Stacking Moxon Rectangles
Part 2: Vertically Stacking Vertically Oriented Rectangles

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In Part 1, we reviewed the situation surrounding the vertical stacking of horizontally oriented Moxon rectangles. Mechanically, this practice is applicable to almost any HF or VHF frequency. However, we discovered that there was a very wide difference between the separation that yields maximum gain (0.61-0.67 wavelength) and the separation that yields a maximum front-to-back ratio (1.0-1.1 wavelength). The maximum gain separation shows a low front-to-back ratio (about 13 dB compared to a maximum 180-degree front-to-back ratio of 50 dB for a single antenna). Conversely, the maximum front-to-back separation showed about 1 dB less forward gain than the maximum gain separation.

The end result is simply an inability to recommend or dis-recommend a stack of horizontally oriented Moxons. To reach a conclusion in either direction would require a set of operational specifications against which to measure the extremes of either maximum gain or maximum front-to-back ratio--or some intermediate separation yielding the best compromise between the two extremes.

When we turn to vertically oriented Moxon rectangles, we find a much simplified situation. First, a vertical stack of vertically oriented Moxons is normally applicable only at VHF and UHF ranges, where the physical size of each antenna is small and the separation as a function of a wavelength is also reasonable. Second, as we shall see, we do not encounter a quite so radically disparate set of extremes with respect to maximum gain and maximum front-to-back ratio. The simplified conditions, however, do offer us more options, including 2-, 3-, and 4-stack possibilities.

The Vertically Oriented Moxon and Its Stacking Potentials

Fig. 1 shows the range of possibilities that we shall explore. If the performance of one or more of the vertical stacks of Moxons has the right performance characteristics, then a stack may be the order of the day for numerous communications tasks. The Moxon's high front-to-back ratio allow close mounting to a conductive mast or tower behind the reflector. Hence, one may set up a stack of Moxons without undue concern for wind resistance and loading of the support boom.

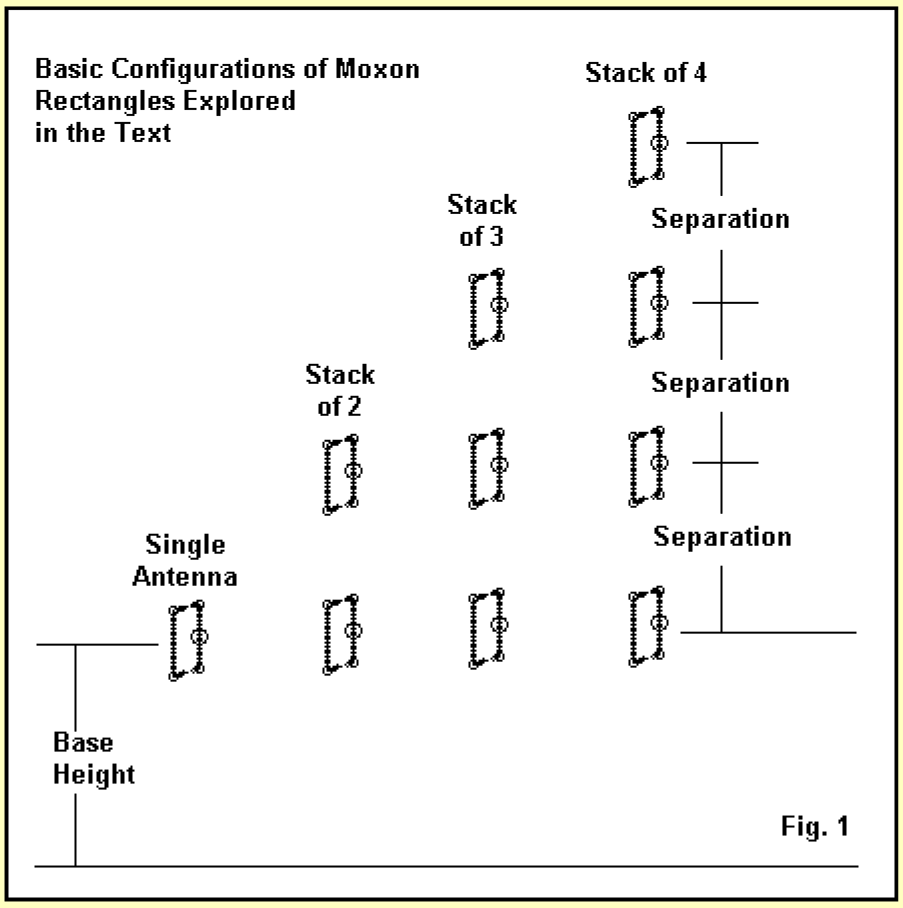

Fig. 1

The first step in our progression is to examine the performance potential of a single Moxon rectangle when vertically oriented. The following table lists the free-space performance figures, along with figures for heights of 2, 3.3, 4.6, and 5.9 wavelength above average ground. We shall reveal the reasons for using those special heights above 2 wavelengths as we proceed. However, the 2-wavelength height represents the baseline height for our work, on the presumption of a 2-meter (146-MHz) Moxon rectangle.

