most practical combination. However, it is not the only possible combination. Due to their very high front-to-back ratios, one may place 2 Moxon rectangles back-to-back with a quite small spacing and obtain full performance from each—in directions that are 180 degrees apart. The exact spacing would vary depending on the frequency used. However, a 12-10-meter combination might require as little spacing as 1-2 feet. The resulting overall boom-length would then be less than 12 feet.

Since the dimensions for the Moxon rectangles involved in back-to-back arrays are not at all different from the dimensions of isolated versions of the antenna, we need not provide a table of possibilities. Rather, the attached calculation programs and models will supply dimensions that are precise to the materials for the arrays. However, we do need to note 2 disadvantages of back-to-back arrays. First, they require separate feedlines to each of the antennas in the array. The two driven elements are at opposite ends of the boom. Second, in use, we cannot simply switch bands to check the propagation toward any given area. Instead, we must turn the beam 180 degrees to perform the check.

Nevertheless, the back-to-back properties of the Moxon rectangle will prove useful in certain applications, most notably in the VHF and UHF ranges. In fact, those higher frequencies are our next target.

* * *

Appended models used in this chapter:
mox-c3-2010.ez, c3-type-2010.ez, moxyag-1712.ez

7. VHF/UHF Designs and Applications

Moving the Moxon rectangle into the VHF and UHF ranges presents us with new opportunities and new challenges. The Moxon continues to exhibit the same patterns with which we have become familiar when we orient the array horizontally. However, vertical orientation opens the doorway to a number of new applications, including both foxhunting and repeater uses. The latter application is especially apt where repeater ranges overlap and we can make good use of a high front-to-back ratio combined with a very wide beam width. Those very qualities, combined with the ability to place the rear elements of Moxons in close proximity without significant interaction, make the antenna a prime candidate for polling arrays.

In this chapter, we shall sample two aspects of VHF/UHF Moxons. The first will be a simple task of constructing a 2-meter Yagi and seeing how the project differs from HF antenna building. The second will explore the potential use of Moxons in polling arrays.

Building a 2-Meter Moxon

What the Moxon Can Do: The basic azimuth pattern of a Moxon shows, at its design frequency, a deep null, with some forward gain. For most VHF uses, it is the pattern shape, with its very high front-to-rear ratio, that holds more interest than the antenna's gain.

Fig. 7-1 shows the azimuth pattern of a 2-meter Moxon when the antenna is vertically oriented and, hence, vertically polarized. Patterns are shown across the 2-meter band for a model designed for 146 MHz. Even though the deepest null occurs only in the vicinity of the design frequency, the front-to-rear ratio—accounting for the full rear quadrant—is very good anywhere in the band.

Moreover, as **Fig. 7-2** shows, the antenna has a very broad operating bandwidth. The SWR curve never reaches 1.4:1 anywhere in the band. For reference, here are band edge and center numbers for a modeled 3/16" element diameter Moxon placed at a height of 30', with readings taken at an elevation angle of 3 degrees:

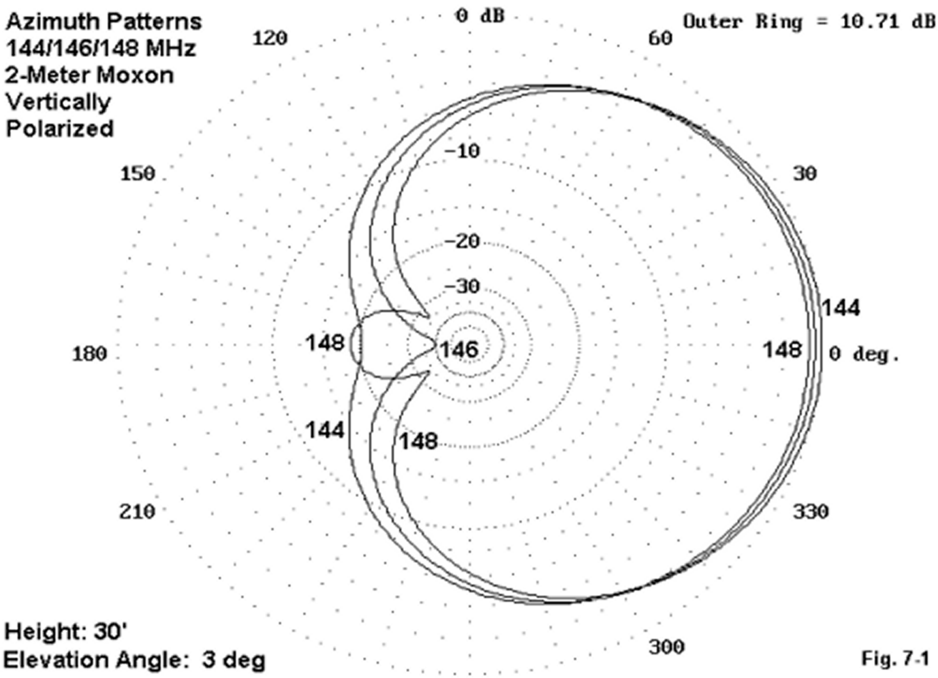
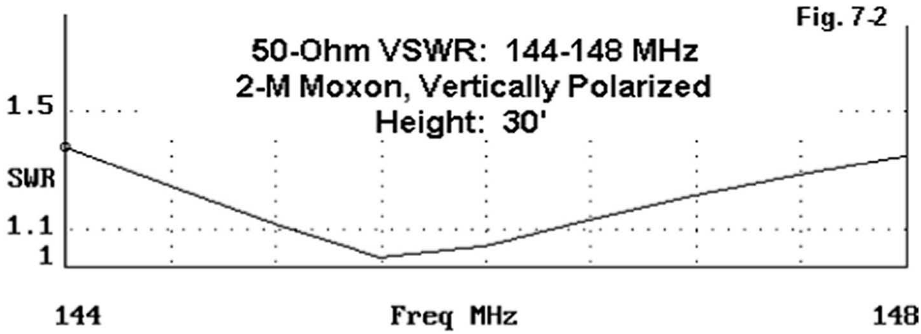


Fig. 7-1

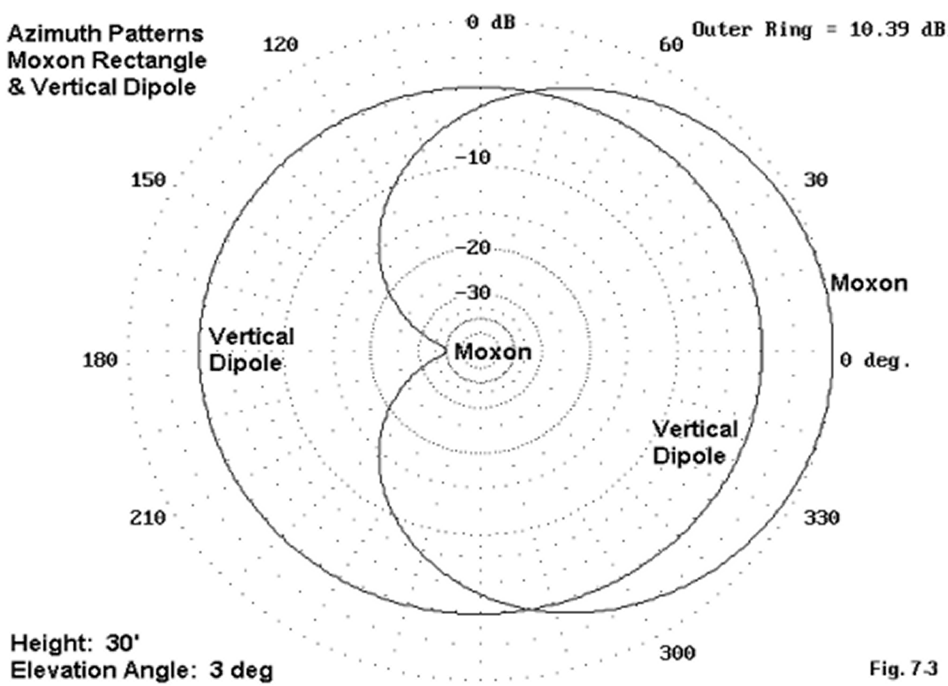
Freq. MHz	Gain dBi	F-B dB	Feed Z R +/- jX Ohms
144	10.7	18.6	40 - j 10
146	10.4	40.0	52 + j 1
148	10.1	19.7	63 + j 10

A 3-element Yagi might exceed the gain by about 2.5 dB, but would not equal the Moxon's front-to-rear pattern.

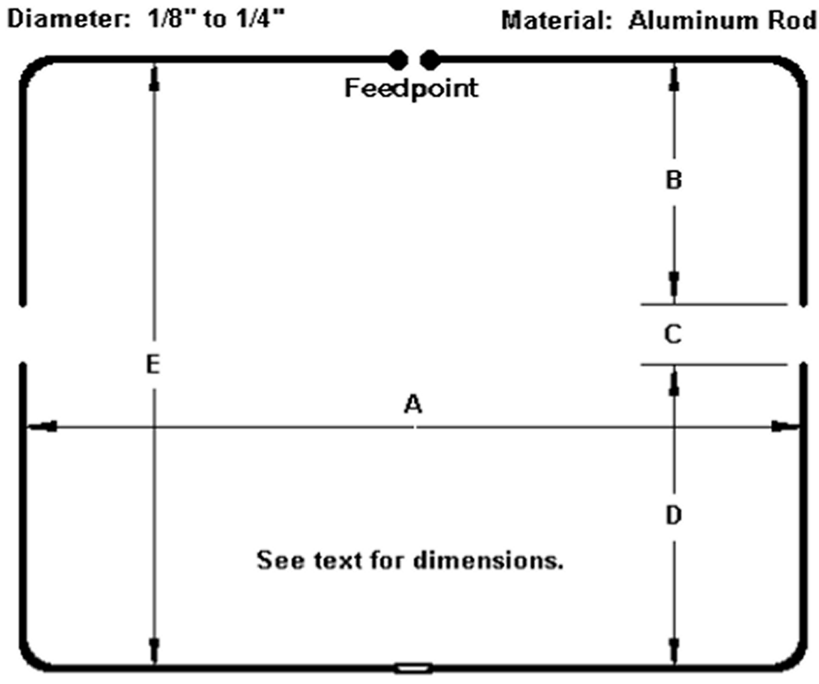
Vertically polarized, the Moxon can be useful in preventing interference when two repeaters use the same channel and can be accessed from some particular location. The fact that access is already possible suggests that gain is not an important consideration. However, reducing one's signal to the repeater not desired is a very significant goal. Likewise, at a repeater site itself, being able to direct one's signal away from a co-channel repeater may also be necessary on occasion.



The advantage of the Moxon over the standard vertical antenna shows clearly in **Fig. 7-3**. The model uses a vertical dipole, but patterns for a monopole with ground-plane radials or a J-pole would be very similar to those for the dipole. The most important portion of the graphic to examine is where the Moxon pattern does



not go. Since my area has a number of very strong repeaters in many directions, I decided to test the Moxon by building one.



General Outline: 2-Meter Moxon Rectangle **Fig. 7-4**

The Basic Antenna Configuration: **Fig. 7-4** shows the basic outline of a Moxon rectangle for 146 MHz using 3/16" aluminum rod elements. The following table lists dimensions for a variety of materials, ranging from AWG #12 wire (0.0808" diameter) up through 1/4" tubing or rod.

Material	A	B	C	D	E	Total DE	Total Ref.
AWG #12	29.17"	4.05"	1.17"	5.56"	10.78"	37.37"	40.29"
1/8"	29.10	3.93	1.28	5.58	10.79	36.96	40.26
3/16"	29.03	3.80	1.40	5.59	10.79	36.63	40.21
1/4"	28.98	3.71	1.48	5.60	10.79	36.40	40.18

The most changeable dimensions are the overall driver length and the gap (C). They change in opposite directions, so the overall front-to-back dimension (E) remains close to constant.

I selected 3/16" aluminum rod initially because I had some on hand from another project. However, for full band coverage with maximal front-to-back values, 3/16" rod (a bit over 4 mm) or larger material is necessary.

The antenna and support details appear in **Fig. 7-5**. Looking at details B-B and C-C, we can see the plan of assembly and feeding. The antenna will consist of 4 rods, each threaded to 10-24 on one end. The driver will have pairs of 10-24 stainless or aluminum nuts to hold terminal rings from the feedline. The reflector half-elements will join in a stainless steel coupling nut (a short piece threaded all the way through). You can purchase these or make one from a small piece of 1/2" by 1/2" aluminum stock. Simply drill though the piece from end to end and tap the required 10-24 threading.

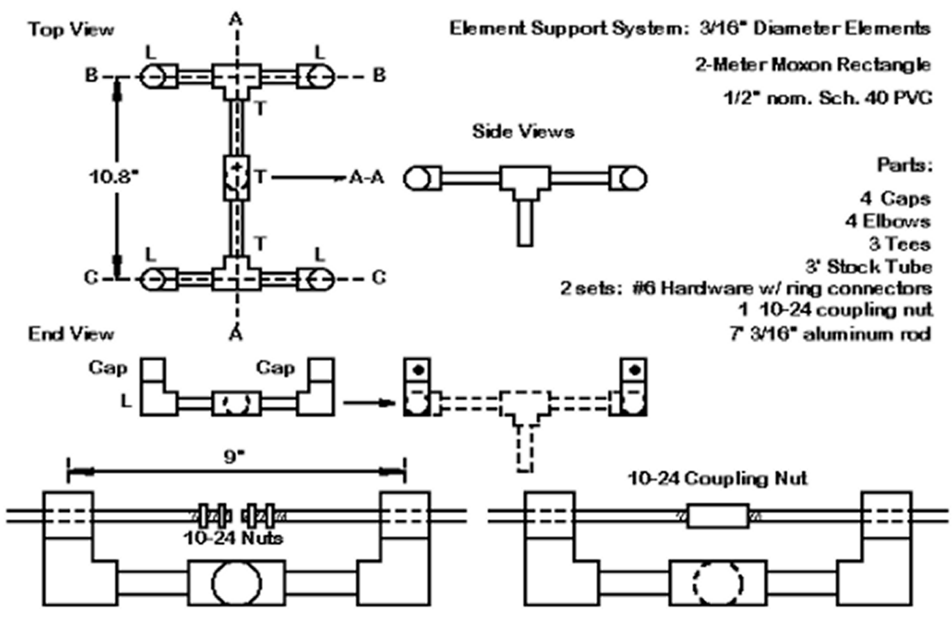


Fig. 7-5

My favorite antenna support material is Schedule 40 PVC. As frequency increases, I like to minimize contact with the material. It would appear that Schedule 40 PVC varies in exact composition from one part of the U.S. to another. In some places, UV retardants are effective, while in others, they are either ineffective or non-existent. Likewise, RF characteristics may vary from one manufacturer to another. By minimizing contact with the elements, any RF deficiencies in the PVC have little or no effect on the antenna.

In **Fig. 7-5**, you can see the scheme I used. 1/2" nominal PVC is glued into a T, with elbows pointing upward in the sketch. The elements pass through end caps. These caps and the pipe stubs necessary to cement them to the elbows permit the use of set screws that pass through threaded holes in the double thickness of PVC. With threading that deep, set screws work well, although other methods can be used to ensure that the element do not move. One system that also works is to use short pieces of plastic tubing over the rods between the PVC supports and the nuts.

Fig. 7-5 also shows a center Tee fitting for connection to a mast. This fitting is optional and would be suited more to the horizontal use of the antenna. Lets look at the alternative I actually used in **Fig. 7-6**.

When vertically orienting the Moxon, a rear support system is very useful. We can make one up out of more PVC fittings and pipe. For my test antenna, I used a single PVC pipe section between elements, with the reflector center point holding a 4-way cross fitting. Another pipe stub proceeds rearward and friction fits into the Tee in the support. I drilled two sets of holes through the stub so that I could change the antenna's orientation from vertical to horizontal and back by removing only a single bolt.

The support consists of a straight section and an angular section, forming a strong triangle. The terminating sections are 1.25" to 1/2" adapters sections. The antenna support pipes fit into the 1/2" side ports, while the 1.25" through sections receive piping of the same size to fit over a standard TV mast. Clamps mounts are shown, although one might also use set screws. The space between the upper and lower adapters can consist of the short clamps pipe sections shown, or the space can be filled with a single section of 1.25" nominal PVC. The resulting structure flexes a bit, but stands up to abuse very well.

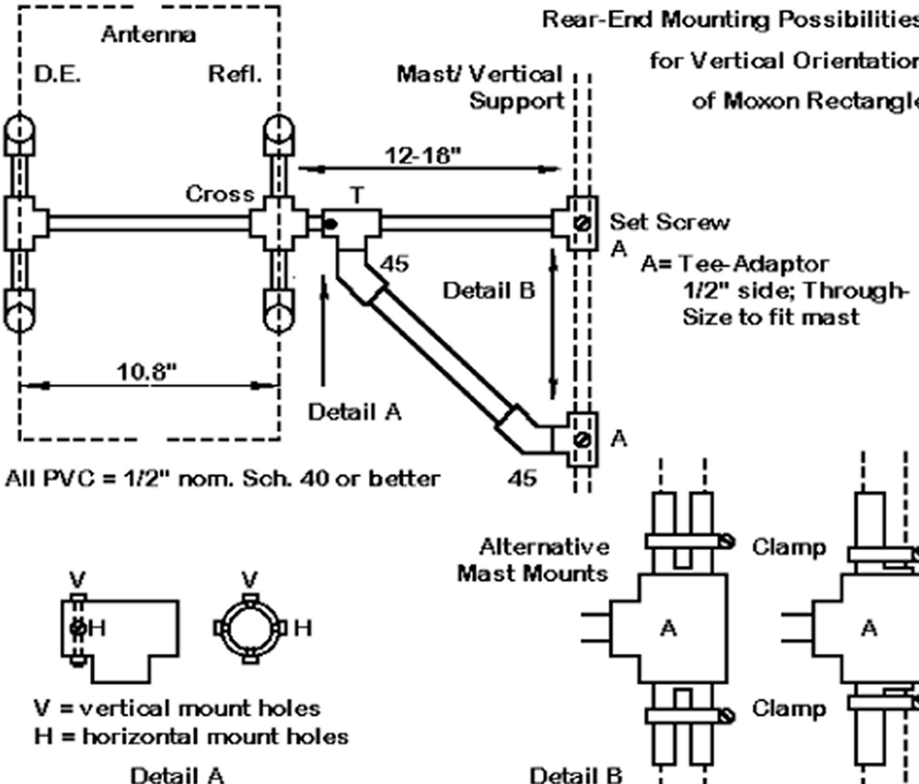


Fig. 7-6

One of the keys to building a good PVC structure is to be prepared in advance for aligning portions of the structure that must be at right angles or parallel to each other. PVC cement may give you as little as 15 seconds before glued parts become immovable. I have cataloged a number of right-angle junctions in the shop suitable for aligning PVC pieces. Among them are legs and other supports for the work bench. If a Tee or an elbow requires fitting, I usually put a scrap of pipe dry into the open end. The longer section makes alignment much easier than a junction stub. I simply glue the junction in question and then press it against my sturdy preformed angle.

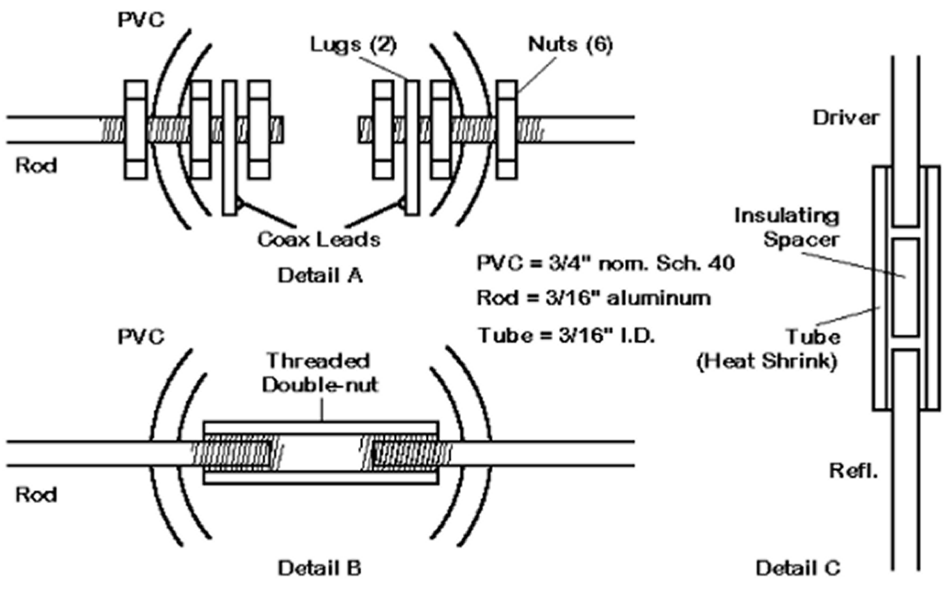
For the element mountings in their caps, I first cemented the junction pipe stubs in the caps. (These stubs will be glued into the elbows later.) Then I drilled the caps and stubs together. A drill press makes easy work of centering the holes on both sides of each cap. Next, I pushed each pair of caps over a scrap of 3/16" diameter rod to keep them aligned while cementing each one into its corresponding elbow joint. These and similar techniques simplify making almost any conceivable structure from PVC parts.

