Designing a Shortened Vertical for 75 and 160 Meters

If you have limited real estate, consider a vertical to get your signal out on 75 meters and Top Band.

Christoph Kunze, DK6ED

Many radio amateurs use horizontal antennas like dipoles and loops for 75 and 160 meters. However, the radiation patterns for these antennas, when strung at heights achievable by most amateurs, show that most of the signal is directed into space. Figure 1 contrasts two antennas for 160 meters, which is affectionately known as "Top Band" among its aficionados. The vertical radiation pattern for the horizontal dipole, at 0.1λ (52 feet) above the ground, shows its strongest signal direction is straight up. On the other hand, the 52 foot vertical antenna's radiation pattern shows almost no vertical signal and the bulk of its energy, directed more closely to the horizon, which favors long distance communication.

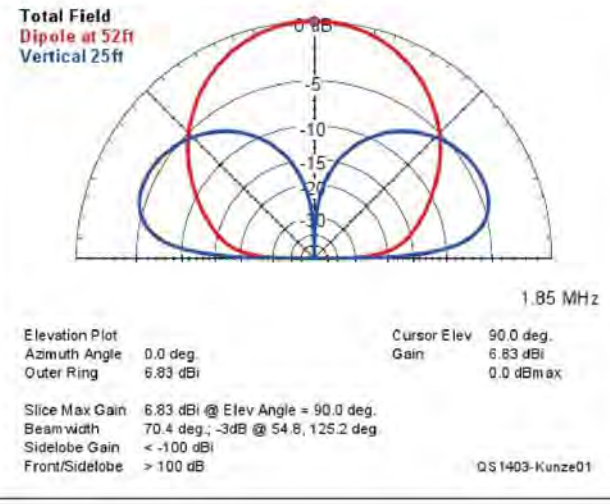


Figure 1 — Contrasting vertical radiation patterns at 1.85 MHz (160 meters) of a dipole (red) and a vertical (blue), subject to space constraints. The height limit is 0.1 λ (52 feet) and each element of the dipole has a length of 0.1 λ. With these constraints, the dipole's strongest signal is straight up and the 52 foot vertical has its strongest radiation closer to the horizon, making it a better DX performer.

Like many amateurs, I am forced to compromise when it comes to the height of the antenna that I can erect. While I would love to have a quarter wave vertical for Top Band or even 75 meters, I have been forced to contend with a much more "down to Earth" height restriction. Yet with a combination of a vertical element and a horizontal element with a trap, I am able to do quite well making DX contacts on both 75 and 160 meters.

This project came into being through three stages (see Figure 2). The first phase was the construction of a shortened vertical antenna for 75 meters. Phase II added a trap and extension for Top Band. The third and final phase added improved coupling that gave improved matching within the 75 meter band DX regions. However, before beginning Phase I, I had to make a fundamental decision about the type of shortened vertical that I was going to build — a vertical with a loading coil at its base or one with a capacitance hat.

