a high-efficiency top-loaded vertical

You don't need traps, coils, or vast acreage to get good performance on 160, 80, or 40 meters

The efficient, easy-to-build antenna described in this article requires no radials, traps, or loading coils. The reader with an appetite for low-band DX should be able to duplicate or better my results on 160 meters and, by appropriate scaling, on 80 and 40 meters as well.

Like any serious low-band DXer, I wanted to join the "big boys" using a vertically polarized signal because it has long been demonstrated that horizontals, unless raised to astronomical heights, are unable to do much more than take up space at the bottom of the pile-ups.[1] The customary current-fed, 1/8- or 1/4-wave type verticals require an immense radial ground system to be efficient and competitive — yet my terrain consists of deep ravines, gullies, and cliffs that make the installation of radials, or even elevated counterpoise systems, virtually impossible. To add to the misery, the soil at my QTH is almost 100 percent hard sandstone and as such approaches pure silicon in conductivity. Obviously a "non-standard" approach to an antenna was necessary. After reviewing many texts and articles I decided that some form of "ground independent" antenna would be required, particularly one that had its feed point at ground level. The "Bobtail Curtain"[2,3] version of ground-independent systems met the basic requirements, but for 160 or even 80 meters the dimensions become truly heroic; in addition, my requirement was for unidirectional transmission. My first step was to contact my old friend Woody Smith, W6BCX, who had fathered the fabulous Bobtail, in order to get firsthand information on the "care and feeding" of this type of system.

My call to Woody obviously struck a responsive chord and after a few thousand well-chosen words and equations, we agreed upon the novel form of vertical that this article describes. Sparing you the background — which covered inverted ground planes, slopers, center-fed loaded dipoles, and of course the Bobtail itself — the general parameters decided upon were that the new vertical design should require supports no higher than 70 feet (21.34 meters) for the 160 meter version or 35 feet (10.67 meters) on 80; should not need more than 95 feet (28.96 meters) spacing between supports on 160 and half that on 80; should be highly efficient in power transfer; should exhibit a high impedance feed point at the bottom of the vertical radiator and should be relatively easy to construct

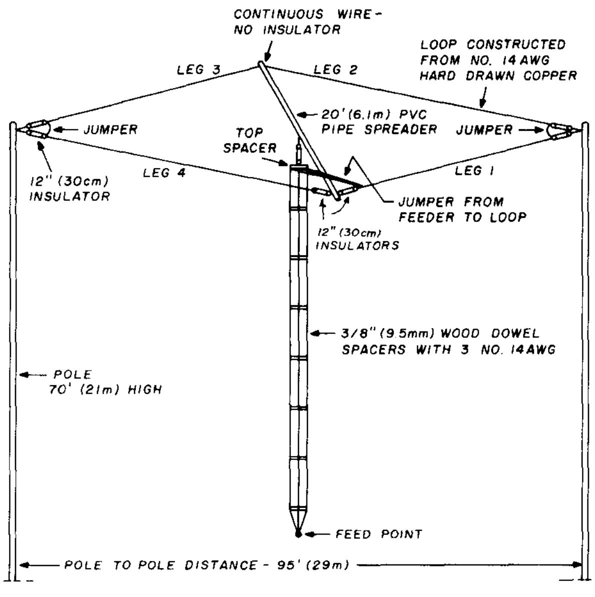

fig. 1. Efficient top-loaded vertical dimensioned for 160-meter operation.

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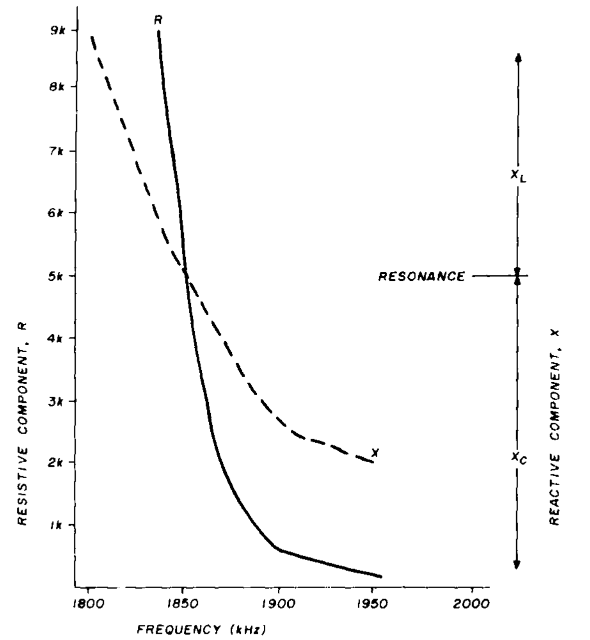

fig. 2. Plot of resistive and reactive component of 160-meter top-loaded vertical versus frequency.