Bending rod elements is most simply done with a copper tubing bender, a small device that can be found at most hardware depots. The bender will make a 1" radius bend. 3/16" rod and smaller will easily handle bends of this radius with no noticeable weakening or visible cracks. I first cut each element section to length and mark the point (away from the threaded end) that corresponds to one half the side-to-side width. I place this point in the middle of the 90-degree bend. This technique has yielded results identical to those predicted by models using sharp corners.

Some Alternative Mounting Structures: The cradle shown in **Fig. 7-5** and **Fig. 7-6** can be modified for other materials. For example, the Moxon can be made from aluminum strap or flat stock easily obtained from hardware depots. The only change required in the construction techniques shown so far is to replace the cap holes through which the rods pass. In their place, cut slots in each cap to a depth of at least 2/3 the width of the aluminum flat stock used. 1" wide by 1/16" thick stock makes a good assembly, and set-screws will hold the pieces in place, especially if the flat stock is tapped for the set screw thread. In addition, flat stock can be bent into tighter radius corners. (However, be sure there is at least a small radius—perhaps 1/8"—to prevent the stock from cracking.)

For this version of the antenna, the overall side-to-side width should be about 28.2" or a bit shorter than the rod model. The front-to-back overall width should be about 13.2" with a 2" gap to separate 4.4" driver tails and 6.8" reflector tails. The wider gap emerges from the greater surface area between ends. However, widening the gap requires alteration to the other dimensions to achieve a 50-Ohm feedpoint impedance. The strap alternative shows a marginally higher gain (about 0.1 to 0.2 dB) due to the slightly squarer rectangle that emerges. In addition, it also shows a lower reactance swing across the band (+/-6 Ohms, compared to +/- 10 Ohms for the round elements), resulting in a slightly shallower SWR curve.

Rod elements can be used in a simplified structure composed of 3/4" nominal Schedule 40 PVC, as shown in **Fig. 7-7**.

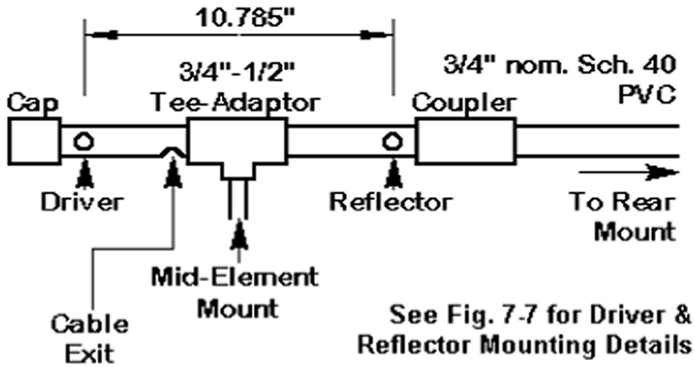


Alternative Construction Details

Fig. 7-7

A single boom holds this version of the Moxon together. The sketch shows both a Tee for balanced horizontal mounting and a coupler for rear mounting suitable for vertical or horizontal orientations. The front cap is simply a brace to prevent the slow distortion of the boom from the weight of the driver, which passes through the tube. Note the hole in the boom for passing the feedline from inside the boom to the external world.

Fig. 7-8 shows some of the mounting details. As in the initial version of the antenna, the 4 rod element sections are threaded (10-24) on one end. The driver is pinned to the walls of the boom tube by inside and outside nuts, while another set of nuts secures the ring terminals from the feed line. A coupling nut holds the reflector ends together. Be sure these are screwed in place before securing the open ends of the tails in their final alignment, since turning the coupling nut will simply loosen one end while the other one tightens.



Alternative Boom & Mount Details **Fig. 7-8**

Once the tail gaps are adjusted, they can be secured by a length of tight-fitting tubing and a spacer, as shown in **Fig. 7-7**. To keep an air gap between the ends, you can omit the spacer and use heat shrink tubing. I usually use a double thickness of tubing, shrinking them one at a time. The outer piece is a bit longer than the inner piece, to cover the inner piece ends. Of course, a rigid piece of plastic tubing with set screws that set into dimples in the tail ends would work as well.

The variations on these techniques are without end. However, these few will provide a basis for some creative uses of adapted materials that you may have available.

Adjustments and Tests: The first task after placing all of the Moxon element pieces in their PVC holders and attaching the feedline is to adjust and temporarily lock the gaps between element ends. The first rod Moxon showed a 50-Ohm resonance at about 145.5 MHz, just about where the design placed it. The SWR curve over the 2-meter band was too close to the modeled curve to need retracing.

It is usually dangerous to assume that, because an antenna is tuned to provide a good match for the feedline, it will also show the modeled gain and front-to-back ratio. However, in this case, the antenna geometry that determines the source impedance also determines the pattern shape. Since the elements were uniform in diameter, there was no reason to expect any performance surprises. Therefore, I locked the assembly tight and moved on to performance tests.

The Knoxville, TN, area has repeaters from close to 145 MHz up to nearly 148 MHz. All of them are easily accessed and heard at full quieting from my location with only a low elevation ground-plane vertical. In fact, a telescoping whip on my hand-held will access all of our main repeaters. On a 15' mast, the Moxon made telephone copy of all of the repeaters when the antenna pointed anywhere near the forward direction to them. A distant repeater that I hear poorly on a vertical was now full quieting. The Moxon's gain can make a difference for signals at the FM threshold.

When the antenna faced away from the repeaters, only 1 of 6 that I checked could still be heard, and then at far less than full quieting. I could not access any of the repeaters with 5 watts of power—the limit of my gear.

I repeated the test using two hand-helds on simplex across the FM portion of the band. Differences in the patterns at the band edges and at the design frequency were not especially detectable at distances of a quarter mile. Face forward, communications was easy and full quieting. With the antenna pointed in the other direction, communications was virtually impossible. More power at one or the other end of the line might have broken through, but that can be said for almost any system.

The proto-type vertical rod Moxon has proven a very effective antenna at blocking unwanted signals from the rear. I fully suspect that it would be effective in limiting reflected signals from rearward objects because so little signal is radiated in that direction.

The Moxon can be scaled for 220 or 440 MHz use—so long as one remembers also to rescale the element diameter or to make appropriate adjustments in dimensions if a scaled element cannot be used. The thinner the wire relative to the original, the smaller the gap; the fatter the element, the wider the gap. Other dimensions will also alter slightly to obtain the maximum null at the new design frequency, with the resonant point slightly lower to obtain full operational coverage of a band or the subsection of interest.

Of course, the simplest design procedure is to use one of the dimension-calculating programs or models attached to this volume. However, there is one limitation to the program. Above about 300 MHz, every set of dimensions requires checking against a modeling program such as NEC-2 or NEC-4 (for example, EZNEC or NEC-Win Plus). MININEC 3.13 is usable only if corrected for its inherent frequency bias, for example, as done in the Antenna Model version by Terisoft. As well, one might consider creating 440-MHz and higher frequency Moxons on printed circuit boards. PC fabrication would require considerable revision of the calculated element values, given the wide, thin nature of the elements.

A 3-Moxon Polling Array for 914 MHz

The use of multiple antennas in a polling system—especially for repeaters—is common practice. Independent receiving antennas can be placed at specially selected sites to overcome terrain and other problems that reduce received signal strength and prevent effective use of the repeater. The left portion of **Fig. 7-9** shows the basic outline of such a system.

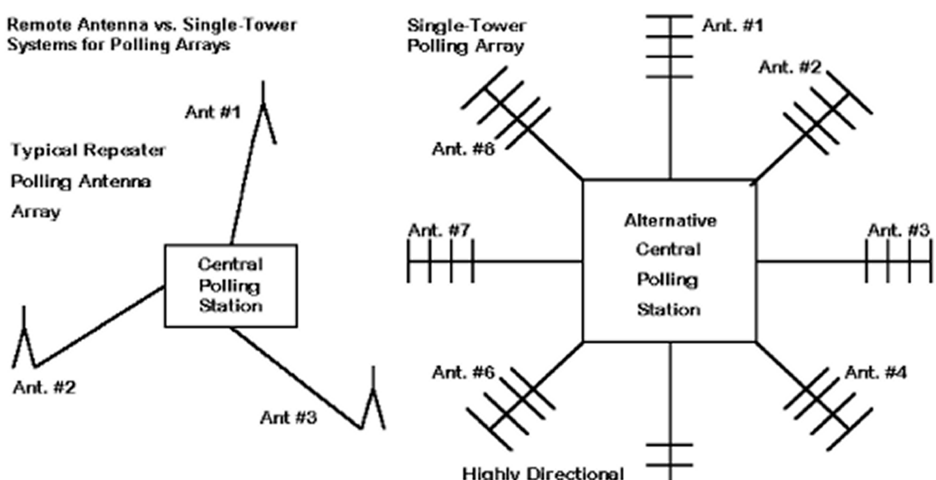


Fig. 7-9

The actual polling in a system of this order occurs at a central receiving site, which is ordinarily the transmitting site as well. Signal strength, easily measured in terms of audio fed to the central station via phone or other hard-wire lines (or even via RF links), determines which antenna-receiver is allowed to send its signal to the repeater transmitter.

A one-tower alternative, used in public service communications, appears in the right portion of the figure. The principle of this system is to use a collection of relatively high gain antennas—such as multi-element Yagis—in a polling system located at atop a single tower. The number of antennas required is a direct function of the gain of the individual antennas. More accurately, the number is determined by the horizontal beamwidth, so that coverage is overlapping with no excluded sectors. Since gain tends to be roughly proportional to boom length and element numbers in well-designed arrays and since beamwidth tends to be inversely proportional to these numbers, the higher the gain of individual antennas, the more we require to provide the desired coverage.

In most systems, the user antenna will be vertically polarized, so the Yagis in the polling system will also be vertically polarized. The beamwidth in this mode tends to be greater than the beamwidth of the same antenna when horizontal, so fewer antennas can do the job.

However, arrays of long-boom Yagis tend to show rear lobes that interact with other antennas in the array of Yagis. This phenomenon tends to force wide separation of the antennas so that an effective array can have a considerable radius, even at frequencies nearing 1 GHz. In many cases, the gain of long-boom Yagis is unnecessarily high for a desired level of coverage. However, short boom (2-element) Yagis tend to have poor front-to-back ratios (10-12 dB maximum), enforcing the same wide separation of antennas.

For lower gain (6 dBi or about 4 dBd) systems, the polling array can be simplified and physically compressed through the use of vertically oriented Moxon rectangles. To test what is possible, I took a long modeling look at the Moxon rectangle scaled and adjusted for maximum performance at 914 MHz (in the amateur 33 cm band). A single rectangle for this band is a very small affair. **Fig. 7-10** outlines the basic Moxon rectangle, with dimensions in millimeters and element diameters standardized at 4 mm.

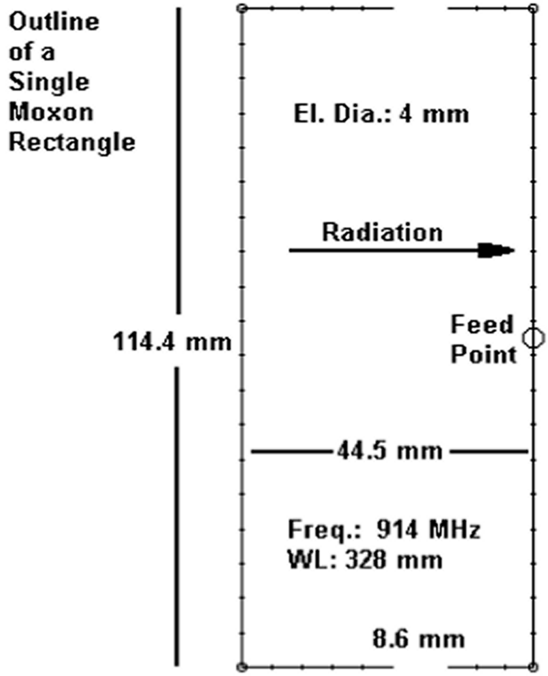


Fig. 7-10

The modeled and calculated dimensions for this antenna form an interesting test of the claculation program ability to handle antennas above 300 MHz. All dimensions are in millimeters for the 4-mm diameter elements.

Dimensions	A	B	C	D	E
Modeled	114.4	12.9	8.6	23.0	44.5
Calculated	116.5	12.9	7.9	22.9	43.8

Only the side-to-side dimension and the gap show any significant variation between the two methods of finding usable dimensions for the 914-MHz Moxon. The calculations thus appear to be adequate as a starting point for modeling Moxon rectangles in the 1 GHz range.

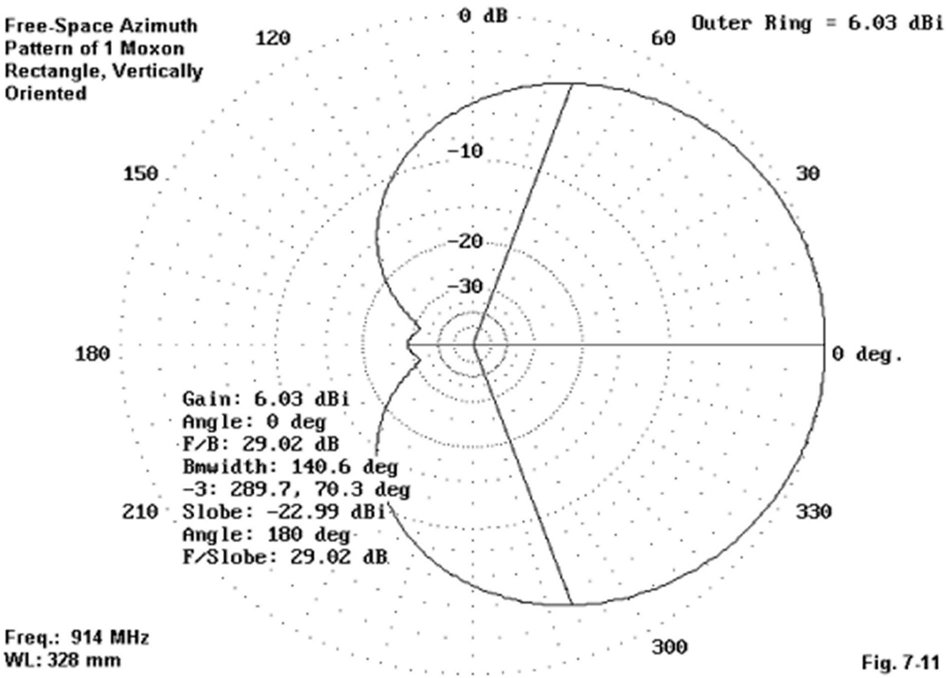


Fig. 7-11

The Moxon rectangle measures under 2" wide and under 5" side-to-side at 914 MHz. It shows a free-space gain of about 6.0 dBi, with a front-to-back ratio of over 29 dB, as shown in the azimuth pattern in **Fig. 7-11**. This particular version of the rectangle was optimized for a 50-Ohm feedline and shows a feedpoint impedance of 50.8 - j0.6 Ohms on the target frequency. Of special note is the -3 dB horizontal beamwidth of nearly 141 degrees. The antenna becomes a serious candidate for a simple one-tower polling array.

A Minimum-Spacing 3-Moxon Polling Array: Because the Moxon rectangle is relatively insensitive to influences to its rear, it is a candidate for a very small radius array. The wide beamwidth of the antenna suggests that an effective array can be constructed using only three of the antennas. A typical experimental array for 914 MHz appears in **Fig. 7-12**.

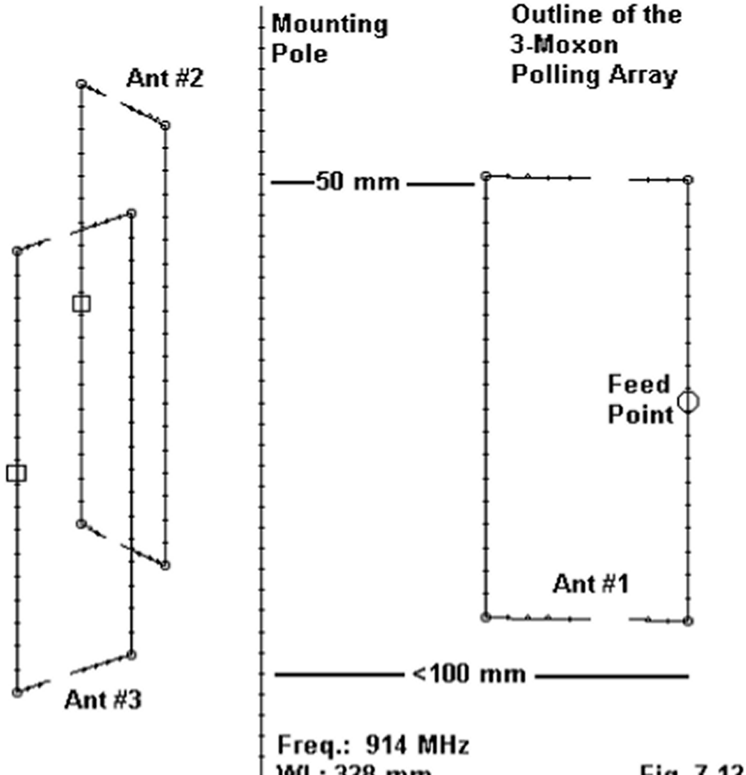


Fig. 7-12

The model for this array consists of 3 identical Moxon rectangles, each the very same as the single Moxon. The only difference is that each Moxon points in directions 120 degrees apart. As well, each model is displaced from the Z-axis by a certain distance.

I modeled the array for a 50-mm separation of each antenna from a central axis. The radius of the result is under 100 mm (4"). The sketch shows a central mounting pole, and loads (squares) at the feedpoints of the unused (or inactive) antennas. In fact, I modeled the system in 4 separate ways: 1. with and without a metal central mounting pole (25 mm), and 2. with the feedpoints of the unused antenna closed and open. To open the unused feedpoints, I simply inserted a resistive load of 10E10 Ohms. In tabular form, the results of the variations are as follows.

Array Performance with Antennas 50 mm from Center

Arrangement	F-S Gain dBi	Front-to-Back Ratio dB	B/W deg.	Feedpoint Z R +/- j X Ohms
1. No pole, closed f-p	6.69	15.95	120	52.3 - j 1.6
2. No pole, open f-p	6.56	16.58	123	52.0 - j 1.6
3. Pole, closed f-p	6.70	14.39	114	53.4 + j 0.6
4. Pole, open f-p	6.60	15.96	119	53.4 + j 0.5

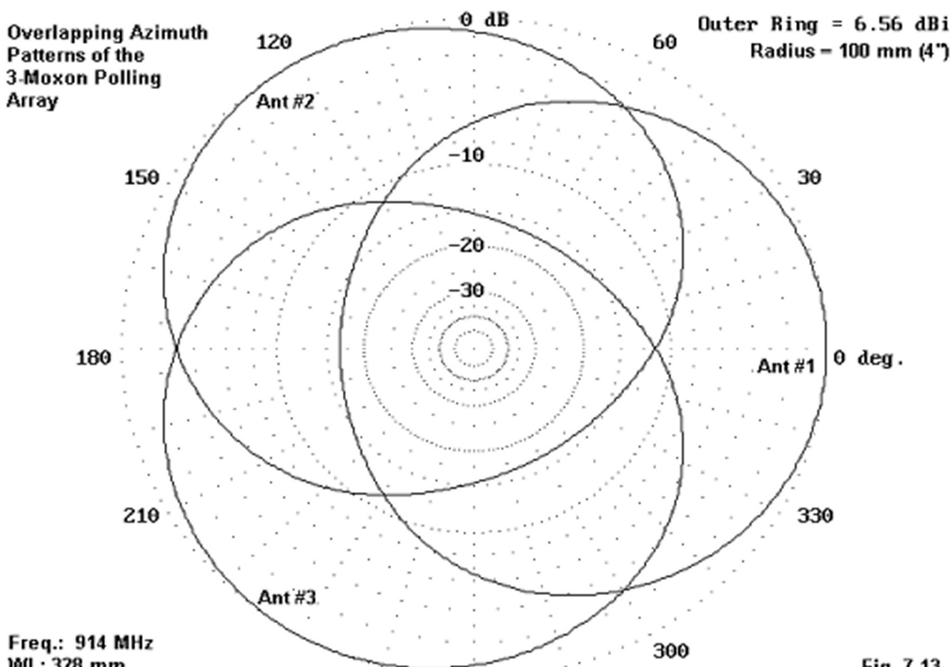


Fig. 7-13

Overall, the close proximity of the individual antennas in the array is reaching a limit. The effects of the unused antennas show up as increased gain in the active antenna, accompanied by a decrease in the front-to back ratio. **Fig. 7-13** shows the overlapping azimuth patterns of the three antennas in the array for case 2, which uses a form of RF-transparent mounting. The pattern cross-over points are almost precisely at -3 dB points on the individual patterns. The front-to-back ratio should be sufficient to prevent any “falsing” of the system.

