Designing a Vertical Antenna

Graphs cut through the mathematical headaches of antenna design. Put them to work and build a vertical that will shake the air with energy.

By Walter Schulz,* K3OQF

Here is a vertical designed and built from graphs contained in *The ARRL Antenna Book* and *ARRL electronics data book*. In my case the antenna was completely made from discarded Yagi beam elements — a junk box vertical!

By combining information found on transmission lines and antennas in *The ARRL Antenna Book* a design concept may be realized. Explaining further, antennas go through impedance variations in a manner similar to transmission lines. An open-ended transmission line exhibits inductive and capacitive reactances above and below "resonance," respectively. However, at resonance inductive reactance cancels capacitive reactance, leaving only a resistive component. The characteristics of a vertical are similar to those of an open ended transmission line.[1] Engineers use this concept to calculate conjugate impedance at an antenna feed point.

By using graphs of the universal reactance curves[2] and radiation resistance curves,[3] knowledge of mathematics other than simple arithmetic is not necessary. These charts make the solution to feed-point conjugate impedance and top loading problems simple.

Let's Design a Vertical

The antenna selected for illustration in this article is a top-loaded vertical for the 40-meter band, operating at one quarter wavelength or 90 electrical degrees.

Electrical degrees are often employed as units of measure when working with antennas. Their use not only helps one to mentally visualize antenna length, regardless of wavelength, but they are essential when working with the graphs mentioned above.

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[1]Footnotes appear on page 21.

In the broadcast industry the practical physical limit for top loading is considered as approximately 30 electrical degrees[4] when applied to a disk. To find the actual physical length of a vertical antenna having this full limit of top loading, subtract 30° from 90°. The resulting 60° may then be converted to feet (or meters) by this equation:[5]

$$\text{Length in ft} = \frac{2.73 \times \ell}{f_{MHz}} \qquad \text{(Eq. 1a)}$$

$$\text{Length in m} = \frac{0.83 \times \ell}{f_{MHz}}$$

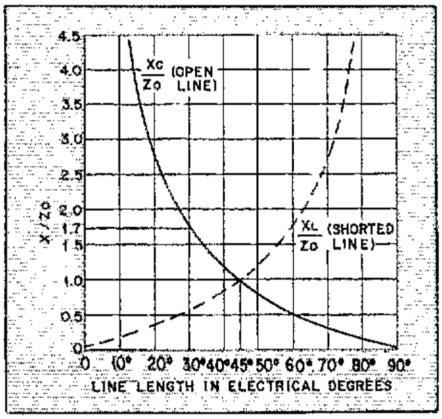
where ℓ = length in degrees

Thus,

$$\text{length} = \frac{2.73 \times 60}{7} = 23.4 \text{ ft} \qquad \text{(Eq. 1b)}$$

In order to proceed to the next step in the calculations, one should survey the aluminum stock on hand, and select masting having the desired outside diameter (OD). The tubing selected as an example for this article had an outside diameter of one inch. To obtain dimensions in meters (millimeters) multiply feet by 0.3048 (304.8) inches by 0.0254 (25.4).

Fig. 1 — Universal reactance curves for open and shorted transmission lines.



Let's now consider the vertical mast as an open-ended transmission line, so that the conjugate impedance and 30° top-loading dimensions can be determined. This equation is for computing the characteristic impedance:[6]

$$Zo = 60 \left[\ln\left(\frac{2h}{a}\right) - 1 \right] \qquad \text{(Eq. 2)}$$

where
ln = natural log (2.3 times the common log),
h = length or height of vertical mast in inches
a = *radius* of mast in inches

Thus,

$$Zo = 60\left[\ln\left(\frac{2 \times 280.8}{0.5}\right) - 1\right] = 361 \text{ ohms}$$

By referring to the universal reactance curves in Fig. 1 the 30° of top-loading reactance can be found. Look across on the abscissa (line length in electrical degrees) finding 30°, and run along the projection vertically to a point on the Xc/Zo (open line) curve. At that point proceed horizontally toward the ordinate reading X/Zo = 1.7. By transposing X/Zo = 1.7 we observe that X = 1.7 × Zo, with the result X = 1.7 × 361 = 614 ohms reactance for 30° top loading.