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2-Meter Vertically Oriented Moxon Rectangle: 146 MHz

Single Antenna	Gain dBi	Front-Back Ratio dB	TO Angle degrees	H-B/W degrees	Feed Z R+/-jX Ohms
Free-Space	**5.95**	**32.88**	**----**	**143**	**54 - j 1**
2-WL 13.47'	**8.77**	**32.62**	**5.9**	**143**	**54 + j 1**
3.3-WL 22.23'	**9.86**	**32.76**	**3.9**	**143**	**54 + j 1**
4.6-WL 30.99'	**10.39**	**33.03**	**2.9**	**143**	**54 + j 1**
5.9-WL 39.75'	**10.72**	**32.76**	**2.3**	**143**	**54 + j 1**

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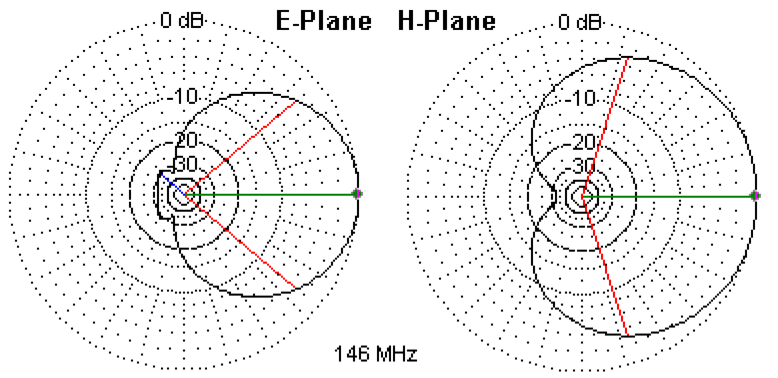
Over the same range of heights, a horizontally oriented Moxon would have shown gain values between 11.5 and 12.5 dBi. However, vertically oriented antennas are more sensitive to ground losses and thus show lower gain values at lower heights. However, the gain values increases more rapidly with height than would a corresponding horizontally oriented Moxon. Eventually, the gain values coincide closely, but the height exceeds 10 wavelengths.

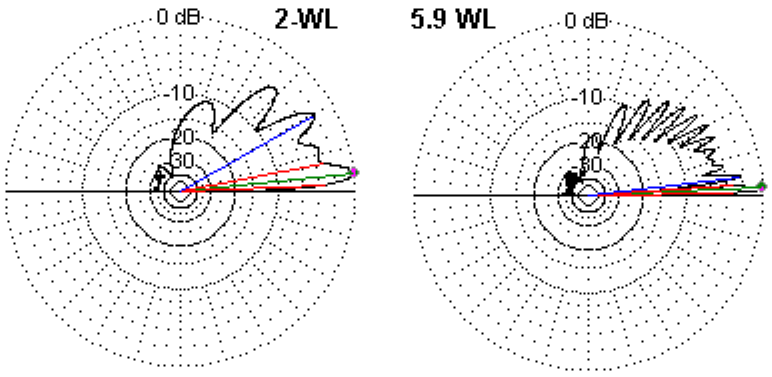


Free-Space H-Plane & E-Plane Patterns of a 2-Meter Moxon Rectangle

Fig. 2

Remarkably constant is the beamwidth and the front-to-back ratio. **Fig. 2** shows the E-plane (corresponding to an elevation pattern over ground) and the H-plane (corresponding to an azimuth pattern over ground) patterns for the vertically oriented Moxon in free-space. The H-plane pattern shows the deep rear null and cardioidal pattern typical of a vertical Moxon. The E-plane pattern shows significant radiation beyond 90-degrees distant from the forward bearing, but not as strong to the rear as in the H-plane. Hence, we shall anticipate antenna interactions within a stack that yield less disparate performance differences with changing separation than when we stacked horizontal Moxons.

Except for the forward gain value, the azimuth patterns for the single Moxon do not vary when we take each pattern at its take-off (TO) angle--or elevation angle of maximum radiation. The beamwidths and the 180-degree front-to-back ratios are virtually the same for every new height at which we place the antenna.



Elevation Patterns of a Vertically Oriented Moxon Rectangle at 2 and at 5.9 WL

Fig. 3

However, we do find significant differences in the elevation patterns. **Fig. 3** shows 2 samples, one at a height of 2 wavelengths, the other at a height of 5.9 wavelengths. As we might expect, the number of elevation lobes increases with increasing height. Unlike single horizontally oriented arrays, however, the vertically oriented antenna shows a variability in the strength of some of the lower elevation lobes. Hence, connecting the lobe points of maximum strength does not yield a smooth curve. Still, if we were to overlay the upper half of the E-plane pattern on top of either elevation pattern, the lobes would fit wholly within the idealized shell.

Stacking 2 Vertically Oriented Moxon Rectangles

The next step in our progression is to stack 2 Moxons, with the lower antenna at 2 wavelengths above ground. We shall gradually increase the height of the upper antenna in 0.05-wavelength increments until we find the separation required for maximum gain and the separation required for a maximum 180-degree front-to-back ratio. That work yields the following table of values. Separation (and height) represent the values for the centerline of each antenna structure. Hence, parts of the antenna extend above and below the listed value. To find the separation of the element tails for any situation, subtract about 0.35 wavelength from the listed separation value.