Despite the small differences in whether the unused antennas have open or closed feedpoints and whether or not a metal mounting pole is used, option 2 remains the method of choice for any implementation of this system. The addition of a metallic mounting pole decreases the front-to-back ratio significantly and, as well, reduces the -3 dB beamwidth below the desired 120-degree value. The modeled mounting pole does show more than a minuscule current magnitude.

Using open feedpoints for the unused antennas provides the highest front-to-back ratio and the widest beamwidth for the array (123 degrees). Given the usual disruptive influences in normal antenna mounting situations, beginning with the best configuration reduces the effect of unpredictable factors in degrading system performance.

This smallest feasible system offers some physical advantages to installations. At the test frequency, the entire set of 3 antennas, plus a small electronic changeover unit or central cable terminal block, can be installed under an RF-transparent dome for complete weather protection. The diameter of the dome could be as small as 200 mm (about 8"), and the height would be determined more by the electronics and connectors than by the 120 mm (5") need to clear the antennas. Indeed, it would be feasible to use more than one Moxon spaced up to 1 wl center-to-center to increase the gain in each direction without creating a structural problem in the dome.

Widening the System: The degree of isolation among the antennas increases rapidly as one widens the spacing of each antenna from the center point. If we double the distance from 50 mm to 100 mm, the array radius grows to about 150 mm (about 6"). At the same time, the individual patterns come closer to their form when a single Moxon is tested. See **Fig. 7-14**.

The patterns shown are for the use of a non-metallic mounting pole and for open unused feedpoints. The following table compares the array values at the wider spacing with both open and closed unused feeders.

Array Performance with Antennas 100 mm from Center

Arrangement	F-S Gain dBi	Front-to-Back Ratio dB	B/W deg.	Feedpoint Z R +/- j X Ohms
1. No pole, closed f-p	6.14	23.94	135	50.3 - j 0.6
2. No pole, open f-p	6.23	26.60	130	50.3 - j 0.6

Either open or closed feeders would be equally useful, and the wider beamwidths in both cases ensure pattern cross-over points at about -2.5 dB signal levels. Front-to-back ratios are close to the value for an independent rectangle, and gain reductions simply reflect the lesser interactions among the three antennas. If a radius as large as 6" is acceptable, the wider-spaced version of the array is to be recommended.

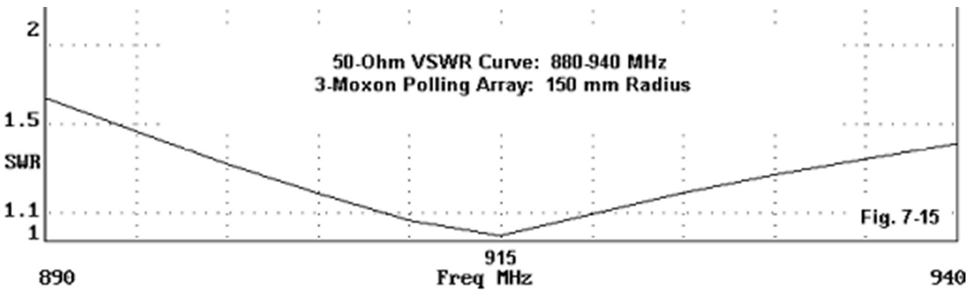
In either form, the 3-Moxon polling array shows a fairly broad operating bandwidth. In terms of operating parameters, here are the numbers for the edges and center of a 50 MHz range from 890 to 940 MHz

Array Performance with Antennas 100 mm Apart from 890 to 940 MHz

Frequency	F-S Gain dBi	Front-to-Back Ratio dB	B/W deg.	Feedpoint Z R +/- j X Ohms
890	7.08	21.63	109	34.8 - j14.8
915	6.19	25.85	131	50.9 - j 0.1
940	5.14	19.41	158	66.8 + j 9.7

For this table, I used the no-pole, open-unused-feedpoint option. As the frequency increases, the beamwidth also increases, while the gain decreases—both fairly linearly. The front-to-back ratio is near maximum at the center of this operating range. Although it would be desirable to optimize the antennas in the array for a target operating frequency, small discrepancies will not adversely affect the array's performance to a noticeable degree.

The VSWR bandwidth of the array is not severely tested by the 50 MHz bandwidth of the modeling test, as shown in **Fig. 7-15**. It peaks at about 1.6:1 at the low end of the range and does not reach 1.4:1 at the high end. In setting up an array such as this one, operating characteristics other than SWR will be the dominant concern.



Conclusion: The 3-Moxon polling array shows considerable promise as a simple polling array for one tower with full horizon coverage in only three steps. The gain of 4 dB over a vertical dipole or equivalent antenna offers a level of reception in specific areas that might otherwise require a separate remote antenna installation. The front-to-back ratio of each antenna permits close spacing of the individual antennas in the array, as well as freedom from false signal control of the polling electronics.

In the 900 MHz region, the array can be placed under a protective dome of no more than 12" diameter. Of course, the array can be scaled for the amateur 432, 223, or 146 MHz bands, becoming no larger than 6 times the size of the 914 MHz test antenna system. At the larger sizes and lower frequencies, the individual antennas can be mounted with even greater separation on each leg of a support tower in a unified structure with balanced stresses upon the tower. This type of system would make a polling repeater on the receive side very practical for almost any installation.

The individual antennas lend themselves to many forms of construction, with increasing versatility as the frequency increases. At lower VHF frequencies, tubing or rod elements are practical, and an RF-transparent mounting system is quite practical for the antenna boom. As we move above 500 MHz, circuit board traces become feasible antenna elements and feedlines to a center "plus-in" terminal. Of course, the antenna dimensions would require re-optimization for circuit board trace implementation.

One factor might be overlooked in this discussion. The individual antennas of each array were unchanged for all dimensions relative to the original isolated Moxon rectangle. This fact makes the fabrication and testing of individual antennas in the array a very simple matter. If the antenna works properly in isolation, it will work within the array.

The 3-Moxon polling array may have other applications than repeater use. But this one use alone makes the array well worth further experimentation.

* * *

Appended models used in this chapter:
mox-146-316v.ez, mox914-4v.ez, mox914-4v-3.ez

8. Moxon Rectangles and Satellite Communications

When we are just getting interested in amateur satellite operation, the thought of investing in a complex azimuth-elevation rotator system to track satellites across the sky can stop us in our tracks. For starters, we need a simple, reliable, fixed antenna—or set of antennas—to see if we really want to pursue this phase of amateur radio to its limit. We shall look at the basics of fixed antenna satellite work and develop a simple antenna system suited for the home workshop. There will be versions for both 146 MHz and 435 MHz.

Turnstiles and Satellites

For over 2 decades, most fixed position satellite antennas for VHF and UHF have used a version of the turnstile. The word "turnstile" actually refers to 2 different ideas. One is a particular antenna: 2 crossed dipoles fed 90-degrees out of phase. The other is the principle of obtaining omni-directional patterns by phasing almost any crossed antennas 90 degrees out of phase. The first idea limits us to a single antenna. The second idea opens the door to adapting many possible antennas to omni-directional work.

Fig. 8-1 shows one general method of obtaining the 90-degree phase shift that we need for omni-directional patterns. Note that the coax center conductor connects to only one of the two crossed elements. A 1/4-wavelength section of transmission line that has the same characteristic impedance as the natural feedpoint impedance of the first antenna element alone connects one element to the next. The opposing ends of the two elements go to the braid at each end of the transmission line. If the elements happen to be dipoles, then a 70 to 75 Ohm transmission line is ideal for the phase line. However, the resulting impedance at the overall antenna feedpoint will be exactly half the impedance of one element alone. So we will obtain an impedance of about 35 Ohms. For the dipole-based turnstile antenna, we shall either have to accept an SWR of about 1.4:1 or we shall have to use a matching section to bring the antenna to 50 Ohms. A parallel set of RG-63 1/4-wavelength lines will yield about 43 Ohms impedance, about right to bring the 35-Ohm antenna impedance to 50 Ohms for the main coax feed line. For all such systems, we must remember to account for the velocity factor of the transmission line, which will yield a line-length that is shorter than a true quarter wavelength.

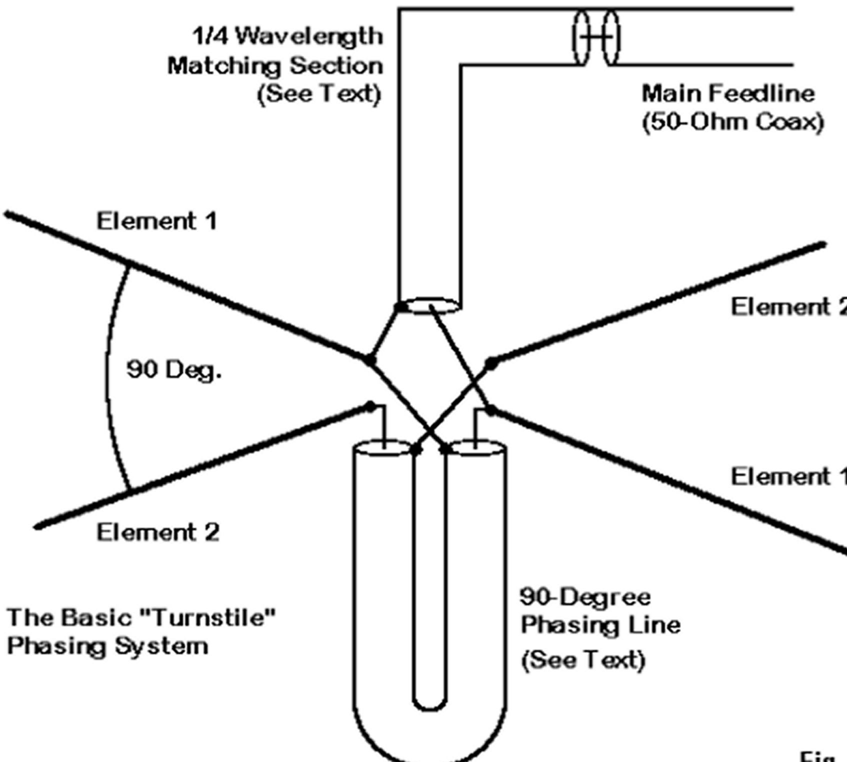


Fig. 8-1

The dipole-based turnstile has been used with considerable success for fixed-position satellite work. **Fig. 8-2** shows—on the left—one recommended system that has been in *The ARRL Antenna Book* since the 1970s. For 2 meters, a standard dipole-turnstile sits over a large screen that simulates ground. Spacing the elements from the screen by between 1/4 and 3/8 of a wavelength is recommended for the best pattern. For satellite operation, the object is to obtain close to a dome-like pattern overhead. The most desirable condition is to have the dome extend as far down toward the horizon as possible to let us communicate with satellites as long as possible during a pass.

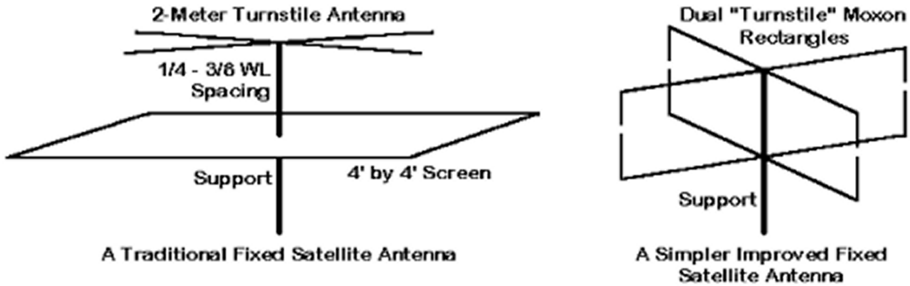


Fig. 8-2

The turnstile-and-screen system, while simple, is fairly bulky and prone to wind damage. However, the turnstile loses performance if we omit the screen. One way to reduce the bulk of our antenna is to find an antenna with its own reflector. However, it must have a good pattern for the desired goal of a transmitting and receiving dome in the sky. The dual Moxon rectangle array, shown in outline form on the right of **Fig. 8-2**, offers some advantages over the traditional turnstile. First, it yields a somewhat better dome-like pattern. Second, it is relatively easy to built and compact to install.

Almost every fixed satellite antenna shows deep nulls at lower angles, and the number of nulls increases as we raise the antenna too high, thus defeating the desire for communications when satellites are at low angles. **Fig. 8-3** shows the elevation patterns of a turnstile-and-grid and of a pair of Moxon rectangles when both are 2 wavelengths above the ground. A 1-wavelength height will reduce the low angle ripples even more, if that height is feasible. However, the builder always has to balance the effects of height on the pattern against the effects of ground clutter that may block the horizon.

The elevation patterns show the considerably smoother pattern dome of the Moxon pair over the traditional turnstile. The middle of the turnstile dome has nearly 2 dB less gain than its peaks, while the top valleys are nearly 3 dB lower than the peaks. The peaks and valleys can make the different between successful communications and broken-up transmissions. Hence, for the purpose of obtaining a good dome, the Moxon pair may be superior.

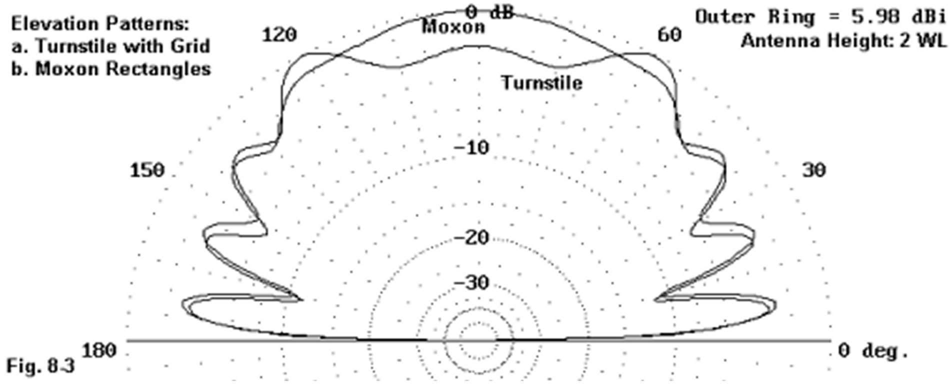


Fig. 8-3

A reasonable suggestion offered to me was to simply add reflectors to a standard dipole turnstile and possible obtain the same freedom from a grid or screen structure. Unfortunately, **Fig. 8-4** shows the limitation of that solution. The result of placing reflectors behind the dipole turnstile is a pair of crossed 2-element Yagi beams fed 90 degrees out of phase. The pattern is indeed circular and stronger than that of the Moxon pair. However, the beamwidth is reduced to only 56 degrees at the half-power points. The antenna would make an excellent starter for a tracking AZ-EL rotator system, but it does not have the beamwidth for good fixed-position service.

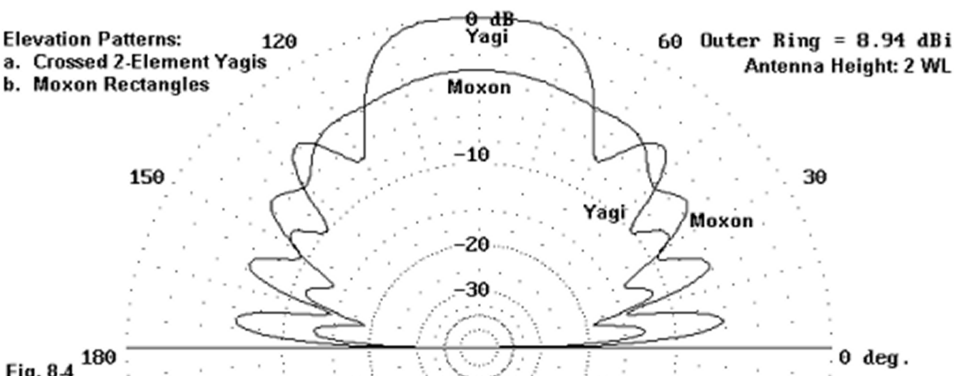


Fig. 8-4

The Moxon pair, with lower but smoother gain across the sky dome, offers the fixed-antenna user the chance to build a successful beginning satellite antenna. The pattern will be circular within under a 0.2-dB difference for 145.5 to 146.5 MHz, and within 0.5 dB for the entire 2-meter band. Since satellite work is concentrated in the 145.8- to 146.0-MHz region, the broad-banded antenna will prove fairly easy to build with success. A 435.6 MHz version, designed to cover the 435 to 436.2 MHz region of satellite activity will have an even larger bandwidth.

Like the dipole-based turnstile, the Moxons will be fed 90 degrees out of phase with a 1/4-wavelength phase line of 50-Ohm coaxial cable. The drivers will be connected just as shown in **Fig. 8-1**. Since the natural feedpoint impedance of a single Moxon rectangle of the design used here is 50 Ohms, the pair will show a 25-Ohm feedpoint impedance. Paralleled 1/4-wavelength sections of 70- to 75-Ohm coaxial cable will transform the low impedance to a good match for the main 50-Ohm coaxial line to the rig. In short, we have "turnstiled" the Moxon rectangles into a reasonable fixed-position satellite antenna.

Building the Moxon Pairs

The Moxon rectangle is a modification of the reflector-driver Yagi parasitic beam. However, instead of using linear elements, the driver and reflector are bent back toward each other. The coupling between the ends of the elements, combined with the coupling between parallel sections of the elements, combines to produce a pattern with a broad beamwidth. By carefully selecting the dimensions, we can obtain both good performance (meaning adequate gain and an excellent front-to-back ratio) and a 50-Ohm feedpoint impedance.

In fact, a single Moxon rectangle might be used on each band for reasonably adequate satellite service. When pointed straight up, the Moxon rectangle pattern is a very broad oval, although not a circle. The oval pattern also gives the Moxon another advantage over dipoles in a turnstile configuration. If the phase-line between dipoles is not accurately cut, the normal turnstile near-circle pattern degrades into an oval fairly quickly because the initial single dipole pattern is a figure 8. The single Moxon oval pattern allows both dimensional and phase-line inaccuracies of considerable amounts before degrading from a nearly perfect circle.

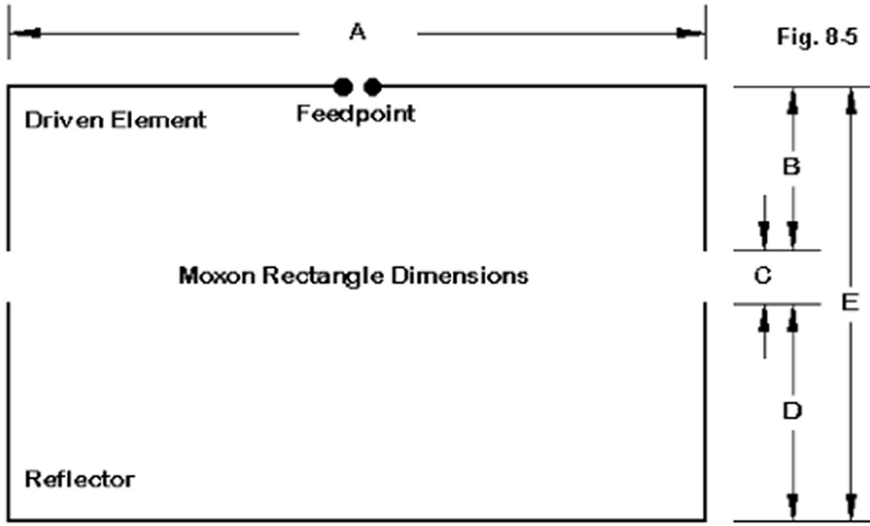


Fig. 8-5 shows the critical dimensions for a Moxon rectangle. The lettered references are keys to the dimensions in **Table 1**. The design frequencies for the two satellite antenna pairs are 145.9 MHz and 435.5 MHz, the centers of the satellite activity on these two bands. The 2-meter Moxon prototype uses 3/16" diameter rod, while the 435 MHz version uses #12 AWG wire with a nominal 0.0808" diameter. (Single Moxons built to these dimensions would cover all of 2-meters and about 12 MHz of the 432 MHz band.) Going one small step up or down in element diameter will still produce a useable antenna, but major diameter changes will require that the dimensions be recalculated.

Dimensions for Moxon Rectangles for Satellite Use

See **Fig. 8-5** for letter references. All dimensions in inches.

