

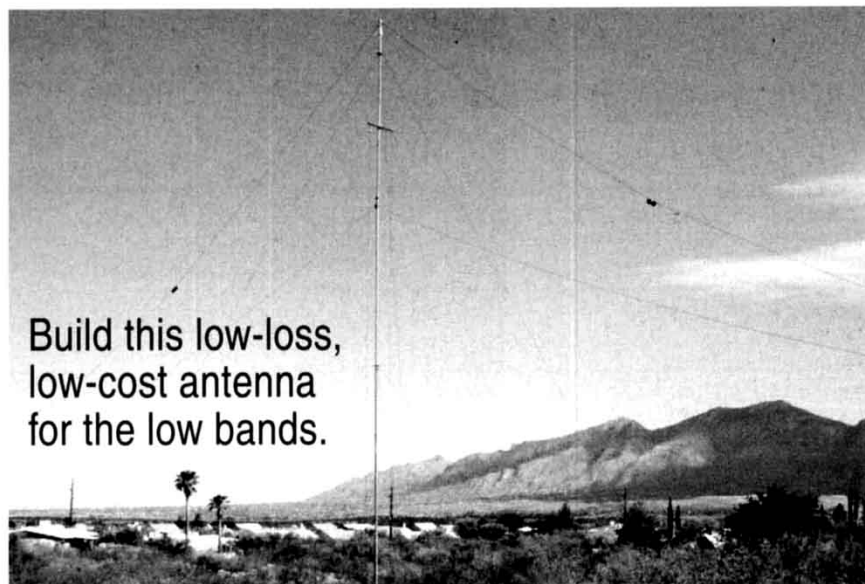
# An Efficient Multiband Vertical for 160 through 20 Meters

I have had the pleasure of hearing the well-known antenna master, Lew McCoy, W1ICP, half jokingly malign the reputation of the vertical antenna. Although there is some uncertainty about who actually was the first to state that "vertical antennas radiate equally poorly in all directions," Lew did make this statement in his antenna presentation at the 1996 ARRL Southwestern Division Convention. Well, despite this folklore, I have always found vertical antennas to be surprisingly good performers. Considering their simplicity, it is hard to beat them as low-cost DX antennas. In my personal experience, they often defy their reputation for poor performance.

The antenna described here is a versatile, multiband vertical designed for use on 160, 80, 40 and 20 meters. My goals were to produce a reduced-size design that would fit on a modest lot, could be erected by just a few people, has maximized efficiency and costs no more than \$200. Even if you decide not to build the antenna as described, you can apply the principles to single-band antennas or scale the antenna for the 80 through 10-meter bands.

Figure 1 shows the major points of the design. The main support is a Rohn 50 telescoping mast, commonly used for fringe TV installations. Fully extended, the mast height is a little over 44 feet; it serves as the vertical element on both 160 and 80 meters. With the help of two short cross arms, the mast also supports vertical wires for 40 and 20 meters. The remainder of the antenna consists of two top-hat wires that add capacitive loading on 160 and 80 meters. On 80 meters, a pair of parallel-resonant traps disconnect some of the 160-meter top hat to provide appropriate loading. This is the only use of traps in the antenna, and I've made every effort to minimize their loss.

Alternatively, the mast can be made



from many different materials, such as aluminum tubing, military-surplus cast-aluminum mast sections, tower sections or a wire hung from a conveniently placed tree. The primary effects of such substitutions will be variations of the wire lengths shown in Figure 1.

The operation on each band may not be completely evident, so a band-by-band explanation may help:

## 160 Meters

The 44-foot mast is well short of the 132 feet required for  $\lambda/4$  resonance on 160 meters; therefore, loading is required to establish resonance. Rather than resort to inductive loading, with its inherently high losses, I incorporated a low-loss capacitance hat. A "folded top hat" design provides the additional capacitance necessary for resonance and requires less horizontal space than a flat top hat. The top hat approach also increases the radiation resistance, which improves the antenna's efficiency.<sup>1</sup>

With a vertical length less than  $0.1 \lambda$  on 160 meters, this antenna system's total re-

sistance ( $R_A$ ) will be low—usually in the range of 5 to 25  $\Omega$ .  $R_A$  is the combination of radiation resistance ( $R_R$ ) and ground-return resistance ( $R_G$ ). The final  $R_A$  value depends heavily on the physical installation of the top hat and the value of  $R_G$  (see Note 1). On this band, a lower  $R_A$  indicates that system losses are low, and one can expect reasonable efficiency.

