By Mike Loukides, W1JQ

A Dipole Curtain for 15 and 10 Meters

W1JQ tackles the construction of a version of one of the largest types of HF antennas. It's the main radiator at some of the most powerful international shortwave broadcast stations—the curtain array.

Looking at a shortwave broadcaster's Web site, I noticed that their antenna was a "dipole curtain." I wondered what a dipole curtain was as I'd always wanted an antenna that I could call a "curtain"… Sterba, Bobtail—whatever. I've had a lot of fun with my G5RV multiband dipole, but it's clearly not the antenna to use as the sunspot cycle declines.

At around 2 AM of a sleepless night, I decided that a dipole curtain must be an array of dipoles, fed in phase. Jim Peterson, K6EI, pointed me to a Web site (**www.tcibr.com/NewFiles/hfbroadants.html**) that showed I was correct. Dipole curtains have long been the "gold standard" of shortwave broadcast antennas. They are among the largest antennas I've ever seen. An array can have up to two dozen dipoles, stacked up to six high, with a design frequency as low as 5 MHz. A commercial dipole curtain looks like the backstop for a baseball field, designed for 100 foot-tall players. They can yield a gain of 20 dBi or more—as much gain as an EME antenna, on frequencies as low as 60 meters! These arrays typically use a nonresonant reflecting screen to give a unidirectional pattern. It's common to put a set of driven elements on either side of the reflector, so the pattern is switchable. Curtains with two or more stacks of dipoles are also slewable; that is, the pattern can be steered by changing the phasing between the stacks.

Could some of the world's largest antennas, with price tags in the millions of dollars, be adapted to amateur service? I didn't know, but there were many reasons to try. Dipole curtains are very

