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Having a Field Day with the Moxon Rectangle

Good gain and a high front-to-back ratio are a couple of reasons to consider this antenna for Field Day use.

Field Day antenna installations tend to pass through phases. Phase 1 is the starter for any group: Get some antennas—usually dipoles and inverted Vs—into the air and see how well they perform. Phase 2 rests on an evaluation of the initial results. It generally consists of mechanical improvements to place the same or similar antennas higher using stronger materials. It also includes making better use of potential antenna supports at the site.

Real antenna design work usually begins with Phase 3. Based on the improved results with Phase 2 changes, the group begins to think about where they want the signals to go and how to get them there. At this stage, the group takes its first steps toward designing wire beams for the HF bands. (In Phase 4, we find the use of portable crank-up towers, rotators and multi-band arrays. I'll not delve into Phase 4 in this article.)

Wire beams and arrays have one significant limitation: We can't 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 with the beamwidth available from gain arrays. Dreamers will always wonder if they could have garnered a few more contacts lost to the deep front-to-side ratio offered by most two-element Yagi designs.

So let's explore an alternative to the two-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.

The Moxon Rectangle

In its most fully developed monoband form, a Moxon Rectangle outline looks like the sketch in Figure 1. 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.

The history of the Moxon Rectangle is

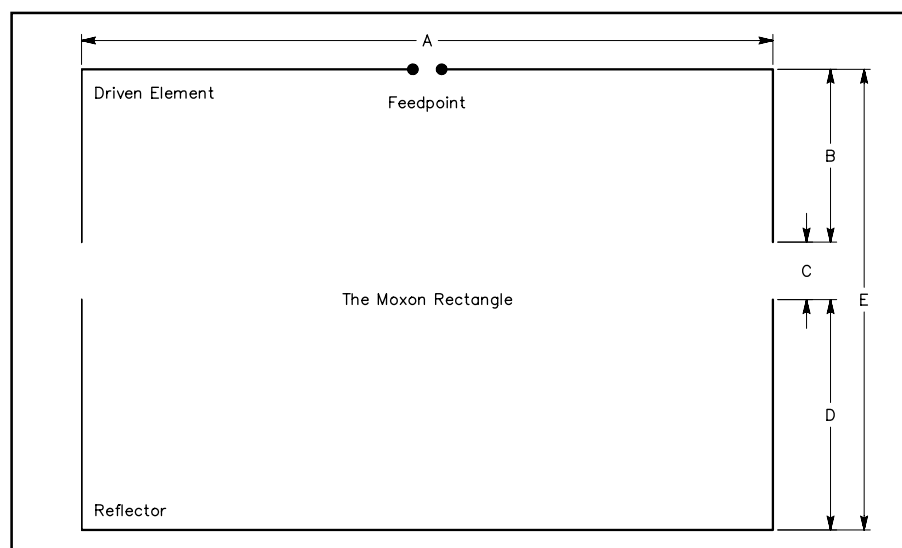


Figure 1—Outline of a Moxon Rectangle with various dimensions labeled. See the text for an explanation of the labels.

Table 1

Dimensions of Wire Moxon Rectangles for 80-10 Meters

All dimensions refer to designations in Figure 1. Dimensions are in feet and apply to #14 AWG bare-wire antennas.

Band	Frequency (MHz)	A	B	C	D	E
80	3.6	99.98	15.47	2.16	18.33	36.96
75	3.9	92.28	14.28	2.00	16.92	33.20
40	7.09*	50.69	7.82	1.15	9.35	18.32
20	14.175	25.30	3.87	0.62	4.70	9.19
15	21.225	16.88	2.56	0.44	3.14	6.14
10	28.3*	12.65	1.90	0.35	2.36	4.61

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

itself fascinating.¹ Basically, it derives from early experiments with a square shape by Fred Caton, VK2ABQ, although the very first experiments were performed in the 1930s. Les Moxon, G6XN, outlined in his classic *HF Antennas for All Locations*, a rectangular variant in which he remotely tuned the driver and the reflector.² Curious about the basic properties of the rectangle, I modeled and built variations of the design for about eight years, using wire and aluminum tubing.³

The Moxon Rectangle has three properties that recommend it for Field Day use:

- It is not as wide as an equivalent wire Yagi, because the two elements fold toward each other.
- It offers—with the right dimensions—a 50-Ω feedpoint impedance so no matching system is required (although use of a choke to suppress common-mode currents is always desirable).
- It presents a very useful Field Day pattern, with good gain and a very high F/B.

