large vertical antenna for 160 and 80 meters

A design approach for dealing with problems of erecting an efficient radiator to compete on the two lower bands

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The decrease in sunspot activity has caused a renewed interest in low-frequency DX operation. On the 80- and 160-meter bands beams are impractical, and even dipoles must be unreasonably high to get the low-angle radiation necessary for DX. That leaves vertical antennas. Although omnidirectional, they are very good low-angle radiators. In theory, a short vertical radiates as well as a tall one; but in practice, the low radiation resistance of a short vertical, compared with ground and other resistances, makes its overall efficiency low.

My friend Liscum Diven, W7IR, decided to erect a good-sized vertical hoping to increase his DX contest scores on 80 and 160. He is blessed with enough real estate to make this practical, considering the area required for guying and a good ground system. While all amateurs are not so fortunate, the design procedures described in this article are applicable to more modest antennas — or larger ones.

height considerations

The first thing to be decided, of course, was the height. This factor is always a compromise between desired performance and cost. There is no good reason why a vertical, or any other antenna, has to be self resonant. An antenna will radiate all the power it can absorb. When an antenna is an odd multiple of a quarter-wavelength long the feed-point impedance is conveniently low for coax transmission lines, and the reactance is zero; but these are the only advantages to resonant antennas: they are easier to feed.

As for the vertical, the practical efficiency increases until a height of about 0.6 wavelength is reached. At greater heights the vertical radiation angle rises rapidly, making the antenna less desirable for DX.

Since W7IR's antenna was to be used on both 80 and 160, the height could not exceed 0.6x80 meters, or 157 feet (48m). This was a little too high for W7IR's tastes. Top-loading to reduce the physical height while maintaining the electrical height was considered but rejected because of mechanical difficulties.

Even if you're not particularly interested in erecting a vertical antenna, the following piece is well worth reading for a firm grasp on some of the physical aspects of all antennas. The part on characteristic impedance, which is treated in terms of an antenna as a transmission line, should help to dispel some of the misconceptions on antenna theory that we hear on the amateur bands. The graphs of resistance as a function of antenna height-to-diameter ratio, which were taken from reference 1, should provide a convenient design aid for those seriously contemplating the construction of a large vertical antenna. **Editor**

It was finally decided to make the vertical 91 feet (28m) high, consisting of 70 feet (21m) of aluminum lattice tower sections, surmounted by a 21-foot (6.4m) whip that happened to be available. This configuration would make the electrical height of the antenna 0.347 wavelength on 80 and 0.166 wavelength on 160 meters.

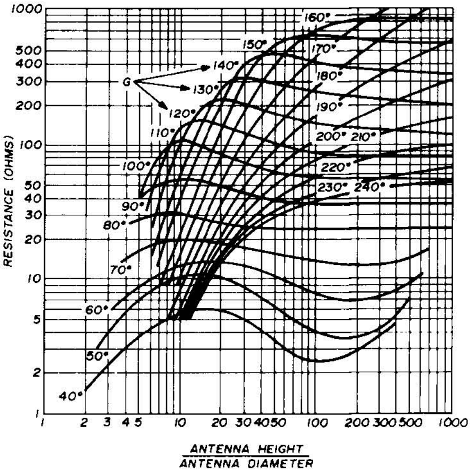


fig. 1. Resistance as a function of antenna height-to-diameter ratio.

It was decided to guy the antenna at two levels. The base insulator was to be a cluster of heavy-duty ceramic pillars. Since the dead weight of the antenna would be only about 100 pounds (37kg), and ceramic is very strong in compression, this type of base was quite practical.

The guys were to be 1/8 inch (3mm) diameter steel cable, with 6-foot (1.8m) sections of 1/2-inch (13mm) polypropylene rope to insulate the guys from the tower, and small egg insulators to break up the guys. The guy anchors would be 5-foot (1.5m) long earth augers.

matching system characteristics

A lot of thought was given to the matching network. It was decided not to use the usual cut and try method; instead, the network would be engineered. The network was built before the antenna was erected, and required only minor adjustment when installed.

The following characteristics were desired in the network:

1. Obviously it must match the resistance and tune out the reactance. The antenna would be highly reactive on both bands since it would not be resonant on either.

2. It should use as few elements as possible and should be easily switched between bands.

3. It should have a permanent dc path to ground on both bands for lightning protection.

The design achieved all of these objectives.

First to be determined was, "what were we matching?" Any antenna is really a transmission line. Its termination is its own losses to space; but since this is a poor termination, the vswr is very high, as a graph of the voltage and current shows. As with all transmission lines, an antenna has a characteristic impedance. This is *not* the sending-end impedance. What is seen at the sending end is the antenna's losses to space, which are distributed along its length, transformed by the characteristics of the transmission line to a single resistance value called the base radiation resistance of the antenna. This resistance, when multiplied by the square of the current measured at that point, tells how much power is actually being radiated.

The characteristic impedance of the antenna is a function of the length-to-diameter ratio. A thin wire will have a characteristic impedance of 600 ohms or more; a lattice tower might have a characteristic impedance of 200 ohms or less. The lower the characteristic impedance, the less will be the impedance excursions with frequency at the sending end, which is true of all transmission lines. This means greater bandwidth.

