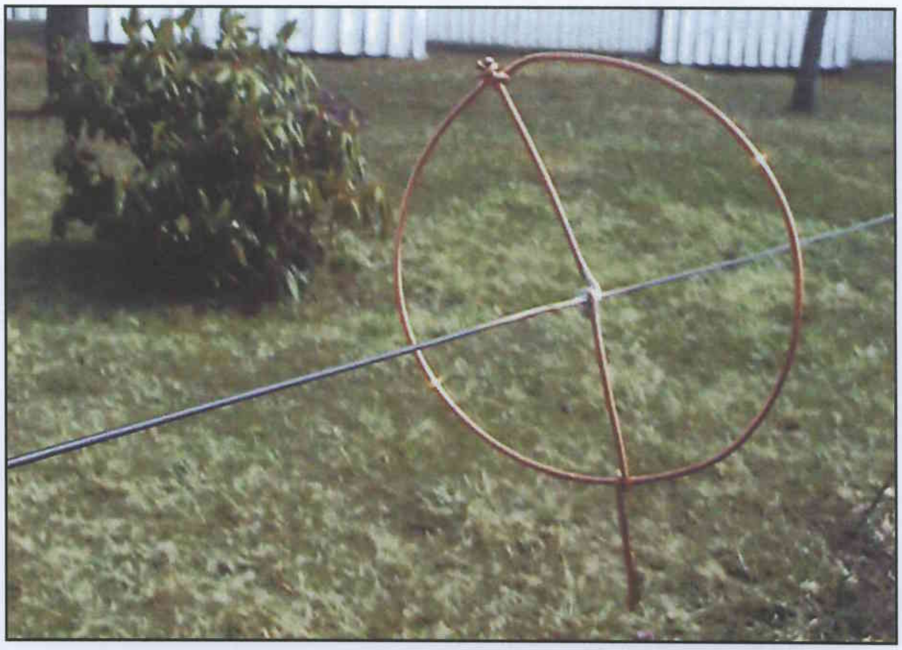
By Sylvia Hutchinson, K8SYL

K8SYL's 75 and 10-Meter Dipole

On getting licensed, upgrading and entering the wide world of HF.



In June 2000, I retired after 36 years of teaching and moved from Connecticut to my native state of Michigan. At first, my days were completely consumed with getting settled into our house and working around the lawn and gardens. It wasn't easy, but it was fun.

As Labor Day approached, I had the feeling that it was time to get ready for school. The outdoor work, while not over, was under control. I had time for me, and because I wouldn't be teaching I decided to be the student.

Chuck, K8CH, had received his first ham license while we were still dating. Back then, I learned a phrase in Morse code because he would tap it out on my hand during church. Even today, I can recognize "I love you honey" at 25 wpm but I'm not sure if I'd recognize my own call sign at that speed. A few years later, I remember sitting in a school gymnasium with my husband of nearly a year as he handled messages for the Red Cross. It was interesting, but it wasn't for me—not then. I was a full-time student at Michigan State University, and my first son was on the way.

For 40 years I had watched Chuck enjoy operating his radio, and I knew he would like to share that with me. I too wanted to share it with him. It looked like fun, and now I finally had the time for Amateur Radio. Being a wife, mother and bilingual (Spanish) special-education teacher had been very demanding of my time. I decided to go for my Technician class license. We had a copy of *Now You're Talking!* on the bookshelf.[1] I spent about an hour a day studying, and in the process set the goal of achieving 100% on the exam.

In February 2001, I met my goal, passing the exam with a perfect score. (Thanks, HQ staff who wrote the book!) The first thing I did as a new ham was to send my money and application for life membership in ARRL. The second was to apply for a vanity call sign. I didn't want to be KC8QKB if I could be, say, K8SYL. Then I checked into the Ionia County ARES (ICARES) net on the N8ZMT repeater in Portland, Michigan. That's something I continue to do regularly. I had met these folks at their monthly Saturday morning breakfast meetings. They were all supportive and made me feel welcome.

One of the ICARES group is long-time family friend Donna Burch, W8QOY. As soon as I had that Technician class license, she and Myriam Gregg, K8ILN, began to encourage me to upgrade to General. I would have 75-meter privileges and could join The Auto State YL Net (TASYLs). That sounded like fun and besides I was ready to learn more code than "I love you honey."

Time to study for that General. Back to the books, this time *The ARRL General Class License Manual*.[2] I set the same 100% goal for the written exam as before, and thanks again to Larry, WR1B, and the ARRL HQ staff, I reached that goal.

I had learned the Morse characters a long time before, but now I needed to relearn the characters and build some proficiency. Chuck downloaded the program *Morse Academy* from the Internet and I got started. Soon after, we ordered *Morse Tutor Gold* software from ARRL and that became my favorite learning tool. Once my code speed began to approach 5 wpm, I started using W1AW code practice. I particularly liked the *Real Audio* files available online at: **www.arrl.org/w1aw/morse.html**. Those files allowed me to listen at my convenience. For other code learning ideas check out **www.arrl.org/FandES/ead/learncw/** on *ARRLWeb*.

My First HF Antenna

With my new General class license about to arrive, I wanted antennas for 75 and 10 meters. With help from Chuck, I put together a 120-foot center-fed dipole and we installed it about 35 feet high. This allowed me to join the other members of the TASYLs on their weekly 75 meter (3940 kHz) net. With leg lengths of 60 feet, my dipole was resonant at 3.900 MHz and the 2:1 SWR points were at 3.830 and 3.980; see Figure 1. It was good enough for my purposes, so we didn't bother pruning it further.

I was doing very well on 75 meters, but what was I to do for 10? Chuck had a

[1]Notes appear on page 34.

partially built 10-meter ground-plane antenna in the basement that he was building for the book he was writing.[3] That was nice, but that ground plane wasn't going to do me much good until it was finished and he was working on other chapters. I wasn't going to wait. One afternoon I was tuning across the 10-meter band when I heard KP4NU calling CQ from Caguas, Puerto Rico. I really wanted to have a QSO in Spanish, so I did what you would probably do—I called José using my 75-meter dipole (after first engaging the internal antenna tuner in my transceiver). I had a nice QSO. Was it luck, good conditions or what? After I bragged about my contact, I asked Chuck what he thought about it.

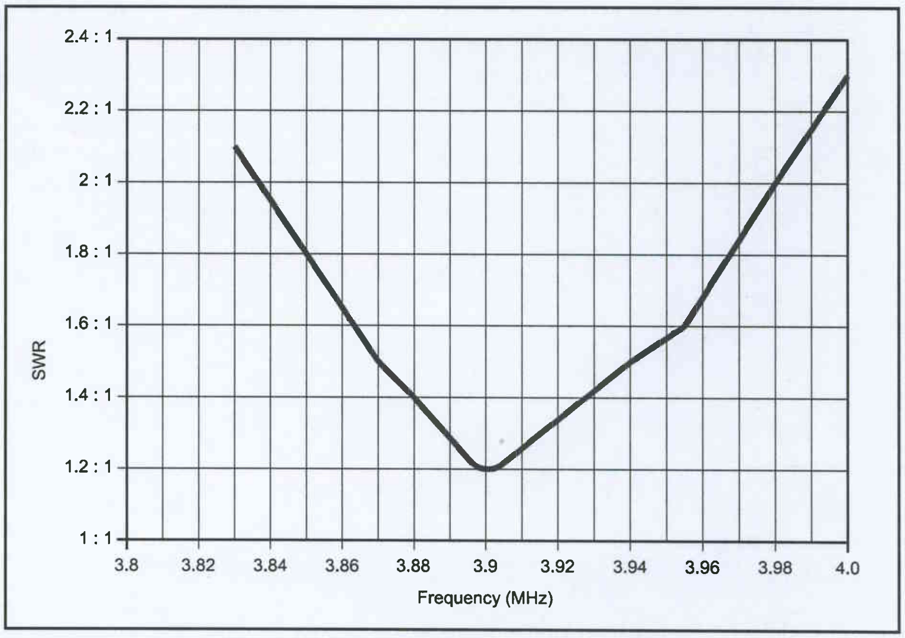


Figure 1—SWR of K8SYL's original 75-meter dipole with 60-foot legs.

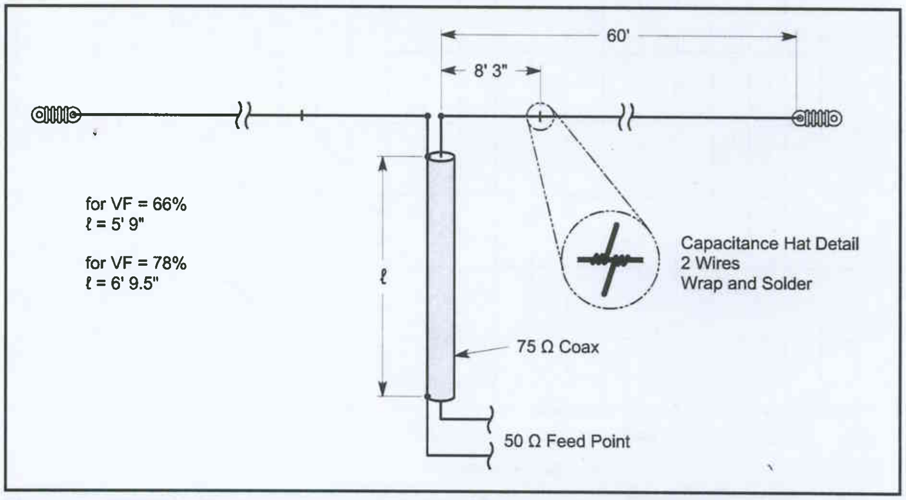


Figure 2—K8SYL's dipole as first modified for 75 and 10-meter operation. A quarter-wave section of 75-Ω coax transforms the 10-meter impedance. Capacitance hat wires wrap securely around the dipole and are soldered. They extend about 5 inches from the main dipole wire. See text for tuning instructions and final dimensions. This drawing is not to scale.

The Explanation

We both knew that a dipole is resonant on odd harmonics (3rd, 5th, 7th, etc), but 28 MHz is 8 times 3.5 MHz. That's true, but my dipole is cut for the high end of the band—closer to 4 MHz. Hmm, 4 times 7 is 28, and harmonic resonance is higher than one would expect. In other words, while you might expect that a 75-meter antenna that is resonant at 3940 kHz would have a 7th harmonic resonance at 27.58 MHz, it will actually be over a MHz higher.

We both understood the theory, but to better answer my questions Chuck next connected our MFJ-259B analyzer to the antenna feed line. The analyzer showed a resonance just below 29 MHz with an SWR of less than 3:1. He then modeled my antenna in *EZNEC*, which confirmed what the analyzer had just shown. At this point there were two options. The first was to leave well enough alone and use the transceiver's automatic antenna tuner.

The second option was to make my 75-meter antenna usable on 10 meters without the need of an antenna tuner. That's what we opted to do.

The Design

We had to deal with two issues in order to use my dipole on 10 meters. The first was to improve the 10-meter match without upsetting 75-meter operation. The second was to move the dipole's 10-meter resonance point a bit lower in the band.

At resonance on 10 meters, the feed-point impedance is about 120 Ω. We used a calculator to confirm that a quarter-wave transformer made with 75-Ω coax would take care of the 10-meter impedance match. At the same time, the length of this coaxial transformer is short enough to have no significant effect on the antenna's 75-meter operation.

I used RG-11 to build the series-matching transformer. For low-power operation, RG-59 can substitute. The physical length of the stub depends on the velocity factor. My RG-11 (Belden 8238) has a 66% velocity factor, which means the stub is 5 feet, 9 inches long. If you use 75-Ω coax with a 78% velocity factor such as Belden 8213 or 8212, you'll need to make your stub 6 feet, 9.5 inches long.

I had built my antenna to cover the upper (General class) end of the 75-meter band. Chuck and I thought about lengthening the dipole to move 10-meter resonance to the vicinity of 28.4 MHz. The *EZNEC* model said it would only require 4.5-inch extensions to each dipole leg. The downside to this is that it moves the 75-meter resonance to 3.89 MHz, and that's lower than what I wanted. I asked if we could find a method to lower the 10-meter resonance without substantially moving the 75-meter resonant frequency? Chuck had an affirmative answer.

He told me that Rus Healy had described adding capacitance hats on a 40-meter dipole to move the 3rd harmonic resonance lower in the 15-meter band.[4] We could use a similar technique to lower the 7th harmonic resonance of the 75-meter dipole. In the case of my antenna, *EZNEC* indicated that it took only the little bit of loading provided by a pair of short (3-inch) wires on each leg of the dipole. We modified my 75-meter dipole as shown in Figure 2. It was easy, and tune-up went smoothly.

Tuning the Antenna

First I'm going to explain the process to follow in tuning this two-band dipole. Then I'll tell you how it worked for me.

With the 75-Ω quarter-wave transformer section in place, tune the antenna for resonance in the upper part of the 75-meter band. As I found out through experience, you should do your tuning with the antenna in its final position. You'll need to trim for best SWR above about 3.89 MHz or you're apt to lose some 10-meter coverage. If you tune for about 3.925 MHz, you should cover the entire General class band of 3.850 to 4.000 MHz with an SWR of 2:1 or better.

Next, check the 10-meter resonant frequency. (For the dipole dimensions given in Figure 2, it was just below 29 MHz.) If you need to lower that frequency, add the capacitance hats as shown in the drawing. You may want to make the wires a bit longer to start with. Check the resonant frequency again—it will be lower. To raise the frequency you can trim the fingers of the capacitance hat or you can just bend them a bit. It's that easy—at least in theory.

Chuck used the support mast for my dipole to hold a 2-element 17-meter Yagi (a project for his book). That meant we had to move my dipole, and it ended up being only 28 feet above the ground. Between that move and the addition of the 75-Ω quarter-wave transformer, my dipole's 75-meter resonant frequency shifted another 20 kHz lower. To compensate, I ended up shortening each leg by 8 inches, making the leg lengths 59 feet 4 inches. This gave me an SWR of 2:1 or better across the entire General class portion of the 75-meter band (see Figure 3).

As you might guess, that raised the 10-meter resonant frequency so that the simple loading wires were not sufficient to give me good SWR at the lower end of the band. I used a couple of 16-inch lengths of bare copper wire to make capacitance hats. I formed these into circles by wrapping them around a piece of 4-inch PVC drainpipe. I then fastened and soldered the circles to the loading wires as shown in the title photo. As you can see, I didn't bother to trim the extra loading wire. This gave me coverage of 28 to 29.1 MHz with an SWR of 2:1 or better, as you can see in Figure 4.

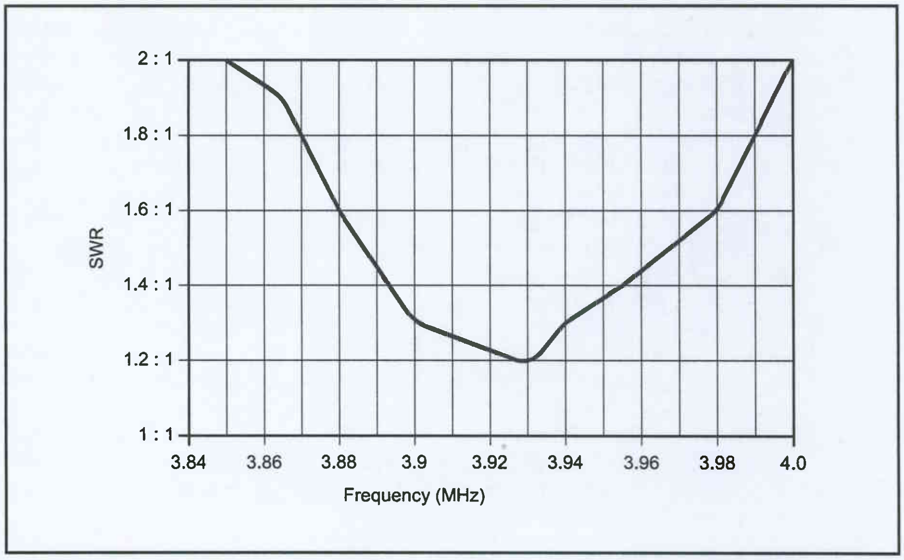


Figure 3—SWR of the modified K8SYL dipole after the two legs have been shortened to 59 feet 4 inches. The dipole now covers the entire General class portion of the 75-meter band with an SWR of 2:1 or better.

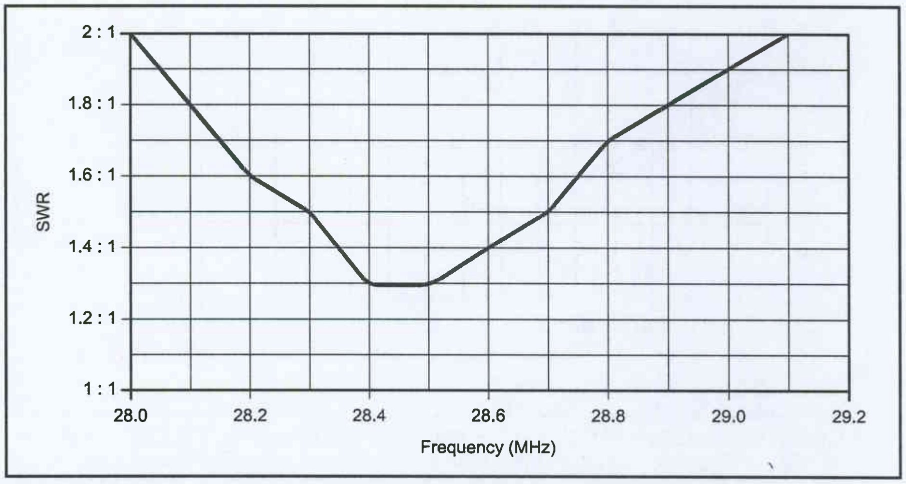


Figure 4—SWR of the K8SYL dipole covers over 1 MHz of the 10-meter band with an SWR of 2:1 or better. If you operate CW, you may want to lower the 10-meter resonant frequency by adding a bit more loading with larger capacitance hats.

The Results

I have been using my dual-band dipole for nearly a year with very good results. I make 75-meter contacts with ease. Okay, I don't chase exotic DX, but I have no trouble talking with my friends. On 10 meters, I'm able to make contact with the US and most of the world. Amateur Radio is really fun!

In case you're wondering, Chuck completed that 10-meter ground-plane antenna shortly after we finished this project. In head-to-head comparisons, sometimes his ground plane works better, and sometimes my dipole comes out ahead. The reason for that is wrapped up in the antenna patterns and angle of arrival of the signals. I could show you the theoretical patterns of our antennas, but you will probably put yours up in a different configuration. The point for telling you this is to let you know that it's always good to have a choice between antennas—especially when you're talking about simple antennas like dipoles and verticals.

Around here, we're pretty much convinced that my dipole has become a permanent fixture in our ham station. I'd like to get up it a bit higher for better 75-meter performance, but it works very well on 10 meters. Perhaps this is what you should try for your next (or first) HF antenna.

Notes

[1]L. Wolfgang and J. Kleinman, *Now You're Talking!*, ARRL, Newington, CT, 2000.

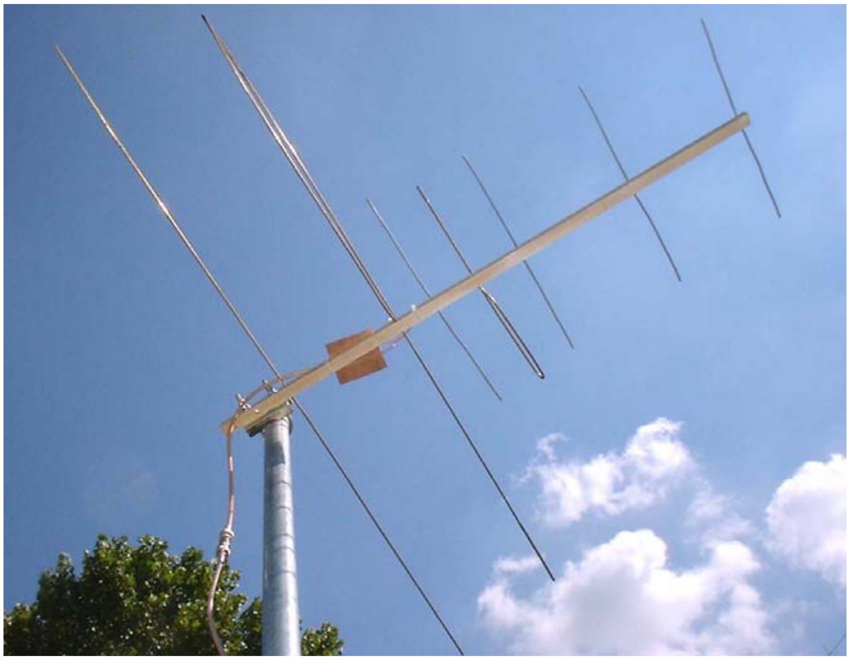
[2]L. Wolfgang, *The ARRL General Class License Manual*, ARRL, Newington, CT, 2000.

[3]C. Hutchinson and R. D. Straw, *Simple and Fun Antennas for Hams*, ARRL, Newington, CT, 2002.

[4]J. W. (Rus) Healy, *Antenna Here is a Dipole*, *QST*, Jun 1991, pp 23-26.

In addition to Amateur Radio, the author enjoys reading, gardening and spending time with family—especially her granddaughter, Briana. You can contact Sylvia at 9145 Bliss Rd, Lake Odessa, MI 48849; **k8syl@starband.net.**

Cheap Antennas for the AMSAT LEO's
Kent Britain -- WA5VJB



Cheap LEO Antenna

Drew, KO4MA, using the Cheap LEO antenna during a Dayton AMSAT LEO Demonstration

Hand held dual band antennas are popular for QSO's through many of the Low Earth Orbit (LEO) satellites. This article covers several 145 MHz antennas, a larger number of 435 MHz antennas, and how to combine them into one antenna.

Got a STRONG arm or plan to use it with a Tripod, then by all means the 4 Element 145 MHz and the 8 element 435 MHz can be used together. Or there is the 2 element 145 and 5 element 435 MHz used in the AMSAT demonstrations. It's is only 32 inches long. Something much lighter for backpacking? How about using a 20 inch long 2 elements on 145 MHz and a 3 elements on 435

MHz. For the 'Arrow' Enthusiasts, this smaller 2 elements on 145 MHz and 3 elements on 435 MHz will actually out perform the standard 'Arrow'. *More on that in a bit.*

One popular commercial antenna mounts the elements 90 degrees to each other. This is a mechanical, not really an electrical, decision. On this antenna the elements can be mounted cross ways, but mounting them flat makes the antenna much easier to lay down in the back of the truck or store in the garage.

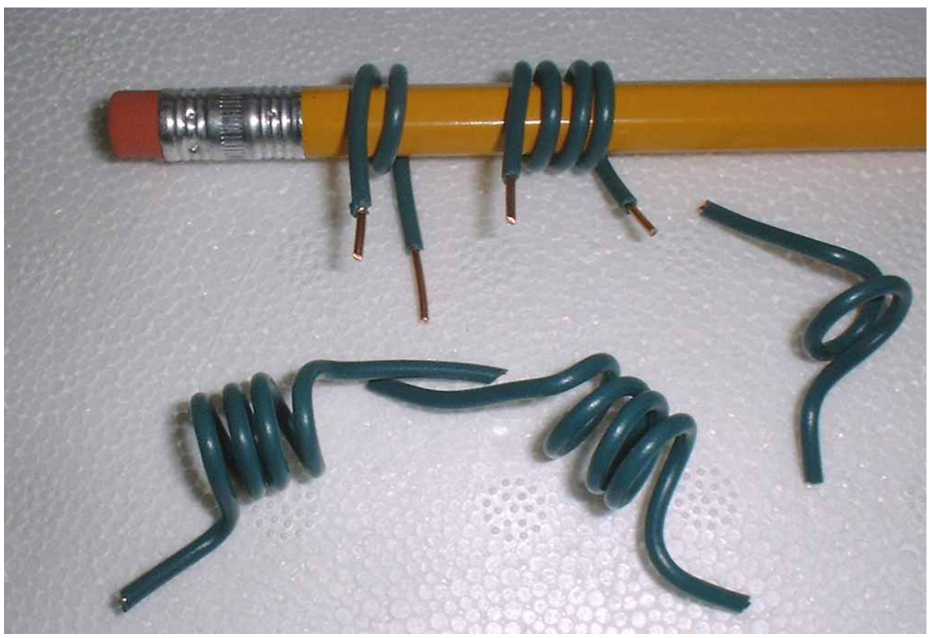
Construction:
For the boom 5/8 x 5/8" or ¾ x ¾" wood works well. If you plan to mount the antenna outside for a long term, a coat of spar varnish, spray enamel, or some of that water proofing stuff you use on wood decks will add years to the life of the antenna.
For the elements I used 1/8" material. The 435 MHz reflector and directors were from a roll of Radio Shack Aluminum Ground Rod wire. RS Stock number 15-035. 40 feet will run you about 5 bucks and make a lot of antenna elements. But #10 bare Copper wire, Bronze Welding Rod, and Hobby tubing have all been used. If you want to use 3/16" diameter elements, cut them 0.2 inches shorter than the dimensions in the tables to compensate for the thicker material. The 2 Meter elements were all made from Bronze or Brass welding rod. I like to use something I can solder the coax to and the Welding Rod solders well.


Element Splice

The Welding Rod is only 36" long. A section of 1/8” i.d. Copper or Brass hobby tubing makes a good splice. Just slip it on and solder them together. Save some of that hobby tubing. If you have a habit of "I trimmed the antenna twice, and it's still too short!", then you can solder a piece on the end of the driven element and start over.

I usually hold the elements in place on the boom with a drop of super glue. But Silicon glue and even paint have been used.

The 145/435 MHz Band Splitter



Winding the Band Splitter Coils

Splitter:

The band splitter is just a 250 MHz High Pass Filter and a 250 MHz Low Pass Filter connected together. This doesn't have to be very complex, or even very accurate. As long as the filters cut off somewhere between 200 and 400 MHz, they will work fine. So if the coils get squished, just bend them kind of back in shape, and go for it. This one is built cheap, just out in the air on a piece of PC Board. You can build the splitter into a box if you like, with connectors and all, but it's not going to change their performance. And this Band Splitter even makes a good project if you want to use two other 145/435 MHz antennas.

Remember, we are not trying to filter off harmonics, just make the 2 Meter energy go to the 2 Meter antenna, and the 435 MHz signals go to the 435 MHz antenna.

Parts list:

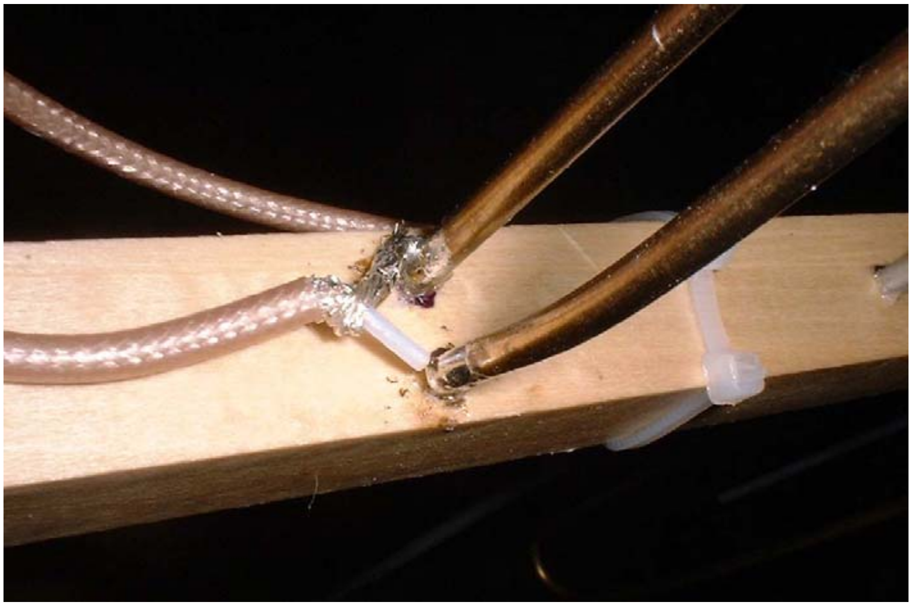
Antenna Version	Capacitors	Coils	Wire & Turns
435 MHz High Pass	2 x 4.7 pF Caps	1 Coil	1-1/2 turns #18 or #20 wire on a Pencil
145 MHz Low Pass	1 x 10 pF Cap	2 Coils	3 turns #18 or #20 wire on a Pencil

You're too late, I have already been asked if it needs to be a #2 or a #3 pencil.
For the record I wound my coils on a Red grading pencil. For those of you with a more mature sense of humor, just about all wood pencils make a 0.3" coil form.

We are frequency spitting the signals, not power dividing, so the length of the coax between the splitter and the antenna is not critical. You want to keep the coax as short a practical, but its exact length is not important. Got a box of 4.7 pF's? You can use 2 of them instead of the 10 pF. Be sure to keep those leads very short. I used Teflon coax on my splitter, it solders so much easier than foam RG-58, but you're free to build it in a box and use connectors if you like, but it's not really necessary.

Power Handling
Power handling of this band splitter depends almost entirely on your caps. With 50 volt caps, 20 watts is about your limit. Dig up some 1 kV caps, and the coax will probably melt first as you warm up that 4CX250.

One of my first prototypes tried to use the last 2 Meter director as the 435 MHz reflector. An interesting idea to save weight and make the antenna shorter, but performance suffered too much. So all versions now have a reflector on the 435 MHz portion. The last 145 MHz director and the 435 MHz reflector will interact. If you plan to mount them in the same plane, *what I find easiest,* space them 3 inches apart.



Close Up of Driven Element

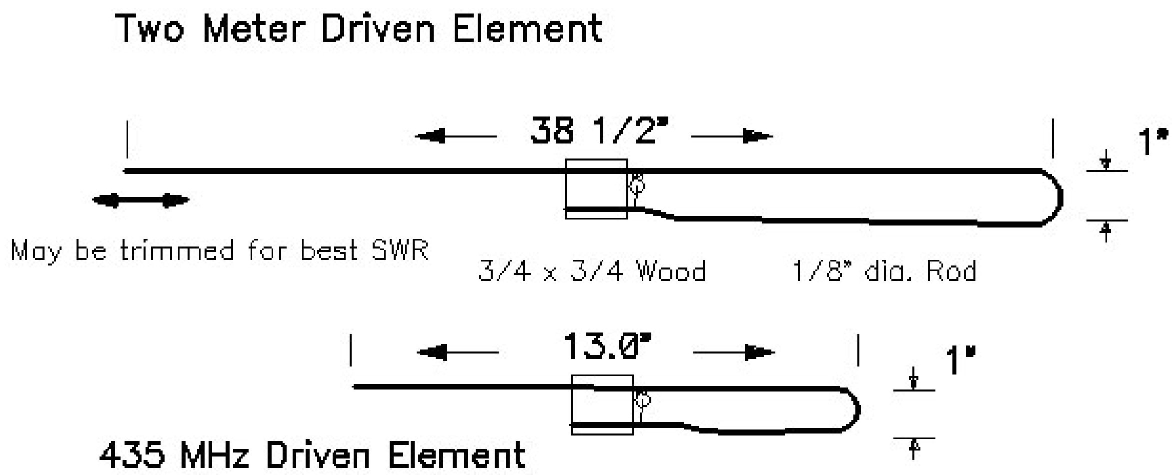
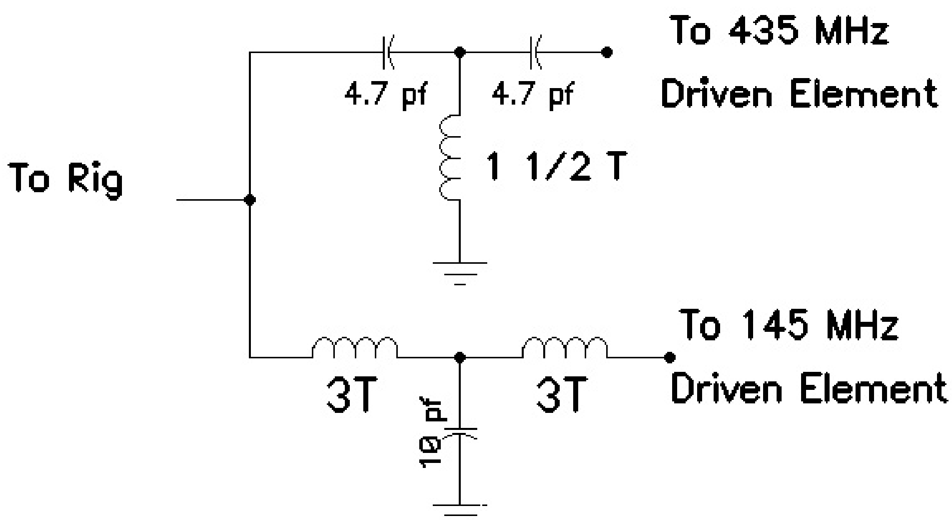


Figure 1 Dimensions of the Driven Elements

These J driven elements usually bring several comments from people new to "Cheap Yagi's".
The shield of the coax goes near the center of the top of the element. This is a voltage null and directly soldering the coax to the driven element has a lot of advantages.
The tip of the coax goes to the tip of the J. So you can think of this driven element as 3/4ths of a folded dipole or a gama-match with no capacitor. In free space, the J driven element has about a 150 Ohm impedance. As other elements are added, they load down the impedance of the driven element. If the antenna has relatively wide element spacing, then a direct match to 75 Ohms is possible. Bring in the reflector and directors a little closer, then you have a direct match to 50 Ohms. So the impedance matching is the length and spacing of the other elements. Just build the antenna to the dimensions, solder on the coax, and start talking. No tuning required.



Schematic of the Band Splitter

Tuning it up:
For the ultimate in performance connect a coax to just the 2 Meter portion and trim the free end of the J for best SWR for your favorite LEO uplink frequency. Then connect the coax to just the 435 MHz portion and again trim the free end of the element for best SWR. Now install the band splitter and this time tweak the coil spacing for best SWR at your spot frequencies.

You have now gotten the last 0.1 dB out of the antenna.
For everyone else, just build the antenna to the dimensions and the SWR will be under 2 to 1 on both frequencies. Just build it and talk. The design is pretty Idiot Resistant.
This antenna can be built in 30 combinations of elements and polarization's. One should fit your need. The 2 elements on 145 and 5 elements on 435 MHz version has done great in the field tests. Now you can have fun with the LEO's for less than $10.

Element Dimensions -- **145 MHz Version**				
	Ref	DE	D1	D2
2 element				
Length	40.5	**		
Spacing	0.0	7.0		
3 element				
Length	40.5	**	36.5	
Spacing	0.0	8.5	19.75	
4 element				
Length	40.5	**	37.0	32.5
Spacing	0.0	8.5	19.0	40.0

Element Dimensions -- **435 MHz Version**								
	Ref	DE	D1	D2	D3	D4	D5	D6
3 element								
Length	13.5	**	12.2					
Spacing	0.0	2.5	5.5					
4 element								
Length	13.5	**	12.4	11.5				
Spacing	0.0	2.5	5.5	11.5				
5 element								
Length	13.5	**	12.5	12.25	11.75			
Spacing	0.0	2.5	5.25	12.0	18.5			
6 element								
Length	13.4	**	12.4	12.0	12.0	11.0		
Spacing	0.0	2.5	5.5	11.25	17.5	24.0		
8 element								
Length	13.4	**	12.4	12.0	12.0	12.0	12.0	11.1
Spacing	0.0	2.5	5.5	11.25	17.5	24.0	30.5	37.75

** Driven element Dimensions from Figure 1

Ref is the Reflector, DE is the Driven Element, and all spacings are measured from the Reflector element.

My first question was why the 'Arrow' has performed so poorly in the AMSAT demos. Arrows have been on the antenna range at several conferences showing 435 MHz gains as low a 4 dBi. I would like to thank SAM, G4DDK for sending me the detailed dimensions of his Arrow antenna. I built a NEC model of the 435 MHz portion, and the model showed the forward gain peak to be near 457 MHz, not 435 MHz.

Insulated element mounting on the left, direct on the right.

When you change the diameter of an element, you also have to change the length of that element to compensate for the new diameter. Two common ways to mount elements are to make the antenna element part of the boom, or using insulators, electrically isolate the element from the boom. When you make the element part of the boom, you radically change the diameter of the element in that area. Now the length of the element must be changed to allow for this new diameter. This is called the "Boom Correction Factor". I try to avoid correction factors best I can by using thin wood booms with my Cheap Yagi's. I don't know the history of the development of the Arrow antenna, but the model suggests that the dimensions for a 435 MHz Yagi using insulated elements were used for Arrow, but mechanically the elements were made electrically part of boom. It appears no Boom Correction Factor was used.