How to Find Your Hat Size

Refer to Fig. 2 for the nomograph for LC constants, taken from the *ARRL data book*.[7] Place a ruler across 7 MHz and 614 ohms Xc reactance. The ruler crosses the capacitance line at 37 pF. For 30° of top loading, 37 pF of capacitance is required.

Turn next to Fig. 3, the graph of capacitance vs. diameter,[8] where the proper diameter for 37 pF can be found. Note

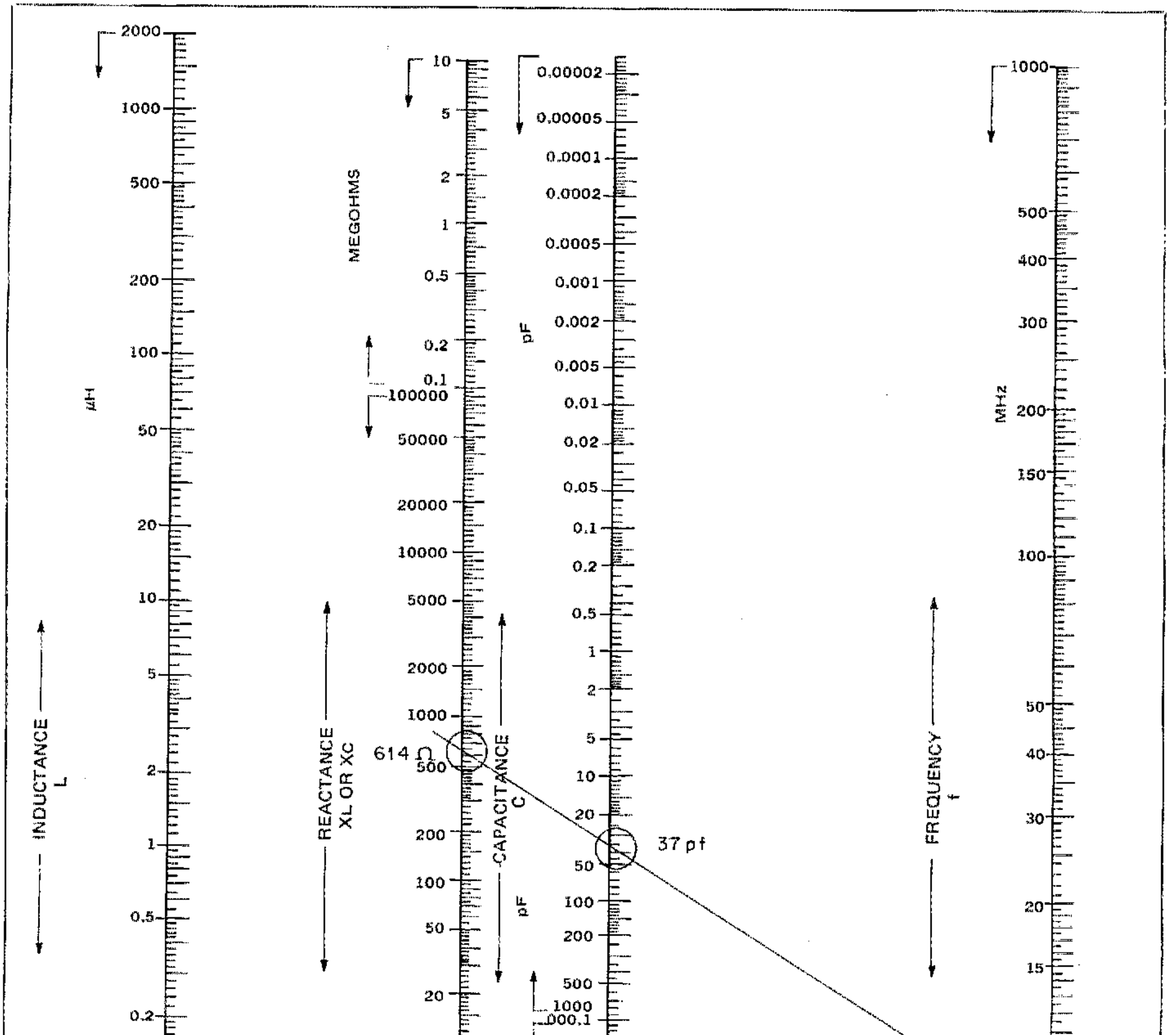


Fig. 2 — Nomograph for LC constants showing how values for the antenna described in the text are plotted.

