A Compact Two-Element, 2-Meter Beam

What do you get when you take an already-unusual design for an HF beam antenna, scale it to VHF and turn it on its ear? A vertically polarized modified Moxon, of course! Build this wire and PVC beauty to solve your 2-meter troubles in a jiffy.

I'd been looking for an antenna to monitor 2-meter simplex and Skywarn frequencies that was affordable and easy to install in my attic. Bob, WA1FXT, and I live in an area that sees Skywarn activations for tornado and severe thunderstorm watches several times a year. I also live in a house where my shack is in a new addition, separated from the rest of the house. When I'm in the older part of the house, I have a much better view of weather approaching from the west and north (the usual directions), but I can't hear the radios in my shack. I'm also out of touch with local 2-meter simplex frequencies when I'm not near the radio room. Bob has a similar situation at his home.

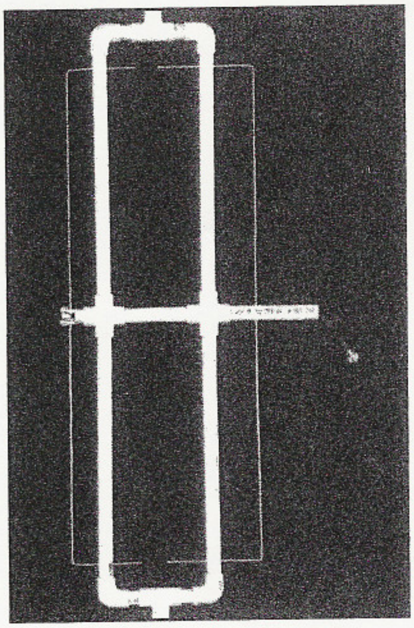
Finding the Design

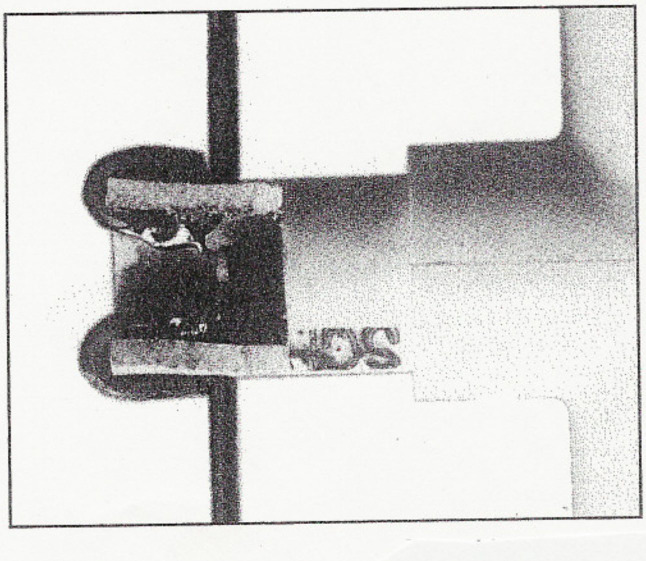
Bob and I had been discussing HF and 6-meter Field Day antennas. One day, I visited L.B. Cebik's (W4RNL) Web site at: **www.cebik.com**. The site is an excellent place to find antenna information and it's a valuable resource for those educating themselves about antennas. While considering his refinement of HF beams designed by Les Moxon, G6XN, I realized that these interesting gain antennas had the characteristics I considered ideal for a 2-meter attic antenna—smooth, wide front lobes with no notches, reasonable gain, relatively compact dimensions and ease of construction and feeding.

Modifying the Design

I cut and pasted W4RNL's dimensions for horizontally polarized HF wire Moxon beams into a spreadsheet and derived formulas for the dimensions. I oriented the antenna to achieve the vertical polarization needed for 2-meter FM and took the 10-meter dimensions and put them into Roy Lewallen's *EZNEC* antenna design and analysis program. Using the formulas I had derived from Cebik's plans, I rescaled the antenna for 2 meters and tweaked it a bit to overcome the large shift in the element length-to-diameter ratio. The resulting design characteristics contained a pleasant surprise. The single, smooth front lobe widened to about 135° along the horizon (the –3dB beamwidth). This vertically polarized variant was much broader than its horizontally polarized cousin.