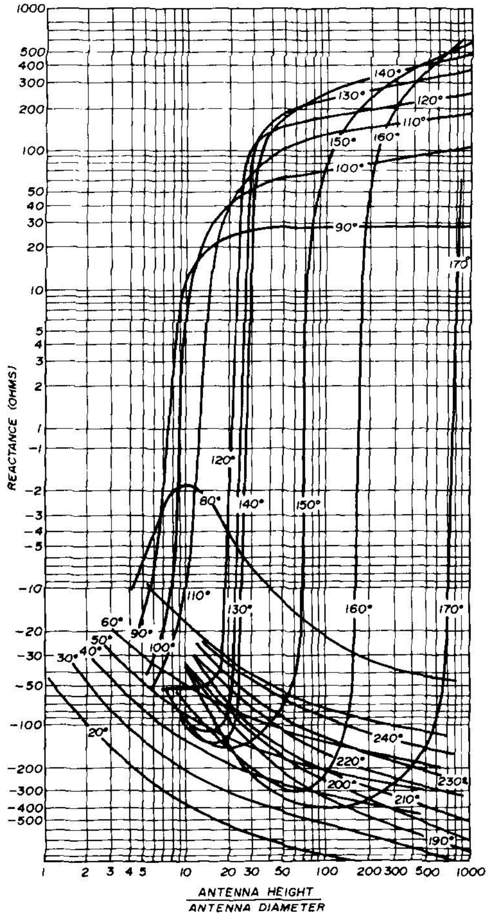
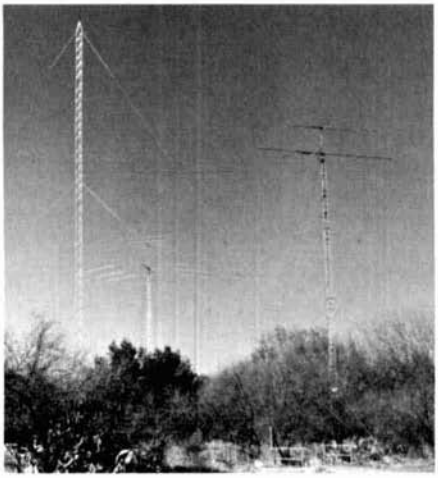


fig. 2. Reactance as a function of antenna height-to-diameter ratio.

The accurate calculation of the resistance and reactance of an antenna of irregular shape is impractical, but graphs are available that give fairly realistic values. These graphs, reproduced in **figs. 1** and **2** and described in reference 1, were generated from vhf scale models and give resistance and reactance values for solid cylindrical antennas of different height-to-diameter ratios over a perfect ground, with the height of the antenna in electrical degrees as the parameter.



Antenna farm at W7IR includes beams for 20 and 15 meters, right, beams for 40 and 10 meters, center, and 91-foot vertical for 80 and 160 meters, left.

design assumptions

We didn't know how a lattice tower of triangular cross-section related to a solid cylinder, but we guessed that it might be something like the diameter of a circle inscribed within the 11-inches (28cm) on-a-side triangular mast or 6 inches (15cm). We also thought that the top 21 feet (6.4m) of the antenna, which was a small-diameter whip, would reduce this dimension further. Since it was a nice number to work with, our final guesstimate was a height-to-diameter ratio of 200, which proved to be a good choice. Because W7IR's antenna would be 0.166 wavelength on 1.8 MHz and 0.347 wavelength on 3.75 MHz, the electrical heights on those bands would be 59 and 125 degrees respectively.

The graphs, as closely as they could be read, yielded the following R and X values for the two bands:

frequency	resistance, R (ohms)	reactance, X (ohms)
1.8 MHz	7	-160
3.75 MHz	180	±240

We further assumed that the ground system, fair but far from ideal, might represent a loss of 3 dB at 1.8 MHz. Adding 7 ohms, a loss resistance equal to the 1.8-MHz radiation resistance, might compensate for ground-system losses. The effective resistance values thus would be 14 and 187 ohms, respectively.

The antenna would require a series inductive reactance of 160 ohms to tune it to 1.8 MHz, but a shunt reactance was desired to provide a direct path to ground for lightning protection. So the series R and X from the graphs were translated to their equivalent parallel values:

$$Q = \frac{X_s}{R_s}$$

$$R_p = R_s\,(Q^2 + 1)$$

$$X_p = \frac{R_p}{Q}$$

This gave the following values:

frequency	resistance, R (ohms)	reactance, X (ohms)
1.8 MHz	1820	-160
3.75 MHz	495	+386

Thus a shunt reactance of +160 ohms (14.1 μH) would tune the antenna. The parallel resistance value of 1820 ohms could most easily be matched by using the loading coil as an autotransformer, connecting the 50-ohm transmission line to a tap on the coil. The fraction of coil turns across which the line should be connected was:

$$\sqrt{\frac{50}{1820}} = 0.166 = 16.6\%$$

neglecting leakage inductance. This took care of the 160-meter band.

