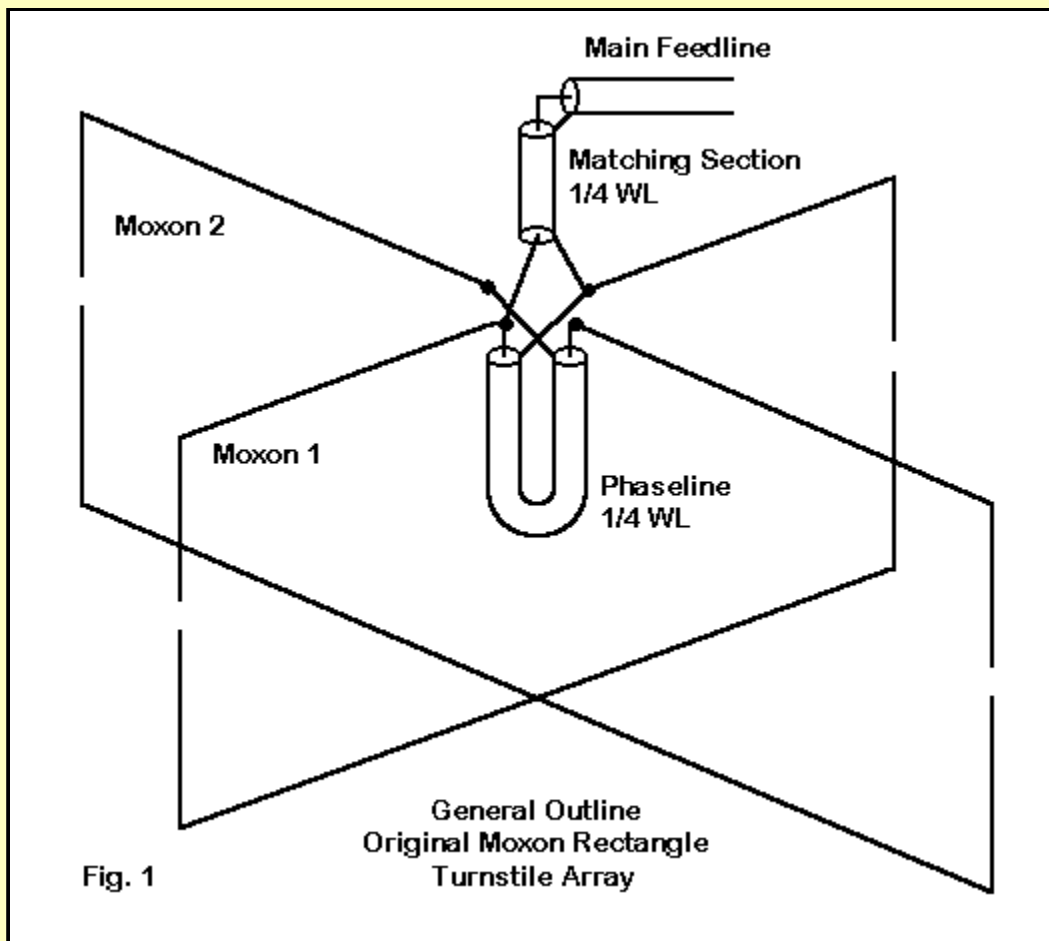


Simplifying the Turnstile Moxon Rectangle Fixed-Position Satellite Antennas

L. B. Cebik, W4RNL (SK)

Recently, I presented some information on building turnstiled Moxon rectangle antennas for use as fixed-position amateur satellite antennas. The basic article appeared in *QST*, (Aug. 2001), pp. 38-41, with some supplemental information in the Technical Correspondence column of *QST*, Oct, 2001, pp. 78-79. In reading the following notes, I recommend these articles as background.

The basic principle of the turnstiled Moxon rectangles appears in **Fig. 1**. The two antennas are placed at right angles to each other, with the feedpoint separated. (The centers of the reflectors may be touching or separated. No change of performance is detectable between the two options.)



