

# Moxon Mighty Mite

*Tiny terrestrial TV antenna pulls in over-the-hill stations and shows promise for the 70 cm band.*

J. Barry Shackelford, W6YE

“But it’s so small,” exclaimed my wife when I showed off my solution for recapturing the local programming that had disappeared from our satellite TV provider. The programming was switched to a digital TV subchannel and our only recourse was to use a terrestrial antenna. I knew from experience during pre-satellite days that reception would be problematic due to our hilly location.

Somewhat apprehensively, I plugged the tiny Moxon antenna into the ATSC terrestrial antenna input of the tuner supplied by our satellite TV provider. This was plan C and reputations were at stake here — mine, and by proxy, that of the ARRL. After some fiddling with the three axes of the antenna mount that I had cobbled together from PVC pipe fittings, a glorious digital TV picture appeared on the screen — reputations saved!

Levity aside, it’s hard to beat the price performance of this antenna that can be built for pocket change, requiring only a few feet of #12 AWG house wire and some PVC parts.

Before describing the construction of this UHF Moxon, we’ll look at some background and design aspects of the Moxon antenna and Amateur Radio applications in the 70 cm band.

## The Moxon Antenna

The shape that amateurs identify as a “Moxon antenna” is actually one of a number of configurations that Les Moxon, G6XN (SK), referred to as “two element close-spaced beams.”<sup>1</sup> The Moxon made its *QST* debut in an article by L.B. Cebik, W4RNL (SK), in which he discussed design parameter variations and their effect on performance.<sup>2</sup> L.B. called his antenna a “Moxon rectangle” — perhaps to distinguish it from the other shapes described in Moxon’s book.

The year after he first introduced the Moxon rectangle in *QST*, L.B. described Moxon VHF/UHF satellite receiving antennas.<sup>3,4</sup> His 435 MHz antenna was con-

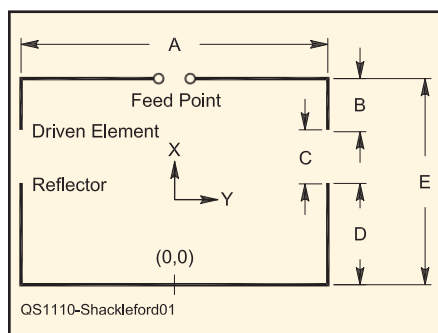
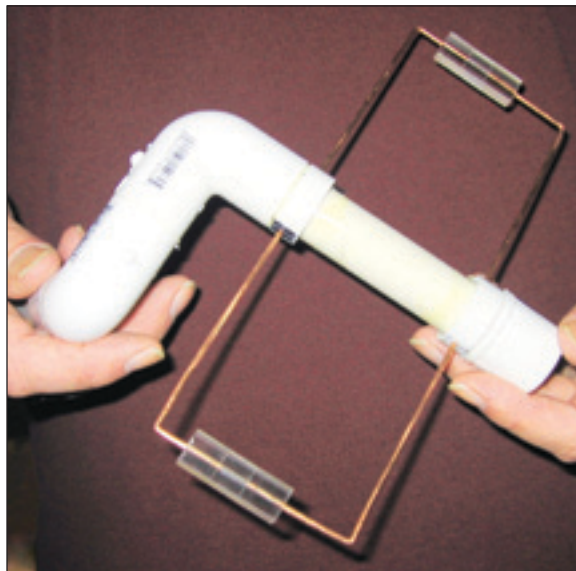


Figure 1 — Moxon antenna schematic. The coordinate system (main lobe on x-axis) and dimensions A–E are those used by the *MoxGen* antenna synthesis tool.

structed using #12 AWG house wire and PVC tubing.

## MoxGen

Dan Maguire, AC6LA, used an algorithm by Cebik to create a free downloadable tool called *MoxGen* that calculates the antenna’s dimensions as a function of frequency and element diameter.<sup>5</sup> The tool also generates both *EZNEC* and *NEC* models.<sup>6</sup>

Cebik’s algorithm targets antennas that have a  $Z_0$  of 50 to 54  $\Omega$ , a reactance of less than 1  $\Omega$ , a free-space gain in the range of 5.95 dBi to 6.05 dBi and a front to back ratio (F/B) greater than 35 dB.

His methodology considered a range of conductor diameters from  $10^{-5}$  to  $10^{-2} \lambda$ . He created seven antenna designs that met his target criteria logarithmically spaced across this range. He then used a mathematical technique known as regression analysis to “fill in the space” between the seven discrete designs.<sup>7</sup>

Regression analysis simply tries to fit a continuous curve through a series of data points with a minimum of error. The continuous curve can then be represented by a simple equation, allowing antenna dimensions in the design range to be readily calculated.