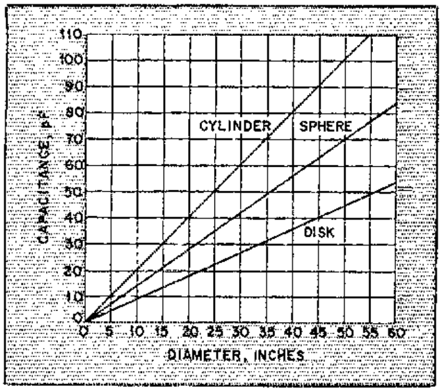


Fig. 3 — Capacitance of sphere, disk and cylinder as a function of diameter. The cylinder length is assumed equal to its diameter.

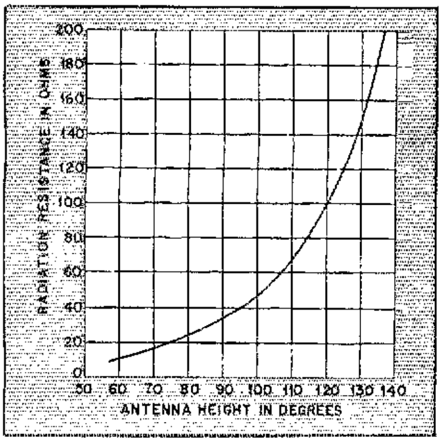


Fig. 4 — Radiation resistance vs. antenna height in degrees, for a vertical antenna over perfectly conducting ground or a highly conducting groundplane.

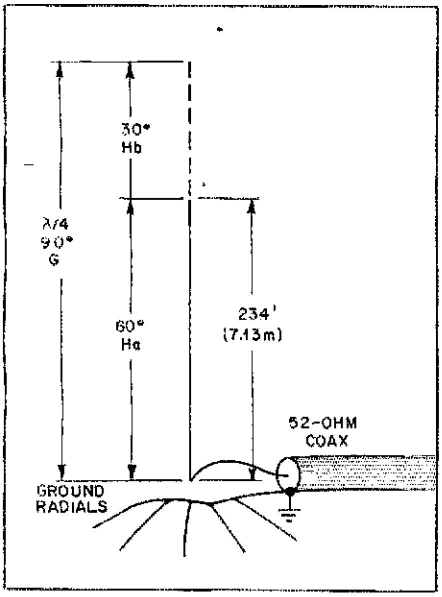


Fig. 5 — Dimensions for a quarter-wave vertical antenna with 30° of top loading. The dimensions in electrical degrees are provided. H_a represents the vertical portion and H_b is the capacitance hat. The antenna is series fed by the coaxial transmission line. There are 60 radials, each 0.2 wavelength long, in the ground system.

the position of 37 pF on the ordinate and the position of the point marked "disk" on horizontal projection. At this point follow the projection down to the abscissa (diameter, inches). The value, 40 inches, is the required diameter of the top-hat disk.

The skeleton disk shown in the photograph is fashioned into a wagon-wheel configuration. Six 20-inch lengths of 1/2-inch wide OD aluminum tubing are used as spokes, each emanating from the hub at equidistant intervals. The spokes terminate at a loop made of no. 14 copper wire. Note that the loop will increase the capacitance slightly.

To find conjugate impedance refer to the radiation-resistance-vs.-antenna-height graph, Fig. 4. Looking at the curve we see that for 90° (on the abscissa) we will have 36-ohms radiation resistance (on the ordinate). An estimated radial ground system loss resistance of 4 ohms for 60 radials, each 0.2 wavelength long,[9] may be added to the 36-ohms radiation-resistance value. This results in a total resistive value of 40 ohms. (Note: 60 radials were used with the antenna selected for the example).

Again referring to the universal reactance curves, Fig. 1, we see that 90° on the abscissa yields a reactance value of zero. Therefore, the conjugate impedance at the feedpoint is $Z = 40 \pm j0\ \Omega$. The electrical design for the completed antenna is shown in Fig. 5.

