A common problem when operating portable is finding a temporary antenna that can work on more than one band, and still be easily put up, taken down and carried to another location. K1EHZ has one solution — a vertical End-Fed Half Wave (EFHW) that can be built to operate on as many as six HF bands (and even one VHF band).

A Portable 7-Band EFHW Vertical Antenna

BY JAY TAFT*, K1EHZ

A portable antenna is a trade-off among many factors, including radiating efficiency, launch angle, bandwidth, cost, transportability, size, weight, ease of deployment, single or multiple band coverage, power limit, antenna system losses, and others. I have used various portable antennas dipoles, random wires, quarter-wave verticals with radials, end-fed half-wave verticals, and loaded whips, some commercial and some homebrew. With favorable propagation I was able to make international SSB contacts with each antenna using QRP power levels.

After experiencing the various trade-offs, I settled on the end-fed half-wave (EFHW) vertical antenna for its low launch angles without requiring radials like a quarter-wave vertical. An EFHW with two traps should work 10, 15, and 20 meters without a tuner. It should be easy to deploy from a tree or a telescoping fiberglass pole. It could also cover 40 meters as an inverted-L or inverted-V with a 20-meter trap and additional wire. The antenna shown here was fully operational while deployed in my New Hampshire yard throughout the winter of 2013-14.

Modeling the Design

I used EZNEC+ by Roy Lewallen[1], W7EL, and AutoEZ, an Excel® spreadsheet by Dan Maguire[2], AC6LA, that links to EZNEC+, to test basic configurations and to evaluate launch angles and trap losses. I used the "Transmission Line for Windows" program by Dean Straw, N6BV, to calculate transmission line losses.

Traps can resonate within amateur bands or outside them. The lowest SWR on each band is influenced by trap resonance effect and trap loading effect, as well as wire length, composition and diameter effects. I chose resonance at the low end of bands to reduce trap losses on the SSB frequencies where I operate.