While tracking how the antenna's pattern changed at several points in the 2-meter band, I found a point about 500 kHz above the design frequency that had a single rear notch in the gain pattern at the cost of marginally higher SWR. This resulted in a cardioid-type pattern with a relatively narrow notch to the rear that was about 35 dB down from the maximum forward gain (which models at around 6 dBi in free space). Far from being a disappointment, this was a useful foxhunting antenna





A closeup view of the connection between the coax and the radiating element.

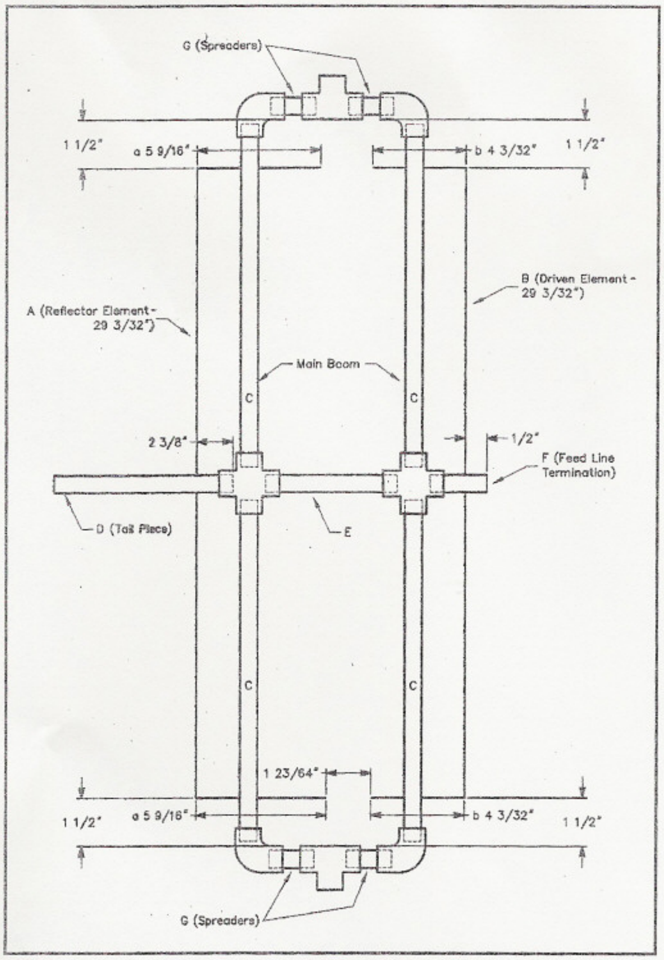


Figure 1—A construction diagram of the Moxon 2-meter beam antenna. See text and tables for details.

Table 1

Bill of Materials

10 feet	$^1/_2$-inch Schedule 40 PVC pipe
4	$^1/_2$-inch Schedule 40 PVC 90° elbows
2	$^1/_2$-inch Schedule 40 PVC crosses
2	$^1/_2$-inch Schedule 40 PVC tees
Approx 10 feet	No. 10 AWG copper wire
1	PL-259 coax connector
1	UG-176U coax adapter
2	Wire ties
3	Amidon Ferrite Beads (FB-43-5621) Amidon Associates 240-250 Briggs Ave Costa Mesa, CA 92626
RG-8X coax	As needed
Misc	Plastic electrical tape

PVC and Wire Cutting Schedule

Reflector element **A** consists of one piece of #10 AWG copper with a straight section and two tails bent at 90°. Total length is a single piece of $40^7/_{32}$ inches.

Driven element **B** is two half elements fed in the middle. Total length is a nominal $37^9/_{32}$ inches, but build it according to the text. A slightly longer wire is required to wrap around the PVC and secure the feed point to the pipe.

See Figure 1 for the drawing labels.