## Dimensional Sensitivity across the 70 cm Band

*MoxGen* dimensions are listed to the nearest 0.01 inch. I was not sure how critical these dimensions are, so I created three *EZNEC* models for a 435 MHz antenna — M0, M1 and M2:

- M0 served as the baseline and used unmodified dimensions from *MoxGen*.

- M1 was used to explore the antenna’s sensitivity to variation of a single dimension. I varied the end point of dimension B nearest the gap, with all other end points unchanged.

- For M2, I flipped a coin to add either +0.1 inch or –0.1 inch to the x and y coordinates of the corners and end points of the M0 model. This represented a build with “relaxed tolerances.”

<sup>1</sup>Notes appear on page 00.

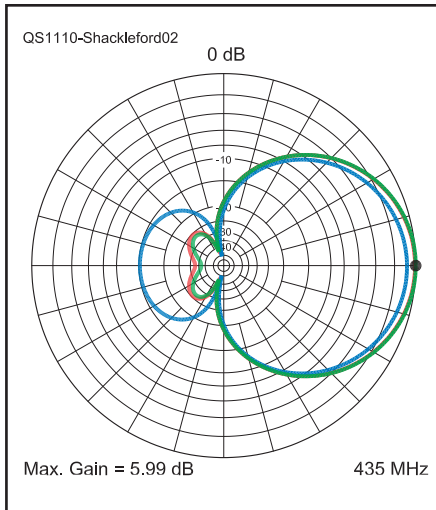


Figure 2 — Free space EZNEC composite azimuth plots for M0 (red), M1 (green) and M2 (blue).

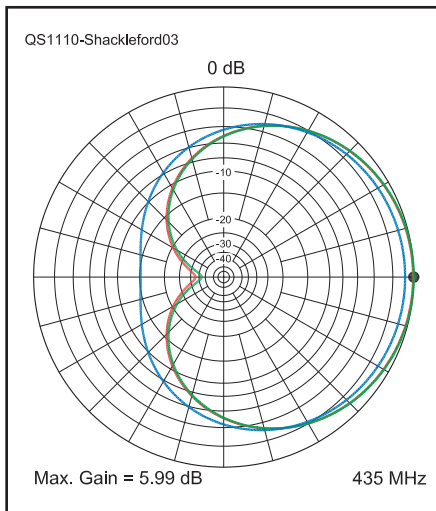


Figure 3 — Free space EZNEC composite elevation plots for M0 (red), M1 (green) and M2 (blue).

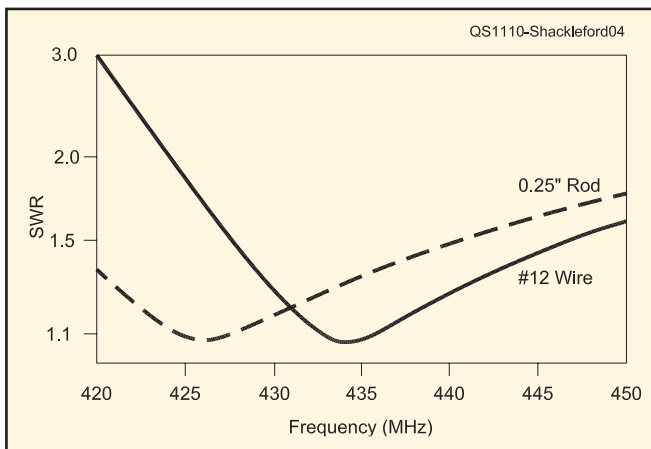


Figure 4 — SWR plots for two MoxGen designs targeted at 435 MHz.

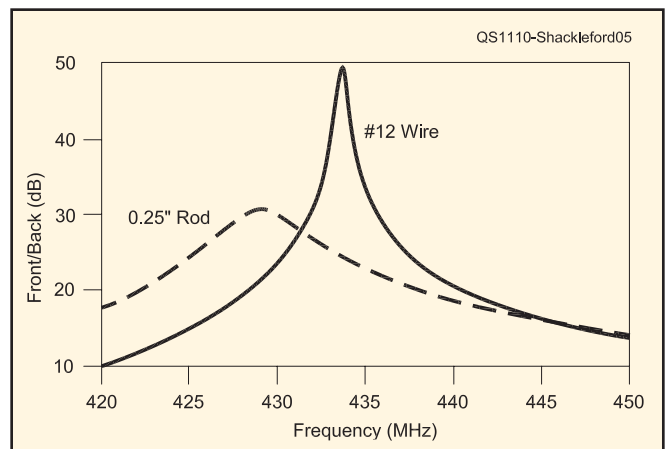


Figure 5 — F/B plots for two MoxGen designs targeted at 435 MHz.

For the baseline model, M0, the dimensions in inches as shown in Figure 1 were  $A = 9.73$ ,  $B = 1.25$ ,  $C = 0.49$ ,  $D = 1.88$  and  $E = 3.62$ , where  $E = B + C + D$ . The maximum free-space gain was 5.93 dBi with a F/B of 32.69 dB. The free-space  $Z_0$  was  $53.78 - j 1.307 \Omega$ . The composite free space azimuth and elevation plots for the three cases are shown in Figures 2 and 3.