The coax trap calculator by Tony Fields[3], VE6YP, provides basic trap L

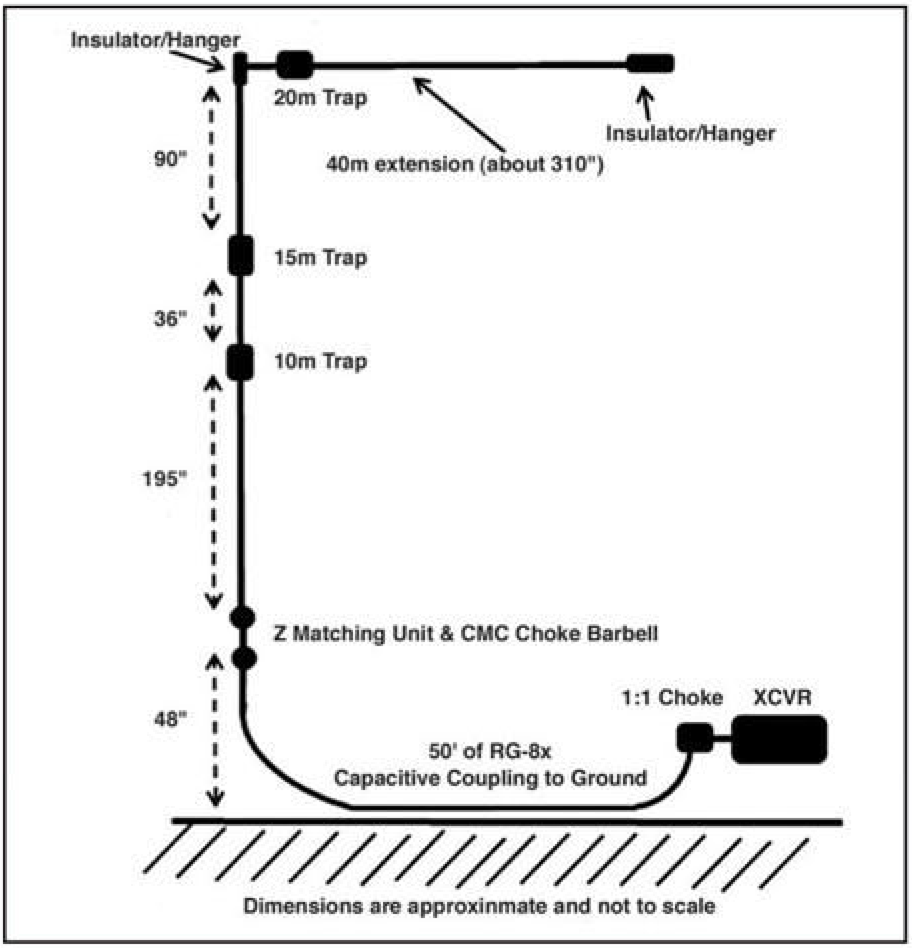

Figure 1. Sketch of EFHW antenna.

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and C for modeling. The calculator estimates trap resonant frequency within a few percent error. However, the excellent review by Bill Wortman[4], N6MW, concludes the L values should be multiplied by 4 and the C values divided by 4 to correct for the bootstrap configuration. In bootstrap, the center conductor and shield are connected in series (the center conductor from one end of the coax is connected to the shield from the other end). I used this modification for modeling traps, and made small adjustments of L and C in AutoEZ to achieve trap resonance at the lower end of the bands of interest.

An EFHW antenna requires a counterpoise, which can be a separate wire or the outside of the coax shield. Although common mode currents are expected on the outside of the shield, I chose this configuration for the convenience of not deploying a counterpoise. The outside of the shield was modeled in EZNEC+ as a separate wire 0.2 inches in diameter with a velocity factor of 0.95.

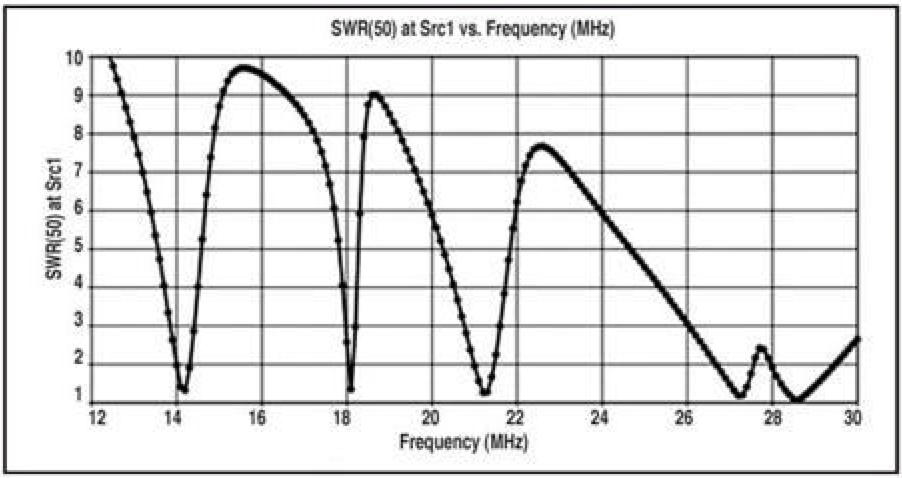

Figure 2. SWR plot of the model antenna with minima at 14.2, 18.1, 21.3, and 28.5 MHz. The minimum at 18.1 MHz was unexpected, and was sensitive to the position and amount of coax capacitive coupling to ground. The other frequencies were much less sensitive to capacitive coupling.

