A Tale of 4 Beams: The X, the Hex, the Square, and the Rect

L. B. Cebik, W4RNL (SK)

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

As yet, I do not have any parallelograms, pentagons, or octagons in my collection.

The Folded X-Beam

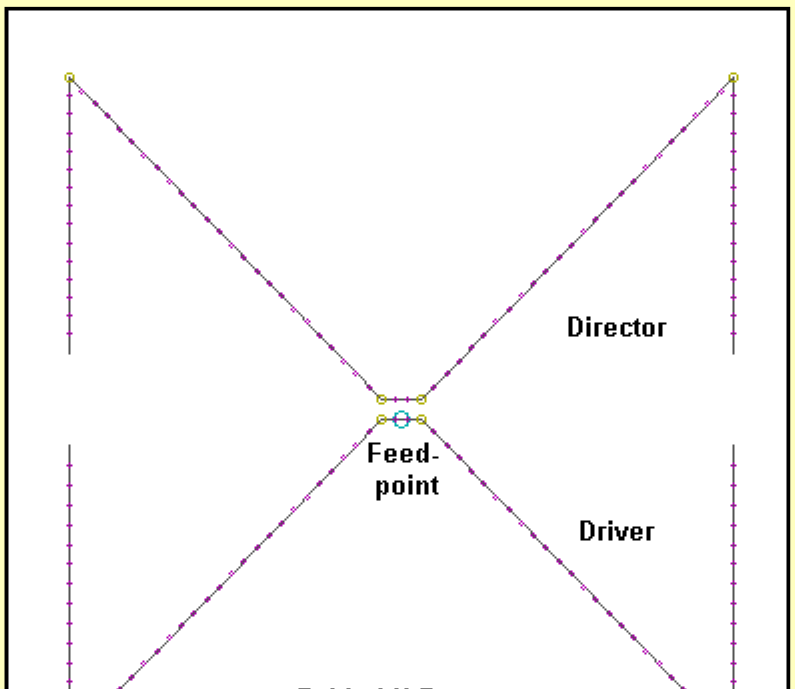


Fig. A

Fig. A 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 the program 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-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. A**, 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
```

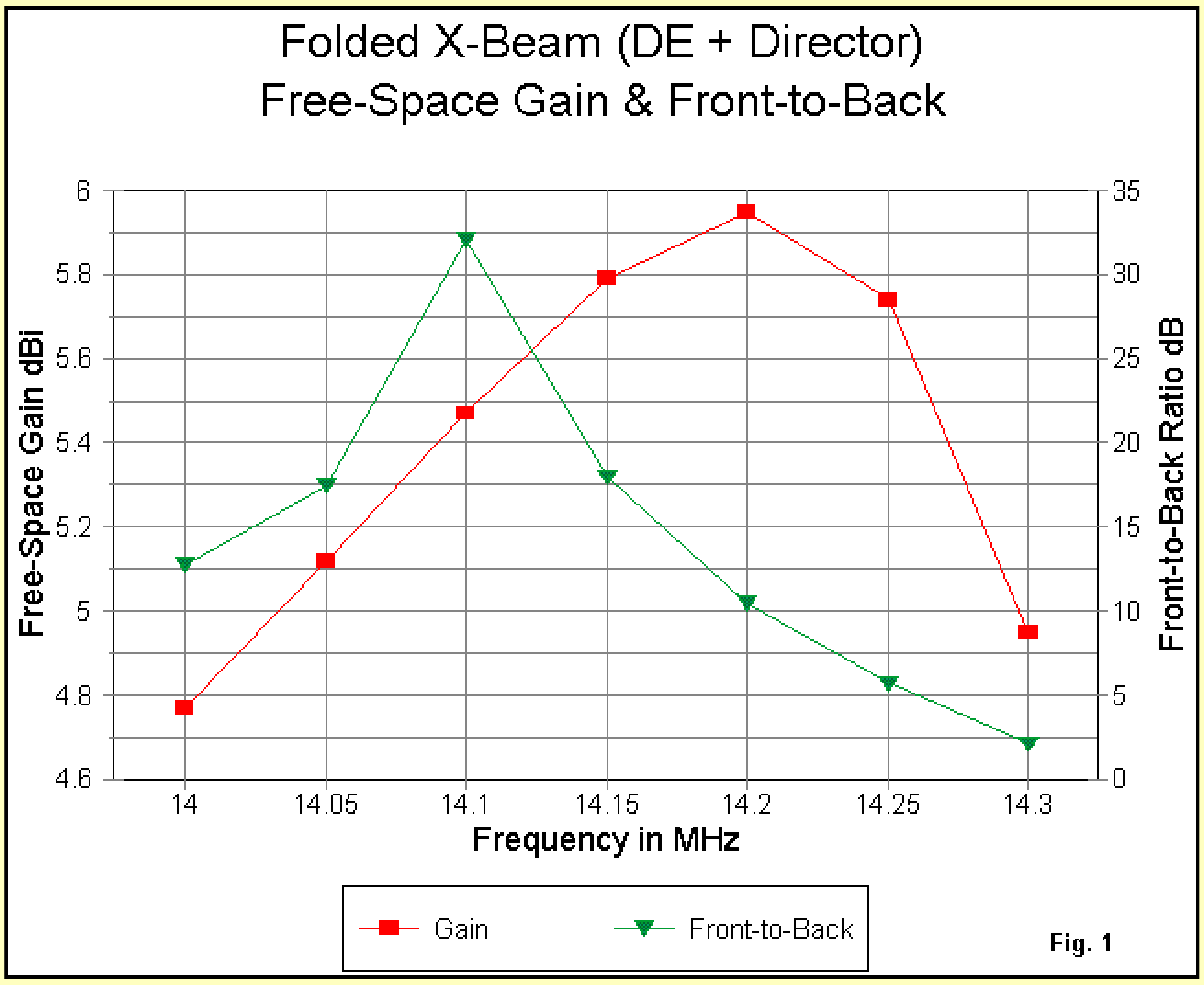


Fig. 1

In **Fig. 1**, 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, 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 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.