SWR plots for M0 and a variation with 0.25 inch diameter elements are shown in Figure 4. As would be expected, the implementation with larger diameter elements has a greater SWR bandwidth. However, somewhat surprising is the downward shift of the optimum SWR point away from the design frequency of 435 MHz (approximately 1 MHz for #12 AWG wire and 9 MHz for 0.25 inch rod). This may be due to the curve-fitting algorithm and approaching the  $10^{-2} \lambda$  element-diameter limit of the data set. Figure 5 shows the F/B variation for the two implementations.

Figure 6 illustrates the effect of ground on the antenna. Realistically, this can only be considered an approximation since minor variations in the ground angle, buildings and even automobiles parked in the neighborhood will have a significant effect on the pattern. Once the antenna is properly aimed at a fixed station, however, you can count on 5 or 6 dB over the free-space maximum gain.

For the M1 experiment, the B-segment end point y-value ( $D + C$ ) was varied in 0.01 inch steps from 2.34 inches to 2.47 inches, straddling the MoxGen nominal length of 2.37 inches. The maximum gain and front/back ratio was noted for each endpoint. Figure 7 is a plot of F/B vs the y-value of the B segment end point. In the vicinity of the M0 baseline a variation of 0.01 inch of the B segment end point results in nearly a 1 dB change in the F/B. The maximum F/B occurred with a value of 2.43 inches. At this

point the  $Z_0$  was  $49.88 - j10.84 \Omega$  and the gain was 5.99 dB. Over the experimental range the gain varied linearly from 5.90 dB at 2.34 inches to 6.03 dB at 2.47 inches.

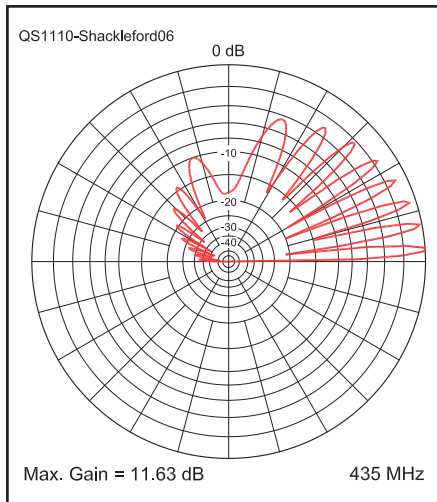
For M2 there are  $2^{16} - 4$  possible geometry perturbations possible in the x-y plane by the method I described above. The “4” represents diagonal displacements of the baseline model that do not alter the geometry. For this particular instance, the gain was reduced to 5.19 dBi and the F/B was reduced to 13.42 dB.

It seems from these few trials that if you are only interested in forward gain then adequate gain can probably be had with fairly loose construction tolerances. However, if you want to realize the full potential of the antenna then fairly tight construction tolerances appear necessary. Don't despair — in the Construction section I'll describe some machinists' techniques that will enable you to build to 0.01 inch tolerances with hand tools.

### Feeding the Moxon

The Moxon is an inherently balanced antenna, yet the applications that I have seen only feed it with unbalanced coax. I'm sure that the fact that it can be designed to have a  $50 \Omega$  impedance has a lot to do with this.

John Stanley, K4ERO, recently described a class of “hairpin” balanced antenna system tuners that perform well in the 70 cm band.<sup>8</sup> John pointed out that parallel feed lines such as open wire line can outperform large diameter coax, and do so at a fraction of the cost. He posed the question: If balanced tuners were available, would ladder line be as popular at VHF (and, by implication, the 70 cm band) as it has become at HF? I believe the question is worthy of consideration. If you think about it from a cost perspective, feeding an antenna that cost pennies with low-loss coax that can cost several dollars per foot really does not seem



**Figure 6 — Elevation plot for M0 over real ground. The height above ground was 4 wavelengths or 108 inches.**

like a “balanced” arrangement.

At UHF, line loss and SWR are more critical than at HF and should be considered if feeding a Moxon in the 70 cm band. Figure 8 shows three possible feeding schemes for a 435 MHz Moxon that we’ll look at below:

(A) 50 Ω coax augmented with a ferrite bead common mode choke;

(B) a hairpin tuner driving a 300 Ω balanced open wire line with a transition to 50 Ω at the antenna via a 122 Ω quarter wave transmission line transformer; and

(C) a hairpin tuner driving the 300 Ω balanced open wire line as in (B), but with a fixed-value hairpin tuner at the antenna to transform the 300 Ω  $Z_0$  of the open wire line

to the nominal 50 Ω  $Z_0$  of the Moxon.