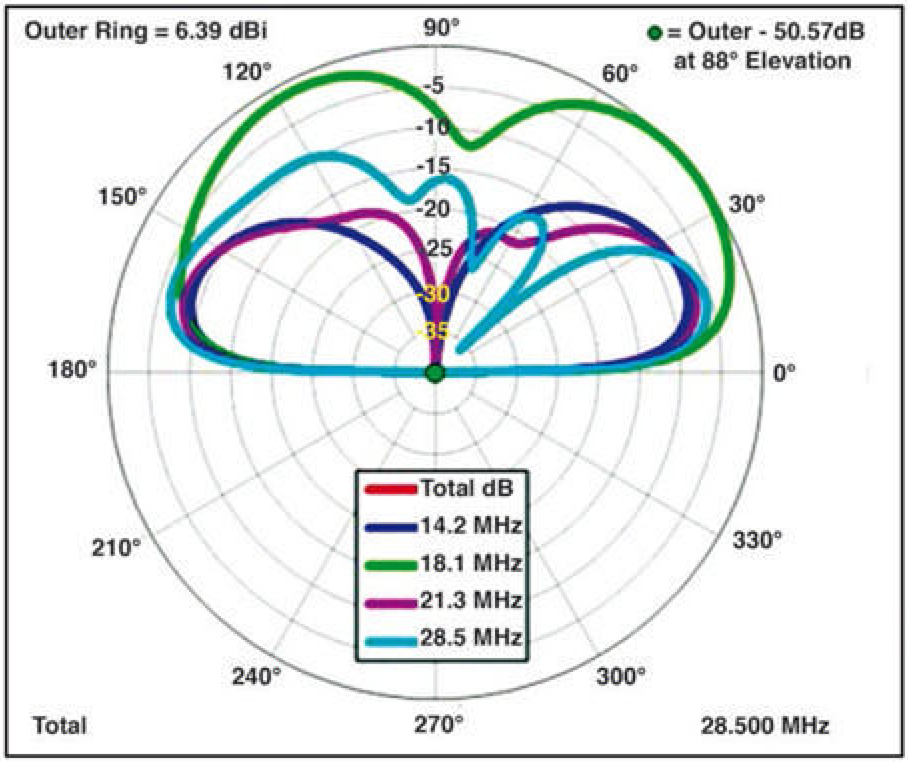

Figure 3. Elevation patterns at the three design frequencies plus 18.1 MHz.

Other design elements include matching unit impedance ratio, counterpoise characteristics, mechanical strength, weather resistance, and protection from RF voltage. We also need to be aware of maximum permissible exposure to RF when operating portable. For SSB, 50 feet of coax is an adequate length for antenna siting flexibility, and much more than enough safety separation between the antenna and the operating position.

The model EFHW antenna, sketched in Figure 1, is a vertical with an impedance matching transformer, 10-meter and 15-meter traps, the coax shield as a counterpoise coupled capacitively to ground, a common-mode choke near the antenna feed point, and a second common-mode choke at the transceiver. The model wire lengths were adjusted to give SWR of <2:1 at 14.2, 21.3, and 28.5 MHz. It was an unintended benefit that SWR <2:1 also occurred in the EZNEC+ model at 18.1 MHz (Figure 2). The SWR minimum at 18.1 MHz was sensitive to the amount and position of capacitive coupling to ground in the model, and was optimized with 10 pf of coupling midway along the coax and at the transceiver. Calculated elevation patterns in Figure 3 show peaks at 16° to 18°, except for 18.1 MHz, which shows a peak at 45° and generally more gain.

Impedance Matching

Impedance at the end of a half-wave antenna usually ranges from 1,800 to 3,500 ohms. The 50-ohm coax transmission line is matched to the higher impedance antenna with a toroid transformer. EZNEC+ showed that impedances at the low end of the range gave reasonable SWR across the bands of interest. To confirm, I tested physical matching transformers with secondary impedances ranging from 1,000 to 3,000 ohms (toroid primary to secondary turns ratios of 2:10 to 2:16). SWR optimized across multiple bands at 1,500 ohms. Therefore, the matching transformer has two primary turns and 11 secondary turns, using #16 enameled wire and bifilar split winding on an FT114-43 core. The wound toroid fits in a 1-$^1/_2$-inch Schedule 40 PVC reducer bushing covered with a 1-$^1/_2$-inch PVC cap.

Potential Power Losses

Potential power losses in the system are also important. Loss calculations at each frequency for the traps, common

MHz	SWR	R	X	Trap + CMC Loss, db	Trans Line Loss, db	Total Loss, db	Total Loss, Watts
14.2	1.32	37.95	0.33	-0.67	-0.64	-1.31	-1.4
18.1	1.35	66.22	-5.95	-1.13	-0.74	-1.87	-1.5
21.3	1.28	46.57	-11.29	-0.66	-0.80	-1.46	-1.4
28.5	1.10	49.72	-4.67	-0.17	-0.94	-1.11	-1.3

Table 1. Trap, common mode choke (CMC), and transmission line losses calculated for the model antenna at 5 watts power with 50 feet of RG-8X feedline.

