folded umbrella top loaded vertical antenna

Design data for operation on 160 meters — adaptable to any band

Interest in the 160-meter band has traditionally been limited to a persevering few who delight in the technical challenge of working DX on this "top band" — almost to the exclusion of operation on the other bands. The antenna requirements and the lack of suitable equipment have, to some extent, restricted operations on this band. For example, until recently, few transceivers tuned to the 160-meter band, and most antenna tuners would not tune to this band. Today, however, nearly every manufacturer of Amateur Radio equipment has one or more transceivers that tune to 160.

Popular antennas for the 160-meter band are various versions of wire radiators. For example, the series of articles by Bob Eldridge[1] describes a double-size G5RV antenna and the G8ON antenna, which is an up-over-down-and-back version of the former. This latter description gives some insight into the problem. Most wire antennas are also too close to the ground to provide good low-angle radiation, and the construction of an efficient vertical antenna for DX is considered by most to be out of reach. A quarter-wave tower antenna would be 125 feet (38 meters) high at 1.815 MHz, which is higher than most Amateurs care to go, and a 5/8-wavelength antenna (an ideal DX antenna) would be 309 feet (94 meters) high.

Practical considerations with regard to height and size usually mean that some form of capacitive top loading must be used to limit the height of the

By John S. Belrose, VE2CV, 3 Tadoussac Drive, Alymer, Quebec, J9J 1G1 Canada

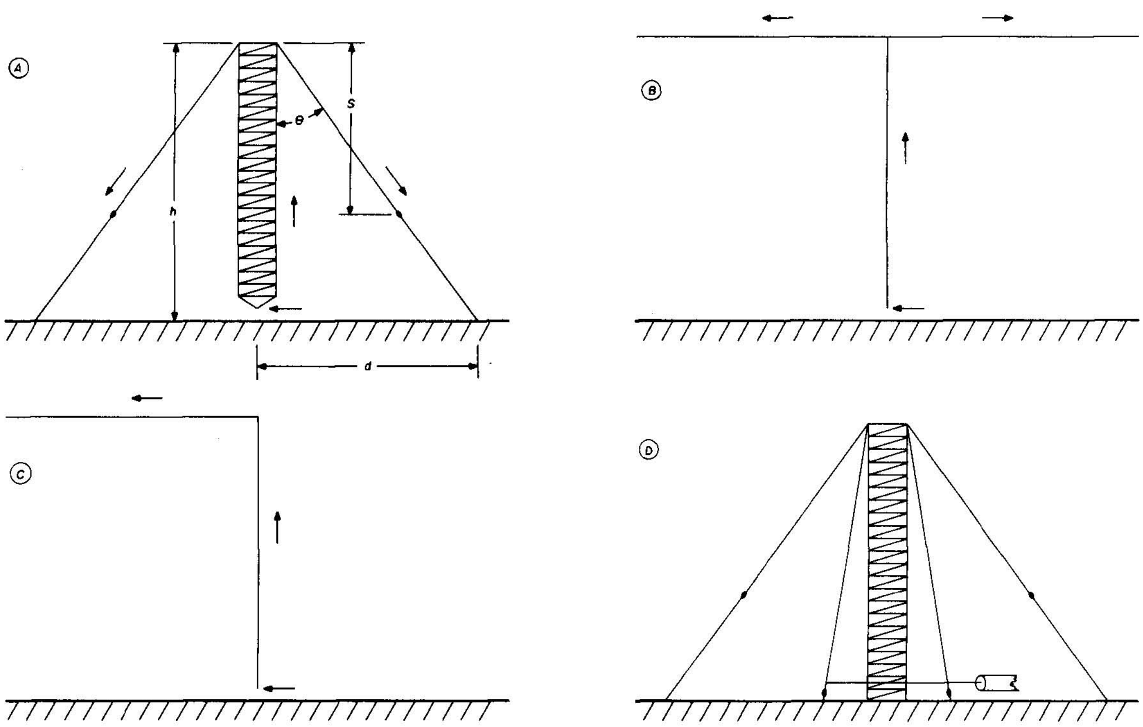

fig. 1. Wire antennas discussed in the text. *A*, the umbrella type top loaded vertical antenna, base-insulated tower (arrows illustrate the phasing of the current on the antenna). *B*, T-type top loaded vertical radiator (insulated base). *C*, L-type top loaded vertical radiator (insulated base), and *D*, folded umbrella antenna.

