A 3-Moxon Polling Array for 914 MHz

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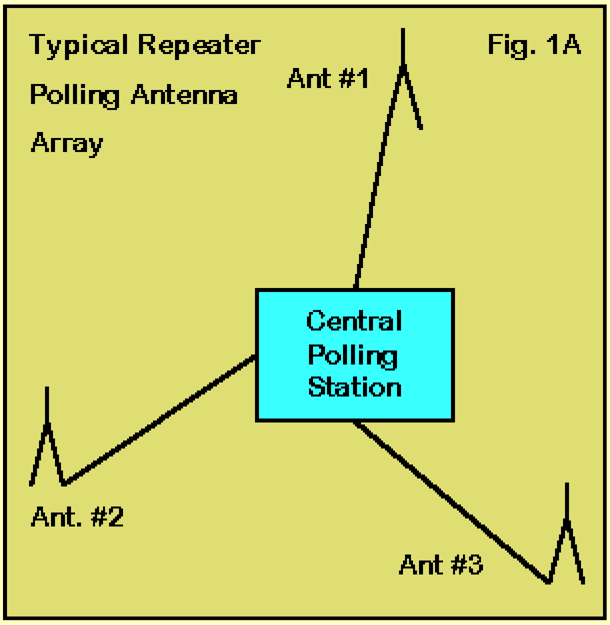
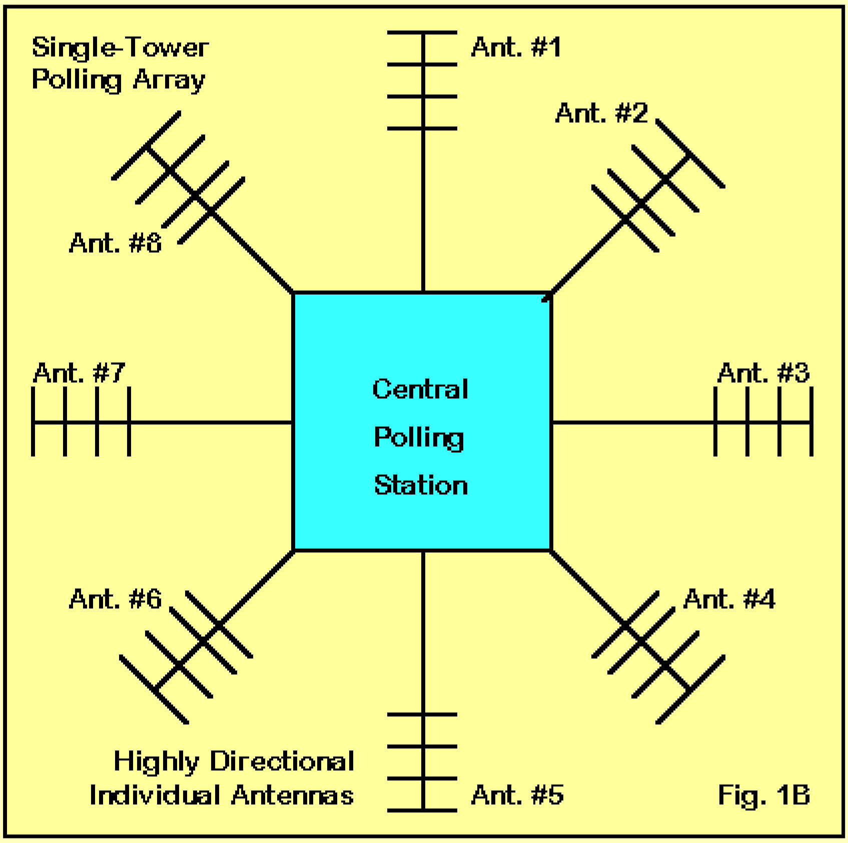
The use of multiple antennas in a polling system--especially for repeaters--is common practice. Independent receiving antennas can be placed at specially selected sites to overcome terrain and other problems that reduce received signal strength and prevent effective use of the repeater. **Fig. 1A** shows the basic outline of such a system.