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Vertically Oriented Moxon 2-Stack: 146 MHz: Base Height: 2 wl

Separation WL	**Gain dBi**	**Front-Back Ratio dB**	**TO Angle degrees**	**Top Z R+/-jX Ohms**	**Bottom Z R+/-jX Ohms**
0.85	**12.16**	**22.87**	**4.9**	**57 - j 0**	**57 - j 1**
0.90	**12.17 +**	**23.62**	**4.8**	**57 - j 2**	**57 - j 1**
0.95	**12.16**	**24.58**	**4.8**	**56 - j 2**	**56 - j 1**
1.00	**12.13**	**25.81**	**4.7**	**55 - j 3**	**55 - j 3**
1.05	**12.09**	**27.34**	**4.7**	**55 - j 3**	**55 - j 3**
1.10	**12.04**	**29.28**	**4.6**	**54 - j 3**	**54 - j 3**
1.15	**11.99**	**31.77**	**4.5**	**54 - j 2**	**54 - j 2**
1.20	**11.95**	**35.16**	**4.5**	**53 - j 2**	**53 - j 2**
1.25	**11.92**	**40.40**	**4.5**	**53 - j 2**	**53 - j 2**
1.30	**11.90**	**51.18 +**	**4.5**	**53 - j 1**	**53 - j 1**
1.35	**11.88**	**45.08**	**4.4**	**53 - j 1**	**53 - j 1**
1.40	**11.87**	**38.69**	**4.3**	**53 - j 1**	**53 - j 1**

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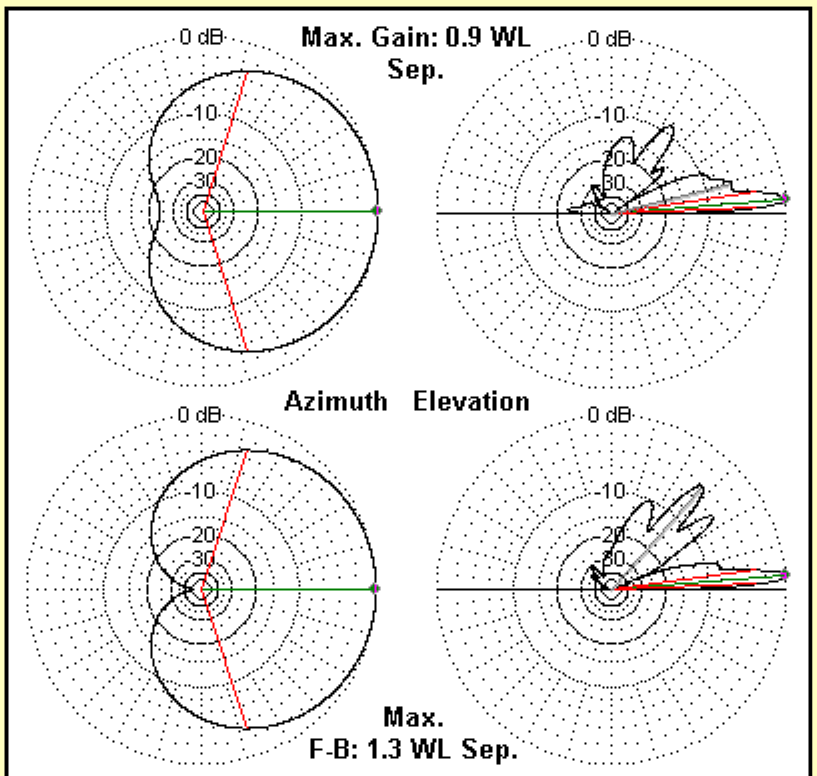
Maximum gain occurs with a separation of 0.9 wavelength between antenna centerlines. Maximum front-to-back occurs with a separation of 1.3 wavelengths. **Fig. 4** shows the azimuth and elevation pattern differences for those two conditions.



Vertical Stack of 2 Moxons: Max. Gain and F-B Separations

Fig. 4

One of the main features of a vertically oriented Moxon rectangle that gives it a nearly unique place among parasitic arrays is the extreme rear null that we can obtain. I shall assume--in the absence of task-driven specifications--that we wish to retain that deep null in any stack that we create. Therefore, the separation value of 1.30 wavelengths will become a key to further developments. That value is also the one used in choosing increments of height above the base height for successive performance reports of a single Moxon.