I have been sent an Arrow to play with on the antenna range, so stand by for another article. It looks like we can squeeze several dB more gain out of the basic Arrow. At the Central States VHF Society Antenna range we measured 7.0 dBd gain out of the 435 MHz section of the Arrow. Several simple mods increased gain 0.3 dB, but I know there are more dB's hiding in there.

For even longer versions of AMSAT Cheap Yagi's visit http://wa5vjb.com/references.html

A Compact Multiband Dipole

This three-band dipole makes a perfect first antenna for HF.

Zack Lau, W1VT

This antenna is short and sweet. It uses 20 feet of #14 AWG ladder line as an impedance matching element on three popular HF bands — 10, 20, and 40 meters. Add an antenna tuner to load it up on 40 meters, and you can put out a good signal, despite its short 48-foot length.

Covering Three Bands

I optimized the impedance and length of a ladder line matching section to cover three bands, while factoring in the available choices of commercial products. My "magic" combination is 20 feet of 359 Ω ladder line and a flat top 48-foot end-to-end dipole of bare copper wire. This produced very low SWR across both 20 and 10 meters, as well as a reasonable feed point impedance on 40 meters.

The 48-foot dipole has a six-lobed pattern on 10 meters. Rather than trying to aim this dipole, just get it up as high as possible — at least 17 feet or a half wavelength on 10 meters — with the supports you have available. On 20 meters, it has a figure-eight pattern like that of a half-wave dipole. The 40 meter pattern is rather omni-directional.

Locate the antenna up in the clear, away from any branches, and use antenna insulators at the ends. The ladder line should be up in the air — not on the ground or wrapped around a metal pole. In contrast, the coax cable can be taped to metal supports with no adverse effects.

Construction

Figure 1 shows the antenna details and parts list. Use enough RG-58 coax to comfortably reach your station's single point entrance panel, including extra cable to form a "drip loop."[1] Use as many PL-258 UHF double female barrel connectors as necessary to allow more flexibility in choosing coax cable segments. The center insulator provides strain relief for the soldered connection between the ladder line and the antenna wires. A ½-inch PVC T connector (see Figure 2) works well for this purpose. Loop about 7 inches of wire through the holes on either side, and wrap the wires around themselves. Don't solder the wraps. After soldering the wires to the ladder line, bolt the ladder line to the T part of the connector. I used a ½-inch-long 4-40 stainless steel screw, nut, and lock washer. You can also use hot glue to keep the hardware from working loose. The center insulator is a high impedance point, so you do need a good insulator. Attach the end insulators so that the ends of the wires are exactly 24 feet from the center of the center insulator when stretched out. No need to solder, just twist the wires to hold the insulators in place.

You can make an effective current choke balun using 8 feet of RG-58 coax wound up into an eight-turn bundle held together with black tie wraps. This choke isolates the antenna from the outside shield of the feeding coax cable. I crimped a UHF connector to one end and soldered the other end to the ladder line. To protect the coax from corrosion, cover the solder joints with Scotch 2228 rubber mastic electrical tape,

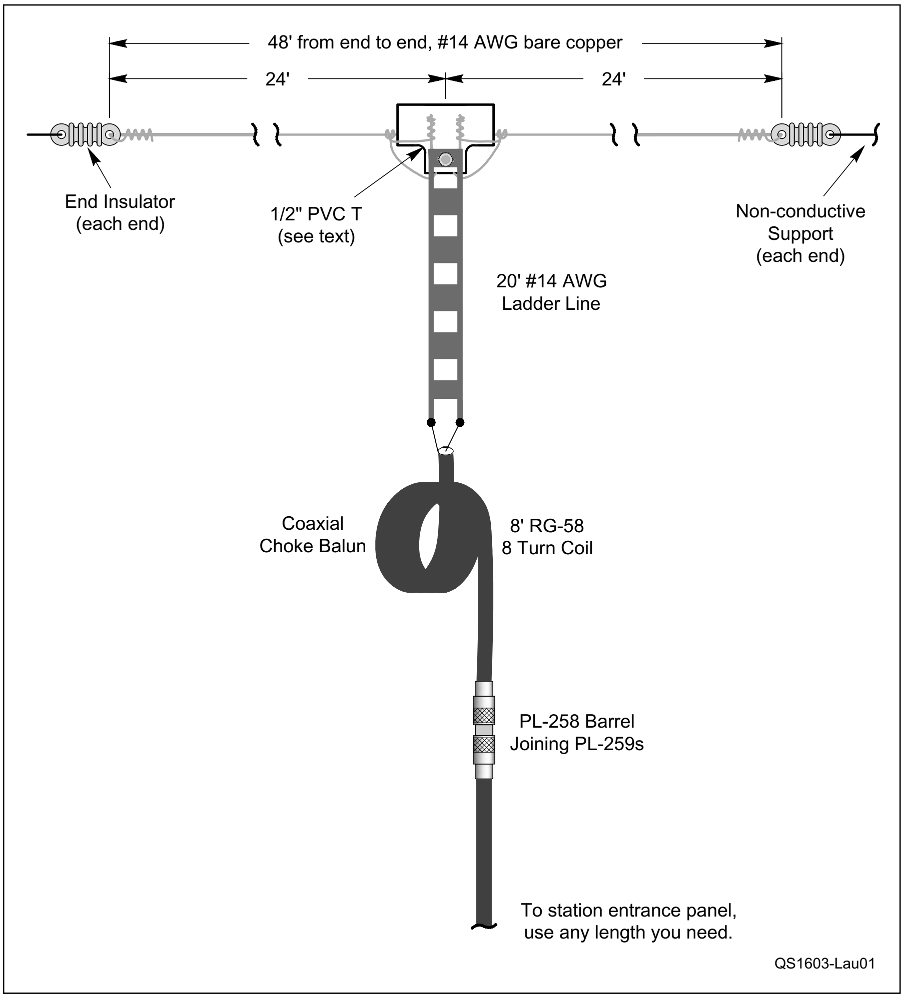


Figure 1 — You can make this 10, 20, and 40 meter multiband dipole from the following parts: 50 feet of #14 AWG wire, 2 dipole end insulators, ½ inch PVC T for a center insulator, 20 feet of high impedance ladder line (JSC #1313, **www.jscwire.com** or Wireman #554, **https://thewireman.com**), PL-258 UHF double female barrel connector, 8 feet of RG-58 for the current choke, and RG-58 coax to comfortably reach your station's single point entrance panel.

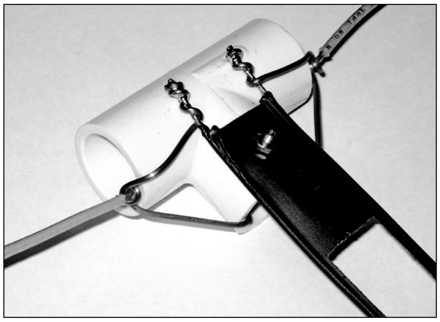


Figure 2 — Detail of the PVC T center insulator connections. [Zack Lau, W1VT, photo]

and then wrap everything up with Scotch 33 electrical tape. The coax-to-ladder line junction is a low impedance point, allowing the use of rubber to seal everything against the weather. The rubber mastic is also useful for sealing the PL-259 connectors — one layer of mastic and then a layer of electrical tape.

Antenna Tuning

You may need to tune the antenna for your particular location and height above ground. Proximity to metallic objects such as electrical wiring and other antennas will affect the resonant frequency. Tune in 6-inch increments by folding each side back 3 inches to raise the resonant frequency by 0.2 MHz on 10 meters. It isn't necessary to solder the wire; just wrap the wire around for a solid mechanical connection. Increasing the end-to-end length of the dipole will lower the resonant frequency. Once tuned, you should just leave the wire folded back, as there will be a small shift in frequency if you cut the wire. Start off with 25 feet of wire for each side of the dipole, and you should have sufficient trimming range, but you can solder on more wire if the antenna is too short. You should add equal lengths to both sides.

40 Meter Band Losses

You can expect about 2 dB of loss from the 20 feet of ladder line, 50 feet of RG-58, and antenna tuner. By comparison, if you tried to feed a 48-foot dipole with 70 feet of RG-58 and a tuner, you would lose a whopping 12.4 dB! A 48-foot dipole fed with 62 feet of ladder line and a balanced tuner would have about 1.2 dB of loss in the tuner and feed line — if you had no losses in the balanced to unbalanced transition. If you were to use the coaxial balun between the ladder line and the tuner, losses would shoot to 3.4 dB.

Variations on a Theme

If you use #14 AWG THHN house wire, start out with an end-to-end length of 47 feet. With #18 AWG ladder line and #14 AWG house wire, start with an end-to-end length of 44 feet and increase the length of the ladder line portion to 21 feet. You may need to compromise between a good SWR on 10 versus 20 meters, as the match isn't as good with this more commonly available ladder line. The shorter version may also work well on the low end of 6 meters, where CW, SSB, and JT65 activity can be found. But the shorter you go, the worse the efficiency is on 40 meters.

A suitable high-power choke balun would be four or five $1\frac{1}{8}$-inch type 31 ferrite beads slipped over some RG-213 or LMR-400/9913 coax and held in place with black tie wraps.[2] This should work well as long as the SWR is low. But if the SWR is high, force feeding the antenna with a transmatch may overheat the ferrites and damage them permanently. You may see some SWR drift as a warning that the balun is overheating.

I attached a SO-239 female UHF connector directly to the ladder line, using a UG-177/U hood for some weather protection. I used some hot-melt glue re-flowed with a heat gun for weather protection. Using 42 feet of low loss LMR-400 would lower the total feed line loss on the ladder line and coax cable to just 0.5 dB.

I homebrewed a version of the ladder line using #14 AWG THHN house wire and Zareba Fin tube insulators, one inch-long insulator every 6 inches. After making a V groove in a block of wood to hold the insulators, I drilled $\frac{7}{64}$-inch holes with $\frac{5}{8}$-inch spacing. It was a lot of work to make the 20 feet of transmission line, but it worked quite well. You can eliminate two solder joints by using the same piece of wire for both the antenna and transmission line.

Notes

[1]**www.arrl.org/lightning-protection**

[2]Ferrite beads, Fair-Rite 2631102002, Mouser P/N 623-2631102002 (**www.mouser.com**).

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Feedback

■ There was a typo in Figure 4 of "Antenna Gain, Part III: How Much Signal Gets Received?" by Joel Hallas, W1ZR, in the January 2016 issue of *QST*, pp 45 – 48. The correct expression for the receive aperture of a half-wave dipole should have been shown as: $\lambda/2 \times \lambda/4 = \lambda^2/8 = 0.125\ \lambda^2 \sim 0.13\ \lambda^2$.

■ "Microwavelengths," on page 57 in the October 2015 issue of *QST,* presented an incorrect formula for path loss. The correct formula is:

$$Path\ Loss = 10 log(4\pi d)^2 - G_{TX} - G_{RX}$$

■ In the article "All-Mode 1 kHz to 1.7 GHz SDR Receiver" by Jim Forkin, WA3TFS, published in the January 2016 issue of *QST*, there are two typographical errors. On page 30, a reference is made to using a dongle with an 850T tuner. This should read 820T. The proper designation is made in the parts list on page 31. In the parts list, C2 is listed as 140 pF, but is 150 pF. The DigiKey part number, however, is correct.

■ In the article "Done In One: Battery Backup For Your Wall Wart" by Paul Danzer, N1II, in the January 2016 issue of *QST*, the mechanical drawing of Q1, a P-channel MOSFET shows connections that may be unique to some RadioShack parts. Other sources for this part may use different connections for the gate (G), source (S) and drain (D). For example, if Q1 is purchased from a different source, the pinout diagram would be effectively reversed. D could be the middle pin and S the one on the right. It would be best to verify these connections for the part you buy.

In the same article, the positive and negative designations of Pins 1 and 2 of the 741 op-amp shown in Figure 1 are backward. The correct label should be Pin 2 (negative) and Pin 3 (positive). The circuit functions properly as shown, however.

■ In the article "Desk Microphone Power-On and PTT Indicators" by Don Dorward, VA3DDN, in the January 2016 issue of *QST*, LED1 in Figure 1 is reversed. The green cathode should connect to point Kg while the red cathode should connect to Kr.

A True Plumber's Delight for 2 Meters–An All-Copper J-Pole

By Michael P. Hood, KD8JB
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Grand Rapids, MI 49507-3148

KD8JB was not happy with how his old J-Pole held up in the weather, so he made a much more rugged one.

A number of years ago, I built a J-Pole antenna from some scrap aluminum tubing and a 5-foot stick of TV mast.[1] The antenna tuned easily, and operated well for a few years until nature did it in. After taking it down, I found a number of problems not contemplated in the original construction, such as dissimilar metals and other types of corrosion, and deterioration of parts of the coaxial feed line. These problems are identified and explained in the accompanying sidebar.

With the shortcomings of the original J-Pole in mind, I set about planning for another, similar antenna, using parts commonly available from a single source. If you spend much time in hardware stores and home improvement places, you get a feel for what's available at a moment's notice. In my case, rigid copper tubing, fittings, and assorted hardware, came to my attention as the material of choice. See **Fig 1**. The entire assembly can be soldered together when copper is used, thus ensuring electrical integrity, and making the whole antenna weatherproof in the bargain.

I'll bet you could solder one of these together faster than using the nuts and bolts I did in my previous design. This antenna can be easily used for ARES/RACES groups that spot antennas around for emergency use, since it requires little, if any, maintenance during its lifetime.

The J-Pole will take about an hour or so out of your day to build and tune, making a great antenna for a VHF base station.

No special hardware or machined parts are used in this antenna, nor are insulating materials needed, since the antenna is always at dc ground. Best of all, even if the parts aren't on sale, the antenna can be built for less than $15. If you only build one antenna, you'll have enough tubing left over to make most of a second antenna, or perhaps to finish that small plumbing project the XYL has been hounding you about.

Materials

Copper and brass is used exclusively in this antenna. These metals get along together, so dissimilar metal corrosion is eliminated. Both metals solder well, too. **Table 1** provides a detailed parts listing for the antenna.

Construction

Cut the copper tubing to the lengths indicated in Table 1. Item 9 is a 1¼-inch nipple cut from the 20 inch length of ½-inch tubing. This leaves 18¾ inches for the $\lambda/4$-matching stub. Item 10 is a 3¼-inch long nipple cut from the 60-inch length of ¾-inch tubing. The ¾-wave element should measure 56¾ inches long. Remove burrs from the ends of the tubing after cutting, and clean the mating surfaces with sandpaper, steel wool, or emery cloth.

After cleaning, apply a very thin coat of flux to the mating elements and assemble the tubing, elbow, tee, endcaps, and stubs. Solder the assembled parts with a propane torch and rosin-core solder. Wipe off excess solder with a damp cloth, being careful not to burn yourself. The copper tubing will hold heat for a long time after you've finished soldering. After soldering, set the assembly aside to cool.

Flatten one each of the ½-inch and ¾-inch pipe clamps. Drill a hole in the flattened clamp as shown in **Fig 2**. Assemble the clamps and cut off the excess metal from the flattened clamp using the unmodified clamp as a template. Disassemble the clamps.

Assemble the ½-inch clamp around the ¼-wave element and secure with two of the screws, washers, and nuts as shown in Fig 2. Do the same with the ¾-inch clamp around the ¾-wave element. Set the clamps initially to a spot 4 inches or so above the bottom of the "J" on their respective elements. Tighten the clamps only finger tight, since you'll have to move them when tuning.

Tuning

Tuning an antenna couldn't be simpler.[2] The toughest part might be determining what type feed line you are going to use. Anything from RG-58 to open-wire line is

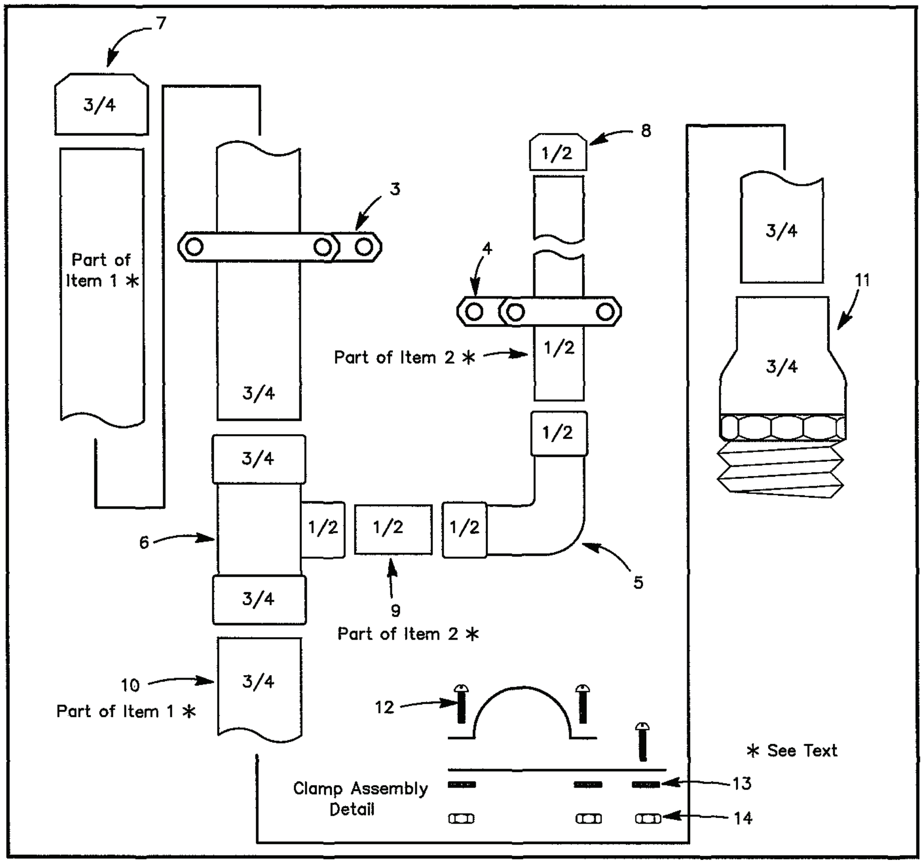

Fig 1—Exploded assembly diagram of all-copper J-Pole antenna. Item numbers refer to parts list in Table 1.

Table 1
Detailed Parts List (See Fig 1)

Item No.	*Qty*	*Part or Material Name*
1	1	3/4 inch × 10 foot length of rigid copper tubing (enough for 2 antennas, 60 inches per antenna)
2	1	1/2 inch × 10 foot length of rigid copper tubing (enough for 6 antennas, 20 inches per antenna)
3	2	3/4 inch copper pipe clamps
4	2	1/2 inch copper pipe clamps
5	1	1/2 inch copper elbow
6	1	3/4 × 1/2 inch copper tee
7	1	3/4 inch copper end cap
8	1	1/2 inch copper end cap
9	1	1/2 × 1 1/4 inch copper nipple (Make from item 2. See text)
10	1	3/4 × 3 1/4 inch copper nipple (Make from item 1. See text)
11	1	Your choice of coupling to mast fitting (3/4 × 1 inch NPT used at KD8JB)
12	6	8-32 × 1/2 inch brass machine screws (round, pan, or binder head)
13	6	no. 8 brass flat washers
14	6	8-32 brass hexnuts
15	A/R*	Rosin core solder
16	A/R*	Paste flux
17	A/R*	Fine sandpaper, steel wool, or emery cloth
18	A/R*	Solvent to clean away flux after soldering

*As required.

usable. The J-Pole can be fed directly from 50 Ω coax alone or with a 1/2-wave balun, or twin lead, or whatever. Before tuning, mount the antenna vertically, about 5 to 10 feet from the ground. A short TV mast on a tripod works well for this purpose.

When tuning VHF antennas, keep in mind that they are extremely sensitive to nearby objects—such as your body. Attach the feed line to the clamps on the antenna, and make sure all the nuts and screws are at least finger tight. If using coax, it really doesn't matter to which element (3/4-wave element or stub) you attach the coaxial center lead. I've done it both ways with no variation in operational effectiveness. Tune as follows:

1. Apply RF at the frequency you want the antenna to perform best.
2. Check the SWR.
3. Turn off the RF.
4. Move the clamps *equally* up from the original position 1/2 inch.
5. Reapply RF.
6. Check the SWR again, and turn off the RF.
   a. If the SWR went higher, move the clamps 1 inch downward, equally.
   b. If the SWR went lower, move the clamps 1/2 inch upward, equally.
7. Reapply RF.
8. Check the SWR once more, then turn off the RF. By this time you will be approaching minimum SWR (You may *never* get a 1:1 SWR. Don't sweat it, it's not important enough to worry about.)
9. Adjust the clamps a small amount in the direction of minimum SWR.
10. Repeat Steps 7 through 9 until minimum SWR is achieved.
11. Remove RF.

A point to remember about tuning the antenna is this: It will tune with any type of feed line, but the clamps will not be in the same place for all types of line. In other words, 50-Ω coaxial cable will tune further down the antenna than 600-Ω open-wire line. You have to think of this feedpoint as being similar to a delta match, which it is, except the elements run parallel and not away from each other.

Final Assembly

The final assembly of the antenna will determine its long-term survivability. Perform the following steps with care:

1. After adjusting the clamps for minimum SWR, mark the clamp positions with a pencil.
2. Remove the feed line and clamps.
3. Apply a very thin coating of flux to the inside of the clamp and the corresponding surface of the antenna element where the clamp attaches.
4. Install the clamps and tighten the clamp

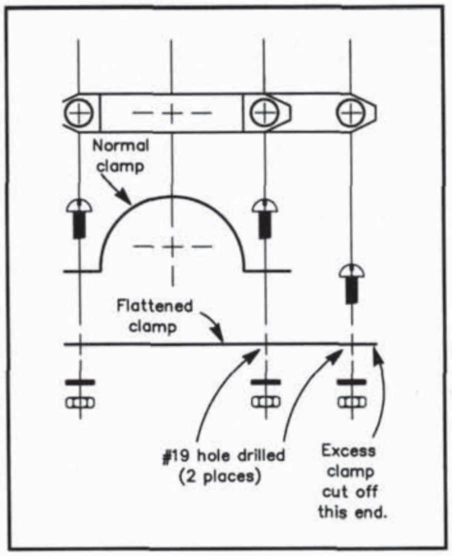

Fig 2—Detail of clamp assemblies. Both clamp assemblies are the same.

Post Inspection/Evaluation of the Original J-Pole

1. ALUMINUM MOUNTING PLATE: The plate was rust-stained from contact with the non-stainless steel elements of the antenna. The alloy used for the plate was 2024 aluminum, which is quite hard and holds its finish well. However, the rust deposits affect the continuity between elements. This plate was reused after cleaning.
2. GALVANIZED PAINTED 3/4-WAVE SECTION: The painted portion of this element survived the ravages of weather very well. The small portion where the paint was removed to make contact with the aluminum plate was completely coated with rust, as were the U-bolts holding the element to the plate, and the screw (probably zinc plated) used to ensure contact between the section and the mounting plate's upper edge. The hole drilled for the stainless screw used to attach the coaxial cable shield was in as good a condition as when originally drilled owing to the liberal application of Silastic 732 RTV[4] after assembly. This section was reused as a 5-foot mast section. I would use 1 1/4-inch aluminum tubing if this antenna were rebuilt in this form.
3. NON-STAINLESS HARDWARE: All plated and unplated hardware exhibited varying degrees of oxidation (rust). Some of the galvanized hardware came through with only spot rust where the galvanized coating had either deteriorated or been scraped away. The cadmium-plated mast brackets bought at Radio Shack showed rust only where excess length on the U-bolts was removed and at the bends in the bracket plates. These brackets were reusable, but the nuts were replaced. The U-bolts holding the 3/4-wave section to the mounting plate were so badly rusted that when removal was attempted, the bolts broke off.
4. STAINLESS STEEL HARDWARE: As expected, all stainless steel came through in great shape. Even though mated with some non-stainless hardware like star washers or nuts with integral star washers, the stainless hardware was easy to disassemble. Never use other than stainless steel or brass hardware in antenna construction! It's well worth the extra cost.
5. COAXIAL CABLE: This antenna was fed with RG-8X (foam) made for LaCue Communications. Some cable was cut off for inspection when the antenna was taken down. (I do this whenever I take down an antenna to get a visual idea of how the coax is doing.) The cable was terminated at the antenna with crimp lugs, which I crimped and soldered. The shield remained in good condition throughout except for normal copper oxide near the lug. (I used RTV[4] to seal the spot where the center lead passed through the shield. The sealant worked well.) However, the foam dielectric between the shield and the terminal lug cracked in a number of places causing water to leak in and wick down the center conductor. Not good! Interestingly, the foam that had melted near the soldered terminal lug protected the center conductor well at that point.
   Lesson: When terminating coax in this fashion, the foam dielectric should be sleeved or taped to prevent cracking. In your haste to use a new antenna, always solder the lugs—never leave them just crimped. I should point out that I was responsible for the deterioration of the coaxial cable because of the way I used it. LaCue had nothing to do with what happened in this instance. I use LaCue's RG-8X cable for most of my feed lines, and when properly terminated, it works very well.

screws. Don't attach the feed line yet, and leave off the final washer and nut at the feedline attachment point.

5. Solder the clamps where they are attached to the antenna elements.
6. Apply a small amount of solder around the screw heads and nuts where they contact the clamps. Don't get solder on the screw threads!
7. Clean away excess flux with a non-corrosive solvent.

After final assembly and erecting/mounting the antenna in the desired location , attach the feed line you tuned the antenna for, and secure with the remaining washer and nut. It would be a good idea to weather-seal this joint with RTV. Otherwise, you may find yourself repairing the feed line after a couple years.

On-Air Performance

Years ago, prior to building the first J-Pole antenna for this station, I used a standard 1/4-wave ground plane vertical antenna. While there is no problem working the various repeaters around town with my 1/4 wave antenna, simplex operation left a lot to be desired, so I felt something with a little more gain was necessary. Hence the switch to the J-Pole. In on-air comparisons with the Ringo Ranger 2B, a popular antenna everywhere, a small difference in bandwidth was noted. This J-Pole's bandwidth, as built here, is slightly wider, probably from the greater element thickness, resulting in a lower Q. Actual performance differences between antennas of similar dimensions, such as those of the Ringo Ranger are negligible, although significantly better than the 1/4-wave ground-plane vertical.

References

[1] M. P. Hood, "All-Metal 2-Meter J-Pole Antenna" (and References), *Ham Radio*, Jul 1984, pp 42-44.

[2] "A Combination 6 and 2 Meter J-Pole," *FM and Repeaters* (Newington: ARRL, 1972). (Out of print.)

[3] "Building and Using VHF Antennas," *VHF Handbook* (Newington: ARRL, 1972). (Out of print.)

[4] Silastic 732 RTV is made by the Dow Corning Company.

Editor's note: Section and figure references in this article are from the 2013 edition of the ARRL Handbook. *This material was originally contributed to the* Handbook *by Joe Moell, KØOV.*

Direction-Finding Techniques

The ability to locate a transmitter quickly with RDF techniques is a skill you will acquire only with practice. It is very important to become familiar with your equipment and its limitations. You must also understand how radio signals behave in different types of terrain at the frequency of the hunt. Experience is the best teacher, but reading and hearing the stories of others who are active in RDF will help you get started.

Verify proper performance of your portable RDF system before you attempt to track signals in unknown locations. Of primary concern is the accuracy and symmetry of the antenna pattern. For instance, a lopsided figure-8 pattern with a loop, Adcock, or TDOA set leads to large bearing errors. Nulls should be exactly 180° apart and exactly at right angles to the loop plane or the array boom. Similarly, if feed-line pickup causes an off-axis main lobe in your VHF RDF beam, your route to the target will be a spiral instead of a straight line.

Perform initial checkout with a low-powered test transmitter at a distance of a few hundred feet. Compare the RDF bearing indication with the visual path to the transmitter. Try to "find" the transmitter with the RDF equipment as if its position were not known. Be sure to check all nulls on antennas that have more than one.

If imbalance or off-axis response is found in the antennas, there are two options available. One is to correct it, insofar as possible. A second option is to accept it and use some kind of indicator or correction procedure to show the true directions of signals. Sometimes the end result of the calibration procedure is a compromise between these two options, as a perfect pattern may be difficult or impossible to attain.

The same calibration suggestions apply for fixed RDF installations, such as a base station HF Adcock or VHF beam. Of course it does no good to move it to an open field. Instead, calibrate the array in its intended operating position, using a portable or mobile transmitter. Because of nearby obstructions or reflecting objects, your antenna may not indicate the precise direction of the transmitter. Check for imbalance and systemic error by taking readings with the test emitter at locations in several different directions.

The test signal should be at a distance of 2 or 3 miles for these measurements, and should be in as clear an area as possible during transmissions. Avoid locations where power lines and other overhead wiring can conduct signal from the transmitter to the RDF site. Once antenna adjustments are optimized, make a table of bearing errors noted in all compass directions. Apply these error values as corrections when actual measurements are made.

MOBILE RDF SYSTEM INSTALLATION

Of these mobile VHF RDF systems, the Doppler type is clearly the simplest from a mechanical installation standpoint. A four-whip Doppler RDF array is easy to implement with magnetic mount antennas. Alternately, you can mount all the whips on a frame that attaches to the vehicle roof with suction cups. In either case, setup is rapid and requires no holes in the vehicle.

You can turn small VHF beams and dual-antenna arrays readily by extending the mast through a window. Installation on each model vehicle is different, but usually the mast can be held in place with some sort of cup in the arm rest and a plastic tie at the top of the window, as in **Fig 21.139**. This technique works best on cars with frames around the windows, which allow the door to be opened with the antenna in place. Check local vehicle codes, which limit how far your antenna may protrude beyond the line of the fenders. Larger antennas may have to be put on the passenger side of the vehicle, where greater overhang is generally permissible.

The window box (**Fig 21.140**) is an improvement over through-the-window mounts. It provides a solid, easy-turning mount for the mast. The plastic panel keeps out bad weather. You will need to custom-design the box for your vehicle model. Vehicle codes may limit the use of a window box to the passenger side.

For the ultimate in convenience and versatility, cast your fears aside, drill a hole through

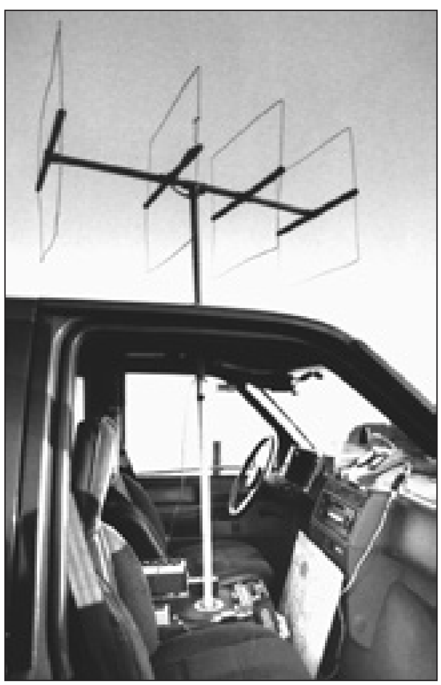

Fig 21.134 — KØOV uses this mobile setup for RDF on several bands, with separate antennas for each band that mate with a common lower mast section, pointer and 360° indicator. Antenna shown is a heavy gauge wire quad for 2 meters.

Fig 21.139 — A set of TDOA RDF antennas is light weight and mounts readily through a sedan window without excessive overhang.

Fig 21.140 — A window box allows the navigator to turn a mast mounted antenna with ease while remaining dry and warm. No holes in the vehicle are needed with a properly designed window box.

the center of the roof and install a waterproof bushing. A roof-hole mount permits the use of large antennas without overhang violations. The driver, front passenger and even a rear passenger can turn the mast when required. The installation in **Fig 21.134** uses a roof-hole bushing made from mating threaded PVC pipe adapters and reducers. When it is not in use for RDF, a PVC pipe cap provides a watertight cover. There is a pointer and 360° indicator at the bottom of the mast for precise bearings.

PREPARING TO HUNT

Successfully tracking down a hidden transmitter involves detective work — examining all the clues, weighing the evidence and using good judgment. Before setting out to locate the source of a signal, note its general characteristics. Is the frequency constant, or does it drift? Is the signal continuous, and if not, how long are transmissions? Do transmissions occur at regular intervals, or are they sporadic? Irregular, intermittent signals are the most difficult to locate, requiring patience and quick action to get bearings when the transmitter comes on.

Refraction, Reflections and the Night Effect

You will get best accuracy in tracking ground wave signals when the propagation path is over homogeneous terrain. If there is a land/water boundary in the path, the different conductivities of the two media can cause bending (refraction) of the wave front, as in **Fig 21.141A**. Even the most sophisticated RDF equipment will not indicate the correct bearing in this situation, as the equipment can only show the direction from which the signal is arriving. RDFers have observed this phenomenon on both HF and VHF bands.

Signal reflections also cause misleading bearings. This effect becomes more pronounced as frequency increases. T-hunt hiders regularly achieve strong signal bounces from distant mountain ranges on the 144-MHz band.

Tall buildings also reflect VHF/UHF signals, making mid-city RDF difficult. Hunting on the 440-MHz and higher amateur bands is even more arduous because of the plethora of reflecting objects.

In areas of signal reflection and multipath, some RDF gear may indicate that the signal is coming from an intermediate point, as in Fig 21.141B. High gain VHF/UHF RDF beams will show direct and reflected signals as separate S-meter peaks, leaving it to the operator to determine which is which. Null-based RDF antennas, such as phased arrays and loops, have the most difficulty with multi-path, because the multiple signals tend to make the nulls very shallow or fill them in entirely, resulting in no bearing indication at all.

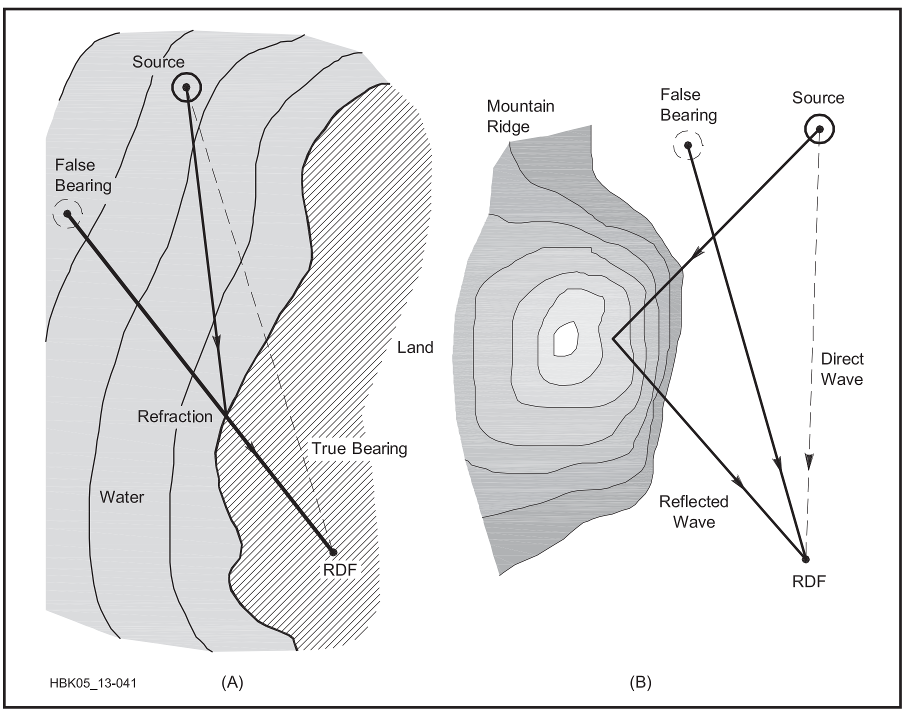

Fig 21.141 — RDF errors caused by refraction (A) and reflection (B). The reading at A is false because the signal actually arrives from a direction that is different from that to the source. At B, a direct signal from the source combines with a reflected signal from the mountain ridge. The RDF set may average the signals as shown, or indicate two lines of bearing.

If the direct path to the transmitter is masked by intervening terrain, a signal reflection from a higher mountain, building, water tower, or the like may be much stronger than the direct signal. In extreme cases, triangulation from several locations will appear to "confirm" that the transmitter is at the location of the reflecting object. The direct signal may not be detectable until you arrive at the reflecting point or another high location.

Objects near the observer such as concrete/steel buildings, power lines and chain-link fences will distort the incoming wavefront and give bearing errors. Even a dense grove of trees can sometimes have an adverse effect. It is always best to take readings in locations that are as open and clear as possible, and to take bearings from numerous positions for confirmation. Testing of RDF gear should also be done in clear locations.