antenna. The *ARRL Antenna Handbook*[2] illustrates several methods to realize practical 160-meter antennas; grounded towers supporting plumber's-delight (grounded) beam antennas can be shunt fed for 160-meter operations as described by True.[3] In fact this is probably the easiest way to achieve satisfactory operation on this band. Various methods of constructing and feeding 160-meter antennas have been described by Booth.[4]

One of those briefly discussed in the *Antenna Handbook* was the umbrella top-loaded vertical radiator. The umbrella antenna is more economical than the T- or L-type radiators because, for the same peformance, it uses only one mast. The other types require two. A further simplification is obtained by folding the vertical element to raise its impedance to that required by the feedline which, if the antenna is resonant, can be connected directly to the transmission line without the need of a matching circuit. While such an antenna is used for fixed point-to-point communications and for broadcasting (Nolan[5]), it is virtually unkown to Radio Amateurs. Furthermore, published information on the umbrella antenna does not give curves that are useful for design. This article explains how to design an umbrella antenna, and it will be shown that a mast height of about 1/10 wavelength (54 feet, or 16.5 meters at 1.815 kHz) can be designed for a radiation efficiency of 70 percent or better, and bandwidth of 200 kHz or less.

the umbrella antenna

The umbrella top-loaded antenna is illustrated in **fig. 1A**. The top loading consists of a number of wires strung obliquely to ground from the top of the radiator, and insulated from the ground. The important parameters for such an antenna are the height, h, of the radiator, the horizontal distance, d, from the base of the radiator to the extremities of the guys supporting the umbrella wires, and the vertical distance, s, from the top of the tower to the height at which the umbrella wires are broken by an insulator. This antenna was first used by Smith and Johnson[6] at broadcast frequencies in 1947. It was investigated experimentally by Belrose, *et al*;[7] and by Gangi, *et al*.[8] These authors, along with Smeby,[9] examined the antenna theoretically. Smith and Graf[10] have experimentally investigated umbrella antennas using multiwire rib construction, which is particularly applicable for very short antennas at VLF.

The sketches in **figs. 1A, B,** and **C** show by the direction of the arrows the phasing of the currents on the umbrella top-loaded vertical, the T-, and the L-type antennas thus illustrating the difference between these types of radiators. In the case of the T- and L-type radiator, the currents on the flat top and the vertical part of the radiator do not interfere, since these currents are orthogonal to each other in space. Recall that only the currents on the vertical part of the radiator contribute appreciably to the radiation. The currents on the flap top and the image of the flat top in the ground plane are in phase opposition and essentially cancel insofar as radiation is concerned, whereas the currents on the vertical part of the radiator and its image are in phase. However, the current on the umbrella wires have a vertical component that is oppositely directed to the current on the tower; therefore, the radiation from the top part of the tower over the distance s and that from the umbrella wires partially cancel.

If there are many umbrella wires, the current on the top part of the tower over the distance s is essentially "screened." Thus, as the length of the umbrella wires is increased, the radiation resistance first increases due to the increased current area on the tower, then it decreases. The maximum in radiation resistance occurs for $s/h = 0.43$ for umbrella antennas operated on frequencies equal to or less than the fundamental frequency of the antenna. For resonant antennas s/h_0 can be adjusted such that the tower height, $h = h_0/\lambda_0$, is resonant at the operating wavelength, λ_0.

While these considerations seem to be fairly straightforward, and, although many measurements have been made on short umbrella antennas, insufficient attention was paid to operation at frequencies near the fundamental frequency of the antenna, which is the desirable situation at low and medium frequencies. The author and a colleague in 1970 therefore decided to make an extensive study of the umbrella antenna by modeling, supplemented by measuring the field radiated from full-size low-frequency antennas. The curves presented here, which have not so far been published, summarize the observational data in a very compact way, make clear the performance of the umbrella antenna, and simplify its design.