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 Fig. 1B.



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 a large physical 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. 2** outlines the basic Moxon rectangle, with dimensions in millimeters and element diameters standardized at 4 mm.

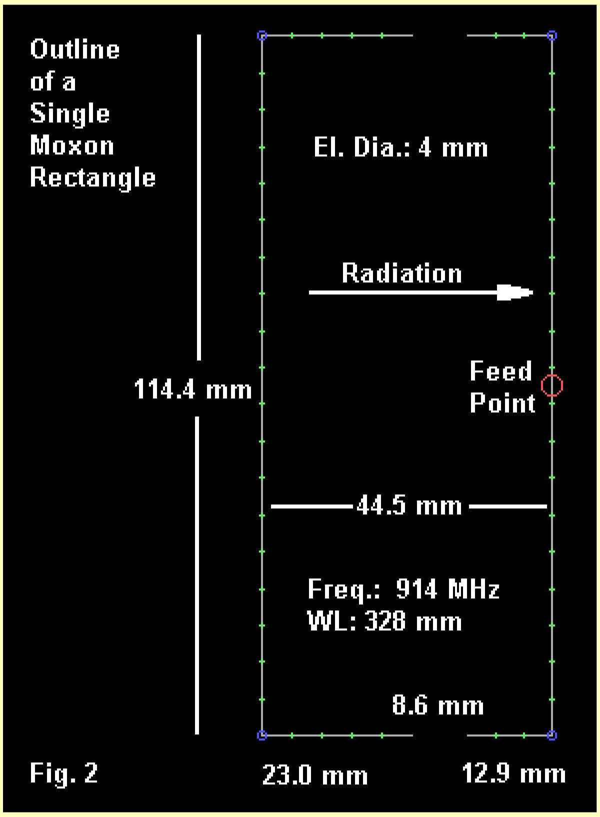


Fig. 2

The model description for this antenna provides more detail on the element dimensions and coordinates.

```
914 MHz Moxon Rectangle                  Frequency = 914  MHz.

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

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

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

1          4.300,  0.000,-57.200  W2E1  17.200,  0.000,-57.200 4.00E+00   3
2     W1E2  17.200,  0.000,-57.200  W3E1  17.200,  0.000, 57.200 4.00E+00  19
3     W2E2  17.200,  0.000, 57.200        4.300,  0.000, 57.200 4.00E+00   3
4         -4.300,  0.000,-57.200  W5E1 -27.300,  0.000,-57.200 4.00E+00   5
5     W4E2 -27.300,  0.000,-57.200  W6E1 -27.300,  0.000, 57.200 4.00E+00  19
6     W5E2 -27.300,  0.000, 57.200       -4.300,  0.000, 57.200 4.00E+00   5

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

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

1         10     2 / 50.00   (  2 / 50.00)     1.000       0.000        V

Ground type is Free Space
```

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. 3**. 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.