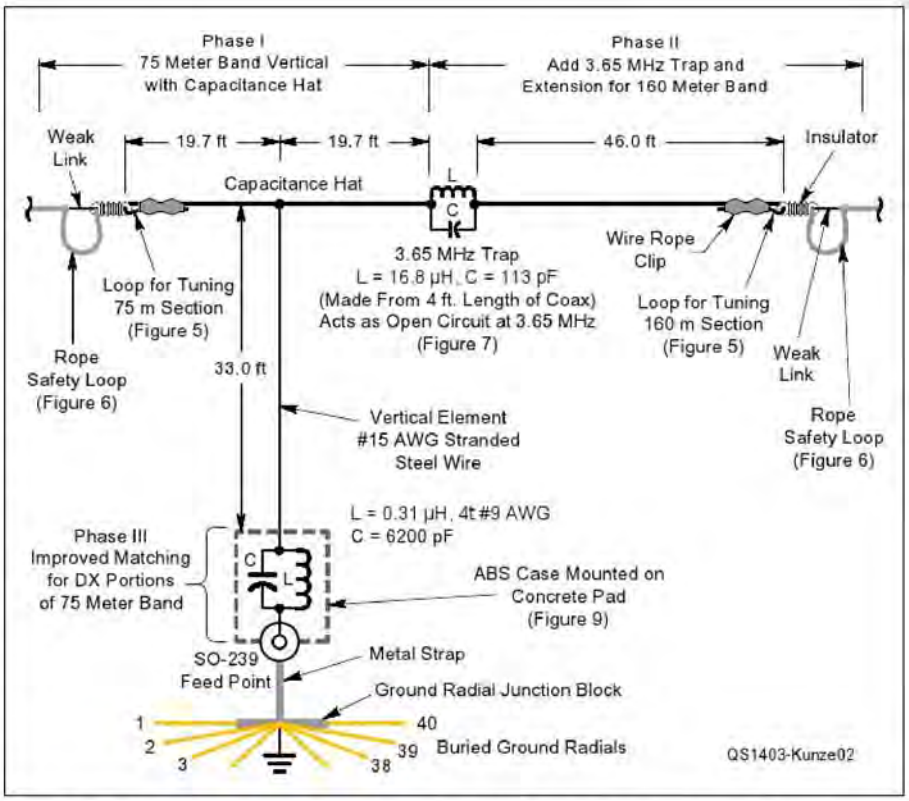


Figure 2 — The shortened vertical antenna for 75 and 160 meters was implemented in three phases. Phase I was a shortened vertical with a capacitance hat for 75 meters. Phase II added a trap and extension for 160 meters. Phase III added improved matching for wider bandwidth in the DX portions of the 75 meter band.

Shortened Vertical Antennas

A good vertical should be at least a quarter wavelength long and it also needs an effi-

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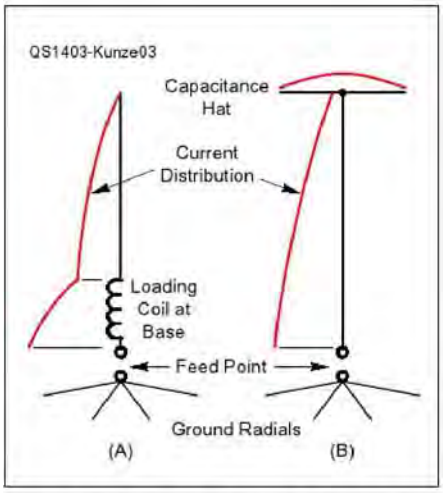


Figure 3 — Current distribution in a shortened vertical antenna with a capacitance hat (at A) versus a shortened vertical with a base loading coil (at B).

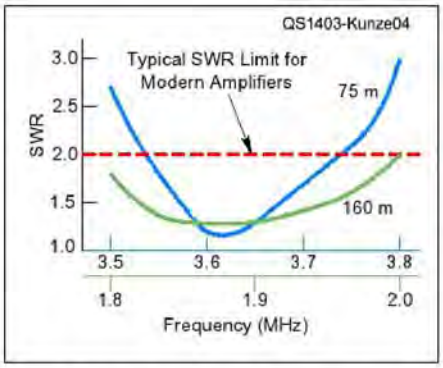


Figure 4 — SWR on 75 meter and 160 meter bands of the Phase II version of the antenna.

cient ground system. For 75 meters, even a quarter wave vertical is too long for most amateurs and a quarter wave for Top Band is too long for almost everyone. Practicality forces us to shorten a vertical antenna for these bands.

To shorten a vertical, there are two primary choices: you can use a coil at the base or you can use some kind of a capacitance hat (see Figure 3). In making your choice, it is important to consider the current distribution on the antenna, because it is the current that is responsible for the antenna's radiation.

A vertical with a coil at its base is not a very good radiator. There are ways to avoid losses in the coil, but this is a point of minor importance. As the current antinode (point of maximum current in a standing wave) is wound up into the coil, the antenna's radiation is reduced (see Figure 3A). A vertical antenna with a capacitance hat is the better choice because of the increased current distribution along the antenna (see Figure 3B).

Phase I: T Antenna for 75 Meters

In my case the antenna height was limited to roughly 35 feet and there were just two points to fix a horizontal wire for a capacitance hat. Therefore, it was easy to decide on a T antenna. The antenna's vertical element is 33 feet long and it connects to the center of the capacitance hat, which is formed by two horizontal elements, each 19.7 feet long (see Figure 2). One of the horizontal elements has an extra length that loops back through the supporting insulator and is clamped with a wire rope clip for easy length adjustment when tuning.

Tuning

The T antenna simply tuned by adjusting its length for minimum SWR in the center of the portion of the 75 meter band that you want to work.

Phase II : Extension for 160 Meters

Extending one of the horizontal elements by 46 feet meant that I could now resonate the antenna on Top Band (see Figure 2). To prevent this extension from affecting the tuning of the 75 meter T antenna, I inserted a trap between the original horizontal element and the new extension.