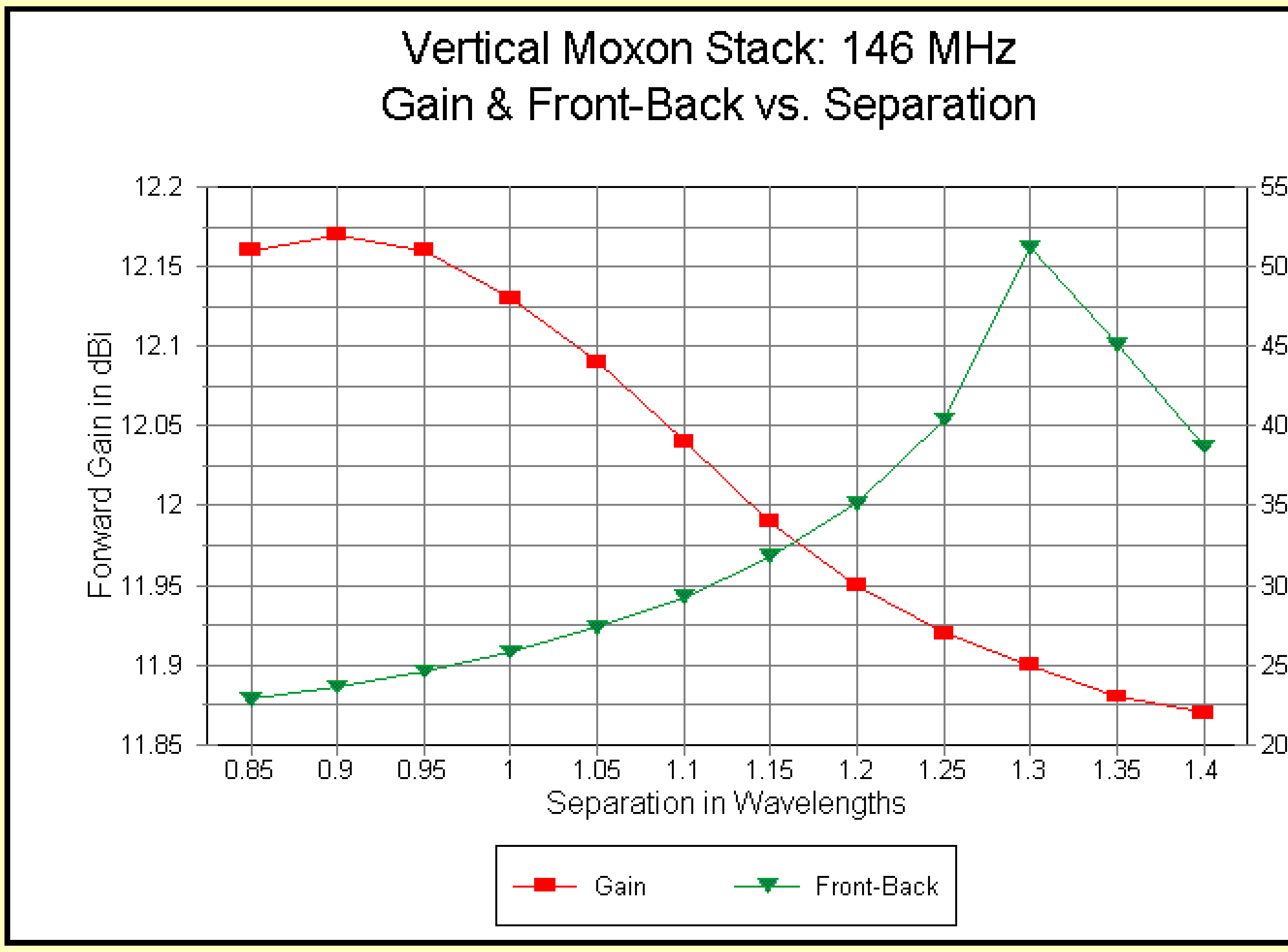


Fig. 5

Fig. 5 graphs both the forward gain and the 180-degree front-to-back ratio for the Moxon stack at the 0.05 increments of increasing separation. The graph clearly shows the separate peaks for the two phenomena. However, unless we examine the Y-axis labels carefully, we may make too much of the relative sharp peaks.

The gain differential between the maximum gain and maximum front-to-back conditions is only 0.27 dB, or about 1/4 of the difference we obtained for a 2-stack of horizontal Moxons. As well, the front-to-back ratio at maximum gain is nearly 24 dB, a very respectable figure for most types of operation. The conclusion that we must reach from these numbers is that stacking separation for a pair of vertically oriented Moxons is far less critical than for a pair of horizontal rectangles. Mechanically, the beneficial consequence is that in an actual structure, we may move an antenna in a stack a few inches either way for mounting convenience without jeopardizing the stack performance. The stability of the feedpoint impedance values adds a further vote of confidence to such maneuvers that are typical of real construction projects.

Recognizing our freedom to alter optimal settings without unduly reducing array performance, we shall nonetheless use the 1.3-wavelength separation as our marker for creating taller stacks and evaluation their performance.

Taller and Higher Stacks of Vertically Oriented Moxon Rectangles

All stacks in our progressions presume standard techniques of in-phase feeding. However, the performance figures that we use do not take into account any power losses in the feed system. Since vertically oriented antennas in a stack tend to place the antennas further apart, the lengths of cable in the feed distribution system will be longer than in many, if not most, stacks of horizontally oriented antennas. The stack designer must take these losses into account when designing and evaluating an overall system.

Nothing in principle prevents us from creating a stack of as many vertical Moxons as we desire. However, for brevity, we shall examine only 2 more steps in the progression--the 3-stack and the 4-stack. The following table compares the performance of all of the configurations in **Fig. 1**, each with a base height of 2 wavelengths. In each stack, the separation used is the maximum front-to-back ratio spacing: 1.3 wavelengths.