Locating local signal sources on frequencies below 10 MHz is much easier during daylight hours, particularly with loop antennas. In the daytime, D-layer absorption minimizes skywave propagation on these frequencies. When the D layer disappears after sundown, you may hear the signal by a combination of ground wave and high-angle skywave, making it difficult or impossible to obtain a bearing. RDFers call this phenomenon the *night effect*.

While some mobile T-hunters prefer to go it alone, most have more success by teaming up and assigning tasks. The driver concentrates on handling the vehicle, while the assistant (called the "navigator" by some teams) turns the beam, reads the meters and calls out bearings. The assistant is also responsible for maps and plotting, unless there is a third team member for that task.

MAPS AND BEARING-MEASUREMENTS

Possessing accurate maps and knowing how to use them is very important for successful RDF. Even in difficult situations where precise bearings cannot be obtained, a town or city map will help in plotting points where signal levels are high and low. For example, power line noise tends to propagate along the power line and radiates as it does so. Instead of a single source, the noise appears to come from a multitude of sources. This renders many ordinary RDF techniques ineffective. Mapping locations where signal amplitudes are highest will help pinpoint the source.

Several types of area-wide maps are suitable for navigation and triangulation. Street and highway maps work well for mobile work. Large detailed maps are preferable to thick map books. Contour maps are ideal for open country. Aeronautical charts are also suitable. Good sources of maps include auto clubs, stores catering to camping/hunting enthusiasts and city/county engineering departments.

A *heading* is a reading in degrees relative to some external reference, such as your house or vehicle; a *bearing* is the target signal's direction relative to your position. Plotting a bearing on a hidden transmitter from your vehicle requires that you know the vehicle location, transmitter heading with respect to the vehicle and vehicle heading with respect to true north.

First, determine your location, using landmarks or a navigation device such as a GPS receiver. Next, using your RDF equipment, determine the bearing to the hidden transmitter (0 to 359.9°) with respect to the vehicle. Zero degrees heading corresponds to signals coming from directly in front of the vehicle, signals from the right indicate 90°, and so on.

Finally, determine your vehicle's true heading, that is, its heading relative to true north. Compass needles point to magnetic north and yield magnetic headings. Translating a magnetic heading into a true heading requires adding a correction factor, called *magnetic declination*, which is a positive or negative factor that depends on your location. (*Declination* is the term as denoted on land USGS topographic maps. *Deviation* and *Variation* are terms used on nautical and aviation charts, respectively.)

Declination for your area is given on US Geological Survey (USGS) maps, though it undergoes long-term changes. Add the declination to your magnetic heading to get a true heading.

As an example, assume that the transmitted signal arrives at 30° with respect to the vehicle heading, that the compass indicates that the vehicle's heading is 15°, and the magnetic declination is +15°. Add these values to get a true transmitter bearing (that is, a bearing with respect to true north) of 60°.

Because of the large mass of surrounding metal, it is very difficult to calibrate an in-car compass for high accuracy at all vehicle headings. It is better to use a remotely mounted flux-gate compass sensor, properly corrected, to get vehicle headings, or to stop and use a hand compass to measure the vehicle heading from the outside. If you T-hunt with a mobile VHF beam or quad, you can use your manual compass to sight along the antenna boom for a magnetic bearing, then add the declination for true bearing to the fox.

Triangulation Techniques

If you can obtain accurate bearings from two locations separated by a suitable distance, the technique of *triangulation* will give the expected location of the transmitter. The intersection of the lines of bearing from each location provides a *fix*. Triangulation accuracy is greatest when stations are located such

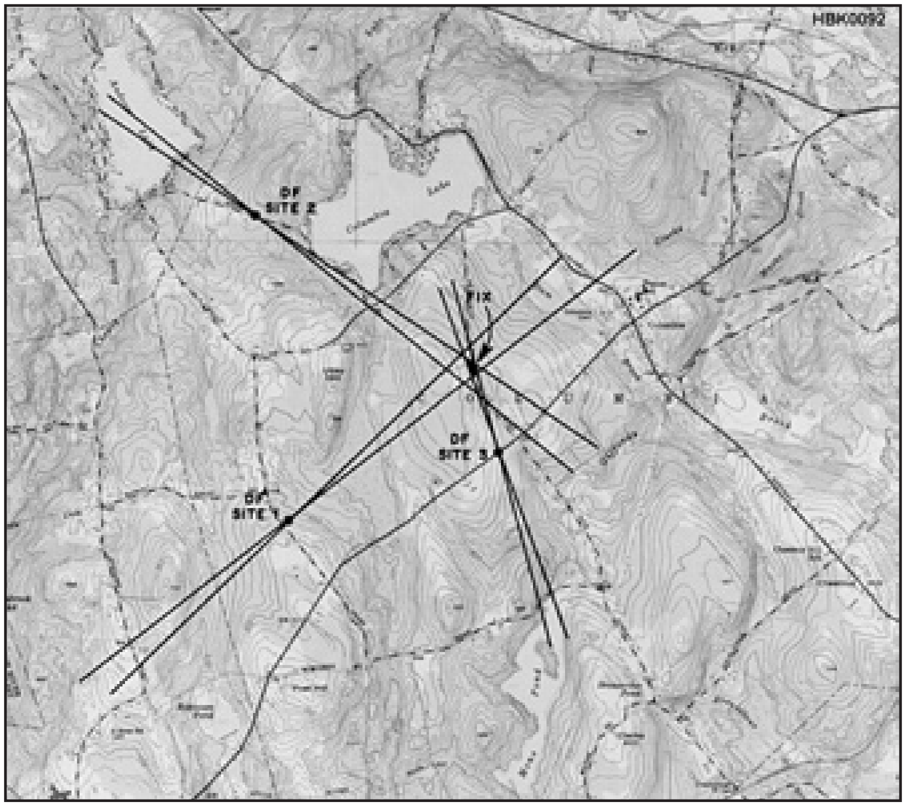

Fig 21.142 — Bearing sectors from three RDF positions drawn on a map for triangulation. In this case, bearings are from loop antennas, which have 180° ambiguity.

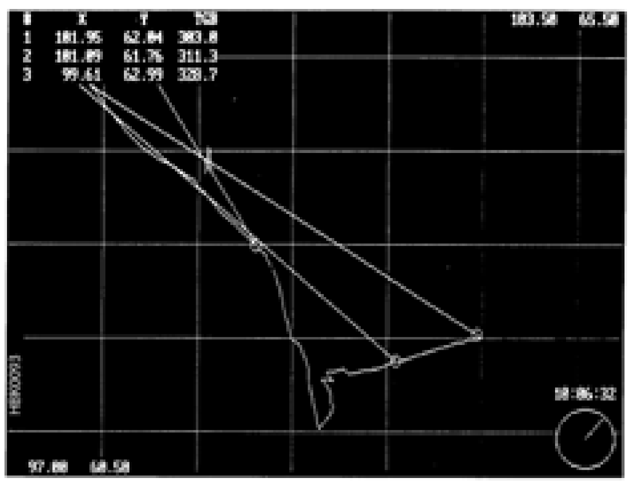

Fig 21.143 — Screen plot from a computerized RDF system showing three T-hunt bearings (straight lines radiating from small circles) and the vehicle path (jagged trace). The grid squares correspond to areas of standard topographic maps.

that their bearings intersect at right angles. Accuracy is poor when the angle between bearings approaches 0° or 180°.

There is always uncertainty in the fixes obtained by triangulation due to equipment limitations, propagation effects and measurement errors. Obtaining bearings from three or more locations reduces the uncertainty. A good way to show the probable area of the transmitter on the triangulation map is to draw bearings as a narrow sector instead of as a single line. Sector width represents the amount of bearing uncertainty. **Fig 21.142** shows a portion of a map marked in this manner. Note how the bearing from Site 3 has narrowed down the probable area of the transmitter position.

Computerized Transmitter Hunting

A portable computer is an excellent tool for streamlining the RDF process. Some T-hunters use one to optimize VHF beam bearings, generating a two-dimensional plot of signal strength versus azimuth. Others have automated the bearing-taking process by using a computer to capture signal headings from a Doppler RDF set, vehicle heading from a flux-gate compass, and vehicle location from a GPS receiver (**Fig 21.143**). The computer program can compute averaged headings from a Doppler set to reduce multipath effects.

Provided with perfect position and bearing information, computer triangulation could determine the transmitter location within the limits of its computational accuracy. Two bearings would exactly locate a fox. Of course, there are always uncertainties and inaccuracies in bearing and position data. If these uncertainties can be determined, the program can compute the uncertainty of the triangulated bearings. A "smart" computer program can evaluate bearings, triangulate the bearings of multiple hunters, discard those that appear erroneous, determine which locations have particularly great or small multipath problems and even "grade" the performance of RDF stations.

By adding packet radio connections to a group of computerized base and mobile RDF stations, the processed bearing data from each can be shared. Each station in the network can display the triangulated bearings of all. This requires a common map coordinate set among all stations. The USGS Universal Transverse Mercator (UTM) grid, consisting of 1×1-km grid squares, is a good choice.

The computer is an excellent RDF tool, but it is no substitute for a skilled "navigator." You will probably discover that using a computer on a high-speed T-hunt requires a full-time operator in the vehicle to make full use of its capabilities.

SKYWAVE BEARINGS AND TRIANGULATION

Many factors make it difficult to obtain accuracy in skywave RDF work. Because of Faraday rotation during propagation, skywave signals are received with random polarization. Sometimes the vertical component is stronger, and at other times the horizontal. During periods when the vertical component is weak, the signal may appear to fade on an Adcock RDF system. At these times, determining an accurate signal null direction becomes very difficult.

For a variety of reasons, HF bearing accuracy to within 1 or 2° is the exception rather than the rule. Errors of 3 to 5° are common. An error of 3° at a thousand miles represents a distance of 52 miles. Even with every precaution taken in measurement, do not expect cross-country HF triangulation to pinpoint a signal beyond a county, a corner of a state or a large metropolitan area. The best you can expect is to be able to determine where a mobile RDF group should begin making a local search.

Triangulation mapping with skywave signals is more complex than with ground or direct waves because the expected paths are great-circle routes. Commonly available world maps are not suitable, because the triangulation lines on them must be curved, rather than straight. In general, for flat maps, the larger the area encompassed, and the greater the error that straight-line triangulation procedures will give.

A highway map is suitable for regional triangulation work if it uses some form of conical projection, such as the Lambert conformal conic system. This maintains the accuracy of angular representation, but the distance scale is not constant over the entire map.

One alternative for worldwide areas is the azimuthal-equidistant projection, better known as a great-circle map. True bearings for great-circle paths are shown as straight lines from the center to all points on the Earth. Maps centered on three or more different RDF sites may be compared to gain an idea of the general geographic area for an unknown source.

For worldwide triangulation, the best projection is the *gnomonic*, on which all great circle paths are represented by straight lines and angular measurements with respect to meridians are true. Gnomonic charts are custom maps prepared especially for government and military agencies.

Skywave signals do not always follow the great-circle path in traveling from a transmitter to a receiver. For example, if the signal is refracted in a tilted layer of the ionosphere, it could arrive from a direction that is several degrees away from the true great-circle bearing.

Another cause of signals arriving off the great-circle path is termed *sidescatter*. It is possible that, at a given time, the ionosphere does not support great-circle propagation of the signal from the transmitter to the receiver because the frequency is above the MUF for that path. However, at the same time, propagation may be supported from both ends of the path to some mutually accessible point off the great-circle path. The signal from the source may propagate to that point on the Earth's surface and hop in a sideways direction to continue to the receiver.

For example, signals from Central Europe have propagated to New England by hopping from an area in the Atlantic Ocean off the northwest coast of Africa, whereas the great-circle path puts the reflection point off the southern coast of Greenland. Readings in error by as much as 50° or more may result from sidescatter. The effect of propagation disturbances may be that the bearing seems to wander somewhat over a few minutes of time, or it may be weak and fluttery. At other times, however, there may be no telltale signs to indicate that the readings are erroneous.

CLOSING IN

On a mobile foxhunt, the objective is usually to proceed to the hidden T with minimum time and mileage. Therefore, do not go far out of your way to get off-course bearings just to triangulate. It is usually better to take the shortest route along your initial line of bearing and "home in" on the signal. With a little experience, you will be able to gauge your distance from the fox by noting the amount of attenuation needed to keep the S-meter on scale.

As you approach the transmitter, the signal will become very strong. To keep the S-meter on scale, you will need to add an RF attenuator in the transmission line from the antenna to the receiver. Simple resistive attenuators are discussed in another chapter.

In the final phases of the hunt, you will probably have to leave your mobile and continue the hunt on foot. Even with an attenuator in the line, in the presence of a strong RF field, some energy will be coupled directly into the receiver circuitry. When this happens, the S-meter reading changes only slightly or perhaps not at all as the RDF antenna rotates, no matter how much attenuation you add. The cure is to shield the receiving equipment. Something as simple as wrapping the receiver in foil or placing it in a bread pan or cake pan, covered with a piece of copper or aluminum screening securely fastened at several points, may reduce direct pickup enough for you to get bearings.

Alternatively, you can replace the receiver with a field-strength meter as you close in, or use a heterodyne-type active attenuator. Plans for these devices are at the end of this chapter.

The Body Fade

A crude way to find the direction of a VHF signal with just a hand-held transceiver is the body fade technique, so named because the blockage of your body causes the signal to fade. Hold your HT close to your chest and turn all the way around slowly. Your body is providing a shield that gives the hand-held a cardioid sensitivity pattern, with a sharp decrease in sensitivity to the rear. This null indicates that the source is behind you (**Fig 21.144**).

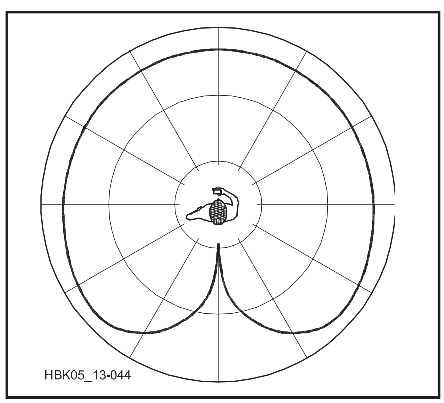

Fig 21.144 — When performing the body fade maneuver, a hand-held transceiver exhibits this directional pattern.

If the signal is so strong that you can't find the null, try tuning 5 or 10 kHz off frequency to put the signal into the skirts of the IF passband. If your hand-held is dual-band (144/440 MHz) and you are hunting on 144 MHz, try tuning to the much weaker third harmonic of the signal in the 440-MHz band.

The body fade null, which is rather shallow to begin with, can be obscured by reflections, multipath, nearby objects, etc. Step well away from your vehicle before trying to get a bearing. Avoid large buildings, chain-link fences, metal signs and the like. If you do not get a good null, move to a clearer location and try again.

Air Attenuators

In microwave parlance, a signal that is too low in frequency to be propagated in a waveguide (that is, below the *cutoff frequency*) is attenuated at a predictable logarithmic rate. In other words, the farther inside the waveguide, the weaker the signal gets. Devices that use this principle to reduce signal strength are commonly known as *air attenuators*. Plans for a practical model for insertion in a coax line are in *Transmitter Hunting* (see Bibliography).

With this principle, you can reduce the level of strong signals into your hand-held transceiver, making it possible to use the body fade technique at very close range. Glen Rickerd, KC6TNF, documented this technique for *QST*. Start with a pasteboard mailing tube that has sufficient inside diameter to accommodate your hand-held. Cover the outside of the tube completely with aluminum foil. You can seal the bottom end with foil, too, but it probably will not matter if the tube is long enough. For durability and to prevent accidental shorts, wrap the foil in packing tape. You will also need a short, stout cord attached to the hand-held. The wrist strap may work for this, if long enough.

Fig 21.145 — The air attenuator for a VHF hand-held in use. Suspend the radio by the wrist strap or a string inside the tube.

To use this air attenuation scheme for body fade bearings, hold the tube vertically against your chest and lower the hand-held into it until the signal begins to weaken (**Fig 21.145**). Holding the receiver in place, turn around slowly and listen for a sudden decrease in signal strength. If the null is poor, vary the depth of the receiver in the tube and try again. You do not need to watch the S-meter, which will likely be out of sight in the tube. Instead, use noise level to estimate signal strength.

For extremely strong signals, remove the "rubber duck" antenna or extend the wrist strap with a shoelace to get greater depth of suspension in the tube. The depth that works for one person may not work for another. Experiment with known signals to determine what works best for you.

Several RDF projects may be found on the *Handbook CD*.

Project: Dual-Band Antenna for 146/446 MHz

This project by Wayde Bartholomew, K3MF (ex-WA3WMG), first appeared in *The ARRL Antenna Compendium, Volume 5*. This mobile whip antenna won't take long to build, works well and only requires one feed line for the two-band coverage.

Wayde used a commercial NMO-style base and magnetic mount. For the radiator and decoupling stub, he used brazing rod coated with a rust inhibitor after all the tuning was done. You can start with a 2 meter radiator that's 20.5 inches long. This is an inch longer than normal so that it may be pruned for best SWR.

Next, tack on the 6.5-inch long 70-cm decoupling stub. Trim the length of the 2 meter radiator for best SWR at 146 MHz and then tune the 70-cm stub on 446 MHz by moving it up and down along the antenna for best SWR. There should be no significant interaction between the adjustments for either frequency.

Final dimensions are shown in **Fig 21.110**. The SWR in the repeater portions of both bands is less than 2:1.

ADAPTING FOR FIXED-STATION USE

You can use the dual-band mobile whip as the radiating element for the ground-plane antenna in Fig 21.108. Don't change the 2 meter radials. Instead, add two 70-cm radials at right angles to the 2 meter set as in **Fig 21.111**. The antenna is no longer two-dimensional, but you do have two bands with one feed line *and* automatic band switching.

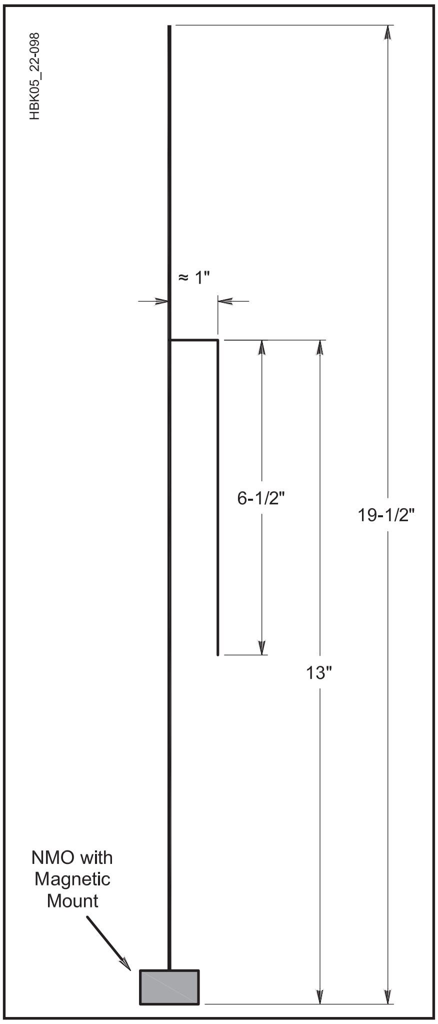

Fig 21.110 — Diagram of K3MF's dual-band 146/446-MHz mobile whip. Brazing rod is used for the 2 meter radiator and for the 70-cm decoupling stub.

Fig 21.111 — K3MF's whip can be used to make a dual-band ground-plane antenna. Separate radials for 2 meters and 70-cm simplifies tuning. *(Photo by K8CH)*

type of coaxial cable for the traps. The dc resistance of 40.7 Ω per 1000 feet of RG-59 coax seems rather high. However, W8NX has found no coax other than RG-59 that has the necessary inductance-to-capacitance ratio to create the trap characteristic reactance required for the 80, 40, 20, 15 and 10 meter antenna. Conventional traps with wide-spaced, open-air inductors and appropriate fixed-value capacitors could be substituted for the coax traps, but the convenience, weatherproof configuration and ease of fabrication of coaxial-cable traps is hard to beat.

Project: Extended Double-Zepp for 17 Meters

Although the Extended Double-Zepp (EDZ) antenna shown in **Fig 21.42** has several attractive features, it is rarely used by hams, perhaps out of concern over the Zepp's high feed point impedance. The antenna's overall length is 1.28 λ and its pattern is bidirectional broadside to the antenna. The SWR of the antenna is low enough near the design frequency that it can be fed with coax and an impedance-matching unit or open-wire line can be used for wider range and multiband use. This project describes an EDZ for 17 meters.

The Zepp antenna (a half-wave dipole, fed at one end) was introduced earlier in this section. The Zepp can be modified in two ways. The first is to double the length of the antenna and feed it in the middle, making a *double-Zepp*. This creates a one-wavelength dipole, with the expected high feed point impedance and about 1.6 dBd gain. A ½ λ center-fed dipole operated on its second harmonic is effectively a double-Zepp. The second modification is to extend the double-Zepp to be 0.64 λ (close to ⅝ λ) long on each side of the feed point. The feed point is then no longer at a high-impedance point on the antenna. This creates the extended, double-Zepp. (The EDZ is described in more detail in the *ARRL Antenna Book*.)

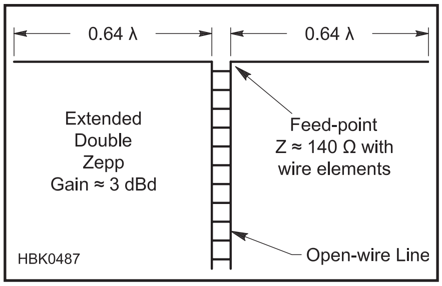

Fig 21.42 — The Extended Double-Zepp antenna consists of two 0.64 λ sections placed end to end and fed in the middle. The high-impedance points of the antenna have been moved away from the feed point, lowering feed point impedance. The antenna has gain of approximately 3 dBd broadside to the antenna.

The overall length of the EDZ is calculated as follows:

$$984/f(MHz) \times 1.28 = \text{length in feet} \quad (5)$$

Using this formula, an 18.1 MHz EDZ is 69.6 feet (69 feet, 7 inches.) long. The EDZ has 3 dBd of gain in a figure-8 pattern of two major lobes broadside to the antenna and four minor lobes at smaller angles to the axis of the antenna. The feed point impedance is approximately 140 Ω.

The EDZ is useful at lower frequencies, as well. On 20 meters, the 17 meter EDZ is just slightly longer than the double-Zepp, with 1.6 to 2 dBd of gain and a rather high feed point impedance of several hundred ohms. On 40 meters, the antenna is a slightly long ½ λ dipole. If your antenna tuner has sufficient range, the antenna can also serve as a shortened dipole for 75/80 meters. At these lower frequencies, the antenna's radiation pattern is a single lobe, broadside to the antenna.

On higher frequencies, the pattern continues to split into more lobes. For example, on 15 meters, there are four lobes at approximately 45° from the antenna axis. On 10 meters, where the antenna is approximately two full-wavelengths long, the pattern is similar, with the lobes a bit closer to the antenna axis and smaller lobes beginning to appear.

Some hams use a 4:1 impedance transformer to reduce the feed point impedance and improve SWR as the operating frequency moves away from the design frequency. This works best if the antenna is to be used on a single band. However, if the antenna is to be used on multiple bands, a better solution is to use open-wire feed line and an antenna tuner. If you wish to operate on a frequency at which the feed point impedance is high, use a feed line length near an odd multiple of a quarter-wavelength long, presenting a lower impedance to your antenna tuner that may be easier to match.

(This project is based on a "Hints and Kinks" item by Bob Baird, W7CSD, from the January 1992 issue of *QST*.)

21.3 Vertical (Ground-Plane) Antennas

One of the more popular amateur antennas is the *vertical*. It usually refers to a single radiating element erected vertically over the ground. A typical vertical is an electrical ¼ λ long and is constructed of wire or tubing. The vertical antenna is more accurately named the *ground plane* because it uses a conductive surface (the ground plane) to create a path for return currents, effectively creating the "missing half" of a ½ λ antenna. Another name for this type of antenna is the *monopole* (sometimes *unipole*).

The ground plane can be a solid, conducting surface, such as a vehicle body for a VHF/UHF mobile antenna. At HF, this is impractical and systems of *ground radials* are used; wires laid out on the ground radially from the base of the antenna. One conductor of the feed line is attached to the vertical radiating element of the antenna and the remaining conductor is attached to the ground plane.

Single vertical antennas are omnidirectional radiators. This can be beneficial or detrimental, depending on the situation. On transmission there are no nulls in any direction, unlike most horizontal antennas. However, QRM on receive can't be nulled out from the directions that are not of interest unless multiple verticals are used in an array.

Ground-plane antennas need not be mounted vertically. A ground-plane antenna can operate in any orientation as long as the ground plane is perpendicular to the radiating element. Other considerations, such as minimizing cross-polarization between stations, may require a specific mounting orientation though. In addition, due to the size of HF antennas, mounting them vertically is usually the most practical solution.

A vertical antenna can be mounted at the Earth's surface, in which case it is a *ground-mounted vertical*. The ground plane is then constructed on the surface of the ground. A vertical antenna and the associated ground plane can also be installed above the ground. This often reduces ground losses, but it is more difficult to install the necessary number of radials. *Ground-independent* verticals are often mounted well above the ground because their operation does not rely on a ground plane.

21.3.1 Ground Systems

When compared to horizontal antennas, verticals also suffer more acutely from two main types of losses — *ground return losses* for currents in the near field, and *far-field ground losses*. Ground losses in the near field can be minimized by using many ground radi-

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QST Issue: Jun 2000
Title: Having a Field Day with the Moxon Rectangle
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By L. B. Cebik, W4RNL

Having a Field Day with the Moxon Rectangle

Good gain and a high front-to-back ratio are a couple of reasons to consider this antenna for Field Day use.

Field Day antenna installations tend to pass through phases. Phase 1 is the starter for any group: Get some antennas—usually dipoles and inverted Vs—into the air and see how well they perform. Phase 2 rests on an evaluation of the initial results. It generally consists of mechanical improvements to place the same or similar antennas higher using stronger materials. It also includes making better use of potential antenna supports at the site.

Real antenna design work usually begins with Phase 3. Based on the improved results with Phase 2 changes, the group begins to think about where they want the signals to go and how to get them there. At this stage, the group takes its first steps toward designing wire beams for the HF bands. (In Phase 4, we find the use of portable crank-up towers, rotators and multiband arrays. I'll not delve into Phase 4 in this article.)

Wire beams and arrays have one significant limitation: We can't rotate them. Therefore, we must resort to carefully planned aiming during installation. Still, we can only cover so much of the area across the country with the beamwidth available from gain arrays. Dreamers will always wonder if they could have garnered a few more contacts lost to the deep front-to-side ratio offered by most two-element Yagi designs.

So let's explore an alternative to the two-element wire Yagi, one that is only about 70% as wide, side to side, and which offers some other benefits as well: the wire Moxon Rectangle.

The Moxon Rectangle

In its most fully developed monoband form, a Moxon Rectangle outline looks like the sketch in Figure 1. A is the side-to-side length of the parallel driver and reflector wires. B is the length of the driver tails, while D is the length of the reflector tails. C is the distance between the tips of the two sets of tails. If any dimension of the Moxon Rectangle is critical, it is C. E, the total front-to-back length of the array, is simply the sum of B, C, and D.

The history of the Moxon Rectangle is

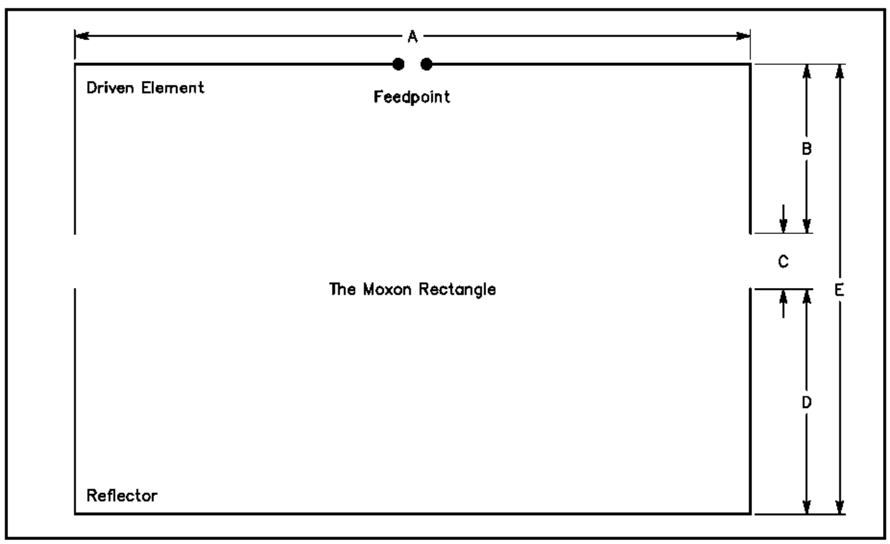


Figure 1—Outline of a Moxon Rectangle with various dimensions labeled. See the text for an explanation of the labels.

Table 1
Dimensions of Wire Moxon Rectangles for 80-10 Meters
All dimensions refer to designations in Figure 1. Dimensions are in feet and apply to #14 AWG bare-wire antennas.

Band	*Frequency (MHz)*	*A*	*B*	*C*	*D*	*E*
80	3.6	99.98	15.47	2.16	18.33	36.96
75	3.9	92.28	14.28	2.00	16.92	33.20
40	7.09*	50.69	7.82	1.15	9.35	18.32
20	14.175	25.30	3.87	0.62	4.70	9.19
15	21.225	16.88	2.56	0.44	3.14	6.14
10	28.3*	12.65	1.90	0.35	2.36	4.61

*Because of bandwidth versus wire-size considerations, 40- and 10-meter design frequencies are below the mid-band points to obtain less than 2:1 50-Ω SWR over as much of the band as possible. See the text for alternative strategies.

itself fascinating.[1] Basically, it derives from early experiments with a square shape by Fred Caton, VK2ABQ, although the very first experiments were performed in the 1930s. Les Moxon, G6XN, outlined in his classic *HF Antennas for All Locations*, a rectangular variant in which he remotely tuned the driver and the reflector.[2] Curious about the basic properties of the rectangle, I modeled and built variations of the design for about eight years, using wire and aluminum tubing.[3]

The Moxon Rectangle has three properties that recommend it for Field Day use:

• It is not as wide as an equivalent wire Yagi, because the two elements fold toward each other.

• It offers—with the right dimensions—a 50-Ω feedpoint impedance so no matching system is required (although use of a choke to suppress common-mode currents is always desirable).

• It presents a very useful Field Day pattern, with good gain and a very high F/B.

Figure 2 overlays the pattern for a typical two-element Yagi (reflector-driver design) and the Moxon Rectangle. The pattern may appear odd since it uses a linear decibel scale (rather than the usual log decibel scale) to enhance the detail at the pattern center. Although the Yagi has slightly more gain, the Moxon's deficit won't be noticeable in operation. Most apparent is the F/B advantage that accrues to the Moxon. In practical terms, the Moxon effectively squelches QRM to the rear. Of equal importance is the broader beamwidth of the Moxon. The azimuth pattern does not show deep nulls off the ends of the beam elements. Instead, the deep nulls are about 15 to 20° farther back. Signals off the beam sides are stronger than those of a Yagi, even though the rear quadrants themselves are that much quieter than the Yagi. (At low heights, from 3/8 λ to 1λ, the Moxon's side gain ranges from 2 to 6 dB greater than that of a similarly positioned two-element Yagi.) As a result, the Moxon provides useful signal strength from one side to the other—as if it had good peripheral vision.

A Moxon Rectangle aimed in the general direction of the greatest number of potential Field Day contacts will generally gather signals from a broader sector of the horizon than most other antennas—with the bonus of good QRM suppression from the rear. Stations located near one of the US borders may discover that a basic, fixed Moxon Rectangle is all they need. For those stations located inland and needing coverage in all directions, I'll have a solution a bit later. But first, let's design a Moxon Rectangle.

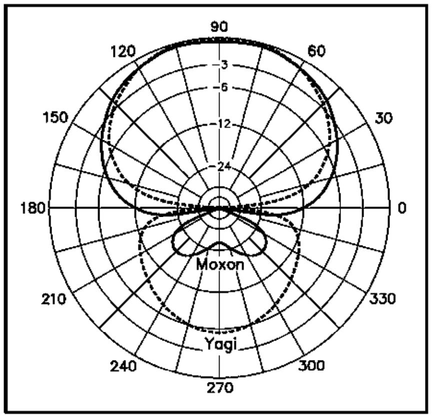


Figure 2—Relative free-space azimuth patterns at 14.175 MHz for a wire Yagi (driver and reflector) and a wire Moxon Rectangle. These patterns use a linear decibel scale to enhance detail at the pattern center (rather than the more usual log-decibel scale). Compare the pattern scale to that used in Figure 5.

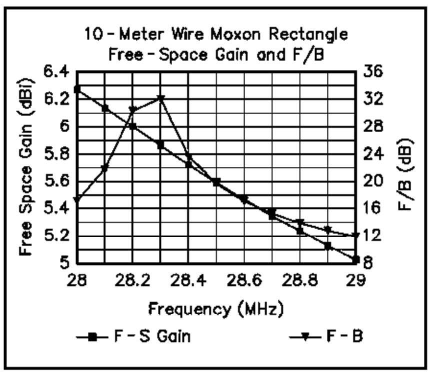


Figure 3—The pattern of free-space gain and 180° F/B across 10 meters for a #14 AWG wire Moxon Rectangle.

Designing a Moxon Rectangle

The objective in designing a Moxon Rectangle is to produce a set of dimensions for the wire diameter used that yields maximum F/B, maximum gain and a 50-Ω feedpoint impedance at the design frequency. For this exercise, I chose #14 bare copper wire, perhaps the most popular Field Day antenna material. I also aligned the maximum F/B and 50-Ω resonant feedpoint frequencies. Of course, gain varies across the band as it does with any two-element parasitic array.

With these design criteria, Table 1 provides the dimensions of Moxon Rectangles for 80, 75, 40, 20, 15 and 10 meters—all potential Field Day bands of operation. The design frequencies are listed with the band of operation. Because the 40- and 10-meter bands are wide relative to the wire size used, I moved their design frequencies below the mid-band point in order to obtain low-end coverage at an SWR under 2:1.[4]

The Moxon Rectangle functions by virtue of the mutual coupling between parallel element segments and the coupling between the facing element tips. Hence, the gap between element tips (dimension C in Figure 1) is the most critical dimension. Measure the gap accurately and ensure that the spacing does not change over time. The other dimensions follow from setting the gap in order to obtain the desired performance characteristics.

Figure 3 shows the gain and F/B curves for a 10-meter version of the #14 wire Moxon Rectangle, designed for 28.3 MHz. I chose 10 meters because even the first megahertz represents a very wide band. Note that the gain curve is nearly linear across the band. However, the F/B peaks near the design frequency and tapers off—more rapidly below the design frequency than above it. Figure 4 shows a similar curve for the 50-Ω SWR, with the rate of increase more rapid below the design frequency than above it.

There is no absolute need to align the maximum F/B frequency with the resonant 50-Ω feedpoint. We can move one or both of them by small adjustments in the antenna dimensions. To sample the rates of change in performance parameters relative to small changes in dimensions, I altered some dimensions of a 20-meter version of the antenna by one inch. (One inch at 20 meters is, of course, approximately equivalent to changes of four inches on 80, two inches on 40, and a half-inch on 10 meters.) In all cases, the gap (dimension C) is held constant.

• Decreasing or increasing the side-to-side dimension (A in Figure 1) raises or lowers the maximum F/B and the resonant feedpoint frequencies by about 40 kHz. For small changes in dimension A, the resonant feedpoint impedance does not change.

• Increasing or decreasing only the length of the driver tails (dimension B) by one inch lowers or raises the resonant frequency of the driver by about 70 kHz. The new resonant feedpoint impedance will be a few ohms lower (for an increase in driver length) than before the change. The frequency of maximum F/B will not change significantly.

• Increasing or decreasing only the length of the reflector tails (dimension D) by one inch lowers or raises the peak F/B frequency by about 70 kHz. The driver's resonant frequency will not significantly change, but the impedance will be higher (for an increase in reflector length) than before the change.

With these guidelines, you can tailor a basic Moxon Rectangle design to suit what you decide is best for your operation.

One of the realities of Field Day is that you will not operate your antenna in free space. Actual antenna heights over real

[1]Notes appear on page 42.

ground may range from 1/4λ to over 1λ, depending on the band and the available supports. To sample the operation of the Moxon Rectangle at various heights, I modeled a 10-meter version of the antenna at various heights, listed in Table 2 in terms of fractions of a wavelength. The performance of versions for other bands will not materially differ for equivalent heights.