Wire

Qty	*Label*	*Description*	*Length*
1	A	Reflector Element	$29^3/_{32}$"
	a	Reflector Element Tail	$5^9/_{16}$"
1	B	Driven Element	$29^3/_{32}$"
	b	Driven Element Tail	$4^3/_{32}$"

PVC

Qty	*Label*	*Description*	*Length*
4	C	Main Boom	$15^9/_{16}$"
1	D	Tail Piece	6"
1	E	Middle Boom Spreader	$5^1/_8$"
1	F	Feedline Termination	2"
4	G	End Boom Spreader	$2^1/_{16}$"

of manageable size. This was something Bob and I had both been looking for!

We needed a framework to support the wire elements, so I put the dimensions for the two wire elements into a CAD program and worked up a PVC framework to support them. When Bob saw the antenna pattern and construction plans he became excited about the antenna's possibilities—especially as a foxhunter.

Build One of your Own

Please note that the dimensional accuracy used here is overkill. If you cut your elements to within an eighth of an inch, your antenna should work like a champ, with no practical loss in performance. Put away the calipers and pick up a ruler! The most critical dimension of these "modified Moxons" is the distance between the tips of the reflector tails and driven elements, which can be fine-tuned after assembly.

The first step in construction is to cut the $^1/_2$-inch schedule 40 PVC pipes to the lengths needed for the support frame. The quantities and lengths are listed in the sidebar. If you're going to vary from the pipe lengths shown in the table, be sure to allow $^3/_4$-inch to accommodate the various PVC fittings.

After cutting the PVC to length (per the accompanying table), measure and drill the holes for the wire antenna elements. Use a drill press and a fence to center the holes in the pipe (or mark the holes and drill carefully by hand).

Place the tip of a center punch or a nail at the drilling point and tap with a hammer to dimple the surface. This will hold the tip of the drill bit in place and keep it from spinning off target as you drill.

Follow the diagram in Figure 1 as you begin to assemble the antenna. Drill a hole completely through each of the four pipes labeled **C**, $1^1/_2$ inches from one end. This will go at the end farthest from the antenna center. The hole drilled in pipe **F** should pass all the way through, $^1/_2$-inch from the pipe end. Mark one end of pipe **D**; that end that will be inserted into the PVC cross. Drill a hole completely through pipe **D** $2^3/_8$ inches from the marked end. Make sure to orient the pipe properly when assembling the PVC frame or you will end up with a bowed reflector element (**A**).

Use solid #10 AWG copper wire for the antenna elements. Number 10 copper wire is a nominal 0.1-inch in diameter, but ours was a bit too large for a $^7/_{64}$-inch hole, so we used a $^1/_8$-inch drill bit. This allows the wire to pass through easily without too much slop. If your wire slips through the holes after building the antenna, hold the elements in place with wire ties, heat shrink tubing, hot glue, RTV sealant or tape (anything that won't detune the antenna). If you're making a permanent outdoor antenna, use UV-resistant material to secure the elements.

The next step is to assemble the PVC frame. This is best done on a flat surface. Use a rubber or wooden mallet to persuade the pipes to seat snugly in the fittings, being careful to keep the wire holes in the correct plane.

Align the four vertical pipes (**C**) by sighting through the holes you drilled in each pipe for wire tails **a** and **b**, aligning them with the corresponding holes in the opposite vertical pipe. If necessary, a pair of pliers can be used to fine tune the alignment by twisting the pipe in the fittings. The front and tail pipes, **F** and **D**, are aligned by sighting along the lengths of the vertical support pipes to be sure that the holes for wire sections **A** and **B** run parallel with the frame.

Next, prepare and install the wire elements. Straighten some #10 wire before starting the installation. After inserting the

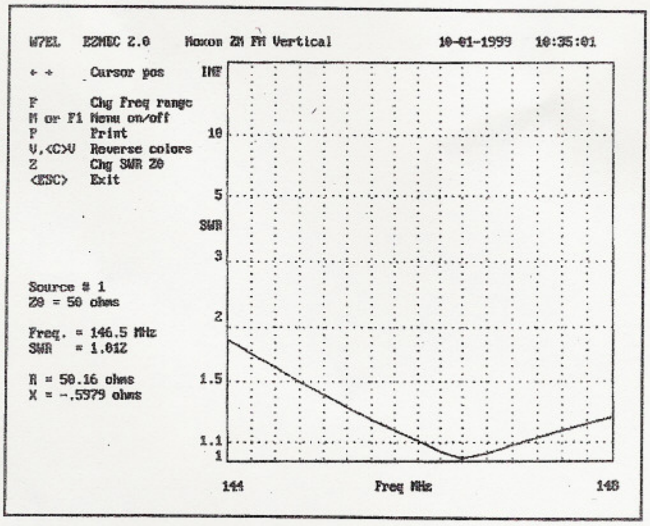


Figure 2—The predicted SWR bandwidth of our 2-meter beam, from 144 to 148 MHz.