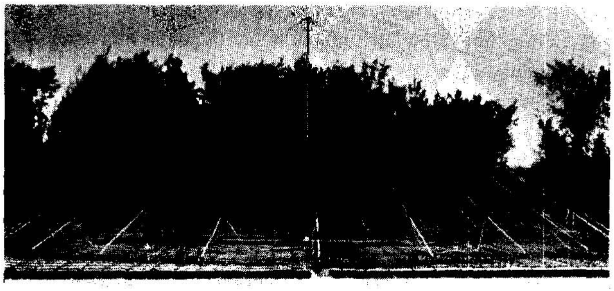

fig. 2. Model umbrella antenna above the elevated ground plane ($N = 24, s/h = 0.71$).

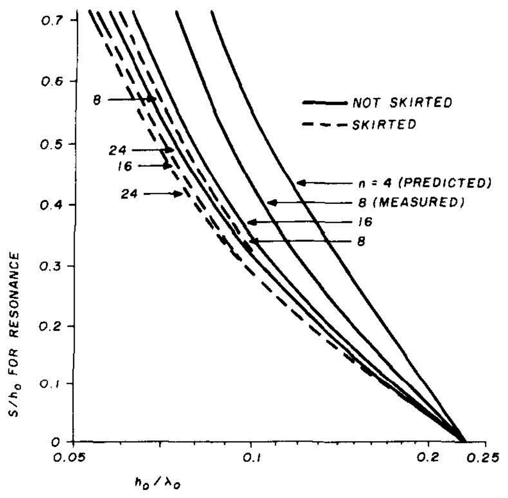

fig. 3. h_0/λ_0 for resonance versus s/h_0 as a function of the number of umbrella wires. Curve for $n = 4$ was not measured but was interpolated from observed data.

experimental setup

The umbrella antenna was modeled as follows. The tower was 1/4-inch (0.6 mm) square aluminum rod 30 inches (76 cm) long. The umbrella wires were No. 24 (0.5 mm) wire. Dimension d/h was fixed and equal to 1.4 (42 inches, or 107 cm for the model). It is clear that d should be as large as possible for maximum top loading, since as d becomes large, the umbrella antenna becomes more like a disk top-loaded radiator. The dimension $d/h = 1.4$ is considered to be a practical design.

The fundamental frequency (for quarter-wave resonance) of the tower alone was measured to be 90.6 MHz. That is, the physical length of the monopole was 82.8 degrees. Laport[11] gives $H(\lambda/4) = 84$ *degrees* for a vertical antenna where $h/2a = 107$ (a is the effective radius of the tower).

The model antenna (**fig. 2**) was mounted at the center of a 20-foot (6-meter) diameter hexagonal shaped ground plane, which was elevated so that the impedance measuring equipment, a Hewlett Packard vector impedance meter, model 4815A, could be connected directly to the antenna base from beneath the ground plane. A Hewlett Packard frequency counter, model 5247M, was used so that the frequency could be measured accurately.

Several umbrella antenna configurations were constructed full size and the radiation resistance at low frequency was deduced from field strength measurements. A Stoddard model NM-12AT field-strength meter was used. Field strength measurements were made at eight sites in the distance range 3-22 km so that ground loss and site errors could be accounted for. From these measured field strengths the radiation resistance, R_r, was determined. Using the appropriate radiation resistance together with the measured model antenna resistance, R_a, the ground loss resistance, R_g, could be estimated. Recall that $R_a = R_r + R_g$.[12] For the model at the frequencies of the measurement, R_g was about 3/4 ohms.

experimental results

Antenna impedances for the model were measured over a range of frequencies up to and above the fundamental frequency of the antenna (2-100 MHz) for a) no top loading, b) various amounts of top loading, $s/h = 0.43$, 0.57 and 0.71; and c) numbers of umbrella wires, $n = 8, 16$, and 24, both skirted and not skirted. Graphs summarizing the results of the measurements are given in **figs. 3** through **6**.