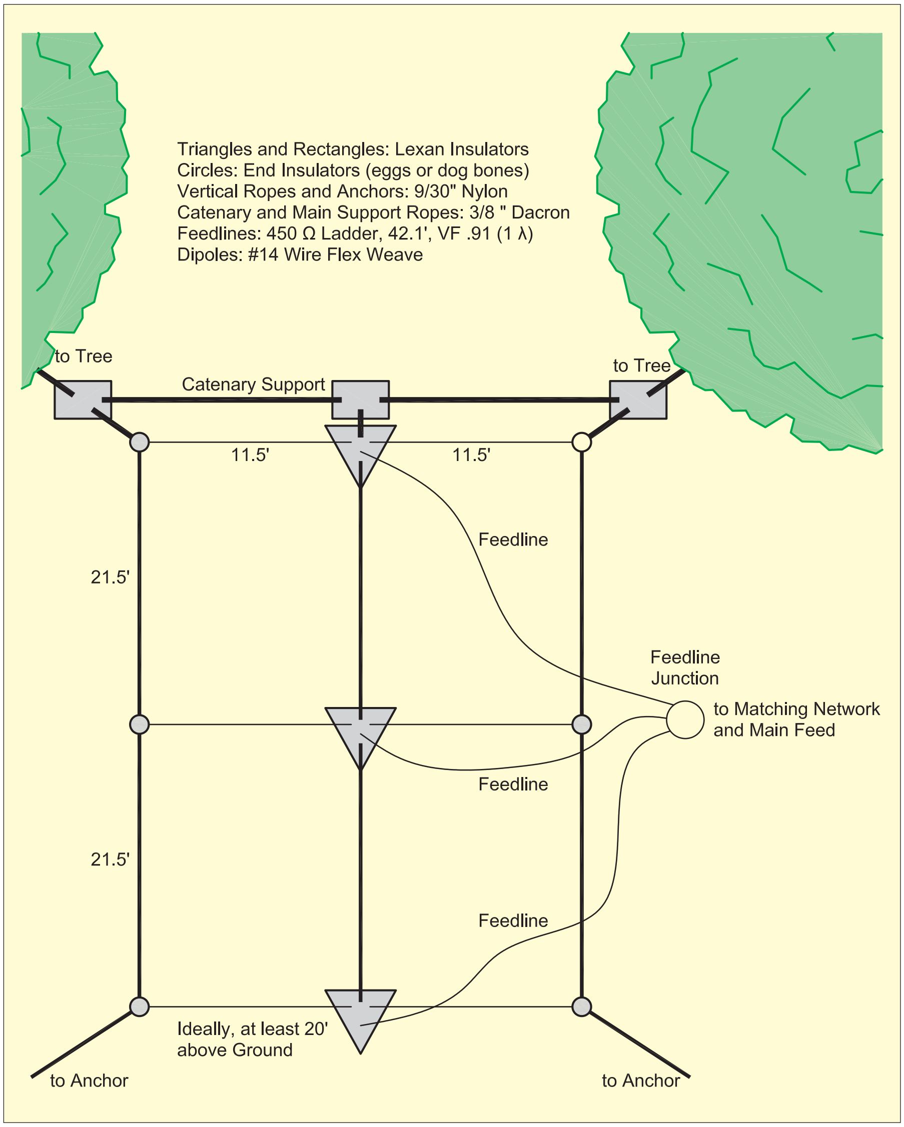

Figure 1—15-meter dipole curtain geometry.

broad; their properties don't change very much as you move across a band or even band to band. They have excellent low-angle radiation characteristics and they are ideal antennas for DX work. The optimum radiation angle for DX propagation is 10 to 20°,[1] and that's where curtains show their maximum gain. Additionally, they have a very broad beamwidth, particularly compared to antennas with equivalent gain. Although they deliver high gain, their radiation pattern allows them to cover a lot of territory without any rotation.

I decided to see whether I could trim the dipole curtain down to size and build an antenna that would fit into a suburban backyard. A few things go away immediately—the reflecting screen looks difficult to build and, at least for a first antenna, a single stack of dipoles is sufficient. With a design frequency in the 15 meter band, closer than ideal spacing and ground proximity lower than ideal, a stack of 3 or 4 dipoles can be made to fit easily in a backyard. Figure 1 shows the general idea of my dipole curtain. Its gain is competitive with a beam and its radiation characteristics are in some ways superior. It didn't cost much, it didn't require a tower (just some good trees) and it's even "stealthy." Dollar for dollar, I don't think it's possible to buy or build a more effective antenna for the upper HF bands. It's the only wire antenna I know about that has both high gain and broad beamwidth.

The Design

I started by stacking four 15 meter dipoles at 15 foot intervals, starting at 20 feet, with the top dipole at 65 feet. That height sounds arbitrary, but it represented the highest elevation I thought I could achieve. My trees are mature maples, close to 100 feet tall and I've never been able to use more than 2/3 of a tree's height effectively. A minimum height of 20 feet was an educated guess; I thought it represented the point at which ground loss would outweigh the advantages of wider spacing.

The four-dipole design yielded decent gain, an excellent maximum radiation angle of about 12°, a nice broad beamwidth and very similar performance on 12 and 10 meters. I traded e-mail with Dean Straw, N6BV, who pointed out that I'd be better off if I cut the antenna back to two dipoles. With four dipoles that close together, coupling between the elements would significantly reduce the gain. I really did want those extra dipoles—so I tried putting one dipole back in (dipoles at 20, 41.5 and 63 feet). The third dipole didn't help 15 meters but it didn't hurt, either, and it was exactly what the antenna needed for 10 meter performance.

I spent lots of time tweaking the basic design shown in Figure 1, but my initial guess was fairly close to optimal, given my assumption that I could get the top dipole to 65 feet. If I made the spacing between dipoles larger, the bottom dipole was too low and performance suffered; if I made the spacing smaller, the elements were too close together and, again, performance suffered.

So, I stuck with dipoles at 20, 41.5 and 63 feet, cut for 21.25 MHz (23 feet total length). This array yields 11.38 dBi gain over real ground on 15 meters, and 13.34 dBi on 10 meters, according to *EZNEC*. The half-power beamwidth is 80° on both bands and the take-off angle is around 13°.