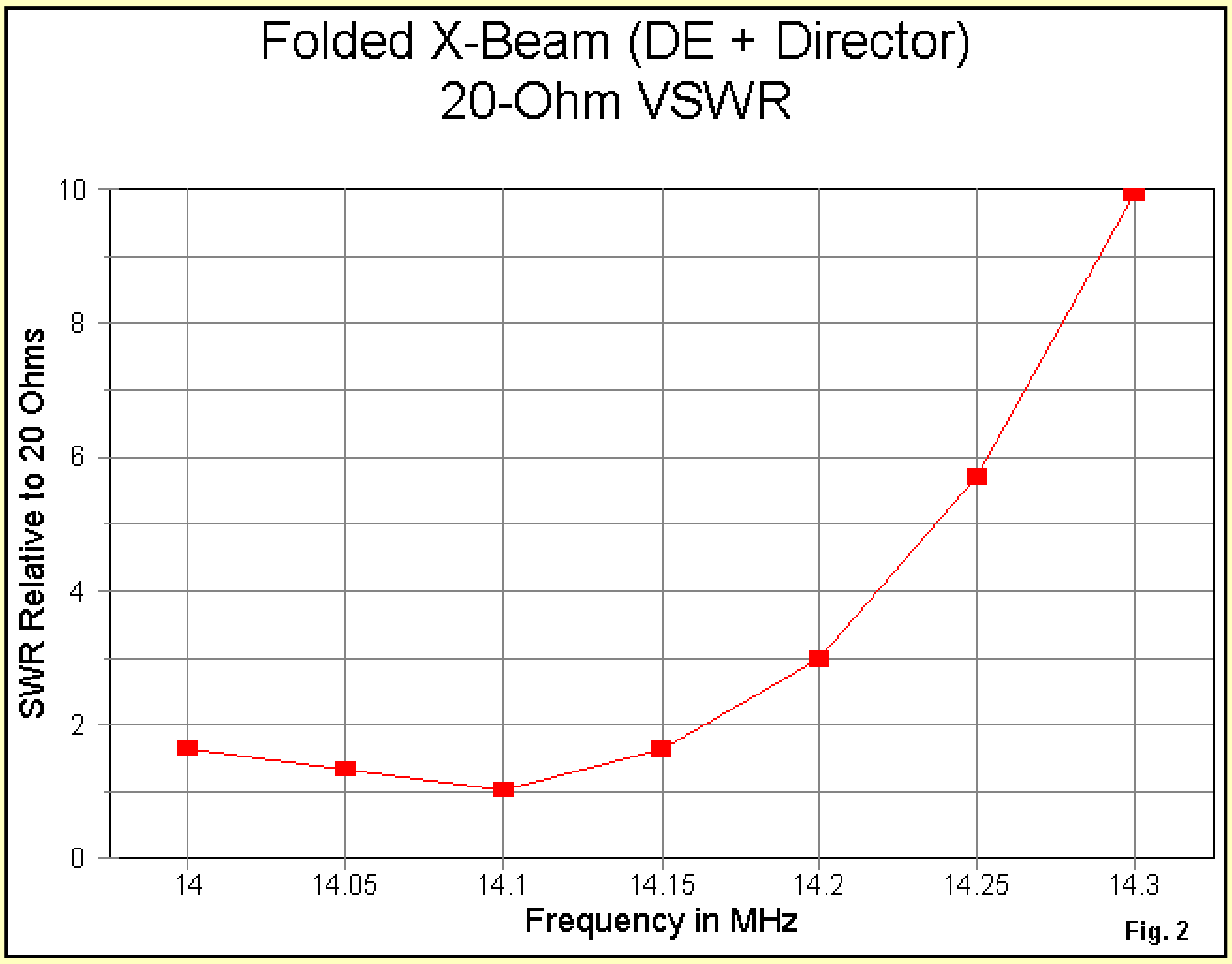


Fig. 2

The SWR curve, in **Fig. 2**, 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 low end of the ranges indicated, while tubular and hybrid versions yield impedances values at the higher ends of the ranges.

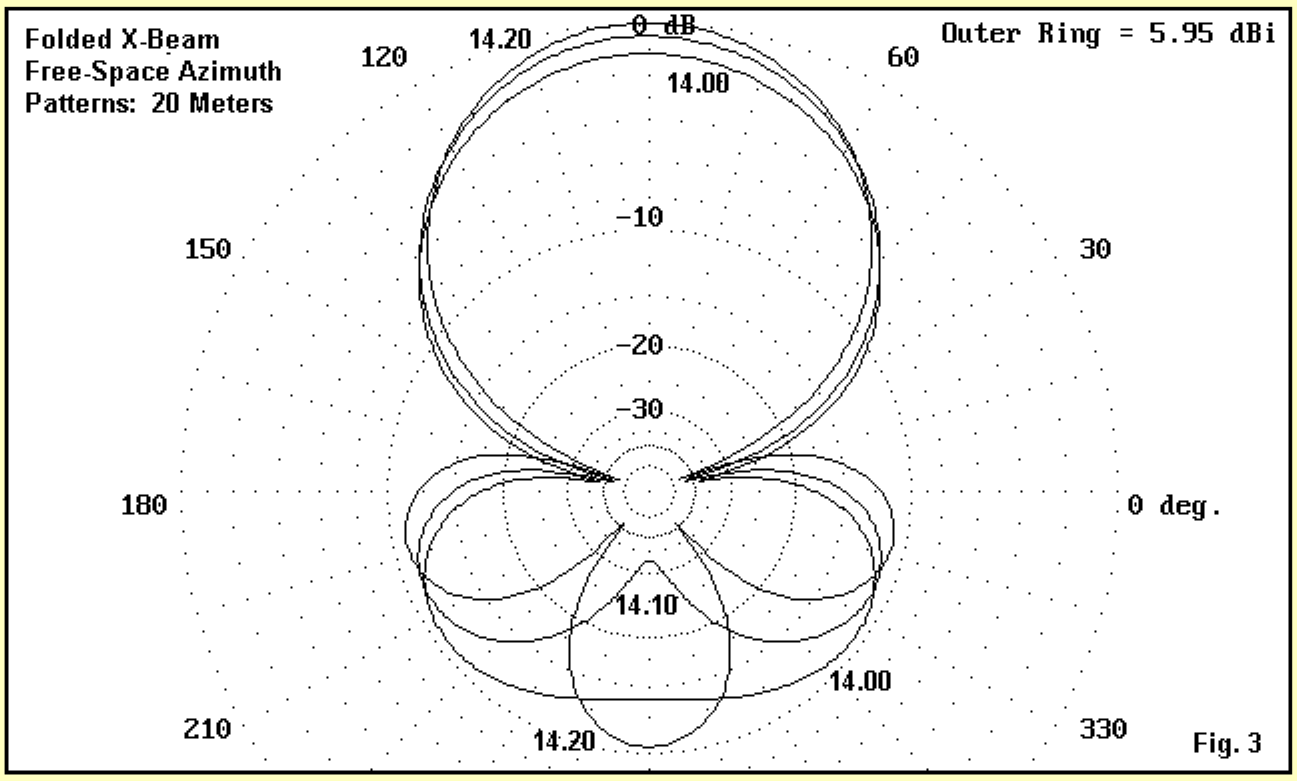
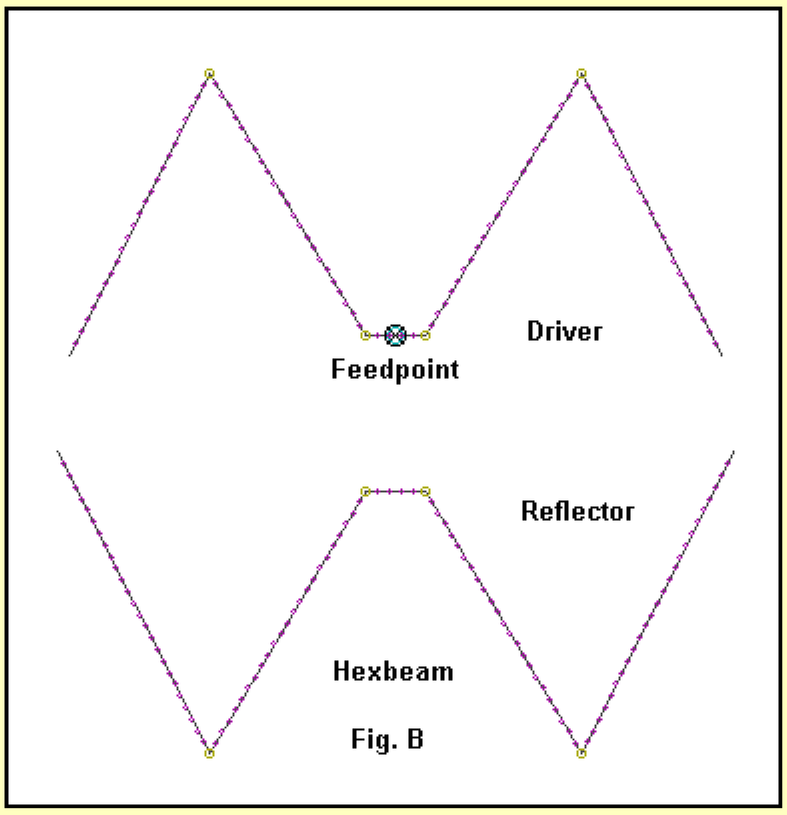


Fig. 3

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 ration of over 32 dB sounds impressive. However, the patterns in **Fig. 3** tell a somewhat different tale (as do the passband graphs 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.

The Hex Beam



Hexbeam

Fig. B

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. **Fig. B** 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, follow in the chart.