The curves in **fig. 3** give the size of the umbrella hat, as measured by the parameter s/h_o, necessary to resonate the antenna of height h_o/λ_o. That is, h_o is the height of antenna, which together with umbrella top-loading s/h_o, resonates at λ_o. Naturally as the height of the radiator increases, less and less top loading is required for resonance, until $h_o/\tau_o = 0.23$ is reached when the antenna is quarter-wave resonant with no top loading ($s/h_o = 0$). The effect of skirting the umbrella wires can also be seen in this figure, which is equivalent to increasing the number of umbrella wires. According to these data, 8, 16, and 24 wires skirted are approximately equivalent to 21, 33, and 40 umbrella wires without a skirt.

The curves in **fig. 4** show how the radiation resistance, R_r, with top loading adjusted for resonance, increases with decrease in top loading and increase in h; that is, decreases in s/h_o. As expected, when the top loading decreases to zero or $s/h_o = 0$, R_r is the radiation resistance of a quarter-wave monopole, or 35.5 ohms according to our measurements.

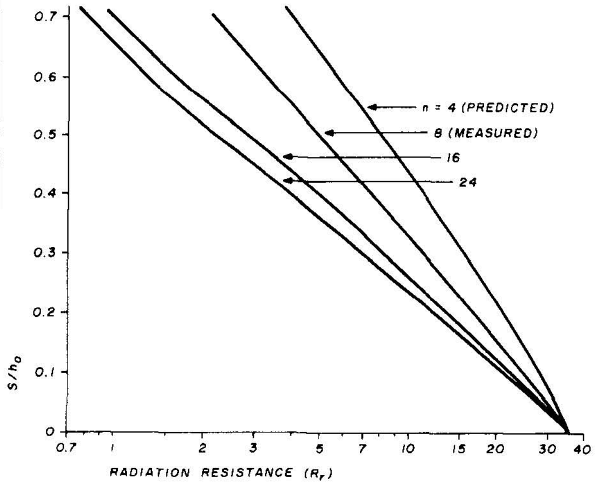

fig. 4. Radiation resistance, R_r, for resonance versus s/h_o as a function of number of umbrella wires. Curve for $n = 4$ was not measured but was interpolated from observed data.

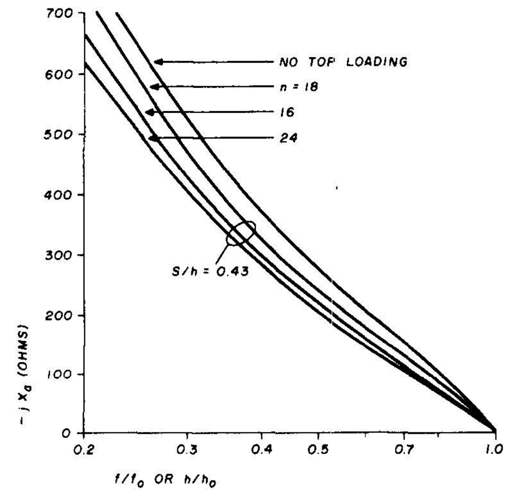

fig. 5. Antenna reactance $-jX_a$ versus f/f_o or h/h_o for antennas shorter than that for resonance.

If the realizable antenna height is shorter than can be resonated with optimum top loading; that is, $s/h_o = 0.43$ (for the case where eight umbrella wires are used), the antenna will be capacitively reactive. The curves in **fig. 5** show how the antenna reactance $-j\ X_a$ increases as the frequency decreases below the resonant frequency, f_o. Since frequency and height scale directly, this graph can also be used to estimate the reactance for an antenna of height h less than h_o for which the antenna is resonant. The graph also gives the reactance for a tower antenna with no top loading ($h/2a = 107$).

The radiation resistance for antenna shorter than that for resonance is calculated according to

$$R_r = R_{r(h_o)} \left(\frac{h}{h_o} \right)^2 \tag{1}$$

where h is the height of the umbrella antenna and h_o is the height required for resonance.