Now, how to feed it? For the two-dipole array, N6BV suggested equal lengths of 50 Ω coax to the dipoles and then a quarter wave matching section of parallel 75 Ω coax (with an effective impedance of 37.5 Ω). That would work reasonably well for the three-dipole array—except it wouldn't work on 10 meters. My strategy was to feed the dipoles with some number of half waves of transmission line on 15 meters. Regardless of the transmission line's impedance, its input impedance will equal the load impedance every half wave. That way, I had a workable feed system for 15 meters: the impedance at the junction of the transmission lines was about 25 Ω, and it could be matched to 50 Ω with a quarter-wave transformer. I played with different combinations of transmission line length and impedance to find something that would yield a reasonable match on 10 meters.

The winning combination turned out to be full-wavelength feeders of 450 Ω ladder line, which is 42.1 feet (according to the formula $\lambda = VF \times [984/f]$, where f is 21.25 MHz, and VF is the velocity factor; I assumed 0.91 for ladder line). The quarter-wave matching transformer is 9 feet long (assuming a VF of 0.78 for RG-11). *EZNEC* predicts a minimum SWR of about 1.3:1, and an SWR below 2:1 across the entire 15 meter band. On 10 meters, full-wave feeders conveniently yield a secondary resonance with a reasonably low SWR at 28.5 MHz—about 1.75:1, and below 3:1 between 28.125 and 29 MHz (Figure 2 shows the feed line construction). That's a higher minimum SWR than many hams are comfortable with, but it's really not a problem. Walt Maxwell's *Reflections*[2] argues that we shouldn't be scared away by high SWR or, for that matter, waste our time trying to tune our antenna systems for a perfect 1:1 match… that's what antenna tuners are for.

Still, I spent some time seeing if I could do better—and found some interesting red herrings. It turns out that, if you feed the top dipole or the bottom dipole with 300 Ω line, and the other two dipoles with 450 Ω line, the 10 meter SWR drops significantly. I discovered that this configuration had significantly less gain, however. A good SWR wasn't worth a few dB of signal strength. While I never analyzed why the 300 Ω line improved the SWR but reduced the gain, the answer is almost certainly that it upset the current distribution between the elements.[3] I tried other transmission line impedances, from 200 Ω up to 800 Ω, and none worked as well as 450 Ω.

So I stuck with full-wave feeders of 450 Ω line, and a quarter wave section of two lengths of RG-11U in parallel, all fed with 50 Ω coaxial cable. Since the SWR on the transmission line is on the high side, particularly on 10 meters, I chose to use high-quality low-loss cable. I settled on one of the many Belden 9913F7-equivalent (buriable, low-loss foam, RG-8-style) cables.[4] To ensure that the feed system could handle high power, I simulated all the feed lines using N6BV's *TLW* program, and satisfied myself that, when used on 15 and 10 meters, the antenna and feed system are capable of 1500 W—though it's getting close to the maximum voltage for RG-8 style foam coax. If you really want to run high power, you might be better off using "solid" RG-8, rather than foam.

If you're more adventurous, here are some other ideas for feeding the antenna. Perhaps the most obvious is using ladder line end-to-end. That's no doubt the best solution for those who have figured out how to route parallel line inside their house. A recent *QST* article[5] suggested another interesting possibity…a weatherproof, automatic antenna tuner mounted in the trees. Several vendors, most notably SGC and LDG, have tuners that will fill the bill. They are relatively expensive and I thought long and hard about whether to spend the money. I decided against it—but you might not.

Building It

This antenna proved to be the most complex piece of aerial engineering I've ever tried. Getting it up into the air without turning it into a tangled mass of wire and rope was a challenge.

I started by making center insulators from 6×6 inch squares of 1/4 inch Lexan (from the McMaster-Carr Supply Company, another vendor I've come to love[6]) using a design suggested by Joe Wonoski, N1KHB. Figure 3 shows the basic design.

[1]Notes appear on page 38.