Frequency, MHz	Trap EFHW Gain, dbi	Mono-band EFHW Gain, dbi	Mono-band Advantage, dbi
14.2	-1.24	-0.24	1.00
18.1	4.00	-0.07	-4.07
21.3	-0.25	0.08	0.33
28.5	0.61	0.33	-0.28

Table 2. Gain difference (Mono-band EFHW – Trap EFHW) for each band of interest. Gain taken at elevations of 16° to 18°. The same transmission line losses at the respective frequencies were used for both types of antennas. On balance, the mono-band EFHWs show little or no advantage over the trap EFHW.

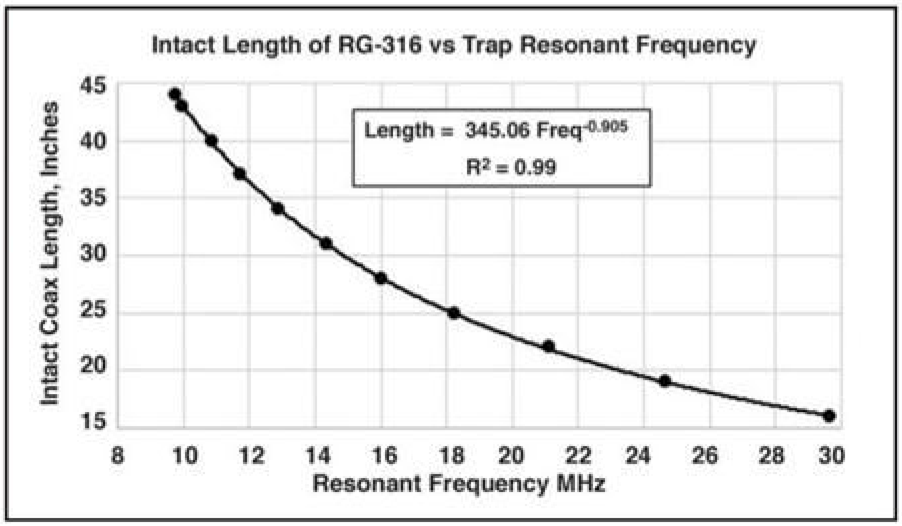

Figure 4. Intact length of RG-316 coax close wound on a $^1/_2$-inch PVC form compared to resonant frequency of the trap. The stripped coax forming the connections adds about 2 inches on each end of the intact length.

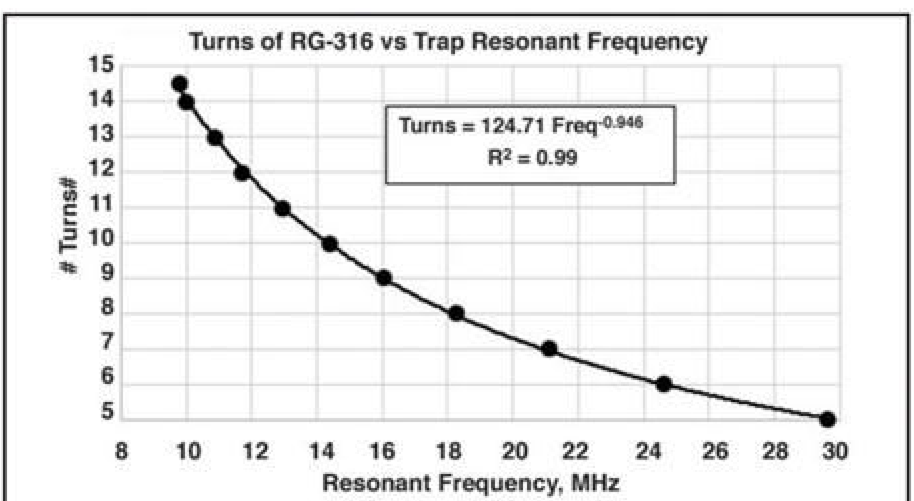

Figure 5. Relationship between turns of RG-316 on $^1/_2$-inch PVC pipe and trap resonant frequency.

mode chokes, and 50 feet of RG-8X transmission line are shown in Table 1. Total loss is about 1.3 to 1.5 watts at 5 watts transmitter power. I also compared the gains in radiated RF computed with EZNEC+ for the trap antenna to gains for individual mono-band EFHWs in Table 2. The mono-banders show little to no gain advantage over the multi-band trap EFHW.