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Vertically Oriented Moxon Stacks: 146 MHz: Base Height: 2 wl

Stack Size	Gain dBi	Front-Back Ratio dB	TO Angle degrees	Bot Z/3 Z R+/-jX Ohms	2 Z/4 Z R+/-jX Ohms
1	8.77	32.88	5.9	54 - j 1	
	Gain over 1: 3.13 dB				
2	11.90	51.18	4.5	53 - j 1	53 - j 1
	Gain over 1: 4.95 dB	Gain over 2: 1.82 dB			
3	13.72	47.26	3.5	53 - j 1	52 - j 2
				53 -1	
	Gain over 1: 6.24 dB	Gain over 2: 3.11 dB	Gain over 3: 1.29 dB		
4	15.01	43.69	2.9	53 - j 1	51 - j 1
				51 - j 1	53 - j 1

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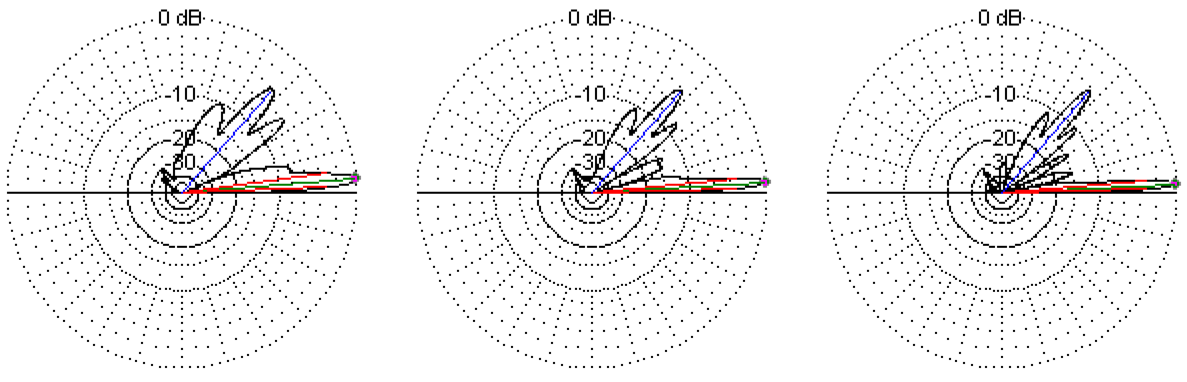
For each added antenna in the stack, we obtain a smaller increase in gain. However, the added gain of a 4-stack over a 2-stack is about 3.1 dB, just about what we should expect in theory for a doubling of the stack height. Obviously, to add another 3 dB to the array, we would need to go to an 8-stack. Since the 4-stack is already 26.28' between the bottom and top antennas, an 8-stack is likely not feasible physically. As well, the feeding complexity would be considerable. However, at UHF, the physical size of the array would be no hindrance to its use.



Elevation Patterns: Vertical Stacks of 2, 3, & 4 Moxon Rectangles
Base Height: 2 WL; Separation: 1.3 WL

Fig. 6

Fig. 6 shows the elevation patterns of the 2-, 3-, and 4-stack arrays. Because the overall height of the dull arrays differs for each case, the exact number and angle of the secondary lobes also suffers. However, it is interesting to compare these patterns with the free-space E-plane pattern for a single Moxon rectangle. In each of our elevation patterns, all of the forward lobes fits within the envelope created by the upper half of the free-space patterns. As well, the strongest forward secondary elevation lobe is about 4 dB weaker than the lowest main lobe. To the rear, the strongest lobe is about 30 dB down from the main forward lobe.

We can obtain some of the improvement in gain simply by using a 2-stack at a top height equal to the third or fourth antennas. The following table compares potential performance from 2-stacks with the top height of each of the stacks in the table just listed.

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Vertically Oriented Moxon 2-Stacks: 146 MHz: Variable Base Heights

Top Height WL	Gain dBi	Front-Back Ratio dB	TO Angle degrees	Top Z R+/-jX Ohms	Bottom Z R+/-jX Ohms
3.3	11.90	51.18	4.5	53 - j 1	53 - j 1
4.6	12.88	50.42	3.2	53 - j 1	53 - j 1
5.9	13.38	52.86	4.8	56 - j 2	56 - j 1

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Relative to the 3-stack, the 2-stack with the same top height (4.6 wavelengths) is about 0.85 dB down. Relative to a 4-stack, the 2-stack with the same top height (5.9 wavelengths) is over 1.6 dB down. The conclusion we might reach is that for a given top height, reducing the stack size by 1 antenna and removing it from the bottom creates a loss that we might live with in some operating circumstances. However, removing 2 from the bottom yields losses that may be less acceptable. The decisions to be made, of course, require reference to a set of operational specifications related to the communications goals. Nevertheless, the technique of redoing this exercise from the top down (in contrast to our basic procedure of working from the bottom up) will yield a different set of comparative numbers and in some design situations may be the more applicable procedure.

Tentative Conclusions

The vertical stack of vertically oriented Moxon rectangles represents a viable way of increasing total array gain while preserving the most desired aspects of the Moxon performance figures. These figures include the deep rear null and the very wide beamwidth in the azimuth pattern. We have not mentioned the beam width because it has changed by no more than 0.2 degrees in any of the stacks that appear in the examples. All of the examples exhibit -3 dB beamwidths between 143.2 and 143.4 degrees.