I cut each square diagonally (to be precise, Joe cut the squares diagonally for me), making two insulators from each piece. To prevent abrasion, I used a small rat-tail file to round off the edges of the holes through which the wires pass; I also sanded down the edges of the insulators slightly. When you've made an insulator, punch some holes in the "webbing" of the ladderline, and lace it to the insulator using black cable ties. The insulator thus serves as a strain relief. You could also use the WA1FFL Ladder-Locs for the same purpose.[7]

Once I had a piece of ladderline tied to an insulator (without the dipole), it was time to cut the feed line to 1 wavelength at 21.25 MHz. The antenna's behavior is fairly sensitive to getting the feed lines the right length, and the velocity factor of parallel transmission line can vary quite a bit, even within the same piece of cable. Rather than cut blindly, I borrowed N1KHB's MFJ Antenna Analyzer, which allowed me to measure a full wave precisely: cut the cable at about 45 feet, short it at the insulator end, tie the insulator up in the air (it doesn't have to be high), stretch the cable out so it was above ground, and trim the loose end for minimum impedance. Repeat until you have three insulators with roughly 42 foot long pieces of ladderline attached.

I became a complete convert to FlexWeave antenna wire (available from RadioWare[8] and other suppliers). That wire just doesn't want to tangle! You can tie knots in it as easily as in nylon rope.

I used standard egg insulators at the ends, though these turned out to be a poor choice given the antenna's geometry. If I build another curtain, I'll make triangular Lexan insulators for the ends (one hole for the wire, one hole for the upper support rope and one hole for the lower support rope). For pruning, I left some extra wire at the ends, tied back so as not to lengthen the dipole. I didn't try pretuning the dipoles with the MFJ Analyzer. Hoisting the dipoles to their eventual height purely for tuning was too much work, and at more convenient heights of 4 or 5 feet off the ground, the resonant frequency and impedance of a dipole is significantly different from what it will be in the air, making the value of "low-altitude" measurements questionable. *EZNEC* showed that the antenna wasn't particularly sensitive to the length of the dipoles—and the FlexWeave was so easy to work with that it was easy to measure the dipoles fairly precisely.

After reading some articles in *More Wire Antenna Classics,*[9] I decided to use a catenary rope at the top of the antenna. The catenary gives the antenna additional strength in windstorms and ice storms, both frequent in New England. The catenary—which is basically a "dipole" made out of rope, about 3 feet longer than the real dipoles—gave me a point from which I could support the center insulators, and allowed me to use more tension than I would have dared otherwise.

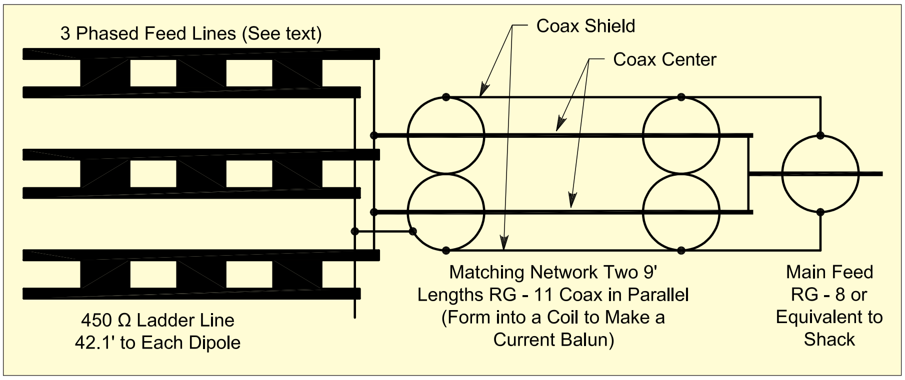

Figure 2—Transmission line schematic.