The curves in **fig. 6** show how the antenna Q-factor increases with increase in top loading; that is, with increase in s/h_o. The curves apply to resonant antenna conditions. The antenna Q-factor can be estimated for full-scale antennas where the ground loss resistance is more than 3/4 ohm from the ratio

$$Q_a = Q_{model} \left(\frac{R_{a\,model}}{R_{a\,full\,scale}} \right) \tag{2}$$

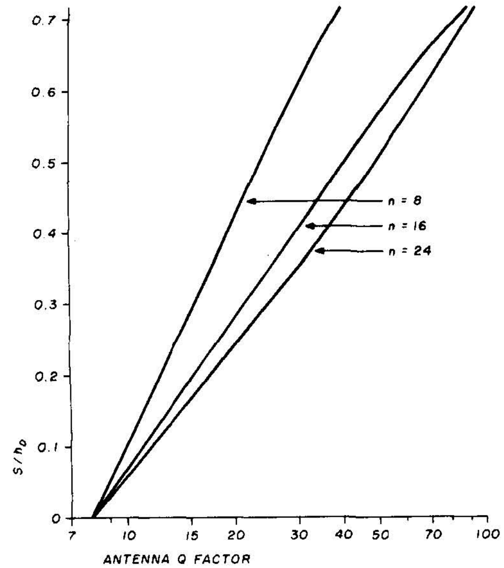

fig. 6. Antenna Q factor, as deduced from the bandwidth of the antenna, versus s/h_o as a function of number of umbrella wires (for resonant antennas).

design examples

Resonant antenna. The following considers the design, step-by-step, for a 160-meter antenna

$$f_o = 1.815\ MHz$$

$$\lambda_o = \frac{984}{1.815} = 542.1\ feet\ (165\ meters)$$

For $s/h = 0.43$, from **fig. 3**, for an antenna employing eight radials

$$h_o/\lambda_o = 0.1$$

or $h_o = 0.1\,(542.1) = 54\ feet\ (16.5\ meters)$

Suppose we choose a tower having a nominal height of 56 feet (17 meters), comprising seven sections 8 feet (2.4 meters) long. If the tower sections overlap by 4.25 inches (11 cm) the actual height is approximately 54 feet (16.5 meters). Since

$$\frac{d}{h} = 1.4$$

$$d = 75.6\ feet\ (23\ meters)$$

According to **fig. 4**, the radiation resistance, R_r is 6.75 ohms. If ground loss resistance R_g is 5 ohms, the radiation efficiency[12] is

$$\eta = \frac{R_r(100)}{R_r + R_g + R_c}$$

$$= \frac{6.75(100)}{6.75 + 5 + 0} = 57\ percent$$

Note that R_c, the coil tuning loss, is zero since the *antenna is resonant.*

The antenna Q factor is given in **fig. 6**, $Q_{model} = 20$, and using **eq. 2**

$$Q_a = \frac{20(7.5)}{11.75} = 12.8$$

and the antenna bandwidth is

$$BW = \frac{2f_o}{Q} = \frac{(2)(1815)}{12.8} = 283\ kHz$$

The factor of 2 accounts for the fact that the antenna bandwidth is doubled when driven by a transmitter that is matched to the load.

Folded umbrella antenna. A further simplification can be obtained by folding the vertical element to raise its impedance to the value required by the feeder. The latter may then be connected directly to the antenna without the need for a matching unit. The mast is grounded at the base (see sketch in **fig. 1D**), and a cage of wires surrounds the tower, connected to the top and insulated at the bottom. The feeder is connected directly to the bottom of this cage of wires supporting the mast and a skirt wire joins their ends.

Four or more wires in the cage will be needed. The antenna must first be made self-resonant; that is, the capacitance of the umbrella top must tune with the inductance of the mast and the cage of wires in parallel. This will require slightly more top loading than discussed above. The input impedance (base of mast insulated), which was estimated above to be about 11.75 ohms, will then be raised by about a factor of four to 47 ohms.

Antenna shorter than resonance. To illustrate use of the curves, suppose we design an antenna of height h that is shorter than that required for resonance (h_o). If the height of the tower is, say, 30 feet (9 meters), then

$$\frac{h}{\lambda_o} = \frac{30}{542.1} = 0.055$$

(in metric terms, $\frac{h}{\lambda_o} = \frac{9}{165} = 0.05$)

For eight umbrella wires, and $s/h_o = 0.43$, see above* $h_o/\lambda_o = 0.1$.