Note that as the antenna height increases, the take-off angle (or the elevation angle of maximum radiation) decreases, as do the vertical and horizontal beamwidths between half-power points. These properties are in line with those of any horizontally polarized array. Hence, the gain increases slightly with antenna height increases. Figure 5 overlays the azimuth patterns for all of the heights in the table to demonstrate the small differences among them. Moreover, the feedpoint impedance of the antenna undergoes only small changes with changes in heights. Indeed, the excellent F/B performance at the low height of 3/8λ holds promise for 40-meter and lower-frequency installations. The upshot of this exercise is that a Moxon Rectangle falls in the class of "well-behaved" antennas, requiring no finicky field adjustments once the basic design is set and tested.

Of course, you should always pretest your Field Day antennas using circumstances as close as possible to those you will encounter at the actual site. Testing over a prairie and operating in a forest can produce surprises (and problems) for almost any antenna. However, the semi-closed design configuration of the Moxon Rectangle tends to yield fewer interactions with surrounding structures than antennas with linear elements, an added advantage for Field Day operations.

A Direction-Switching Moxon Rectangle

If you live somewhere within the vast central region of the country, you may be interested in signals from both sides of the Moxon Rectangle. The antenna can accommodate you with fair ease. Following the design lead of Carrol Allen, AA2NN, we can design the Moxon Rectangle for direction-switching use.[5] Figure 6 shows the outline. Essentially, we create two resonant drivers using the same dimensions as for the basic antenna. Then we load the one we select as the reflector so that it becomes electrically long enough to perform as a reflector. Our loading technique employs a length of shorted 50-Ω cable. By bringing equal length stubs to a central point, we can switch them. The one we short becomes part of the reflector. The other one is connected to the main feed line and simply becomes part of the overall system feed line.

One switching caution: Use a double-pole double-throw switch so that you switch the center conductor and the braid of the

Table 2
Relative Performance of a Wire Moxon Rectangle at Different Heights above Ground

Height (λ)	*TO angle (Degrees)*	*Gain (dBi)*	*F/B (dB)*	*VBW (Degrees)*	*HBW (Degrees)*	*Feedpoint Z (R±jX Ohms)*
Free-space	—	5.9	37.1	—	78	53 + *j*2
0.375	34	9.5	30.1	44	86	53 + *j*8
0.5	26	10.5	21.3	32	82	59 + *j*3
0.75	18	11.0	23.5	20	79	50 + *j*1
1.0	14	11.3	30.4	5	79	56 + *j*3

The modeled antenna is a 10-meter #14 AWG wire Moxon Rectangle at 28.5 MHz. Take-off (TO) angle refers to the elevation angle of maximum radiation. The 180° F/B is used in this table. Vertical bandwidth (VBW) and horizontal bandwidth (HBW) refer to the beamwidth between points at which power is down –3 dB relative to the maximum power. The feedpoint impedance (Z) is given in conventional resistance/reactance terms. See Figure 5 for comparative azimuth patterns.

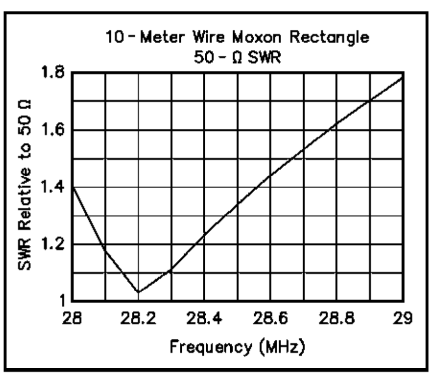


Figure 4—50-Ω SWR pattern across 10 meters for the #14 AWG wire Moxon Rectangle in Figure 3.

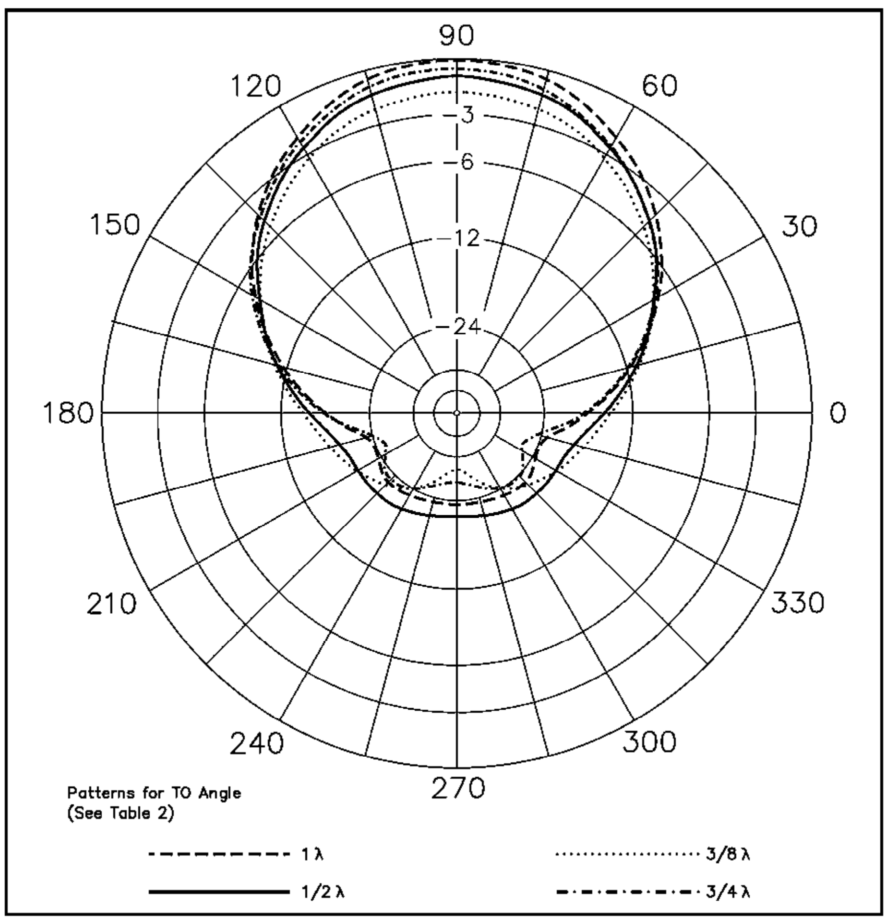


Figure 5—Typical azimuth patterns of a wire Moxon Rectangle at different heights (in wavelengths) above ground. Each azimuth pattern is taken at the elevation angle of maximum radiation (take-off angle).

coax lines used as stubs. When in use as a shorted stub, the line should not be electrically connected to the main feed line at all. A plastic box used to insulate the coax fittings from each other makes a good Field Day switch mount.

Table 3 lists the suggested dimensions for Field Day directional-switching Moxon Rectangles for 80 through 10 meters. Because two drivers are used, with their shorter tails, the overall front-to-back dimension (E) of each antenna is smaller than that of its one-way versions. The shorter front-to-back dimension lowers the feedpoint impedance by 5 to 7 Ω into the mid-40-Ω range, still a very good match for a coax feed line.

Table 3 also lists two stub lengths. The shorter one is the basic length of a shorted 50-Ω stub to achieve the required reflector loading. All of the designs required just about 65 Ω inductive reactance to electrically lengthen the reflector so that the maximum F/B frequency aligns with the driver resonant point. Hence, the basic stub length for the shorted stub is about 52.4°. Because you have a choice of cables with solid and foam dielectrics, you must multiply the listed length by the *actual velocity factor* of your stub cable. In general, solid-dielectric 50-Ω cables have velocity factors of 0.66 to 0.67, while foam cables tend toward a velocity factor of about 0.78. However, I have found significant departures from the listed values, so measuring the velocity factor of your line is a good practice. Otherwise, expect to cut and try lengths until you hit the right one.

Because the shorter length of the stub for some bands may leave them hanging high in the air, I have also listed the lengths of stubs that add a $1/2\lambda$ of line to them. The loading effect will be the same as for the shorter stub, but the lines may now reach a more convenient level for switching, especially in field conditions. It is wise to keep the lines suspended in the air, with the switch box hanging from a tree limb or tied to a post or stump. Again, multiply the listed values of longer lines by the velocity factor of the line you are actually using. Finally, be aware that coax stubs are not lossless and thus may slightly alter the performance of the array relative to the perfect lines used in models. In most cases, the differences will not be noticeable in practice.

The principles of reflector loading apply not only to Moxon Rectangles, but as well to wire Yagis, deltas, quads and a host of other two-element parasitic arrays. With good preplanning, they yield antennas simple enough to be manageable in the field. At the same time, you gain the benefits of a directional pattern that may nearly double your score. In non-scoring terms, a directional-switching array means more effective communication under almost all conditions.

Field Construction of a Moxon Rectangle

Despite their simplicity and low cost, wire beams can be ungainly. Hence, you should survey the Field Day site in advance—and if possible, practice raising and lowering the antennas. For the Moxon Rectangle, look for or plan for suitable supports to stretch the antenna at its corners. Of course, the higher the support, the better. Because the Moxon Rectangle is only about 70% the side-to-side width of a comparable two-element Yagi, its space requirements are relatively modest, allowing the site designer somewhat greater flexibility.

Figure 7 outlines two types of systems for supporting the Moxon Rectangle. Consider them to be only the barest starting points for a real system. The four-post system at the left is suitable for any band. The posts can be trees, guyed masts, or building corners. The rope terminating at the post can be tied off there, if the ring point is accessible. Or, run the rope over a limb or through an eyebolt so that the corner can be easily raised and lowered.

The ring at the end of the corner rope through which the wire passes is used to reduce mutual abrasion of the wire and rope and can be a simple loop in the rope or even a plastic bottleneck. Because the shape of the Moxon Rectangle is important, the corner bends should be locked. A short piece of wire that runs from main wire to tail, but which goes around the corner ring, can effectively keep the corner in place. A permanent installation might call for soldering the ends of the locking wire to the antenna elements, but a short-term field installation can usually do well with just a few twists of the locking wire on the element.

The two-post construction method is more apt to the upper HF bands. It uses a long pole, PVC tube, or similar nonmetallic structure to anchor the corner ropes. The corner rope can be terminated at the pole or passed through it and run to the post. The

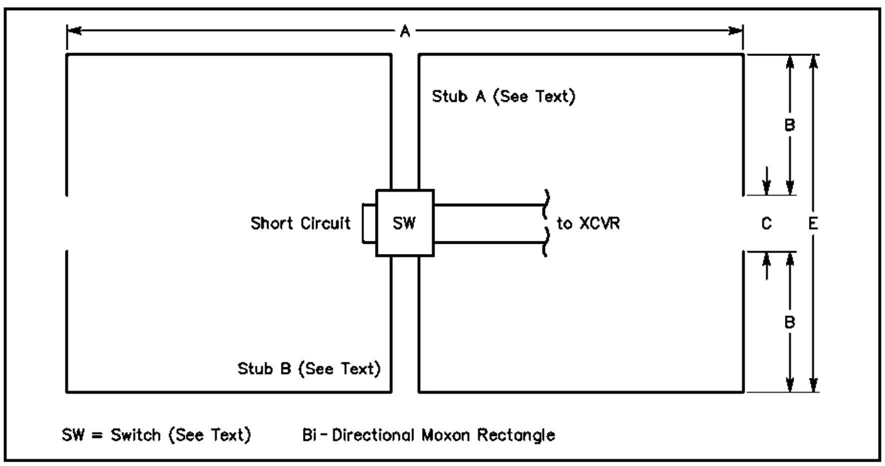


Figure 6—Outline of a direction-switching Moxon Rectangle, using transmission-line stub loading to electrically lengthen the reflector. See the text for details of the switching arrangement.

Table 3

Dimensions of Direction-Switching Wire Moxon Rectangles for 80-10 Meters

All dimensions refer to designations in Figure 6. Dimensions are in feet and apply to #14 AWG bare-wire antennas.

Band	*Frequency (MHz)*	*A*	*B*	*C*	*E*	*Simple*	*Stub +1/2λ*
80	3.6	99.98	15.47	2.16	33.10	39.78	176.39
75	3.9	92.28	14.28	2.00	30.56	36.72	162.82
40	7.09	50.69	7.82	1.15	16.79	20.20	89.56
20	14.175	25.30	3.87	0.62	8.36	10.10	44.80
15	21.225	16.88	2.56	0.44	5.56	6.75	29.92
10	28.3	12.65	1.90	0.35	4.15	5.06	22.44

Stub lengths are based on an inductively reactive load of 65 Ω for the reflector element at the design frequency. Listed stub lengths are for 50-Ω cable with a 1.0 velocity factor. Multiply listed lengths by the *actual velocity factor of the line* to obtain the final length.

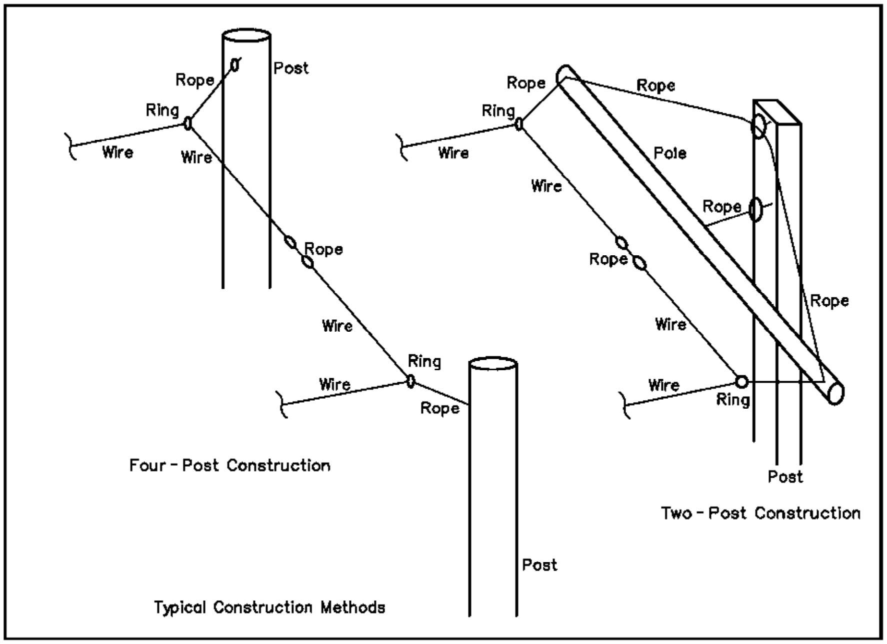


Figure 7—Four-pole and two-pole mounting arrangements for a wire Moxon Rectangle, shown only in barest outlines.

sketch shows a two-anchor mounting for the pole. The upper support ropes align the pole horizontally. Thus, the rope should be locked to the ring or other support to keep everything horizontal. Alternatively, you can brace the pole directly to the support post, tree, or mast so that it remains horizontal. The remaining attachment mechanisms are the same as for the four-post method of support.

The rope that separates the driver and reflector tails should not stretch. Its job is to maintain the tail gap spacing as securely as possible. In addition, since the degree of coupling between tails is a function of the wire diameter, the wire fold-back used to make an attachment loop in the element tails should be as tight and flat as possible without weakening the antenna wire. For added strain relief and dimensional precision for upper HF versions of the Moxon Rectangle, it is possible to place the nonmetallic pole at or inside the perimeter of the antenna. With some judicious use of electrical tape where the elements end along the pole, you can omit the tail-to-tail rope altogether. For a larger, lower, HF-band version of the antenna, you can use a rope that runs from each front ring to the corresponding rear ring and tape the driver and reflector tails wires to it.

For field use, lightweight coax (ie, RG-8X for 50-Ω applications) helps reduce the stress on the driven element(s) at the feedpoint. However, where conditions permit, supporting the element centers is advisable. In fact, slightly Ving the elements will normally produce no adverse effects in performance. However, if you contemplate a shallow inverted-V form of the antenna, pretest the assembly to assure that everything will work as planned.

Field Day antenna construction is a primary exercise in adapting easily obtainable materials to particular site configurations. Hence, it is not possible to provide universal guidance for every situation. However, these notes should get you started. Survey your local Home Depot and other such outlets for fixtures and nonmetallic connectors that might prove useful for a Field Day antenna. You may find them anywhere in the store. The plumbing and electrical departments are good starting places to find adaptable PVC fittings.

The Moxon Rectangle offers good potential for Phase 3 antenna improvements in Field Day installations. It is certainly not the only good antenna for this important exercise. The final decision you make in selecting an antenna should be the result of extended planning activities that review: (A) What is possible at the site; (B) what is possible with the available construction crew and (C) which antennas when properly oriented will improve communications the most from a given site. What you learn about various antennas that may be candidates for the next Field Day will serve you well in the long run—both at home and in the field.

Of course, the Moxon Rectangle—when it has done its Field Day service—need not be retired to storage awaiting next year's duty: It can serve very well in many home-station installations. The size and the signal pattern may be perfectly suited to the needs of at least some operators.

Notes

[1]For a more complete history, see L. B. Cebik, W4RNL, "Modeling and Understanding Small Beams: Part 2: VK2ABQ Squares and The Modified Moxon Rectangle," *Communications Quarterly*, (Spring, 1995), pp 55-70. There are a number of notes on this antenna type at my Web site (**http://www.cebik.com**) in the "Tales and Technicals" collection. As an example of a VHF version of the antenna, see Lee Lumpkin, KB8WEV, and Bob Cerrito, WA1FXT, "A Compact Two-Element, 2-Meter Beam," *QST*, Jan 2000, pp 60-63. Other VHF applications have appeared in *antenneX* an on-line magazine (**http://www.antennex.com**).

[2]Les A. Moxon, G6XN, *HF Antennas for All Locations* (RSGB, 1982), pp 67, 168, 172-175. Available from the ARRL, order no. 4300, $15. See the ARRL Bookcase in this issue for ordering information.

[3]For aluminum versions of the antenna, see L. B. Cebik, "An Aluminum Moxon Rectangle for 10 Meters," *The ARRL Antenna Compendium*, Vol 6 (ARRL, 1999), pp 10-13 and Morrison Hoyle, VK3BCY, "The Moxon Rectangle," *Radio and Communications* (Australia), Jul 1999, pp 52-53.

[4]If you want to use other wire sizes (including center-supported versions made from aluminum tubing in diameters up to well over an inch in diameter), a small GW Basic program is available that will ease the design work. The program's output is accurate to within under 0.5% relative to the *NEC-4* models used to derive the algorithms. You can download this program and explanatory text from **http://www.arrl.org/files/qst-binaries/** as *MOXONBAS.ZIP*.

A full account of the technique used to derive the program will appear in a forthcoming issue of *antenneX* (**http://www.antennex.com**). The program will also be added to the *HAMCALC* suite of GW BASIC electronics utility programs available from George Murphy, VE3ERP. Those having access to *NEC-Win Plus*, a *NEC-2* antenna modeling software package available from Nittany Scientific, can simplify the process of deriving dimensions and checking the resultant model. The model-by-equation facility of the spreadsheet input system permitted me to transfer the design equations directly into a model, which the user can set for any desired design frequency. The output will include both the dimensions and a standard *NEC-2* calculation of the antenna pattern and source impedance, with options for changing any of variables, including the wire conductivity, size, etc. A copy of the MOXGENE8 .NWP file is available among the examples at the NEC-Win Web site (**http://www.nittany-scientific.com**).

[5]Carrol Allen, AA2NN, "Two-Element 40-Meter Switched Beam," *The ARRL Antenna Compendium*, Vol 6 (ARRL, 1999), pp 23-25. See especially Carrol's improved method of stub construction.

An ARRL Life Member and educational advisor, L. B. Cebik, W4RNL, recently retired from The University of Tennessee, Knoxville, to pursue his interests in antenna research and education, much of which appears at his Web site (**http://www.cebik.com**). *A ham for over 45 years, his articles have appeared in several League publications including* QST, QEX, NCJ *and* The ARRL Antenna Compendium. *You can contact L. B. at 1434 High Mesa Dr, Knoxville, TN 37938-4443;* **cebik@utk.edu**.

Editor's note: Section and figure references in this article are from the 2013 edition of the ARRL Handbook.

Five-Band, Two-Element HF Quad

Two quad designs are described in this article, both nearly identical. One was constructed by KC6T from scratch, and the other was built by Al Doig, W6NBH, using modified commercial triband quad hardware. The principles of construction and adjustment are the same for both models, and the performance results are also essentially identical. One of the main advantages of this design is the ease of (relatively) independent performance adjustments for each of the five bands. These quads were described by William A. Stein, KC6T, in *QST* for April 1992. Both models use 8-ft-long, 2-inch diameter booms, and conventional X-shaped spreaders (with two sides of each quad loop parallel to the ground).

These designs can also be simplified to monoband quads by using the formulas in Fig 21.77 for loop dimensions and spacing. It is recommended to the antenna builder unfamiliar with quads that a monoband quad be attempted first in order to become acquainted with the techniques of building a quad. Once comfortable with constructing and erecting the quad, success with a multiband design is much easier to achieve.

THE FIVE-BAND QUAD AS A SYSTEM

Unless you are extraordinarily lucky, you should remember one general rule: Any quad must be adjusted for maximum performance after assembly. Simple quad designs can be tuned by pruning and restringing the elements to control front-to-rear ratio and SWR at the desired operating frequency. Since each element of this quad contains five concentric loops, this adjustment method could lead to a nervous breakdown!

Fig 21.78 shows that the reflectors and driven elements are each independently adjustable. After assembly, adjustment is simple, and although gamma-match components on the driven element and capacitors on the reflectors add to the antenna's parts count, physical construction is not difficult. The reflector elements are purposely cut slightly long (except for the 10 meter reflector), and electrically shortened by a tuning capacitor. The driven-element gamma matches set the lowest SWR at the desired operating frequency.

As with most multiband directive antennas, the designer can optimize any two of the following three attributes at the expense of the third: forward gain, front-to-rear ratio and bandwidth (where the SWR is less than 2:1). These three characteristics are related, and changing one changes the other two. The basic idea behind this quad design is to permit (without resorting to trimming loop lengths, spacing or other gross mechanical adjustments):

- The forward gain, bandwidth and front-to-rear ratio may be set by a simple adjustment after assembly. The adjustments can be made on a band-by-band basis, with little or no effect on previously made adjustments on the other bands.
- Setting the minimum SWR in any portion of each band, with no interaction with previously made front-to-back or SWR adjustments.

The first of the two antennas described, the KC6T model, uses aluminum spreaders with PVC insulators at the element attachment points. (The author elected not to use fiberglass spreaders because of their high cost.) The second antenna, the W6NBH model, provides dimensions and adjustment values for the same antenna, but using standard tri-band quad fiberglass spreaders and hardware. If you have a tri-band quad, you can easily adapt it to this design. When W6NBH built his antenna, he had to shorten the 20 meter reflector because the KC6T model uses a larger 20 meter reflector than W6NBH's fiberglass spreaders would allow. Performance is essentially identical for both models.

MECHANICAL CONSIDERATIONS

Even the best electrical design has no value if its mechanical construction is lacking. Here are some of the things that contribute to mechanical strength: The gamma-match capacitor KC6T used was a small, air-variable, chassis-mount capacitor mounted in a plastic box (see **Fig 21.79**). A male UHF connector was mounted to the box, along with a screw terminal for connection to the gamma rod. The terminal lug and wire are for later connection to the driven element. The box came from a local hobby shop, and the box lid was replaced with a piece of 1⁄32-inch ABS plastic, glued in place after the capacitor, connector and wiring had been installed. The capacitor can be adjusted with a screwdriver through an access hole. Small vent (drain) holes were drilled near corresponding corners of each end.

Enclose the gamma-match capacitor in such a manner that you can tape unwanted

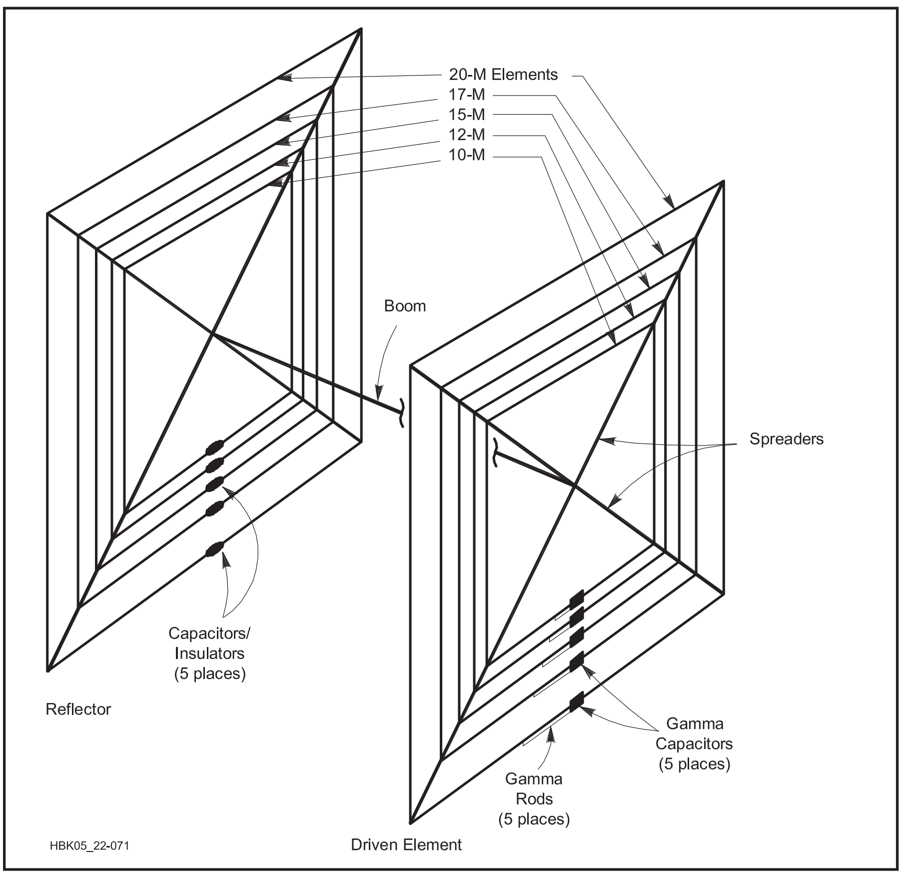


Fig 21.78 — Mechanical layout of the five-band quad. The boom is 8 ft long; see Table 21.16 for all other dimensions.

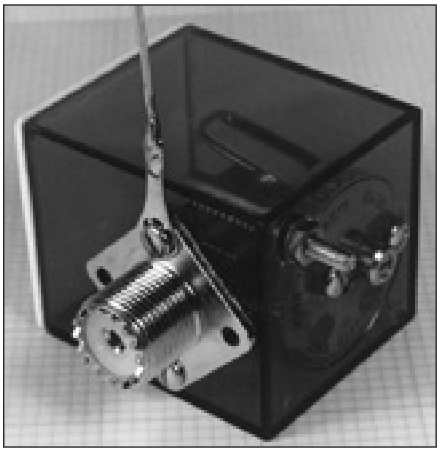


Fig 21.79 — Photo of one of the feed point gamma-match capacitors.

Table 21.16
Element Lengths and Gamma-Match Specifications of the KC6T and W6NBH Five-Band Quads

KC6T Model

Band (MHz)	Driven Element Length (in)	Gamma Match Length (in)	Gamma Match Spacing (in)	Gamma Match C_g (pF)	Reflector Length (in)	C_R (pF)
14	851.2	33	2	125	902.4	68
18	665.6	24	2	110	705.6	47
21	568	24	1.5	90	604.8	43
24.9	483.2	29.75	1	56	514.4	33
28	421.6	26.5	1	52	448.8	(jumper)

W6NBH Model

Band (MHz)	Driven Element Length (in)	Gamma Match Length (in)	Gamma Match Spacing (in)	Gamma Match C_g (pF)	Reflector Length (in)	C_R (pF)
14	851.2	31	2	117	890.4	120
18	665.6	21	2	114	705.6	56
21	568	26	1.5	69	604.8	58
24.9	483.2	15	1	75.5	514.4	54
28	421.6	18	1	41	448.8	(jumper)

openings closed so that moisture can't be directly blown in during wind and rainstorms. Also, smaller boxes and sturdy mounts to the driven element ensure that you won't pick up gamma capacitor assemblies along with the leaves after a wind storm.

Plastic gamma-rod insulators/standoffs were made from 1⁄32-inch ABS, cut ½-inch wide with a hole at each end. Use a knife to cut from the hole to the side of each insulator so that one end can be slipped over the driven element and the other over the gamma rod. Use about four such insulators for each gamma rod, and mount the first insulator as close to the capacitor box as possible. Apply five-minute epoxy to the element and gamma rod at the insulator hole to keep the insulators from sliding. If you intend to experiment with gamma-rod length, perform this gluing operation after you have made the final gamma-rod adjustments.

ELEMENT INSULATORS

As shown in Fig 21.78, the quad uses insulators in the reflectors for each band to break the loop electrically, and to allow reflector adjustments. Similar insulators were used to break up each driven element so that element impedance measurements could be made with a noise bridge. After the impedance measurements, the driven-element loops are closed again. The insulators are made from ¼ × 2 × ¾-inch phenolic stock. The holes are ½-inch apart. Two terminal lugs (shorted together at the center hole) are used in each driven element. They offer a convenient way to open the loops by removing one screw. **Fig 21.80** shows these insulators and the gamma-match construction schematically. **Table 21.16** lists the component values, element lengths and gamma-match dimensions.

ELEMENT-TO-SPREADER ATTACHMENT

Probably the most common problem with quad antennas is wire breakage at the element-to-spreader attachment points. There are a number of functional attachment methods; **Fig 21.81** shows one of them. The attachment method with both KC6T and W6NBH spreaders is the same, even though the spreader constructions differ. The KC6T model uses #14 AWG, 7-strand copper wire; W6NBH used #18 AWG, 7-strand wire. At the point of element attachment (see **Fig 21.82**), drill a hole through both walls of the spreader using a #44 (0.086-inch) drill. Feed a 24-inch-long piece of antenna wire through the hole and center it for use as an attachment wire.

After fabricating the spider/spreader assembly, lay the completed assembly on a flat surface and cut the element to be installed to the correct length, starting with the 10 meter element. Attach the element ends to the insulators to form a closed loop before attaching the elements to the spreaders. Center the insulator between the spreaders on what will become the bottom side of the quad loop, then carefully measure and mark the element-mounting-points with fingernail polish (or a similar substance). Do *not* depend on the

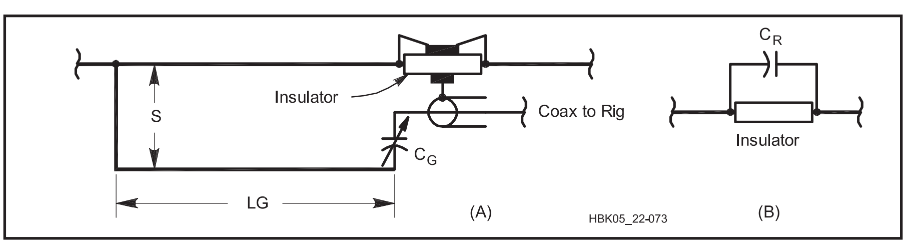


Fig 21.80 — Gamma-match construction details at A and reflector-tuning capacitor (CR) attachment schematic at B. The gamma matches consist of matching wires (one per band) with series capacitors (Cg). See Table 21.16 for lengths and component specifications.

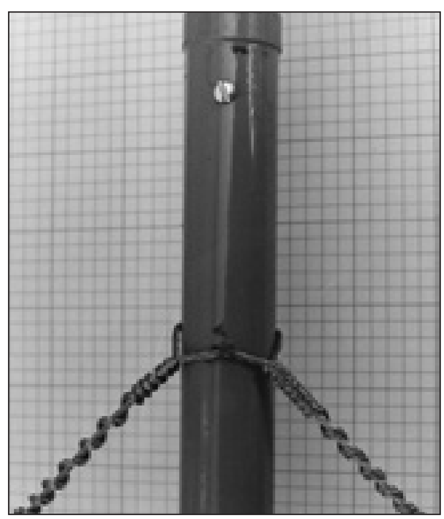


Fig 21.81 — Attaching quad wires to the spreaders must minimize stress on the wires for best reliability. This method (described in the text) cuts the chances of wind-induced wire breakage by distributing stress.

at-rest position of the spreaders to guarantee that the mounting points will all be correct.

Holding the mark at the centerline of the spreader, tightly loop the attachment wire around the element and then gradually space out the attachment-wire turns as shown. The attachment wire need not be soldered to the element. The graduated turn spacing minimizes the likelihood that the element wire will flex in the same place with each gust of wind, thus reducing fatigue-induced wire breakage.

FEEDING THE DRIVEN ELEMENTS

Each driven element is fed separately, but feeding five separate feed lines down the tower and into the shack would be costly and mechanically difficult. The ends of each of these coax lines also require support other than the tension (or lack of thereof) provided by the driven element at the feed point. It is best to use a remote coax switch on the boom approximately 1 ft from the driven-element spider-assembly attachment point.

If the gamma match is used, the cables connecting the gamma-match capacitors and the coax switch help support the driven elements and gamma capacitors. The support can be improved by taping the cables together in several places. A single coaxial feed line (and a control cable from the remote coax switch, if yours requires one) is the only required cabling from the antenna to the shack.

If the synchronous transmission line transformer is used, the ¼-wavelength of cable required is of convenient lengths that allow a remote antenna switch to be mounted on the antenna boom and the matching sections connected between the switch and driven elements. The drawback of the matching section technique is that it is not easily adjustable.

THE KC6T MODEL'S COMPOSITE SPREADERS

If you live in an area with little or no wind, spreaders made from wood or PVC are practical, but if you live where winds can reach 60 to 80 mi/h, strong, lightweight spreaders are a must. Spreaders constructed with electrical conductors (in this case, aluminum tubing) can cause a myriad of problems with unwanted resonances, and the problem gets worse as the number of bands increases.

To avoid these problems, this version uses composite spreaders made from machined PVC insulators at the element-attachment points. Aluminum tubing is inserted into (or over) the insulators 2 inches on each end. This spreader is designed to withstand 80 mi/h winds. The overall insulator length is designed to provide a 3-inch center insulator clear of the aluminum tubing. The aluminum tubing used for the 10 meter section (inside dimension "A" in Fig 21.82) is 1⅛-inch diameter × 0.058-inch wall. The next three sections are ¾-inch diameter × 0.035-inch wall, and the outer length is made from ½-inch diameter × 0.035-inch wall. The dimensions shown in Fig 21.82 are *attachment point* dimensions only.

	Dim	Driven	Reflector
	A	74.5	79.4
	B	85.4	90.9
	C	100.4	106.9
	D	117.6	124.7
KC6T:	E	150.4	159.5
W6NBH:	E	150.4	157.4

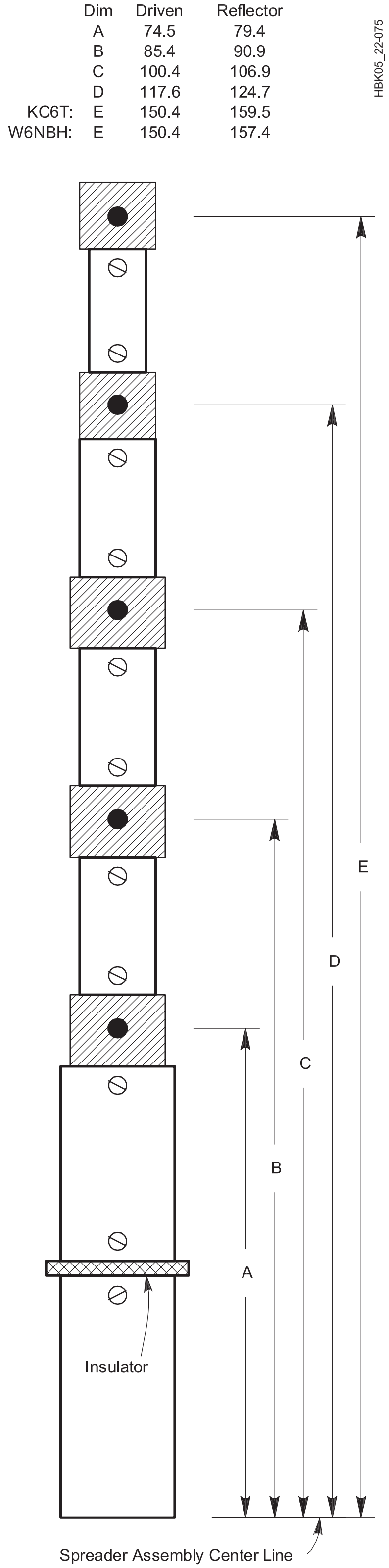


Fig 21.82 — Spreader-drilling diagram and dimensions (in.) for the five-band quad. These dimensions apply to both spreader designs described in the text, except that most commercial spreaders are only a bit over 13 ft (156 inches) long. This requires compensation for the W6NBH model's shorter 20 meter reflector as described in the text.