Dimension	145.9 MHz	435.6 MHz
A	29.05	9.72
B	3.81	1.25
C	1.40	0.49
D	5.59	1.88
E (B + C + D)	10.80	3.62

1/4 Wavelength	20.22	6.77
0.66 VF phase and match lines	13.35	4.47

Table 1. Dimensions for 145.9 and 435.6 MHz Moxon Rectangles. Two are required for each antenna. The phase-line is 50-Ohm coaxial cable and the matching line is parallel sections of 75-Ohm coaxial cable. Low power cables less than 0.15" in outer diameter were used in the prototypes.

The reflectors are constructed from a single piece of wire or rod. I use a small tubing bender to create the corners. The rounding of the corners creates a slight excess of wire for the overall dimensions in the table. I normally arrange the curve so that the excess is split between the side-to-side dimension (A) and the reflector tail (D). The total reflector length should be A + 2 times D.

The driver consists of two pieces, since we shall split the element at its center for the feeding and phasing system. I usually make the pieces a bit longer before bending and trim them to size afterwards. The total length of the driver, including the open area for connections, should be A + 2 times B.

Perhaps the most critical dimension is the gap, C. I have found nylon tubing, available at hardware depots, to be very good to keep the rod ends aligned and correctly spaced. When everything has been tested and found correct, a little super-glue on the tubing ends and aluminum stands up to a lot of wind. I usually nick the aluminum just a little to let the glue settle in and lock the junction. For the UHF version, a short length of heat-shrink tubing provides a lock for the size of the gap and the alignment of the element tails.

It is one thing to make a single Moxon and another to make a working crossed pair. **Fig. 8-6** shows the general scheme that I used for the prototypes, using CPVC. Standard schedule 40 or thinner PVC or fiberglass tubing can also be used.) The support stock is 3/4" nominal. The reflectors go into slots at the bottom of the tube and are locked in two ways. Whether or not the two reflectors make contact at their center points makes no difference to performance, so I ran a very small sheet screw through both 2-meter reflectors to keep their relative positions firm. I soldered the centers of the 435-MHz reflectors. Then I added a coupling the to bottom of the

CPVC to support the double reflector assembly and to connect the boom to a support mast. Cementing or pressure fitting the cap is a user option.

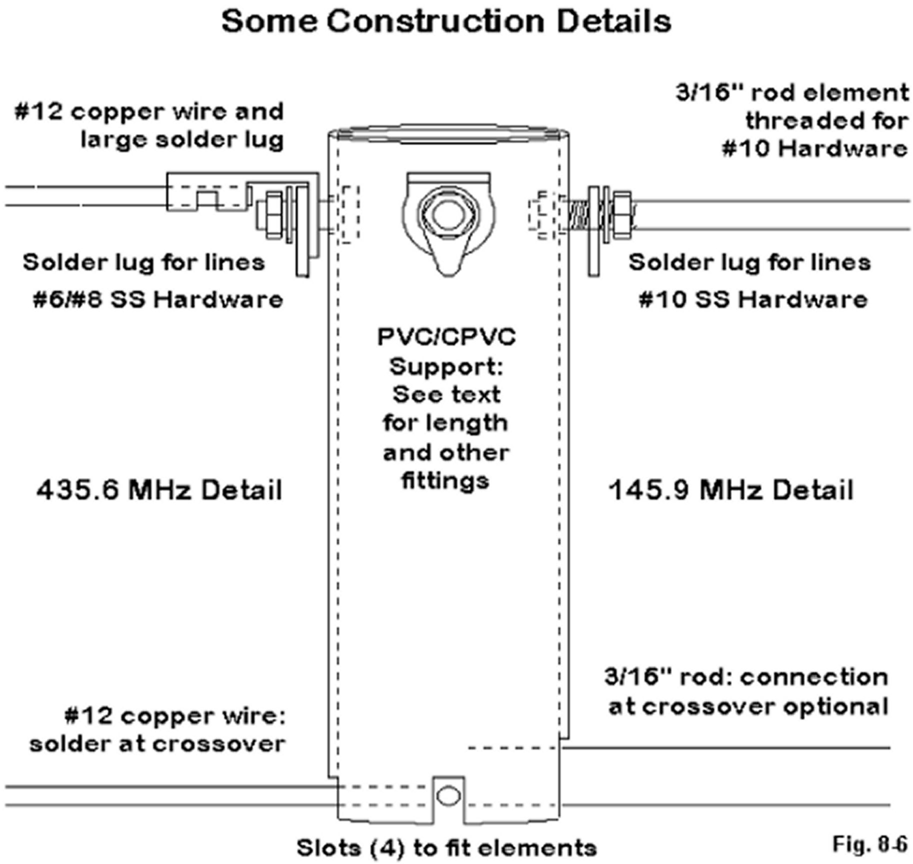


Fig. 8-6

The feedpoint assemblies are attached to solder lugs. The phase line is run down one side of the support, while the matching-section line is run down the other. Good electrical tape holds them in places. For worse weather, the tape may be over-sealed with butylate or other coatings. Likewise, the exposed ends of the coax sections and the contacts themselves should be sealed from the weather.

The overall assembly of the two antennas is very straightforward. For a single mount, the PVC from individual support Tees can go to a center Tee that also holds the main support for the two antennas. A series of adapters, made from miscellaneous PVC parts to fit over a standard length of TV mast. Alternatively, the antennas can be separately mounted about 10' apart. The 10' height of the assembly has proven adequate for general satellite reception, although I live almost at the peak of a hill.

The antennas can be mounted on the same mast. However, for similar sky-dome patterns, they should each be the same number of wavelengths above ground. For example, if the 2-meter antenna is about 2 wavelengths up at about 14' or so, then the bottom of the 435-MHz antenna should be only about 4.5' up from ground. Placing the higher-frequency antenna below the 2-meter assembly will create some small irregularities in the desired dome pattern, but not serious enough to affect general operation.

There is no useful adjustment to these antennas except for making the gap between the drivers and reflectors as accurate as possible. Turnstiled antennas show a very broad SWR curve. Across 2-meters, for example, the highest SWR is under 1.1:1. However, serious errors in the phase line length can in distortions to the desired circular pattern. Hence, there is no substitute for checking the lengths of the phase line and the matching section several times before cutting. The correct length is from one junction to the next, including the portions of exposed cable interior.

These two little antennas will not compete with tracking AZ-EL rotating systems for horizon-to-horizon satellite activity. However, for satellite work, power is no problem (except for using too much) and modern receiver front-ends have enough gain to make communications easy. So when the satellite reaches an angle of about 30 degrees above the horizon, these antennas will give a very reasonable account of themselves. When you do get so addicted to satellite communications that you invest in the complete tracking system, these antennas can be used as back-ups while parts of the complex system are down for maintenance.

Simplifying the Turnstile Moxon Rectangle

The basic information appeared in *QST* (Aug. 2001), pp. 38-41, with some supplemental information in the Technical Correspondence column of *QST*, Oct, 2001, pp. 78-79. I am grateful to The American Radio Relay League for permission to use the material here.

The basic principle of the turnstiled Moxon rectangles appears in **Fig. 8-7**. The two antennas are placed at right angles to each other, with the feedpoints separated. (The centers of the reflectors may be touching or separated. No change of performance is detectable between the two options.)

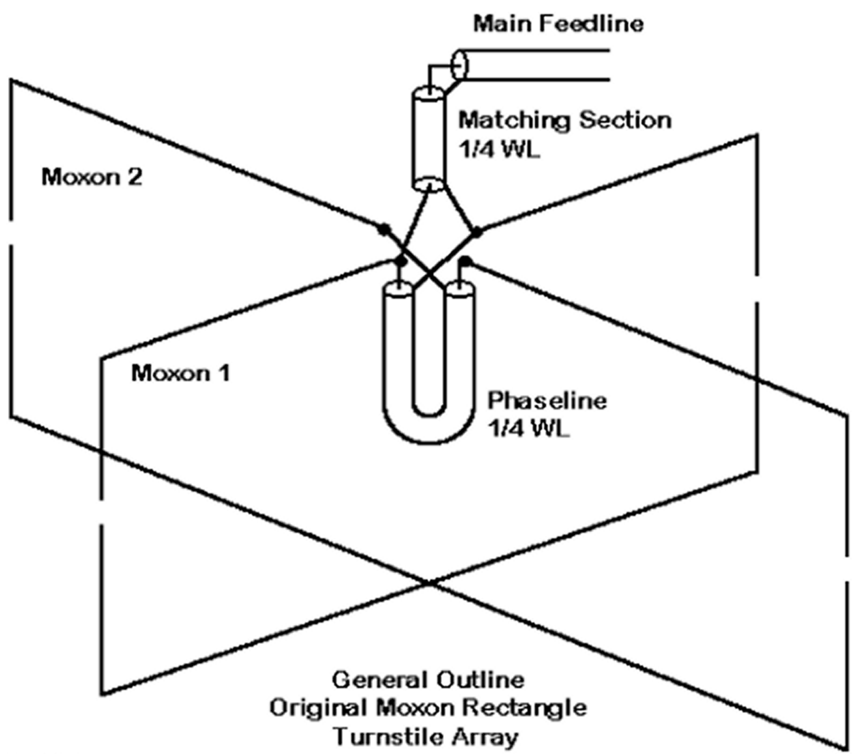


Fig. 8-7

A main feedline connects to one rectangle driver. From that element, a 1/4-wavelength phaseline composed of a transmission line runs from the fed driver to the second driver. The phaseline should have a characteristic impedance (Zo) that is the same as the natural resonant feedpoint impedance of a single rectangle when used independently. The rectangles used in the initial designs were 50-Ohm versions, calling for a 50-Ohm phaseline between drivers.

The condition that we obtain is called quadrature. That is, each rectangle receives the same power level or current magnitude. However, the two feedpoints show a current phase angle of 90 degrees under ideal conditions. Because the Moxon rectangles have such a wide -3 dB beamwidth, when we point the turnstiled array straight up, we obtain an almost perfect circle if we take an azimuth pattern. As well, the elevation pattern shows a very wide and smooth dome of radiation with a beamwidth in excess of 100 degrees. The exact -3 dB beamwidth depends in part on the height of the antenna above the ground surface. Heights up to 2 wavelength provide smooth coverage of the sky from about 30 degrees above the horizon in any direction. The horizontal and vertical components of the pattern are very nearly equal, suggesting good performance as a satellite changes polarization relative to the ground station as it traverses the sky.

One limitation of the satellite Moxons is the need for a matching section between the main feedline and the element terminals. The feedpoint impedance of a perfectly phased turnstile antenna of any type is one-half the impedance of the individual resonant antennas when set up independently. The 50-Ohm Moxons result in a feedpoint impedance of 25 Ohms.

The solution used in the original design was to employ a 35-37-Ohm 1/4-wavelength matching section to raise the impedance from 25 to 50 Ohms. This system works well if carefully constructed. I originally used 75-Ohm video cable that was about 0.15" in diameter (along with even thinner RG-174 50-Ohm cable for the phaseline). The thin 75-Ohm cable is not usually available in amateur outlets, although the Wireman (in South Carolina) has a stock. The thin cables simplified the physical arrangement of the cables around the feedpoint, since they permit short connecting leads and easy manipulation to keep them separate. A number of difficulties have arisen wherever individuals have tried using fatter RG-58 and RG-59 cables, especially for the 435.6-MHz antenna. Indeed, where thin cables are not obtainable, I have suggested using a single Moxon rectangle directly fed with a 50-

Ohm cable. The beamwidth off the edges of the antenna is not as wide, but overall performance may be better than that of a UHF version of the antenna that has wads of cable attached.

The matching section consists of two 1/4-wavelength sections of cable connected in parallel, that is, with their braids connected together and their center conductors connected together at each end of the line. I have recommended that these sections be spliced to a length of main feedline to avoid errors introduced by the use of cable connectors. BNC connectors would be satisfactory, but UHF connectors in this application would be metallic overkill.

An alternative method of returning the Moxon feedpoint impedance would be to employ a hybrid coupler-power splitter of the basic design shown in **Fig. 8-8**.

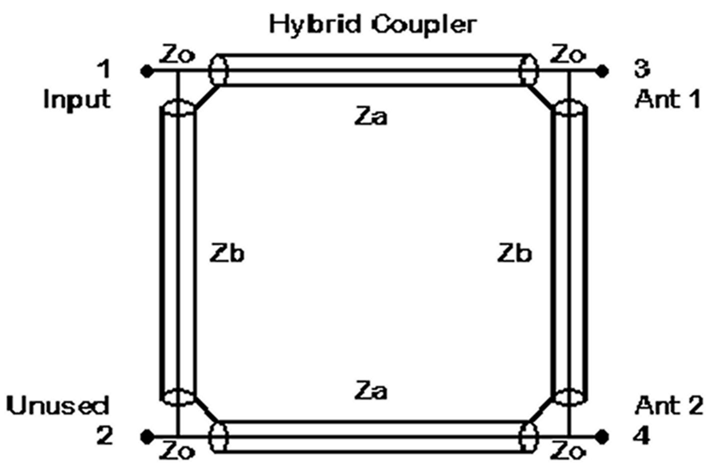


Fig. 8-8

For the present application, Zb in the sketch would be a 50-Ohm line and Za in the sketch would be 35-Ohm line. At the design frequency, the hybrid coupler achieves the desired equality of impedances at the 4 corners—one of which is unused. The hybrid coupler achieves the desired 50-Ohm main feedpoint impedance at terminal 1. The current at terminal 2, the unused input port, is negligible, that is, more than an order of magnitude less than the current at the main feedpoint. The model of this arrangement uses lossless lines, although the line lengths suggest that losses would not distort matters more than the slight vertical separation of the Moxon rectangles forming the turnstile array.

The hybrid coupling system offers no advantage over the simpler system used in the original models, but it does introduce two more line lengths. When we operate the turnstile off its design frequency, the nearly circular patterns begin to pick up severe azimuth distortion. **Fig. 8-9** shows the basic and hybrid coupling systems at 144 MHz. There is no significant difference in the degree of distortion, although the direction of the main lobes reverses between the two schemes. Consequently, the hybrid couple scheme offers nothing but additional complexity for the satellite arrays.

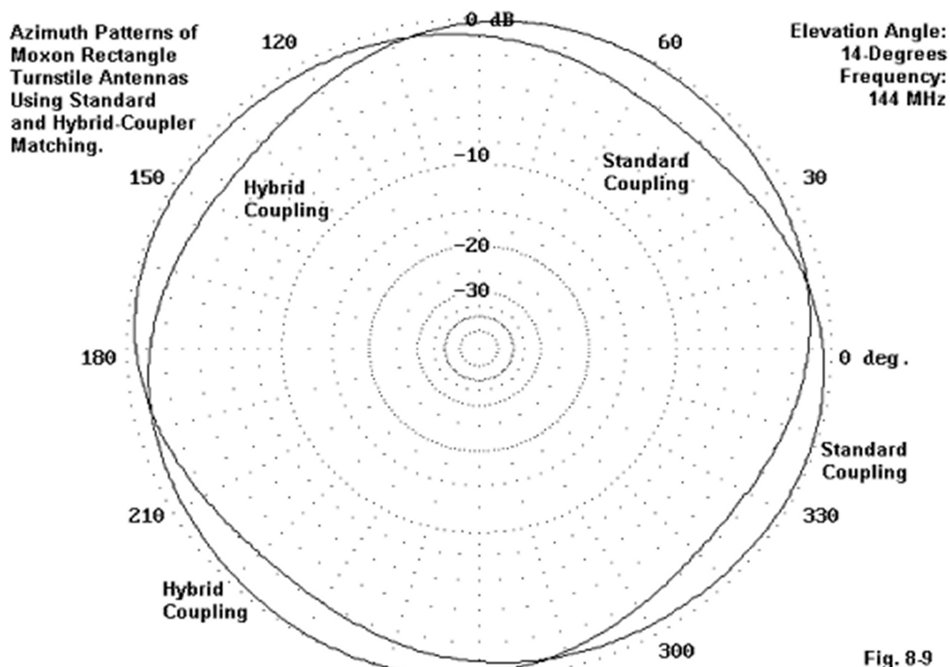


Fig. 8-9

However, the exercise is a reminder that turnstile arrays require careful construction so that we end up with two virtually identical antennas, both of which are resonant at the design frequency. Achieving quadrature requires equal current magnitudes on the two elements with as precise a 90-degree phase shift as we can obtain. Significant distortion, as shown in **Fig. 8-9**, begins to appear at under a 1.5% frequency shift from the design frequency, and the condition worsens with added shifts of frequency. The condition arises by operating the array off frequency or by failing to use sufficient care to ensure that all components of the array are well within 1% of their ideal sizes. Consequently, it is unwise to change materials without careful redesign to account for the altered electrical properties.

In the original design, I suggested the use of 3/16" (0.1875") diameter elements for the 145.9-MHz array and AWG #12 (0.0808" diameter) copper wire for the 435.6-MHz array. As a result of many requests for dimensions suited to the use of other materials for the 2-meter version of the antenna, the following table provides supplemental information on the arrays.

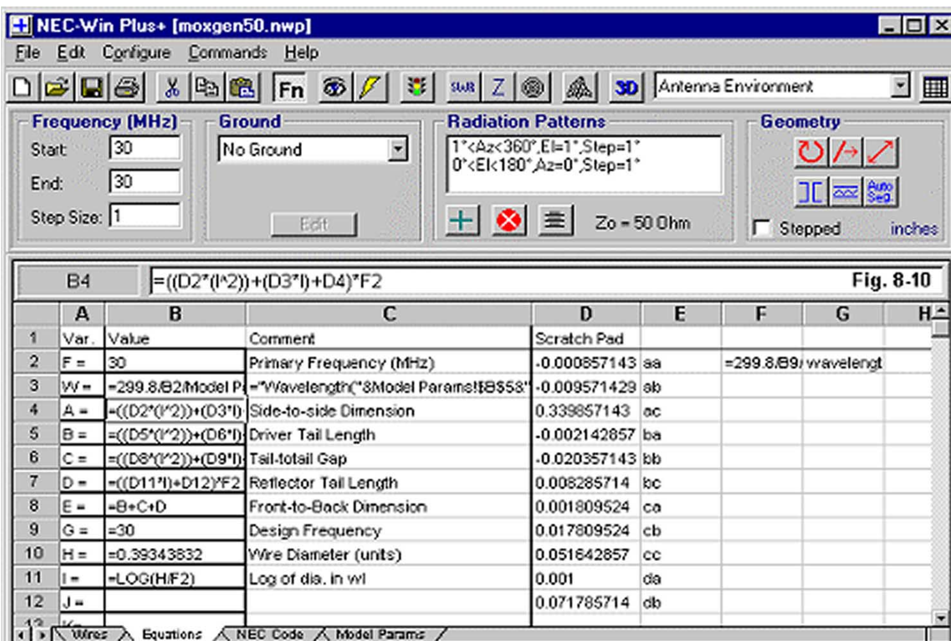
Dimension		Stock Diameter for the 145.9-MHz Antenna		
	1/8 (0.125)”	3/16 (0.1875)”	1/4 (0.25)”	0.1575" (4 mm)
A	29.122	29.052	29.000	29.082 (739 mm)
B	3.930	3.806	3.712	3.861 (98 mm)
C	1.285	1.398	1.484	1.348 (34 mm)
D	5.580	5.594	5.604	5.588 (142 mm)
E	10.794	10.798	10.800	10.796 (274 mm)

Because there was considerable interest in adapting the array for use on 137 MHz, here is information for that frequency.

Dimension		Stock Diameter for the 137-MHz Antenna		
	1/8 (0.125)”	3/16 (0.1875)”	1/4 (0.25)”	0.1575" (4 mm)
A	31.025	30.951	30.896	30.983 (787 mm)
B	4.204	4.074	3.975	4.137 (105 mm)
C	1.350	1.469	1.560	1.417 (36 mm)
D	5.940	5.955	5.966	5.949 (151 mm)
E	11.494	11.499	11.501	11.497 (292 mm)

Simplifying the Arrays—Slightly: The Moxon rectangle designs used in the initial arrays derived from now standard designs originally developed for HF and VHF use. The designs achieved a direct 50-Ohm feed. However, it is possible to design a Moxon rectangle for virtually any feedpoint impedance well above 100 Ohms, at which point the array becomes more square, resembling the VK2ABQ square array from which G6XN originally developed his rectangular version.

Moreover, it is also possible to optimize a series of models using stepped-wire diameters. From those models and some regression analysis, we may develop a model-by-equation master model that requires only the element diameter and the design frequency in order to create output models that are accurate from 3 to 500 MHz. **Fig. 8-10** shows the NEC-Win Plus equation page for the 50-Ohm version of the master model. The equations can also be applied independently to a spreadsheet, although placing them in a model-by-equation spreadsheet permits instant NEC-2 analysis of the resulting dimensions.