The rear null combined with the wide beam width result in an array that covers fully 1/3 of the horizon. Hence, we would require only 3 such stacks, aimed at 120-degree intervals, to create a polling array for any of the VHF/UHF bands. (A polling array is one in which we measure the signal strengths from each of the 3 receiving array directions and automatically select the one having the strongest signal. A polling array can consists of however many antenna we need to provide full horizon coverage, relative to the beamwidth of the individual antennas or sub-arrays.)

For repeater operations on the border between 2 different coverage areas, the very high front-to-back ratio and the pattern shape of the Moxon, when vertically oriented, can eliminate keying up the wrong repeater. Indeed, a pair of arrays situation to place each unwanted repeater in the null, can be switched to use only one with high confidence that the other will be unaffected by the operation.

Additionally, the high rear null of the vertically oriented Moxon permits relatively close mounting to a vertical supporting conductive mast or tower. The closer the antenna to its support tower, the less problems we shall suffer relative to the durability of the supporting boom during high wind or ice loading. A UHF polling array set might well be covered totally by a single shell composed of RF-transparent material that also sheds wind and ice effectively.

Horizontal Stacking of Vertically Oriented Moxon Rectangles

To complete our survey of stacking possibilities with the Moxon rectangle, we should deal with a final possibility for stacking vertically oriented antennas: the horizontal stack. Also called the side-by-side stack, this possibility has the general appearance of the antennas in **Fig. 7**.

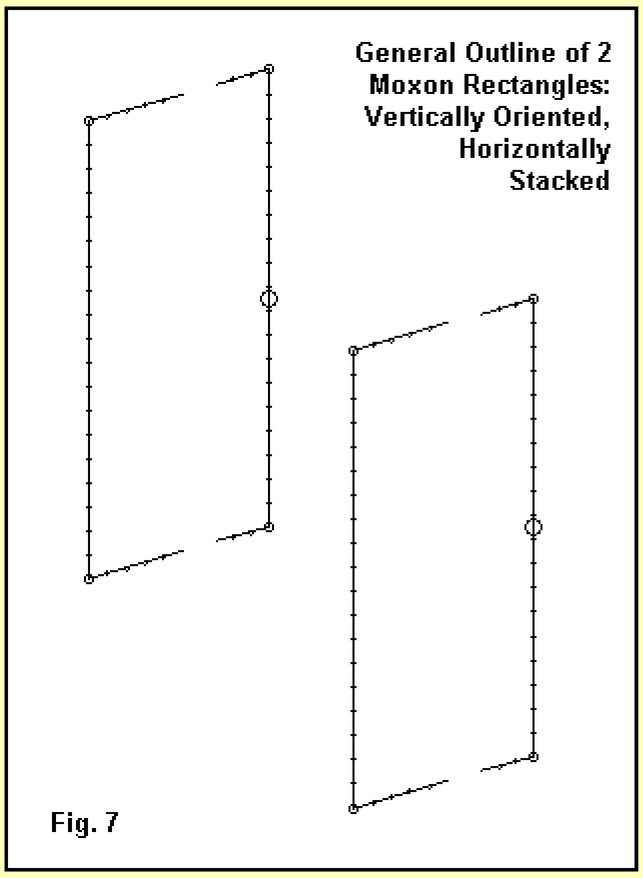

Fig. 7

For our purposes, we may use the same base height that we have used throughout this exercise: 2 wavelengths. The base height uses the antenna centerline as a reference, so the rectangle extends above and below this line by equal amounts.

When we stacked horizontally oriented Moxons vertically, we found that the maximum front-to-back separation was 1.1 to 1.15 wavelength. However, when we tip the resulting array on its side to obtain a horizontally stacked pair of vertically oriented antennas, we obtain the azimuth pattern that appears in **Fig. 8**.

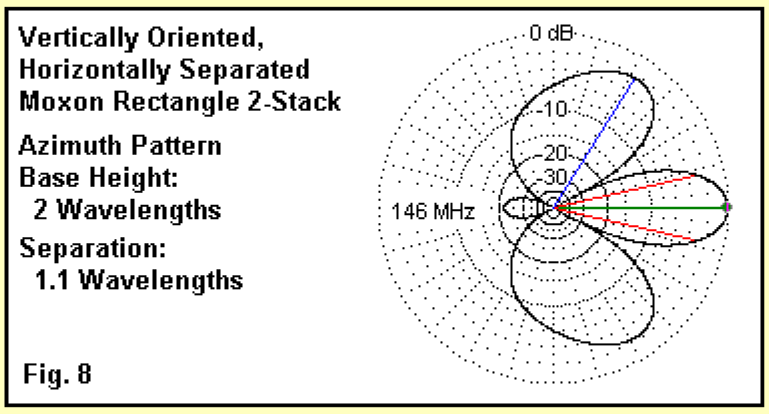

Fig. 8

The gain of the array in this configuration is about 11.6 dBi at a TO angle of 5.9 degrees. The front-to-back ratio approaches 21 dB. However, we can hardly miss the forward side lobes. When we set the array for horizontal polarization, these side lobes combined (due to ground reflection) to produce a relatively harmless secondary high-angle elevation lobe. However, in the present configuration, the lobes are free to extend at angles to the main lobe and at a strength only a bit over 2 dB less than the main lobe. The presence of these side lobes also narrows the Moxon forward lobe to a very small beamwidth.