Attach the insulators to the aluminum using #6 sheet metal screws. Mechanical strength is provided by Devcon no. S 220 Plastic Welder Glue (or equivalent) applied liberally as the aluminum and plastic parts are joined. Paint the PVC insulators before mounting the elements to them. Paint protects the PVC from the harmful effects of solar radiation. As you can see from Fig 21.82, an additional spreader insulator located about halfway up the 10 meter section (inside dimension "A") removes one of the structure's electrical resonances not eliminated by the attachment-point insulators. Because it mounts at a relatively high-stress point in the spreader, this insulator is fabricated from a length of heavy-wall fiberglass tubing.

Composite spreaders work as well as fiberglass spreaders, but require access to a well-equipped shop, including a lathe. The main objective of presenting the composite spreader is to show that fiberglass spreaders aren't a basic requirement — there are many other ways to construct usable spreaders. If you can lay your hands on a used multiband quad, even one that's damaged, you can probably obtain enough spreaders to reduce construction costs considerably.

GAMMA ROD

The gamma rod is made from a length of #12 AWG solid copper wire (W6NBH used #18 AWG, 7-strand wire). Dimensions and spacings are shown in Table 21.16. If you intend to experiment with gamma-rod lengths and capacitor settings, cut the gamma-rod lengths about 12 inches longer than the length listed in the table. Fabricate a sliding short by soldering two small alligator clips back-to-back such that they can be clipped to the rod and the antenna element and easily moved along the driven element. Note that gamma-rod spacing varies from one band to another. When you find a suitable shorting-clip position, mark the gamma rod, remove the clip, bend the gamma rod at the mark and solder the end to the element.

THE W6NBH MODEL

As previously mentioned, this model uses standard 13-ft fiberglass spreaders, which aren't quite long enough to support the larger 20 meter reflector specified for the KC6T model. The 20 meter W6NBH reflector loop is cut to the dimensions shown in Table 21.16, 12 inches shorter than that for the KC6T model. To tune the shorter reflector, a six-inch-long stub of antenna wire (conductors spaced two inches) hangs from the reflector insulator, and the reflector tuning capacitor mounts on another insulator at the end of this stub.

GAMMA-MATCH AND REFLECTOR-TUNING CAPACITOR

Use an air-variable capacitor of your choice for each gamma match. Approximately 300 V can appear across this capacitor (at 1500 W), so choose plate spacing appropriately. If you want to adjust the capacitor for best match and then replace it with a fixed capacitance, remember that several amperes of RF will flow through the capacitance. If you choose disc-ceramic capacitors, use a parallel combination of at least four l-kV units of equal value. Any temperature coefficient is acceptable. NP0 units are not required. Use similar components to tune the reflector elements.

ADJUSTMENTS

Well, here you are with about 605 ft of wire. Your antenna will weigh about 45 pounds (the W6NBH version is slightly lighter) and have about nine square ft of wind area. If you chose to, you can use the dimensions and capacitance values given, and performance should be excellent. If you adjust the antenna for minimum SWR at the band centers, it should cover all of the lower four bands and 28 to 29 MHz with SWRs under 2:1; front-to-back ratios are given in **Table 21.17**.

Instead of building the quad to the dimensions listed and hoping for the best, you can adjust your antenna to account for most of the electrical environment variables of your installation. The adjustments are conceptually simple: First adjust the reflector's electrical length for maximum front-to-rear ratio (if you desire good gain, and are willing to settle for a narrower than maximum SWR bandwidth), or accept some compromise in front-to-rear ratio that results in the widest SWR bandwidth. You can make this adjustment by placing an air-variable capacitor (about 100-pF maximum) across the open reflector loop ends, one band at a time, and adjusting the capacitor for the desired front-to-rear ratio. The means of doing this will be discussed later.

During these reflector adjustments, the driven-element gamma-match capacitors may be set to any value and the gamma rods may be any convenient length (but the sliding-short alligator clips should be installed somewhere near the lengths specified in Table 21.16). After completing the front-to-rear adjustments, the gamma capacitors and rods are adjusted for minimum SWR at the desired frequency.

ADJUSTMENT SPECIFICS

Make a calibrated variable capacitor (with a hand-drawn scale and wire pointer). Calibrate the capacitor using your receiver, a known-value inductor and a grid-dip meter (plus a little calculation) or SWR analyzer.

Adjust each band by feeding it separately if the gamma match technique is used. If transmission line matching sections are used, they must all be connected to the remote switch when adjusting the antenna because each unused section acts as a short coaxial stub, adding reactance at the connection to the antenna.

To adjust front-to-back ratio, simply clip the (calibrated) air-variable capacitor across the open ends of the desired reflector loop. Connect the antenna to a portable receiver with an S meter. Point the back of the quad at a signal source, and slowly adjust the capacitor for a dip in the S-meter reading.

Table 21.17
Measured Front-to-Back Ratios

Band	*KC6T Model*	*W6NBH Model*
14	25 dB	16 dB
18	15 dB	10 dB
21	25 dB	>20 dB
24.9	20 dB	>20 dB
28	20 dB	>20 dB

After completing the front-to-back adjustments, replace the variable capacitor with an appropriate fixed capacitor and seal the connections against the weather. Then move to the driven-element adjustments. Connect the coax through the SWR bridge to the 10 meter gamma-match capacitor box. Use an SWR bridge that requires only a watt or two (not more than 10 W) for full-scale deflection in the calibrate position on 10 meters. Using the minimum necessary power, measure the SWR. Go back to receive and adjust the capacitor until (after a number of transmit/receive cycles) you find the minimum SWR. If it is too high, lengthen or shorten the gamma rod by means of the sliding alligator-clip short and make the measurements again.

Stand away from the antenna when making transmitter-on measurements. The adjustments have minimal effect on the previously made front-to-rear settings, and may be made in any band order. After making all the adjustments and sealing the gamma capacitors, reconnect the coax harness to the remote coax switch.

Adjusting the SWR when using transmission-line matching sections requires first measuring the impedance of each loop at the feed point. To avoid standing next to the antenna while making the measurement, connect the test equipment to the antenna using a ½-λ piece of transmission line of any characteristic impedance. Cut a ¼-λ section of transmission line with an appropriate impedance a few percent longer than the exact value. Attach the matching section to the loop feed point. Measure the resulting impedance at the output of the matching section and trim its length to place the minimum SWR point at the desired frequency. Using this technique, it is not likely that an SWR of 1:1 can be obtained, but values below 1.5:1 should be attainable.

Medium-Gain 2 Meter Yagi

Editor's note: Section and figure references in this article are from the 2013 edition of the ARRL Handbook. This material was originally contributed to the Handbook *by the late L.B. Cebik, W4RNL.*

This project was designed and built by L. B. Cebik, W4RNL (SK). Practical Yagis for 2 meters abound. What makes this one a bit different is the selection of materials. The elements, of course, are high-grade aluminum. However, the boom is PVC and there are only two #6 nut-bolt sets and two #8 sheet metal screws in the entire antenna. The remaining fasteners are all hitch-pin clips. The result is a very durable six-element Yagi that you can disassemble with fair ease for transport.

THE BASIC ANTENNA DESIGN

The 6-element Yagi presented here is a derivative of the *optimized wide-band antenna* (OWA) designs developed for HF use by NW3Z and WA3FET. **Fig 21.115** shows the general outline. The reflector and first director largely set the impedance. The next 2 directors contribute to setting the operating bandwidth. The final director (Dir. 4) sets the gain. This account is over-simplified, since every element plays a role in every facet of Yagi performance. However, the notes give some idea of which elements are most sensitive in adjusting the performance figures.

Designed using *NEC-4*, the antenna uses 6 elements on a 56-inch boom. **Table 21.21** gives the specific dimensions for the version described in these notes. The parasitic elements are all ³⁄₁₆-inch aluminum rods. For ease of construction, the driver is ½-inch aluminum tubing. Do not alter the element diameters without referring to a source, such as RSGB's *The VHF/UHF DX Book*, edited by Ian White, G3SEK, (Chapter 7), for information on how to recalculate element lengths.

The driver is the simplest element to readjust. Table 21.21 shows an alternative driver using ³⁄₁₆-inch diameter material. Of all the elements, the driver is perhaps the only one for which you may extrapolate reasonable lengths for other diameters from the two lengths and diameters shown. However, the parasitic elements may require more work than merely substituting one diameter and length for another. The lower portion of the table shows the design adjusted for ⅛-inch elements throughout. Not all element lengths change by the same amount using any single formula.

The OWA design provides about 10.2 dBi of free-space gain with better than 20 dB front-to-back (or front-to-rear) ratio across the entire 2 meter band. Azimuth (or E-plane) patterns show solid performance across the entire band. This applies not only to forward gain but rejection from the rear.

One significant feature of the OWA design is its direct 50-Ω feed point impedance that requires no matching network. Of course, a choke balun to suppress any currents on the feed line is desirable, and a simple ferrite bead balun (see the **Transmission Lines** and **Station Accessories** chapters) works well in this application. The SWR, shown in **Fig 21.116**, is very flat across the band and never reaches 1.3:1. The SWR and the pattern consistency together create a very useful utility antenna for 2 meters, whether installed vertically or horizontally. The only remaining question is how to effectively build the beam in the average home shop.

THE BEAM MATERIALS

The boom is Schedule 40, ½-inch nominal PVC. Insulated booms are good for test antennas, since they do not require recalculating the element lengths due to the effects of a metal boom.

White PVC stands up for a decade of ex-

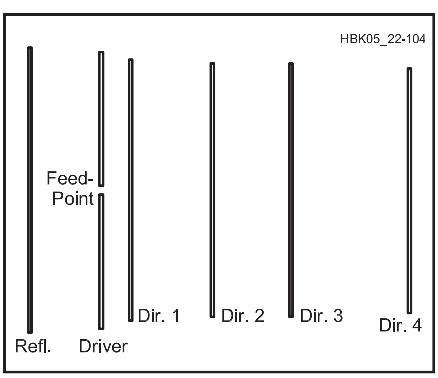


Fig 21.115 — The general outline of the 2 meter 6-element OWA Yagi. Dimensions are given in Table 21.21.

Table 21.21
2 Meter OWA Yagi Dimensions

Element	*Element Length (in)*	*Spacing from Reflector (in)*	*Element Diameter (in)*
Version described here:			
Refl.	40.52	——	0.1875
Driver	39.70	10.13	0.5
Alt. Driver	*39.96*	*10.13*	*0.1875*
Dir. 1	37.36	14.32	0.1875
Dir. 2	36.32	25.93	0.1875
Dir. 3	36.32	37.28	0.1875
Dir. 4	34.96	54.22	0.1875
Version using 1/8-inch diameter elements throughout:			
Refl.	40.80	——	0.125
Driver	40.10	10.20	0.125
Dir. 1	37.63	14.27	0.125
Dir. 2	36.56	25.95	0.125
Dir. 3	36.56	37.39	0.125
Dir. 4	35.20	54.44	0.125

Table 21.22
Parts List for the 2 Meter OWA Yagi

Qty	*Item*
17'	0.1875" (³⁄₁₆") 6061-T6 aluminum rod (Source: Texas Towers)
3.5'	0.5" (½") 6063-T832 aluminum tubing (Source: Texas Towers)
7'	Schedule 40, ½" PVC pipe (Source: local hardware store)
3	Schedule 40, ½" PVC Tee connectors (Source: local hardware store)
2	Schedule 40, ½" PVC L connectors (Source: local hardware store)
—	Miscellaneous male/female threaded pipe diameter transition fittings (Source: local hardware store)
1	Support mast
10	Stainless steel hitch-pin clips (hairpin cotter pins), ³⁄₁₆" to ¼" shaft range, 0.04" "wire" diameter (McMasters-Carr part number 9239A024, or local hardware store)
2	Stainless steel #6 nut/bolt/lock-washer sets, bolt length 1" (Source: local hardware store)
2	Stainless steel #8 sheet metal screws (Source: local hardware store)
1	BNC connector (Source: local electronics outlet)
2"	¹⁄₁₆" thick aluminum L-stock, 1" per side (Source: local hardware store)
1	VHF bead-balun choke (Source: Wireman, Inc.)

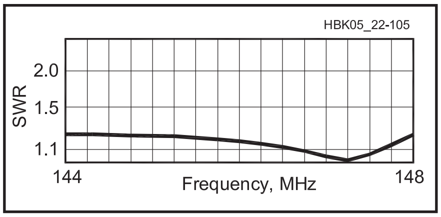


Fig 21.116 — SWR curve as modeled using *NEC-4* for the 2-m 6-element OWA Yagi.

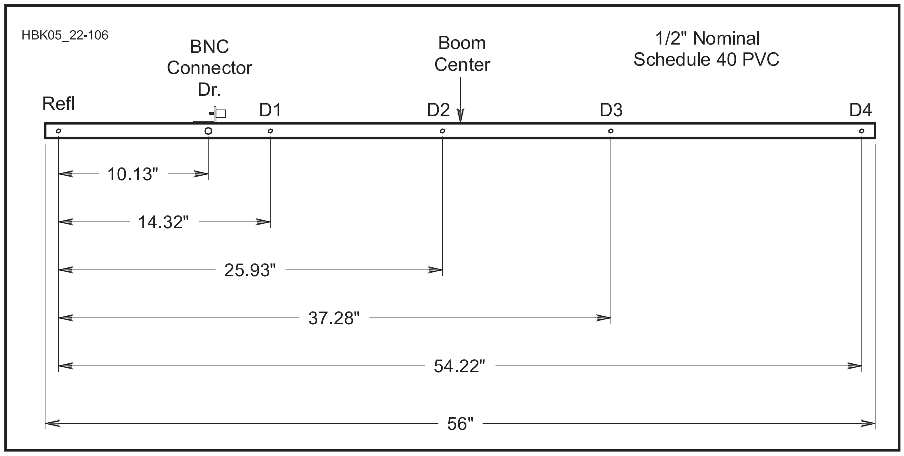


Fig 21.117 — Layout of elements along the PVC boom for the 2 meter 6-element OWA Yagi, showing placement of the BNC connector and the boom center.

posure in Tennessee, but apparently does not do as well in every part of the US. You may wish to use the gray electrical conduit version. If you use any other material for your boom, be sure that it is UV-protected. You'll find a parts list in **Table 21.22**. Sources for the parts are given in the table. However, you are encouraged to develop your own sources for antenna materials.

Fig 21.117 shows the element layout along the 56-inch boom. Centering the first element hole 1 inch from the rear end of the boom results in a succession of holes for the 3⁄16-inch pass-through parasitic elements. Only the driver requires special treatment. We shall use a 3⁄8-inch hole to carry a short length of fiberglass rod that will support the two sides of the driver element. Note that the antenna uses a BNC connector, mounted on a small plate that we shall meet along the way.

The boom is actually a more complex structure than initially meets the eye. You need a support for the elements, and a means of connecting the boom to the mast. If you break the boom in the middle to install a Tee connector for the mast junction, you come very close to the 2nd director. **Fig 21.118** shows how to avoid the predicament.

Before drilling the boom, assemble it from common Schedule 40 ½-inch fittings and insert the lengths of PVC pipe. Fig 21.118 shows the dimensions for the center section of the boom assembly. However, PVC dimensions are always *nominal*, that is, meeting certain minimum size standards. So you may have to adjust the lengths of the linking pieces slightly to come up with a straight and true boom assembly.

Use scrap lumber to help keep everything aligned while cementing the pieces together. A 1×4 and a 1×6 nailed together along the edges produce a very good platform with a right-angle. Start with the two upper Tees and the Ls below each one. Dry-fit scrap PVC into the openings except for the short link that joins the fitting. Cement these in place and align them using the dry-fit pieces as guides to keep everything parallel. Next, cement the two short (2¾-inch) links into the third Tee. Then, cement one link into its L, using the dry-fit tube in the upper Tee as an alignment guide.

Before proceeding further, carefully mea-

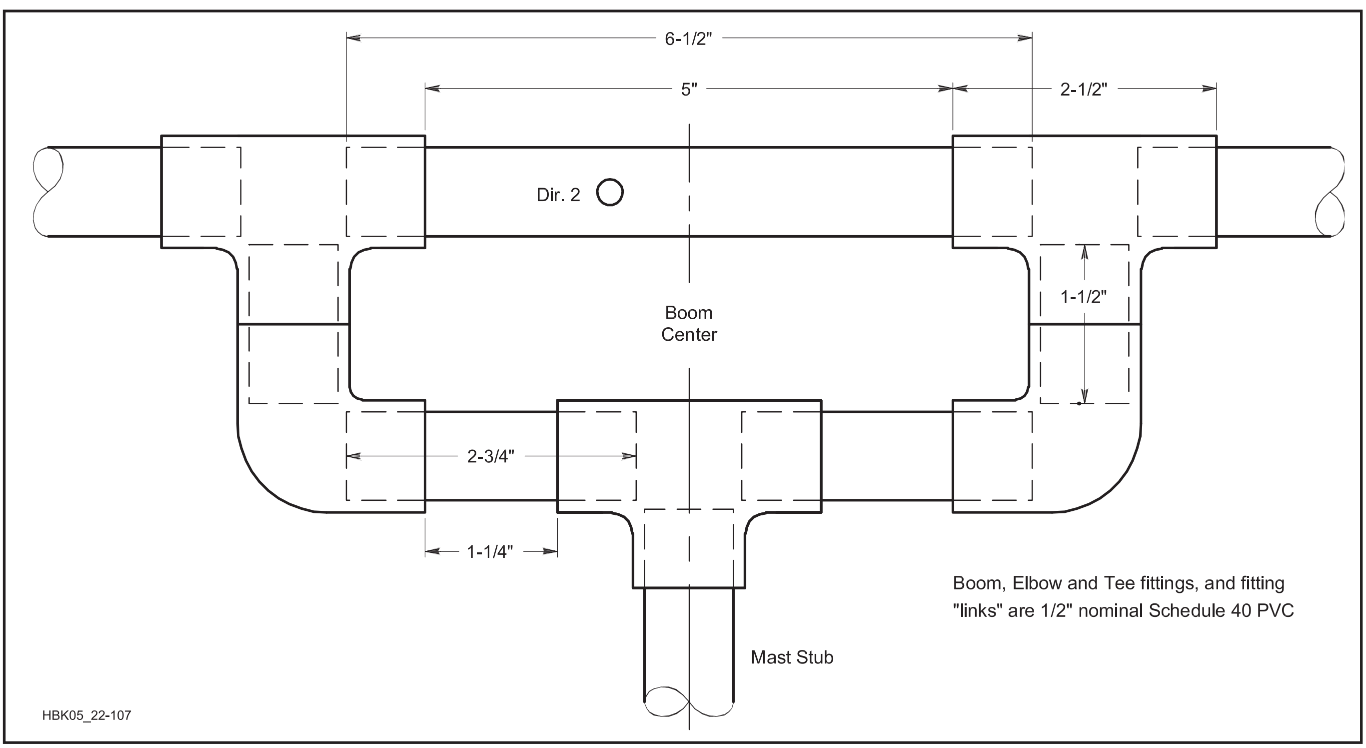
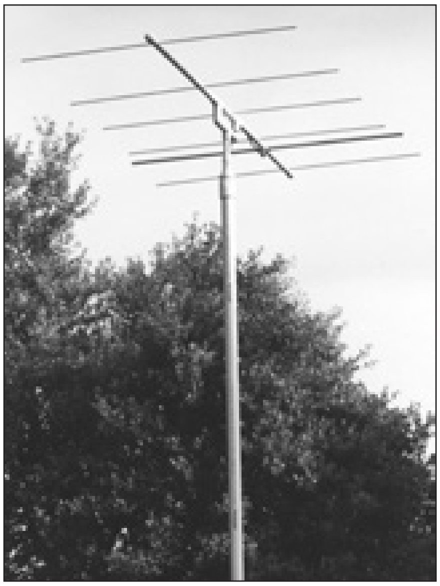


Fig 21.118 — Details of a parallel PVC pipe structure for the Yagi boom and mount.



(A)

(B)

Fig 21.119 — The completed Yagi is shown at A. A close-up view of the parallel PVC boom and mount, the sequence of threaded fittings, and the hitch-pin clips used to secure parasitic elements is shown at B.

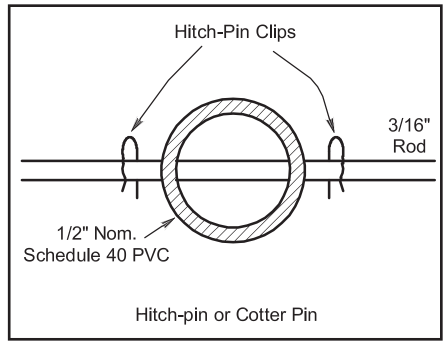


Fig 21.120 — The parasitic element mounting system, showing the placement of the hitch-pin clips and the shape of the clips.

sure the required length of PVC for the boom section between Tees. How well you measure here will determine whether the boom will be straight or whether it will bow up or down. Now, cement both the L and the Tee at the same time, pressing the cemented sections into the 2-board jig to assure alignment.

The final step in the process is to add the 23-inch boom end pieces to the open ends of the upper Tees. For the brief period in which the PVC cement is wet, it is possible to misalign the tubing. Dry-fit end caps on the boom ends and do the cement work using the 2-board jig. By pressing the assembly into the right angle of the boards, you can assure that you have a very true boom. When you've put the PVC cement back onto its shelf, your boom should be ready to drill.

Consider the boom-to-mast connection. The lower Tee in Fig 21.118 receives a short length of ½-inch nominal Schedule 40 PVC. This material has an outside diameter of about ⅞-inch, not a useful size for joining to a mast. However, PVC fittings have a handy series of threaded couplers that allow you to screw-fit a series of ever-larger sizes until you reach a more useful size. As **Fig 21.119B** shows, enough of these fittings will finish off with a 1¼-inch threaded female side and a 1¼-inch cement-coupling side. To this fitting, cement a length of 1¼-inch tubing that slides over a length of common TV mast. For a tight fit, wrap the TV mast with several layers of electrical tape in two places — one near the upper end of the PVC pipe section and the other close to where the PVC pipe ends. You may then use stainless steel through-bolts or set-screws to prevent the PVC assembly from turning.

BOOM AND ELEMENTS

Before installing the elements, you need to drill the holes in the boom. The two-board jig comes in handy once more. The key goals in the drilling process are to: A) precisely position the holes; B) create holes that are a fairly tight fit for the rod elements; and C) keep the elements aligned in a flat plane. For this purpose, a drill press is almost a necessity for all but those with the truest eyes.

Use the jig and a couple of clamps to hold the boom assembly in place. Because the assembly has two parallel sections, laying it flat will present the drill press with the correct angle for drilling through the PVC in one stroke. Drill the holes at pre-marked positions, remembering that the driver hole is ⅜ inch while all the others are 3⁄16 inch. Clean the holes, but do not enlarge them in the process.

By now you should have the rod and tube stock in hand. For antenna elements, don't rely on questionable materials that are designed for other applications. Rather, obtain 6063-T832 tubing and 6061-T6 rods from mail order sources, such as Texas Towers, McMasters-Carr, and others. These materials are often not available at local hardware depots.

Cut the parasitic elements to length and smooth their ends with a fine file or sandpaper. Find the center of each element and carefully mark a position about 1⁄16 in. outside where the element will emerge from each side of the boom. You'll drill small holes in these locations. You may wish to very lightly file a flatted area where the hole is to go to prevent the drill bit from slipping as you start the hole.

Drill 1⁄16-inch holes at each marked location all the way through the rod. De-burr the exit ends so that the rod will pass through the boom hole. These holes are the locations for hitch-pin clips. **Fig 21.120** shows the outline of a typical hitch-pin clip, which is also called a hairpin cotter pin in some catalogs and stores. Obtain stainless steel pins whose bodies just fit tightly over the rod when installed. Initially, install 1 pin per parasitic element. Slide the element through the correct boom hole and install the second pin. Although the upper part of the drawing shows a bit of room between the boom and pin, this space is for clarity. Install the pins as close to each side of the boom as you can.

Pins designed for a 3⁄16-inch rod are small enough that they add nothing significant to the element, and antenna tests showed that they did not move the performance curve of the antenna. Yet, they have held securely through a series of shock tests given to the prototype. These pins — in various sizes — offer the home builder a handy fastener that is applicable to many types of portable or field antennas. Although you may wish to use better fasteners when making permanent metal-to-metal connections, for joining sections of Field Day and similar antennas, the hitch-pin clips perform the mechanical function, while clean tubing sections themselves provide adequate electrical contact for a limited period of use.

THE DRIVER AND FEED LINE CONNECTOR

The final construction step is perhaps the one requiring the most attention to detail, as shown in **Fig 21.121**. The driver and feed point assembly consists of a 4- to 6-inch length of ⅜-inch fiberglass or other non-

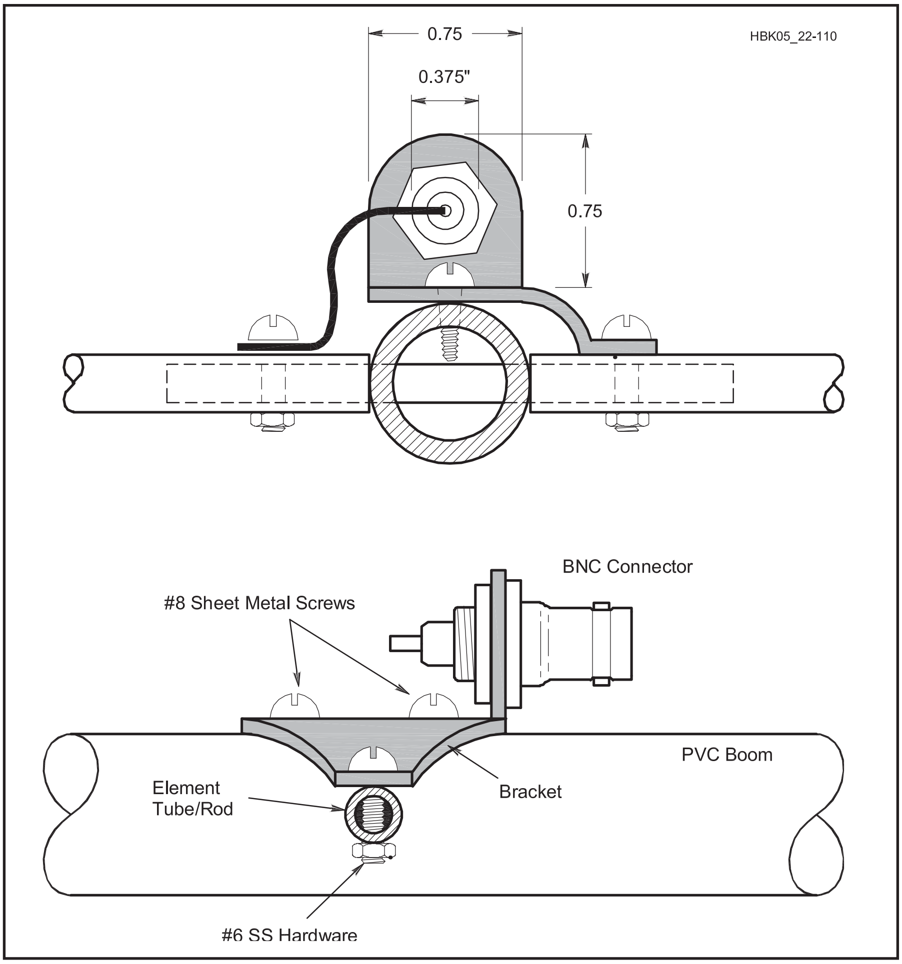


Fig 21.121 — Details of the feed point of the Yagi, showing the BNC connector, mounting plate, and connections to the ½-inch driver element halves placed over a central ⅜-inch fiberglass rod.

conductive rod, two sections of the driver element made from ½-inch aluminum tubing, a BNC connector, a home-made mounting plate, two sets of stainless steel #6 nuts, bolts, and lock-washers, and two stainless steel #8 sheet metal screws. Consult both the upper and lower portions of the figure, since some detail has been omitted from each one to show other detail more clearly.

First, trial fit the driver tubing and the fiberglass rod, marking where the rod exits the boom. Now pre-drill 9⁄64-inch holes through the tubing and the fiberglass rod. Do not use larger hardware, since the resulting hole will weaken the rod, possibly to the breaking point. If you use an alternative plastic material, observe the same caution and be certain that the rod remains strong after drilling. Do not use wooden dowels for this application, since they do not have sufficient strength. Position the holes about ¼ to ⅜ inch from the tubing end where it presses against the boom. One hole will receive a solder lug and the other will connect to an extension of the BNC mounting plate.

Second, install the fiberglass rod through the boom. You can leave it loose, since the elements will press against the boom and hold it in place. Alternatively, you may glue it in place with a two-part epoxy. Slide the driver element tubes over the rod and test the holes for alignment by placing the #6 bolts in them.

Next, cut and shape the BNC mounting plate from 1⁄16-inch thick aluminum. The fitting is made from a scrap of L-stock 1 inch on a side. Before cutting the stock, drill the ⅜-inch hole needed for the BNC connector. Then cut the vertical portion. The horizontal portion requires a curved tab that reaches the bolt on one side of the boom. Use a bench vise to bend the tab in a curve and then flatten it for the bolt-hole. It takes several tries to get the shape and tab exact, so be patient. When the squared-edge piece finds its perfect shape, use a disk sander and round the vertical piece to follow the connector shape. Taper the tap edges to minimize excess material. The last step is to drill the mounting holes that receive the #8 sheet metal screws.

Mounting the assembly involves loosely attaching both the #6 and #8 hardware and alternately tightening up all pieces. Be certain that the side of the BNC connector that receives the coax points toward the mast. Next, mount the BNC connector. The shield side is already connected to one side of the driver. Mount the other side of the driver, placing a solder lug under the bolt head. Connect a short wire as directly as possible from the solder lug to the center pin of the BNC connector. After initial testing, you may coat all exposed connections with Plasti-Dip for weather protection.

TUNE-UP

Testing and tuning the antenna is a simple process if you build carefully. The only significant test that you can perform is to ensure that the SWR curve comes close to the one shown in Fig 21.116. If the SWR is high at 148 MHz but very low at 144 MHz, then you will need to shorten the driver ends by a small amount — no more than ⅛ inch per end at a time. Shaving the ends with a disk sander is most effective.

Using the antenna with vertical polarization will require good spacing from any support structure with metal vertical portions. One of the easiest ways to devise such a mounting is to create a PVC structure hat turns the entire boom by 90°. If you feel the need for added support, you can create can angular brace by placing 45° connectors in both the vertical and horizontal supports and running a length of PVC between them.

As an alternative, you can let the rear part of the boom be slightly long. To this end you can cement PVC fixtures — including the screw-thread series to enlarge the support pipe size. Create a smooth junction that you attach with a through-bolt instead of cement. By drilling one side of the connection with two sets of holes, 90° apart, you can change the antenna from horizontal polarization to vertical and back in short order.

The six-element OWA Yagi for 2 meters performs well. It serves as a good utility antenna with more gain and directivity than the usual three-element general-use Yagi. When vertically polarized, the added gain confirms the wisdom of using a longer boom and more elements. With a length under five feet, the antenna is still compact. The ability to disassemble the parts simplifies moving the antenna to various portable sites.

Editor's note: Section and figure references in this article are from the 2013 edition of the ARRL Handbook. *This material was originally contributed to the* Handbook *by the late L.B. Cebik, W4RNL.*

Rotatable Dipole Inverted-U Antenna

This simple rotatable dipole was designed and built by L. B. Cebik, W4RNL (SK), for use during the ARRL Field Day. For this and other portable operations we look for three antenna characteristics: simplicity, small size, and light weight. Complex assemblies increase the number of things that can go wrong. Large antennas are difficult to transport and sometimes do not fit the space available. Heavy antennas require heavy support structures, so the overall weight seems to increase exponentially with every added pound of antenna.

Today, a number of light-weight collapsible masts are available. When properly guyed, some will support antennas in the 5-10 pound range. Most are suitable for 10 meter tubular dipoles and allow the user to hand-rotate the antenna. Extend the range of the antenna to cover 20-10 meters, and you put these 20-30-foot masts to even better use. The inverted-U meets this need.

THE BASIC IDEA OF THE INVERTED-U

A dipole's highest current occurs within the first half of the distance from the feed point to the outer tips. Therefore, very little performance is lost if the outer end sections are bent. The W4RNL inverted-U starts with a 10 meter tubular dipole. You add extensions for 12, 15, 17 or 20 meters to cover those bands.

You only need enough space to erect a 10 meter rotatable dipole. The extensions hang down. **Fig 21.31** shows the relative proportions of the antenna on all bands from 10 to 20 meters. The 20 meter extensions are the length of half the 10 meter dipole. Therefore, safety dictates an antenna height of at least 20 feet to keep the tips above 10 feet high. At any power level, the ends of a dipole have high RF voltages, and we must keep them out of contact with human body parts.

Not much signal strength is lost by drooping up to half the overall element length straight down. What is lost in bidirectional gain shows up in decreased side-nulls. **Fig 21.32** shows the free-space E-plane (azimuth) patterns of the inverted-U with a 10 meter horizontal section. There is an undetectable decrease in gain between the 10 meter and 15 meter versions. The 20 meter version shows a little over a half-dB gain decrease and a signal increase off the antenna ends.

The real limitation of an inverted-U is a function of the height of the antenna above ground. With the feed point at 20 ft above ground, we obtain the elevation patterns shown in **Fig 21.33**. The 10 meter pattern is typical for a dipole that is about ⅝ λ above ground. On 15, the antenna is only 0.45 λ high, with a resulting increase in the overall elevation angle of the signal and a reduction in gain. At 20 meters, the angle grows still higher, and the signal strength diminishes as the antenna height drops to under 0.3 λ. Nevertheless, the signal is certainly usable. A full-size dipole at 20 meters would show only a little more gain, and the elevation angle would be similar to that of the invert U, despite the difference in antenna shape. If we raise the inverted-U to 40 feet, the 20 meter performance would be very similar to that shown by the 10 meter elevation plot in Fig 21.29.

The feed point impedance of the inverted-U remains well within acceptable limits for virtually all equipment, even at 20 feet above ground. Also, the SWR curves are very broad, reducing the criticalness of finding exact dimensions, even for special field conditions.

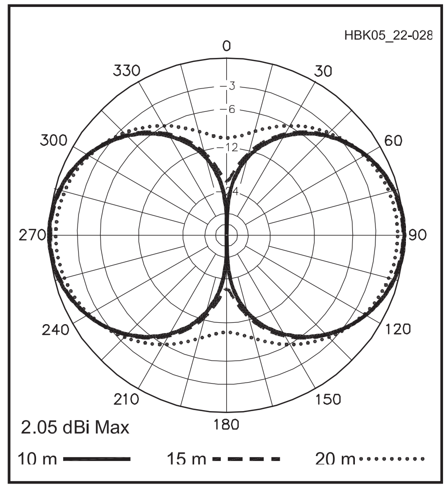


Fig 21.32 — Free-space E-plane (azimuth) patterns of the inverted-U for 10, 15, and 20 meters, showing the pattern changes with increasingly longer vertical end sections.

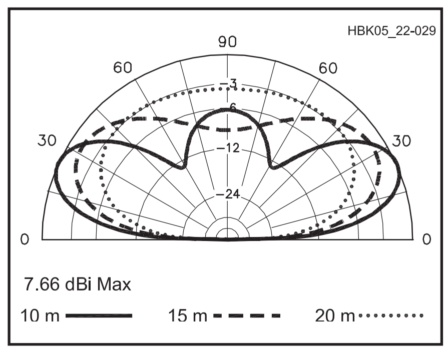


Fig 21.33 — Elevation patterns of the inverted-U for 10, 15, and 20 meters, with the antenna feed point 20 ft above average ground. Much of the decreased gain and higher elevation angle of the pattern at the lowest frequencies is due to its ever-lower height as a fraction of a wavelength.