Now the simplification: Although the phaseline must be present in the turnstiles antenna (of whatever type), we may eliminate the matching section if we design Moxon rectangles with an inherent resonant feedpoint impedance of about 93 Ohms. Under these conditions, we may employ RG-62 (Zo: 93 Ohms; velocity factor: 0.84) as the phaseline. The resulting system feedpoint impedance will be close to 50 Ohms (46.5 Ohms), and we may omit the matching section.

To permit such design work, I created a series of optimized models having feedpoint impedances between 90 and 95 Ohms and performed standard regression analysis upon them. All optimized models maximized the 180-degree front-to-back ratio at resonance as defined by less than 1-Ohm reactance. As with the 50-Ohm master model, third-order equations proved sufficient for dimensions A through C, while a second-order equation sufficed for D, which changes slowly. The result was the master model, whose equation page appears in **Fig. 8-11**.

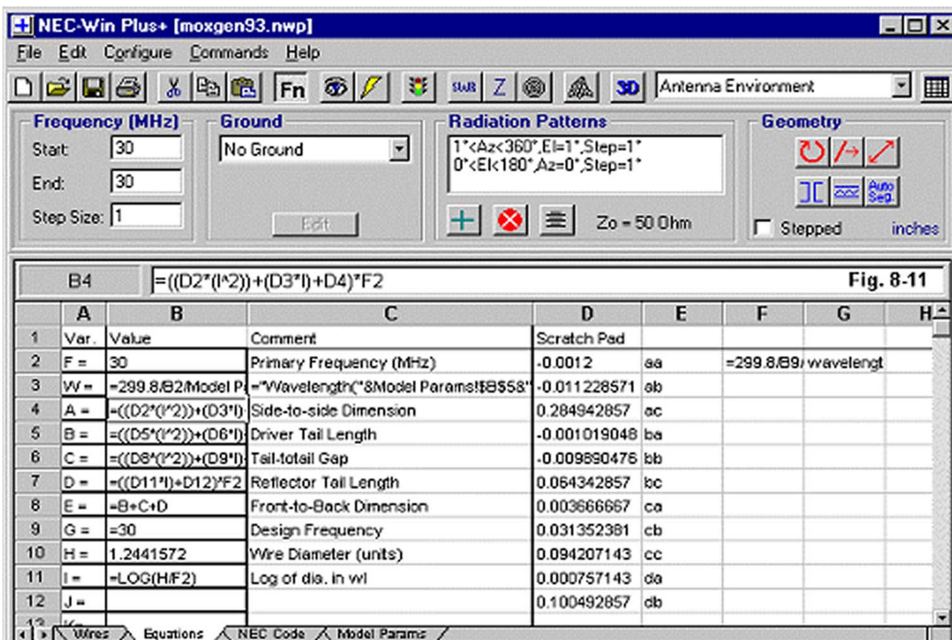


Fig. 8-11

The range of wire diameters in both master models is 1E-5 through 1E-2 wavelength. A diameter of 1E-5 is smaller than anyone will ever use, while 1E-2 is fatter than one will use, even at UHF. Therefore, the fact that the impedance of the perfect wire model drops to 89.8 Ohms for the thinnest wire at 30 MHz and rises to 100.2 Ohms for the very fattest perfect wire poses no design problem.

The following tables replicate those for the lower impedance Moxons presented earlier, but with the design set for a 90-95-Ohm feedpoint impedance.

Dimensions for 93-Ohm Moxon Rectangles for Satellite Use

See **Fig. 8-5** for letter references. All dimensions in inches.

Dimension	145.9 MHz: 3/16"	435.6 MHz: AWG #12
A	24.77	8.28
B	6.74	2.24
C	3.00	1.04
D	7.97	2.67
E (B + C + D)	17.71	5.95
1/4 Wavelength	20.22	6.77
0.84 VF phaseline	16.99	5.69

Dimensions for 145.9 and 435.6 MHz Moxon rectangles. Two are required for each antenna. The phaseline is 93-Ohm coaxial cable

Dimension		Stock Diameter for the 145.9-MHz Antenna		
	1/8 (0.125)”	3/16 (0.1875)”	1/4 (0.25)”	0.1575" (4 mm)
A	24.84	24.77	24.72	24.80 (630 mm)
B	6.80	6.74	6.69	6.77 (172 mm)
C	2.84	3.00	3.12	2.93 (74 mm)
D	7.96	7.97	7.98	7.96 (202 mm)
E	17.60	10.71	17.79	17.66 (448 mm)

Dimension		Stock Diameter for the 137-MHz Antenna		
	1/8 (0.125)”	3/16 (0.1875)”	1/4 (0.25)”	0.1575" (4 mm)
A	26.46	26.39	26.34	26.42 (671 mm)
B	7.26	7.19	7.14	7.22 (183 mm)
C	2.99	3.16	3.30	3.09 (78 mm)

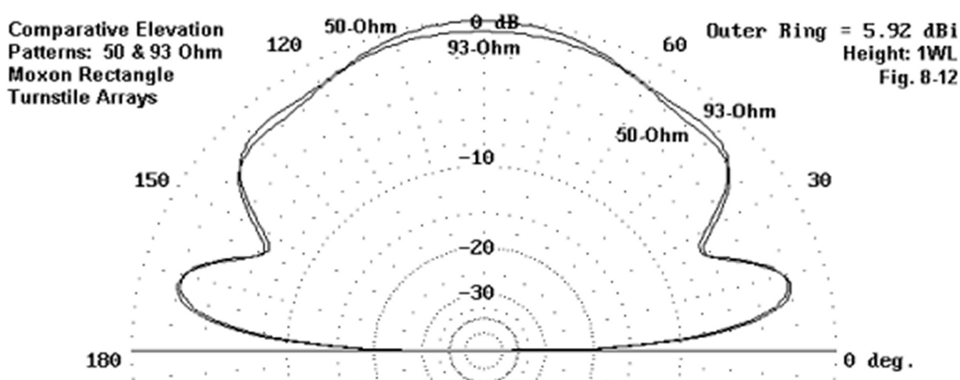
D	8.47	8.48	8.49	8.48 (215 mm)
E	18.72	18.83	18.93	18.79 (476 mm)

Although the differences in dimensions from one material to the next may seem small, 1% precision in construction remains an important goal, if we are to obtain the correct performance from the array.

Several things should be clear from a comparison of the 50-Ohm and the 93-Ohm tables. First, the new arrays are squarer or less elongated than the 50-Ohm versions. Second, the gap sizes are larger. These two factors correlate in the design of a Moxon rectangle for any desired feedpoint impedance. Hence, it is in principle possible to design an even longer, narrower Moxon rectangle for a 35-Ohm feedpoint impedance or a squarer model for a 125-Ohm impedance.

Changing the shape of the Moxon rectangle to achieve a desired feedpoint impedance also changes the gain and the -3 dB beamwidth of the array. The maximum achievable front-to-back ratio does not change significantly throughout a reasonable set of shapes. The squarer the array, the longer the element tails that face each other and the shorter the parallel portions of the elements. Hence, as we make the array more square, gain drops and beamwidth increases.

Fig. 8-12 compares the elevation pattern of the 50-Ohm Moxon 2-meter array with a 93-Ohm array, both 1 wavelength above ground at 145.9 MHz. The new array shows about 0.5 dB less gain, but increases the beamwidth by about 5 degrees. Neither change should alter practical operation significantly, since there are



more intervening variables in the average back yard than between versions of the array.

However, the higher impedance Moxon rectangles do permit us to simplify construction by using only the 93-Ohm phaseline and a master 50-Ohm feedline, with no required matching section.

Why Simplify? The simplification of the arrays by elimination of the matching section is likely to occasion few benefits at 137 MHz and 145.9 MHz. However, the somewhat cramped quarters of a wire-based 435.6-MHz array may yield easier overall construction and more reliable replication of the prototypes. Eliminating the parallel line section and the splices removes more than one point of potential construction error from the process.

The simplification also should ease the task of creating arrays for UHF an up, especially if such arrays follow the recommendation of being constructed of foil strips on a fiberglass or other suitable substrate. As I have noted in the past, development of such antennas requires considerable materials investigation and experimental work. Correlating the strip elements to modeled round-wire dimensions is the first step. It is likely that the required gap distances will take on a new correlation to the element length dimensions, since the end capacitance of a strip varies significantly from that of a round wire.

However, the use of strip construction on a substrate also permits one to etch the phaseline on one of the two interlocking boards forming the turnstile array. The key element here is likely to be finding the velocity factor created by the substrate separating the phaseline strips in a two-sided etching process.

Solid boards, of course, create a wind-block situation. Hence, the very small UHF and up versions of the array might well have unused sections of board cut away to slip the wind. Alternatively, we might cover the antenna with an RF- transparent dome. Polycarbonate should be serviceable up to several hundred MHz.

The turnstile Moxon rectangle array offers some interesting further applications, especially for aeronautical signal transmission, reception, or both. As we move some services formerly in the VHF range upward toward the GHz region, etched-board arrays may become very practical. The system is applicable wherever we need a dome of radiation or reception without nulls. The following possibilities seem especially apt: airport and airways communications; data and other identification or positioning signaling, wherever a vertical null is not desired; and communications from aircraft.

The last application is especially interesting, since the satellite array need be only turned upside down and mounted beneath an aircraft to provide the dome of coverage relative to ground communications and other signal points. The array eliminates any “over-station” nulling of signals—assuming that the station antenna does not itself have a vertical null. The high front-to-back ratio of the antenna should make the aircraft itself relatively invisible to the antenna, and even a large wing structure should offer minimal change in the pattern shape or omni-directionality. For some modern aircraft with non-conductive surface “skins,” the antenna may be mounted wholly within the aircraft surface boundaries. For slower aircraft, a small dome on the underside of the fuselage should provide good service.

The simplified 93-Ohm Moxon rectangle as the basis for turnstiled arrays should ease the development of such systems. Indeed, one might even etch on the interlocking antenna boards both the phaseline and the main feedline, using only a single coax line board-mounted connector just ahead of the reflector. Indeed, it is likely that the reflectors can be connected together at the center and connected to the aircraft system master ground buss, thus providing good immunity from lightning and other discharge damage.

The end result is that the turnstiled Moxon rectangles have a good bit of untapped potential. Indeed, every time I think that the array has run the gamut of possibilities and needs a design rest, I encounter a new potential that sets me to work again. I once described the Moxon rectangle as a “niche” antenna. However, it now appears that the array may profitably occupy quite a few niches, if not an entire shelf in the antenna store.

* * *

Appended models used in this chapter:
moxsat2m.ez, moxsat4m.ez, turn2gr2.ez, moxgen93.nwp, moxsat2m-93.ez

9. A Few Moxon Rectangles Cousins

The Moxon rectangle has cousins, that is, related antenna designs that make use of multiple forms of coupling to achieve their performance and feedpoint characteristics. We shall examine—perhaps all too briefly—two branches of the family. The first set of kin includes arrays that fold themselves back in order to achieve the minimum possible turning radius. All of the arrays that we shall examine have perimeters that measure just about 1 wavelength. The second branch on the tree involves arrays that Vee their elements to bring the element tips close enough together to activate the end-coupling that plays such a prominent role in the optimized mono-band Moxons that we have explored. We shall be less than systematic in our exploration, but the samples that we shall present may spur further design efforts in compact beam development.

Minimum Turning-Radius Arrays

From time to time, interest reemerges in some long-standing designs for compact planar (2-dimensional) beams. Unfortunately, the interest seems to focus on a single design at a time, rather than on the design as a member of a family of designs. Equally, unfortunately, the interest usually stems from the publication of some peak performance figures for a particular design rather than from the antenna's performance across an entire band. Consequently, misunderstandings of antenna potentials multiply endlessly.

One of the family of beams whose members rouse periodic interest is the end-coupled clan. If the ends were connected, these would all make versions of a loop. However, with the ends spaced properly, each member forms a directional beam. Another apt name for the group might refer to the semi-closed geometry of the antennas. With closed loops, these antennas share the feature of tending toward larger dimensions with significant increases of element diameter.

Under any name, the family has two branches: those whose center structures form Vees that point at each other bottom to bottom and those whose centers parallel each other. Among the features that clan members have in common is a flat structure with an area that is just over 0.6 square wavelengths—in other words, about 1/4 by 1/4 wavelength. Hence, the lure of the family is its compact size.

It may be useful to explore the main members of the family individually to seek out their potential. I have selected 20 meters as the test band. To keep comparisons fair, I have constructed all models of #12 copper wire. However, some of the family members lend themselves to self-supporting aluminum tubing construction, and I shall note the potential performance changes that may result from building a tubing version of the antenna. The use of tubing for part or all of the structure, of course, will alter the dimensions from the ones used with the #12 wire versions.

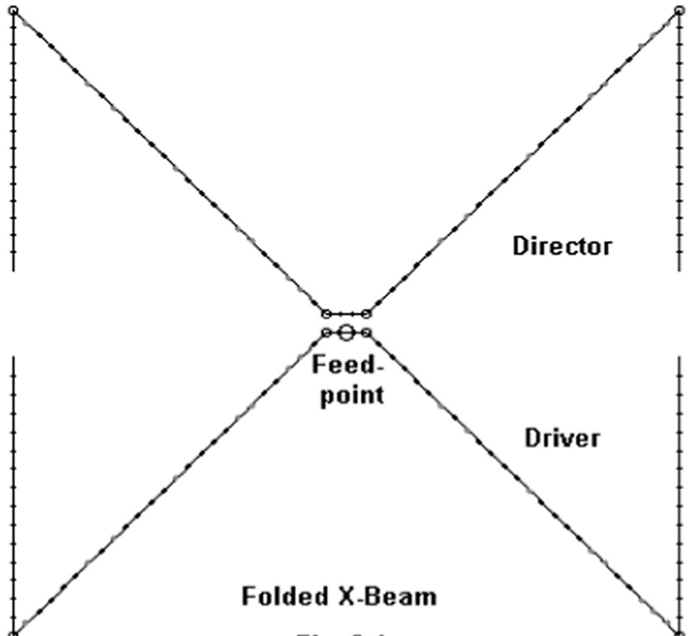
The antennas that we shall examine are these:

1. The folded X-beam
2. The hex beam
3. The VK2ABQ square
4. The Moxon rectangle

In the context of this effort to profile family members, the Moxon rectangle becomes just one of the gang, without any special privileges. As yet, I do not have any parallelograms, pentagons, or octagons in my collection of compact designs, although vertical plane quads with element insets are available for study or use.

The Folded X-Beam: **Fig. 9-1** shows the outlines of a folded X-beam. If you are interested in the history and details of the folded X-beam, see "Modeling and Understanding Small Beams: Part 1: The X-Beam," *Communications Quarterly*, 5 (Winter, 1995), 33-50. Ordinarily, the Vee portions of the folded X-beam are constructed of tubing supported by a center hub. Then wire tails for the driver and director are run from one corner toward the other, often taped to a perimeter cord that also holds the four arms in a fixed arrangement.

Modeling the usual construction of an X-beam is not feasible with NEC, since it has an invariant tendency to yield inaccurate results with angular junctions of wires having different diameters. So, I have fashioned a model using #12 copper wire throughout. The performance differences are these: the all-wire version has a slightly lower maximum gain (by about 0.2 dB) and a slightly narrower 2:1 SWR bandwidth (about 50 kHz narrower) than the hybrid tubing/wire version. Incidentally, the hybrid version can be directly modeled with public-domain MININEC, if one uses length-tapering toward the sharp angle corners.



Folded X-Beam

Fig. 9-1

Folded X-beams are normally designed for driver-director arrangements, since it is difficult to obtain significant performance with a driver-reflector arrangement. In the folded configuration of **Fig. 9-1**, the parasitic element almost “wants” to be a director. In less metaphorical terms, a modestly performing driver-reflector design, with only a slight change of reflector length, will reverse its pattern and hold that reversal, even though the parasitic element is considerably longer than one might expect for a director. It is also possible to tune the director to move the peak front-to-back portion of the operating curve across the band. By lengthening the director and adding a remotely adjusted bit of capacitive reactance at the center, the peak performance region can be moved across an amateur band. However, the model used here employs a fixed construction, as the following table shows.

```
X-Beam          Frequency = 14.1  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -99.000, 17.000,  0.000  W2E1 -99.000, 99.000,  0.000    # 12   15
2     W1E2 -99.000, 99.000,  0.000  W3E1  -6.000,  3.000,  0.000    # 12   25
3     W2E2  -6.000,  3.000,  0.000  W4E1   6.000,  3.000,  0.000    # 12    3
4     W3E2   6.000,  3.000,  0.000  W5E1  99.000, 99.000,  0.000    # 12   25
5     W4E2  99.000, 99.000,  0.000        99.000, 17.000,  0.000    # 12   15
6          -99.000,-11.000,  0.000  W7E1 -99.000,-99.000,  0.000    # 12   15
7     W6E2 -99.000,-99.000,  0.000  W8E1  -6.000, -3.000,  0.000    # 12   25
8     W7E2  -6.000, -3.000,  0.000  W9E1   6.000, -3.000,  0.000    # 12    3
9     W8E2   6.000, -3.000,  0.000 W10E1  99.000,-99.000,  0.000    # 12   25
10    W9E2  99.000,-99.000,  0.000        99.000,-11.000,  0.000    # 12   15

              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1           2     8 / 50.00   (  8 / 50.00)      1.000       0.000       V
```

In **Fig. 9-2**, we find both the gain and front-to-back curves of the folded X-beam. Because the direction of the beam reverses between 14.3 and 14.35 MHz,

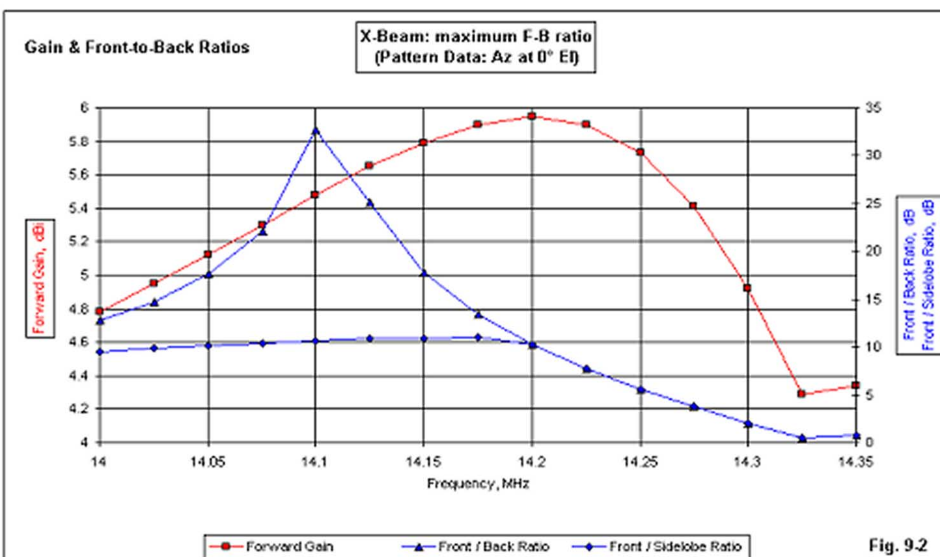


Fig. 9-2

the curves are cut off at 14.3 MHz. (The reversal to a driver-reflector beam yields only poor results, never reaching a 10 dB front-to-back ratio.) One of the inherent difficulties of the folded X-beam is that the maximum gain and the maximum 180-degree front-to-back ratio are always separated in frequency. The gain at the maximum front-to-back peak is about 0.5 dB below peak. Both the gain and the front-to-back curves are quite steep, indicating a narrow operating passband, whatever the feedpoint impedance characteristics might be. In the past, the chief use of the folded X-beam has been on 10 meters as a home-brew project for those interested in the 28.3 to 28.5 MHz region of the band.