Figure 2 overlays the pattern for a typical two-element Yagi (reflector-driver design) and the Moxon Rectangle. The pattern may appear odd since it uses a linear decibel scale (rather than the usual log decibel scale) to enhance the detail at the pattern center. Although the Yagi has slightly more gain, the Moxon's deficit won't be noticeable in operation. Most apparent is the F/B 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° farther back. Signals off the beam sides are stronger than those of a Yagi, even though the rear quadrants themselves are that much quieter than the Yagi. (At low heights, from $\frac{3}{8}\lambda$ to 1λ , the Moxon's side gain ranges from 2 to 6 dB greater than that of a similarly positioned two-element Yagi.) As a result, the Moxon provides useful signal strength from one side to the other—as if it had good peripheral vision.

A Moxon Rectangle aimed in the general direction of the greatest number of potential Field Day contacts will generally gather signals from a broader sector of the horizon than most other antennas—with the bonus of good QRM suppression from the rear. Stations located near one of the US borders may discover that a basic, fixed Moxon Rectangle is all they need. For those stations located inland and needing coverage in all directions, I'll have a solution a bit later. But first, let's design a Moxon Rectangle.

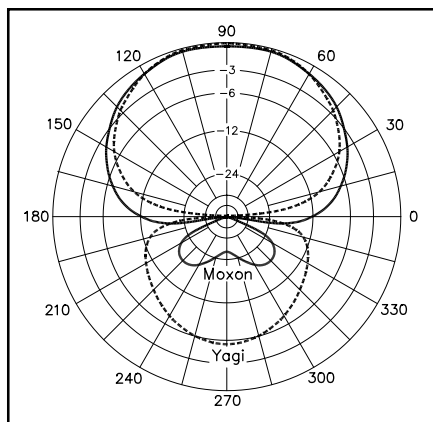


Figure 2—Relative free-space azimuth patterns at 14.175 MHz for a wire Yagi (driver and reflector) and a wire Moxon Rectangle. These patterns use a linear decibel scale to enhance detail at the pattern center (rather than the more usual log-decibel scale). Compare the pattern scale to that used in Figure 5.

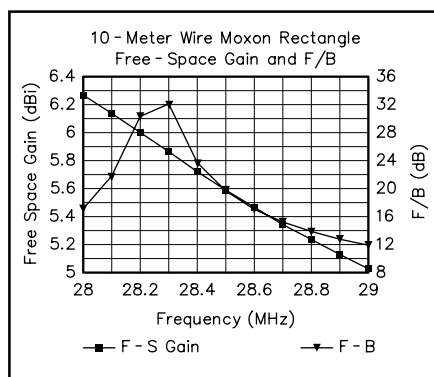


Figure 3—The pattern of free-space gain and 180° F/B across 10 meters for a #14 AWG wire Moxon Rectangle.

Designing a Moxon Rectangle

The objective in designing a Moxon Rectangle is to produce a set of dimensions for the wire diameter used that yields maximum F/B, maximum gain and a 50-Ω feedpoint impedance at the design frequency. For this exercise, I chose #14 bare copper wire, perhaps the most popular Field Day antenna material. I also aligned the maximum F/B and 50-Ω resonant feedpoint frequencies. Of course, gain varies across the band as it does with any two-element parasitic array.

With these design criteria, Table 1 provides 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 the 40- and 10-meter bands are wide relative to the wire size used, I moved their design frequencies below the mid-band point in order to obtain low-end coverage at an SWR under 2:1.⁴

The Moxon Rectangle functions by virtue of the mutual coupling between parallel element segments and the coupling between the facing element tips. Hence, the gap between element tips (dimension C in Figure 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.

Figure 3 shows the gain and F/B curves for a 10-meter version of the #14 wire Moxon Rectangle, designed for 28.3 MHz. I chose 10 meters because even the first megahertz represents a very wide band. Note that the gain curve is nearly linear across the band. However, the F/B peaks near the design frequency and tapers off—more rapidly below the design frequency than above it. Figure 4 shows a similar curve for the 50-Ω SWR, with the rate of increase more rapid below the design frequency than above it.

There is no absolute need to align the maximum F/B frequency with the resonant 50-Ω feedpoint. We can move one or both of them by small adjustments in the antenna dimensions. 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 one inch. (One inch at 20 meters is, of course, approximately equivalent to changes of four inches on 80, two inches on 40, and a half-inch on 10 meters.) In all cases, the gap (dimension C) is held constant.