```
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 direct 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 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 tip are end-to-end.

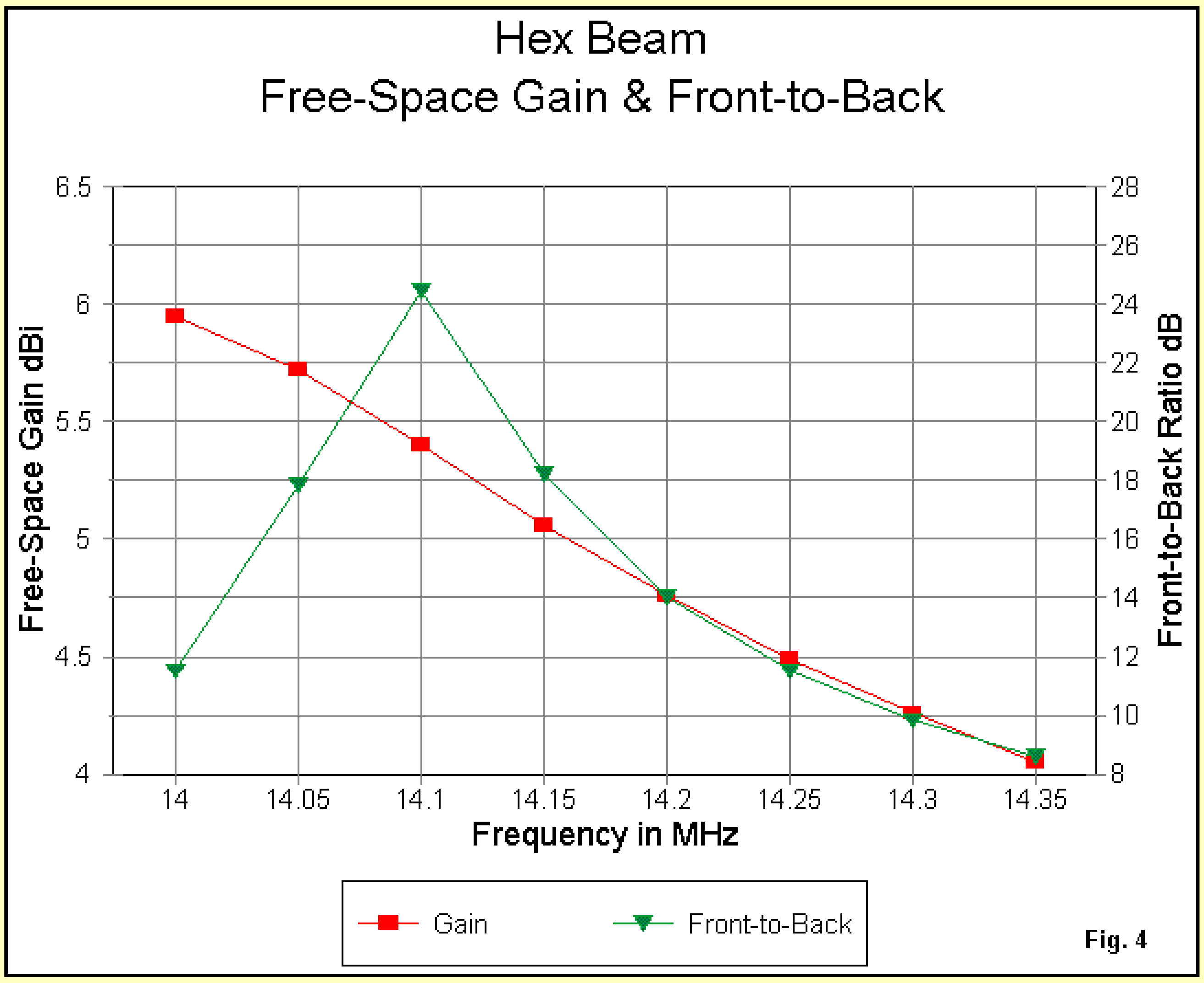


Fig. 4 presents the gain and 180-degree front-to-back ratio figures across 20 meters. The gain variation across the band is nearly 2 dB, a fairly high figure among common 2-element beam designs. The front-to-back ratio shows a very sharp peak, but decreases rapidly to band-edge values in the 8 to 12 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.