In order to achieve a match to a 50- $\Omega$  feed line, a matching transformer with some latitude is required. Figure 2 details a broadband transformer that allows a number of impedance-matching ratios; one of them should satisfy the  $R_A$  at your particular installation. Should a higher impedance ratio be required (high  $R_A$ ), make taps in the primary winding. The figure also shows how an SPDT relay can switch out the transformer secondary on 80 through 20 meters.  $R_A$  is already close to 50  $\Omega$  on these bands, so a transformer usually isn't required. Leaving the transformer primary in the circuit on other bands has no adverse affect, and provides a direct path to ground for static discharge. The dc relay voltage can be supplied by a separate cable, or through the feed line if isolation chokes and capacitors are used.

<sup>1</sup>Notes appear on page 49.

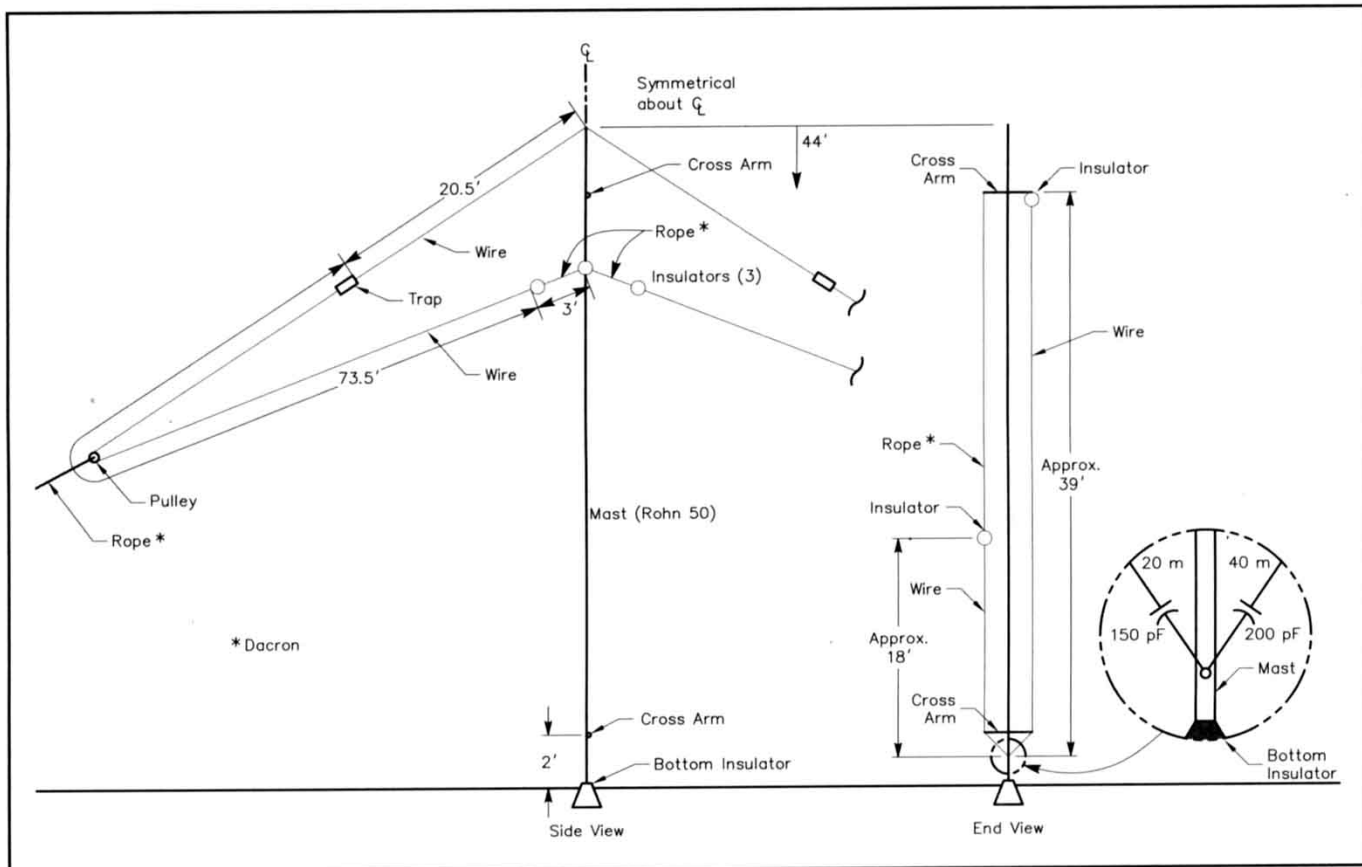


Figure 1—A diagram of AC7A's multiband vertical antenna system.