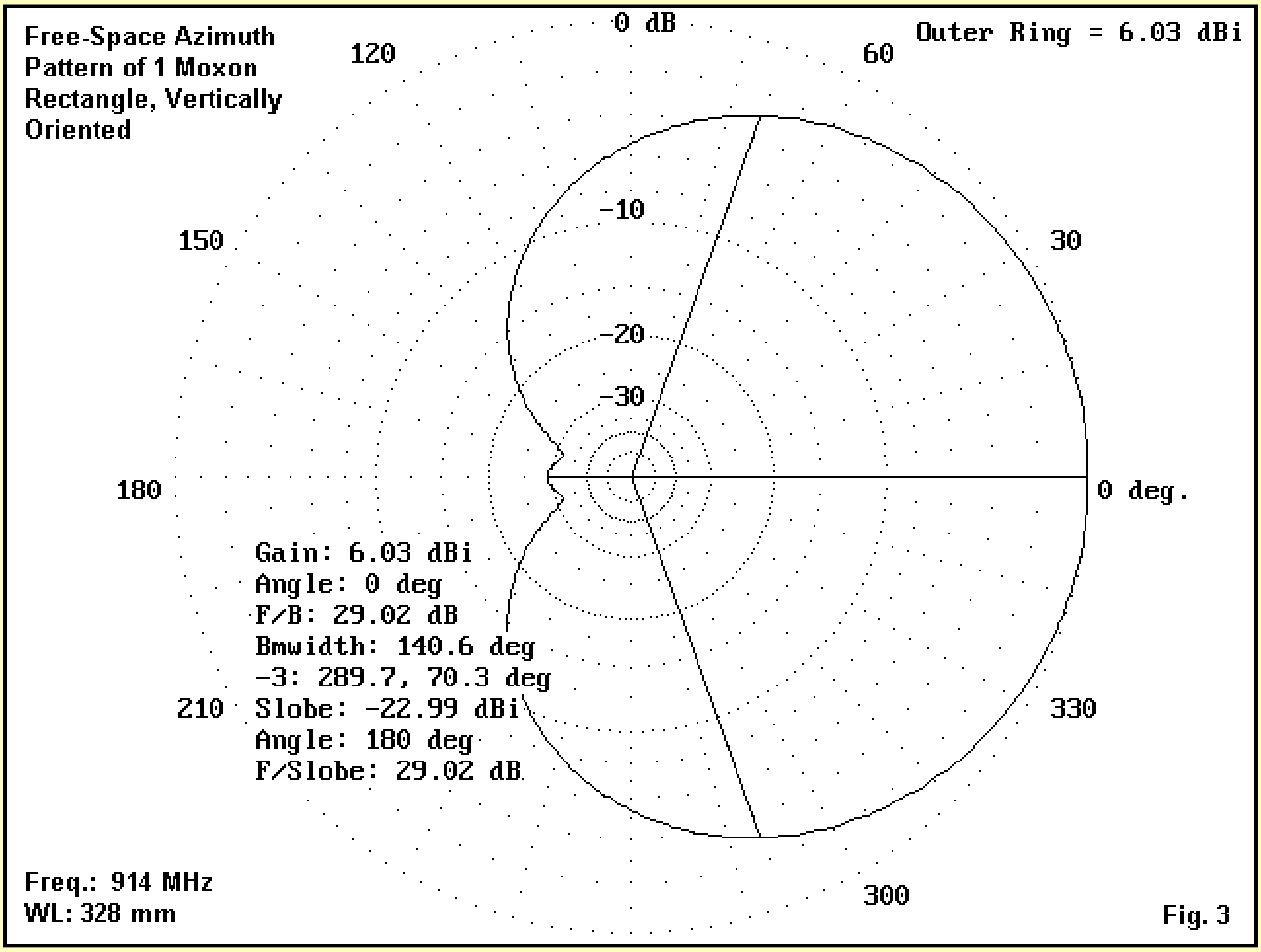


Fig. 3

The antenna can be scaled to any of the amateur or other service bands by the usual means of multiplying the element dimensions by the ratio of the baseline frequency to the new frequency. A 2-meter version of the antenna will be about 6 time larger than the 914 MHz models, with the element diameter scaled to about 1". If other element diameters are used, dimensional adjustments will be required along the lines of charts of values presented in past articles on this antenna.

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. 4**.