At its resonate frequency a trap has a high impedance, so anything connected beyond it will, in effect, disappear from the system — almost like opening a switch. At other frequencies a trap has a low impedance, in effect acting like a closed switch. By designing the trap's resonant frequency to be 3.650 MHz, the new extension has little effect on the original T antenna when I am working the 75 meter band. However, when I am working 160 meters, the extension comes into play and the antenna system resembles an inverted L.

On 75 meters there is good radiation from the vertical element but on 160 meters, I must accept that there is also radiation from the horizontal element. As a result of this radiation from the horizontal element, the system acts like an isotropic radiator when working Top Band.

The radiation resistance and hence the antenna's efficiency can be increased by lowering the ground resistance.[1] Short of moving to the sea shore, this is best accomplished by increasing the number of ground radials. However, keep in mind that going from 50% efficiency to the theoretical maximum of 100% efficiency will only increase your signal by 3 dB, which is just half of an S unit on most receivers.

Tuning

First, set the resonance of the trap to 3.620 MHz in the shack. After having erected the antenna, tune the whole system to resonate in the center of the desired portion of the 75 meter band. This antenna will cover about 200 kHz with an SWR of 1:2 and 300 kHz with an SWR of 1:3 (see Figure 4). Next, adjust the long part of the antenna beyond the trap for the portion of Top Band that you want to use.

Measurements on this antenna should be made at the base of the vertical element. If that is not convenient, then use an extension coax cable one half-wavelength long. However, be sure to reduce the cable length by its velocity factor fraction (VF).

Construction

The antenna system has three equally important parts — the antenna itself comprised of the wire, insulators, a means of

[1]Notes appear on page 34.



Figure 5 — End support for the antenna. The extra length loop and wire rope clip make easy work of adjusting the length when tuning the antenna to obtain minimum SWR at the target operating frequency.

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Figure 6 — Safety link in antenna support is designed to break before the antenna stretches when the supporting tree sways in a storm. The extra loop prevents the antenna from falling to the ground when the weak link breaks.



Figure 8 — 3.650 MHz trap.

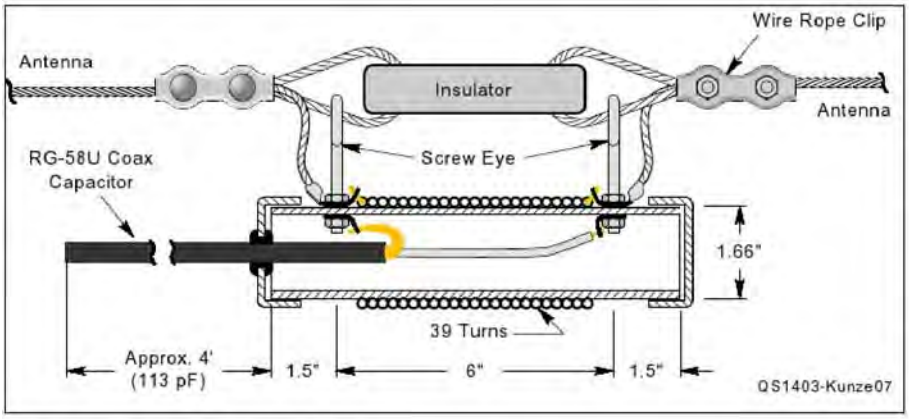


Figure 7 — Diagram of 3.650 MHz trap.

tuning and support, the trap, and the ground system.

Antenna

For my low band antenna I used #15 AWG stranded steel wire. Tuning is easier if the wire has no insulation at the ends. At each end, I folded it back to form a loop that I secured with a wire rope clip, as shown in Figure 5. The antenna is tuned by lengthening or shortening the loop, which shifts its resonant frequency.

An antenna fastened to a tree is subject to extra stress during a storm and the antenna may break or be stretched if there is no means to absorb the extra tension as it moves. I have tried using springs in the past, but they must be partially stretched to hold the antenna reasonably flat and with the first good storm, they often end up "sprung" and holding up a droopy antenna. I finally came up with the scheme shown in Figure 6, which adds a weak link that will break before the antenna stretches. The extra loop keeps the antenna from falling to the ground.

Trap

The trap coil is made from 39 turns on a 1.66 inch diameter form of #13 AWG insulated copper wire used for electrical appliance power cords (see Figures 7 and 8).