For almost all purposes, the maximum front-to-back spacing yields a wholly unsatisfactory pattern. To overcome the side-lobe problem, we must narrow the separation between the arrays. The following table shows the results for separation starting at a high of 0.65 wavelength and extending to a low of 0.35 wavelength. The table lists only one feedpoint impedance, since that value applies to each antenna in the array. The added data, relative to past tables, lists the front-to-side ratio, that is, the ratio in dB of the main forward lobe to the side lobe.

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Vertically Oriented Horizontal Moxon 2-Stacks: 146 MHz: Base Height: 2 WL

Separation WL	Gain dBi	Front-Back Ratio dB	TO Angle degrees	Front-Side Ratio dB	Bottom Z R+/-jX Ohms
0.65	**12.62 +**	**13.06**	**5.9**	**10.47**	**67 - j 15**
0.60	**12.47**	**12.80**	**6.0**	**14.30**	**72 - j 9**
0.55	**12.19**	**12.77**	**6.0**	**20.10**	**73 - j 2**
0.50	**11.84**	**12.92**	**6.0**	**----**	**71 - j 3**
0.45	**11.46**	**13.17**	**6.0**	**----**	**69 + j 6**
0.40	**11.08**	**13.49**	**6.0**	**----**	**69 + j 6**
0.35	**10.71**	**13.84 +**	**5.9**	**----**	**69 + j 6**

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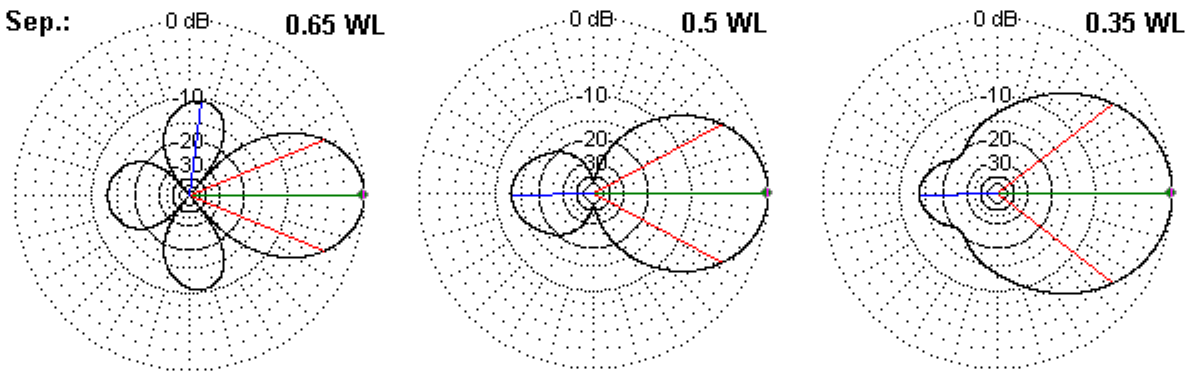
From the table, we can see that any selection of a separation for the horizontal 2-stack is a compromise. The highest gain in the list occurs in conjunction with the worst front-to-sidelobe ratio. Conversely, the gain continuously decreases as we shrink the separation, although the front-to-back ratio continues to climb.

As we might expect, the sidelobes disappear whenever the separation is 0.5 wavelength or less. However, the azimuth patterns of array are not identical once the sidelobes diminish. **Fig. 9** gives us a view of the azimuth patterns of the array at spacings of 0.65, 0.5, and 0.35 wavelength.



Vertically Oriented, Horizontally Separated Moxon Rectangle 2-Stack: Variable Separation; Base Height: 2 WL Above Average Ground

Fig. 9

Although the 0.65-wavelength configuration provides the most gain--about 4 dB more than a single vertically oriented Moxon, the array has a narrow beamwidth, large sidelobes, and a modest front-to-back ratio. In contrast, the 0.5-wavelength configuration eliminates the sidelobes altogether. However, we have lost about 0.8 dB gain and have a worse front-to-back ratio. We can notice a trend: the closer the spacing, the broader the beamwidth. With the 0.35-wavelength configuration, we obtain a front-to-back ratio of nearly 14 dB with a broader beamwidth still, but the gain has dropped by nearly 2 dB relative to the 0.65-wavelength version of the stack. Moreover, we are no where near to the 140-degree beamwidth we obtained with a single Moxon or with the vertical stacks.

Close spacing produces another effect of note: interaction that modifies the feedpoint impedances of the arrays. The single Moxon used as the basis for these stacks has a feedpoint impedance of 54 - j 1 Ohms. The impedances of our stacks show resistances in the high 60s and low 70s, with a variable reactance. to make an effective array of the sort that we are examining here, we likely would have to further modify the basic Moxon rectangle for a lower single-antenna feedpoint impedance in order to achieve values near to 50 Ohms in the stack.