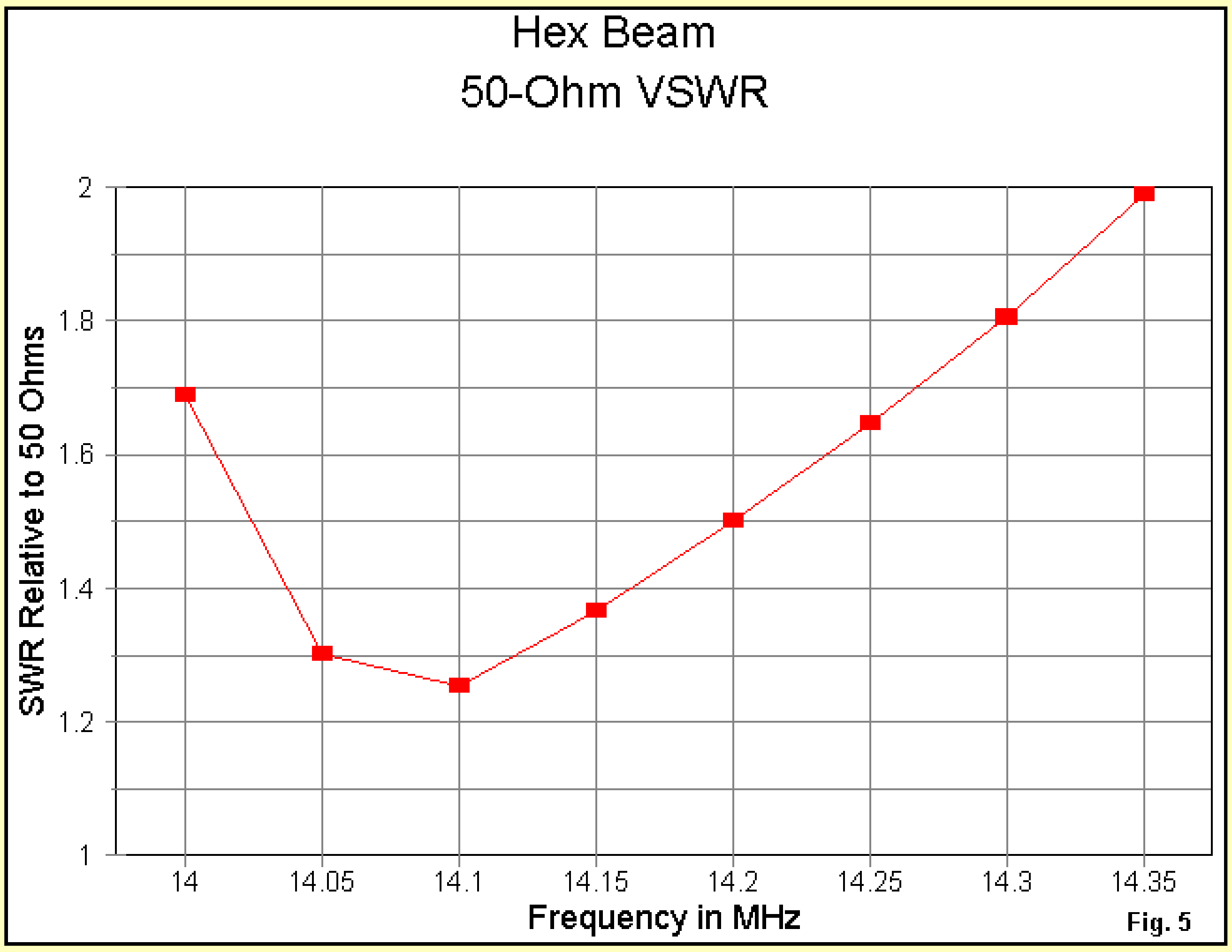


Fig. 5 illustrates one of the illusions of SWR. One could suggest that this model of the hex beam antenna has an operating bandwidth that covers the entire band, since the 50-Ohm SWR is less than 2:1 across 20 meters. However, operating bandwidth involves more parameters than just the SWR. Evaluating 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.

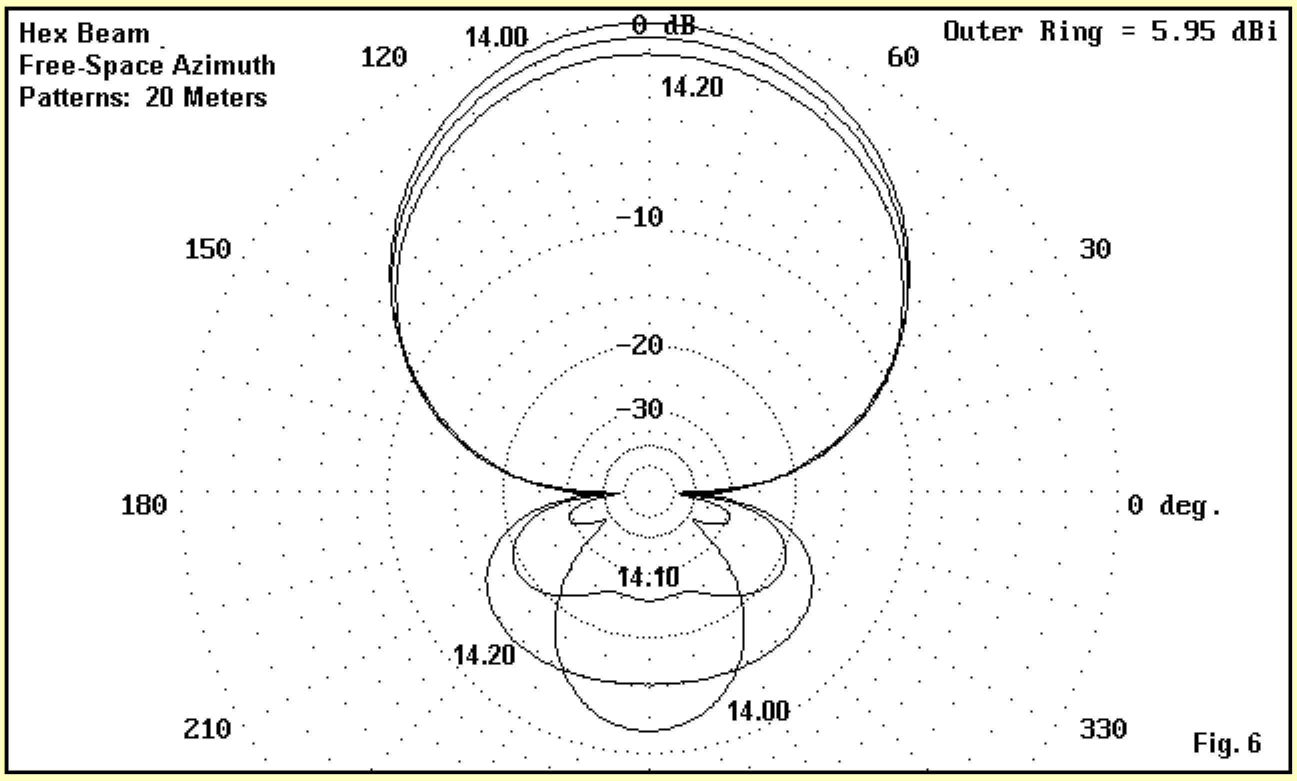


Fig. 6

Fig. 6 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.