- Decreasing or increasing the side-to-side dimension (A in Figure 1) raises or lowers the maximum F/B and the resonant feedpoint frequencies by about 40 kHz. For small changes in dimension A, the resonant feedpoint impedance does not change.

- Increasing or decreasing only the length of the driver tails (dimension B) by one inch lowers or raises the resonant frequency of the driver by about 70 kHz. 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 F/B will not change significantly.

- Increasing or decreasing only the length of the reflector tails (dimension D) by one inch lowers or raises the peak F/B frequency by about 70 kHz. 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.

One of the realities of Field Day is that you will not operate your antenna in free space. Actual antenna heights over real

¹Notes appear on page 42.

ground may range from $1/4\lambda$ to over 1λ , depending on the band and the available supports. To sample the operation of the Moxon Rectangle at various heights, I modeled a 10-meter version of the antenna at various heights, listed in Table 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 antenna height increases. Figure 5 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 F/B performance at the low height of $3/8\lambda$ holds promise for 40-meter and lower-frequency installations. The upshot of this exercise is that a Moxon Rectangle falls in the class of "well-behaved" antennas, requiring no finicky field adjustments once the basic design is set and tested.

Of course, you should always pretest your Field Day antennas using circumstances as close as possible to those you will encounter at the actual site. Testing over a prairie and operating in a forest can produce surprises (and problems) for almost any antenna. However, 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 Field Day operations.

A Direction-Switching Moxon Rectangle

If you live somewhere within the vast central region of the country, you may be interested in signals from both sides of the

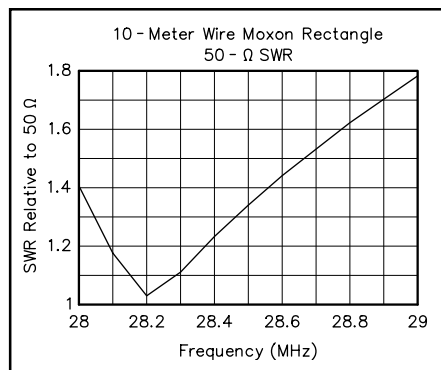


Figure 4—50-Ω SWR pattern across 10 meters for the #14 AWG wire Moxon Rectangle in Figure 3.

Moxon Rectangle. The antenna can accommodate you with fair ease. Following the design lead of Carrol Allen, AA2NN, we can design the Moxon Rectangle for direction-switching use.⁵ Figure 6 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 loading technique employs a length of shorted 50-Ω 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 feed line and simply becomes part of the overall system feed line.

One switching caution: Use a double-pole double-throw switch so that you switch the center conductor and the braid of the

Table 2

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

Height (λ)	TO angle (Degrees)	Gain (dBi)	F/B (dB)	VBW (Degrees)	HBW (Degrees)	Feedpoint Z ($R \pm jX$ Ohms)
Free-space	—	5.9	37.1	—	78	$53 + j2$
0.375	34	9.5	30.1	44	86	$53 + j8$
0.5	26	10.5	21.3	32	82	$59 + j3$
0.75	18	11.0	23.5	20	79	$50 + j1$
1.0	14	11.3	30.4	5	79	$56 + j3$

The modeled antenna is a 10-meter #14 AWG wire Moxon Rectangle at 28.5 MHz. Take-off (TO) angle refers to the elevation angle of maximum radiation. The 180° F/B 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 Figure 5 for comparative azimuth patterns.