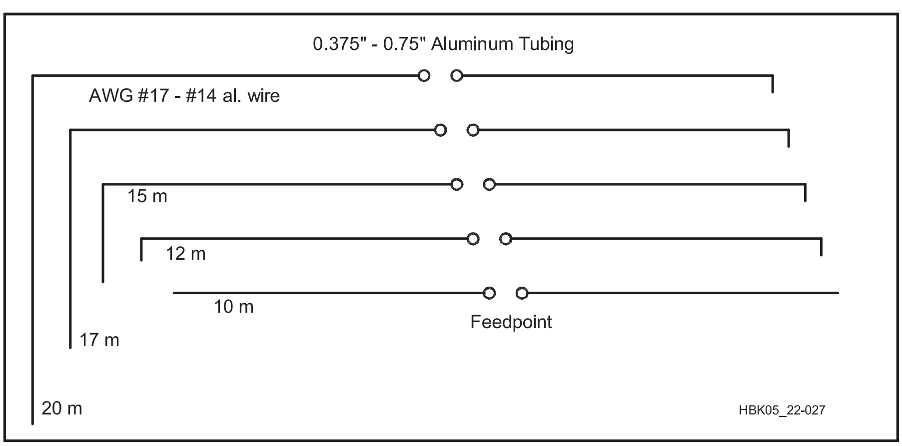


Fig 21.31 — The general outline of the inverted-U field dipole for 20 through 10 meters. Note that the vertical end extension wires apply to both ends of the main 10 meter dipole, which is constant for all bands.

BUILDING AN INVERTED-U

Approach the construction of an inverted-U in 3 steps: 1) the tubing arrangement, 2) the center hub and feed point assembly, and 3) the drooping extensions. A parts list appears in **Table 21.2**.

The Aluminum Tubing Dipole for 10 Meters

The aluminum tubing dipole consists of three longer sections of tubing and a short section mounted permanently to the feed point plate, as shown in **Fig 21.34**. Let's consider each half of the element separately. Counting from the center of the plate — the feed point — the element extends five inches

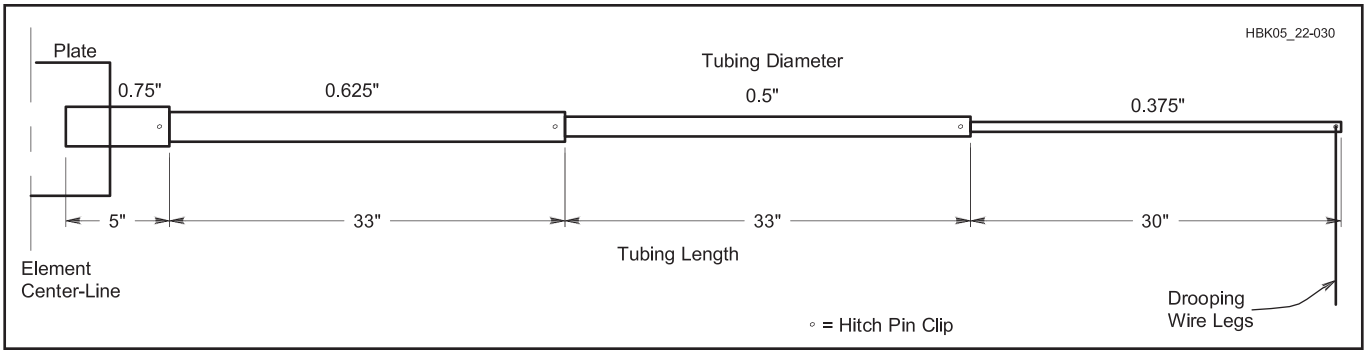


Fig 21.34 — The general tubing layout for the inverted-U for each half element. The opposite side of the dipole is a mirror image of the one shown.

Table 21.2
Parts List for the Inverted-U

Amount	*Item*	*Comments*
6'	0.375" OD aluminum tubing	2 - 3' pieces
6'	0.5" OD aluminum tubing	2 - 3' pieces
6'	0.625" OD aluminum tubing	2 - 3' pieces
10"	0.75" OD aluminum tubing	2 - 5" pieces
4"	0.5" nominal (⅝" OD) CPVC	
50'	Aluminum wire AWG #17	
8	Hitch pin clips	Sized to fit tubing junctions.
1	4" by 4" by ¼" Lexan plate	Other materials suitable.
2	SS U-bolts	Sized to fit support mast
2	Sets SS #8/10 1.5" bolt, nut, washers	SS = stainless steel
2	Sets SS #8 1" bolt, nut, washers	
2	Sets SS #8 0.5" bolt, nut, washers	
1	Coax connector bracket, 1⁄16" aluminum	See text for dimensions and shape
1	Female coax connector	
2	Solder lugs, #8 holes	
2	Short pieces copper wire	From coax connector to solder lugs

Note: 6063-T832 aluminum tubing is preferred and can be obtained from such outlets as Texas Towers (**www.texastowers.com**). Lexan (polycarbonate) is available from such sources as McMasters-Carr (**www.mcmasters.com**), as are the hitch pin clips (if not locally available). Other items should be available from local home centers and radio parts stores.

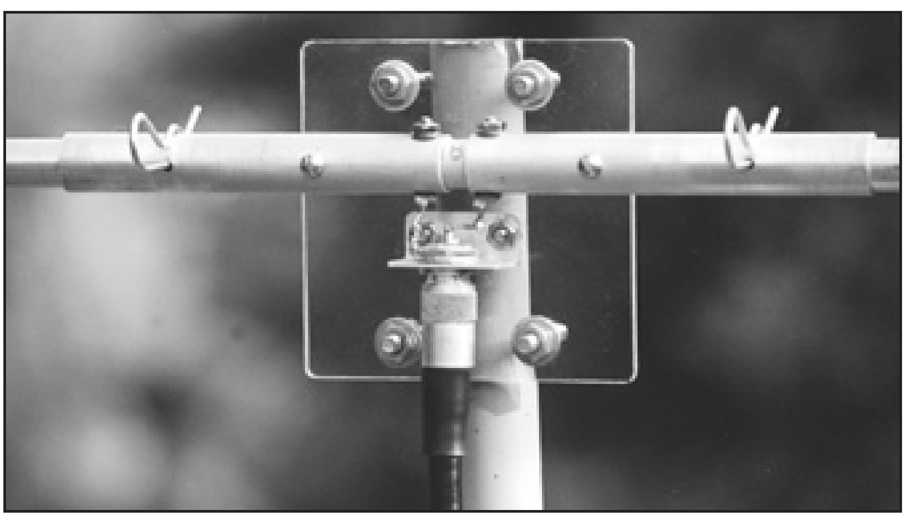


Fig 21.35 — A close-up of the element mounting plate assembly, including the hitch pin clips used to secure the next section of tubing.

using ¾-inch aluminum tubing. Then we have two 33-inch exposed tubing sections, with an additional three inches of tubing overlap per section. These sections are ⅝- and ½-inch diameter, respectively. The outer section is 30 inches long exposed (with at least a three-inch overlap) and consists of ⅜-inch diameter tubing.

Since the ⅝- and ½-inch sections are 36 inches long, you can make the outer ⅜-inch section the same overall length and use more overlap, or you can cut the tubing to 33 inches and use the 3-inch overlap. Three inches of overlap is sufficient to ensure a strong junction, and it minimizes excess weight. However, when not in use, the three outer tubing sections will nest inside each other for storage, and a 36-inch length for the outer section is a bit more convenient to un-nest for assembly. Keep the end hitch pin on the ⅜ inch tubing as an easy way of pulling it into final position. You may use the readily available 6063-T832 aluminum tubing that nests well and has a long history of antenna service.

The only construction operation that you need to perform on the tubing is to drill a hole at about the center of each junction to pass a hitch pin clip. Obtain hitch pin clips (also called hairpin cotter pin clips in some literature) that fit snugly over the tubing. One size will generally handle about two or three tubing sizes. This antenna uses 3⁄32 (pin diameter) by 2⅝-inch long clips for the ¾- to ⅝-inch and the ⅝- to ½-inch junctions, with 3⁄32 by 1⅝-inch pins for the ½- to ⅜-inch junction and for the final hitch pin clip at the outer end of the antenna. Drill the ⅛-inch diameter holes for the clips with the adjacent tubes in position relative to each other. Tape the junction temporarily for the drilling. Carefully de-burr the holes so that the tubing slides easily when nested.

The hitch pin clip junctions, shown in **Fig 21.35**, hold the element sections in position. Actual electrical contact between sections is made by the overlapping portions of the tube. Due to the effects of weather, junctions of this type are not suitable for a permanent installation, but are completely satisfactory for short-term use. Good electrical contact requires clean, dry aluminum surfaces, so do not use any type of lubricant to assist the nesting and un-nesting of the tubes. Instead, clean both the inner and outer surfaces of the tubes before and after each use.

Hitch pin clips are fairly large and harder to lose in the grass of a field site than most nuts and bolts. To avoid losing the clips, attach a short colorful ribbon to the loop end of each clip.

Each half element is 101 inches long, for a total 10 meter dipole element length of 202 inches (16 ft 10 inches). Length is not critical within about one inch, so you may pre-assemble the dipole using the listed dimensions. However, if you wish a more precisely tuned element, tape the outer section in position and test the dipole on your mast at the height that you will use. Adjust the length of the outer tubing segments equally at both ends for the best SWR curve on the lower 1 MHz of the 10 meter band. Even though the impedance will be above 50 Ω throughout the band, you should easily obtain an SWR curve under 2:1 that covers the entire band segment.

The Center Hub: Mounting and Feed Point Assembly

Construct the plate for mounting the element and the mast from a 4 × 4 × ¼-inch-thick scrap of polycarbonate (trade name Lexan), as shown in **Fig 21.36**. You may use other materials so long as they will handle the element weight and stand up to field conditions.

At the top and bottom of the plate are holes for the U-bolts that fit around the mast. Since masts may vary in diameter at the top, size your U-bolts and their holes to suit the mast.

The element center, consisting of two five-inch lengths of ¾-inch aluminum tubing, is just above the centerline of the plate (to allow room for the coax fitting below). ½-inch nominal CPVC has an outside diameter of about ⅝ inch and makes a snug fit inside the ¾-inch tubing. The CPVC aligns the two aluminum tubes in a straight line and allows for a small (about ½ inch) gap between them. When centered between the two tubes, the CPVC is the same width as the plate. A pair of 1.5-inch #8 or #10 stainless steel bolts — with washers and a nut — secures the element to the plate.

Note in the sketch that you may insert the ⅝-inch tube as far into the ¾-inch tube as it will go and be assured of a three-inch overlap. Drill all hitch pin clip holes perpendicular to the plate. Although this alignment is not critical to the junctions of the tubes, it is important to the outer ends of the tubes when you use the antenna below 10 meters.

Mount a single-hole female UHF connector on a bracket made from a scrap of ¹⁄₁₆-inch-thick L-stock that is 1 inch on a side. Drill the UHF mounting hole first, before cutting the L-stock to length and trimming part of the mounting side. Then drill two holes for ½-inch long #8 stainless steel bolts about 1 inch apart, for a total length of L-stock of about 1.5 inches. The reason for the wide strip is to place the bolt heads for the bracket outside the area where the mast will meet the plate on the back side. Note in Fig 21.36 that the bracket nuts are on the bracket-side of the main plate, while the heads face the mast. The bracket-to-plate mounting edge of the bracket needs to be only about ¾ inch wide, so you may trim that side of the L-stock accordingly.

With the element center sections and the bracket in place, drill two holes for one-inch long #8 stainless steel bolts at right angles to the mounting bolts and as close as feasible to the edges of the tubing at the gap. These bolts have solder lugs attached for short leads to the coax fitting. Solder lugs do not come in stainless steel, so you should check these junctions before and after each use for any corrosion that may require replacement.

With all hardware in place, the hub unit is about 4 × 10 × 1 inch (plus U-bolts). It will remain a single unit from this point onward, so that your only field assembly requirements will be to extend tubing sections and install hitch pin clips. You are now ready to perform the initial 10 meter resonance tests on your field mast.

The Drooping Extensions for 12-20 Meters

The drooping end sections consist of aluminum wire. Copper is usable, but aluminum is lighter and quite satisfactory for this application. **Table 21.3** lists the approximate lengths of each extension *below* the element. Add three to five inches of wire — less for 12 meters, more for 20 meters — to each length listed.

Common #17 AWG aluminum electric fencing wire works well. Fence wire is stiffer than most wires of similar diameter, and it is cheap. Stiffness is the more important property, since you do not want the lower ends of the wire to wave excessively in the breeze,

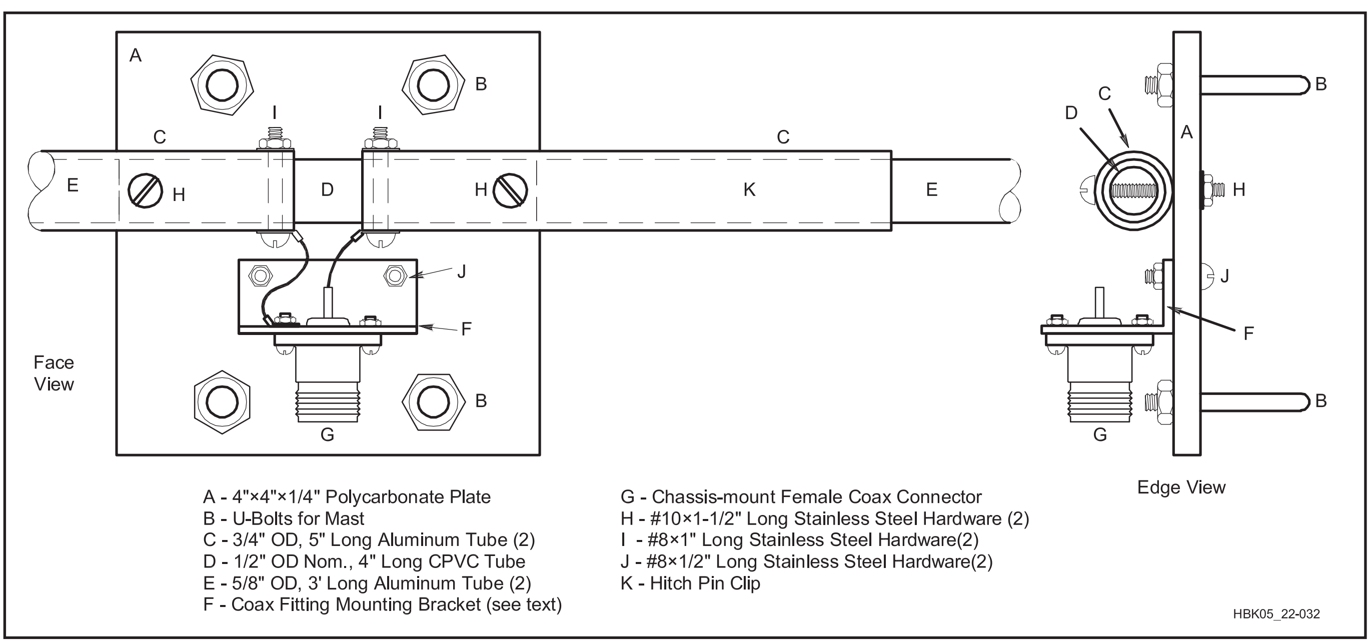


Fig 21.36 — The element and feed point mounting plate, with details of the construction used in the prototype.

Table 21.3
Inverted-U Drooping Wire Lengths

Band (meters)	*Wire Length (inches)*
10	n/a
12	15.9
15	37.4
17	62.0
20	108.0

Note: The wire length for the drooping ends is measured from the end of the tubular dipole to the tip for #17 AWG wire. Little change in length occurs as a function of the change in wire size. However, a few inches of additional wire length is required for attachment to the element.

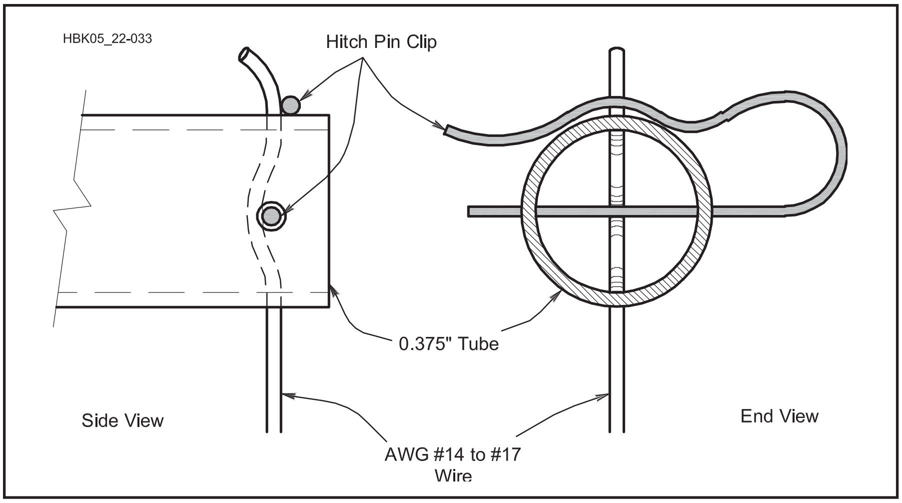


Fig 21.37 — A simple method of clamping the end wires to the ⅜-inch tube end using a hitch pin clip.

potentially changing the feed point properties of the antenna while it is in use.

When stored, the lengths of wire extensions for 12 and 15 meters can be laid out without any bends. However, the longer extensions for 17 and 20 meters will require some coiling or folding to fit the same space as the tubing when nested. Fold or coil the wire around any kind of small spindle that has at least a two-inch diameter (larger is better). This measure prevents the wire from crimping and eventually breaking. Murphy dictates that a wire will break in the middle of an operating session. So carry some spare wire for replacement ends. All together, the ends require about 50 ft of wire.

Fig 21.37 shows the simple mounting scheme for the end wires. Push the straight wires through a pair of holes aligned vertically to the earth and bend the top portion slightly. To clamp the wire, insert a hitch pin clip though holes parallel to the ground, pushing the wire slightly to one side to reach the far hole in the tube. The double bend holds the wire securely (for a short-term field operation), but allows the wire to be pulled out when the session is over or to change bands.

Add a few inches to the lengths given in Table 21.3 as an initial guide for each band. Test the lengths and prune the wires until you obtain a smooth SWR curve below 2:1 at the ends of each band. Since an inverted-U antenna is full length, the SWR curves will be rather broad and suffer none of the narrow bandwidths associated with inductively loaded elements. **Fig 21.38** shows typical SWR curves for each band to guide your expectations.

You should not require much, if any, adjustment once you have found satisfactory lengths for each band. So you can mark the wire when you finish your initial test adjustments. However, leave enough excess so that you can adjust the lengths in the field.

Do not be too finicky about your SWR curves. An initial test and possibly one adjustment should be all that you need to arrive at an SWR value that is satisfactory for your equipment. Spending half of your operating time adjusting the elements for as near to a 1:1 SWR curve as possible will rob you of valuable contacts without changing your signal strength is any manner that is detectable.

Changing bands is a simple matter. Remove the ends for the band you are using and install the ends for the new band. An SWR check and possibly one more adjustment of the end lengths will put you back on the air.

FINAL NOTES

The inverted-U dipole with interchangeable end pieces provides a compact field antenna. All of the parts fit in a 3-ft long bag. A draw-string bag works very well. **Fig 21.39** shows the parts in their travel form. When assembled and mounted at least 20 feet up (higher is even better), the antenna will compete with just about any other dipole mounted at the same height. But the inverted-U is lighter than most dipoles at frequencies lower than 10 meters. It also rotates easily by hand — assuming that you can rotate the mast by hand. Being able to broadside the dipole to your target station gives the inverted-U a strong advantage over a fixed wire dipole.

With a dipole having drooping ends, safety is very important. Do not use the antenna unless the wire ends for 20 meters are higher than any person can touch when the antenna is in use. Even with QRP power levels, the RF voltage on the wire ends can be dangerous. With the antenna at 20 feet at its center, the ends should be at least 10 feet above ground.

Equally important is the maintenance that you give the antenna before and after each use. Be sure that the aluminum tubing is clean — both inside and out — when you nest and un-nest the sections. Grit can freeze the sections together, and dirty tubing can prevent good electrical continuity. Carry a few extra hitch pin clips in the package to be sure you have spares in case you lose one.

Scaling Up the Inverted-U

To inverted-U's rotatable dipole can be scaled up by as much as a factor of three with correspondingly heavier mounting plate and tubing diameters. This results in a rotatable dipole that can be used as low as 30 meters with excellent performance. A full-sized dipole is a very efficient antenna and will hold its own with two-element Yagis at comparable heights.

Suitable tubing and mounting hardware can be obtained by scavenging pieces from old tri-band HF Yagis that have been damaged or taken out of service. Metal boom-to-mast plates can be used if the antenna elements are insulated by enclosing them in a piece of exterior plastic electrical conduit whose inside diameter is a close match to the element's outside diameter. Cut a ¼-inch slot along the length of the conduit so that it can be compressed around the element by the U-bolt or muffler clamp.

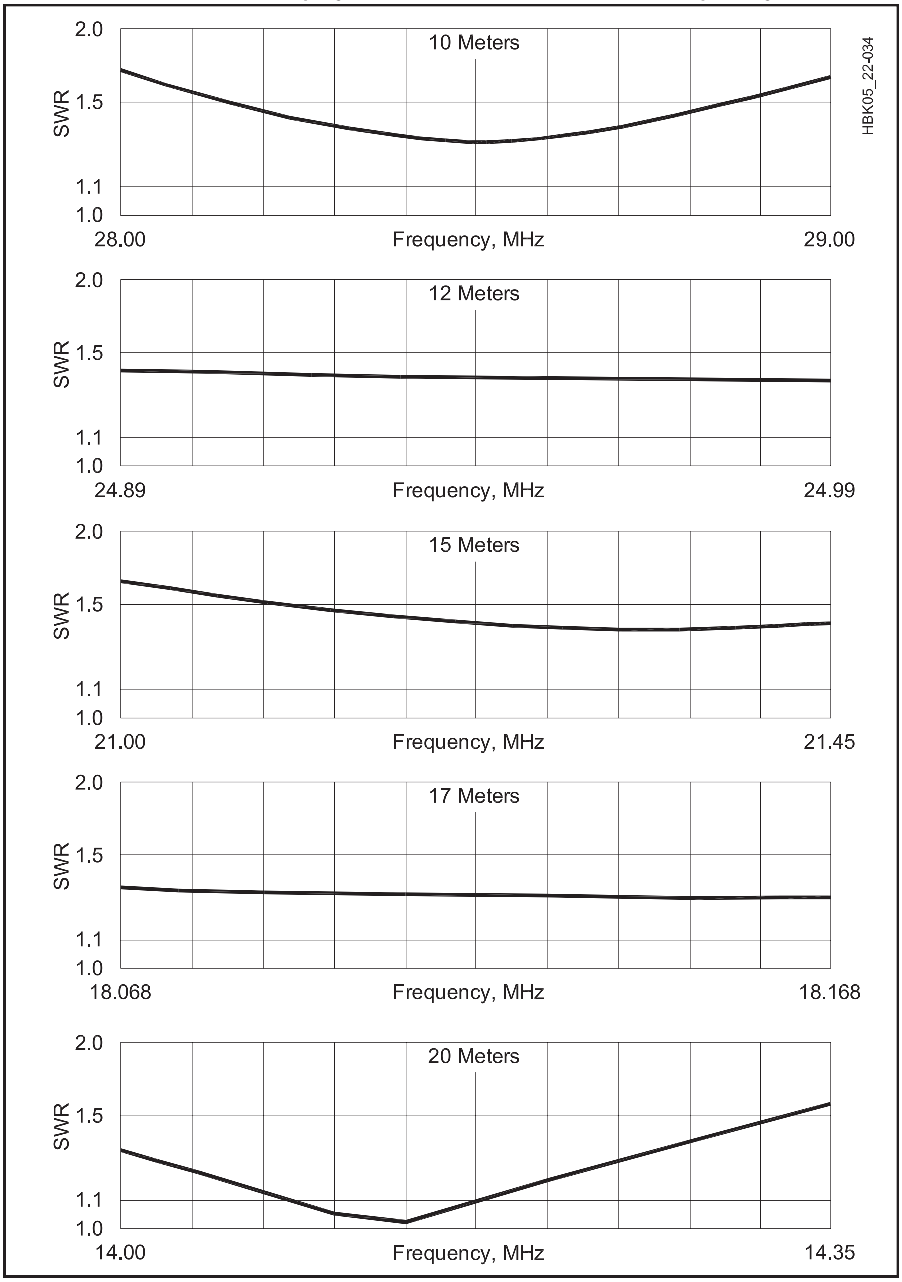


Fig 21.38 — Typical 50-Ω SWR curves for the inverted-U antenna at a feed point height of 20 ft.

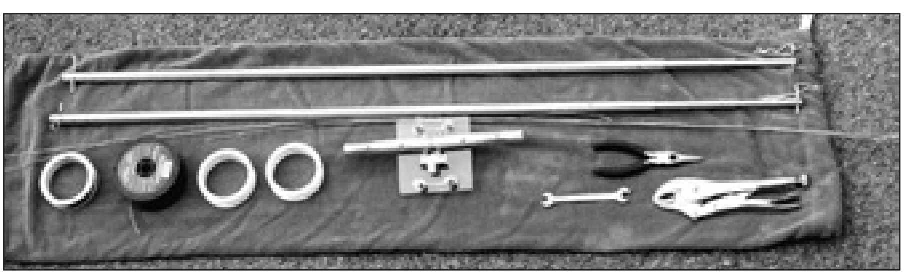


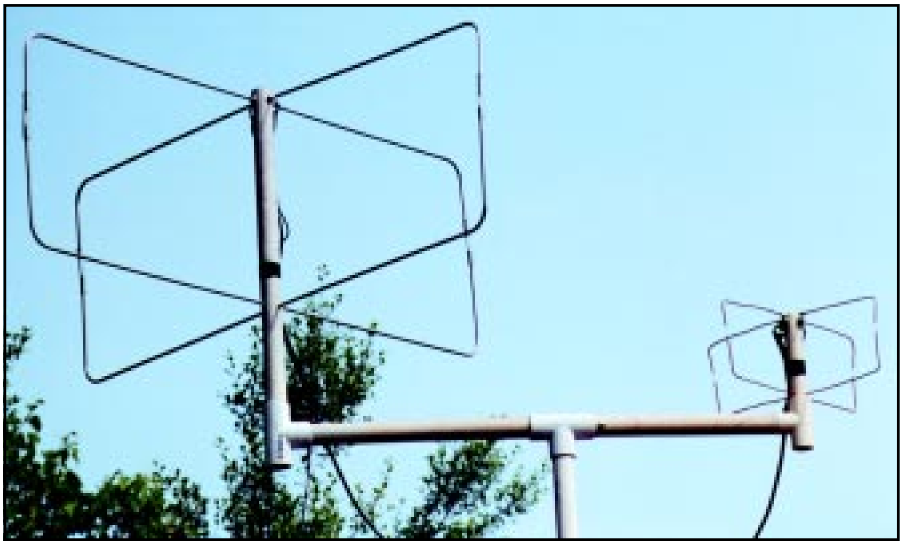
Fig 21.39 — The entire inverted-U antenna parts collection in semi-nested form, with its carrying bag. The tools stored with the antenna include a wrench to tighten the U-bolts for the mast-to-plate mount and a pair of pliers to help remove end wires from the tubing. The pliers have a wire-cutting feature to help replace a broken end wire. A pair of locking pliers makes a good removable handle for turning the mast. The combination of the locking and regular pliers helps to uncoil the wire extensions for any band; give them a couple of sharp tugs to straighten the wire.

By L. B. Cebik, W4RNL

A Simple Fixed Antenna for VHF/UHF Satellite Work

Explore the low-Earth orbiting amateur satellites with this effective antenna system.

When we are just getting interested in amateur satellite operation, the thought of investing in a complex azimuth-elevation rotator system to track satellites across the sky can stop us in our tracks. For starters, we need a simple, reliable, fixed antenna—or set of antennas—to see if we really want to pursue this aspect of Amateur Radio to its limit. We'll look at the basics of fixed antenna satellite work and develop a simple antenna system suited for the home workshop. There will be versions for both 145 and 435 MHz.



Turnstiles and Satellites

For more than decades, many fixed-position satellite antennas for VHF and UHF have used a version of the turnstile. The word "turnstile" actually refers to two different ideas. One is a particular antenna: two crossed dipoles fed 90° out of phase. The other is the principle of obtaining omnidirectional patterns by phasing almost any crossed antennas 90° out of phase. The first idea limits us to a single antenna. The second idea opens the door to adapting many possible antennas to omnidirectional work.

Figure 1 shows one general method of obtaining the 90° phase shift that we need for omnidirectional patterns. Note that the coax center conductor connects to only one of the two crossed elements. A $^{1}/_{4}$-λ section of transmission line that has the same characteristic impedance as the natural feed point impedance of the first antenna element alone connects one element to the next. The opposing ends of the two elements go to the braid at each end of the transmission line. If the elements happen to be dipoles, then a 70 to 75-Ω transmission line is ideal for the phasing line. However, the resulting impedance at the overall antenna feed point will be exactly half the impedance of one element alone. So we will obtain an impedance of about 35 Ω. For the dipole-based turnstile antenna, we'll either have to accept an SWR of about 1.4:1 or we'll have to use a matching section to bring the antenna to 50 Ω. A parallel set of RG-63 $^{1}/_{4}$-λ lines will yield about 43 Ω impedance, about right to bring the 35-Ω antenna impedance to 50 Ω for the main coax feed line. For all such systems, we must remember to account for the velocity factor of the transmission line, which will yield a line length that is shorter than a true quarter wavelength.

The dipole-based turnstile is popular for fixed-position satellite work. Figure 2 shows—on the left—one recommended system that has been in *The ARRL Antenna Book* since the 1970s. For 2 meters, a standard dipole-turnstile sits over a large screen that simulates ground. Spacing the elements from the screen by between $^{1}/_{4}$ and $^{3}/_{8}$ of a wavelength is recommended for the best pattern. For satellite operation, the object is to obtain as close to a dome-like pattern overhead as possible. The most desirable condition is to have the dome extend as far down toward the horizon as possible to let us communicate with satellites as long as possible during a pass.

The turnstile-and-screen system, while simple, is fairly bulky and prone to wind damage. However, the turnstile loses performance if we omit the screen. One way to reduce the bulk of our antenna is to find an antenna with its own reflector. However, it must have a good pattern for the desired goal of a transmitting and receiving dome in the sky. The dual Moxon rectangle array, shown in outline form on the right of Figure 2, offers some advantages over the traditional turnstile. First, it yields a somewhat better dome-like pattern. Second, it is relatively easy to build and compact to install.

Almost every fixed satellite antenna

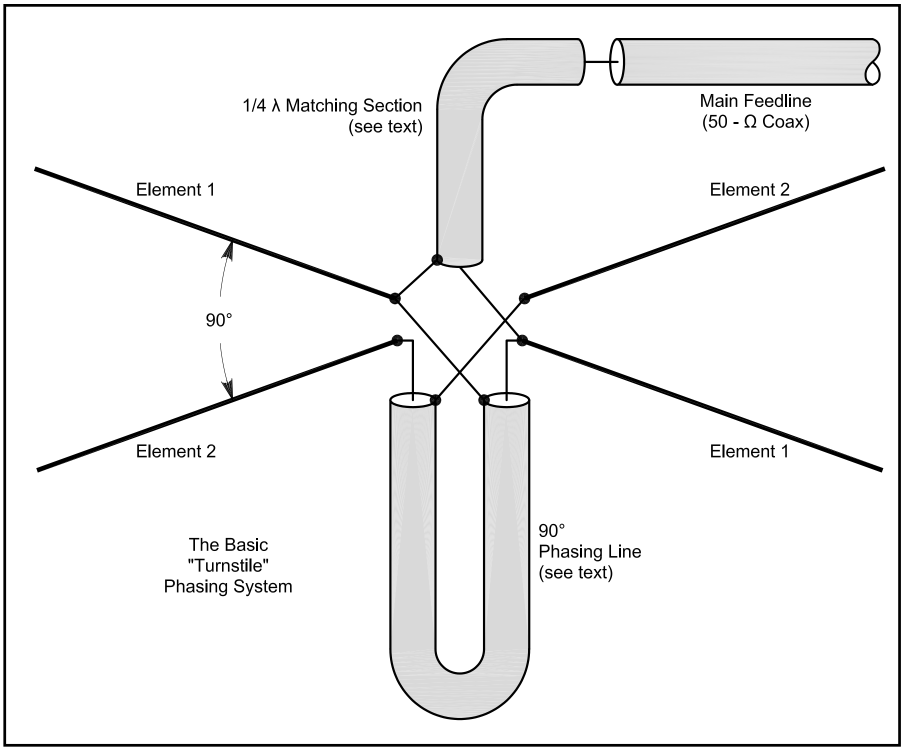


Figure 1—The basic turnstile phasing (and matching) system for any antenna set requiring a 90° phase shift between driven elements in proximity.

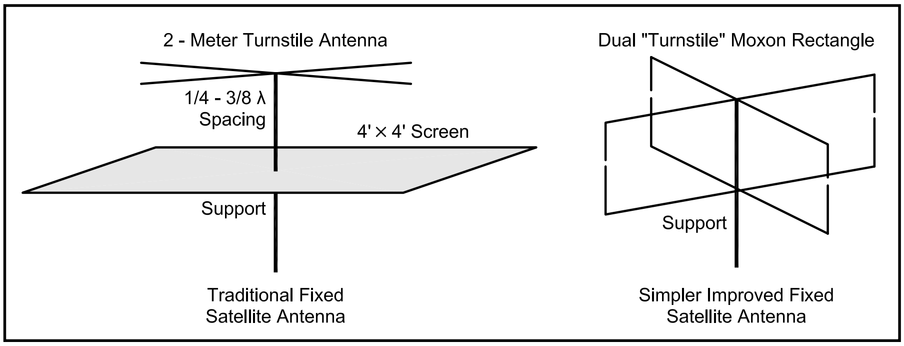


Figure 2—Alternative schemes for fixed-position satellite antennas: the traditional turnstile-and-screen and a pair of "turnstiled" Moxon rectangles.

shows deep nulls at lower angles, and the number of nulls increases as we raise the antenna too high, thus defeating the desire for communications when satellites are at low angles. Figure 3 shows the elevation patterns of a turnstile-and-screen and of a pair of Moxon rectangles when both are 2λ above the ground. A 1λ height will reduce the low angle ripples even more, if that height is feasible. However, the builder always has to balance the effects of height on the pattern against the effects of ground clutter that may block the horizon.

The elevation patterns show the considerably smoother pattern dome of the Moxon pair over the traditional turnstile. The middle of the turnstile dome has nearly 2 dB less gain than its peaks, while the top valleys are nearly 3 dB lower than the peaks. The peaks and valleys can make the difference between successful communications and broken-up transmissions. So, for the purpose of obtaining a good dome, the Moxon pair may be superior.

A reasonable suggestion offered to me was simply to add reflectors to a standard dipole turnstile and possibly obtain the same freedom from a grid or screen structure. Figure 4 shows the limitation of that solution. The result of placing reflectors behind the dipole turnstile is a pair of crossed 2-element Yagi beams fed 90° out of phase. The pattern is indeed circular and stronger than that of the Moxon pair. However, the beamwidth is reduced to only 56° at the half-power points. The antenna would make an excellent starter for a tracking AZ-EL rotator system, but it does not have the beamwidth for good fixed-position service.

The Moxon pair, with lower but smoother gain across the sky dome, offers the fixed-antenna user the chance to build a successful beginning satellite antenna. The pattern will be circular within under a 0.2-dB difference for 145.5 to 146.5 MHz, and within 0.5 dB for the entire 2-meter band. Since satellite work is concentrated in the 145.8 to 146.0 MHz region, the broadbanded antenna will prove fairly easy to build with success. A 435.6 MHz version, designed to cover the 435 to 436.2 MHz region of satellite activity will have an even larger bandwidth.

Like the dipole-based turnstile, the Moxons will be fed 90° out of phase with a 1/4-λ phasing line of 50-Ω coaxial cable. The drivers will be connected just as shown in Figure 1. Since the natural feedpoint impedance of a single Moxon rectangle of the design used here is 50 Ω, the pair will show a 25-Ω feed-point impedance. Paralleled 1/4-λ sections of 70- to 75-Ω coaxial cable will transform the low impedance to a good match for the main 50-Ω coaxial line to the rig. In short, we have "turnstiled" the Moxon rectangles into a reasonable fixed-position satellite antenna.