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.

For further extensive information on home-brew hexbeams, see G3TXQ's website http://www.karinya.net/g3txq/hexbeam/ or K4KIO's site http://www.leoshoemaker.com/hexbeambyk4kio/general.html

The VK2ABQ Square

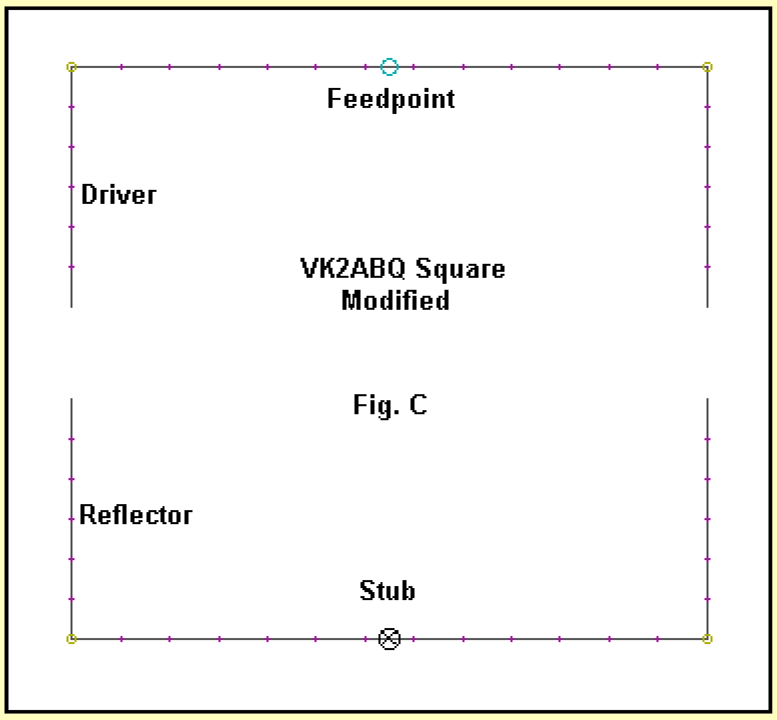


Fig. C

The VK2ABQ Square (and the Moxon Rectangle) are more fully described in "Modeling and Understanding Small Beams: Part 2: VK2ABQ Squares and The Modified Moxon Rectangle," *Communications Quarterly*, (Spring, 1995), 55-70. The origins of the square go back to the 1930s, only to disappear and re-emerge in the 1960s. **Fig. C** 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 narow-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.

```
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.