A main feedline connects to one rectangle driver. From that element a 1/4-wl phase-line composed of a transmission line runs from the fed driver to the second driver. The phase-line should have a characteristic impedance (Z_0) 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 phase-line 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

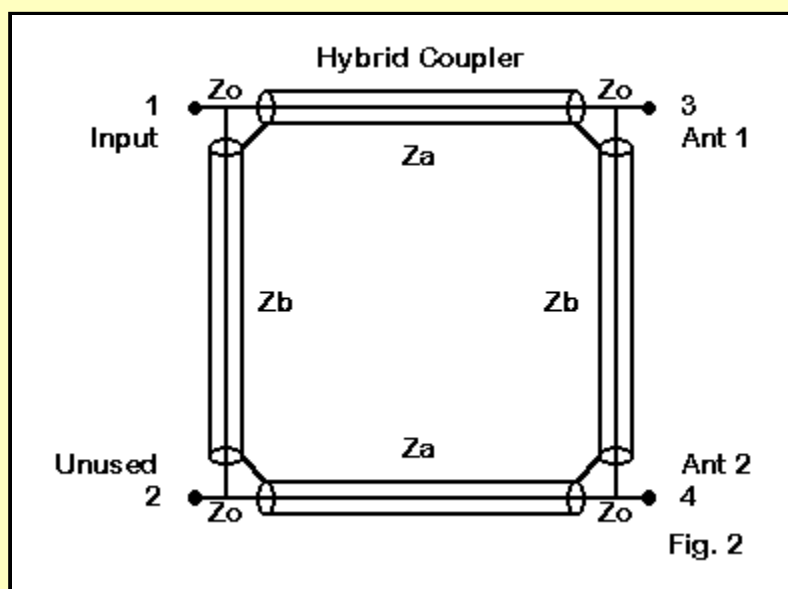
pattern. As well, the elevation pattern shows a very wide and smooth dome of radiation with a beamwidth in excess of 100 degrees. The exact -3 dB beamwidth depends in part on the height of the antenna above the ground surface. Heights up to 2 wl provide smooth coverage of the sky from about 30 degrees 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 articles was to employ a 35-37-Ohm 1/4-wl 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 phase-line). 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-wl 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.

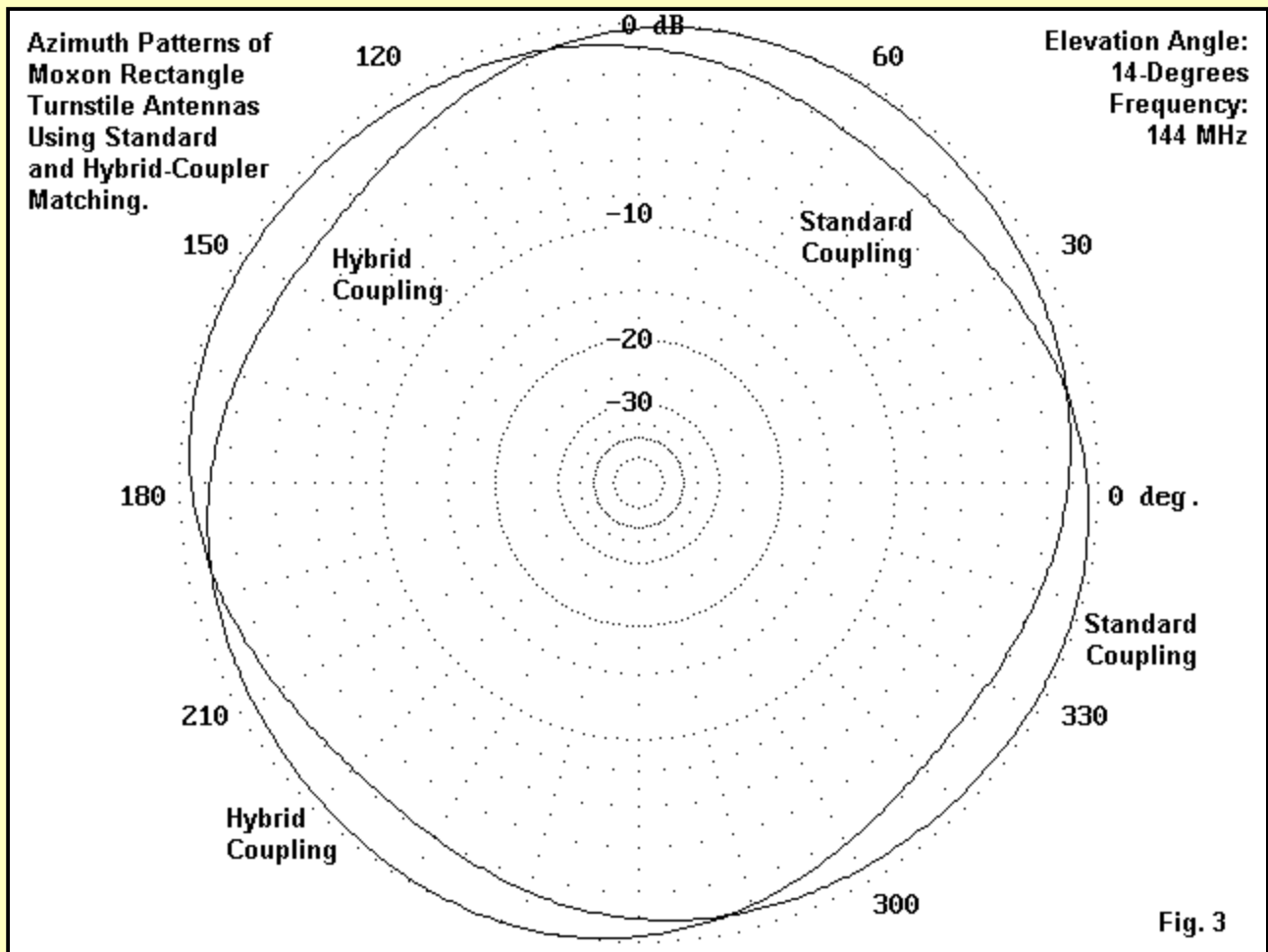
An alternative method of returning the Moxon feedpoint impedance would be to employ a hybrid coupler-power splitter of the basic design shown in **Fig. 2**.