Therefore, $h/h_o = \frac{0.055}{0.1} = 0.55$

and, according to **fig. 5**,

$$X_a = -j215\ ohms$$

The radiation resistance is

$$R_r = R_{r(h_o)} \left(\frac{h}{h_o}\right)^2 = 6.75(0.55)^2 = 2\ ohms$$

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*We could decide to use longer umbrella wires; that is, $\frac{s}{h_o} > 0.43$ or use more of them.

For a tuning coil Q factor of 300,

$$R_c = \frac{215}{300} = 0.72\ ohm$$

and the radiation efficiency is

$$\eta = \frac{2(100)}{2 + 5 + 0.72} = 35\ percent$$

The antenna Q factor is

$$Q = \frac{X_a}{R_a} = \frac{215}{5.72} = 37$$

and the antenna bandwidth is

$$BW = \frac{2f_o}{Q} = \frac{2(1815)}{37} = 96\ kHz$$

ground-screen requirements

As with all short antennas, a radial wire ground screen must be used to realize high radiation efficiency. For a ground loss resistance of 5 ohms, we estimate, (**fig. 7**) that a ground system of at least ten radial wires would be needed, and these wires should be one-quarter to one-half wavelength long (typically broadcasters employ radial wires 0.412 wavelength long). Note the rather unusual scale in **fig. 7**; this is because $R_g \alpha \frac{1}{n}$, where $n = number\ of\ radials$, and R_g has been plotted versus $\frac{1}{n}$. In fact R_g is inversely proportional to the total length of wire employed in the radial ground screen. The more wire that is buried, the lower the ground loss resistance, but there is little point to increasing the number of radial wires to more than 120 or their length to greater than one-half wavelength.

concluding remarks

Design data have been presented for umbrella-type top-loaded vertical antennas for operation on 160 meters. The various curves are plotted as ratios of the height of the antenna to the wavelength and therefore can be used to design such antennas for any frequency. The 54-foot (16.5-meter) high umbrella antenna at 1.815 MHz would be 26 feet (8 meters) high at 3.8 MHz, 14 feet (4.3 meters) high at 7.2 MHz, and 7 feet (2 meters) high at 14.2 MHz. In addition I have shown how to feed a grounded tower vertical radiator — a method that does not seem to have been used by Radio Amateurs. Shunt-fed or gamma-matched grounded towers have been used, but difficulty has been experienced in exciting a "fat" tower employing a "thin" gamma-match element. Besides, the folded unipole type of feed increases the bandwidth over the conventional base-fed radiator; whereas gamma matching introduces additional reactances (the inductance of the gamma section and the capacitances of the tuning and matching elements), which reduce the bandwidth of the radiator.

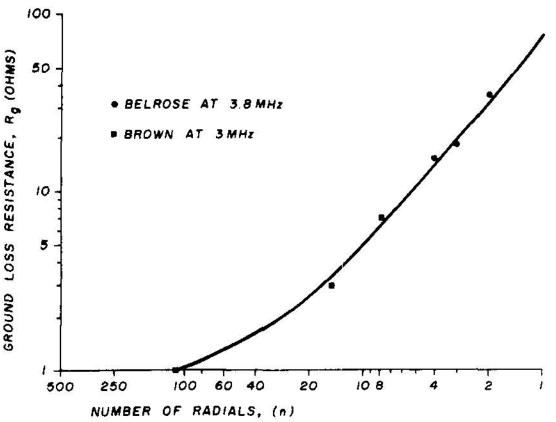

fig. 7. Relationship between ground loss resistance, R_g, and number of radial wires in the ground system. The apparent good agreement between data measured by the author and Brown et al[13] may be coincidental, although both measurements were made over ground of similar conductivity (about 2×10^{-3} mhos/m).

The radiation from the antenna system, of course, requires a return current flow in the tower. Therefore the tower sections must be carefully bonded by jumper straps if the tower is painted, and a good connection to the ground system must be made at the base of the tower. Adequate insulation must be used, especially at the ends of the active guys.

acknowledgments

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