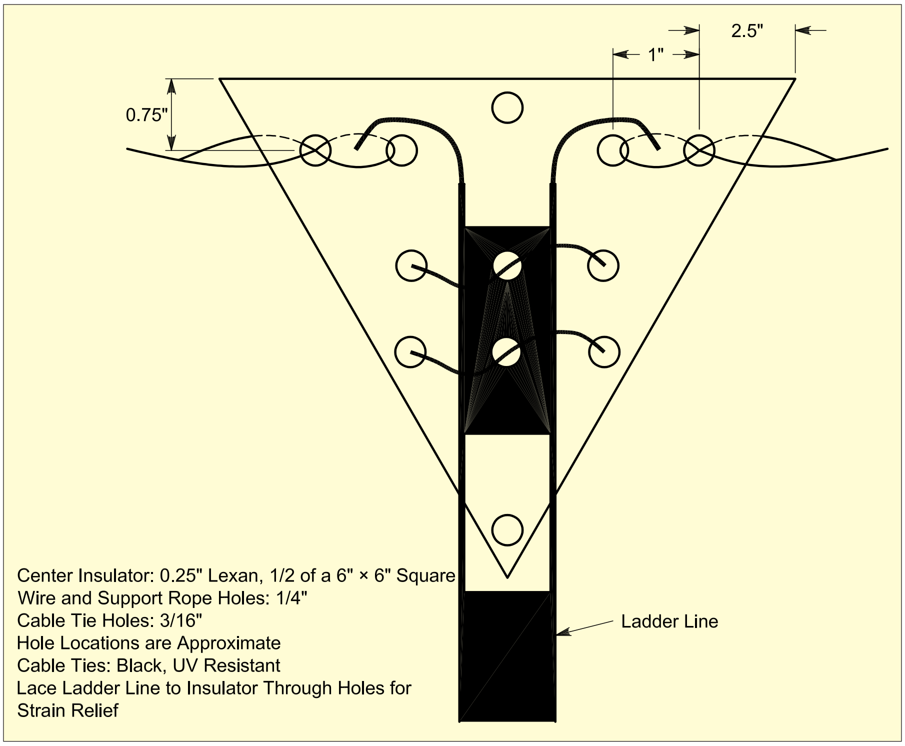

Figure 3—Center insulator.

The trickiest part of the antenna was the junction between the main feed line and the ladder lines to the elements, as shown in Figures 4A and 4B. I made a square of Lexan, on which I mounted two SO-239 coaxial sockets (for the matching section). I drilled holes that allowed me to lace the ladder line to the insulator, placing the three feed lines on top of each other. A few extra holes allowed me to attach ropes for suspending the junction in the air, and for hanging the matching section underneath; one hole allowed me to feed the right side of the three feed lines through to the bottom junction, where I attached them to the SO-239 bodies using spade lugs. I soldered the left side of the transmission lines to a stiff wire that ran between the center conductors of the two sockets.

There are three things to keep in mind when building the junction:

- The SO-239 connectors must be facing down, as you want the matching section and the main (coaxial) feed line to hang from the junction. Use epoxy to prevent water from getting into the sockets. I don't know whether water can get through an SO-239, a PL-259 and into your coax, but if you live in a cold climate, I guarantee you that water collecting in the "well" made by the SO-239 will break the junction apart. I used coax sealant liberally at all junctions. [Trust the fact that water *will* get into an unprotected PL-259 and SO-239 connector and eventually into the coax; these are not waterproof. Seal these connectors and their mating surfaces well.—*Ed*.]

- You must make sure the dipoles are all in phase. This is easy enough. Roll the ladder line for each dipole into a flat coil, stack the coils on top of each other and lace the lines to the junction, making sure that nothing has flipped over. Mark the same side (let's say the left side) of each center insulator. Then, at the junction, solder the ladder line to the SO-239 connectors. When you haul the antenna up, make sure the marked sides of the center insulator are all facing the same direction.
- Once you attach the feed lines to the junction, you have determined the array's stacking order. The top feed line goes to the top dipole, and so on. Label the dipoles so you don't spend lots of time tracing a tangle of cable and wire.

The matching section itself was simple. I used the Antenna Analyzer to cut two quarter-wave pieces of RG-11 cable. Cut pieces of cable that are roughly 10 feet long. Leave one end open, attach the analyzer to the other end and trim the other end for minimum impedance. To make things modular, I used PL-259s on both ends of each piece. At the antenna end, they mate with the SO-239s on the junction; on the other end, I used a "T" connector to attach them to the main feed line. Once you have the matching section built, wind the cables into as tight a coil as possible to form a current balun.

The final step, prior to hoisting the antenna in the air, was to pre-cut 23 foot lengths of rope to use between the elements. I used masking tape to mark 21 foot lengths, which made it easy to set the appropriate spacing between the elements.

Hanging It All

Now you're ready to hang the contraption in the air. The hardest part of the job was finding the right trees. After some hunting, I found a pair of large maples on the edge of the forest, separated by about 25 feet, with no major branches between them. With some careful archery and some friends who are better with a bow and arrow than I am, I managed to get ropes over branches at roughly the 65 foot level and far enough apart to spread the antenna adequately. And I was lucky; I was able to choose branches that "swung" the antenna a bit to the northeast, giving me a 60 degree heading I wanted.