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.

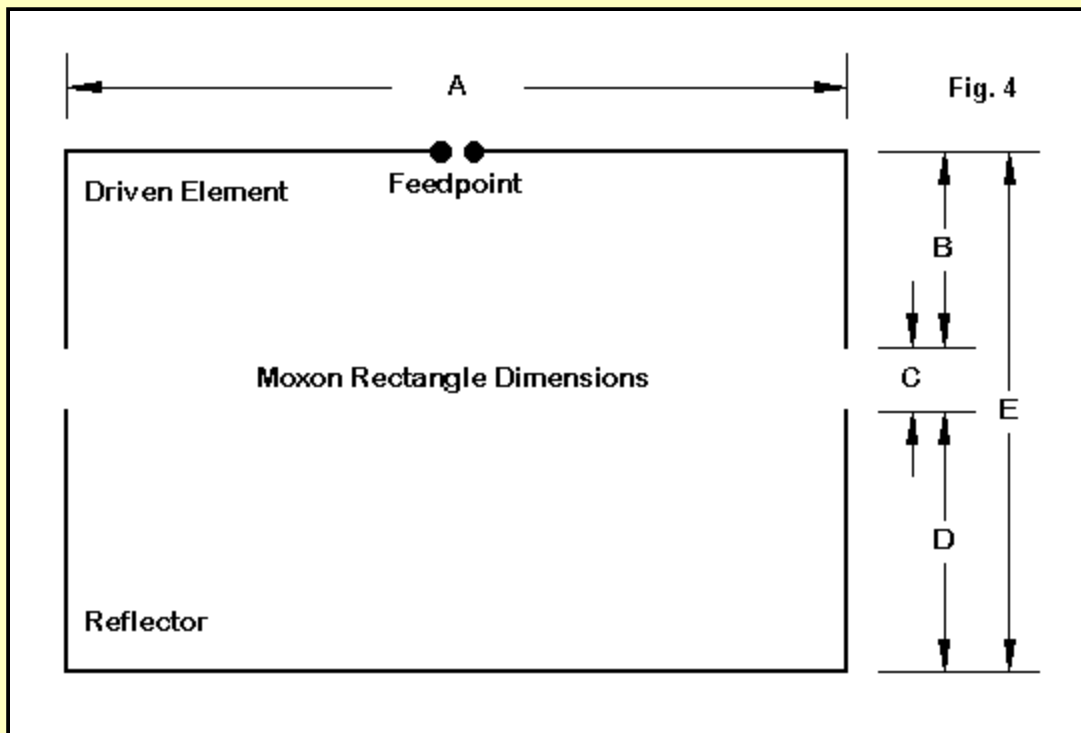
The hybrid coupling system offers no advantage over the simpler system used in the original models, but it does introduce two more line lengths. See **Fig. 3**.