Traps

Traps were wound on $^1/_2$-inch PVC pipe using RG-316 Teflon insulated coax (#160, <www.TheWireman.com>). [I used RG-174 (#139, <www.TheWireman.com>) in early versions, but I went with RG-316 here for confidence and flexibility in using the antenna with up to 100 watts as well as QRP.] To determine the number of turns required for traps at various frequencies, I explored the relationship of intact coax length to resonant frequency, and number of turns to resonant frequency. I wound 15 turns of coax snugly on a $^1/_2$-inch PVC form, made the bootstrap connection, and measured the resonant frequency with an MFJ-259B antenna analyzer fitted with a wire loop. (I also tried the circuit suggested by David Barton[5], AF6S, and mentioned by Joel Hallas[6], W1ZR, which gave resonance readings very close to the loop measurements, but was less sensitive in my hands than the single loop.) I then sequentially removed one turn, trimmed the coax, measured the intact length, reconnected the bootstrap, and measured resonance again to produce the graphs in Figures 4 and 5.

I built traps for 10, 15, and 20 meters with their resonant frequencies at the lower band edge to reduce losses at the

Frequency, MHz	Intact Length, in.	# Turns	SWR	Reactance (X)
14.040	31.0	10.5	1.0	0
21.042	22.0	7.5	1.0	0
28.141	17.5	5.5	1.0	0

Table 3. Dimensions and characteristics of traps wound with RG-316 coax on 1/2-inch PVC pipe. Not all of the intact coax length is wound on the PVC. A short length may be inside the pipe.

higher SSB operating frequencies. Trap resonant frequency can be changed within a narrow range by adjusting coil spacing. Use tape strips to hold turns in place during adjustments, then secure permanently with RTV silicone (Permatex 82180) between the tape strips. Remove the tape when the silicone has cured. Dimensions and characteristics of the traps are shown in Table 3.

Assembly

For assembling and tuning the antenna, use the same type and length of coax transmission line to be used for regular operations. I used 50 feet of RG-8X, but shorter lengths may be used to reduce transmission line loss. Connect a standard common mode choke at the transceiver end of the transmission line. Use a commercial balun such as Balun Designs #1110, or make your own by winding 12 to 15 turns of coax on a #43 ferrite core sized to accommodate the coax.

Construction is illustrated in Photos A-G. A common-mode choke is wound with 10 turns of RG-316 coax on an FT114-43 toroid. It is housed in a 1-$^1/_2$-inch PVC reducer bushing and cap. For mechanical strength, the common-mode choke and the matching unit are connected through $^1/_2$-inch PVC pipe to form a barbell configuration with the toroids separated by about 7 inches. I settled on the 7-inch spacing after examining how distance between toroids influenced antenna reactance and SWR.

Connect an antenna analyzer to the choke at the transceiver end of the transmission line. Connect the other end of the coax to the barbell. Steve Yates[7], AA5TB, has a helpful explanation for tuning an EFHW as a resistive load with minimal reactance. During assembly, this EFHW is tuned for minimal reactance as long as the SWR is less than 2:1.

Begin assembling the antenna with the 10-meter segment and progress to the lower frequency segments one at a time. Pre-thread 200 inches of #26 wire (#534, <www.TheWireman.com>) through the 10-meter trap end cap. Temporarily attach one end to the center conductor of the 10-meter trap. Pre-thread the other end through the matching unit cap and attach to the toroid. Hang the trap temporarily and connect coax to the barbell. Adjust for resonance by trimming the wire length a little at a time to place minimum reactance (and SWR <2:1) where you want it within the 10-meter band. Solder the connections.

Temporarily connect about 36 inches of wire between the shield of the 10-meter trap and the center conductor of the 15-meter trap. Adjust the wire length of 15-meter segment for minimum reactance and low SWR on 15, check 10-meter reactance and SWR, pass the wires through the end caps, and solder the wire at both traps. Repeat the steps above starting with about 96 inches of wire on the shield end of the 15-meter trap and adjust for minimum reactance within the 20-meter band. Solder the wire at the top of the 15-meter trap.