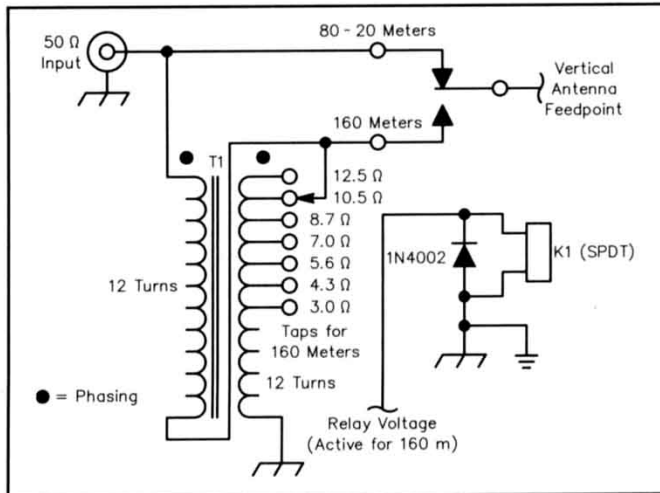


Figure 2—A circuit to switch in a multitap-matching transformer for 160-meter operation. T1 is an FT-140-61 core with 12 bifilar turns of #15 AWG (see text) Polythermaleze wire. Arrange the bifilar wires side-by-side; do *not* twist them. Elevate turns 6 through 11 of the secondary above the toroid's outer face to facilitate taps. K1 is a surplus relay (12 V, with 15 A contacts). Mouser stocks a suitable relay (Magnacraft & Struthers-Dunn; W78RCSX-97, Mouser #528-7880-97) You can contact Mouser at 958 N Main St, Mansfield, TX 76063-4827; tel 800-346-6873; e-mail [sales@mouser.com](mailto:sales@mouser.com), <http://www.mouser.com>. [The author has used this relay and wire with 150-W output.—Ed.]

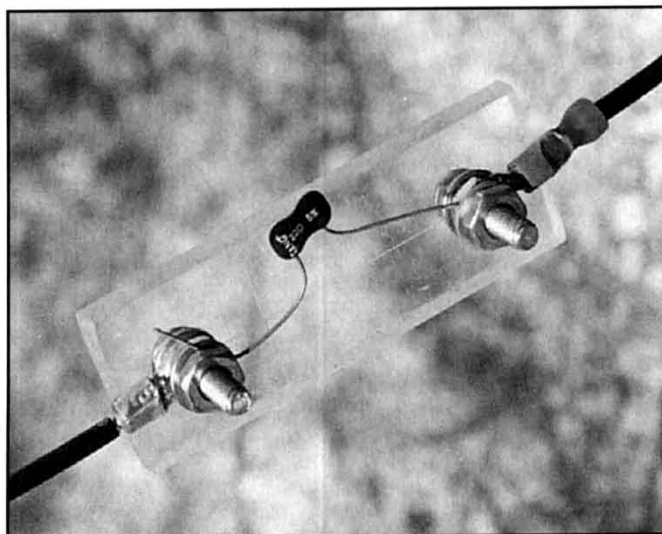


Figure 3—A homebrew spacer relieves strain from the series capacitor at the bottom of the 40 or 20-meter wire elements. For permanent installation, this must be weatherproofed.