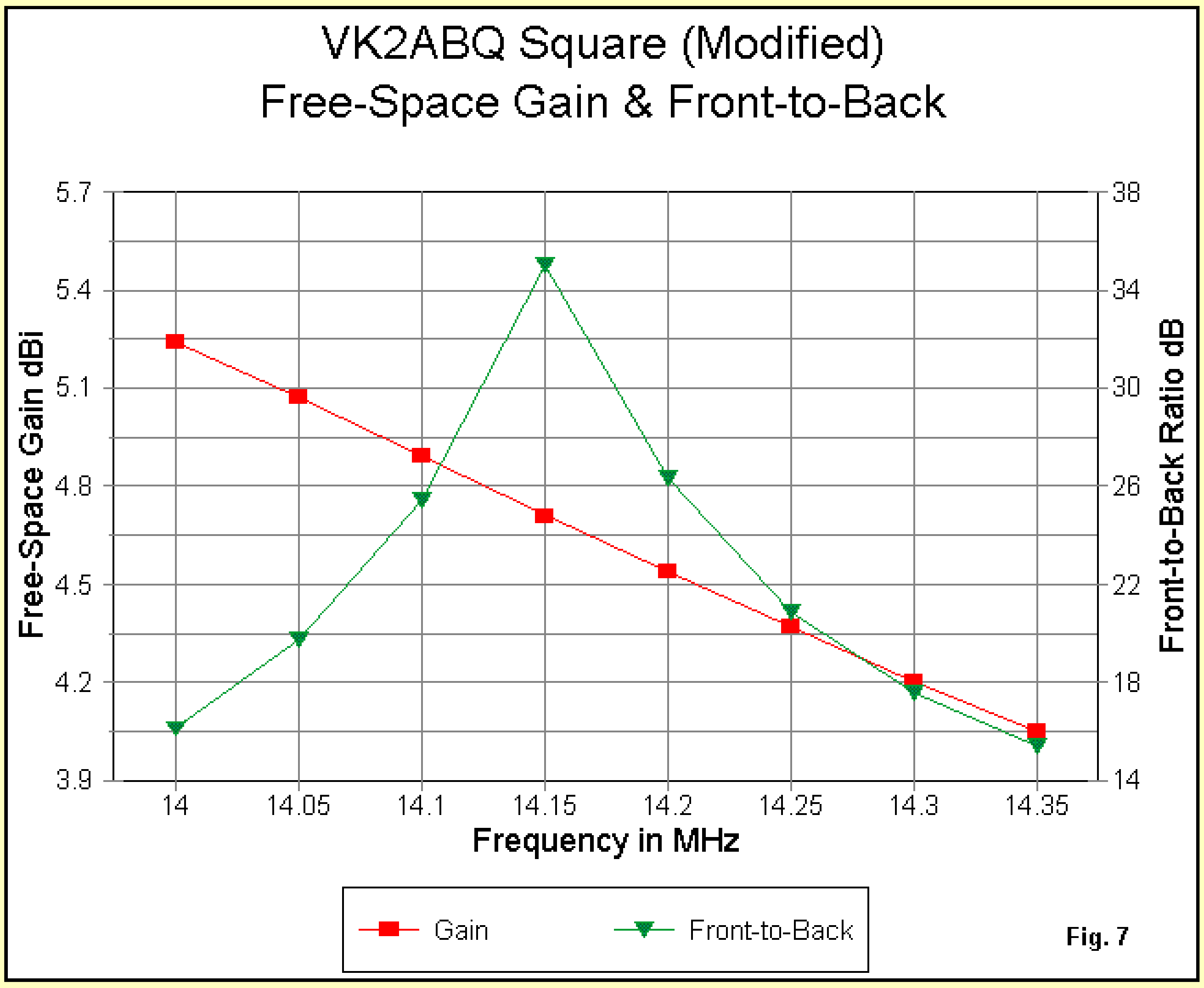


Fig. 7

As shown by **Fig. 7**, 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.

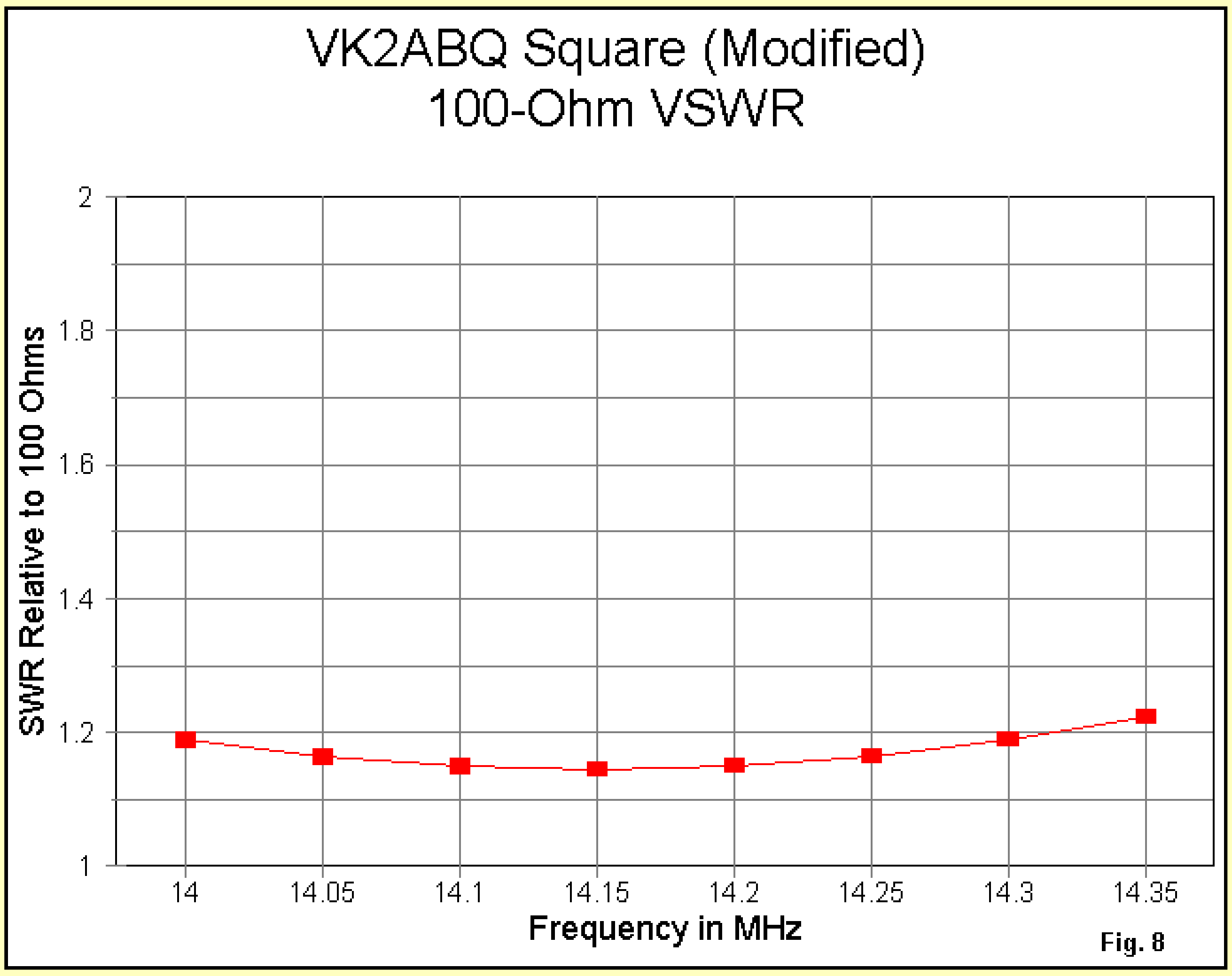


Fig. 8

As **Fig. 8** 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.

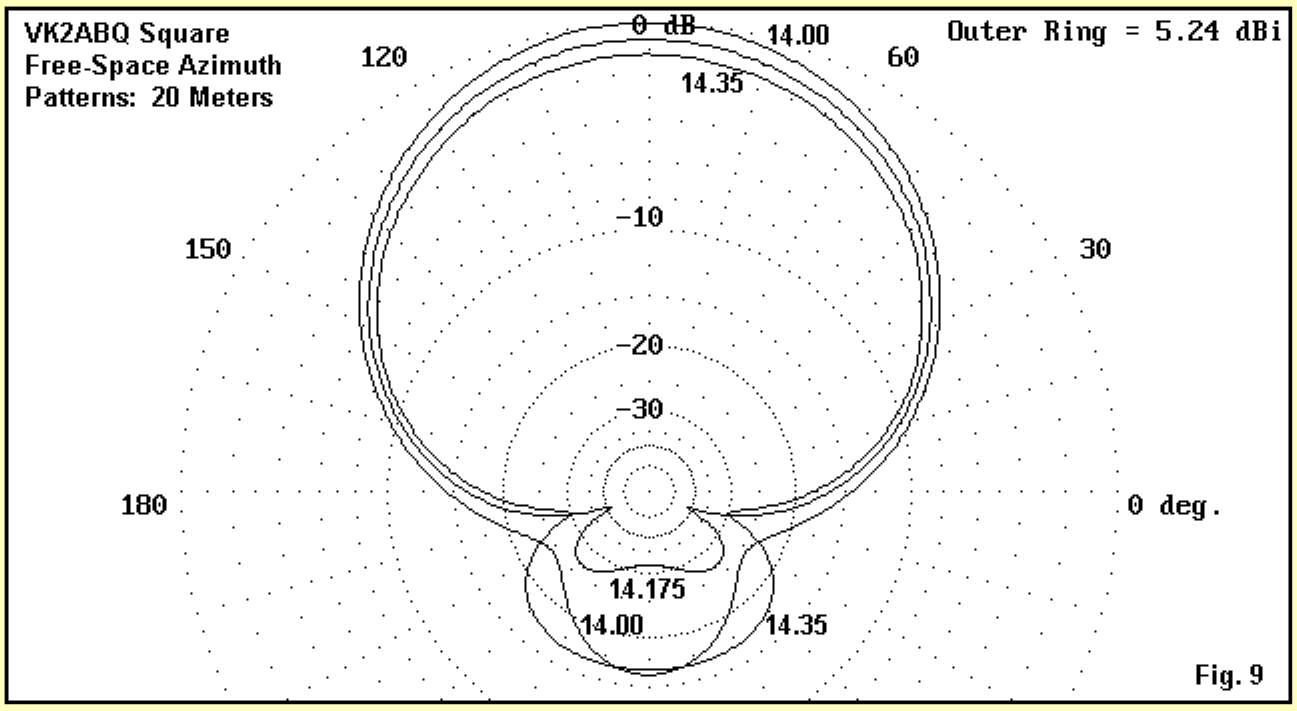


Fig. 9

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** 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 characteristic 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.

The Moxon Rectangle

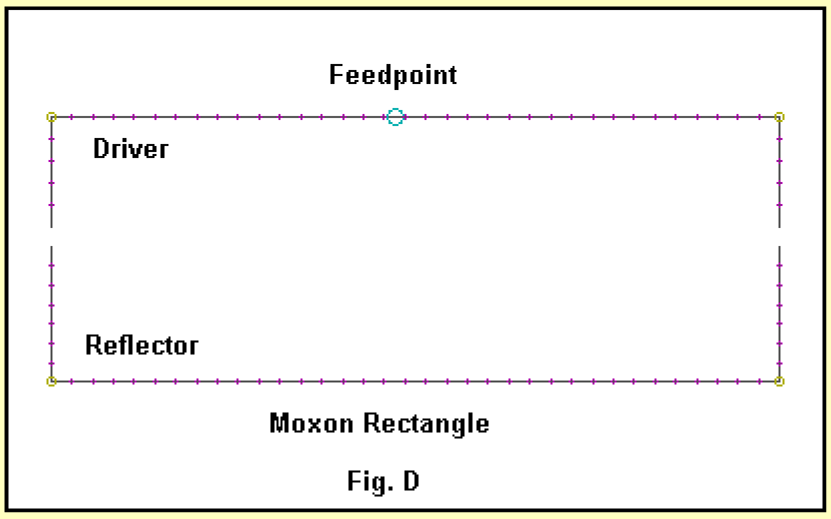


Fig. D

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 the optimized Moxon rectangle, sketched in Fig. D. 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 permit 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:

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
```