Raising the antenna was routine—although there was plenty of potential for snarls. When the upper dipole got to the 40 foot level, it was time to start hauling the junction into the air. I was fortunate to find a convenient branch to support the junction just when I needed it; this was one detail I had tried hard not to think about. To allow the ladder lines to reach the individual dipoles and to keep the ladder lines from tangling, the junction should be 30 to 40 feet above ground and at least 20 feet away from the antenna. To avoid disturbing the antenna's radiation pattern, the junction should also be centered on the antenna.

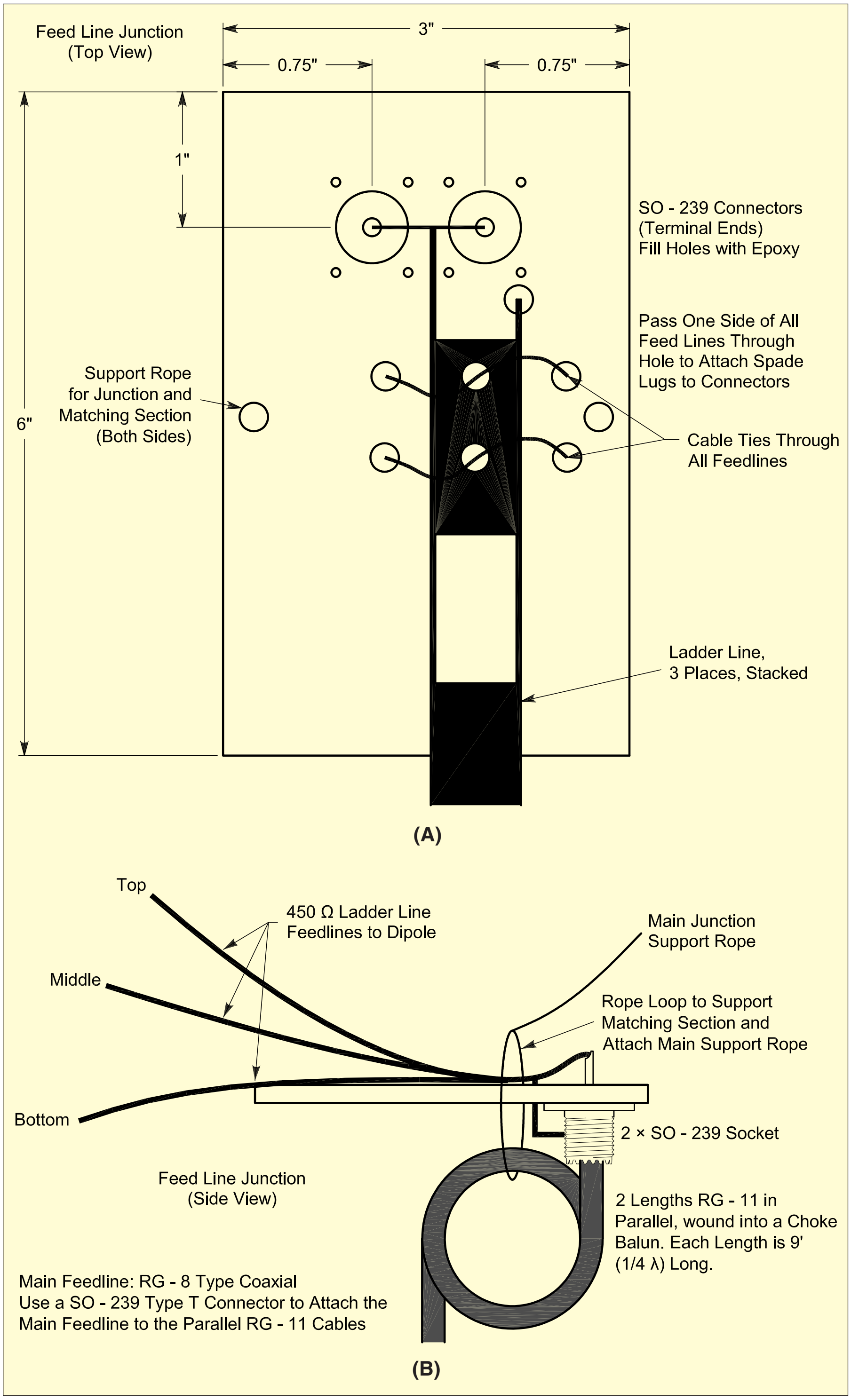

Figure 4A and 4B—Feed line junction, top view and side view.