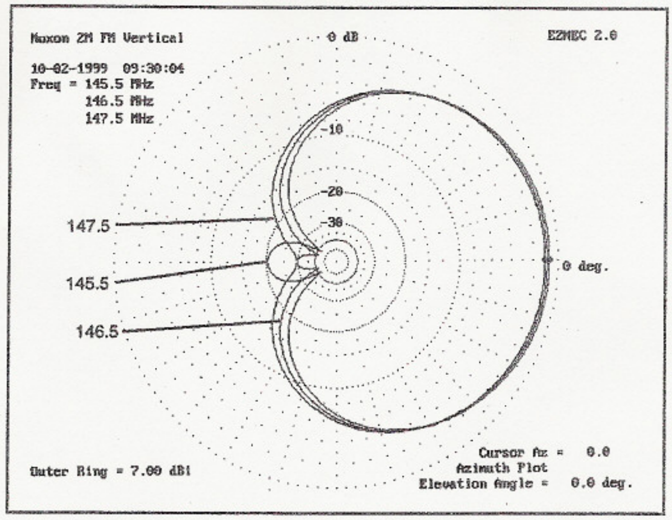


Figure 3—The predicted radiation pattern of the Moxon beam.

wire into the PVC frame, it's difficult to thoroughly clean the wire at the feed point (**F**), so be sure to clean it thoroughly beforehand. Oxidized wire makes it difficult to get a good solder joint, especially in this tight space. So use an abrasive plastic pad or fine steel wool to clean up the wire ends at the feed point to make for easier soldering.

First, install one half of the driven element (**B**). Take a longer piece of #10 wire (about 24 inches) and bend an inch at one end about 90°. Do this at the end you have already cleaned in preparation for soldering at the feed point. Bend about half of that 1-inch bend another 30° to 45° in the same plane. Pass the resulting "J" shape through the feed point hole in PVC pipe **F** from the outside (so the bends end up inside the pipe with about $^1/_2$-inch protruding from the open end of the pipe). Hold the wire against the inside of the PVC pipe with pliers or a dowel and wrap the $^1/_2$-inch of protruding wire back around the outside of the pipe and crimp it tightly against the outside of the pipe. See the close-up photo of the feed point to see the final result.

Once this is done, hold the wire parallel to the front vertical portion of PVC support frame **C** and bend it back at 90° at a point in line with the support holes in PVC pipe **C**, forming element tail **b**. This will be about $14^1/_8$ inches from the outside of PVC pipe **F**.

Measure and cut the bent-back wire tail section (**b**) to $4^3/_{32}$ inches long. Leave extra and trim later if you wish. Pass this tail section through the support hole in the front vertical pipe (**C**) on the PVC frame. Install the other half of driven element **B** using the same steps and dimensions.

Now you need to feed the antenna with coax *before* installing the reflector element (wire **A**). Prepare the feed line by obtaining a three-foot RG-8X jumper (with PL-259s installed on each end) and cutting it in half. This speeds construction and makes it easy to build two antennas at once. You can, of course, make up your own RG-8X coaxial cable and PL-259 assembly.

Strip 1 inch of insulation from the shield and $^3/_4$-inch from the center conductor at the unterminated end of the coax. Use three type-43 ferrite choke beads (Amidon FB-43-5621) to keep RF from returning along the coax shield. Slip the beads onto the feed line and secure them with wire ties and electrical tape as close to the stripped end of the coax as you can without touching the bare copper braid, the center conductor or the wire elements at the feed point. The electrical tape should also help prevent this contact.