Coax (Figure 8A) is certainly the most popular method of driving a Moxon. Ferrite beads strung on the coax at the antenna will help to mitigate current flow on the outside of the coax shield, preventing the shield from radiating and distorting the antenna pattern.<sup>9</sup> At 435 MHz, however, cable attenuation can be significant even if matched. Referring to *The ARRL Antenna Book*, Chapter 24, Figure 23, the loss of RG-8 is approximately 6 dB per 100 feet.<sup>10</sup> Since the SWR is probably less than 1.5, we can ignore the additional loss due to SWR as shown in Figure 14 of the same chapter. [But make sure the coax is really matched at the antenna end, or the loss can get much higher. — *Ed.*]

Reducing the loss further requires the use of coax hardline, which, as noted earlier, can be fairly expensive. Again referring to Figure 23, the loss for matched ½ inch 50 Ω hardline at 435 MHz would be approximately 1.9 dB per 100 feet.

Open wire line (Figure 8B) can also be used to feed the Moxon at 435 MHz. However, a matching arrangement such as the hairpin tuner is needed to match the 50 Ω output of the transmitter to the 300 Ω impedance of the open wire line. At the antenna end of the line, a quarter-wave transformer is used to match the open wire line to the Moxon. The  $Z_0$  of the quarter-wave transformer should be  $(300 \times 50)^{0.5}$ , or about 122 Ω.

At 435 MHz, a quarter wavelength is only about 17.2 cm or slightly more than 6¾ inches. As shown in Figure 9, the 122 Ω quarter wave section could variously take the form of:

(A) dual coax section (in this case it may be easier to fabricate the open wire line to match either the 200 or 450 Ω impedance of the transformer;

(B) strip lines on a PC board;

(C) parallel conductors with a D/d ratio of about 1.57, with D the center-to-center spacing and d the diameter of the conductors; or

(D) a single coaxial conductor with a D/d ratio of 7.7, with D in this case the inside diameter of the outer conductor and d the outer diameter of the inner conductor.

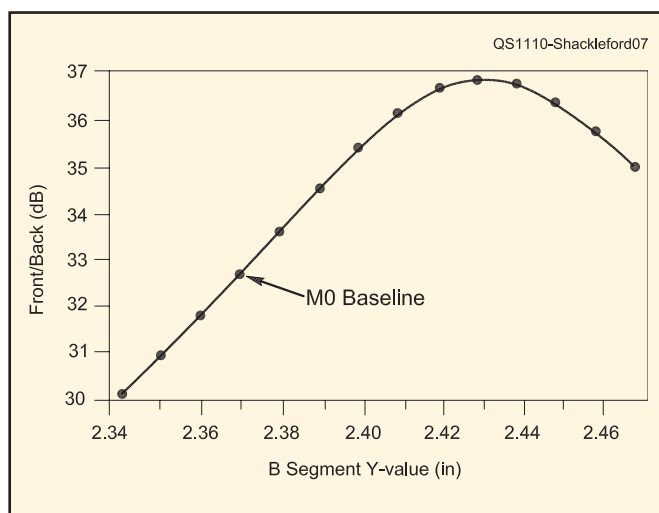
Other impedances and ratios can be determined graphically or calculated directly.<sup>11</sup> For closely spaced parallel conductors the impedance is more accurately calculated as  $120 \operatorname{arccosh}(D/d)$  rather than the more common formula  $276 \log(D/d)$ . The characteristic impedance of a coaxial line with an air dielectric between conductors is  $138 \log(D/d)$ .

To calculate the loss of this feed system, we’ll consider the losses of each of the components: the hairpin tuner, the cable attenuation of the open wire line, the radiation loss of the open wire line and the quarter wave transformer.

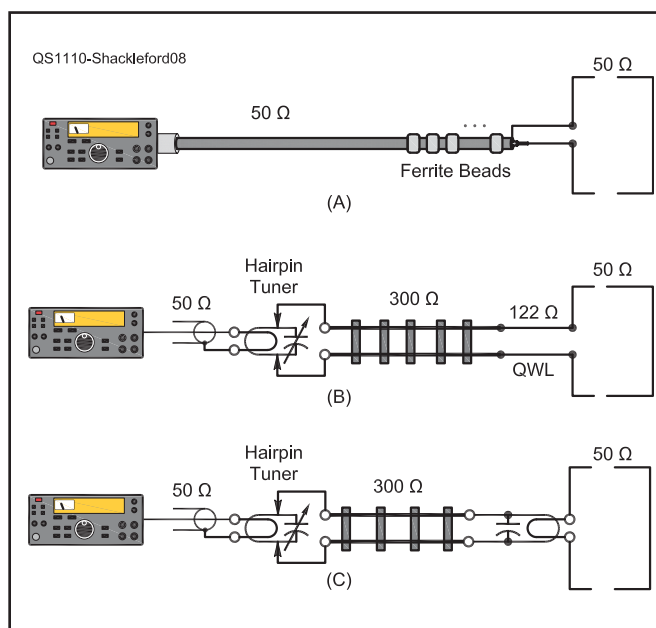
The hairpin tuner loss as measured by John is about 0.6 dB.