The SWR curve, in **Fig. 9-3**, is referenced to 20 Ohms, which is approximately the impedance at the maximum front-to-back peak. Indeed, this design shows operating characteristics that are directly tied to the feedpoint impedance. A near-50-Ohm impedance is possible at the lowest frequency in the passband, with a low gain and relatively poor front-to-back ratio. Where the front-to-back ratio peaks, the impedance is from 20 to 25 Ohms, depending on the thickness of the element materials. At the maximum gain point, the feedpoint impedance drops to the 10-15-Ohm region. Wire versions of the antenna tend to show impedance values at the

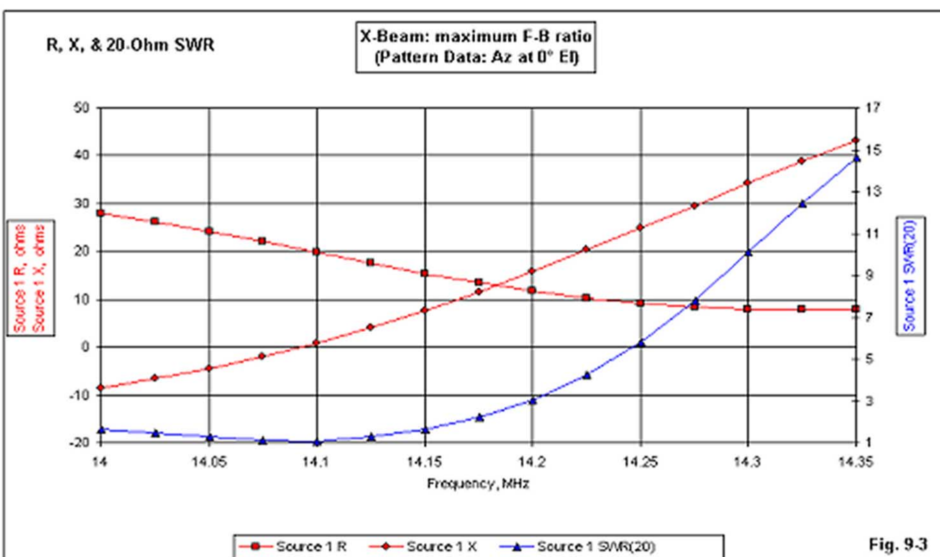


Fig. 9-3

low end of the ranges indicated, while tubular and hybrid version yield impedances values at the higher ends of the ranges.

The peak gain and 180-degree front-to-back ratio figures can give a misimpression. The peak gain of about 6 dBi (free space) rivals that of a 2-element Yagi whose elements take twice the space side-to-side. Likewise, the peak 180-degree front-to-back ratio of over 32 dB sounds impressive. However, the patterns in **Fig. 9-4** tell a somewhat different tale (as do the passband graphs that we have viewed). An averaged front-to-rear ratio for the entire rear area of the beam has, within the 200 kHz of prime operation, a value of between 10 and 15 dB—no better than a common 2-element driver-reflector Yagi. The Yagi would also have superior gain over X-beam at every frequency and be able to cover the entire 20-meter band. A 2-element Yagi with about 1/8 wavelength element spacing and loaded elements that are about 3/4ths full size would occupy about the same area as the X-beam with broader performance curves. Hence, the folded X-beam has fallen into relative disuse.

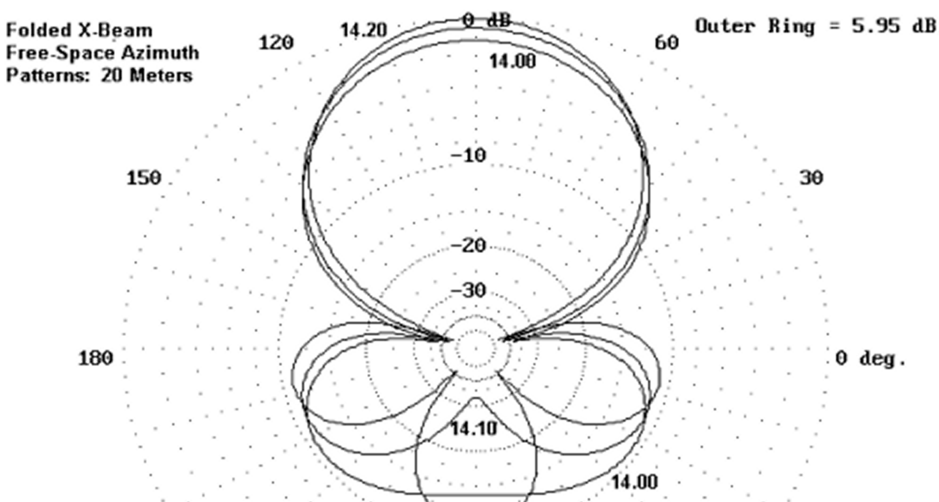


Fig. 9.4

The Hex Beam: If we fold the X-beam tails outward, we obtain the basic configuration of the hex(agon) beam, although true hex beams are built as closely to the hexagon geometry as the support structure will permit. **9-5** shows the outline of the model used to generate performance curves. The details of the model used in this study, which is a significantly modified version of a model originally provided by N7CL, appear in the chart.

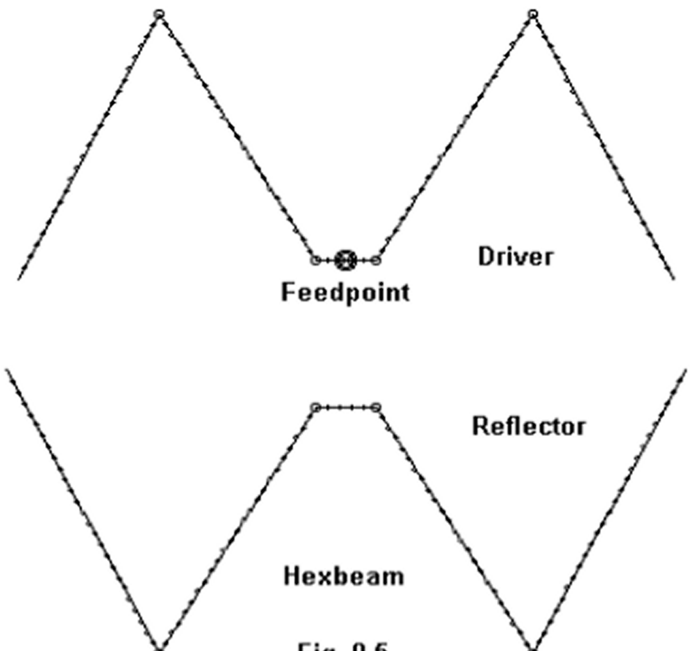


Fig. 9-5

```
hex beam:  20 meters                 Frequency = 14.1  MHz.

Wire Loss: Aluminum -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -108.00, 19.500,  0.000  W2E1 -61.800,113.000,  0.000    # 12   22
2     W1E2 -61.800,113.000,  0.000  W3E1  -9.950, 25.900,  0.000    # 12   26
3     W2E2  -9.950, 25.900,  0.000  W4E1   9.900, 25.900,  0.000    # 12    5
4     W3E2   9.900, 25.900,  0.000  W5E1  61.800,113.000,  0.000    # 12   26
```

```
5     W4E2  61.800,113.000,  0.000       108.000, 19.500,  0.000    # 12   22
6          -112.00,-12.900,  0.000  W7E1 -61.800,-113.00,  0.000    # 12   23
7     W6E2 -61.800,-113.00,  0.000  W8E1  -9.950,-25.900,  0.000    # 12   26
8     W7E2  -9.950,-25.900,  0.000  W9E1   9.950,-25.900,  0.000    # 12    5
9     W8E2   9.950,-25.900,  0.000 W10E1  61.800,-113.00,  0.000    # 12   26
10    W9E2  61.800,-113.00,  0.000       112.000,-12.900,  0.000    # 12   23

              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1           3     3 / 50.00   (  3 / 50.00)      1.000       0.000       I

                -------- TRANSMISSION LINES ---------
Line  Wire #/% From End 1   Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)   Actual  (Specified)                Ohms Fact Norm
1      3/50.0  (  3/50.0)  Short ckt (Short ck)   12.000 in   600.0  1.00
```

One feature of this model is the relatively wide spacing of the centers of the Vee-ed sections. This move tends to lower the feedpoint impedance to the 25-Ohm region, and the model uses a 12" stub of 600-Ohm shorted transmission line as a beta hairpin to effect a 50-Ohm match. It is possible to bring the center points of the driver and reflector closer together to obtain a 50-Ohm match. However, two deficits emerge with this move. First, the 50-Ohm match does not extend across the entire 20-meter band because the sharpness of the geometry yields a corresponding tuning sharpness. In contrast, the beta-matched 25-Ohm impedance does cover the entire 20-meter band with a 50-Ohm SWR of under 2:1. Second, with the center Vee points brought closer together, array performance smooths out across the band, but at much lower levels of gain and front-to-back ratio than we obtain from the wider-spaced center region. Therefore, I have chosen to look at the lower impedance version of the antenna with its better performance peaks.

The hex beam has a design affinity with a number of other members of the end-coupled clan that we shall not examine here. The slope of the outer sections of each end toward the other element is a property shared by several interesting antenna designs, including a 2-element reversible wire beam for 40 meters developed by AA2NN. The 40-meter antenna uses a double slope, since the elements each form an inverted Vee. As well, each element end approaches the corresponding end of the other element. The result is a beam that requires only two center supports. As well, by using rope on the ends of the elements, the tie down points will also be reduced to 2. Equally related to the outer structure of the hex beam is the 3-element 40-meter reversible Yagi developed by WA3FET. It uses a linear driver and a pair of parasitic elements, each of which is sloped toward the end of the driver. One parasitic element is loaded for reflector duty. One advantage of element tips that slope toward each other rather than point directly at each other, is the greater ease of adjustment. Small changes of spacing of the tips produce less radical effects than when the tips are end-to-end.

Fig. 9-6 presents the gain and 180-degree front-to-back ratio figures across 20 meters. The gain variation across the band is nearly 2 dB, a fairly high figure among common 2-element beam designs. The front-to-back ratio shows a very sharp peak, but decreases rapidly to band-edge values in the 8 to 12 dB range. Peak operation of this antenna has a bandwidth of 100 to 150 kHz, with the remainder of the band showing relatively mediocre performance. Nonetheless, like all members of the semi-closed geometry family, the hex beam permits a high front-to-back peak whose decline is steeper below the peak frequency than above it.

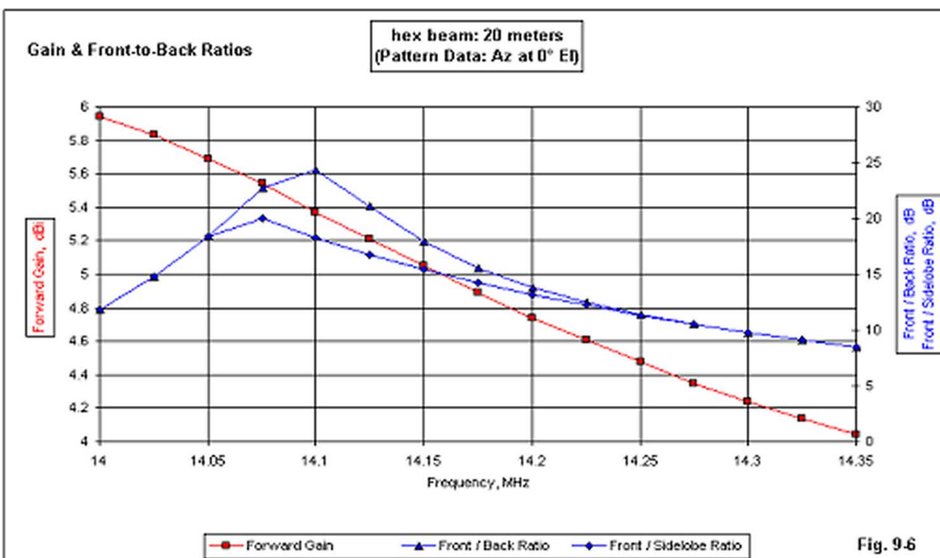


Fig. 9-6

Fig. 9-7 illustrates one of the illusions of SWR. One could suggest that this model of the hex beam antenna has an operating bandwidth that covers the entire band, since the 50-Ohm SWR is less than 2:1 across 20 meters. However, operating bandwidth involves more parameters than just the SWR. Evaluating the gain and front-to-back ratio is equally as important, if not more so, than the SWR. For this particular design of the hex beam, the only wide-band parameter is SWR. Gain and front-to-back ratio values are relatively narrow band properties.

Fig. 9-8 shows free-space azimuth patterns for the first 200 kHz of 20 meters. The pattern at 14.1 MHz is well controlled, but off peak, the rearward pattern spreads to average values in the 15-dB range. Beyond 14.2 MHz, the rearward pattern spreads larger and the forward gain decreases rapidly.

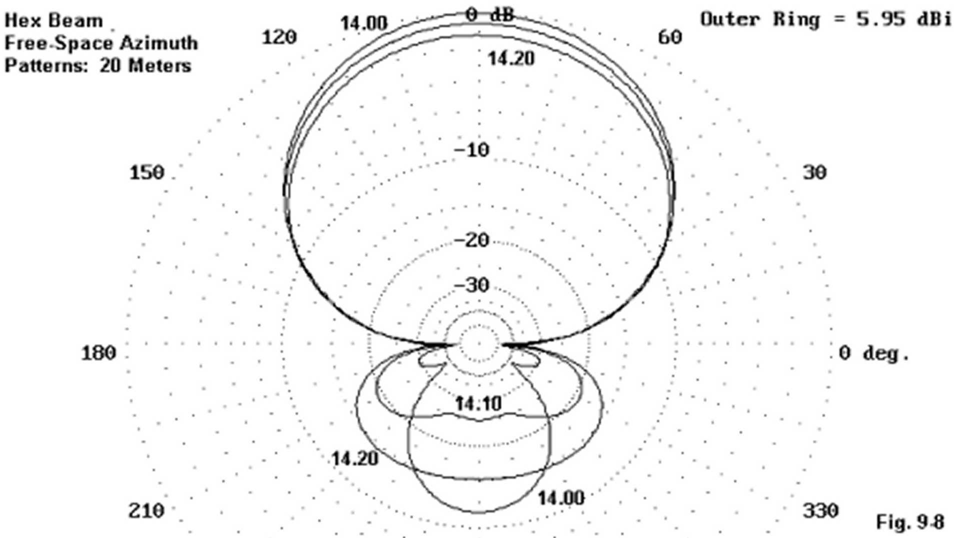


Fig. 9-8

In general, like the X-beam and other beams based upon vee-ing the center parts of the elements, the hex beam shows a quite narrow operating bandwidth relative to gain and front-to-back ratio. The rate and total gain change across the band and the band-edge front-to-back ratio values are very important in evaluating the operating bandwidth of an antenna.

The VK2ABQ Square: The VK2ABQ Square is more fully described in Chapter 1. The origins of the square go back to the 1930s, only to disappear and re-emerge in the 1960s. **Fig. 9-9** shows the outlines of a modified square. The modification consists of loading the reflector with a shorted transmission line stub about 6" long to move the peak performance point without disturbing the square shape.

The original VK2ABQ square used very close-spaced element tips—only a literal coat button apart. However, very close tip spacing creates an array with narrow-band properties, and small variations in construction can yield large variations in performance. Therefore, the model below uses fairly wide spacing (34") for the element tips.

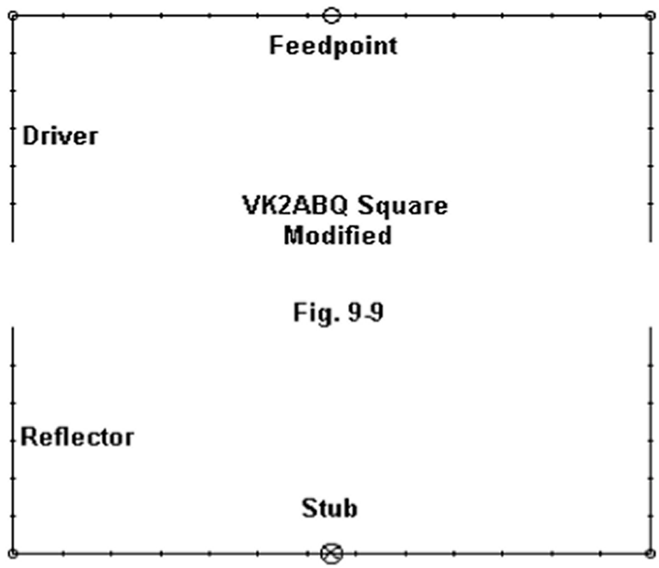


Fig. 9-9

VK2ABQ 20 Meters **Frequency = 14.15 MHz.**

Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

--------------- WIRES ---------------

Wire	Conn.	--- End 1 (x,y,z : in)	Conn.	--- End 2 (x,y,z : in)	Dia(in)	Segs
1		-118.22, 16.889, 0.000	W2E1	-118.22,106.159, 0.000	# 12	6
2	W1E2	-118.22,106.159, 0.000	W3E1	118.222,106.159, 0.000	# 12	13
3	W2E2	118.222,106.159, 0.000		118.222, 16.889, 0.000	# 12	6
4		-118.22,-16.889, 0.000	W5E1	-118.22,-106.16, 0.000	# 12	6
5	W4E2	-118.22,-106.16, 0.000	W6E1	118.222,-106.16, 0.000	# 12	13

```
6     W5E2 118.222,-106.16,  0.000       118.222,-16.889,  0.000    # 12    6
              -------------- SOURCES --------------
Source     Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
           Seg.     Actual      (Specified)
1            7     2 / 50.00   (  2 / 50.00)      1.000       0.000        I

                -------- TRANSMISSION LINES ---------
Line  Wire #/% From End 1  Wire #/% From End 1    Length       Z0   Vel Rev/
      Actual  (Specified)  Actual  (Specified)                Ohms Fact Norm
1      5/50.0  (  5/50.0)  Short ckt (Short ck)    5.892 in   600.0  1.00
```

As the model shows, this version of the antenna is off square by about 12 inches. In this highly square (if imperfectly square) configuration, the feedpoint impedance is about 100 Ohms, making the antenna a candidate for a 2:1 balun at the feedpoint.

As shown by **Fig. 9-10**, the VK2ABQ square is a relatively low-gain beam, although the gain varies only about 1.1 dB across the band. Hence, the 4.05-dB gain at the high end of the band equals that of the hex beam. The square's 180-degree front-to-back ratio peaks above 34 dB. Although the curves are fairly steep, the band edge values are about 15 dB—not bad for a 2-element parasitic beam that is about 1/4 wavelength on a side.

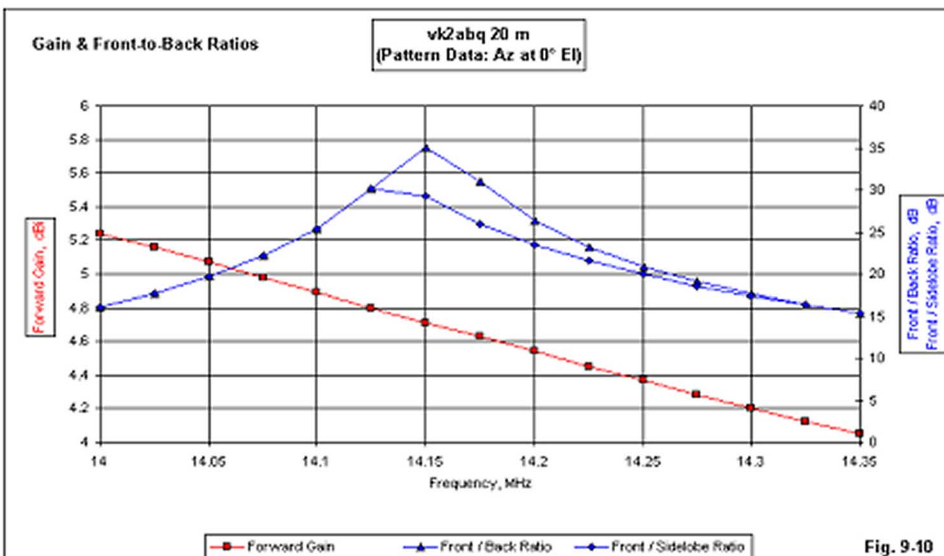


Fig. 9-10

As **Fig. 9-11** shows, the real surprise of the modified VK2ABQ square is the 100-Ohm impedance curve. Across all of 20 meters, the resistive portion of the feedpoint impedance varies by under 6 Ohms, and the reactance varies by a similar amount. Hence, the SWR curve is very flat indeed. A 2:1 balun would permit operation across the entire 20-meter band with an exceptionally low SWR and no conditions to incur losses within the balun.

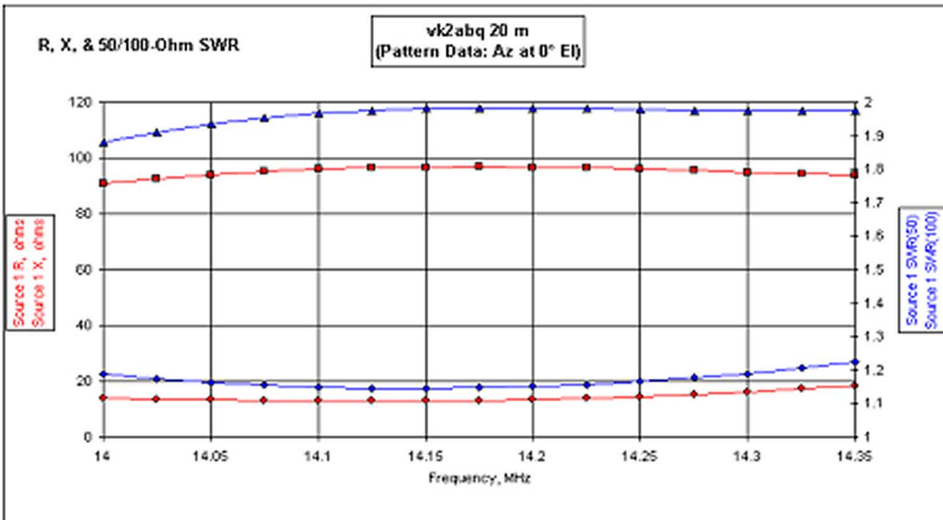


Fig. 9-11

The VK2ABQ was the basis for the later Moxon Rectangle. The key performance feature absorbed from the square was the excellent control of the rear portion of the radiation pattern. **Fig. 9-12** shows the band-edge and mid-band pattern for the square. If the square is constructed of 1" aluminum tubing, the band-edge front-to-back ratio improves to nearly 20 dB, with a small increase in array gain as well.