Building the Moxon Pairs

The Moxon rectangle is a modification of the reflector-driver Yagi parasitic beam. However, instead of using linear elements, the driver and reflector are bent back toward each other. The coupling between the ends of the elements combined with the coupling between parallel sections of the elements combine to produce a pattern with a broad beamwidth. By carefully selecting the dimensions, we can obtain both good performance (meaning adequate gain and an excellent front-to-back ratio) and a 50-Ω feed point impedance.[1]

In fact, a single Moxon rectangle might be used on each band for reasonably adequate satellite service. When pointed straight up, the Moxon rectangle pattern is a very broad oval, although not a circle. The oval pattern also gives the Moxon another advantage over dipoles in a turnstile configuration. If the phasing-line between dipoles is not accurately cut, the normal turnstile near-circle pattern degrades into an oval fairly quickly be-

[1]See "Having a Field Day with the Moxon Rectangle," *QST*, June, 2000, pp 38-42, for further details on the operation of the Moxon rectangle, along with the references in the notes to that article. Also included in the notes is the source for a program to calculate the dimensions for a 50-Ω Moxon rectangle for any HF or VHF frequency using only the design frequency and the element diameter as inputs.

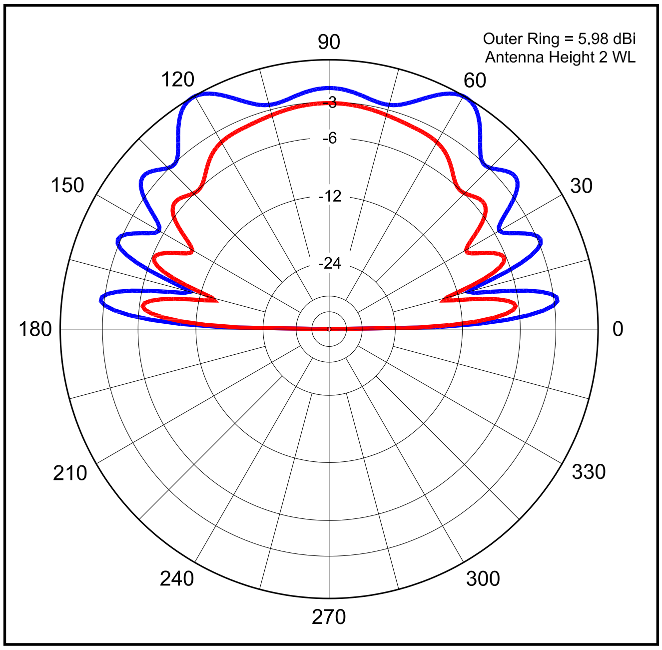


Figure 3—A comparison of elevation patterns for the turnstile-and-screen system (with 3/8λ wavelength spacing, shown in blue) and a Moxon pair (shown in red), both at 2λ height.

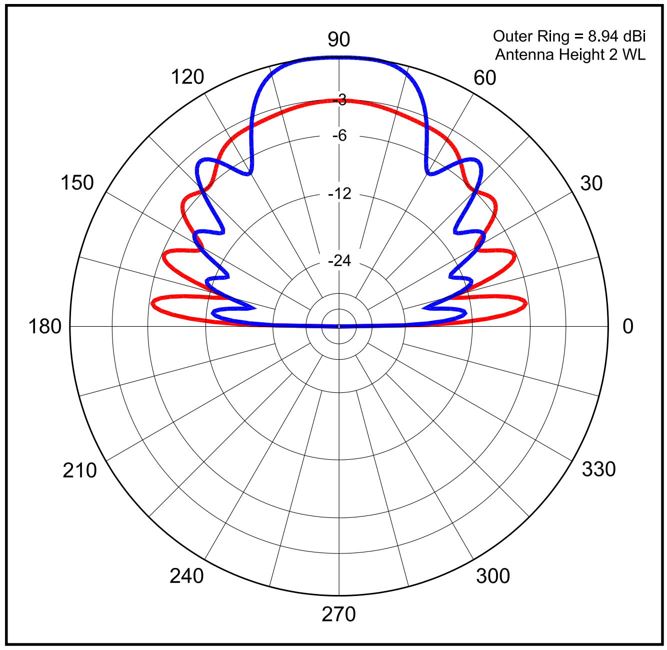


Figure 4—A comparison of elevation patterns for 2-element turnstiles (crossed 2-element Yagis, shown in blue) and a Moxon pair (shown in red), both at 2λ height.

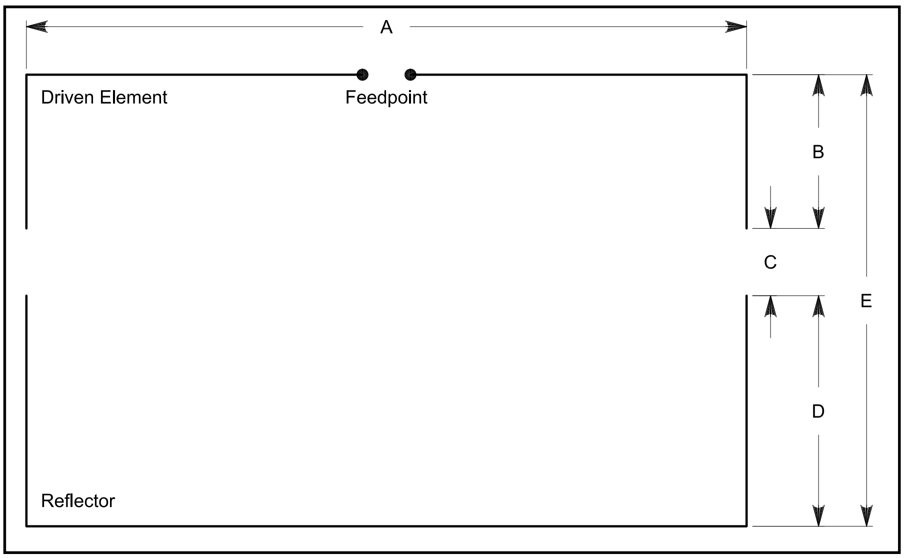


Figure 5—The basic dimensions of a Moxon rectangle. Two identical rectangles are required for each "turnstiled" pair.

Table 1
Dimensions for Moxon Rectangles for Satellite Use

Two are required for each antenna. The phase-line is 50-Ω coaxial cable and the matching line is parallel sections of 75-Ω coaxial cable. Low power cables less than 0.15 inches in outer diameter were used in the prototypes. See Figure 5 for letter references. All dimensions are in inches.

Dimension	*145.9 MHz*	*435.6 MHz*
A	29.05	9.72
B	3.81	1.25
C	1.40	0.49
D	5.59	1.88
E (B + C + D)	10.80	3.62
1/4 wavelength 0.66 velocity factor phasing and matching lines	20.22 13.35	6.77 4.47

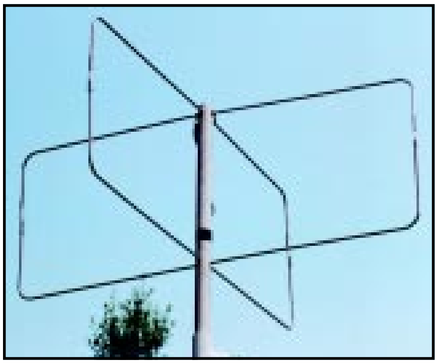
cause the initial single dipole pattern is a figure 8. The single Moxon oval pattern allows both dimensional inaccuracies and phasing-line inaccuracies of considerable amounts before degrading from a nearly perfect circle.

Figure 5 shows the critical dimensions for a Moxon rectangle. The lettered references are keys to the dimensions in Table 1. The design frequencies for the two satellite antenna pairs are 145.9 MHz and 435.5 MHz, the centers of the satellite activity on these two bands. The 2-meter Moxon prototype uses 3/16-inch diameter rod, while the 435 MHz version uses #12 AWG wire with a nominal 0.0808-inch diameter. (Single Moxons built to these dimensions would cover all of 2-meters and about 12 MHz of the 432 MHz band.) Going one small step up or down in element diameter will still produce a usable antenna, but major diameter changes will require that the dimensions be recalculated.

The reflectors are constructed from a single piece of wire or rod. I use a small tubing bender to create the corners. The rounding of the corners creates a slight excess of wire for the overall dimensions in the table. I normally arrange the curve so that the excess is split between the side-to-side dimension (A) and the reflector tail (D). Practicing on some scrap house wire may make the task go well the first time with the actual aluminum rod. The total reflector length should be A + (2 × D).

The driver consists of two pieces, since we'll split the element at its center for the feeding and phasing system. I usually make the pieces a bit longer before bending and trim them to size afterwards. The total length of the driver, including the open area for connections, should be A + (2 × B).

Perhaps the most critical dimension is



A close-up view of the 145.9 MHz rectangle pair.

the gap, C. I have found nylon tubing, available at hardware depots, to be very good to keep the rod ends aligned and correctly spaced. When everything has been tested and found correct, a little super-glue on the tubing ends and aluminum stands up to a lot of wind. I usually nick the aluminum just a little to let the glue settle in and lock the junction. For the UHF version, a short length of heat-shrink tubing provides a lock for the size of the gap and the alignment of the element tails.

It is one thing to make a single Moxon and another to make a working crossed pair. Figure 6 shows the general scheme that I used for the prototypes, using CPVC. (Standard schedule 40 or thinner PVC or fiberglass tubing can also be used.) The support stock is $^3/_4$ inch nominal. The reflectors go into slots at the bottom of the tube and are locked in two ways. Whether or not the two reflectors make contact at their center points makes no difference to performance, so I ran a very small sheet screw through both 2-meter reflectors to keep their relative positions firm. I soldered the centers of the 435-MHz reflectors. Then I added a coupling to the bottom of the CPVC to support the double reflector assembly and to connect the boom to a support mast. Cementing or pressure fitting the cap is a user option.

The feed point assemblies are attached to solder lugs. The phasing line is routed down one side of the support, while the matching section line is run down the other. Electrical tape holds them in place. For worse weather, the tape may be over-sealed with butylate or other coatings. Likewise, the exposed ends of the coax sections and the contacts themselves should be sealed from the weather. The details can be seen—as built for the experimental prototypes in one of the photos—before sealing, since lumps of butylate or other coatings tend to obscure interesting details.

The overall assembly of the two antennas appears in the second photograph. The PVC from the support **T**s can go to a center Tee that also holds the main support for the two antennas. A series of adapters, made from miscellaneous PVC parts to fit over a standard length of TV mast. Alternatively, the antennas can be separately mounted about 10 feet apart. The 10-foot height of the assembly has proven adequate for general satellite reception,

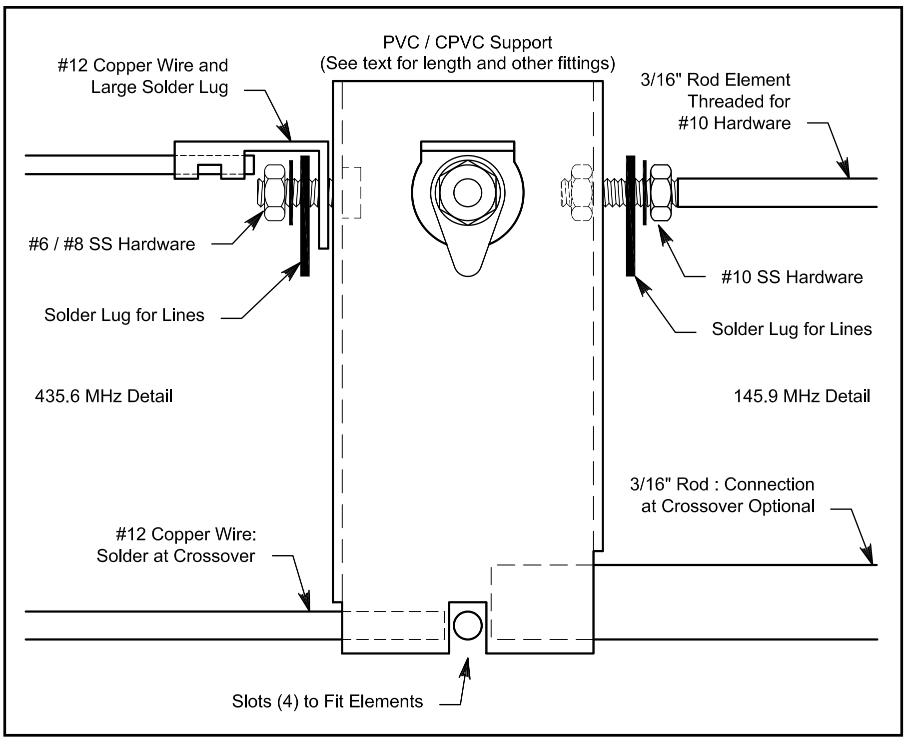
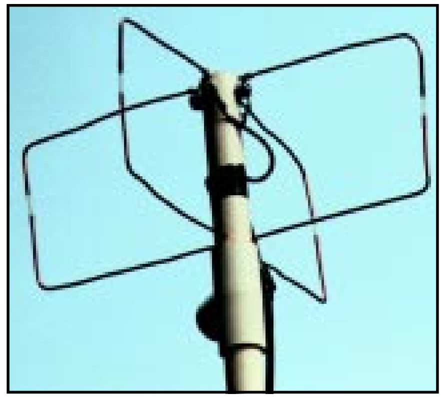


Figure 6—Some construction details for the Moxon pairs constructed as prototypes.



The 435-MHz Moxons.

although I live almost at the peak of a hill.

The antennas can be mounted on the same mast. However, for similar sky-dome patterns, they should each be the same number of wavelengths above ground. For example, if the 2-meter antenna is about two wavelengths up at about 14 feet or so, then the bottom of the 435-MHz antenna should be only about 4.5 feet above the ground. Placing the higher-frequency antenna below the 2-meter assembly will create some small irregularities in the desired dome pattern, but not serious enough to affect general operation.

There is no useful adjustment to these antennas except for making the gap between the drivers and reflectors as accurate as possible. Turnstile antennas show a very broad SWR curve. Across 2 meters, for example, the highest SWR is under 1.1:1. However, serious errors in the phasing line length can result in distortions to the desired circular pattern. There is no substitute for checking the lengths of the phasing line and the matching section several times before cutting. The correct length is from one junction to the next, including the portions of exposed cable interior.

These two little antennas will not compete with tracking AZ-EL rotating systems for horizon-to-horizon satellite activity. For satellite work, however, power is not always the problem (except for using too much) and modern receiver front-ends have enough sensitivity to make communication easy. So when the satellite reaches an angle of about 30° above the horizon, these antennas will give a very reasonable account of themselves. When you become so addicted to satellite communication that you invest in the complete tracking system, these antennas can be used as back-ups while parts of the complex system are down for maintenance!

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ARRL Lab Engineer: **w1vt@arrl.org**

A Triband Dipole for 30, 17, and 12 Meters

W1VT describes a dipole antenna that can fill in some gaps in band coverage for many stations.

Here is a simple wire dipole that works well on the 30 meter, 17 meter, and 12 meter amateur bands. A cleverly designed section of 600 Ω ladder line allows the use of a 1:1 choke balun and 50 Ω coax back to the radio with good efficiency, although a tuner at the radio is necessary to get the very low SWR most hams desire.

If your radio has a built-in autotuner, you can have the efficiency and ease of use of a coax fed monoband dipole on three bands, without the hassle of bringing open wire into the shack. The SWR is below 3:1 over these three bands — low enough to allow efficient matching with a tuner at the radio. This antenna would be a good complement to the many popular antennas that don't cover one or more of these bands. The popular G5RV and ZS6BKW multiband wire dipoles have high SWR on 30 meters — resulting in very poor system efficiencies, if a match can be obtained at all.

I discovered this antenna while running computer simulations based on the ⅓ wavelength dipole — by adding ⅙th wavelength of feed line to this particular length of dipole — one obtains resonances on many harmonics, making it quite useful for multiband operation.[1, 2] I looked at two more variables besides dipole and feeder length — height above ground and ladder line impedance. I found that if I increased the ladder line impedance, I could tweak the harmonic resonances to land precisely on the 10 and 25 MHz bands. The article by Taft mentions harmonic displacement and suggested tuning the transmitter to compensate — I used it to advantage! It helped that I was not looking for a perfect match, or I may not have looked at matching impedances far from the optimum value of 375 Ω for the ⅓ wavelength dipole.

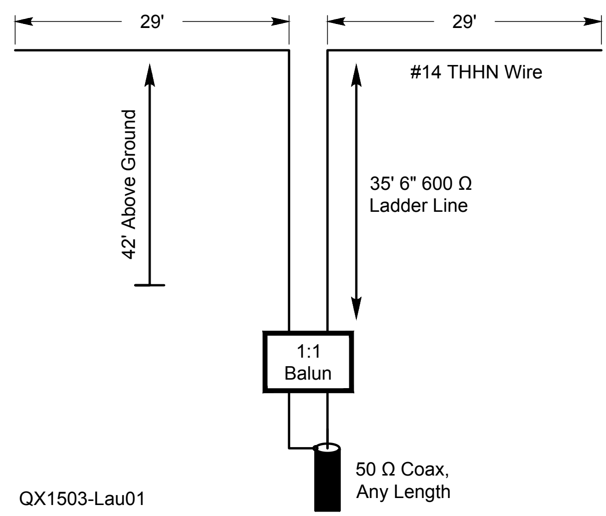


Figure 1 — Here is the basic configuration of the triband dipole. It consists of a 58 foot doublet fed with 35.5 feet of 600 Ω open wire feed line that works with good efficiency on the 30, 17, and 12 meter amateur bands.

Height above ground has a large effect on antenna impedance — from 45 to 98 Ω for the classic half wave dipole — so you should determine the optimum height first, before optimizing anything else.[3] It does little good to design the perfect antenna only to find out that you have no way of putting up your antenna that high, or finding out that your trees are too close together! In designing this antenna, I maximized the height and length of the antenna, while making sure I didn't exceed the practical limits of my support structures. I set the height at 42 feet, the height of the support ropes I have between two trees.

You want a choke balun between the open wire feed line and the coax, to prevent the outside of the coax shield from becoming a radiating antenna element. While it is possible to decouple coax with an excellent ground, such as a radial system, choke baluns are more practical if that is all you need to do. A vertical antenna makes much better use of a radial system; not only is the feed line decoupled, but system efficiency is much improved with a radial system. Either way, you still need a single point entrance panel bonded to a ground rod for lightning protection.

[1]Notes appear on page 38.

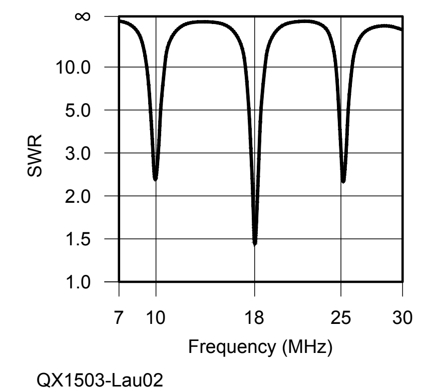
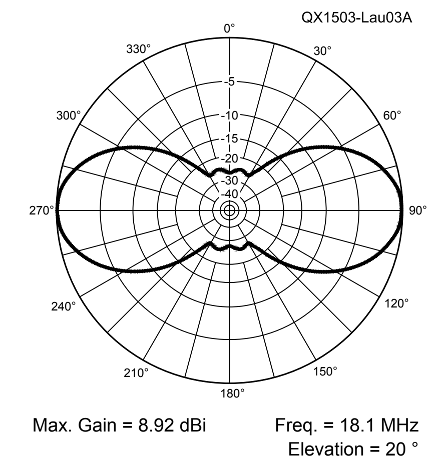


Figure 2 — I used *EZNEC* to calculate the SWR across the entire frequency range. You can see that around 10 MHz there is a dip that results in an SWR of about 2.4 and around 24 MHz there is a slightly deeper dip to an SWR of about 2.3. The lowest SWR is 1.47 at 18 MHz.

I'd suggest using a coaxial choke wound on a ferrite toroid — 11 turns of RG-58A/U on an FT-140-43 core works well from 10 to 30 MHz. Steve Hunt, G3TXQ, published an excellent balun design. He used 11 turns of RG-58 on a stacked pair of FT-240-52 toroids.[4] He measured impedances in excess of 8000 Ω between 10 and 25 MHz. Steve's design is better able to handle the high differential impedances encountered if you want to use this antenna on another band.

The balun is a weak point of many multiband systems — many folks have seen their SWR drift as the balun heated up to destruction when the impedance was just too high for the balun to handle. Fortunately, with this antenna, impedances on 30, 17, and 12 meters are all moderate; you don't really need Steve's design, unless you want to operate on yet another band. Assuming the choking action of the balun is perfect, you can model its effect on the system as a short length of 50 Ω coax. This is easily handled in Roy Lewellan's *EZNEC*, using virtual wires.



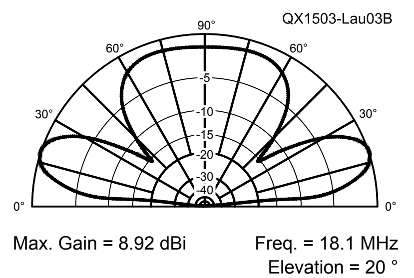
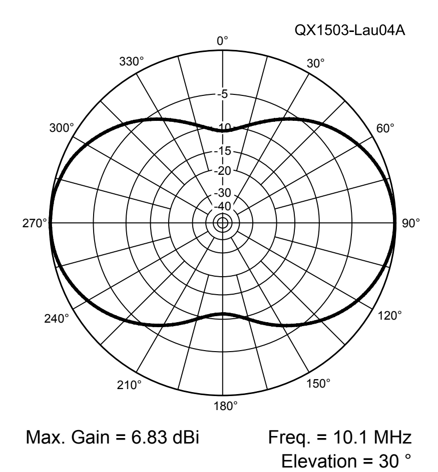


Figure 3 — Part A shows the 17 meter azimuthal radiation pattern, which is close to the pattern we normally expect to see from a dipole, with maximum signals at 90° to the wire orientation. Part B is the elevation pattern. The maximum signal is at an elevation angle of about 20°, but there is a broad lobe at very high elevation angles.



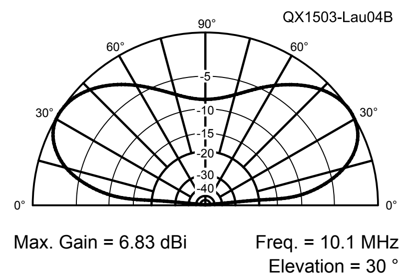


Figure 4 — Part A is the azimuthal radiation pattern on 30 meters, which shows only a slight dip in the radiated signal in the direction of the wire, with most of the signal still being broadside to the wire. Part B is the elevation pattern. The maximum signal is at an elevation angle of about 30°.

I found that a few feet of coax drastically lowers the impedance on 15 meters, making it much harder for an autotuner mounted at the balun to operate efficiently. One solution is to add more coax. An electrical multiple of a half wavelength will reflect the input impedance to the output. The cost to efficiency is high, however. You can expect to lose an S unit with 20 feet of RG-8X, and yet another one with 40 or 60 feet of RG-8X, assuming 6 dB/S unit.

The triband dipole is a 58 foot doublet made out of #14 THHN solid house wire fed with a 35.5 foot matching section of 600 Ω ladder line having a velocity factor of 91%. See Figure 1. The somewhat low velocity factor of the ladder line assumes you are using insulated wire. The #14 THHN house wire has two layers of insulation: 15 mils of PVC and another 4 mils of nylon. While the nylon typically flakes off in less than a year, I modeled the antenna in *EZNEC* using an insulation thickness of 19 mils and a dielectric constant of 3.5. Changing the insulation thickness to 15 mils doesn't appreciably change the resonance points. The length of the 50 Ω cable isn't critical, unless you have tweaked its length to accommodate another band, like 15 or 20 meters. I suggest using the shortest length of 50 Ω coax that will comfortably reach the single point entrance panel for your station.

I used *EZNEC* to determine the theoretical SWR values. I set the loss of the 600 Ω ladder line to 0.20 dB/100 ft at 50 MHz. Figure 2 is the SWR plot across the bands. I later determined that identical impedance values were obtained at 30 MHz with a line loss of 0.153 dB/100 ft and at 10 MHz with a line loss of 0.090 dB/100 ft, in case you want to know how *EZNEC* extrapolates the loss with frequency. I chose a slightly low velocity factor of 91%, as most modern implementations of ladder line use PVC insulated wire as opposed to bare copper. If you wish to use another type of 600 Ω line, I'd suggest using a length of (velocity factor) × 39 feet. I'd avoid extremely low loss 600 Ω open wire — the 6 inch spacing is likely to bring on issues with feed line radiation. *The ARRL VHF Manual* by Ed Tilton suggests 1.5 inch spacing at 50 MHz, which translates to 3 inch spacing at 25 MHz.[5]

On 17 meters, you get a clean bidirectional pattern, with maximum gain broadside to the wires, just like a dipole. Here in New England, this pattern works great when pointed at Europe. Figure 3A gives the azimuthal radiation pattern and Figure 3B shows the elevation radiation pattern.

On 30 meters, you also get gain broadside to the wires, but due to the relatively low height, there is a fair amount of signal in all directions. Figure 4A is the azimuthal radiation pattern and Figure 4B is the elevation pattern.

On 12 meters, as the antenna is higher and longer, the antenna has an azimuthal radiation pattern with four main lobes, 50° off broadside. You still get some gain broadside, but they are small lobes 3.5 dB weaker than the main lobes. See Figure 5A. The elevation pattern is shown in Figure 5B.

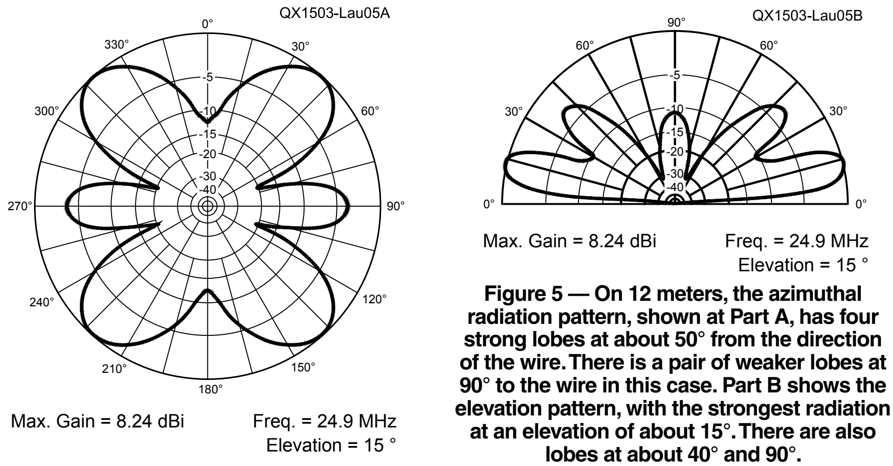


Figure 5 — On 12 meters, the azimuthal radiation pattern, shown at Part A, has four strong lobes at about 50° from the direction of the wire. There is a pair of weaker lobes at 90° to the wire in this case. Part B shows the elevation pattern, with the strongest radiation at an elevation of about 15°. There are also lobes at about 40° and 90°.

Notes

[1]Andrew Griffith, W4ULD, "The ⅓-Wavelength Multiband Dipole," *QST*, Sep 1993, pp 33 – 35.

[2]Taft Nicholson, W5ANB, "Compact Multiband Antenna Without Traps," *QST*, Nov 1981 pp 26 – 27.

[3]Ward Silver, NØAX, *The ARRL Antenna Book for Radio Communications,* 22nd Edition, p 3-5.

[4]Steve Hunt, G3TXQ: **www.karinya.net/g3txq/chokes/**

[5]Tilton, Edward P., W1HDQ, *The Radio Amateur's VHF Manual*, p 163 (ARRL 1972)

Brian Machesney, K1LI / k1li@arrl.net

The TriMox — A Moxon Tribander for a Holiday DXpedition

For the past five years, I've traveled to the Caribbean to "be DX" in the Single-Operator, All Band, Low Power category of the annual ARRL International DX Contest phone event. While trying to erect effective antennas at four different locations — and not succeeding to my own satisfaction — I've learned some hard lessons about the need for a lightweight, compact, unidirectional antenna that covers 10, 15, and 20 meters and can be raised with a single support.

With just 6 weeks to go before this year's February departure, a period punctuated by two more full-weekend contests in which I planned to participate, I still didn't have a solution. The Moxon rectangle,[1] first described by Les Moxon, G4XN (SK), and the wideband hexbeam,[2] developed by Steve Hunt, G3TXQ, were strong contenders. Being driven to achieve the maximum "fun per dollar" from my hobbies, I inventoried the materials on hand and decided to attempt a triband array of Moxon rectangles.

L.B. Cebik, W4RNL (SK), detailed the history and benefits of the Moxon rectangle in *QST*.[3]

- Gain similar to a 2 element Yagi, with very good rejection of rearward signals and 25 percent smaller turning radius
- About 80° forward horizontal beamwidth with gain and F/B pattern integrity across at least one-half of each amateur band
- Low SWR across each full amateur band, using wire element construction

In contrast to W4RNL's suggestion to support the Moxon rectangle from two or four poles, contributors to the Moxon Antenna Project website[4] created by John Labutski, KD6WD, (SK), have built lightweight X frames that allow the antenna to be raised and supported from a single, central point. With a good deal of antenna modeling experience under my belt, I chose to use the *EZNEC+* interface to the *NEC-2* computing engine to develop the antenna, rather than attempting a trial-and-error approach with hardware prototypes.

It has long been recognized that inter-element coupling makes adapting the Moxon rectangle to multiband use a non-trivial problem.[5] While there are reports of progress in this area,[6,7,8] I was unable to

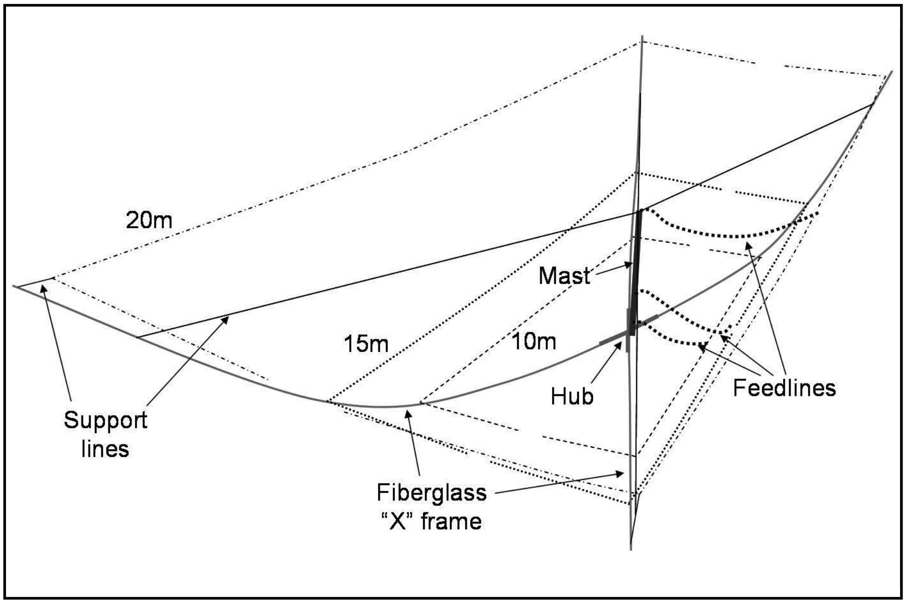


Figure 1 — Diagram of triband array of Moxon rectangles.

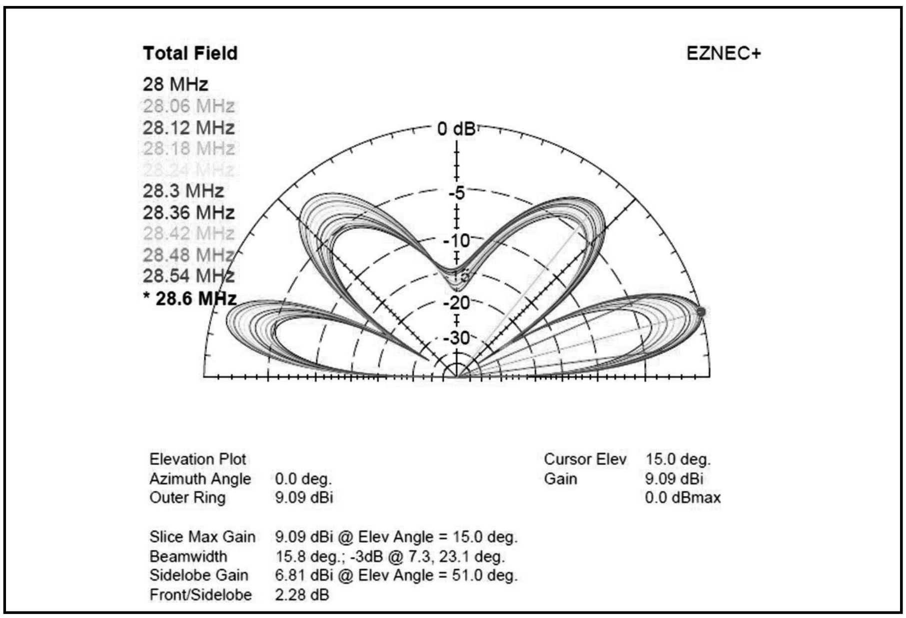


Figure 2 — Elevation plot of triband 10 meter Moxon rectangle with series feed

arrive at working models of these designs in time for my impending trip, so I struck out on my own in search of a simple, workable solution.

Design

After computing dimensions for the three elements using *MoxGen,*[9] my first effort to reduce inter-element interaction followed a key principle of the wideband hexbeam: Use an inverted umbrella-type structure to create vertical separation between the elements (see Figure 1) With the smallest (10 meter) element at the bottom, the 15 and 20 meter elements are spaced 6 inches and 3 feet above the 10 meter element, respectively. Again following G3TXQ's lead, I fed the three elements in series. Despite feeding the elements in different orders and varying the line lengths between the elements, the 10 meter pattern and the SWR on all bands deteriorated beyond what I considered to be useful (see Figure 2), — and the clock was ticking.

Recalling past information I'd read on the use of transmission line stubs to reduce harmonic inter-station interference at multitransmitter stations,[10] I wondered if I could detune the unused elements by connecting them to open-circuit half-wave transmission lines. This would present a short circuit at the elements' feed points at the stubs' resonant frequencies. After examining the strongest inter-element interactions, I determined that feeding the 10 and 20 meter elements with 15 meter half-wave lines and feeding the 15 meter element with a 10 meter half-wave line provided the cleanest set of patterns for the three bands.