A shunt capacitor would be required to tune the 80-meter band. This circuit would not furnish a direct path to ground, so it was decided to see what would happen if the 14.1-μH 160-meter loading coil were left in place on 80 meters. At 3.75 MHz this coil would present a reactance of +332 ohms. This reactance in parallel with the +386 ohms reactance of the antenna at 3.75 MHz gave a net reactance of +179 ohms, the resistance being unchanged. When this combination was translated back to series form, the reactance was R = 57.5 ohms and X = +159 ohms, a convenient value since it meant that on 80, with the 160-meter loading coil in place, the transmission line could be connected directly to the base of the antenna through a capacitive reactance of 159 ohms (267 pF) with negligible mismatch. The two-band matching network was thus very simple, consisting of a single inductor and a single capacitor with a spdt relay to switch bands. The network is shown in **fig. 3**.

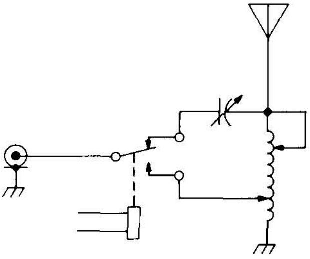


fig. 3. Antenna tuning network for the 2-band vertical with switching relay for changing bands.

W7IR works both phone and CW on 80, so the bandwidth was calculated by obtaining resistance and reactance values for the antenna and network components at 3.5 MHz and 4 MHz and plotting the results on a Smith chart. This data showed that the vswr would be less than 2:1 over the entire band.

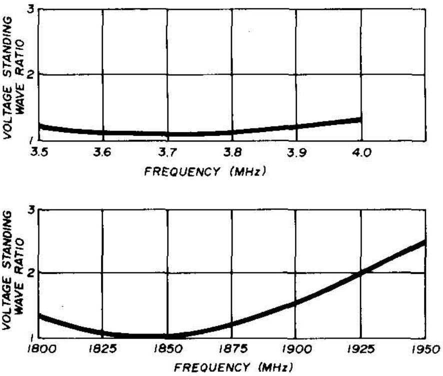


fig. 4. Vswr performance of the large vertical antenna on 80 and 160 meters.

construction and tuneup

The network was built into an old breadbox; components were from an old rig. The coil had a Q of over 200 on both bands, so its loss was negligible. The antenna was erected without mishap. A sign-erection truck was hired for the occasion, and a few local hams held guy wires.*

The radials were put in with the aid of a *mole*, which is a tool about the size of a power lawnmower designed for digging shallow trenches for the pipes of underground sprinkler systems. Sixteen

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*Also try your local phone company or a tree-trimming service. They have mobile cherry pickers with operators that can often be hired for a fairly reasonable fee. **Editor** radials about 125 feet (38m) long were installed. More radials would have been desirable and probably will be installed later. But it was only a week before the start of the DX contest, and even with the mole it was hard work. Then came the tune up. Would the network act as predicted? It had already been built.

Author W7IV supporting W7IR's antenna. Concrete base is 18 inches (45.7cm) by 1 foot (30.5cm). Tuning network and ceramic insulators are shown.

It was our intention first to measure the resistance and reactance of the antenna, as a check on the curves and to get an approximation of the actual ground resistance. This would be done by subtracting the 7 ohms radiation resistance at 1.8 MHz taken from the graph from the measured total value. This turned out to be impossible for an unforseen reason. A local broadcast station produced a signal of *20 volts* at the base of the antenna, making use of an rf bridge impossible. The BC station would not shut down for us so the network was tuned, first on 160, by energizing the network and antenna with enough transmitter power to overcome the BC signal, then adjusting the inductance for maximum voltage across the coil as read by an rf vtvm. Then the transmission line tap on the coil was selected for minimum vswr. Next, power at 3.75 MHz was fed to the network, and the series capacitor adjusted to null the vswr.

The final values came out extremely close to the calculated values. The 160-meter loading coil turned out to be 14 μH (right on the nose) and the 80-meter series capacitor was 320 pF rather than the 267 pF calculated. The transmission line tap on the coil was at 24% rather than 17% of the turns.

Curves of vswr versus frequency are shown in **fig. 4**. The bandwidth is somewhat greater than calculated. This is not necessarily good, however, since it probably means that the ground losses are higher than assumed.

conclusion

As this is being written, the DX contest has just ended. Contest scores, of course, are highly dependent on conditions and the number of stations and countries participating. But W7IR reports that the overall performance on both bands was far superior to that of the high inverted-vees previously used.

On 160, although activity was sparse and noise levels high, W7IR worked every DX station he heard. On 80, W7IR felt that, for the first time, he had an antenna that really put him in a good competitive position. The antenna gave him the feeling that he was really getting through — every serious DXer knows that's what really counts.

references

1. E.A. Laport, *Radio Antenna Engineering*, McGraw-Hill, New York, 1952.

2. R.E. Leo, W7LR, "Vertical Antenna Ground Systems," *ham radio*, May, 1974, page 30.

ham radio