In all, the square is a relatively wide-band array whose characteristics remain reasonably level across the band (gain and impedance) or hold to minimal acceptable levels (front-to-back ratio). However, the chief deficit of the square is gain. In fact, one can preserve the front-to-back performance while improving gain—and as a bonus achieve a direct 50-Ohm match. The cost is going considerably out of square.

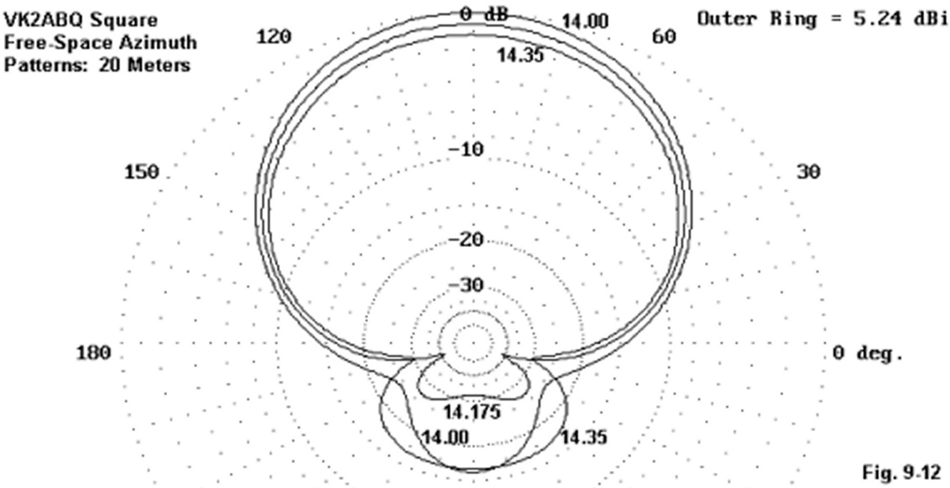
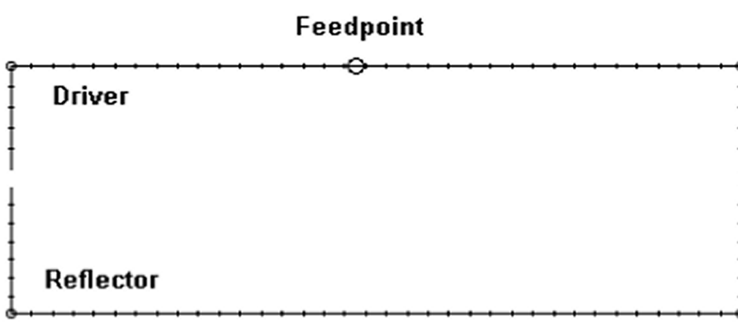


Fig. 9-12

The Moxon Rectangle: Because the 3 family members we have so far examined use relatively wide spacing between facing element tips, many designers have ignored the effects of this dimension. The result has been a number of fairly poor designs. The element-tip spacing influences the relative proportions of every other dimension of any of the family members. Nowhere is this more apparent than with



Moxon Rectangle

Fig. 9-13

the optimized Moxon rectangle, sketched in **Fig. 9-13**. The combination of close tip coupling as well as more extended parallel element coupling allows the Moxon rectangle to recover the gain lost by the square while maintaining fairly wide-band operating characteristics. It is the longer sections of parallel elements that permits the close tip spacing to be controllable without sudden shifts in the direction of the pattern.

The #12 copper wire model for this study reveals that the side-to-side length is about 3/8 wavelength, while the front-to-back size is about 1/8 wavelength. Hence, the total area of the antenna is less than the 1/4 wavelength squares, although the turn radius is greater. The details of the model used here are as follows. As the model shows, the rectangle is about 50% longer (side-to-side) than the squares. Tip-to-tip spacing is about 8".

```
Moxon rectangle                                 Frequency = 14.175  MHz.

Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -151.74, 64.188,  0.000  W2E1 -151.74,110.377,  0.000 8.08E-02   5
2     W1E2 -151.74,110.377,  0.000  W3E1 151.740,110.377,  0.000 8.08E-02  35
3     W2E2 151.740,110.377,  0.000       151.740, 64.188,  0.000 8.08E-02   5
4          -151.74, 56.433,  0.000  W5E1 -151.74,  0.000,  0.000 8.08E-02   7
5     W4E2 -151.74,  0.000,  0.000  W6E1 151.740,  0.000,  0.000 8.08E-02  35
6     W5E2 151.740,  0.000,  0.000       151.740, 56.433,  0.000 8.08E-02   7

              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual     (Specified)
1          17     2 / 47.14   (  2 / 47.14)      0.707       0.000       V
```

The gain curve in **Fig. 9-14** for the Moxon is a full dB better than for the square, although the total change in gain across the band is about the same. Since the Moxon rectangle can easily be fabricated of aluminum tubing, the result will be another 0.2 dB of gain and slightly less change in the gain across the band. As well, the band-edge front-to-back ratio values will improve to nearly 20 dB from the wire values of 15 dB. As with all of the semi-closed geometry designs, the front-to-back ratio is peaked just below the center of the band in order to achieve relatively similar front-to-back values at the band edges.

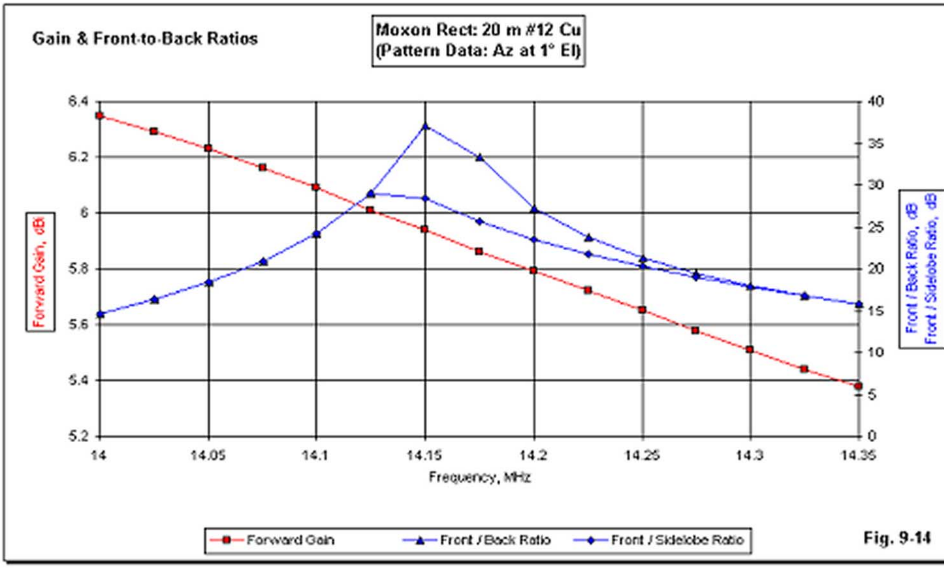


Fig. 9-14

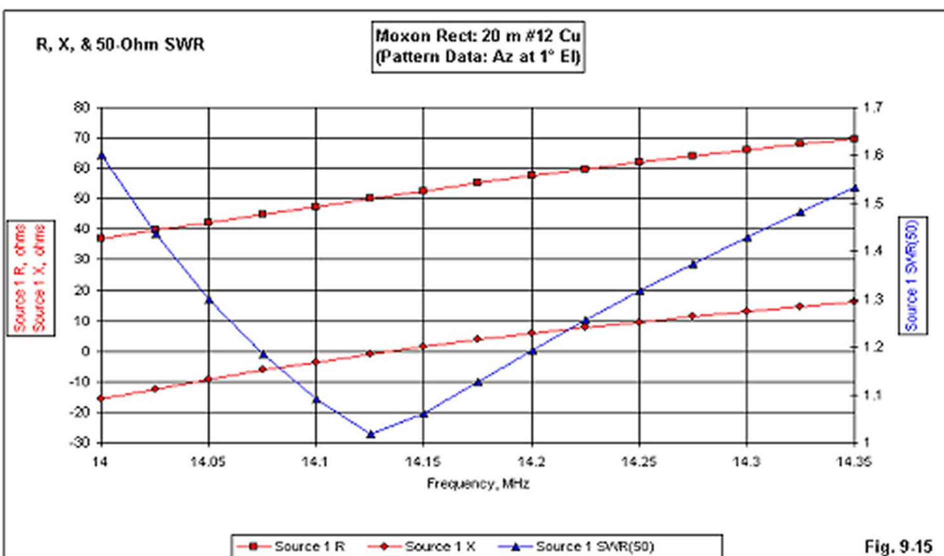


Fig. 9-15

Both the square and the Moxon use the combination of parallel element coupling and end coupling to achieve a very high front-to-back ratio at a design frequency. Indeed, in both cases, the current magnitude and phasing on the parasitic element center is very close to the precise values needed for a maximum front-to-back ratio if each element were to be independently fed and phased. Only the existence of the "tails," which radiate (if only weakly), prevents the pattern from becoming the deep dimple of a perfectly phased pair of elements.

The 50-Ohm SWR curve in **Fig. 9-15** is for a direct match to coaxial cable with no matching required (although a common-mode current suppression choke or 1:1 balun is always in order). Unlike the SWR curve for the VK2ABQ square, the Moxon SWR curve shows a definite slope, although the band edge figures are acceptable under most conditions. The curve flattens further if one uses aluminum tubing of about 1" diameter for the antenna.

The Moxon rectangle shares with the VK2ABQ square a nearly cardioidal pattern. The deepest "side" nulls do not occur at 90 degrees off the bearing of maximum gain, but somewhat further toward the rear, as is evident in **Fig. 9-16**. The rear lobes are well behaved, that is, they have no large quartering side lobes. The rearward lobes for the band edges shrink as the element diameter becomes larger.

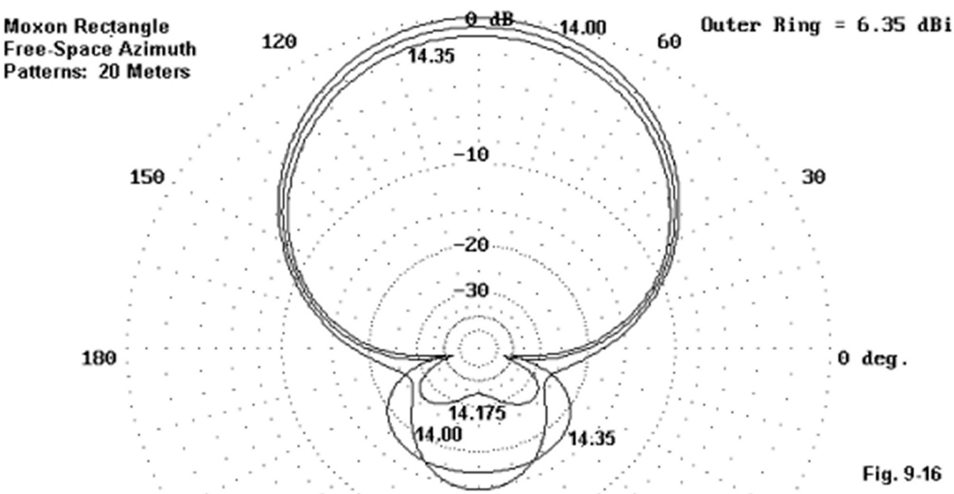


Fig. 9-16

A Few Summary Notes: This survey of semi-closed geometry end-coupled beams should suffice to reveal the family resemblances among the members of the clan. It may be useful to summarize some of the properties that both link and separate the individual members.

1. Designs with element center regions that are parallel or only gently sloped outward toward the ends tend to show wider-band characteristics than those whose element centers are vee'd toward each other.

2. Element tips display two regions of coupling. Wider spacing between tips tends to yield lower gain, although small changes in spacing yield less radical effects. Closely spaced tips tend to be more critical and may be effectively usable only if most of the element length is either parallel or only gently slopes to bring the tips closer together.

3. Semi-closed beam designs tend toward loop properties, such as an increase in perimeter dimensions with an increase in element diameter. Sloping element designs are most immune to this effect and may show more typical linear element properties.

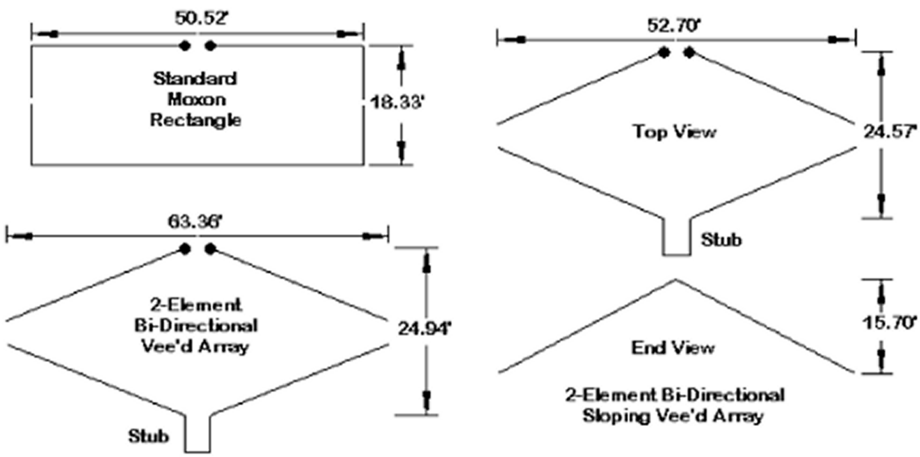
4. Designs that strive for a minimum turning radius tend to have either narrow-band characteristics or lower gain. The Moxon rectangle represents a compromise geometry that achieves as good or better gain than the other 2-element members of the clan while achieving a high front-to-back ratio and relatively broad-band characteristics. Sometimes the best square is a rectangle.

5. Both the front-to-back ratio and SWR curves tend to deteriorate much faster below the design frequency than above it. Therefore, to achieve relatively equal performance at both the lower and upper band edges, the appropriate design frequency is about 1/3 the way up the band. For 2-element driver-reflector designs, whether using a standard Yagi configuration or one of the end-coupled designs, the gain will decrease as frequency increases.

I have over the years built and used most of the designs we have discussed here in 10-meter versions, using both wire and aluminum construction. The models employed here are variants of those antennas, as well as of published data. No commercial antennas are modeled for these notes. Their intent is simply to show both the resemblances and differences among members of the end-coupled clan of beams.

Some Vee'd Cousins of the Moxon Rectangle

Because the Moxon rectangle employs both Yagi-type mutual coupling and element-end coupling, any other antenna type also employing both types of coupling is technically at least a cousin to the Moxon. The most common varieties of cousins Vee their elements toward each other. What the Moxon does with a right angle, these antennas accomplish with a straight but angled line. Whether they match the Moxon in performance, size, or convenience is part of our exploration goal.

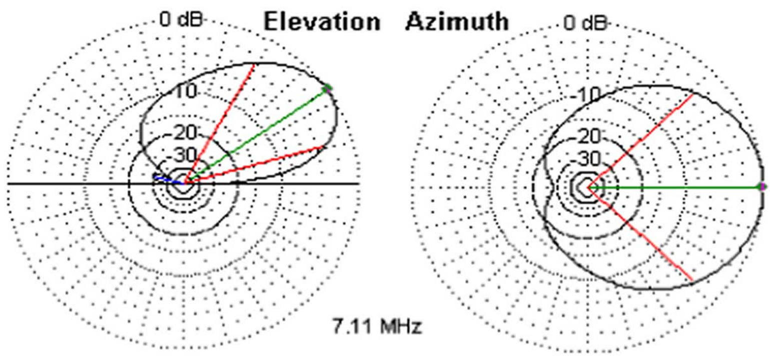


General Outlines of 3 40-Meter Dual Coupling Arrays

Fig. 9-17

Fig. 9-17 shows the outlines of three #12 copper wire antennas that we can compare. One is a standard Moxon rectangle for 40 meters, set at a height of 50' above average ground. The second, below the Moxon, is a Vee'd array that is planar. In other words, only the elements Vee toward each other, and the bi-directional array is everywhere 50' high. The third combines Vee'd elements with a second downward slope (forming an inverted-Vee). Only the center of each element is at 50', while the element ends are nearly 16' lower. Both of the Vee'd arrays are designed as bi-directional arrays, as described in the wire beam chapter, and use shorted stubs of 50-Ohm cable to establish one element as the reflector. The planar array uses 36' of RG-213 (VF = 0.66) for an open stub, while the sloping Vee'd array uses 35.7' as its open stub. Let's compare both the physical and electrical properties of the antennas under this set-up.

The elevation and azimuth plots in **Fig. 9-18** give us a performance snapshot of the Moxon rectangle. The take-off (TO) angle is 35 degrees, but with the typical Moxon wide vertical beamwidth (45 degrees). The horizontal beamwidth is 87 degrees for a gain of 9.6 dBi and a front-to-back ratio of 28 dB. **Fig. 9-19** shows the SWR curve—a point of comparison with the other array designs.



Elevation and Azimuth Plots at 50'
2-Element Moxon Rectangle

Fig. 9-18

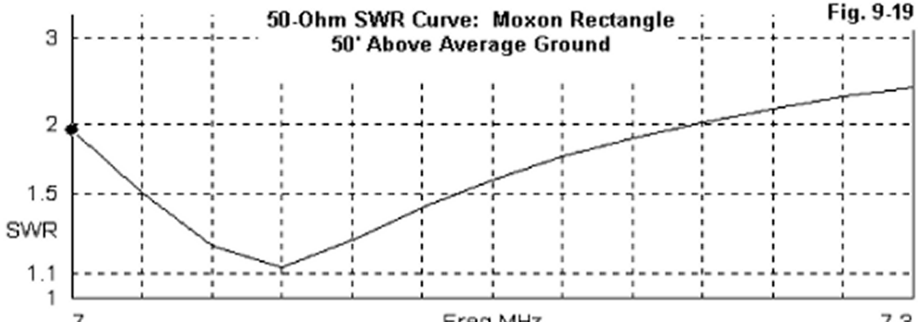
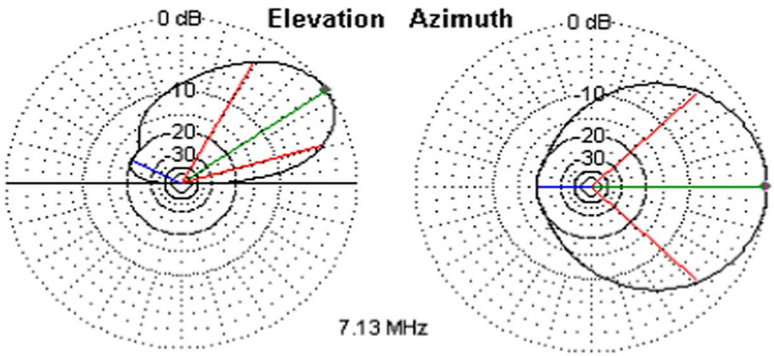


Fig. 9-19

The planar Vee'd array (**Fig. 9-20**) requires a larger footprint than the Moxon. It is 13' longer side-to-side and 6.5' wider front-to-back, despite the fact that the Moxon used a full-size reflector. Physically, the Vee'd array requires a minimum of 4 points of support, which in many circumstances would limit its utility.



Elevation and Azimuth Plots at 50'
2-Element Planar Vee'd Array
Fig. 9-20

The patterns for the Vee'd array are similar to those of the Moxon, with a TO angle of 34 degrees, a forward gain of 9.4 dBi, and a front-to-back ratio of 20 dB. The horizontal beamwidth (87 degrees) and the vertical beamwidth (45 degrees), together with the other data, all suggest that Vee'ing elements is a viable alternative to the right-angle structure of the Moxon to achieve essentially the same results. The deciding factor between the two designs may devolve upon the physical or construction convenience of one or the other.

The 50-Ohm SWR curve for the Vee'd array closely resemble the one for the standard Moxon. The slightly lower resonant impedance (47 vs. 55 Ohms) results from the using a stub to electrically lengthen the reflector element. A similar lowering of the resonant impedance occurs with a bi-directional Moxon. As well, one must slightly change the design frequency to make the curve fit the band. See **Fig. 9-21**.