The capacitor is made from RG-58C/U coax cable, which has a capacitance of 28.5 to 30 pf/foot. About 4 feet of the RG-58 forms a 113 pF capacitor that is reliable to 5 kV, so using up to 500 W of RF should not be a problem, otherwise, if you plan to transmit with more power, you should use a doorknob capacitor.

Tuning the trap to 3.600 MHz in the shack will yield a 3.650 MHz resonant point in the air. If you use a grid dip meter you can tune the trap by cutting the coax to the right length. Take care to keep the coax shield safely apart from the inner lead to avoid arcing. Secure the 4 foot coax capacitor to the side of the antenna where the shield of the coax is connected, so the two leads have the same potential. If cable ties are used to secure the coax capacitor to the antenna, be careful not to over tighten them, which could deform the outer covering of the coax. It's also good idea to protect the free end of the coax capacitor, which is exposed to the weather, with a dab of silicone sealant covered by a length of heat shrink tubing.

I have given up trying to make my traps waterproof; now I build them so that any moisture that collects through either condensation or infusion can drain out easily. The outer cover only protects the trap from water spray and the covers are larger than the pipe.

Ground System

At the base of the vertical element is a small concrete pad that serves as a nexus for the ground radial system and as an anchor point for the antenna's vertical section (see Figure 9). Mounted next to the ground radial junction block is a short piece of ABS pipe roughly 4 inches in diameter with a screw-on lid. A stainless steel screw through the top serves as an anchor for the antenna and is connected to the inner lead of an SO-239 socket at the base of the ABS

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Figure 9 — Concrete pad at the base of the vertical element. The ABS enclosure serves as the anchor point for the vertical element and also contains the LC network for improved matching on 75 meters. At the base of the enclosure is the SO-239 feed point with its shell connected to the ground radial junction block via a low-impedance metal strap. The connection to the shack is made with coax running through buried plastic pipe.



Figure 10 — Parallel LC circuit to improve SWR in DX portions of the 75 meter band. The circuit was installed in the ABS enclosure at the base of the vertical element as Phase III of the antenna project.

pipe section. The shield of the SO-239 is connected to the ground block with heavy gauge metal.

The ground radial system is a critical part of the antenna.[2] As an initial experiment I used just two 65 foot pieces of insulated wire laid on the ground. I was able to tune the antenna and they actually worked quite well for continental contacts. However, for DX a more extensive ground system is required and at present, I have 40 radials, each 20 to 80 feet long, connected to the ground junction block. The radials are #15 AWG zinc-coated wire. After burying the radials they were soon covered by the surrounding grass.

Phase III: Improved Matching

Figure 4 shows the SWR of the dual-band antenna plotted across the 75 and 160 meter bands. Of particular interest to me is the 75 meter band response. Note that the entire band cannot be covered without exceeding an SWR of 1:2, which is the typical limit of modern solid state RF amplifiers where fold-back current limiting begins to take effect.

I am interested in the 75 meter band DX sections of 3.5 and 3.8 MHz.[3] If the center frequency of the antenna were located halfway between these two points at 3.65 MHz, we would need a coil L_0 for the lower section and a capacitor C_0 for the higher section of the band and a relay to switch between the lower and the higher portion. After determining the values of the coil and capacitor, there is an easy way to avoid the necessity of a relay and still cover the 75 meter band DX sections of 3.5 and 3.8 MHz automatically. Because a tuned circuit becomes inductive below its resonance and capacitive above the resonance, we can use this idea for matching the antenna.

To construct this circuit, first determine the values for matching the antenna conventionally. I used an antenna analyzer and the following procedure: to determine L_0, I set the analyzer frequency to 3.5 MHz and connected it to the bottom of the antenna through a hand wound coil that had an inductance of roughly 10 µH. Using a clip lead, I varied the connection point on the coil until I found the minimum SWR point. I then measured the inductance of the portion of the coil feeding the antenna and let this be L_0. To determine C_0, I used a similar procedure, first setting the antenna analyzer to 3.8 MHz and then connecting it to the base of the antenna through an 800 pF variable capacitor. I varied the capacitor until I found the minimum SWR. I then removed the capacitor and measured it and let its value be C_0.