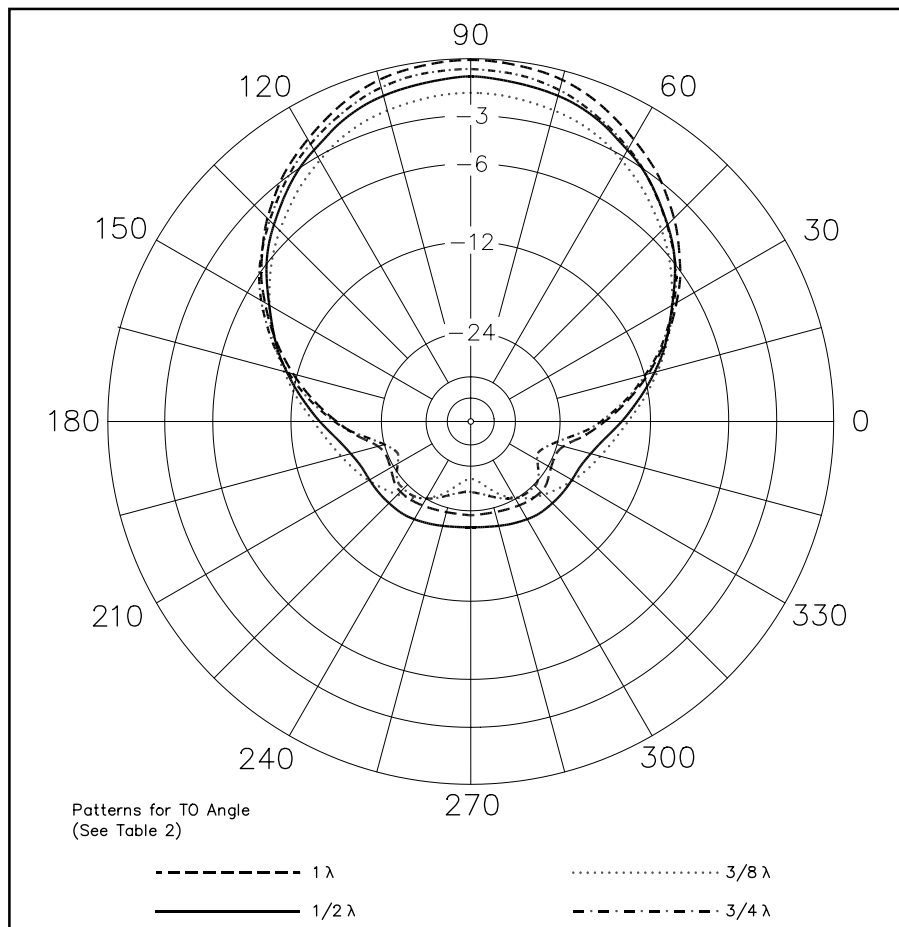


Figure 5—Typical azimuth patterns of a wire Moxon Rectangle at different heights (in wavelengths) above ground. Each azimuth pattern is taken at the elevation angle of maximum radiation (take-off angle).

coax lines used as stubs. When in use as a shorted stub, the line should not be electrically connected to the main feed line at all. A plastic box used to insulate the coax fittings from each other makes a good Field Day switch mount.

Table 3 lists the suggested dimensions for Field Day directional-switching Moxon Rectangles for 80 through 10 meters. Because two drivers are used, with their shorter tails, the overall front-to-back dimension (E) of each antenna is smaller than that of its one-way versions. The shorter front-to-back dimension lowers the feedpoint impedance by 5 to 7 Ω into the mid-40- Ω range, still a very good match for a coax feed line.

Table 3 also lists two stub lengths. The shorter one is the basic length of a shorted 50- Ω stub to achieve the required reflector loading. All of the designs required just about 65 Ω inductive reactance to electrically lengthen the reflector so that the maximum F/B frequency aligns with the driver resonant point. Hence, the basic stub length for the shorted stub is about 52.4°. Because you have a choice of cables with solid and foam dielectrics, you must multiply the listed length by the *actual velocity factor* of your stub cable. In general, solid-dielectric 50- Ω cables 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.

Because 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 $\frac{1}{2}\lambda$ 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 two-element parasitic arrays. With good preplanning, they yield antennas simple enough to be manageable in the field. At the same time, you gain the benefits of a directional pattern that may nearly double your score. In non-scoring terms, a direc-

tional-switching array means more effective communication under almost all conditions.

Field Construction of a Moxon Rectangle

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

Figure 7 outlines two types of systems for supporting the Moxon Rectangle. Consider them to be only the barest starting points for a real system. The four-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, run the rope over a limb or through an eyebolt so that the corner can be easily raised and lowered.

The ring at the end of the corner rope through which the wire passes is used to reduce mutual abrasion of the wire and rope and can be a simple loop in the rope or even a plastic bottleneck. Because 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 call for soldering 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 two-post construction method is more apt to the upper HF bands. It uses a long pole, PVC tube, or similar nonmetallic 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