Disaster struck when the south side of the antenna got stuck at the 45 foot level. The rope was high enough, but was going under a branch that prevented me from raising it further. You probably know the routine. Drop the antenna, shoot another arrow, pull another rope through the tree and start again. This time, I got stuck with the top of the antenna somewhere between 55 and 60 feet above ground…and there was nothing to be done. The obstruction was a long branch that was passing over the antenna, right in the middle. The antenna isn't as high as I had hoped it would be and I'm sure that ground loss is higher than I'd like, but the bottom element is still 12 or 14 feet off the ground, and that seems to be enough.

A number of problems I had expected just never materialized. I was worried that the weight of the transmission lines would pull the centers down and forward, giving me a stack of Vs skewed at an odd angle. In retrospect, elevating the feed line junction was critical to the antenna's geometrical integrity…the rope suspending the junction bore the weight of the transmission lines, not the dipoles themselves. It proved easier than I expected getting the feed line junction into the air without tangling the individual transmission lines.

Does It Work?

This is the part of the article where I'm supposed to write about how I worked YA and P5 on the first call, etc. I'm not going to do that. (Well…just a little.) As exciting as those stories sound, we all know that you can work DX running QRP into a dummy load if the conditions are right. And 100 W running into an antenna with 11-13 dBi of gain is not 1500 W feeding stacked, wide-spaced, monobanders. Antennas radiate; they don't work miracles.

What's the best way to evaluate an antenna? Ultimately, I go by what I hear. If I can hear stations, there's a good chance they can hear me. On 15 meters, signal strengths are literally 6 S-units better than with my G5RV—although I've already implied that the G5RV wasn't the best performer on 15. I worked ZK2TO under very poor conditions, when I couldn't even hear her on my other antenna. And I've gotten a couple of compliments for being one of the loudest signals on the band...something I'd never heard before. Comparing the curtain to an admittedly bad antenna doesn't prove a whole lot, but I'm satisfied that I accomplished what I wanted, which is rough parity with other stations running low power and a Yagi.

I've been reasonably satisfied with the G5RV on 10 meters, so the improvement isn't as striking, but the curtain is usually better by 2 S-units or more. Sometimes the improvement is as much as 4 S-units, sometimes less. On 10 meters, the G5RV has a gain of about 9 dBi, in the right direction. That more or less agrees with my observations. I see the smallest improvements (an S-unit or so) into the South Pacific, where the G5RV has one of its lobes.

On 15 and 10 meters, the SWR is satisfyingly close to what *EZNEC* predicted. The antenna, as I've built it, is a little long —but, given what I've said previously, you shouldn't be surprised that I haven't bothered to tune it. I'd rather spend time operating than minimizing my SWR. The SWR "in the shack" is still below 2:1 across the entire 15 meter band, and below 3:1 between 28 and 29 MHz.

I can't resist pushing my luck and trying my antennas on other bands. The curtain performs decently on 20 meters. The elements and element spacings are really too small to provide a lot of gain, but they're still good for 9 dBi, according to *EZNEC*. *EZNEC* also predicts a resonance in the 20 meter band, where the SWR is high (5:1 to 10:1 and in agreement with what I observe) but not unusable if you have a tuner. I wouldn't make this my only 20 meter antenna but it's something else to try when you're in the middle of a pileup or a contest. Its low radiation angle is a definite asset and it's been very effective. (I can't resist saying that I worked JY on my second call.) On 17 meters the antenna accepts power about as willingly as a rock. On 12 meters, the SWR is also very high, but the antenna delivers about 12 dBi of gain, so it's well worth trying; the only real question is how much additional loss you incur in the feed system due to the high SWR. Since I hadn't planned on either 12 or 20 meters, I feel like I got two extra bands "for free."