In my case I found L_0 = 3.9 µH for 3.5 MHz and C_0 = 490 pF for 3.8 MHz. With these data we can easily calculate a parallel resonant circuit L_1C_1 with the following equations where frequencies are in MHz, reactance is in ohms, inductance is in µH, and capacitance is in pF:

$$f_1 = 3.8 \text{ MHz}$$
$$f_2 = 3.5 \text{ MHz}$$
$$C_0 = 490 \text{ pF}$$
$$L_0 = 3.9 \text{ µH}$$
$$X_C = -10^6/(2\pi f_1 C_0)$$
$$X_C = -10^6/(6.28\times 3.8\times 490)$$
$$X_C = -85.5\ \Omega$$
$$X_L = 2\pi f_2 L_0$$
$$X_L = 6.28\times 3.5\times 3.9$$
$$X_L = 85.8\ \Omega$$
$$f_0 = \sqrt{f_1 f_2 (X_L f_2 - X_C f_1)/(X_L f_1 - X_C f_2)}$$
$$f_0 = \sqrt{\frac{3.8\times 3.5(85.8\times 3.5 + 88.5\times 3.8)}{(85.8\times 3.8 + 85.5\times 3.5)}}$$
$$f_0 = 3.65 \text{ MHz}$$
$$X_0 = X_L\left(\frac{f_0}{f_2} - \frac{f_2}{f_0}\right)$$
$$X_0 = 85.8(3.65/3.5 - 3.5/3.65)$$
$$X_0 = 7.04\ \Omega$$
$$L_1 = X_0/(2\pi f_0)$$
$$L_1 = 7.04/(6.28\times 3.65)$$
$$L_1 = 0.31 \text{ µH}$$
$$C_1 = 10^6/(2\pi f_0 X_0)$$
$$C_1 = 10^6/(6.28\times 3.65\times 7.04)$$
$$C_1 = 6197 \text{ pF}$$

The parallel tuned circuit shown in Figure 10 requires a 0.301 µH inductor and a 6197 pF capacitor. Of course, it is not practical to try to achieve such levels of precision (especially for something that will be left outside). My technique is to check the center frequency of 3.650 MHz with a grid dip meter or an antenna analyzer while spacing the coil turns and/or paralleling the capacitors. The circuit is housed in the ABS enclosure at the base of the antenna (see Figure 9) and is connected between the feed point and the bottom of the vertical element (see Figure 2). After installation,

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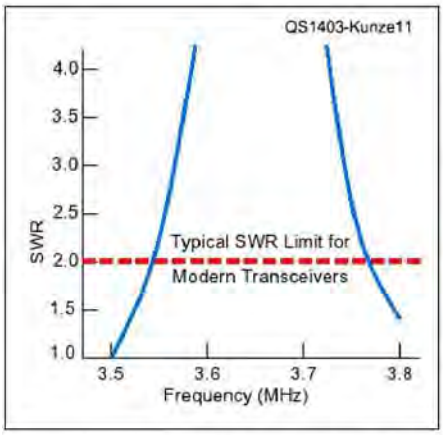


Figure 11 — SWR in the 75 meter band after installing the Phase III improved matching circuit at the base of the vertical element.

the 75 meter band SWR plot is now that of Figure 11, which has an SWR of less than 1:2, just above 3.5 MHz and just below 3.8 MHz.

The inductor is small, so it will not have the negative influence of a base loading coil discussed earlier. I constructed the coil from #9 AWG copper wire wound on a 1 inch diameter form with its four turns spread over 1.5 inches. Heavy wire is needed as the coil is heating up significantly.

For the capacitance, ceramic capacitors are the best choice, but for these low frequencies and using lower levels of RF power, metallized pulse capacitors like WIMA FKP-1 can also be used. The capacitance was obtained by paralleling five capacitors: three 1500 pF, one 1000 pF, and one 470 pF. Nominally, this is slightly less than 6000 pF, but given component tolerances and variation in the coil structure, this particular combination resulted in a center frequency of 3.65 MHz.

Results and a Note on Safety

I reached my goal for a reasonable antenna with reduced dimensions for the low bands. This antenna has good bandwidth on 75 and 160 meters and it is always surprising working DX on the low bands with an antenna that is only 33 feet high. I was able to contact all continents on 75 and 160 meters within a short time.

If you are forced by space restrictions to make a shortened antenna, then it's almost certain that the antenna is in proximity to living spaces, and you should do an evaluation to make sure that the antenna meets the FCC's requirements for maximum permissible exposure, often referred to as MPE. The requirement to do an evaluation is based largely on the frequency and the peak envelope power (PEP) to the antenna. For this 75/160 meter project, evaluation must be made if more than 500 W PEP is input to the antenna. More about antenna evaluation can be found on the ARRL's website and in Ed Hare's book on RF exposure.[4,5]

In closing, I wish you best of luck DXing on the low bands!