The cable attenuation of the open wire line can be determined by *TLW*, or an online calculator such as the one at [vk1od.net/calc/tl/twlc.htm](http://vk1od.net/calc/tl/twlc.htm).<sup>12</sup> The attenuation for 300 Ω #12 open wire line is 0.786 dB per 100 feet. Higher  $Z_0$  open wire line will have less loss.

Radiation loss from open wire line was discussed in Experiment 96 of *QST*’s



**Figure 7 — M1 experiment: a variation in the y-value of the B-segment endpoint (D + C) can result in nearly a 1 dB change in F/B.**



**Figure 8 — UHF Moxon feed: (A) coax; (B) hairpin tuner, open wire line, quarter wave line; (C) fixed hairpin tuner replaces the quarter wave line.**

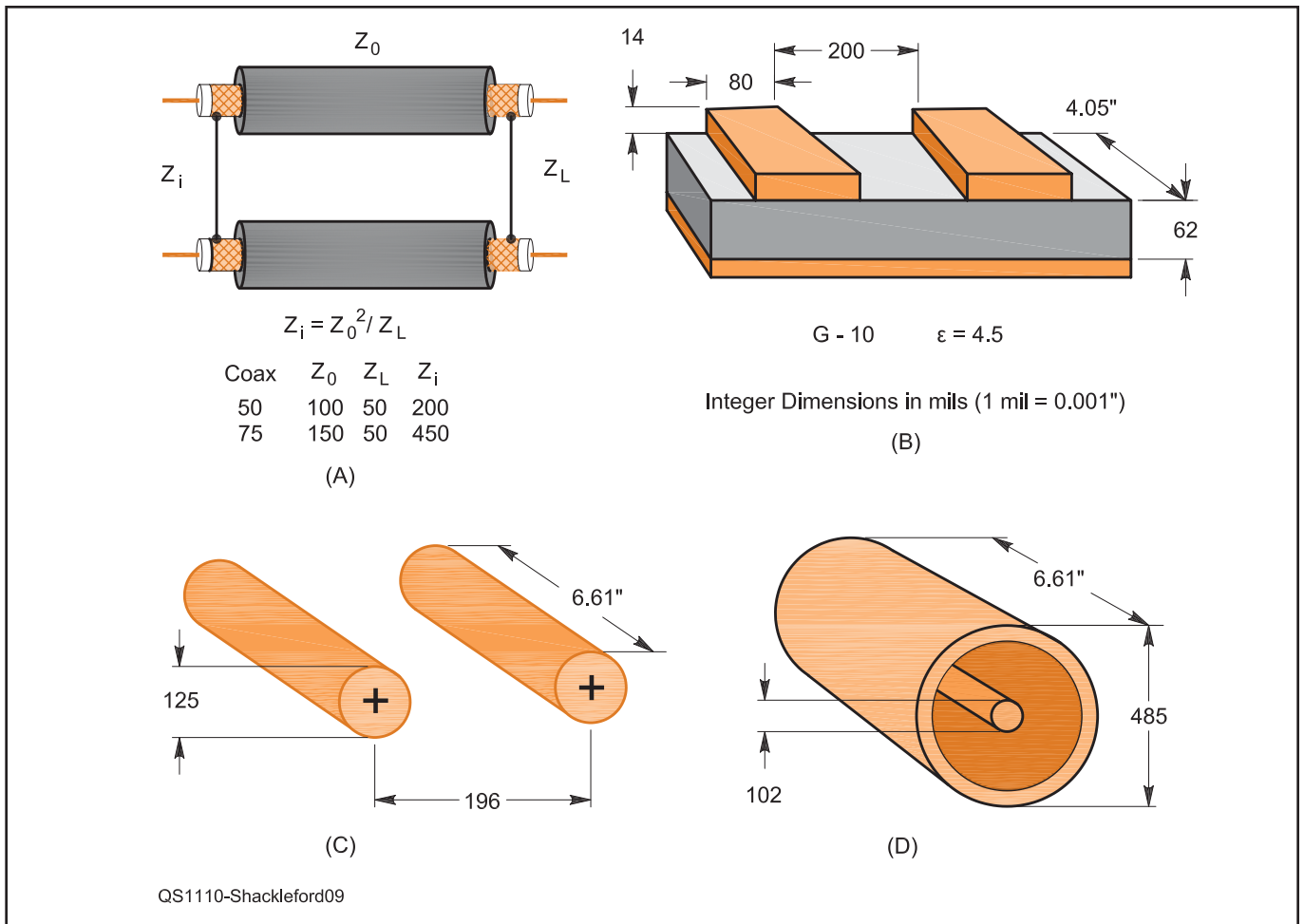


Figure 9 — Various quarter wave transformers: (A) parallel coax; (B) microstrip; (C) parallel lines; (D) air dielectric coax.