When we operate the turnstile off its design frequency, the nearly circular patterns begin to pick up severe azimuth distortion. **Fig. 3** 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.

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. 3, begins to appear at under a 1.5% frequency shift from the design frequency, and the condition worsens with added shifts of frequency, whether created by operating the array off frequency or by failure 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 article, 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. Those recommendations resulted in the following table of dimensions, keyed to **Fig. 4**, the general outline of a Moxon rectangle used in most of notes on the antenna.



.....
Dimensions for Moxon Rectangles for Satellite Use

See Fig. 4 for letter references. All dimensions in inches.

Dimension	145.9 MHz: 3/16"	435.6 MHz: AWG #12
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

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.

.....
 Due to many requests for dimensions suited to the use of other materials for the 2-meter version of the antenna, I placed the following table in the 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, I also provided dimensions 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)

.....

No added dimensions have been provided for the 435.6-MHz version, since AWG #12 wire is so prevalent in the U.S. We shall look at further UHF construction methods before closing this note.

The notes so far summarize the state of Moxon rectangle turnstiles for satellite use to this point. However, the title of these notes implies a simplified assembly, and to that we next turn.

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 and from those models and some regression analysis to 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. 5** 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.

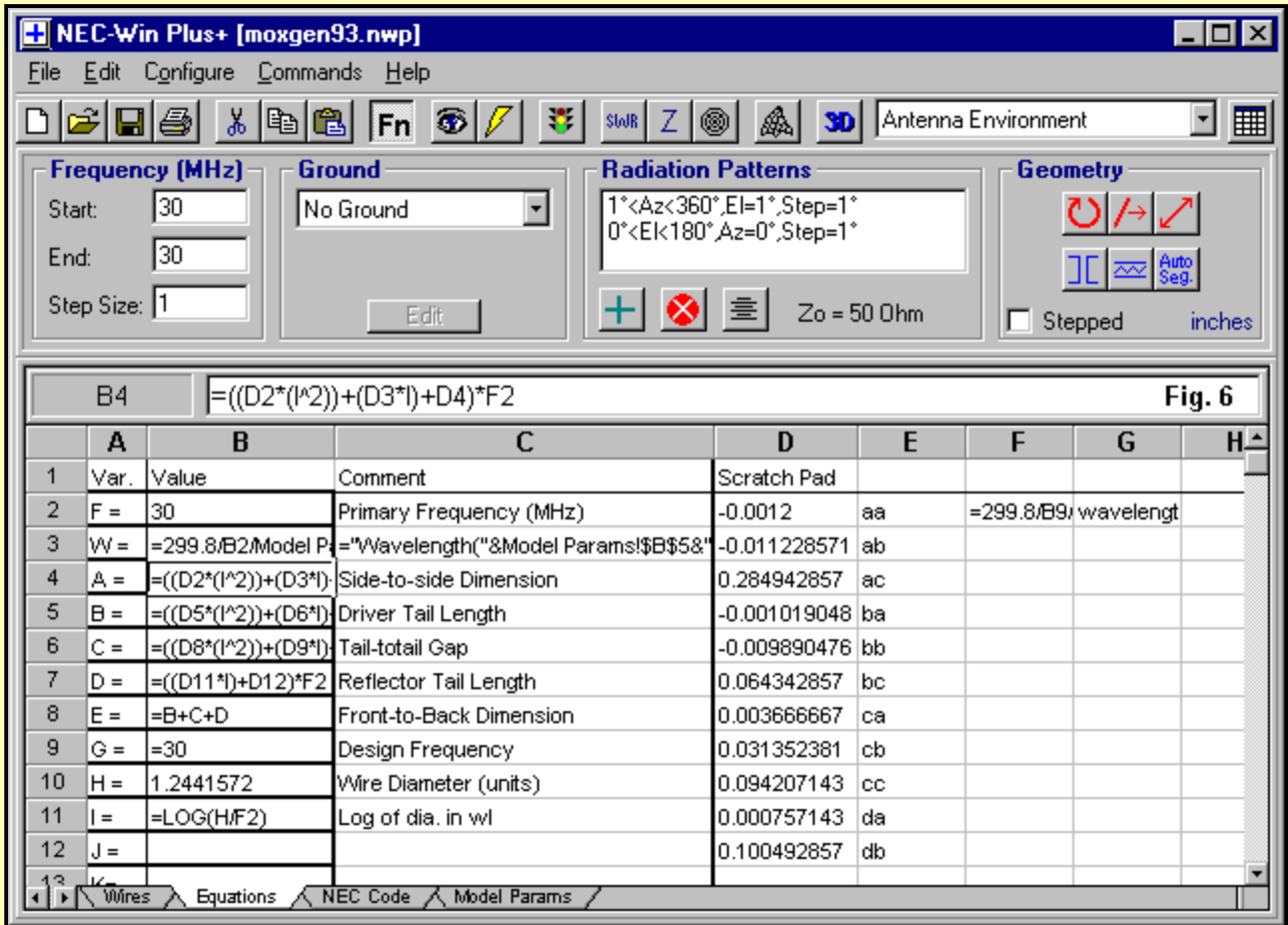
Fig. 5

	A	B	C	D	E	F	G	H
1	Var.	Value	Comment	Scratch Pad				
2	F =	30	Primary Frequency (MHz)	-0.000857143	aa	=299.8/B9/ wavelengt		
3	W =	=299.8/B2/Model P	=Wavelength("&Model Params!\$B\$5&"	-0.009571429	ab			
4	A =	=((D2*(I^2))+(D3*I))	Side-to-side Dimension	0.339857143	ac			
5	B =	=((D5*(I^2))+(D6*I))	Driver Tail Length	-0.002142857	ba			
6	C =	=((D8*(I^2))+(D9*I))	Tail-total Gap	-0.020357143	bb			
7	D =	=((D11*I)+D12)*F2	Reflector Tail Length	0.008285714	bc			
8	E =	=B+C+D	Front-to-Back Dimension	0.001809524	ca			
9	G =	=30	Design Frequency	0.017809524	cb			
10	H =	=0.39343832	Wire Diameter (units)	0.051642857	cc			
11	I =	=LOG(H/F2)	Log of dia. in wl	0.001	da			
12	J =			0.071785714	db			

Now the simplification. Although the phase-line 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 phase-line. 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 impedance 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. 6**.



The range of wire diameters allowed by both master models is 1E-5 wl through 1E-2 wl. 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. 4 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 phase-line 16.99 5.69

Dimensions for 145.9 and 435.6 MHz Moxon Rectangles. Two are required for each antenna. The phase-line 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.