Install the matching unit cap and trap end caps with PVC cement. Install 1-$^3/_8$-inch adhesive-lined heat-shrink tubing (<www.BuyHeatShrink.com>) over the trap windings for additional weather protection. Seal the holes where the wire passes through the trap end caps with RTV silicone. I painted the traps and impedance matching unit gray, but they could be left as is or painted any desirable color. If you plan to add the 40-meter extension wire with the 20-meter trap, secure the top wire to an insulator with stainless steel hardware. I use 4-inch pieces of $^1/_2$-inch PVC pipe for insulators.

For the 40-meter extension, connect 6 to 12 inches of wire to the center conductor of the 20-meter trap. This wire connects with a crimped and soldered lug to the stainless steel bolt on the insulator at the top of the vertical section (see above). Connect a wire about 30 feet long to the other side of the 20-meter trap. Trim small amounts from the 30-foot extension wire to reach minimum reactance and low SWR on 40 meters. After assembly, SWR on all bands should be less than 2:1. According to the EZNEC+ model, the 40-meter extension slightly distorts the vertical radiation pattern on higher

Photo A. Impedance matching toroid in top end of PVC barbell. The first two turns are bifilar wound. The white wire is the coax center conductor connected to the 2-turn primary. Next to it, the primary and secondary wires are connected to the coax braid. Both connections are covered with heat shrink tubing. Cable ties may be added to stabilize wires on the toroid.

Photo B. Common mode choke of 10 turns of RG-316 on FT114-43 toroid in the bottom end of the barbell. Cable ties were used to stabilize the coax on the toroid. The horizontal PVC pipe is only for positioning to take the photo and is not part of the unit.

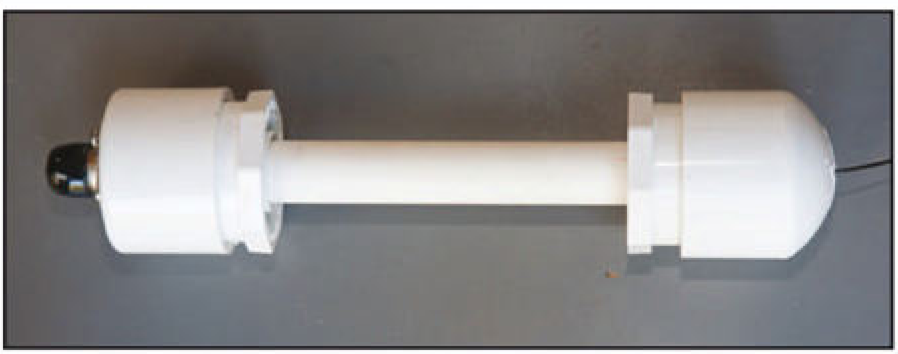

Photo C. Assembled barbell containing impedance-matching toroid at right and common mode choke toroid at left. Total length is 9-$^{1}/_{2}$ inches, excluding the SO-239 coax connector. The spacing between the top and bottom reducer bushings is 4-$^{1}/_{2}$ inches. Separating the toroids by 7 inches is a key dimension.

bands, so I only deploy the extension when operating on 40.

Finally, attach a SOTAbeams wire winder <www.sotabeams.co.uk> to the barbell with cable ties. Use a smaller SOTAbeams winder for the 40-meter extension. The finished antenna weighs 18 ounces for the vertical section and 4 ounces for the 40-meter extension, including winders.

To test for mechanical strength and weather protection, I deployed the antenna on a telescoping fiberglass pole in my New Hampshire yard throughout the winter of 2013-14. It still works fine after prolonged exposure to below-freezing temperatures, wind, rain,

Photo D. Trap assembly for 20 meters, showing short pieces of solid wire for strain relief at connections, and RTV silicone stabilizing the coax windings on a $^{1}/_{2}$-inch PVC form. Silicone sealant is also placed on the antenna wire to seal holes in caps from the inside. A dab of sealant was added on the outside of the holes after final assembly of the antenna.

Photo E. Trap showing end caps secured with PVC cement.

Frequency, MHz	Model				Physical Antenna			
	SWR	R	X	Z	SWR	R	X	Z
14.2	1.3	38	0	38	1.5	74	8	74
18.1	1.3	66	-6	66	1.5	75	5	78
21.3	1.3	47	-11	48	1.2	67	0	62
24.9	4.7	57	82	100	1.4	70	0	70
28.5	1.2	50	-5	50	1.2	64	0	60

Table 4. SWR, R, X, and Z calculated with original EZNEC+ model and measured with the physical antenna, which was tuned for minimum reactance on each band by adjusting wire length.