Hands-On Radio column.<sup>13</sup> If we substitute  $I^2 \times R$  for the radiated power and divide both sides of the equation by  $I^2 \times R$  where  $R$  is the characteristic impedance  $Z_0$  of the open wire line, we get an expression for the relative loss of the line that varies from 0 (none) to 1 (total):  $160 (\pi \times D/\lambda)^2 / Z_0$ , where  $D$  is the center-to-center spacing of the open wire line and  $\lambda$  is the wavelength in the same units as  $D$ . For our example, the relative loss would be  $160 (3.14 \times 0.5/26.25)^2 / 300$  or about 0.0019, which is about 0.008 dB, or for our purposes, negligible.

The loss of the quarter wave transformer section is also small — probably less than 0.2 dB.

A fixed hairpin tuner (Figure 8C) can be substituted for the quarter wave transformer to match the open wire line to the Moxon antenna. The open wire line is shorted in the form of a loop and comprises one of the components of the tuner. A fixed capacitor is placed across this loop and the coupling is adjusted by varying the overlap with that of the loop associated with the antenna. John measured the loss at about 0.3 dB.

The use of a hairpin tuner with a balanced

feed line opens up design regions in which the Moxon is no longer 50  $\Omega$ -resonant, but may have enhanced performance as demonstrated by the M1 experiment.

### UHF TV Application

I used *MoxGen* to calculate the dimensions for channel 27, which is assigned the band from 548 MHz to 554 MHz.<sup>14</sup> I arbitrarily chose the center of the band, 551 MHz, as the working frequency for *MoxGen*, even though the ATSC carrier is listed at 549.31 MHz. It's worthwhile to check the actual channel that your local station is using (our "channel 26" uses channel 27).<sup>15</sup>

### Construction

So how do you mark the drilling positions on a piece of PVC pipe for two sets of holes 3.62 inches apart? I use an inexpensive dial caliper. These are available for less than \$20 from online suppliers such as Harbor Freight and Amazon.com. They enable you to measure and set distances to the nearest 0.001 inch. To mark layout lines, set the dimension on the dial and lock it. Then use

the sharp points of the inside-measurement jaws to lightly scratch lines through previously applied marker pen ink.

My "next best" suggestion would be to use the metric output option of *MoxGen* and transfer the dimension from a metric ruler to a sharp pair of dividers. Then mark the layout lines as with the dial caliper.

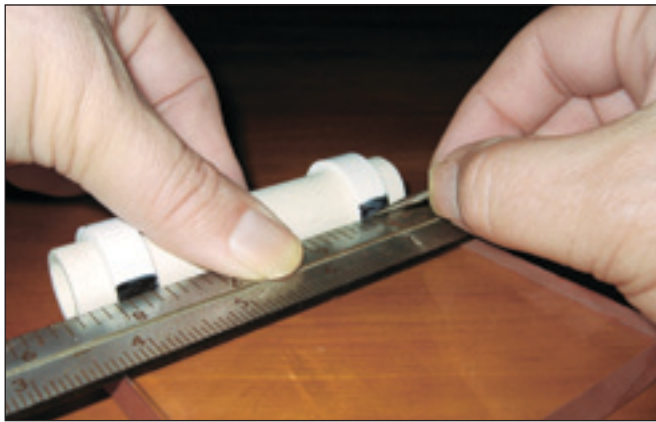
### Core

Begin construction by making the support core. The core for my 551 MHz Moxon is a piece of 1/2 inch PVC pipe about 4 inches long. At each end are collars fashioned from 5/16 inch slices cut from either end of a PVC coupling. The collars add extra support to the #12 AWG copper wire that forms the reflector and driven element and are placed on the pipe so that similar edges are dimension  $E$  apart. Leave about 1/2 inch from the driven element end to the collar edge so that the core can be slipped into a 90° elbow.

Determining the hole positions for the driven element and reflector begins by marking axial reference lines 180° apart on the collars. I did this by supporting a straight edge at roughly half the collar diameter, then



Figure 10 — Marking parallel axial reference lines.



holding the core to the straight edge, marked the first reference lines on each of the collars. This should be done on a flat surface (see Figure 10).

Determine a point 180° opposite the first line by setting a pair of dividers to the collar radius and stepping off three radii from the first line. I would say that it's even okay to "eyeball" the point because the important thing is that the two reference lines be parallel, not that they are in line with the exact center of the support core. After determining the opposite point, align it with the straight edge and mark as before.

The element holes can now be marked. At one end of the core, measuring from the factory edge of the collar, use dividers or a caliper to mark the first element hole on each side of the core by scribing across the axial reference lines. Next, as previously described, set dimension E on the dial caliper (or dividers) and measuring from the mark for the first element hole, mark second element hole by scribing across the axial reference line (see Figure 11).