item	***description***
L1	***40 turns No. 10 AWG spaced 0.2 inch per turn, 4 inch diameter***
L2	***7 turns No. 10 AWG spaced 0.2 inch per turn, 5-1/4 inch diameter***
C1	***two 500 pF, 2000 volt variable capacitors in parallel***
C2	***500 pF, 500 volt variable capacitor with 0.002 μF mica in parallel***
C3	***100 pF, 20 kilovolt fixed vacuum capacitor***

Note: For upper portion of 160 meter band, L1 is tapped down 8 turns by HV relay and 0.002 μF mica is disconnected from C2 by another relay.

and test using easily obtained materials. How did it work out? If you're not one of the fortunate few who already have a full 1/2-wave vertical on 160 complete with at least 120 radials or a solid silver-plated copper ground sheet of comparable size, read on!

Fig. 1 shows the physical layout of the W6US 160-meter vertical. No. 14 AWG copper wire is used throughout. The vertical radiator uses three wires spaced 1 foot (30.48 centimeters) apart by 3/8-inch (0.95 cm) diameter wooden dowels. Because the wires are at the same potential, no special treatment is required for the dowels electrically, but a coat of varnish or wax enhances their weatherability. The use of a four- or six- wire cage feet (1.22 meters) in diameter would be helpful as far as increased bandwidth is concerned; however, unless the effective conductor diameter of the diamond-shaped single-turn top loop is also increased by paralleling wires, don't expect to greatly widen the frequency response.[4] It should be noted that if the vertical radiator is so increased in electrical length, the physical length of the loop will have to be decreased, and provision made for the increased weight of the cage system.

how does it work?

The general theory of operation presents little mystery, but despite the W6US system's resemblance to the usual "top-loaded" short vertical, the reader will note that in essence the feedpoint is at the end of an electrical 1/2-wave of conductor and represents a point of high radiation resistance and impedance. This becomes paramount when the efficiency of this antenna is compared to that of the usual top- or bottom-loaded systems.[5]

$$\text{antenna efficiency} = \frac{R_{rad} \times 100}{R_{rad} + \text{all circuit resistance}} \qquad (1)$$

where R_{rad} = the radiation resistance of the antenna and "all circuit resistance" represents the resistance of the ground system, the loading inductors, wire resistance and *any other resistances present which dissipate power as heat.*

A resonant 1/4-wave vertical exhibits a R_{rad} of about 36 ohms with 10 ohms representing the total resistance of the ground system, coupling circuit, and other loss elements. Inserting these two numbers in **eq. 1** produces an efficiency of 78.26 percent. On 160 that 1/4-wave vertical would be about 130 feet (36.92 meters) tall. If instead a 60-foot vertical (1/8-wavelength high) is used, the R_{rad} drops to around 4 ohms and the efficiency diminishes to 28.57 percent![6] For 100 watts transmitter output, only 28.57 watts would be radiated — about one-third of the radiation from the full size 1/4-wave vertical, assuming the losses were identical (which is really not the case because the shortened vertical would require more coupling inductance and consequently more power would be consumed in the coupling circuit instead of reaching the antenna).

This is where the W6US ground independent system enters the race with a big lead. From **fig. 2**, which depicts the variation in measured antenna resistance and reactance of the system shown in **fig. 1** note that at resonance — i.e., zero reactance — the resistance is close to 5000 ohms. Applying this number in **eq.1** and assuming for the moment that the "all circuit resistance" figure stays at 10 ohms, the efficiency is 99.8 percent — almost four times the indicated

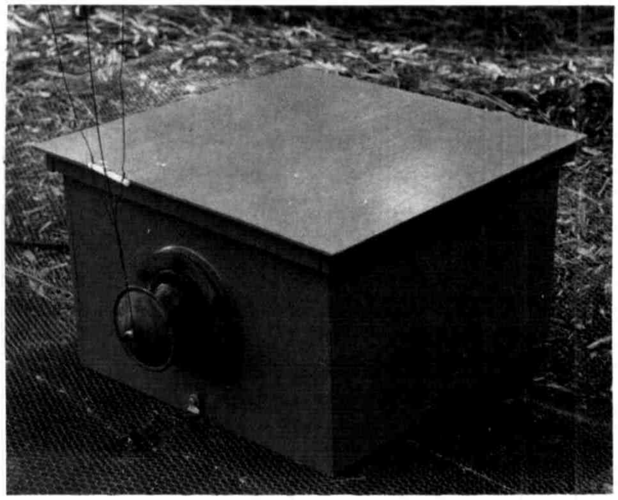

fig. 3. Coupler houses high voltage matching circuit components.