### 80 Meters

A  $\lambda/4$  vertical on 80 meters ought to be about 66 feet in length. Therefore, the mast's 44-foot length fulfills two-thirds of the antenna's requirement. By trapping off most of the top hat, the remainder is used to

establish resonance on 80 meters. The traps were designed as high-Q circuits to minimize losses.

By inclusion of the traps on 80 meters, the small, finite loss resistance of the traps is transformed to a larger value at the feed

point. This small resistance, in conjunction with  $R_R$  and  $R_G$ , produces a good match to a 50- $\Omega$  feed line.

### 40 and 20 Meters

Short cross arms at 2 and 39 feet above

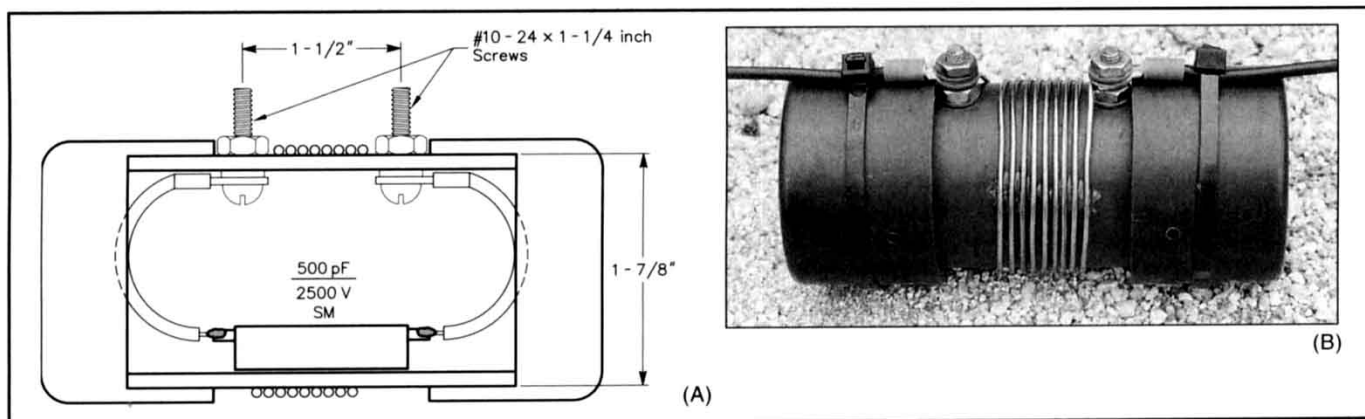


Figure 4—A is a cross section of the traps. B is a photo of the finished trap. Notice the ring terminals on the top-hat wires and the cable ties used for strain relief.

the antenna base support the 40 and 20-meter antenna wires and space them away from the mast. The physical spacing reduces tuning interaction between bands and helps keep the wires out of the way when the mast is being extended or collapsed. They are joined at the bottom of the mast, which serves as a common feed point (see detail in Figure 1).

The 40 and 20-meter antenna wires were intentionally made long. This adds inductive reactance that can be resonated by a series capacitor. This not only allows the antenna to be tuned at the base, but also eliminates the need to raise and lower the mast while adjusting the antenna for these bands. It also raises the  $R_A$  over that of a  $\lambda/4$  vertical, which improves efficiency and provides a good match to a 50- $\Omega$  feed line.

The 40-meter vertical wire is 39 feet long, and the 20-meter vertical is 18.5 feet long. Both are opened about six inches from the base connection point to insert the series capacitors. When tuned, they provide an excellent match to a 50- $\Omega$  feed line. Systems with very low ground losses ( $R_G < 5 \Omega$ ) can achieve a radiation efficiency on the order of 90%.

## Construction

There are no steadfast rules in the construction of a "homebrew" antenna; not everyone has access to the same materials and tools. Therefore, I encourage you to be creative in making do whenever necessary.

As a safety consideration, assess your physical ability to erect the telescoping mast before attempting to do so. When in place, the top end of the bottom section will be more than eight feet above the ground. Each mast section must be pushed up and locked into position while working from this height. This is best accomplished by two people, working from two tall ladders. New mast sections slide easily, but with time, corrosion and dirt buildup make the task more difficult. Keep the mast sections clean and lubricated to help with future disassembly. Aside from extending and collapsing the mast—a physically tiring act—nothing extraordinary is required to erect this antenna.