Sloping the Vee'd elements is an idea developed by Carroll Allen, AA2NN. His technique reduces the support requirements to 2 elevated points, with the potential for using ground or short support posts to tie down the extended ends of the array elements. With sloping elements, the Vee'd side-to-side width drops to under 53' (plus extension ropes to the end supports), while the front-to-back dimension does not change much.

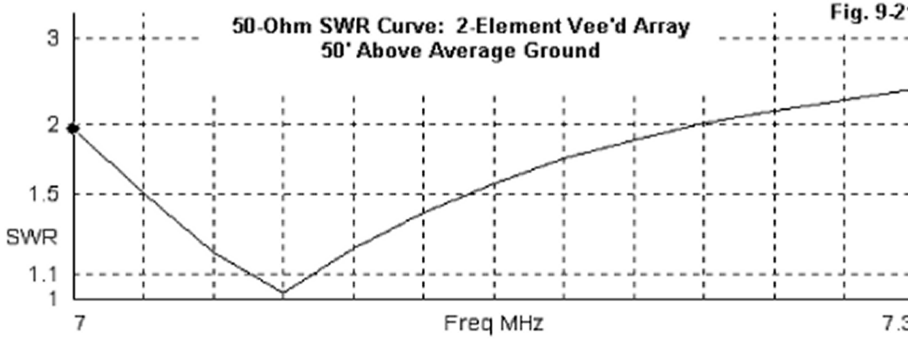
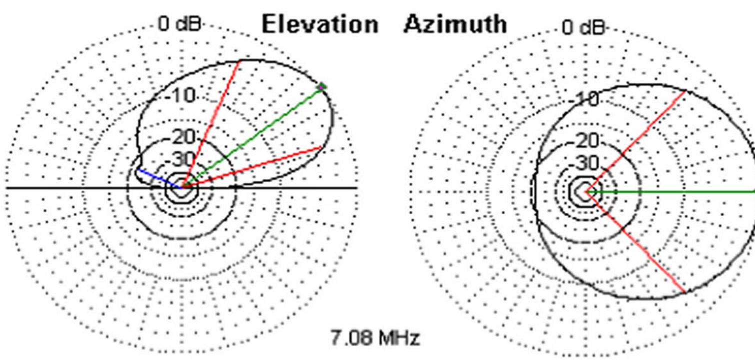


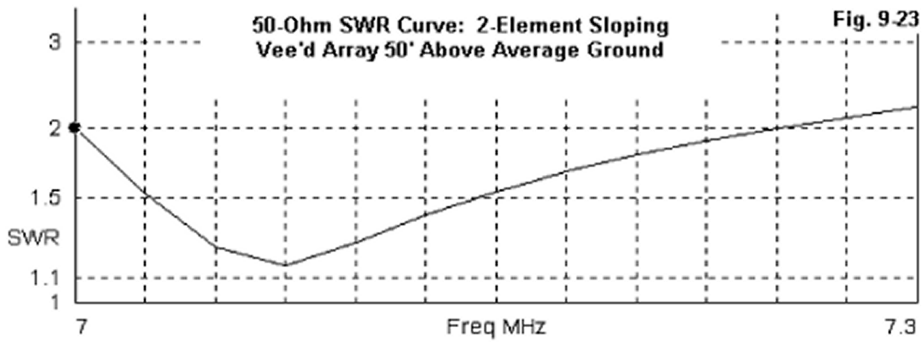
Fig. 9-21



Elevation and Azimuth Plots at 50'
2-Element Sloping Vee'd Array

Fig. 9-22

Fig. 9-22 shows the elevation and azimuth patterns for the array. The forward gain is 8.7 dBi with a front-to-back ratio of about 21 dB. The gain is almost a dB less than for the standard Moxon or the Vee'd array, but that power is not lost. Due to the sloping elements, the TO angle is higher (37 degrees), but the vertical beamwidth is also larger: 50 degrees. As well, the horizontal beamwidth is somewhat wider than for the other arrays: 94 degrees. For some fixed array installations, the wider beamwidths and the 2-support-point installation may combine to make this the design of choice.



As **Fig. 9-23** shows, the SWR curve is comparable to the other 2-element arrays. In fact, with the right choice of element lengths and spacing, you may achieve a slightly wider (by about 25 kHZ) beamwidth for the sloping Vee'd array. For either Vee'd array, you may calculate the element wire lengths by using standard vector addition techniques, referring either to **Fig. 9-7** or to the attached model files for reference. Also refer to Chapter 4 for further stub techniques.

Vee'ing elements toward each other opens the possibility for a 3-element array that uses dual coupling to achieve its performance characteristics. Dick Bird, G4ZU, many years ago developed a 3-element array in which the parasitic elements Vee'd toward the linear driven element. At the time, computer modeling was unavailable, and so his design missed its true potential. At resonance, it showed a maximum free-space forward gain of about 6.5 dBi, just above the gain of a Moxon. The maximum front-to-back ratio was only 14 dB. **Fig. 9-24** compares the Bird Yagi outline with a more recent optimized design.

Where the Bird Yagi shines is in the SWR department. A 10-meter version of the array using #12 copper wire manages to cover all of the first MHz of the band with under 2:1 SWR. **Fig. 9-25** tells the SWR story for the Bird Yagi. However, to obtain true 3-element Yagi performance, we must turn to the V-Yagi design published by Nathan Miller, NW3Z, and Jim Breakall, WA3FET, in *QST* for May, 1998.

Like the 2-element Vee'd array, the V-Yagi uses a stub to electrically create the reflector. Otherwise, both parastic elements are the same physical length.

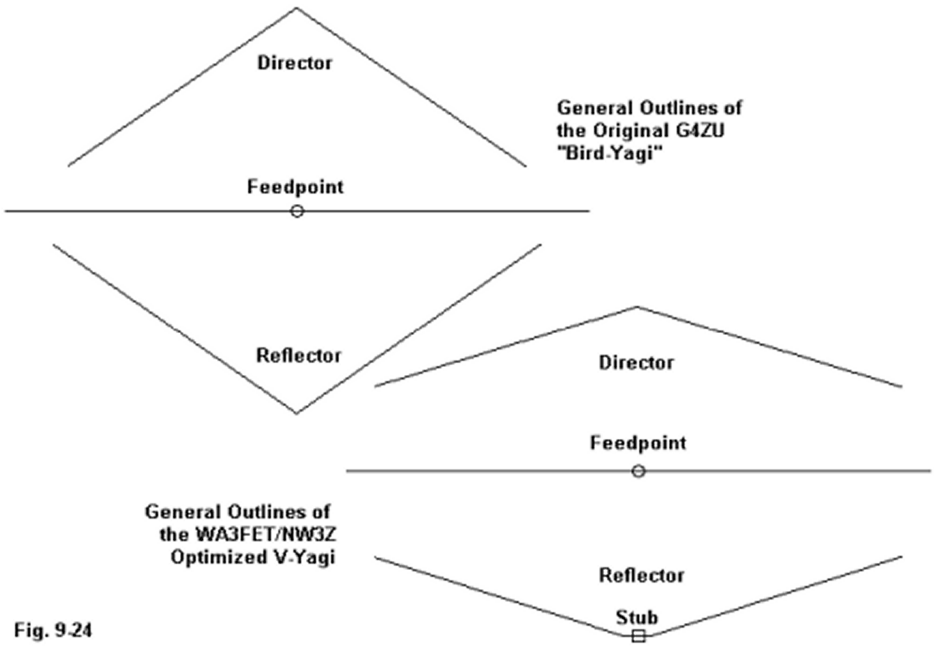
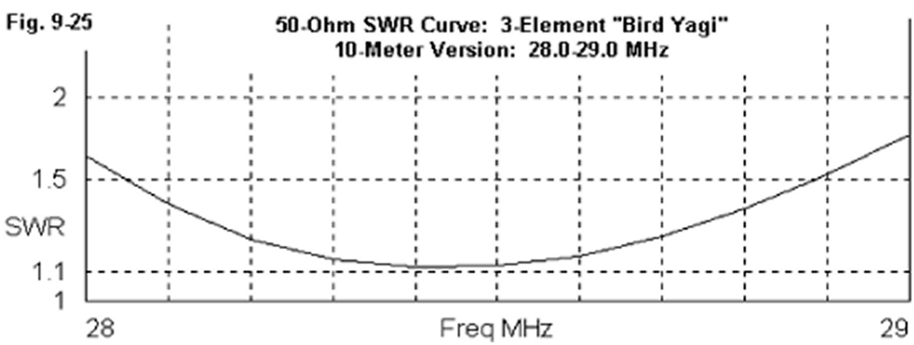


Fig. 9-24

Fig. 9-25



The following table shows the modeled structure of the V-Yagi, including the use of a stepped diameter driven element and the AWG #10 parasitic elements. The table also shows the required reflector load as an inductor. However, builders can replace this load with a shorted or an open transmission line stub using standard textbook calculations.

EZNEC/4 ver. A4.0
3 el 40m V-Yagi-WA3FET/NW3Z 9/19/02 5:36:07 AM ——
—— ANTENNA DESCRIPTION ——
Frequency = 7.1 MHz
Wire Loss: Aluminum (6061-T6) — Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

—— WIRES ——

No.	End 1 Conn.	X	Y	Z	End 2 Conn.	X	Y	Z	Dia (in)	Segs
1		-29.912,	-10.369,	0	W2E1	-1.5,	-20,	0	#10	10
2	W1E2	-1.5,	-20,	0	W3E1	1.5,	-20,	0	#10	1
3	W2E2	1.5,	-20,	0		29.912,	-10.369,	0	#10	10
4		-33.167,	0,	0	W5E1	-31,	0,	0	1.5	1
5	W4E2	-31,	0,	0	W6E1	-25.5,	0,	0	1.75	3
6	W5E2	-25.5,	0,	0	W7E1	-20,	0,	0	1.875	2
7	W6E2	-20,	0,	0	W8E1	-10,	0,	0	2	3
8	W7E2	-10,	0,	0	W9E1	-1,	0,	0	2.25	3
9	W8E2	-1,	0,	0	W10E1	1,	0,	0	2.5	1
10	W9E2	1,	0,	0	W11E1	10,	0,	0	2.25	3
11	W10E2	10,	0,	0	W12E1	20,	0,	0	2	3
12	W11E2	20,	0,	0	W13E1	25.5,	0,	0	1.875	2
13	W12E2	25.5,	0,	0	W14E1	31,	0,	0	1.75	3
14	W13E2	31,	0,	0		33.1667,	0,	0	1.5	1
15		-29.979,	10.3294,	0	W16E1	0,	20,	0	#10	10
16	W15E2	0,	20,	0		29.9788,	10.3294,	0	#10	10

Total Segments: 66

—— SOURCES ——

No.	Specified Pos. Wire #	% From E1	Actual Pos. % From E1	Seg	Amplitude (V/A)	Phase (deg.)	Type
1	9	50.00	50.00	1	1	0	V

—— LOADS (RLC Type) ——

Load	Specified Pos. Wire #	% From E1	Actual Pos. % From E1	Seg	R (ohms)	L (uH)	C (pF)	R Freq (MHz)	Type
1	2	50.00	50.00	1	0.5	2.85	Short	0	Ser

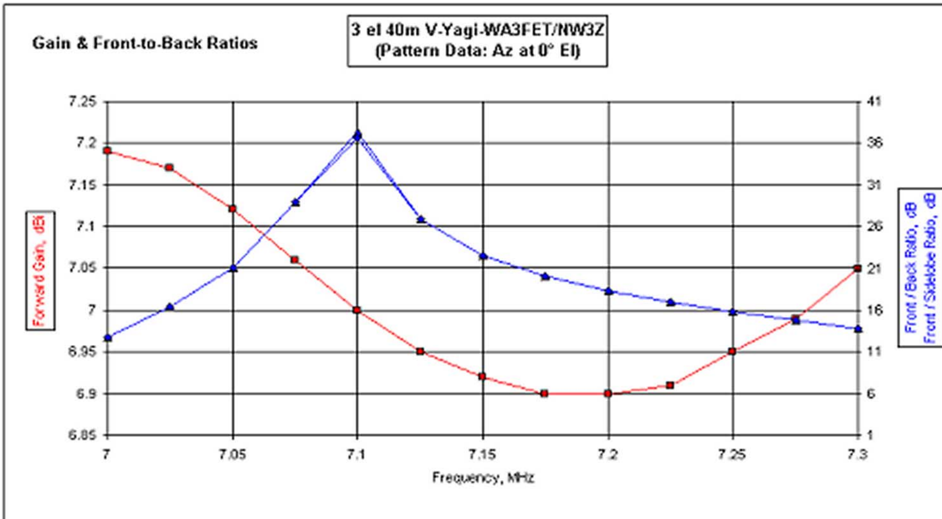


Fig. 9-26

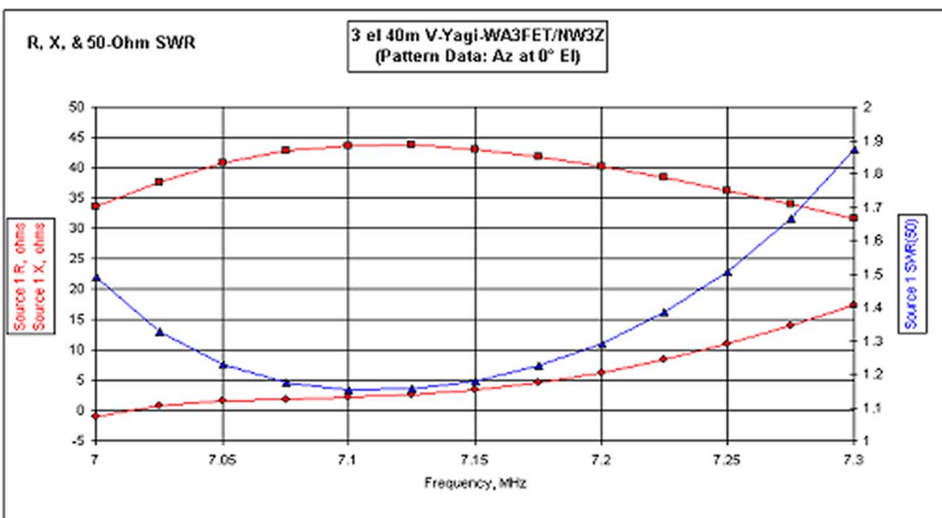
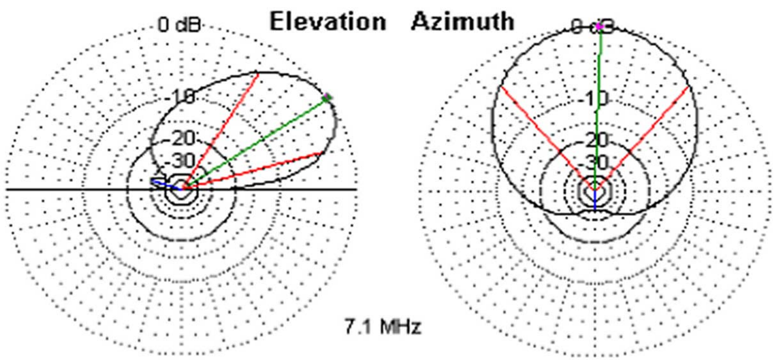


Fig. 9-27

Fig. 9-26 shows one advantage of the design: a very small variation (0.3 dB) in gain across the band, with an average value above 7 dB in free space. The gain is typical of a short-boom 3-element Yagi using linear elements, although the curve does not show the linear-Yagi ascending gain curve. The 180-degree and worst-case front-to-back ratios are closely coincident, ranging from 13 dB at one band edge to 36 dB at the design frequency.

In **Fig. 9-27** we find the feedpoint data across the 40-meter band. The design favors the lower end of the band, although we do not hit a 1.5:1 SWR value until about 7.25 MHz, and the 7.3-MHz value is under 1.9:1. The feedpoint resistance and reactance curves show good behavior, that is, small changes across the pass-band.



Elevation and Azimuth Patterns
40-Meter 3-Element V-Yagi
50' Above Average Ground **Fig. 9-28**

A fairer test might be to set the array at 50' and compare its performance to the 2-element arrays that we have examined. The elevation and azimuth patterns in **Fig. 2-28** show the results of this test of performance potential.

The V-Yagi has a forward gain of about 10.6 dBi at a TO angle of 33 degrees. The gain is about a full dB better than either the Moxon rectangle or the 2-element Vee'd array. The front-to-back ratio at the design frequency is over 35 dB. The horizontal beam width is 80 degrees, while the vertical beamwidth is 42 degrees.

Both beamwidth values suggest very wide coverage for the array. Although we might be able to rotate the V-Yagi, we may also set it up as a fixed reversible array.

The bottom line of our excursion into Vee'd arrays is the discovery that there is more than one way to obtain dual coupling in a parasitic array as a means to setting the operating characteristics of the beam. The Moxon rectangle—with its right-angle bends—draws the dual coupling to our attention in the most vivid way. However, Vee'd elements operate on the very same basis of combining the mutual coupling of parallel elements with element-end coupling. The straight-line elements simply obscure to some degree what is happening. However, the patterns and graphs for the arrays go a long way toward clarifying the operation of Vee'd beams. The chief advantage of the Moxon rectangle within its own extended family is its ability to achieve the smallest footprint of the 2-element cousins.

As well, the Moxon rectangle tends to defy development into a 3-element array. The V-Yagi is likely the prototype for further developments in this department. Indeed, I have tested a 10-meter adaptation of the V-Yagi with good success.

The Moxon rectangle itself has considerable potential for a wide variety of services to communications, despite its limitation to 2 elements. From MF to UHF, oriented horizontally, vertically, or straight upward, the array potentially fulfills a number of needs within the communications industry, both inside and outside of amateur radio. Indeed, there are a number of possibilities that we have not covered, although some of them hold promise. For example, we may stack Moxon rectangles and feed them in phase for an increase in gain. We can create stacks of either horizontally oriented or vertically oriented Moxons. A horizontal stack in the HF region may form an economical way to acquire 2 dB gain over a single array without increasing the footprint. Like all stacks of 2-element arrays, the best spacing to obtain gain and preserve most, if not all, of the front-to-back performance may involve extensive modeling.

We may also stack vertically oriented Moxons. Perhaps the best range for this treatment is in the upper VHF and UHF spectrums, where individual antenna sizes are exceptionally modest. The result—if properly designed—will be increased gain with no significant loss in the very wide beamwidth and in the high front-to-back performance. The latter factor allows multiple stacks to work well with quite close back-to-back (or back-to-back-to-back in a triple array to cover the horizon) spacing of the reflector elements.

I have also suggested that UHF Moxons are very suited for implementation on circuit board, whether used alone, in stacks, or in turnstiled arrays. Since the modeling software available to me does not permit truly accurate modeling of the rectangular and thin elements that result from circuit board traces, I cannot presently follow up on this idea. However, the potential for combining both the antenna and any requisite transmission lines on one assembly promises to yield more durable arrays.

The Moxon rectangle has many potentials—some realized and others waiting for development. As a result, the Moxon rectangle has earned a relatively permanent niche—or collection of niches—within the assemblage of designs that we should consider when trying to decide upon the best antenna for a given task and the set of circumstances within which we must perform the task.

* * *

Appended models used in this chapter:
xbm20-12.ez, hex20-12.ez, vk220-12.ez, mox20-12.ez, mox40-12-50.ez, mv40-12-50.ez, msl40-12-50.ez, birdyagi10.ez, vyagi40.ez

Appendix: Programs and Antenna Models

In a folder called "\models," I have placed the following items for your convenience.

1. 40 EZNEC (.EZ) model files, specifically, the Moxon rectangles used as examples in the various chapters of this volume.
2. 2 programmatic NEC-Win Plus files (MOXGEN.NWP and MOXGEN93.NWP) that allow you to generate Moxon rectangles for any frequency from 3 to 300 MHz—and beyond. These two models, one for 50-Ohm rectangles and the other for 90-95-Ohm rectangles, use the model-by-equation facility of the NEC-Win Plus. See Chapter 3 for instructions.
3. 2 programs (MOXGEN.BAS and MOXGEN.ZIP) for calculating Moxon rectangle dimensions apart from a modeling program. One program is in GW Basic. The other is a stand-alone Windows program developed by Dan Maguire, AC6LA. See chapter 3 for information on the obtaining updates to these programs. Both programs yield dimensions for 50-Ohm Moxon rectangles.

The models and programs are provided solely for informational and educational purposes. Their use for the design of actual antennas is the sole responsibility of the user.

Other Publications

We hope you've enjoyed this Volume of the **Moxon Rectangle Notes.** You'll find many other very fine books and publications by the author L.B. Cebik, W4RNL in the ***antenneX Online Magazine BookShelf*** at the web site shown below.

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