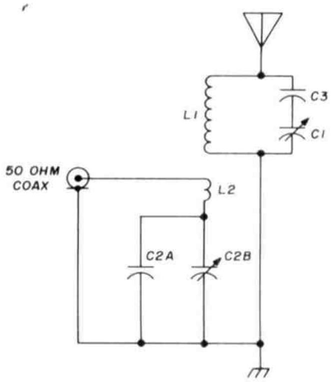

fig. 4. Coupler provides match between high impedance seen at antenna terminals and 50-ohm coax line.

efficiency of the usual 60-foot vertical radiator! This type of effect is exactly what makes the Bobtail and its other cousins such real winners. Best of all, this is achieved without an extensive ground radial system. In this case a 10 × 10 foot (3.05 × 3.05 meter) square of galvanized poultry wire is all that is necessary. A 1/2-inch (1.3 cm) 8-foot (2.43 meter) copper pipe is driven into the ground at the center of the wire screen for lightning protection. The small "coupler house" is placed on this screen as shown in **fig. 3** with the ground portions of the coupling circuit strapped to the pipe, which in turn is bonded to the poultry wire.

The resistance/reactance graph shown in **fig. 2** illustrates that these curves are steep with respect to frequency. Obviously, this antenna is very high "*Q*" and the bandwidth of antenna plus coupler is 6.7 kHz on 160 between the 1.2:1 VSWR points. Because of the narrow bandwidth, I provided for remote adjustment of the tuning capacitor in the coupling network with a 90-volt 60-Hz selsyn pair. The complete coupler circuitry, a parallel tank circuit consisting of L1 and C1 in series with C3 which resonates at the desired frequency, is shown in **fig. 4**. The tank is inductively coupled to the series circuit L2 and C2 into which the 50-ohm coax feedline terminates.[7] Not shown in **fig. 4** is a relay switching arrangement whereby L1 is tapped down and the value of C2 is decreased to provide for a wider total tuning range on 160. The interior view of the coupler housing in **fig. 5** shows the location of all the components. Remote adjustment of the coupler is obtained by having a selsyn drive the capacitor C1 via a reduction ratio chain drive which allows the use of a ten turn dial on the selsyn in the shack. The dial includes a small chart that provides a quick dial versus frequency reference for setting.

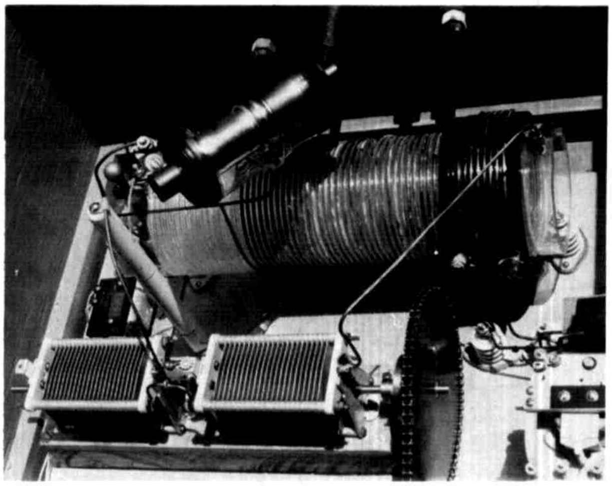

fig. 5. The interior view of the coupler housing illustrates the precautions taken with component placement as a result of high voltages present.

The use of the C1-C3 series combination in the coupler was dictated by the very high voltage developed at the base of the antenna at full legal power input. C3 is a 100 pF, 20,000-volt fixed vacuum capacitor that receives most of the voltage across the tank because C1 is varied from its full capacity of1000 pF to about 300pF to cover the tuning range. This combination also provides some degree of bandspread, helpful in view of the sharpness of tuning. I would suggest that you use high quality insulation, and plenty of it, both at the coupler and diamond loop ends of the antenna. With the impedance ranges involved, the voltages are awesome at all but the lowest power input.

adjusting loop to resonance

Once you've assembled the antenna and set it in place, the next step is the adjustment of the length of the diamond loop to achieve resonance. It is assumed that you will have set the overall length to a half-wave according to the usual equation; $468/f_{MHz}$. For 1850 kHz this figures out to 252.97 feet (77.11 meters). There are a variety of ways to determine whether resonance has been achieved, ranging from loosely coupling a grid dip oscillator to the bottom of the vertical radiator to using an accurate RF impedance bridge, which was the method I used (see **fig. 6**). Another method that is quite easy to use is to resonate the tank circuit in the coupler using a GDO to your desired frequency without having it connected to the antenna. Then attach the antenna temporarily about halfway up the tank inductor from ground. If the antenna is resonant at that frequency, the tank circuit will still resonate with the GDO at the same setting. If not, as almost always is the case, you will have to adjust the GDO to find the dip again. Then try a different diamond loop length and go through the process once more. By noting the movement of the dip, you can easily tell if the antenna length adjustment was made in the right direction. By successive tries you'll find a length for the diamond loop that will closely approximate resonance. The antenna is then connected to the hot end of the tank circuit for adjustment of the VSWR and operation.