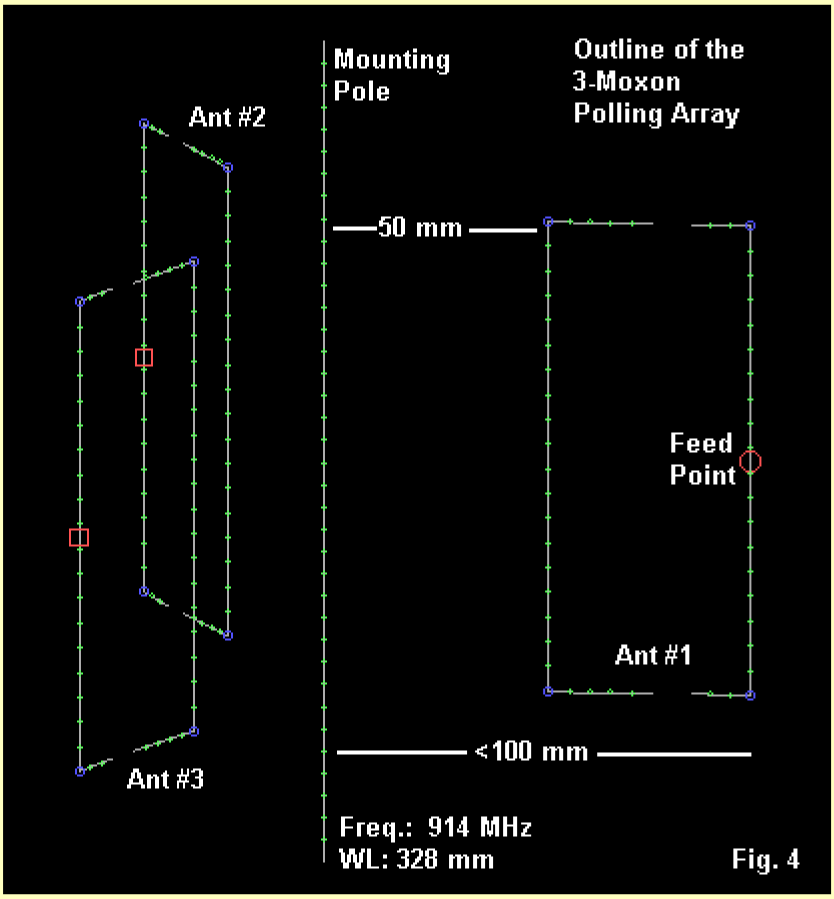


Fig. 4

The model for these tests is described in the following lines.

```
914 MHz 3-Moxon Polling Array                  Frequency = 914  MHz.

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

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

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

1           0.082,  0.000, -0.057  W2E1   0.094,  0.000, -0.057 4.00E+00   3
2     W1E2   0.094,  0.000, -0.057  W3E1   0.094,  0.000,  0.057 4.00E+00  19
3     W2E2   0.094,  0.000,  0.057         0.082,  0.000,  0.057 4.00E+00   3
4           0.073,  0.000, -0.057  W5E1   0.050,  0.000, -0.057 4.00E+00   5
5     W4E2   0.050,  0.000, -0.057  W6E1   0.050,  0.000,  0.057 4.00E+00  19
6     W5E2   0.050,  0.000,  0.057         0.073,  0.000,  0.057 4.00E+00   5
7          -0.041,  0.071, -0.057  W8E1  -0.047,  0.082, -0.057 4.00E+00   3
8     W7E2  -0.047,  0.082, -0.057  W9E1  -0.047,  0.082,  0.057 4.00E+00  19
9     W8E2  -0.047,  0.082,  0.057        -0.041,  0.071,  0.057 4.00E+00   3
10          -0.036,  0.063, -0.057 W11E1  -0.025,  0.043, -0.057 4.00E+00   5
11    W10E2  -0.025,  0.043, -0.057 W12E1  -0.025,  0.043,  0.057 4.00E+00  19
12    W11E2  -0.025,  0.043,  0.057        -0.036,  0.063,  0.057 4.00E+00   5
13          -0.041, -0.071, -0.057 W14E1  -0.047, -0.082, -0.057 4.00E+00   3
14    W13E2  -0.047, -0.082, -0.057 W15E1  -0.047, -0.082,  0.057 4.00E+00  19
15    W14E2  -0.047, -0.082,  0.057        -0.041, -0.071,  0.057 4.00E+00   3
16          -0.036, -0.063, -0.057 W17E1  -0.025, -0.043, -0.057 4.00E+00   5
17    W16E2  -0.025, -0.043, -0.057 W18E1  -0.025, -0.043,  0.057 4.00E+00  19
18    W17E2  -0.025, -0.043,  0.057        -0.036, -0.063,  0.057 4.00E+00   5
19           0.000,  0.000, -0.100         0.000,  0.000,  0.100 2.54E+01  37

            -------------- SOURCES --------------
```