The Rohn 50 telescoping mast can be mail ordered from many Amateur Radio outlets, but be prepared for shipping fees that nearly equal the mast cost. With a little searching, I was surprised to find that they are stocked by a local electronic supplier—at a cost comparable with the mail-order distributors.

The two cross arms were made from a single five-foot piece of antenna mast, the thin-wall type used to support TV antennas. The swaged end was removed with a hacksaw and discarded. The remainder was cut into two equal-length pieces, about 27 inches long. A widely spaced U bolt ( $2^{11}/16$  inches) fits around the lower mast section and through holes drilled for it at the center of the cross arm.

If they're available, use U-bolt clamps to help mount the upper cross arm. They also help keep the cross arms from windmilling when the wires are pulled. Since the lower cross arm does not carry a load like the upper cross arm, I didn't use a clamp, and it hasn't presented a problem.

Holes were drilled 1.5 inches from the cross arm ends to facilitate installing eye bolts through the top cross arm and to pass the 40 and 20-meter wires through on the lower cross arm. Remember that these holes are drilled at 90° to the U-bolt holes.

The 40 and 20-meter wire elements fasten to the upper-cross-arm eyebolts with Dacron rope. An egg insulator is used between the wire and rope. A short piece of rope is sufficient for the 40-meter wire; about 20 feet supports the 20-meter wire. Lay the extended mast on the ground before installation to set up the cross-arm positions and measure the exact rope lengths required to support the wires.

I mentioned that the 40 and 20-meter wires are spaced about six inches from the mast at the antenna base for placement of the series tuning capacitors. The capacitor leads will not withstand the wire tension, but mounting the capacitor across an egg insulator solves the problem. Alternatively, make an appropriate insulator from a piece of acrylic plastic mounted between two

studs. Some form of weatherproofing is necessary. See Figure 3 for details of a homemade insulator.

The wire used for the top hat and vertical wires was purchased from Antennas West.<sup>2</sup> It is sold under the name "Quiet-Flex." It is a durable, 40-strand, #14, 3500-V-insulated copper wire, with a black, UV-resistant jacket. Other #14 insulated wire will work, but Quietflex will stand up to most any kind of sun or weather condition for a long time. It is flexible at most any temperature and is a pleasure to use. To protect it as it passes through the lower cross arm, I slipped a four-inch piece of RG-58 outer jacket over the wire to protect it from chafing— $3/16$ -inch-diameter heat-shrink tubing should work as well. Just remember to slip it over the wire before making any permanent connections.

All antenna-wire connections were made using crimped and soldered ring terminals that fit #10-24 screws. Each terminal ring is sandwiched between a pair of washers and nuts at each connection. I used heavyweight ring terminals and find that they take much more punishment than their lightweight counterparts.

The top-hat wires can be connected to the top of the mast in several ways. You could drill two opposing holes about one-half inch from the mast end and install a #10-24 $\times$ 1/2-inch-long machine screw in each hole, with the threaded end pointing outward. Secure the ends of the top-hat wires to these studs using #10-24 hardware.

I mounted the studs in a piece of heavy-gauge PVC. It is slit at one end, slipped over the end of the mast and held in place by a stainless-steel hose clamp tightened over the slit end. The studs connect to the mast via short jumper wires fabricated from antenna wire and ring terminals. A self-tapping screw in a drilled pilot hole holds each terminal to the mast.

The top hat is folded back upon itself by running the wire through a small pulley at the fold point. This allows the fold-back point to move as necessary for each unique installation. Since the wire is insulated,

either a metal or plastic pulley can be used. The free end of each wire terminates at an insulator. The wire insulators are connected, one to each end, of a six-foot rope that slides through a third insulator. That third insulator is attached to the guy ring at the top of the second highest mast section (see Figure 1).