As the model shows, the rectangle is about 50% longer (side-to-side) than the squares. Tip-to-tip spacing is about 8". In the August, 2000, issue of *antenneX*, I published a small program that inputs only the design frequency and wire diameter to yield optimized dimensions for Moxon rectangles for the HF and VHF regions. The designs provide a direct 50-Ohm match, whether used for rotatable or reversible beams.

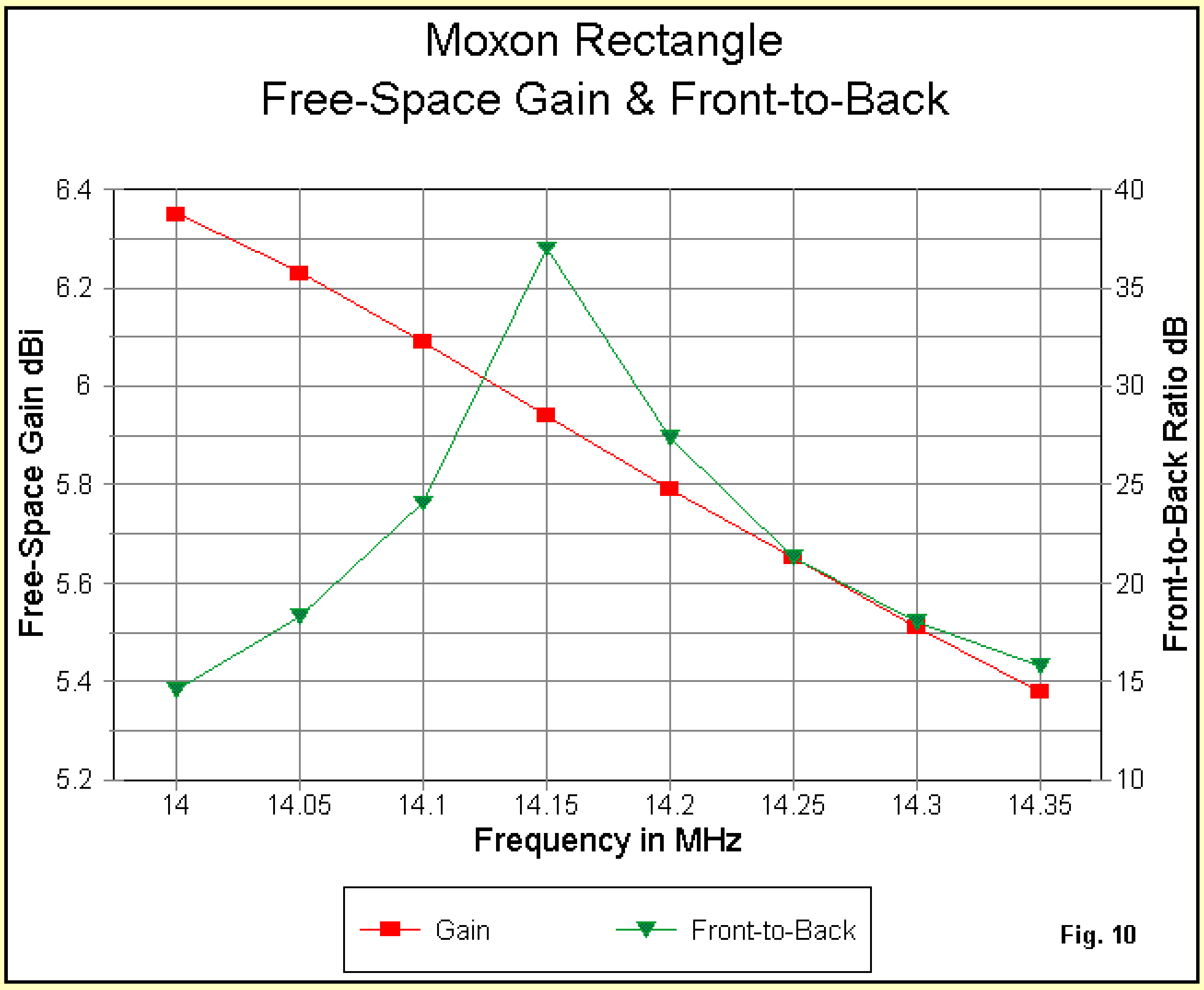


Fig. 10

The gain curve in **Fig. 10** 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.

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.