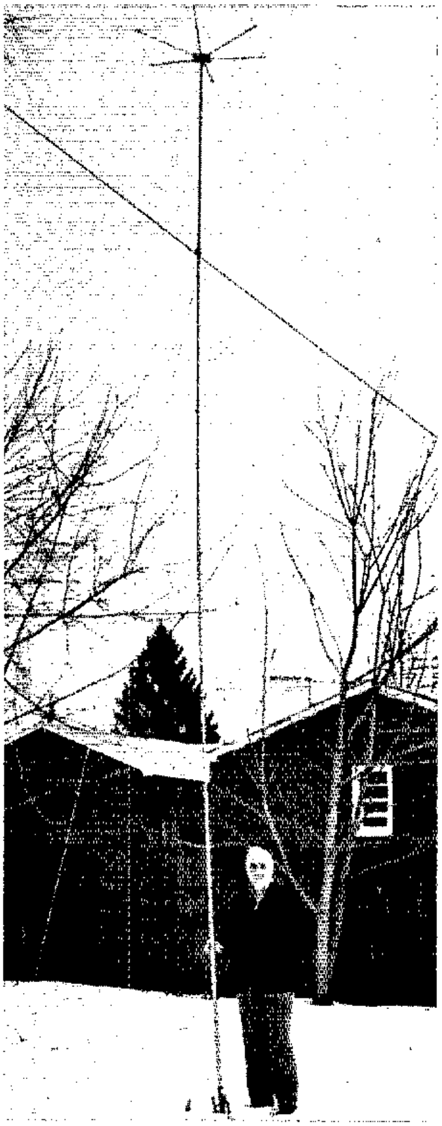
A further word about the universal reactance curves; these curves in reality are trigonometric functions. The two functions of interest here are $X/Zo = \cot \theta°$ for open transmission lines and $X/Zo = \tan \theta°$ for shorted lines. Knowing this information one could make his own graph using trigonometric tables.

For beginning radio amateurs without knowledge of the Smith Chart, use of the graphs facilitates vertical antenna design. They offer numerous possibilities in planning with a simple and direct approach.

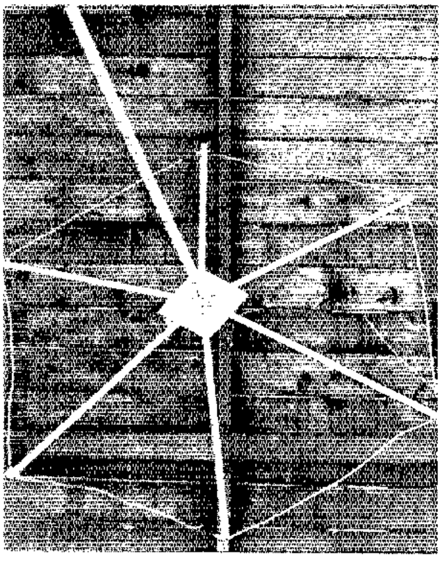
When the 40-meter antenna was finally constructed, stations in Europe could be worked on a daily basis barefoot from the Philadelphia area. On several occasions stations as far away as the Indian Ocean have been worked. QST

Footnotes

[1] Jordan, *Electromagnetic Waves and Radiating Systems*, Prentice-Hall, Inc., 1968. pp. 388-396.
[2] *The ARRL Antenna Book*, 1968, p. 80.
[3] Fig. 2-74, *The ARRL Antenna Book*, 1974, p. 60.
[4] Laport, *Radio Antenna Engineering*, McGraw-Hill, Inc., 1952, p. 80.
[5] Department of Navy, *Naval Shore Electronics Criteria: HF Radio Antenna Systems*, Naval Electronic Systems Command, Washington, DC, 1970, p. A-6.
[6] Jasik, *Antenna Engineering Handbook*, McGraw-Hill, Inc., 1961, p. 19-3.
[7] *ARRL electronics data book*, 1976, p. 27.
[8] Fig. 2-80, *The ARRL Antenna Book*, 1974, p. 62.
[9] Stanley, "Optimum Ground Systems for Vertical Antennas," *QST*, December, 1976, pp. 13-15.



Joseph Blair, W2UI, stands beside a top-loaded 40-meter vertical antenna that is the key to regular contacts with stations in Europe.



A close view of the capacity hat for a 40-meter vertical antenna. The radial arms terminate in a loop of copper wire.