Place the top-hat fold points as high as possible; a horizontal installation is optimum. Higher top hat positions increase the  $R_R$  portion of  $R_A$  on 160 and 80 meters, which helps maximize efficiency. Should tall trees or other structures be available, they will work as end supports. There are few tall trees here in the desert, so I use some thin-wall mast sections. In my installation, a 10-foot mast was used at each end. Since my lot is long, the masts are spaced about 30 feet from the fold points. This positions the top hat ends about 18 feet above ground.

It requires some ingenuity to hold the mast in place and insulate it from the ground. I buried the bottom half of a champagne bottle in the ground, centered the mast's bottom section over the bottle and tightly guyed the mast with galvanized steel wire. Egg insulators isolate the mast and guy wires. The galvanized wire has less give than rope and provides for more rigid mast placement.

Dacron rope was used for all the mast sections above the bottom section. Although you could guy the mast at each telescoping section, I installed guys only at the bottom, center and top sections. The mast bears no load at the top, and the top hat serves to guy the antenna. This approach has worked well, and it's much less confusing when the guys and various wires are being pulled into position. The antenna has withstood strong winds and stayed up without any problems.

*The ARRL Antenna Book* shows many suitable guy-anchor systems.<sup>3</sup> I use three-foot construction stakes obtained at a local home-improvement center. They are strong steel stakes that taper to a point at one end and have three convenient holes through them right near the top. Rather than threading the Dacron rope directly through the stake, I slip a piece of galvanized guy wire through the hole and twist it on itself. The guy then terminates in an egg insulator that provides a good union for the Dacron rope. The guy wire is several feet long to keep the Dacron rope above ground and away from rabbits that might chew through it.

One last point: As with any vertical antenna, the performance of this antenna is highly dependent on the ground conductivity near the antenna. The usual method of improving the ground conductivity is to use many radial ground wires around the antenna base. This and other possibilities for developing a ground system are covered in *The ARRL Antenna Book*.<sup>4</sup> Also, refer to the sources described in end notes of the author's previous articles on build-

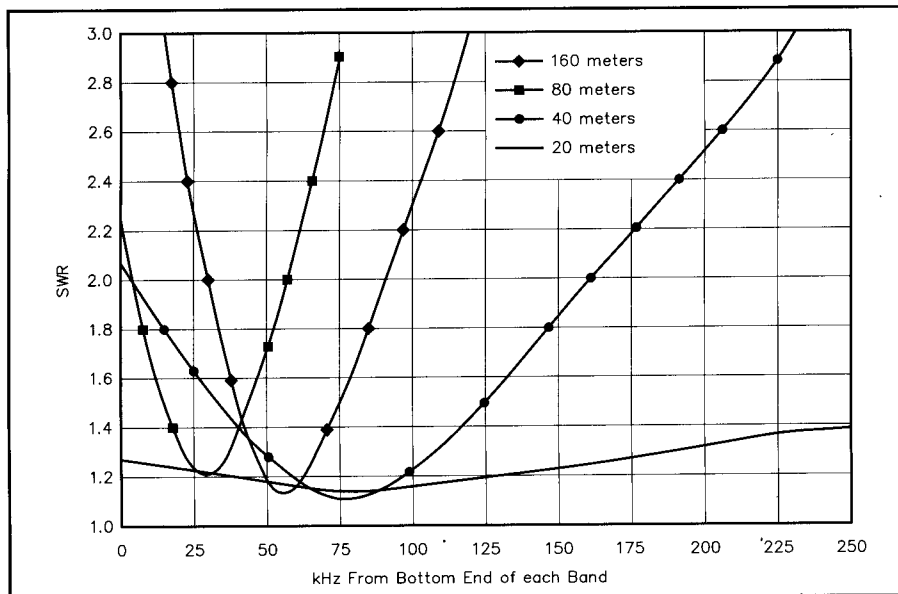


Figure 5—An SWR versus frequency chart for the multiband vertical antenna.

ing efficient, short vertical antennas.

### Trap Construction

The trap construction is shown in the drawing and photograph in Figure 4. Black 1 $\frac{1}{8}$ -inch (OD) ABS serves as the coil form. The coil windings are secured at the ends using studs made from #10-24 $\times$ 1 $\frac{1}{2}$  screws, spaced 1 $\frac{1}{2}$  inches apart. I used brass hardware, but stainless-steel hardware would be better, where corrosion is a problem. Each capacitor is housed inside its coil form and connects under the screw heads with ring terminals.