The elements' individual feed lines would be connected to a remote coax switch mounted on the mast and controlled from the shack. I used open-circuit half-wave

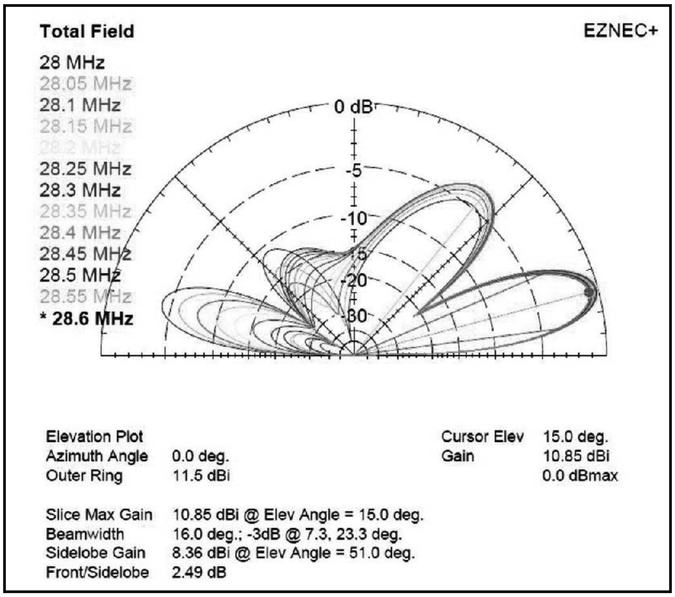


Figure 3 — Elevation plot of triband 10 meter Moxon rectangle with stub feed

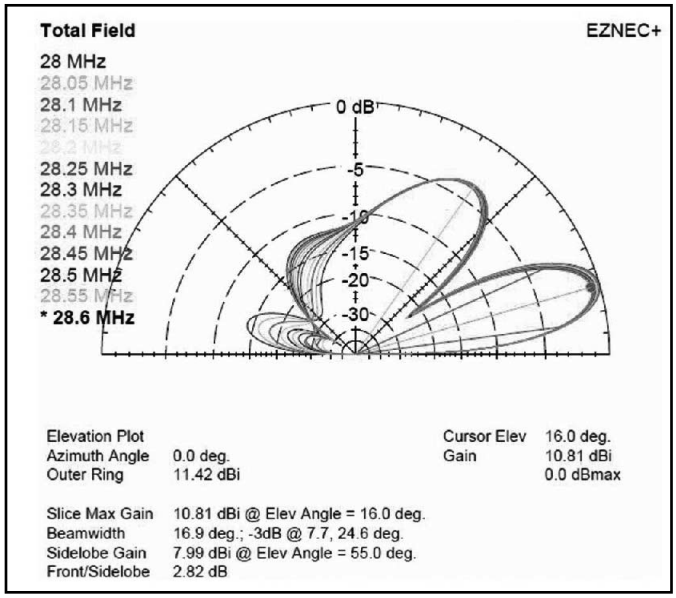


Figure 5 — Elevation plot of triband 10 meter Moxon rectangle with stub feed and increased total vertical spacing

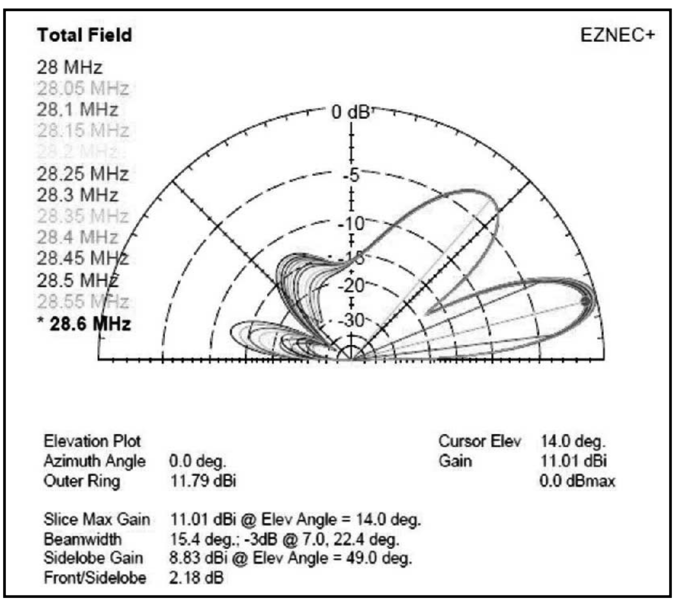


Figure 4 — Elevation plot of monoband 10 meter Moxon rectangle

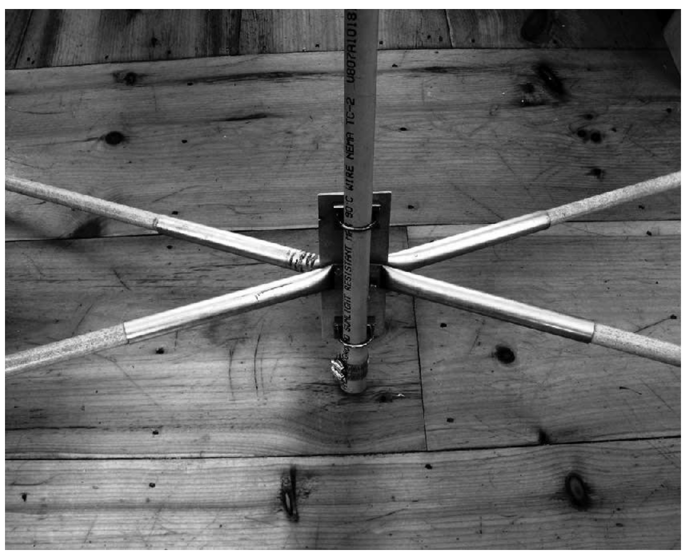


Figure 6 — TriMox hub and mast assembly [K1LI photo]

lines, because I wanted to use the remote coax switch I had on hand. With a shorting coax switch, it might be possible to use short-circuit quarter-wave lines to reduce cost and weight.

There was still one catch, though. The 10 meter pattern bandwidth (see Figure 3) was considerably narrower than it would be for a monoband unit (see Figure 4). Increasing the total vertical spacing between the elements to 5 feet restored the pattern integrity (see Figure 5). Finally, it was time to *build* the antenna.

Construction

A local metal shop cut, pressed and bent 1 inch heavy-wall electrical conduit to form the arms of the hub that receives the mast ends of the four spreaders.[11] I was keen to bring the antenna on an airplane as checked baggage, so all components were broken down into four foot lengths. Each spreader comprises 4 foot lengths of pultruded fiberglass tubing with 0.125 inch walls.[12] Tubes of 1 inch diameter fit into the four hub arms. Three 0.75 inch tubes are internally spliced together with 0.5 inch tubes and secured with hose clamps. This 12 foot long subassembly is inserted into the 1 inch tube with 6 inches of overlap and secured with a hose clamp. So, each spreader is 15 feet long.

To minimize weight and maximize portability, I crimped and soldered ring terminals to the ends of the Flex-Weave™ half-elements and tied Dacron line to the ring terminals to create the critical gaps between the driven elements and reflectors for the respective bands. With the corners of the 20 meter element secured to the ends of the four spreaders, they assume a shape that allows placement of the 15 and 10 meter elements in positions that are very close to the model. I secured a 4 foot mast of PVC electrical conduit to the hub with an aluminum hub-to-mast plate and added low-stretch Dacron lines from the top of the mast to each spreader to relieve some of the stress on the 20 meter element (see Figure 6).

I took two precautions to minimize pattern distortion that might result from interactions between the antenna elements and the three feed lines. At each element's feed point, I wound two turns of the RG-8X feed line through a Fair-Rite 2643102002 Type 43 ferrite bead secured to the Lexan rectangle that serves as the center insulator. I also coiled the excess feed line from each element and secured the coil to the mast, leaving a short lead to the coax switch.

First checks of the antenna produced mixed results. With the antenna sitting on sawhorses a few feet above the ground, the 20 and 15 meter resonant frequencies were shifted up by more than 100 kHz, as expected. But the 10 meter resonant

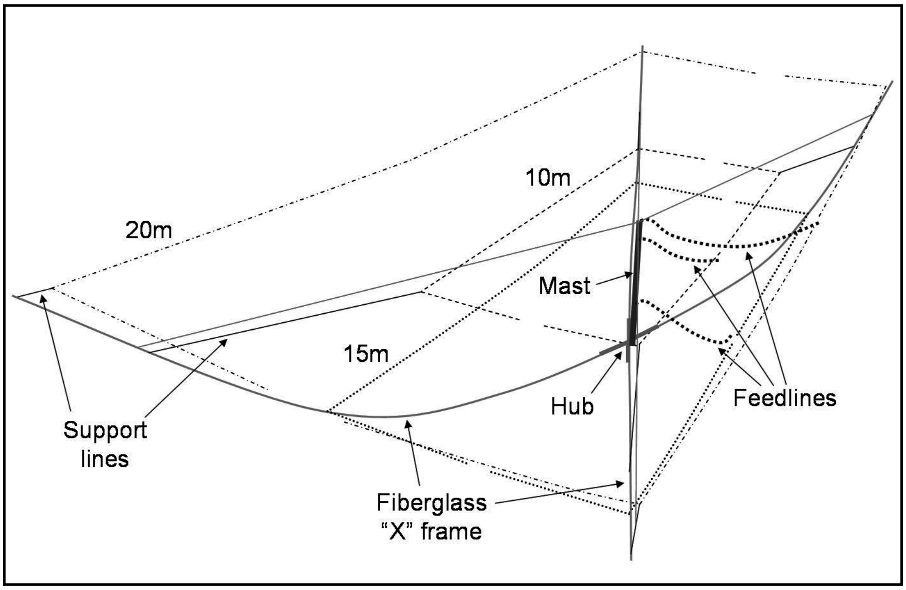


Figure 7 — Diagram of revised triband array of Moxon rectangles

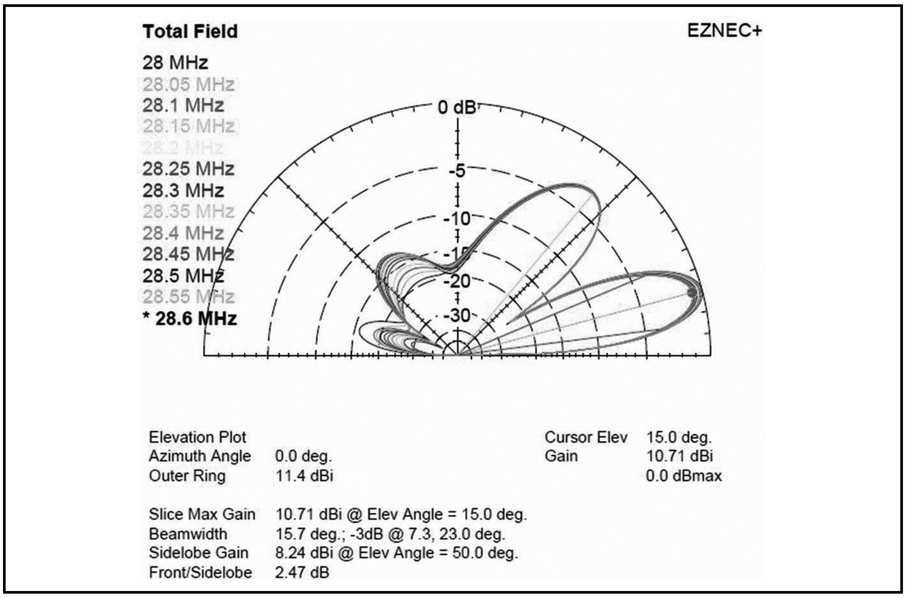


Figure 8 — Elevation plot of revised triband 10 meter Moxon rectangle with stub feed

point was shifted down by more than 300 kHz. Suspecting that the hub assembly might be detuning the 10 meter element, I reversed the vertical positions of the 15 and 10 meter elements (see Figure 7). SWR measurements confirmed the hoped-for results, and this rearrangement of the elements slightly improved the modeled 10 meter pattern, while the simulated azimuth patterns demonstrated no disruption of the pattern on any band (see Figure 8). With the antenna still on sawhorses, I made some 20 meter contacts around the US and as far as Japan with good reports, as well as a few contacts on 15 and 10 — including 3D2RX on 15 CW. Rotating the antenna at ground level while listening to stations in Ontario and Newfoundland, Canada on 20 CW confirmed the desired F/B performance.

With the exception of the remote coax switch, the entire antenna fits into a cardboard container 48 × 6 × 6 inches, just within the airline's 61 inch linear dimension limit for checked baggage. While the box seemed quite robust when stuffed with the antenna components and sealed at the ends, I reinforced all seams and added several radial wraps of Gorilla Tape to ensure a trouble-free passage. Time to head south!

To the Beach!

Our first morning in Belize dawned warm and windy, with a breathtaking view of the

Figure 9 — TriMox supported on cabana roof beneath makeshift wooden tripod [K1LI photo]

turquoise Caribbean Sea just 50 yards to the east of our second-floor balcony. Unfortunately, the antenna situation was not so pretty. No tall trees were within reach of our cabana and, while the space above the tin roof was overspread with a tangle of branches from the surrounding trees, none reached out far enough to support the TriMox footprint. I found three 10 foot wooden poles leaning against a tree, carried them up a ladder and onto the cabana's roof, then lashed them together into a tripod.

After assembling the TriMox at ground level, the groundskeeper and I lifted the 25 lb antenna onto the roof of the cabana. I positioned the makeshift wooden tripod over the TriMox and hoisted the mast into place (see Figure 9). With this arrangement, the topmost (20 meter) element was nearly 10 feet above the tin roof and 35 feet above ground level, but also facing directly into a wide line of metal-roofed condominiums just 25 feet away. While this "tin canyon" didn't allow the TriMox to perform to its full potential, I was able to make more than 1800 contacts on 10, 15 and 20 during the 2013 ARRL International DX phone contest, including 6 hours at more than 150 contacts per hour. While I was running just 100 W, the TriMox allowed me to hold my own in very crowded band conditions.

A version of this article originally appeared in the June 2013 YCCC Scuttlebutt. *It appears here with permission.*

Notes

1 Moxon, Les, *HF Antennas for All Locations* (RSGB, 1982), pp 67, 168, 172–175.

2 Hunt, Steve, *G3TXQ Broadband Hexbeam,* 2007-2013 **www.karinya.net/g3txq/hexbeam/broadband/**.

3 Cebik, L.B., "Having a Field Day with the Moxon Rectangle," *QST,* vol. 84, no 6 (June 2000), pp 38–42.

4 The Moxon Antenna Project, **www.moxonantennaproject.com**.

5 Cebik, L.B., *Multi-Banding the Moxon Rectangle,* 1999, **w4rnl.net46.net/mbm.html**.

6 Todorovic, Andra, "YU1QT 6-Band Moxon," **www.moxonantennaproject.com/yu1qtmoxon.htm.**

7 Todorovic, Andra, "3 Band 3 Element MOXON with single coax feed," **www.s55m.com/teh/3BMOX/3b3lmox.html.**

8 Croft, Phil, *Phil's Multi-band Moxon,* 2003, **www.moxonantennaproject.com/G0WSPmoxon.htm**.

9 Download MoxGen from the Moxon Antenna Project, **www.moxonantennaproject.com/design.htm**.

10 See, for example, K3NA's "Stub Sketch Notes" **www.yccc.org/Articles/K3NA_stubs.pdf** and §20.3 of the 2013 *ARRL Handbook for Radio Communications*.

11 See example hub designs at **www.moxonantennaproject.com/hubs.htm**.

12 See, for example, MaxGain Systems at **www.mgs4u.com.**

The following material was extracted from earlier versions of the *ARRL Handbook*. Figure and equation sequence references are those from the 2012 edition.

Project: Vertical Loop Antenna for 28 MHz

This simple antenna provides gain over a dipole or inverted-V. Its size makes it an excellent antenna with which to experiment. The antenna can easily be scaled to lower (and higher) frequencies: Multiply each dimension by 28.4 / f (MHz), where f is the desired operating frequency in MHz.

The shape of the loop is such that it develops 2.1 dB gain over a dipole at low radiation angles with the top mounted one wavelength or more above ground. The antenna is simple to feed — no matching network is necessary. When fed with 50-Ω coax, the SWR is close to 1:1 at the design frequency, and is less than 2:1 from 28.0-28.8 MHz for an antenna resonant at 28.4 MHz. (If the loop is scaled to resonate at lower frequencies, the effects of ground will affect the antenna's resonant frequency and feed point impedance, but not drastically — be prepared to adjust the dimensions.)

The antenna is made from #12 AWG wire (see **Fig 21.88**) and is fed at the center of the bottom wire. Coil the coax into a few turns near the feed point to provide a simple choke balun. (see the **Transmission Lines** chapter for more information on choke baluns.) A coil diameter of about a foot will work fine. You can support the antenna on a mast with spreaders made of bamboo, fiberglass, wood, PVC or other non-conducting material. You can also use aluminum tubing both for support and conductors, but you may have to readjust the antenna dimensions for resonance.

This rectangular loop has two advantages over a resonant square loop. First, a square loop has just 1.1 dB gain over a dipole — a power increase of only 29%. Second, the input impedance of a square loop is about 125 Ω. You must use a matching network to feed a square loop with 50-Ω coax. The rectangular loop achieves gain by compressing its radiation pattern in the elevation plane. This happens because the top and bottom of the loop (where the current maxima are located) are farther apart than for a square loop. The antenna's beamwidth is slightly higher than that of a dipole (it's about the same as that of an inverted-V). A broad pattern is an advantage for a general-purpose, fixed antenna. The rectangular loop provides a bidirectional gain over a wide range of directions.

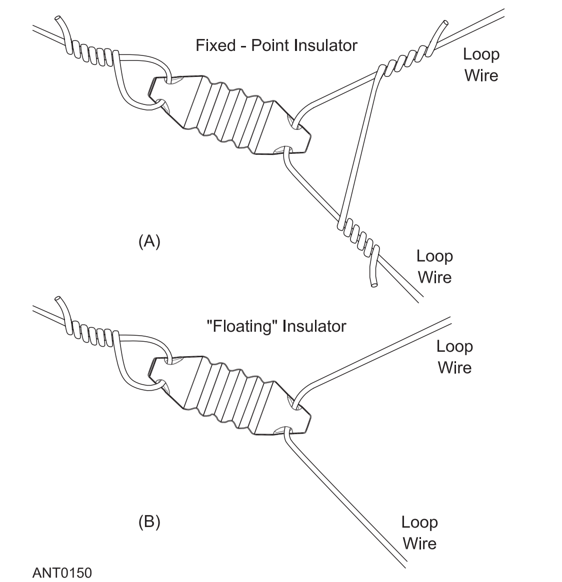


Fig 21.89 — Two methods of installing the insulators at the loop corners.

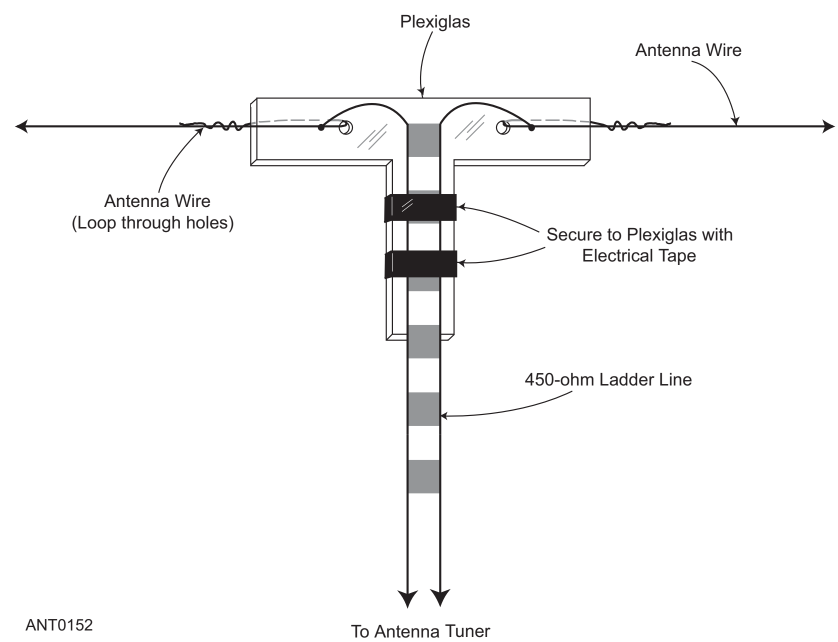


Fig 21.90 — One possible method of constructing a feed point insulator for use with open-wire line.

Mount the loop as high as possible. To provide 1.7 dB gain at low angles over an inverted-V, the top wire must be at least 30 ft high (about one wavelength). The loop will work at lower heights, but its gain advantage disappears. For example, at 20 ft the loop provides the same gain at low angles as an inverted-V.

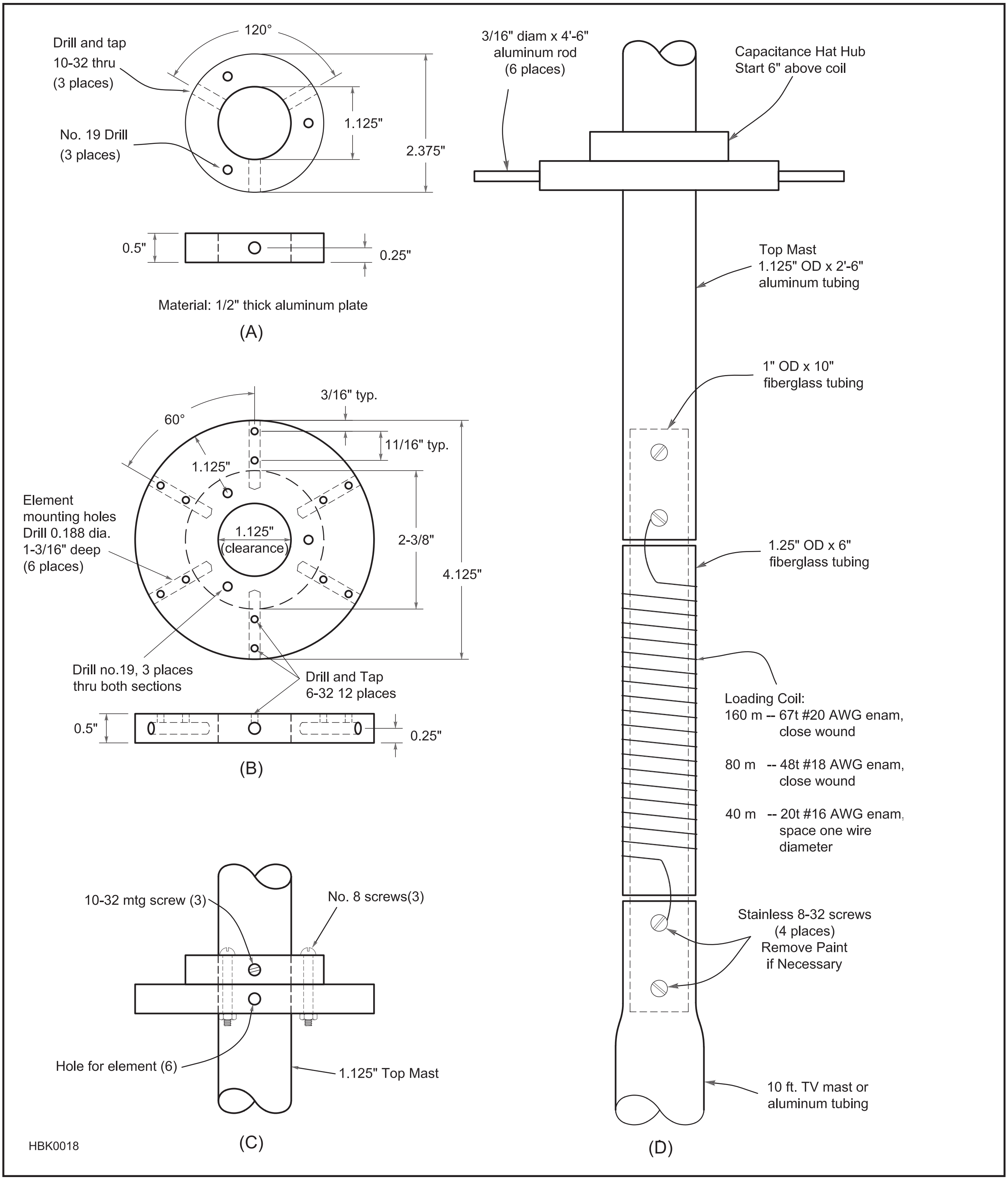


Fig 21.54 — Construction details for the capacitance hat. The hub is made from two pieces of ½-inch aluminum plate (A and B). It's attached to the mast as shown in C. The six elements are made from 4.5-ft lengths of $\frac{3}{16}$-inch aluminum rod. Loading coil details are shown in D.

The following material was extracted from earlier versions of the *ARRL Handbook*. Figure and equation sequence references are those from the 2012 edition.

Project: Wire Quad for 40 Meters

Many amateurs yearn for a 40 meter antenna with more gain than a simple dipole. While two-element rotatable 40 meter beams are available commercially, they are costly and require fairly hefty rotators to turn them. This low-cost, single-direction quad is simple enough for a quick Field Day installation, but will also make a home station very competitive on the 40 meter band.

This quad uses a two-inch outside diameter, 18-ft boom, which should be mounted no less than 60 ft high, preferably higher. (Performance tradeoffs with height above ground will be discussed later.) The basic design is derived from the N6BV 75⁄80 meter quad described in *The ARRL Antenna Compendium, Vol 5.* However, since this simplified 40 meter version is unidirectional and since it covers only one portion of the band (CW or Phone, but not both), all the relay-switched components used in the larger design have been eliminated.

While this antenna is shown as tower-supported with a metal boom, the same antenna can be suspended between trees or towers. The boom is then replaced by a rope stretched between the supports with the tops of each loop attached to the rope with an insulator.

The layout of the simple 40 meter quad at a boom height of 70 ft is shown in **Fig 21.83**. The wires for each element are pulled out sideways from the boom with black ⅛-inch Dacron rope designed specifically to withstand both abrasion and UV radiation. The use of the proper type of rope is very important — using a cheap substitute is not a good idea. You will not enjoy trying to retrieve wires that have become, like Charlie Brown's kite, hopelessly entangled in nearby trees, all because a cheap rope broke during a windstorm! At a boom height of 70 ft, the quad requires a *wingspread* of 140 ft for the side ropes. This is the same wingspread needed by an inverted-V dipole at the same apex height with a 90° included angle between the two legs.

The shape of each loop is rather unusual, since the bottom ends of each element are brought back close to the supporting tower. (These element ends are insulated from the tower and from each other). Having the elements near the tower makes fine-tuning adjustments much easier — after all, the ends of the loop wires are not 9 feet out, on the ends of the boom! The feed point resistance with this loop configuration is close to 50 Ω, meaning that no matching network is necessary. By contrast, a more conventional diamond or square quad-loop configuration exhibits about a 100-Ω resistance.

Another bonus to this loop configuration is that the average height above ground is higher, leading to a slightly lower angle of radiation for the array and less loss because the bottom of each element is raised higher above lossy ground. The drawback to this unusual layout is that four more *tag-line* stay ropes are necessary to pull the elements out sideways at the bottom, pulling against the 10-foot separator ropes shown in Fig 21.83.

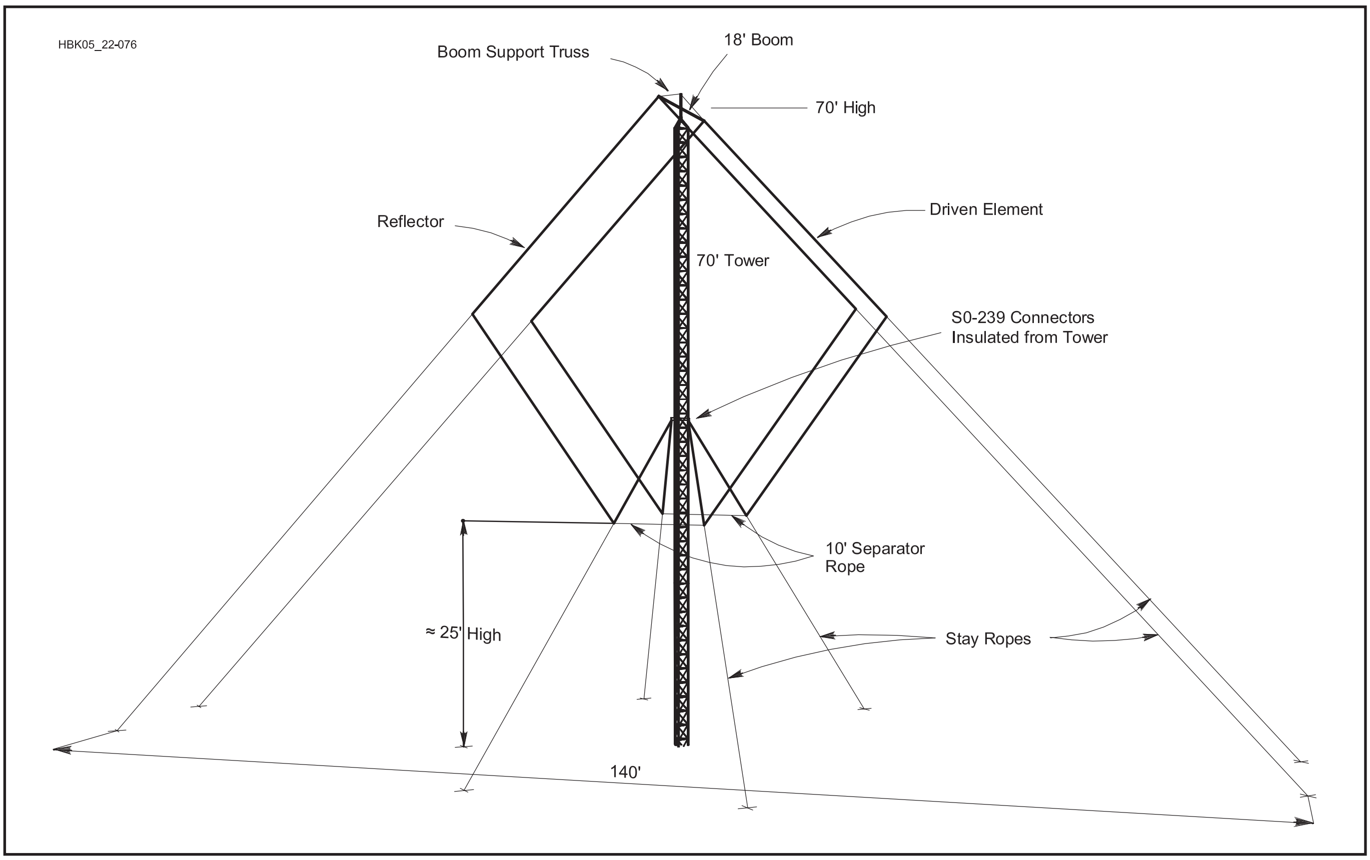


Fig 21.83 — Layout of 40 meter quad with a boom height of 70 feet. The four stay ropes on each loop pull out each loop into the desired shape. Note the 10-foot separator rope at the bottom of each loop, which helps it hold its shape. The feed line is attached to the driven element through a choke balun, consisting of 10 turns of coax in a 1-foot diameter loop. You could also use large ferrite beads over the feed line coax, as explained in the Transmission Lines chapter. Both the driven element and reflector loops are terminated in SO-239 connectors tied back to (but insulated from) the tower. The reflector SO-239 has a shorted PL-259 normally installed in it. This is removed during fine-tuning of the quad, as explained in the text.

CONSTRUCTION

You must decide before construction whether you want coverage on CW (centered on 7050 kHz) or on phone (centered on 7225 kHz), with roughly 120 kHz of coverage between the 2:1 SWR points. If the quad is cut for the CW portion of the band, it will have less than about a 3.5:1 SWR at 7300 kHz, as shown in **Fig 21.84**. The pattern will deteriorate to about a 7 dB F/B at 7300 kHz, with a reduction in gain of almost 3 dB from its peak in the CW band. It is possible to use a quad tuned for CW in the phone band if you use an antenna tuner to reduce the SWR and if you can take the reduction in performance. To put things in perspective, a quad tuned for CW but operated in the phone band will still work about as well as a dipole.

Next, you must decide where you want to point the quad. A DXer or contester in the USA might want to point this single-direction design to cover Europe and North Africa. For Field Day, a group operating on the East Coast would simply point it west, while their counterparts on the West Coast would point theirs east.

The mechanical requirements for the boom are not severe, especially since a top truss support is used to relieve stress on the boom due to the wires pulling on it from below. The boom is 18 ft long, made of two-inch diameter aluminum tubing. You can probably find a suitable boom from a scrapped tri-band or monoband Yagi. You will need a suitable set of U-bolts and a mounting plate to secure the boom to the face of a tower. Or perhaps you might use lag screws to mount the boom temporarily to a suitable tree on Field Day! On a 70-ft high tower, the loop wires are brought back to the tower at the 37.5-ft level and tied there using insulators and rope. The lowest points of the loops are located about 25 ft above ground for a 70-ft tower. **Fig 21.85** gives dimensions for the driven element and reflector for both the CW and the Phone portions of the 40 meter band.

GUY WIRES

Anyone who has worked with quads knows they are definitely three-dimensional objects! You should plan your installation carefully, particularly if the supporting tower has guy wires, as most do. Depending on where the guys are located on the tower and the layout of the quad with reference to those guys, you will probably have to string the quad loops over certain guys (probably at the top of the tower) and under other guys lower down.

It is very useful to view the placement of guy wires using the View Antenna function in the *EZNEC* modeling program. This allows you to visualize the 3-D layout of an antenna. You can Rotate yourself around the tower to view various aspects of the layout. *EZNEC* will complain about grounding wires directly but will still allow you to use the View Antenna function. Note also that it is best to insulate guy wires to prevent interaction between them and the antennas on a tower, but this may not be necessary for all installations.

FINE TUNING, IF NEEDED

We specify stranded #14 AWG hard-drawn copper wire for the elements. During the course of installation, however, the loop wires could possibly be stretched a small amount as you pull and yank on them, trying to clear various obstacles. This may shift the frequency response and the performance slightly, so it is useful to have a tuning procedure for the quad when it is finally up in the air.

The easiest way to fine-tune the quad while on the tower is to use a portable, battery-operated antenna analyzer to adjust the reflector and the driven element lengths for specific resonant frequencies. You can eliminate the

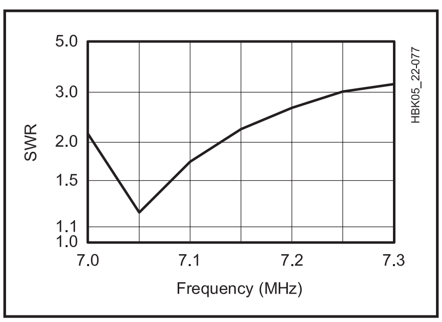


Fig 21.84 — Plot of SWR versus frequency for a quad tuned for CW operation.

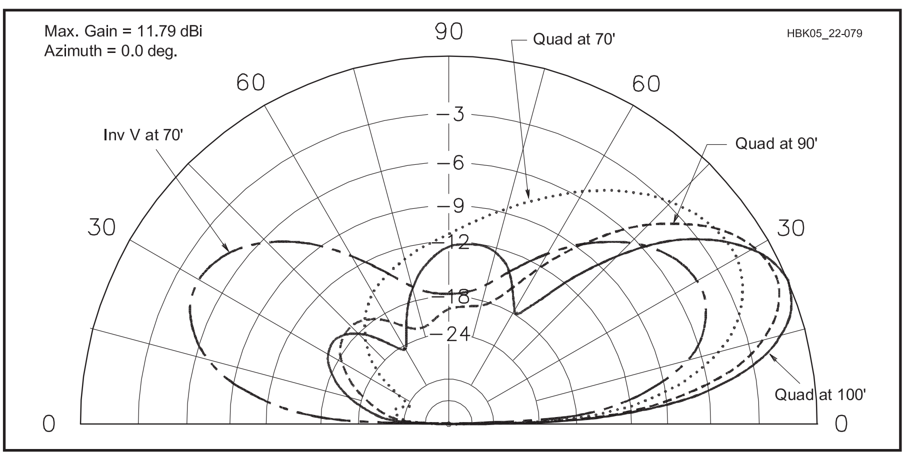
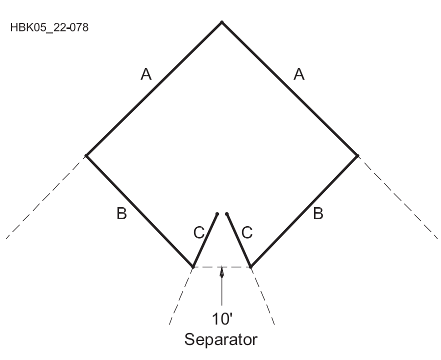


Fig 21.86 — Comparisons of the elevation patterns for quads at boom heights of 70, 90 and 100 ft, referenced to an inverted-V dipole at 70 ft.



	7050 kHz, CW	*7200 kHz, SSB*
Length A, Reflector	31"6"	30"10-¾"
Length B, Reflector	28"2-¼"	27"7"
Length C, Reflector	15"7-¼"	15"
Total, Half Reflector	75"3-½"	73"5-¾"
Resonant Frequency	7030 kHz	7205 kHz
Length A, Driven	30"7-¼"	30"
Length B, Driven	27"3-½"	26"8-½"
Length C, Driven	14"7-½"	14"
Length, Half Driven	72"6-¼"	70"8-½"
Self-Resonant Frequency	7295 kHz	7480 kHz

Fig 21.85 — Dimensions of each loop, for CW or Phone operation.

influence of mutual coupling to the other element by open-circuiting the other element.

For convenience, each quad loop should be connected to an SO-239 UHF female connector that is insulated from but tied close to the tower. You measure the driven element's resonant frequency by first removing the shorted PL-259 normally inserted into the reflector connector. Similarly, the reflector's resonant frequency can be determined by removing the feed line normally connected to the driven element's feed point.

Obviously, it's easiest if you start out with extra wire for each loop, perhaps six inches extra on each side of the SO-239. You can then cut off wire in ½-inch segments equally on each side of the connector. This procedure is easier than trying to splice extra wire while up on the tower. Alligator clips are useful during this procedure, but just don't lose your hold on the wires! You should tie safety strings from each wire back to the tower. Prune the wire lengths to yield the resonant frequencies (±5 kHz) shown in Fig 21.85 and then solder things securely. Don't forget to reinsert the shorted PL-259 into the reflector SO-239 connector to turn it back into a reflector.

HIGHER IS BETTER

This quad was designed to operate with the boom at least 60 ft high. However, it will work considerably better for DX work if you can put the boom up even higher. **Fig 21.86** shows the elevation patterns for four antennas: a reference inverted-V dipole at 70 ft (with a 90° included angle between the two legs), and three quads, with boom height of 70, 90 and 100 ft respectively. At an elevation angle of 20°, typical for DX work on 40 meters, the quad at 100 ft has about a 5 dB advantage over an inverted-V dipole at 70 ft, and about a 3 dB advantage over a quad with a boom height of 70 ft.