To improve access to the feed point, cut a section out of the side of the pipe at the feed point as shown in the photo. First cut into one side of pipe **F** just behind the feed point, perpendicular to the length of the pipe to a depth of about $^1/_3$ of the pipe diameter. Another cut in from the end of pipe **F**, along its length, but cutting in only about $^1/_3$ its diameter, leaves enough support for the center of driven element **B**. This leaves plenty of space for soldering.

We considered making these cuts before installing the driven element wires, but decided that the stresses involved in bending the heavy gauge wire around the PVC at the feed point might cause cracking. You may find that it's okay to make your access cut first. Be sure to use a fine blade, such as a hacksaw or dovetail saw.

Now run the feed line in from the rear of the center horizontal support pipe up to the feed point, through pipes **D**, **E** and **F**. Wrap the coax shield around one side of driven element wire **B** (inside pipe **F**) and the center conductor around the other end of the driven element wire, then solder both connections. Use paste flux and a 100-W iron of sufficient mass. Irons with less thermal capacity can't generate enough heat, or have their thermal energy conducted away too quickly by the #10 wire. Lengthy heating with a smaller iron is likely to melt the PVC.

Now it's time to put reflector element **A** into place. First, pass 45 inches (or more) of #10 wire through the rear center support holes in PVC pipe **D**, being careful to go around the coaxial feed line rather than through it. Bend about six inches of wire at one end back at 90° toward the driven element and support frame (forming tail **a**) and trim it $5^9/_{16}$ inches from the bend. Then, pass this tail through the wire support holes in the rear vertical section (**C**) of the PVC support frame. Measure $29^3/_{32}$ inches from this first bend along reflector wire **A** and make the bend to form the other reflector tail. Trim this tail to $5^9/_{16}$ inches and pass it through its support hole in pipe **C**.

Everything is now in place, so square up the wire elements on the frame. One characteristic of Moxon antennas is a sensitivity to the relative positions of tails **A** and **B**, so make sure the tails are in line with each other and spaced at $1^{23}/_{64}$ inches. This was considered in designing the PVC support frame and the points at which it holds the wire elements. This design allows the wire tails to be held in line with each other, leaving the distance between the tips of the tails to be fine tuned and then taped, glued or otherwise secured to the PVC frame once the antenna is performing to spec.

We didn't cement our PVC frames because my antenna would be installed indoors and the joints were firmly seated without gluing. If you want to cement yours, we'd suggest assembling the frame to align the wire support holes and carefully making reference marks at the junctions of the pipes and fittings. This will allow you to quickly orient the PVC elements before the PVC glue sets up. If you're going to mount your antenna outside, gluing the PVC frame is a good idea. PVC glue sets up very quickly, so if you don't feel confident, you might want to insert small sheet metal screws into predrilled holes instead. Alternatively, you can build the PVC frame and glue it together before drilling the wire support holes.

You should try to run the feed line away from the antenna for a couple of feet before running it parallel with the main sections of the wire elements. Running it parallel to these sections at less than 19 inches or so may distort the pattern of the antenna and change its SWR.

Performance Testing

After building the first antenna, we decided to test its performance before building the second. We took the antenna to a clear spot in the yard and hooked it up to an MFJ-259 antenna analyzer through about 25 feet of RG-213 coax. Bob held the antenna up on a PVC mast while I ran through 2 meters with the analyzer—and I started to laugh.

Bob was dying with curiosity, so we traded places while he swept the band. The antenna came up on the frequency we expected, with an even broader bandwidth (see Figure 2). We decided to check the front-to-back ratio, but had no field strength meter at hand. Bob got in his truck and I aimed the front lobe of the antenna at him until his receiver dropped below S-meter saturation about a mile away.

While I turned the antenna and reported to Bob where he was in the pattern, a station in my normal fringe area called me. This station doesn't receive me full quieting on my base antenna (stacked 5/8-wave omni antennas at 33 feet, fed with about 2 W), but was hearing me now with the Moxon up only eight feet while running 350 mW!

Bob and this other station (11 miles in the opposite direction) reported S-meter readings in line with the computer-predicted pattern as I rotated the antenna in azimuth. At this point, we scrambled back to the garage to build a second antenna before we ran out of time!