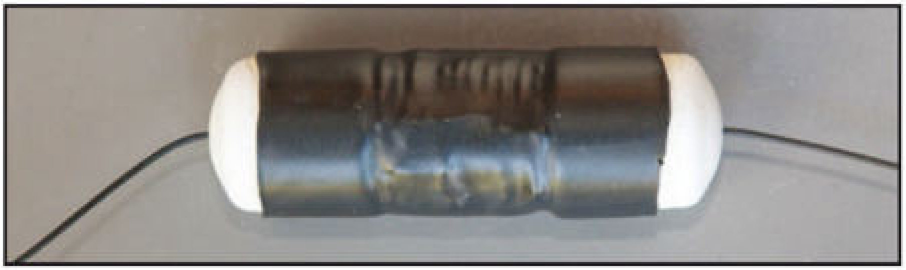

Photo F. Completed 20-meter trap with heat shrink tubing.

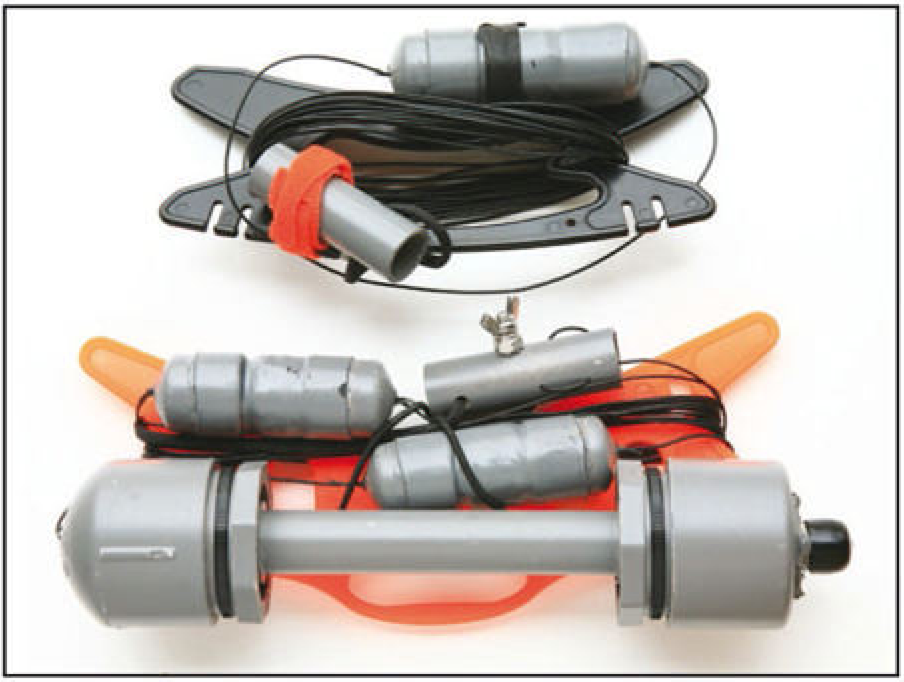

Photo G. Completed EFHW trap antenna (18 oz) with 40-meter extension (4 oz) on SOTAbeam winders.

snow, and ice. The paint was dinged up, so I repainted it for the photos here.

Common Mode Currents

Expecting this design to produce common mode currents, I decided to measure them. I used an RF current meter described by Owen Duffy[8], previously VK1OD. The antenna was suspended vertically (without the 40-meter extension) and connected by 50 feet of RG-8X along the ground to a Yaesu FT-817 transceiver on battery power with no direct ground. The transceiver was keyed with a 5-watt FM carrier on each band. A standing wave pattern is expected with one to three peaks along the coax. As expected, maxima and minima were observed on all bands except 10 meters, where no currents were detected. The maxima ranged from 18 to 30 milliamps on the other bands.