Before drilling the holes, make dimples in the PVC at the marked locations to keep the drill from wandering. For #12 AWG wire that has been work hardened by stretching, a 5/64 inch drill is a very close fit. Drill each hole individually, while aiming at the mark on the opposite side.

### Elements

I formed the reflector and driven element from bare #12 AWG house wire. Before forming, I work-hardened and straightened the wire by stretching it. It's easy to stretch the wire if you use a simple lever arrangement as described in an earlier *QST* article.<sup>16</sup>

The nominal diameter of #12 AWG wire is 0.0808 inches where that of a 5/64 inch drill is 0.078125 inches. Stretching also reduces the wire diameter. The "stretch factor" needed to bring the #12 AWG wire diam-

Figure 11 — Using dial caliper to accurately mark dimension E.



eter down to 5/64 inches can be calculated as  $(0.0808/0.078125)^2 = 1.069$  or about 7%. I monitored the amount of stretch by taping the zero-end of a ruler to the wire and then put a piece of tape on the wire at 10 inches. I then stretched the wire until the tape reached 10.7 inches on the ruler.

Before forming the actual elements, practice "bending to length" with small work-hardened pieces. Note that the A dimension is center-to-center, B and D are center-to-end and C is end-to-end.

I made the right-angle bends by holding the wire in a vise and tapping it with a small hammer to form a sharp bend. If your vise jaws are in rough shape, you might want to file them flat or use some auxiliary jaws made from aluminum angle.

This is the procedure I used to form the driven element and reflector (using the driven element as an example):

- Start with a piece of straightened and work-hardened wire A + 2B + 2 inches long.
- Make a right-angle bend B + 1 inches from one end.
- Measure A/2 from the axial center of the B section wire and, using the sharp point of one of the caliper's inside jaws, scratch a center reference mark in the A section.
- File a point on the end of the long portion of the wire to aid insertion into the core. Before insertion of the radiator, tin the wire around the center mark and wipe off the excess solder so that the wire diameter is not altered (it's already a tight fit).
- Insert the wire into the core and center the reference mark.
- Make a second bend A/2 from the center to form the second B section.
- Mark the B section lengths by scratching the wire with the caliper. Be sure to measure from the axial center of the A section and not the outside edge.
- Rough cut the B sections about 0.05 inches long and then file them to the mark.

For the reflector, use a similar procedure to the above, except substitute D for B. Note: Do not cut the feed point until after the feed

## ..... Hamspeak .....

- **70 cm band** — Radio frequency range of 420 to 450 MHz, allocated by the FCC to the Amateur Radio Service, on a shared basis with the US government in the US. This band is the lowest frequency amateur band in the UHF range and is popular for FM use with repeater stations, amateur television, single sideband, CW and data modes via space or other propagation modes.
- **ATSC** — Set of standards developed by the Advanced Television Systems Committee for digital television transmission
- **F/B** — Front to back ratio. The ratio of the power in the main beam of a directional antenna to that to its rear. This is a key figure of merit for many applications of directional antennas, particularly if used to reject signals from undesired directions.
- **SWR** — Standing wave ratio. Measure of how well a load, such as an antenna, is matched to the design impedance of a transmission line. An SWR of 1:1 indicates a perfect match. Coaxial cables, depending on length, type and frequency can often work efficiently with an SWR of 3:1, sometimes higher. Solid state transmitters frequently require an SWR of 2:1 or less for proper operation.
- **UHF (Ultra-high frequencies)** — The radio frequencies from 300 to 3000 MHz.



Figure 12 — Core with driven element (bottom) and reflector prior to attaching feed line.

line or feed connector has been connected (see Figure 12).

Dimension C, which is the gap between the two elements, is maintained with a plastic spacer roughly  $\frac{1}{4}$  inch square and long enough to provide about  $\frac{1}{2}$  inch extra on either side of the gap. For #12 AWG wire, axially drill a  $\frac{3}{64}$  inch hole through the spacer. Scratch two reference lines dimension C apart and perpendicular to the axis. Insert the B and D sections and align their ends with the reference lines. A drop of cyanoacrylate adhesive may help keep the elements secure. Be sure the wires are clean if using adhesive. Roughing the wire with sandpaper may also make the joint stronger.

Alternatively, you can use C260 seamless brass tubing that is available in fractional inch sizes. This will simplify drilling and enable different element diameters to be easily implemented. The tubing is readily available online at suppliers such as Amazon.com. Rather than bending the tubing, which will cause it to kink, I recommend cutting it (by rolling under a sharp knife) slightly long and then grinding or filing it to length —  $90^\circ$  for the ends at C and  $45^\circ$  for the right-angle joints, which are soldered. The joint can be strengthened by inserting a small piece of L-shaped wire into both pieces before soldering. For this type of work, I prefer to lightly clamp both pieces in position and lay a small length of solder on the joint before heating the joint with either a small butane torch or a propane torch with a very small flame.