Notes

[1]*The ARRL Antenna Book*, 22nd Edition, Sections 3.2.2, 3.2.3. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 6948. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**, **pubsales@arrl.org**.

[2]R. Severns, N6LF, "An Experimental Look at Ground Systems for HF Verticals," *QST*, Mar 2010, pp 30 – 33.

[3]The IARU Band Plan recommends, "Intercontinental operations should be given priority in the segments 3500 – 3510 kHz and 3775 – 3800 kHz." **http://www.iaru-r2.org/documents/explorer/files/Plan%20de%20bandas%20|%20Band-plan/R2%20Band%20Plan%202013.pdf**

[4]**www.arrl.org/fcc-rf-exposure-regulations-the-station-evaluation**

[5]Ed Hare, W1RFI, *RF Exposure and You*, (Newington 1998, 2004). Available from your ARRL dealer, or from the ARRL Store, ARRL order no. 6621. Telephone toll-free in the US 888-277-5289, or 860-594-0355, fax 860-594-0303; **www.arrl.org/shop/**; **pubsales@arrl.org**.

Photos by the author.

Christoph Kunze, DK6ED, was first licensed in 1972. He earned the Five Band DXCC award in 1979 and achieved the DXCC #1 Honor Roll in 2002. Chris is a structural engineer and holds a doctorate in environmental engineering. Chris is also the officer in charge of his municipal fire brigade. You can reach him at **DK6ED@darc**.

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160 Meters — or Bust!

Repurpose your dipole and its feed line as a top-loaded vertical for Top Band.

David Kruh, WB2HTO

My 100 foot by 70 foot suburban lot isn't large enough to build antennas for the lower HF bands. Two trees at opposite ends of my backyard, about 100 feet apart, support a dipole at 25 feet in height. That dipole is just a fraction of a wavelength above the ground, so most of the signals on 160 meters go up, as seen in Figure 1. My solution for the 160 meter band turns the 100 foot dipole and its feed line into a top-loaded vertical antenna.

Top-loaded Vertical

Woody Beckford, WW1WW, suggested that I twist the two leads of the dipole twinlead together and then feed that against ground radials. The now-former dipole acts as a capacitive top hat for the 25 foot vertical section. The elevation pattern calculated by *EZNEC* (see Figure 2) shows a dramatic decrease in elevation angle coverage, with a peak at 26 degrees.

I extended the length of the vertical electrically with a 20 µH coil installed at its base as seen in Figure 3. The loading coil comprises 38 turns of #10 AWG wire wrapped around a 2" diameter piece of PVC. The coil exits the top of the PVC (capped and caulked for waterproofing) where it connects to the twisted wires of the twinlead. The bottom of the coil attaches to the center of an SO-239 connector installed in the PVC. Banana jacks connected to coax shield make it easy to add or remove radials (see Figure 4).

Adding Radials

This antenna requires a number of lengthy radials; I used eight, starting with four ground based radials along the perimeter of the property and the outside of the house, as shown in Figure 5. I ran an additional pair of elevated radials approximately 3.5 feet off the ground and parallel to two of the original ground-based radials (the double lines in Figure 5) using the upper support of the same wooden fence I had used as a guide for the first two ground-based radials, see Figure 6.

Rudy Severns, N6LF, authored a terrific series of *QEX* articles on verticals and radials (see **www.antennasbyn6lf.com**) in which he details how and why elevated radials can be as effective, or sometimes even more effective than ground-based radials.[1] Finally, I added two more radials between the fence and the house, as shown in Figure 5. In all cases the antenna was resonant without the need of an antenna tuner.

Measured Performance

Once the first four radials were installed, I measured the antenna resistance, *R*, across the 160 meter band with an MFJ-259B antenna analyzer. As seen in Figure 7, with

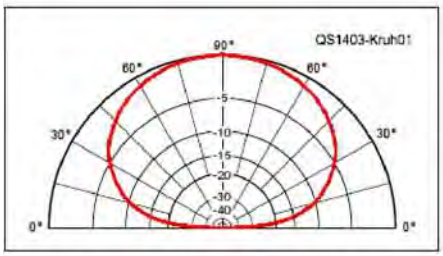


Figure 1 — Elevation pattern of a 100 foot dipole 25 feet above the ground at 1.82 MHz.