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

1         10    2 / 50.00   (  2 / 50.00)      1.000       0.000       V

              --------------- LOADS ---------------

Load      Wire      Wire #/Pct From End 1      R (Ohms)       X(Ohms)
          Seg.    Actual      (Specified)

1         10    14 / 50.00   ( 14 / 50.00)       0.000         0.000
2         10     8 / 50.00   (  8 / 50.00)      0.000         0.000

Ground type is Free Space
```

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: with and without a metal central mounting pole (25 mm), and with the feedpoints of the unused antenna both 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.

Table 1: 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

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. 5** shows the overlapping azimuth patterns of the three antennas in the array for case 2, which presumes 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.

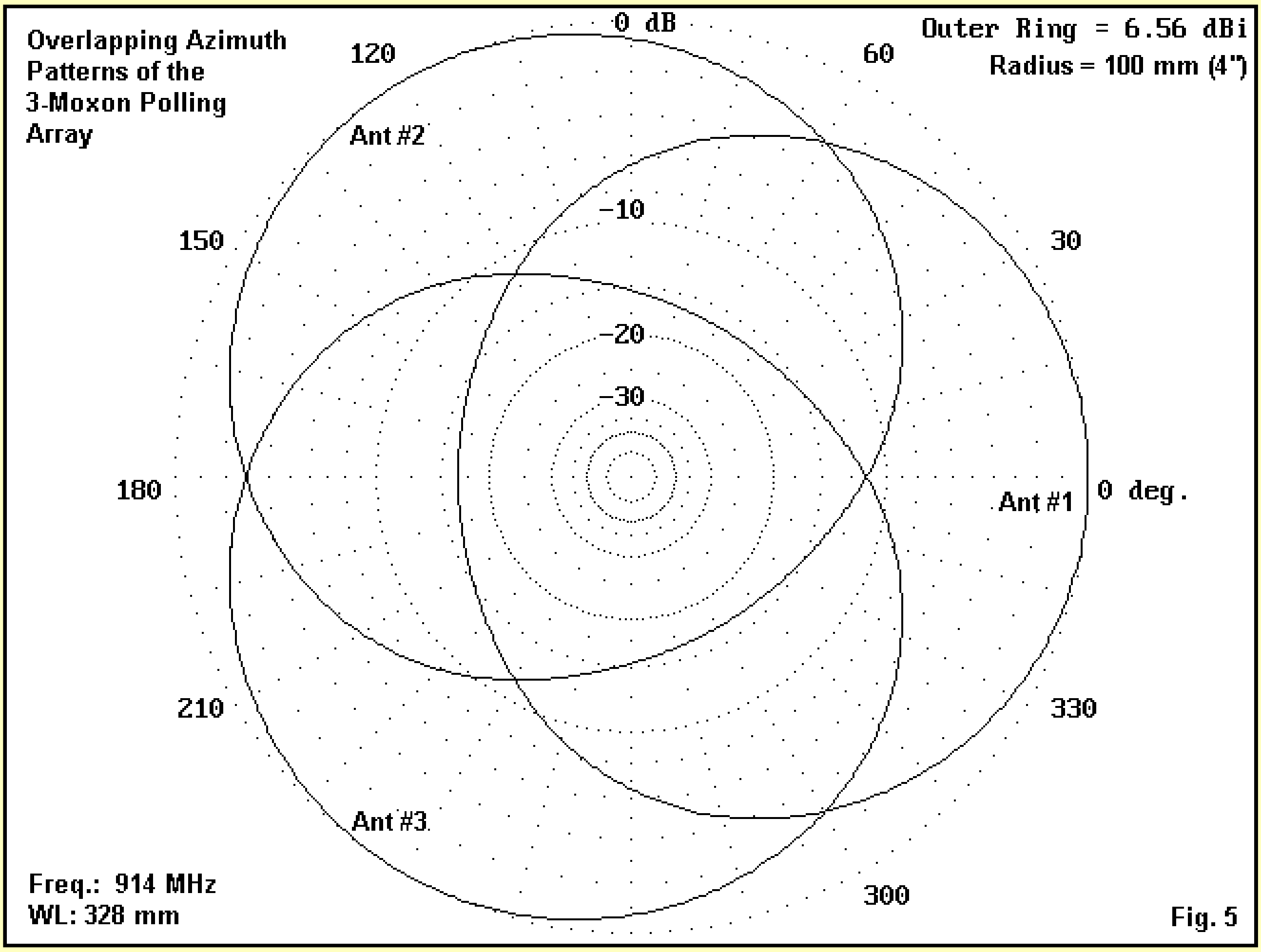


Fig. 5

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 a small but more than insignificant 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 that may degrade 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 tested as isolated single antennas. See **Fig. 6**.

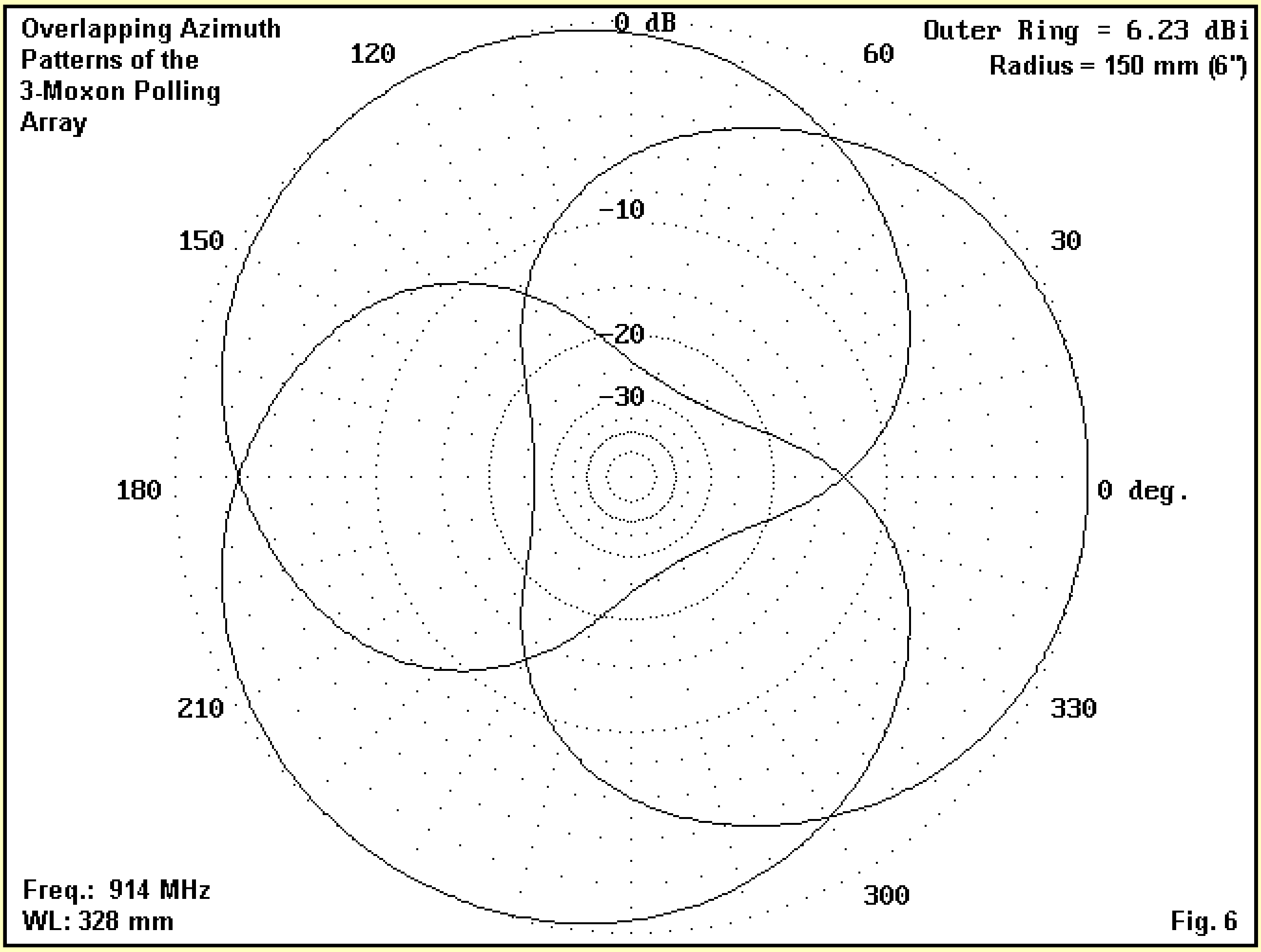


Fig. 6

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.

Table 2: 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**

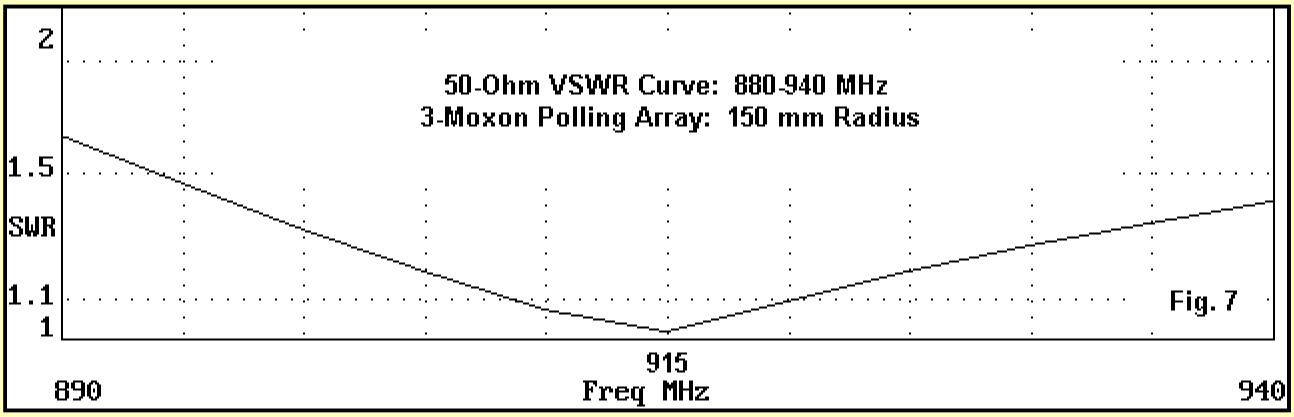
Either open or closed feeders would be equally useful, and the wider beamwidths in both cases ensure pattern cross-over points at about -2.5 dB signal levels. Front-to-back ratios are close to the value for an independent rectangle, and gain reductions simply reflect the lesser interactions among the 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

Table 3: Array Performance with 3 Antennas 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**. 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 concerns.

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 "plug-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 that use alone makes the array well worth some further experimentation.

Go to Main Index