Without a real antenna range, about the only way to evaluate an antenna is subjective. So maybe that's the real bottom line. Do I still feel at a disadvantage compared to stations running equivalent power and a triband beam? The answer is an unequivocal "No!" Whether I'm in a pileup or a contest, I'm now competitive—and with far less expense than a beam, a tower and a rotator.

The Antennas I Didn't Build (But Might Have)

This article wouldn't be complete without mentioning some of the antennas that "got away"—my hope is that these will give you some ideas. So here goes:

- If you can figure out how to get 1500 square feet of chicken wire into the air, about 0.3 wavelengths behind the driven elements, please let me know! A non-resonant reflecting screen roughly 20% larger than the antenna in each direction should give you an additional 2.5 dB gain, or so.
- If you scale the design frequency from 15 meters to 17 meters, the "secondary resonance" obligingly moves from 10 to 12 meters, making a very nice antenna for the 12, 17 and 30 meter bands. (Don't forget to scale the transmission lines and elements heights, too.)
- Scaling the 3-element dipole curtain to 20 meters yields an antenna that's probably too big, unless you have really large trees in the right place. However, a 2×2 curtain looks like it might be practical—and, with an appropriate phasing network, it is slewable about 25 degrees off the center axis.
- Finally, if you have an aluminum farm with multiple towers, the curtain looks like an ideal fixed antenna to me. With optimal spacing and at a greater height, the antenna looks like a real winner, producing gains up to 14 dBi—even without a reflector.

But those antennas are for the future. For now, I'm satisfied with an excellent wire antenna for 10 and 15 meter DXing and contesting—the curtain array.

Notes

[1] *The ARRL Antenna Book*, 19th edition, chapter 23. Available from your local dealer or from the ARRL Bookstore, order no. 8047; tel 888-277-5289; **www.arrl.org/shop**.

[2] M. W. Maxwell, *Reflections II*, Worldradio Books, 2001. Available from the ARRL Bookstore, order no. REF2; tel 888-277-5289; **www.arrl.org/shop**.

[3] One would think that the best performance would come when the currents are equal on all elements. I set up an *EZNEC* model with this property, however, and this wasn't the case; equal currents yielded slightly less gain than my final design.

[4] Davis Bury-Flex (available from many vendors; I bought mine from RadioWare), Wireman CQ-102 or CQ-106; **www.radio-ware.com**; **www.thewireman.com**.

[5] S. Ford, WB8IMY, "One Stealthy Delta," *QST*, May 2002, pp 47-48.

[6] McMaster-Carr Supply Company, **www.mcmaster.com**. The 6×6 inch sample squares I used are PN8574K11. Half inch Lexan is also available in 12×12 inch squares (PN 8742K117) and only slightly more expensive.

[7] **www.thewireman.com**; **www.radio-ware.com**.

[8] **www.radio-ware.com**.

[9] R.Olsen, N6NR, "The NRY: A Simple, Effective Wire Antenna for 80 through 10 Meters," pp 3-26 to 3-28. This article appeared, as well, in *QST*, Mar 1993, pp 22-24. In addition to the catenary support, the "NRY" is also interesting because it's another stacked wire antenna–two 20 meter extended double Zepps, which is (if you think about it) essentially a 2×2 curtain. *More Wire Antenna Classics* is available from your local dealer or from the ARRL Bookstore, order no. 7709; tel 888-277-5289; **www.arrl.org/shop**.

Mike Loukides, W1JQ, was first licensed in 1969, at age 13. After a lapse of 15 years with renewal not possible, he retook the amateur exams and became a new Extra class ham in 2001. His recent attention to Amateur Radio revolves around the HF bands with a particular interest in wire antennas. Mike says they are among the few things in Amateur Radio he can build with his near nonexistent metalworking skills. He's written a software contest-logging program in Java and says he'd like to experiment with the satellite digital modes. Mike has a BSEE from Cornell and a PhD in English Literature from Stanford, and is a senior editor for a major computer book publisher. He can be contacted at 30 Hungry Hill Circle, Guilford, CT 06437 or at **mikel@oreilly.com**.