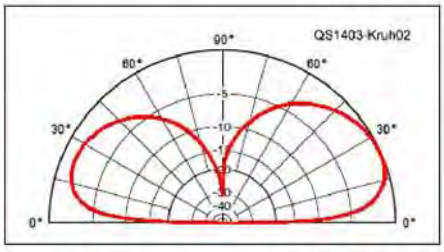


Figure 2 — Elevation pattern of a 25 foot vertical with 100 foot capacitive hat at 1.82 MHz.

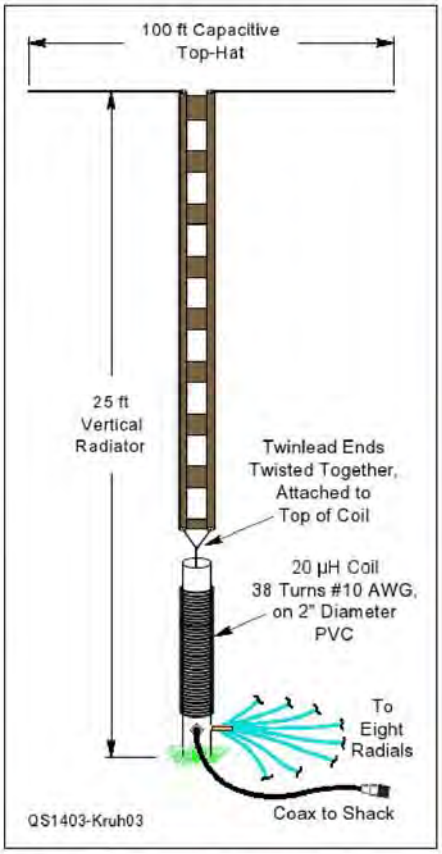


Figure 3 — The 160 meter antenna includes a capacitive top hat, 25 foot vertical radiator, a base loading coil, and radials.



Figure 4 — The loading coil is at the base of the vertical radiator. The green wires feed the radial system.

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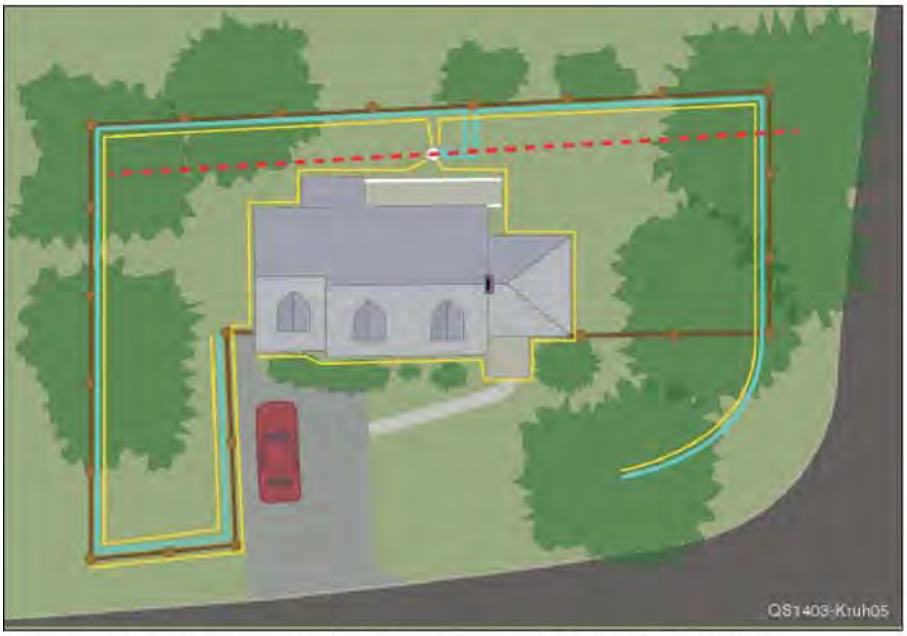


Figure 5 — The author's home, showing eight radials and the original dipole (dashed).