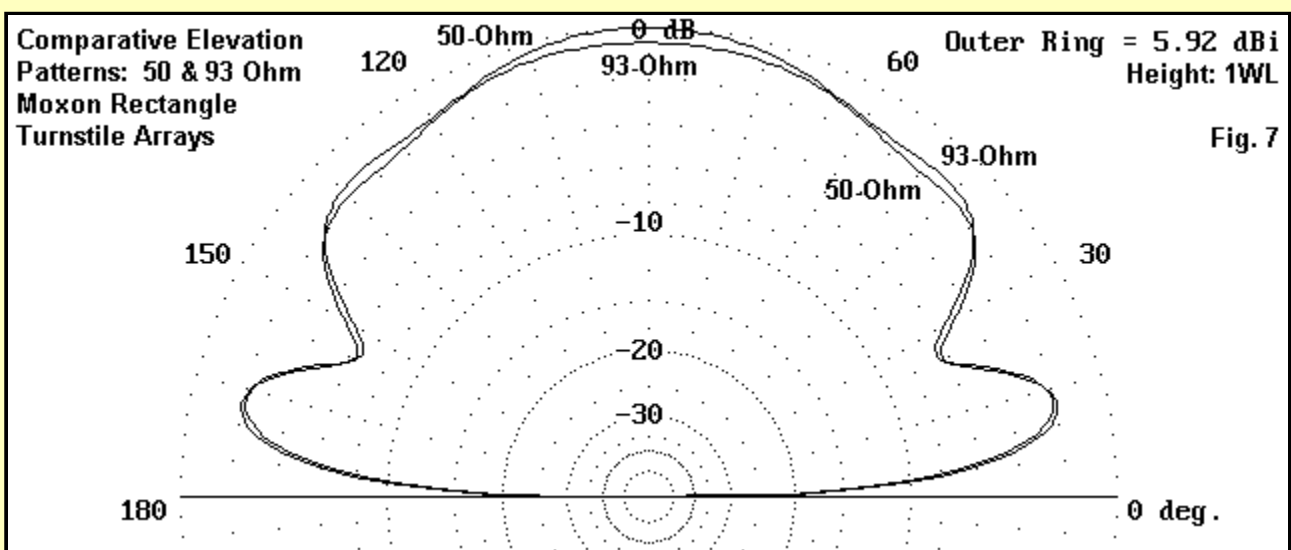


Fig. 7 compares the elevation pattern of the 50-Ohm Moxon 2-meter array with a 93-Ohm array, both 1 wl above ground at 145.9 MHz. The new array shows about 0.5 dB less gain, but increases

the beamwidth by about 5 degrees. Neither change should alter practical operation significantly, since there are more intervening variables in the average backyard than between versions of the array.

However, the higher impedance Moxon rectangles permit us to simplify construction by using only the 93-Ohm phase-line 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 and 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 phase-line on one of the two interlocking board forming the turnstile array. The key element here is likely to be finding the velocity factor created by the substrate separating the phase-line 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.
- 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 phase-line 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 bus, 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.

An On-Line Calculator for the 93-Ohm Moxon Rectangle Dimensions

Below is a version of the Moxon dimension calculator that you may use right on this page, thanks to Joe Faber, KG4UHP, who created the JavaScript and gave me permission to place it here. Remember that the dimensions apply to Moxon rectangles that use the same diameter material throughout. Decide on the design frequency and the diameter of the elements. You may use inches or millimeters for the diameter--or you may select an AWG wire gauge. Be certain to select the unit of measure for the output. Then, click on any of the output boxes if the calculations have not already appeared.

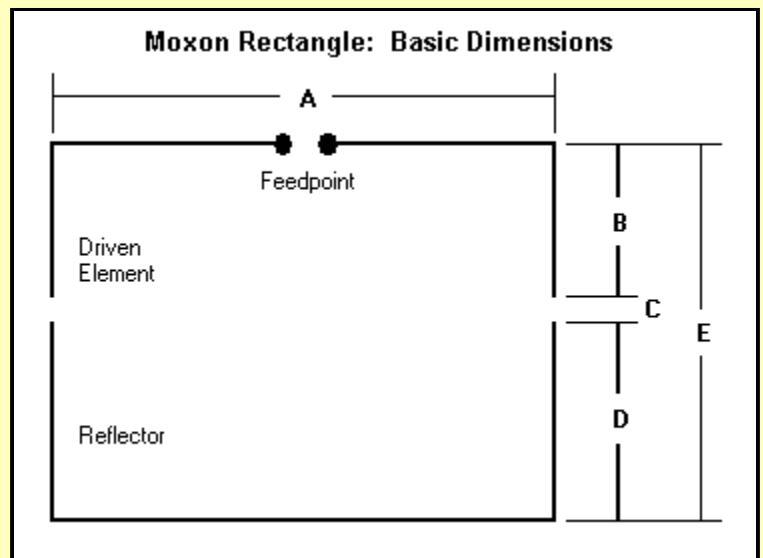
Moxon Rectangle Dimension Calculator

Frequency : MHz

Wire Diam : gauge

Output Units :

- A
- B
- C
- D
- E



[Go to Main Index](#)