Before winding the coil, prepare the capacitor for installation inside the form. A 500 pF, 2500 V mica capacitor is required. Traps must withstand high voltages and a 2000 V to 2500 V rating should be sufficient for power levels in the 100 to 150 W range. If you have problems coming up with high-voltage capacitors, consider connecting several lower-voltage capacitors in series, perhaps four 2000 pF, 500 V silver-mica capacitors. When series connected, they are equivalent to a single 500 pF, 2000 V capacitor. Silver-mica capacitors have low dielectric loss, tight tolerances and are available from a number of electronic suppliers who carry surplus or new components.

The coils are made from nine turns of #15 AWG enameled wire (#14 or 16 AWG should also work), and should have a finished turn spacing of about eight turns per inch. Strip the insulation off one end of the wire and anchor the wire to a stud. Wind the coil tightly and closely space the turns. Strip the free wire end and secure it to the other stud.

The coil turns will be spread during the tuning operation. As the turns are spread, the windings may loosen. If this happens, simply grip a turn with some pliers and twist it to form a wire kink on the form surface. This will tighten the coil winding;

repeat the action for more turns until the winding is tight.

ABS end caps help keep water out of the trap. Connect the top-hat wires to the coil-end studs with heavy-duty ring terminals. (See Figure 4B.) Secure each top-hat wire to the trap end caps with a heavy-duty, UV-resistant nylon cable tie to reduce the load on the ring terminals.

### Trap Tuning

Before venturing outside, the traps must first be tuned. There are several ways to do this using a dip meter or one of the various antenna-measurement devices offered by MFJ or Autek. I use a Heathkit dip meter in conjunction with my station transceiver to get an accurate frequency indication.

You must decide where in the 80-meter band you want to tune the antenna and traps. Since I operate mostly at the low end of 80 meters, I tuned the traps to 3.530 MHz. When the coil turns are close up against each other, the trap resonates below the 80-meter band. As the turns are spread apart, however, the resonant frequency rises. Use a pocketknife and work toward an even spacing of about  $\frac{1}{8}$  inch between turns. Spread and compress the windings until you achieve the desired resonant frequency. Once the tuning is complete, apply a few lines of epoxy lengthwise, across the windings, to hold them in place. After the epoxy cures completely, the traps may be installed in the top-hat wires.

### Antenna Tuning

Antenna tuning can be accomplished using a low-power transmitter and an SWR bridge, or one of the mentioned antenna-measurement instruments. For 80 through 20 meters, no impedance matching is required: Simply adjust the appropriate wire's length or change the capacitor value. For 160 meters, both the top hat length and

feed-point matching must be set.

Begin tuning on 80 meters. Adjust the wire length (between the top of the mast and the traps) until resonance is achieved. A low SWR should accompany the resonant point. Depending on the desired frequency and the environment, the wire lengths should be near those shown in Figure 1. Start with a wire that is a little too long to avoid splicing wires. For my installation, the mast plus 80-meter top hat lengths are:

$$L \text{ (ft)} = 230 / f \text{ (MHz)} \quad (\text{Eq 1})$$

The required length will be shorter if the top hat is installed horizontally.

Once satisfied with the 80-meter tuning, adjust the overall top hat length for resonance on 160 meters. This is accomplished by shortening or lengthening the long, folded wire beyond the traps. As mentioned earlier, the  $R_A$  on 160 meters will be far less than  $50 \Omega$ , which may make it difficult to find the initial resonant frequency with an SWR meter. I suggest connecting the matching transformer of Figure 2, with the  $12.5\text{-}\Omega$  tap selected. This should provide a reasonable match for most installations and allow the minimum-SWR point to be determined. The optimum tap selection can be made after the antenna is resonant at the target frequency. For 160 meters, the total length of the mast plus the full top hat, followed the equation:

$$L \text{ (ft)} = 255 / f \text{ (MHz)} \quad (\text{Eq 2})$$

If you must add long lengths to the 160-meter top hat, the folded ends are too close to the ground.