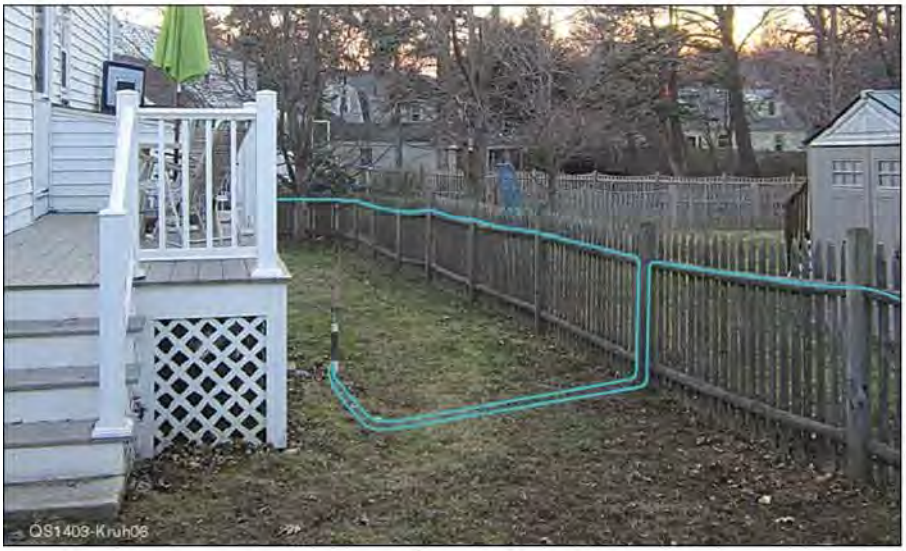


Figure 6 — Location of the elevated radials on fence. Highlighting was added to this image to enhance visibility.

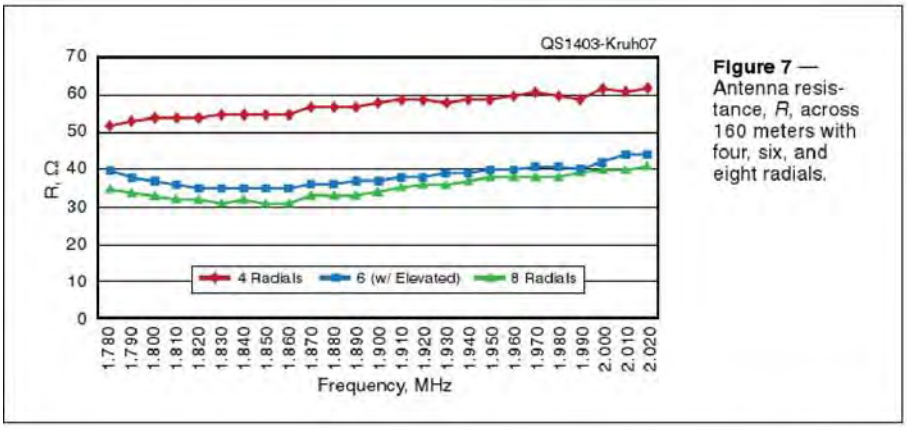


Figure 7 — Antenna resistance, *R*, across 160 meters with four, six, and eight radials.

RF Exposure Safety

Every wire above ground contributes to RF radiation, including the lead wires from the resonator and all the radial wires strung on the fences. You can estimate a "worst case" compliance distance, measured from any portion of any wire, by applying the General-Purpose Table in *RF Exposure and You* by Ed Hare, W1RFI.[A] — *Ed.*

[A]Available from your ARRL dealer, or from the ARRL Store, ARRL order no. 8217. Telephone toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

four radials *R* is between 54 and 62 Ω. I measure again after adding the elevated pair of radials. The two elevated radials reduced *R* by as much as 20 Ω over the four-radial system indicating a reduction of ground losses. I found that two more radials, placed between the fence and the house, reduced *R* by another 5 Ω across much of the band. I had reached a point of diminishing returns. Neither the SWR nor the reactance were substantially affected by the additional radials.

On the Air

After two full seasons of operation, I have completed contacts with all lower 48 states and 26 DXCC entities — including a CW QSO with R3LA, 4461 miles away. Not bad for a 160 meter vertical only 25 feet tall! I look forward to the return of warm weather here in New England for more tweaking and testing, perhaps according to reader suggestions.

[1]J. Severns, N6LF, Experimental Determination of Ground System Performance for HF Verticals, Parts 1 – 7, *QEX*, Jan/Feb 2009 to Jan/Feb 2010.

Photos by the author.

ARRL member David Kruh, WB2HTO, was first licensed as a Novice in 1972 and now holds an Amateur Extra class license. David can be reached at **WB2HTO@comcast.net**.

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