One note of caution in regard to using *MoxGen* when selecting tubing diameter: As previously discussed, Cebik's curve-fitting equations only used data up to  $0.01 \lambda$  for

the wire diameter. For the 70 cm band, this would imply a maximum element diameter of 7 mm, which is slightly larger than a quarter inch.

### Adjustable Support

I used ordinary  $\frac{1}{2}$  inch PVC pipe fittings to make the adjustable support for the antenna core. Two  $90^\circ$  elbows allow for azimuth, elevation and rotation adjustments and can readily adapt to either horizontal or vertical signal polarization. An end cap on the reflector end of the support core keeps moisture and insects out.

Begin by attaching the end cap to the reflector end of the support core. If you have PVC solvent available, apply a small amount with a cotton swab to the inside of the cap and twist it onto the core. If you don't want to invest in a can of solvent just for this project then you can probably use a few drops of cyanoacrylate glue to secure the joint. Also, since it will be used elsewhere, a bit of lithium grease on the joint and between the end cap and collar should keep water from wicking into the joint.

The two  $90^\circ$  elbows are joined with a  $1\frac{1}{8}$  inch length of PVC pipe. One elbow then attaches to the driven element end of the core and the other attaches to a vertical antenna support. Before making these attachments, however, I suggest routing the feed line through each piece separately. Coat the movable joints with lithium grease to keep water out.

One last note — be sure to point the antenna in the right direction. The capped end looks like the front, but it's really the back!

## Acknowledgment

I owe a special note of thanks to John Stanley, K4ERO, for his efforts in reviewing this article and for the many excellent suggestions he provided. The section on feeding the Moxon would not have been possible without John's ideas, the experiments he graciously performed and his ever patient tutelage.

## Notes

- <sup>1</sup>L. Moxon, G6XN, *HF Antennas for All Locations*, 2nd ed, RSGB, 1993, Chapter 5.
- <sup>2</sup>L.B. Cebik, W4RNL, "Having a Field Day with the Moxon Rectangle," *QST*, Jun 2000, pp 38-42.
- <sup>3</sup>L.B. Cebik, W4RNL, "A Simple Fixed Antenna for VHF/UHF Satellite Work," *QST*, Aug 2001, pp 38-41.
- <sup>4</sup>L.B. Cebik, W4RNL, Technical Correspondence, *QST*, Oct 2001, pp 78-79.
- <sup>5</sup>[www.ac6la.com](http://www.ac6la.com)
- <sup>6</sup>Several versions of *EZNEC* antenna modeling software are available from developer Roy Lewallen, W7EL, at [www.eznec.com](http://www.eznec.com).
- <sup>7</sup>[www.cebik.com/content/a10/moxon/moxgen.html](http://www.cebik.com/content/a10/moxon/moxgen.html) (registration required).
- <sup>8</sup>J. Stanley, K4ERO, "Hairpin Tuners for Matching Balanced Antenna Systems," *QST*, Apr 2009, pp 34-36. Also reprinted in J. Hallas, W1ZR, *The ARRL Guide to Antenna Tuners*, 2010, Chapter 15, pp 17-19. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 0984. Telephone 860-594-0355, or toll-free in the US 888-277-5289; [www.arrl.org/shop/pubsales@arrl.org](http://www.arrl.org/shop/pubsales@arrl.org).
- <sup>9</sup>J. Hallas, W1ZR, "Getting on the Air — Feeding a Balanced Antenna with Coax Cable," *QST*, Jan 2011, pp 61-62.
- <sup>10</sup>R. D. Straw, Editor, *The ARRL Antenna Book*, 21st Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 9876. Telephone 860-594-0355, or toll-free in the US 888-277-5289; [www.arrl.org/shop/pubsales@arrl.org](http://www.arrl.org/shop/pubsales@arrl.org).
- <sup>11</sup>*Reference Data for Radio Engineers*, 6th Edition, Howard S. Sams, 1975.
- <sup>12</sup>*TLW* (transmission line for windows) software is one of many provided with *The ARRL Antenna Book*, 21st Edition (see Note 10).
- <sup>13</sup>H. W. Silver, N0AX, "Hands-On Radio — Experiment 96, Open Wire Transmission Lines," *QST*, Jan 2011, pp 59-60.
- <sup>14</sup>[en.wikipedia.org/wiki/Television\\_channel\\_frequencies](http://en.wikipedia.org/wiki/Television_channel_frequencies)
- <sup>15</sup>[www.fcc.gov/mb/engineering/maps/](http://www.fcc.gov/mb/engineering/maps/) (stations in your area, interactive maps).
- <sup>16</sup>J. B. Shackelford, W6YE, "Homebrewing Air Core Inductors," *QST*, Jan 2010, pp 36-38.

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