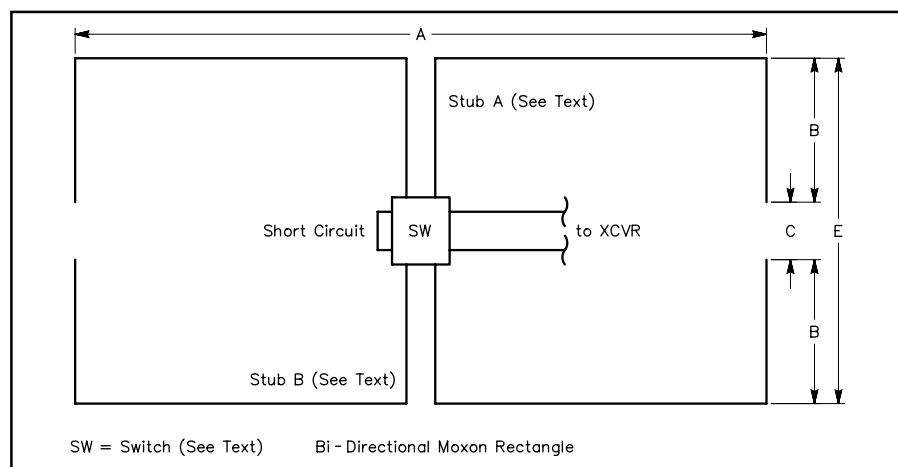


Figure 6—Outline of a direction-switching Moxon Rectangle, using transmission-line stub loading to electrically lengthen the reflector. See the text for details of the switching arrangement.

Table 3
Dimensions of Direction-Switching Wire Moxon Rectangles for 80-10 Meters

All dimensions refer to designations in Figure 6. Dimensions are in feet and apply to #14 AWG bare-wire antennas.

Band	Frequency (MHz)	A	B	C	E	Simple	Stub $+1/2\lambda$
80	3.6	99.98	15.47	2.16	33.10	39.78	176.39
75	3.9	92.28	14.28	2.00	30.56	36.72	162.82
40	7.09	50.69	7.82	1.15	16.79	20.20	89.56
20	14.175	25.30	3.87	0.62	8.36	10.10	44.80
15	21.225	16.88	2.56	0.44	5.56	6.75	29.92
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 Ω for the reflector element at the design frequency. Listed stub lengths are for 50- Ω cable with a 1.0 velocity factor. Multiply listed lengths by the *actual velocity factor* of the line to obtain the final length.

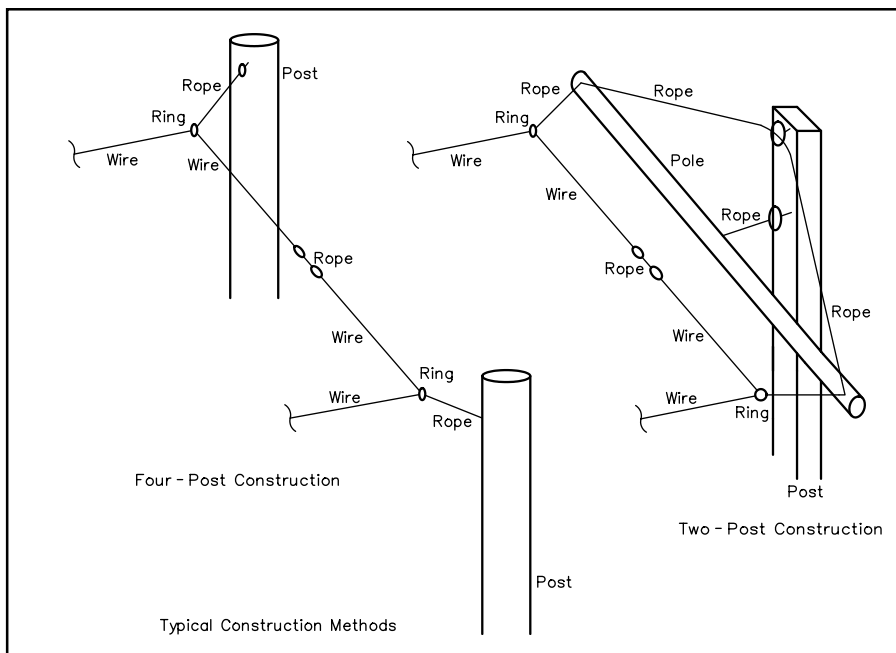


Figure 7—Four-pole and two-pole mounting arrangements for a wire Moxon Rectangle, shown only in bare outlines.

sketch shows a two-anchor mounting for the pole. The upper support ropes align the pole horizontally. Thus, the rope should be locked to the ring or other support to keep everything horizontal. Alternatively, you 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 four-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 fold-back used 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 a 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 field use, lightweight coax (ie, RG-8X for 50- Ω applications) helps reduce the stress on the driven element(s) at the feedpoint. However, where conditions permit, supporting the element centers is advisable. In fact, slightly V-ing the elements will normally produce no adverse effects in performance. However, if you contemplate

a shallow inverted-V form of the antenna, pretest the assembly to assure that everything will work as planned.