The Hunt

About a week later, Bob and I got together for a foxhunt and to check out the front-to-back ratio in a more controlled manner. Bob, his son Matt, and I were on our first hunt together. Bob had borrowed a passive field-strength meter, but we were unsure of its linearity and were unable to get enough useful range out of it to measure the front-to-back ratio on the 2-meter Moxon.

Bob has a well-calibrated attenuator, so we made some measurements and checked the pattern and front-to-back ratio by switching the attenuator to give the same reading on the field-strength meter. The pattern turned out to be in line with the computer model, and the narrow rear notch was down 29 dB from the front lobe, exactly as predicted. We also checked the antenna at 147 MHz, about 500 kHz above the design frequency of 146.5 MHz. Again, as predicted, the rear notch deepened to about –35 dB.

We hunted using the rear notch in the Moxon pattern. We were thrown off several times by reflections from large metal buildings, a power plant that killed the signal, and the unfamiliar terrain. But we overcame the problems and were the third team to find the fox. We covered 19 road miles in the search for the fox, which was about six miles from the start as the crow flies. On one transmission, the fox was on a vertical omni with steady power when we were a couple of miles out. This gave us our best sample. The bearing we took on this transmission was within a couple of hundred feet from the fox's actual position.

The hunter who first found the fox (in half our time) and the team that found it a few seconds ahead of us were both using the same 4-element, balanced feed Yagi that I had used to win two California foxhunts. When tuned properly this Yagi has a single rear notch. The Moxon performed similarly, with the exception of its wider front pattern and reduced forward gain. We were very happy with its performance as a compact foxhunting antenna.

After we had designed and tested this antenna, we decided to see how it would act mounted on a standoff from a metal mast. We haven't checked thoroughly, but computer modeling suggests that at 1/4 wavelength, the rear null is not nearly as deep. The cardioid notch pretty much disappears. At 1/2 and 1 wavelength, the pattern is pretty good, so choose your mounting offsets (from a vertical metal mast) accordingly. This was not a great concern to me because I used PVC tee connectors at the top and bottom of the frame to support the antenna with short sections of PVC pipe attached to the ridge beam and a ceiling joist in my attic. It has performed very respectably there, only 12 feet off the ground. I can make all of my regular 2-meter simplex contacts, and the antenna holds its own when accessing local repeaters.

Resulting Antenna Performance and Potential Uses

No antenna does everything well, but this design has a number of useful characteristics:

- A smooth, wide front lobe (see Figure 3) with modest, but useful gain (of about 6 dBi in free space) and none of the sidelobe notches associated with most Yagi and quad beams of three or more elements.
- A single, deep rear notch (up to –35 dB relative to the maximum front lobe gain). This makes it useful for rejecting single-source interference and for foxhunting.
- A compact and simple design that is inexpensive and easy to build with minimal tools and skills.
- A very good direct match to 50-Ω feed lines.

You can use this antenna to: minimize or eliminate interference or intermod from pagers or other stations while still receiving desired signals from most other directions; access desired repeaters while rejecting an unwanted repeater; and reach a broad swath of stations or repeaters with reasonable gain and no need to rotate a beam or overcome multiple side lobe nulls that accompany multi-element Yagis and quads. You should also be able to foxhunt by placing the fox's signal in the single null and heading in the direction of greatest signal attenuation.

It should be noted that L. B. Cebik is responsible for refining the geometry of the Moxon beam to its full potential. Our antenna is a simple rescaling of his work. He is very generous in sharing his work with anyone who is interested. His work on this antenna was inspired by the designs of Les Moxon, G6XN, and Fred Caton, VK2ABQ, who started out with square HF wire beams using buttons to insulate the element tails.

This particular version of the Moxon antenna should be used as a starting point. Visit Cebik's web site for a horizontal 10-meter version made from aluminum tubing. Cebik has also suggested using the Moxon's wide front lobe to point directly toward the zenith for "unsteered" satellite communication on 2 meters—a use which deserves attention and development.

Bibliography & Resources:

www.cebik.com. Learn from L. B.'s experience and modeling expertise. This site is a wonderful resource for antenna experimenters.

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