It is well to note that the above antenna pruning method can also be used to determine the harmonic resonance by setting up a temporary parallel tuned circuit that will resonate on the harmonic. If this antenna is to be used on both 160 and 80, or 80 and 40, you may wish to choose resonant frequencies that cover the band segments of interest. As shown in **fig. 2**, my antenna has its primary resonance at about 1854 kHz. Testing has shown its second harmonic to be close to 3949 kHz.

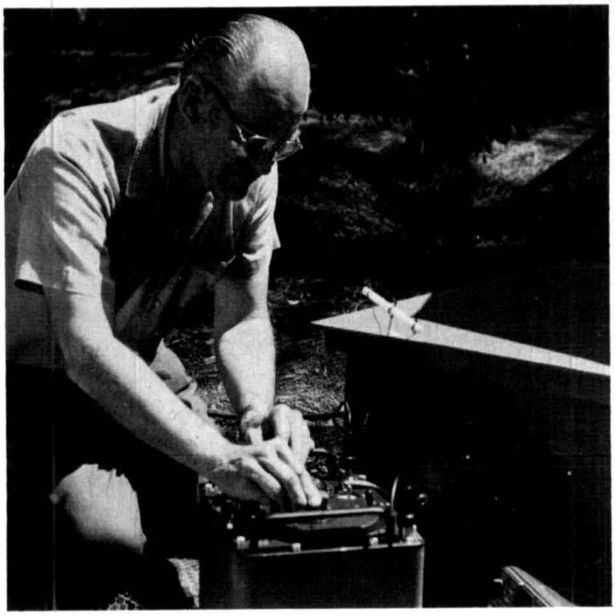

fig. 6. W6US determines the verticals resistive and reactive components with a General Radio GR1606A RF bridge.

If you are seriously interested in this type of ground-independent antenna, I would suggest some reading in books and articles that deal with VLF antenna systems.[8] Some of the earlier systems closely parallel the dimensions of the antenna described here. I would also be interested to learn of your experiences with the W6US antenna on other bands — for example, on 10 meters, where the vertical radiator would be a magnificent 4.32 feet (1.32 meters) high and the total span about 11.88 feet (3.62 meters)! Also left to your experimentation is the question of whether the addition of a conventional radial system might enhance this antenna for DX.

The sticky point in this investigation is probably whether the raising of the current maximum by the ground independent approach lessens the need for radials to lower the angle of radiation. The Bobtail does not seem to profit by them, but here the vertical radiator is only half as long. At least it seems well established that the increased efficiency goes a long way toward successful long-haul DX.

testimonial

No antenna article is complete without a relatively rosy exposition of the superlative reports received and the choice DX worked. To maintain tradition, I will therefore note that compared with a great variety of 160-meter systems previously used, this W6US ground independent system has been a real winner for me. A substantial number of solid QSOs have been logged with stations 500 miles or more distant while running just 10 watts transmitter output on SSB. Believing that more of a good thing is even better, I am presently working on a second version of this antenna. I sincerely hope that those who try this approach will provide still more data to benefit us all.

references

1. Mark Bacon, WA9VWA, "Verticals over Real Ground," *ham radio*, January, 1984, page 35.
2. Woody Smith, W6BCX, "Bet My Money on a Bobtail Curtain," *CQ*, March, 1948, page 21.
3. Woody Smith, W6BCX, "Bobtail Curtain Follow-Up," *ham radio*, March, 1983, page 28.
4. Edmund Laport, *Radio Antenna Engineering*, McGraw-Hill, 1952, page 249.
5. *Antenna Book*, ARRL, 14th Edition, page 2-4, 25.
6. Henry Jasik, *Antenna Engineering Handbook*, page 20-4.
7. *Antenna Book*, ARRL, 14th Edition, page 4-3.
8. Edmund Laport, *Radio Antenna Engineering*, McGraw-Hill, 1952, pages 13 to 76.

bibliography

Frank E. Terman, *Radio Engineering Handbook*, 1943.

Rosen, Rich, K2RR, *From Beverages thru OSCAR — A Bibliography* (Lists all technical articles on vertical antennas that have appeared in the ham journals since 1945; available directly from the publisher, Rich Rosen, K2RR, P.O. Box 350, Greenville, New Hampshire 03048.)

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