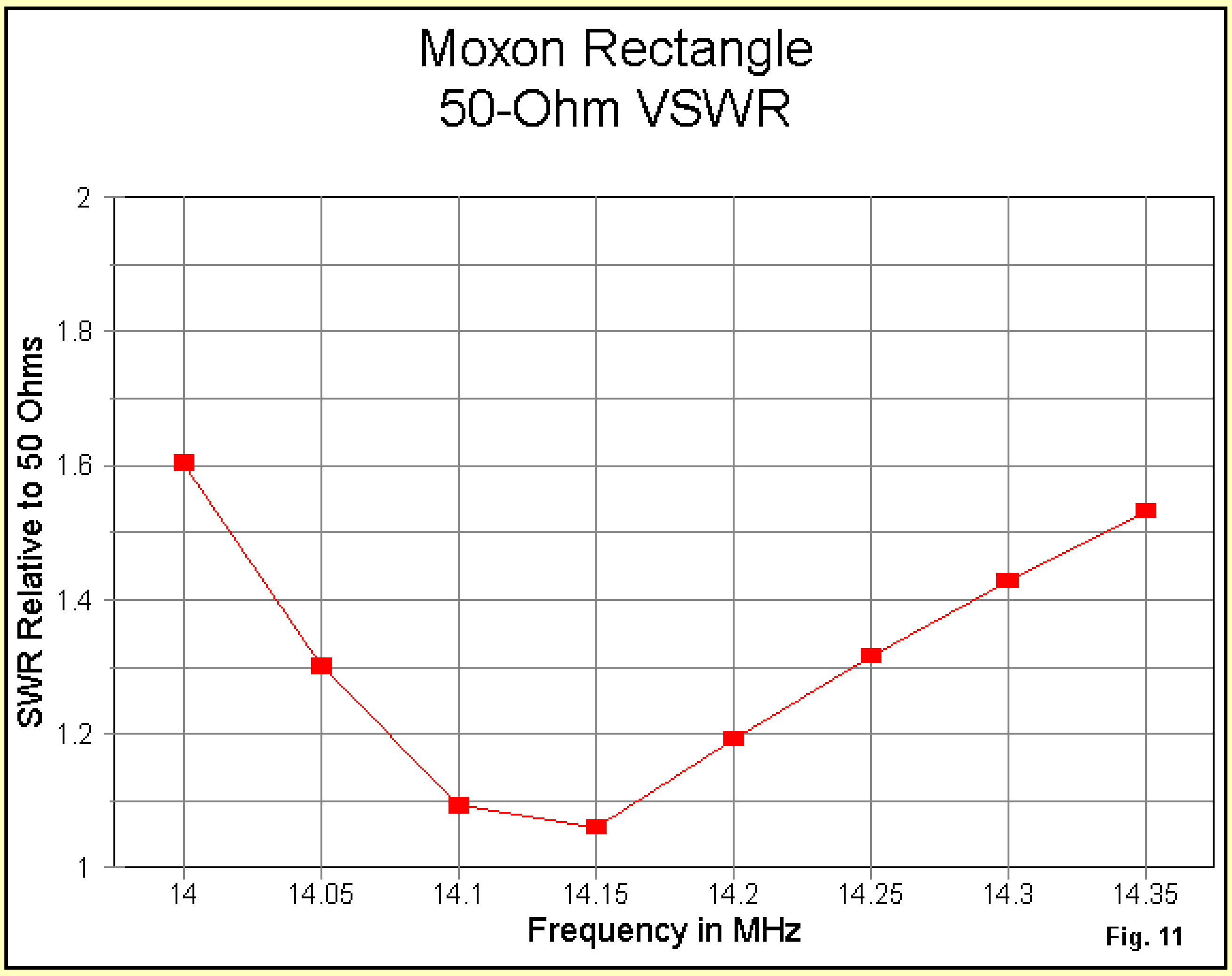
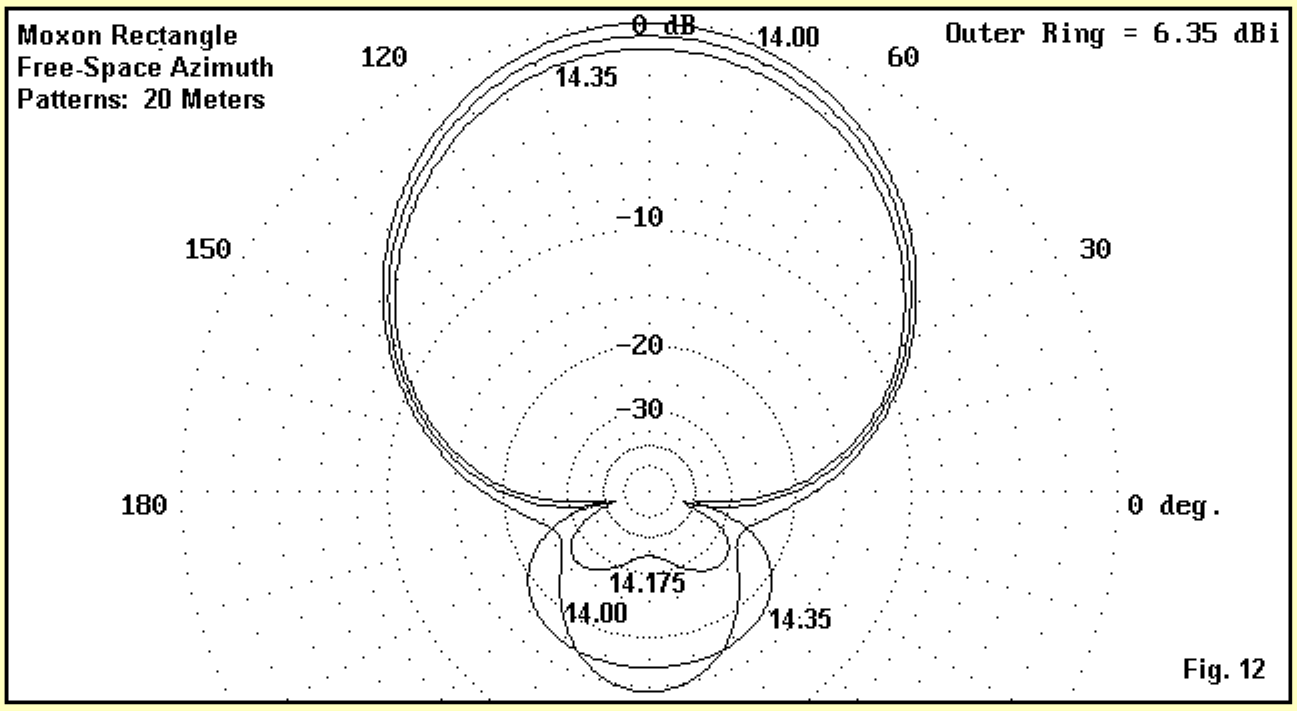


Fig. 11

The 50-Ohm SWR curve in **Fig. 11** 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. 12**. 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.

Some Tentative Conclusions

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-ed toward each other.

2. Element tips display two regions of coupling. Wider spacing between tips tends to produce 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 either to have 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.

Go to Main Index