Field Day antenna 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. Survey your local Home Depot and other such outlets for fixtures and nonmetallic connectors that might prove useful for a Field Day antenna. You may find them anywhere in the store. The plumbing and electrical departments are good starting places to find adaptable PVC fittings.

The Moxon Rectangle offers good potential for Phase 3 antenna improvements in Field Day installations. It is certainly not the only good antenna for this important exercise. The final decision you make in selecting an antenna should be the result of extended planning activities that review: (A) What is possible at the site; (B) what is possible with the available construction crew and (C) which antennas when properly oriented will improve communications the most from a given site. What you learn about various antennas that may be candidates for the next Field Day will serve you well in the long run—both at home and in the field.

Of course, the Moxon Rectangle—when it has done its Field Day service—need not be retired to storage awaiting next year's duty: It can serve very well in many home-station installations. The size and the signal pattern may be perfectly suited to the

needs of at least some operators.

Notes

¹For a more complete history, see L. B. Cebik, W4RNL, "Modeling and Understanding Small Beams: Part 2: VK2ABQ Squares and The Modified Moxon Rectangle," *Communications Quarterly*, (Spring, 1995), pp 55-70. There are a number of notes on this antenna type at my Web site (<http://www.cebik.com>) in the "Tales and Technicals" collection. As an example of a VHF version of the antenna, see Lee Lumpkin, KB8WEV, and Bob Cerrito, WA1FXT, "A Compact Two-Element, 2-Meter Beam," *QST*, Jan 2000, pp 60-63. Other VHF applications have appeared in *antennex* an on-line magazine (<http://www.antennex.com>).

²Les A. Moxon, G6XN, *HF Antennas for All Locations* (RSGB, 1982), pp 67, 168, 172-175. Available from the ARRL, order no. 4300, \$15. See the [ARRL Bookcase](http://www.arrl.org) in this issue for ordering information.

³For aluminum versions of the antenna, see L. B. Cebik, "An Aluminum Moxon Rectangle for 10 Meters," *The ARRL Antenna Compendium*, Vol 6 (ARRL, 1999), pp 10-13 and Morrison Hoyle, VK3BCY, "The Moxon Rectangle," *Radio and Communications* (Australia), Jul 1999, pp 52-53.

⁴If you want to use other wire sizes (including center-supported versions made from aluminum tubing in diameters up to well over an inch in diameter), a small GW Basic program is available that will ease the design work. The program's output is accurate to within under 0.5% relative to the NEC-4 models used to derive the algorithms. You can download this program and explanatory text from <http://www.arrl.org/files/qst-binaries/MOXONBAS.ZIP>.

A full account of the technique used to derive the program will appear in a forthcoming issue of *antennex* (<http://www.antennex.com>). The program will also be added to the *HAMCALC* suite of GW BASIC electronics utility programs available from George Murphy, VE3ERP. Those having access to *NEC-Win Plus*, a NEC-2 antenna modeling software package available from Nittany Scientific, can simplify the process of deriving dimensions and checking the resultant model. The model-by-equation facility of the spreadsheet input system permitted me to transfer the design equations directly into a model, which the user can set for any desired design frequency. The output will include both the dimensions and a standard NEC-2 calculation of the antenna pattern and source impedance, with options for changing any of variables, including the wire conductivity, size, etc. A copy of the MOXGENE8 .NWP file is available among the examples at the NEC-Win Web site (<http://www.nittany-scientific.com>).

⁵Carroll Allen, AA2NN, "Two-Element 40-Meter Switched Beam," *The ARRL Antenna Compendium*, Vol 6 (ARRL, 1999), pp 23-25. See especially Carroll's improved method of stub construction.

An ARRL Life Member and educational advisor, L. B. Cebik, W4RNL, recently retired from The University of Tennessee, Knoxville, to pursue his interests in antenna research and education, much of which appears at his Web site (<http://www.cebik.com>). A ham for over 45 years, his articles have appeared in several League publications including QST, QEX, NCJ and The ARRL Antenna Compendium. You can contact L. B. at 1434 High Mesa Dr, Knoxville, TN 37938-4443; cebik@utk.edu. **QST**