A space is intentionally provided between the top-hat wire ends and the mast by the three-foot ropes shown in Figure 1. This helped reduce a peculiar end effect that made tuning less predictable. Therefore when adjusting the top hat length, change the end of the wire, but do not reduce the wire-to-mast spacing.

The 40 and 20-meter bands are each tuned in similar fashion and do not require raising and lowering the mast. Figure 1 shows approximate values for the series tuning capacitors: 200 pF for the 40-meter element and 150 pF for the 20-meter element. These values provide resonance in the CW subbands, with good bandwidth. You can easily determine exact values by substituting a variable capacitor—such as a 365-pF receiving capacitor—for the fixed value. Using an insulating knob on the capacitor, adjust it until the SWR minimum is at the chosen frequency. Remove the capacitor from the circuit, measure its value and replace it with the closest available fixed-value capacitor. A silver-mica capacitor works nicely in this application, and since it is used at a low-voltage point, it need not have a high working voltage like those of the traps.

Once you are satisfied with the tuning on each band, secure the guys and end ropes.

## Results

The 2:1 SWR bandwidth of an antenna is always of interest. It doesn't indicate radiation performance, but rather the frequency range that can be covered without using a Transmatch. Wide SWR bandwidth can also indicate excessive loss, so keep this in mind. Figure 5 shows SWR plots for each of the bands. The curves are based on measurements made at the antenna feed point.

Just for the sake of curiosity, I checked the SWR on each of the other HF bands, as well. A couple of surprises did show up: The SWR on 30 meters is a little less than 2:1, and it's slightly greater than 2:1 in the FM portion of 10 meters. Although it was not intended for 30 meters, the antenna performs well on the band.

The proof of any antenna design comes down to how well the antenna performs at your particular station, with its particular constraints. I use 16 buried radials at this location—ranging in length from 66 to 130 feet. This is a minimal ground system; but the antenna is located in an area covered with dense desert vegetation and it precludes the installation of a more extensive return system. Despite this limitation, the antenna does a credible job. To date, I've worked all states and continents, except Europe, on 160 meters, using 80 to 90 W on CW. The DX performance has been even better on 80 meters, where stations on all continents have been contacted. Using this latest version and various previous generations of verticals, I have managed to work DXCC on 40 meters with an output power

less than 100 W. That's not a bad accomplishment for an antenna "that radiates equally poorly in all directions."

## Notes

<sup>1</sup>Thomas Kuehl, AC7A, "Build Efficient, Short Vertical Antennas," *QST*, March 1998.

<sup>2</sup>Antennas West is no longer in business. Antennas and More sells all Antennas West products. Contact them at 1038 S 350 E, Provo, UT, 84606; tel 888-277-5718, 801-373-8426 (both lines voice and fax); e-mail [support@antennasmore.com](mailto:support@antennasmore.com); URL [www.antennasmore.com](http://www.antennasmore.com).

<sup>3</sup>R. Dean Straw, N6BV, Editor, *The ARRL Antenna Book* (Newington: ARRL, 1997), ARRL Order No. 6133. See Chapter 22. ARRL publications are available from your local ARRL dealer or directly from the ARRL. Mail orders to Pub Sales Dept, ARRL, 225 Main St, Newington, CT 06111-1494. You can call us toll free at tel 888-277-5289; fax your order to 860-594-0303; or send e-mail to [pubsales@arrl.org](mailto:pubsales@arrl.org). Check out the full ARRL publications line on the World Wide Web at <http://www.arrl.org/catalog>.

<sup>4</sup>R. Dean Straw, N6BV, Editor, *The ARRL Antenna Book*; see Chapter 3.

*Thomas, AC7A, was first licensed in 1969 at age 15, with the call WN6BQI. Early on, he developed an appetite for the technical side of the hobby that remains today. A graduate of Cal-Poly San Luis Obispo, he has spent the better part of the last 19 years employed by Burr-Brown Corporation as a Product Engineer. When not assisting his wife with raising their three children, you may find him chasing DX on the low bands or pruning antenna wires in the backyard. You can reach Thomas at 620 S Avenida Princesa, Tucson, AZ 85748; e-mail [Kuehl\\_Tom@BBrown.com](mailto:Kuehl_Tom@BBrown.com).*

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