Antenna Performance

For assembly and initial testing, I deployed the antenna vertically from a birch tree arching over the driveway at home. The wire hangs in the clear with the impedance matching transformer about four feet above the ground. I measured SWR, R, X, and Z with the MFJ 259B antenna analyzer at the end of 50 feet of RG-8X lying in a straight line on the ground. Table 4 compares data for the original EZNEC+ model with the physical antenna.

Portable on-the-air testing was conducted during a visit to Fox Island, Washington. The antenna was deployed on a 31-foot fiberglass telescoping pole <www.Jackite.com>, and connected to a Yaesu FT-817 through 50 feet of RG-8X with a choke balun (Balun Designs #1110) at the transceiver end. The FT-817 has four power levels specified by Yaesu: 5, 2.5, 1, and 0.5 watts. Table 5 shows contacts on each band at various power levels, uncorrected for trap and line loss. The 10-meter band had the most active propagation at that time. Performance ranged from 42 miles per watt on 40 meters to 3,908 miles/watt on 10 meters. At a distance of 1,954 miles, Mark Gierhart, W8MDG, was kind enough to provide signal reports at three power levels on 10 meters, including 0.5 watt.

These results confirm that the EFHW vertical antenna radiates effectively without a tuner on 10, 12, 15, 17, and 20 meters. With a 20-meter trap and additional wire, it can also be used on 40 meters as an inverted-L or inverted-V for local or regional contacts. Finally, to confirm the antenna's capability with higher power, I worked RI1ANT in Antarctica

Band	Station	Grid	Distance (Miles)	Uncorrected Power (Watts)	Miles/Watt
10m	W8MDG	EN80br	1,954	0.5	3,908
10m	KC4TVZ	EM84be	2,191	1.0	2,191
10m	W8MDG	EN80br	1,954	1.0	1,954
10m	VE3AXW	EN93ue	2,053	2.5	821
10m	KB5WNU	EM40kv	2,008	2.5	803
10m	AC5NB	EM12qw	1,678	2.5	671
15m	W1AW/3	FN20ii	2,371	5.0	474
17m	W1AW/3	FN20ii	2,371	5.0	474
12m	W1AW/4	FM07ij	2,280	5.0	456
10m	W8MDG	EN80br	1,954	5.0	391
12m	K4SOL	EM55nv	1,892	5.0	378
20m	ACØZV	DN70md	1,004	5.0	201
40m	W1AW/7	CN94fh	208	5.0	42

Table 5. Selected stations worked on SSB during April 2014 from Fox Island, Washington (CN87qf) with a Yaesu FT-817 and the EFHW trap vertical antenna. FT-817 power was not corrected for antenna system losses.

from Fox Island using 100 watts on 20-meter SSB with an ICOM 7200.

Postscript: 6 Meters

It occurred to me after this article was completed that if the antenna works on 12 meters, it might also work on six. I expanded the frequency range in EZNEC+, which shows SWR of less than 2:1 from 50 to 52.5 MHz, with a maximum gain at a launch angle of 25 degrees. As currently deployed in my yard, the antenna SWR is less than 2:1 from 50 to 51 MHz, covering virtually all frequencies with CW and SSB activity.

Notes:

1. R. Lewallen, W7EL. EZNEC+. < http://www.eznec.com/>
2. D. Maguire, AC6LA. AutoEZ. <http://ac6la.com/aepurchase.html>
3. T. Field, VE6YP. "Coax Trap Calculator." <http://www.qsl.net/ve6yp/>
4. W. Wortman, N6MW. The Coaxial Trap Confusion (mostly resolved?) <http://n6mw.ehpes.com/CT5.pdf>
5. D. Barton, AF6S. "An Accurate Dip Meter Using Your MFJ-249 Antenna Analyzer." *QST*, Nov. 1993. Page 45
6. J. Hallas, W1ZR. *Understanding Your Antenna Analyzer*, ARRL 2013, Page 7-6
7. S. Yates, AA5TB. "The End Fed Half Wave Antenna." <http://www.aa5tb.com/efha.html> and <http://www.aa5tb.com/efha_wrk.html>
8. O. Duffy. Measuring Common Mode Currents. <http://owenduffy.net/blog/?p=458>. Note that the original of this paper is no longer available on the Internet. For other RF current meters see <http://www.w8ji.com/building_a_current_meter.htm> and the article by Steve Sparks, N5SV, in QST, February 1999, page 34.