Moxon Rectangle 4-Stack: 2 Vertical; 2 Horizontal

Also Called a Square Stack

Not to Scale

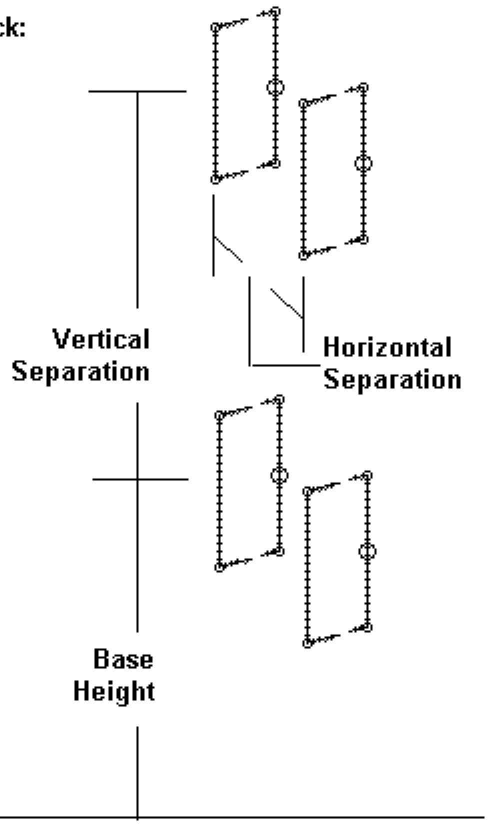


Fig. 10

For the sake of completion, let's perform one more experiment: creating a 4-stack composed of 2 pairs of horizontally separated Moxons with a vertical separation between the pairs. **Fig. 10** shows the outline of our square, although the dimensions do not actually form a square. From our table, the best horizontal spacing for a reasonable front-to-back ratio and the best beamwidth is 0.35 wavelength. The best front-to-back vertical separation for a strictly vertical stack was about 1.3 wavelengths. However, for the square of pairs arrangement, a vertical spacing of 1.15 wavelengths proved the best in terms of achieving the maximum front-to-back ratio possible from the stack.

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Square Moxon 4-Stack: 146 MHz: Base Height: 2 WL

Separation WL	**Gain dBi**	**Front-Back Ratio dB**	**TO Angle degrees**	**Top Pair Z R+/-jX Ohms**	**Bottom Pair Z R+/-jX Ohms**
0.35x1.15	**13.93**	**15.47**	**4.7**	**68 + j 7**	**68 + j 7**

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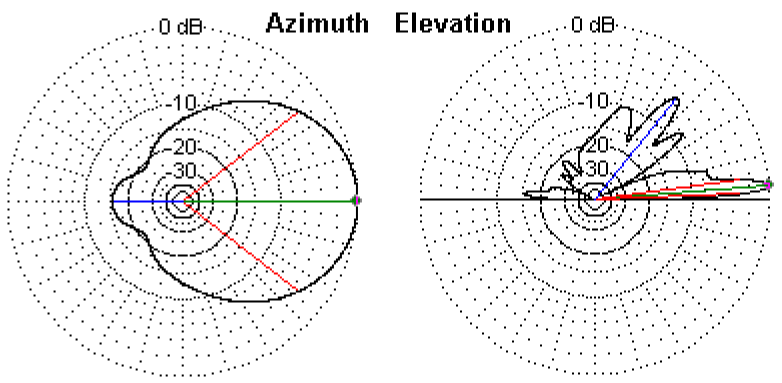
The 4-stack square achieves over 5 dB more gain than a single Moxon at a 2-wavelength base height. However, the front-to-back ratio is mediocre compared to the levels achieved by the strictly vertical stacks. As well we continue to have feedpoint impedances calling for further design efforts to effect in-phase feeding of the entire set of antennas in the array.



Square 4-Stack of Vertically Oriented
Moxon Rectangle Patterns
Base Height: 2 WL

Fig. 11

Fig. 11 shows, especially in the azimuth pattern, that we have not improved upon the beamwidth situation. The end result seems to be that if this form of stacking has a place, it is for applications unlike those we suggested as fitting the strictly vertical stack. At UHF, this stack is likely to be useful for point-to-point circuits, for example, wireless relays. With overall dimensions of 0.35 by 1.5 wavelengths, the array is smaller than many competitive corner reflector and similar designs. The 3-sided reflector, with higher gain, becomes effective with reflector panels about 2-wavelengths per side. For broad beamwidth applications, vertical stacks are likely to prove themselves to be the most versatile array designs.

Conclusion?

This exercise is by no means a complete survey of possibilities or an authoritative set of design dictates. Instead, it is an exploration of some opening possibilities in stacking Moxon rectangles. Because the antenna has some relative unique pattern features relative to standard 2-element Yagis, it requires an exploration of stacking potentials on its own ground. These notes have only opened the door to further exploration.

As well, the techniques used here to examine the stacking potentials of antennas by use of antenna modeling software are also applicable to a systematic treatment of other antenna types. The amateur literature is full of arrangements that builders have experimentally found to be relatively optimal. However, we can well benefit from a set of more complete surveys for each antenna type.

So our conclusion is simply a beginning. . .

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