top-loaded vertical for 80 meters

Ideas and construction notes for a popular version of the 1/4-wave vertical antenna using a capacitive hat for top loading

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The purpose of this article is to pass along my experiences and some ideas on the evolution and construction of an 80-meter top-loaded vertical antenna. To keep things in chronological order, I'll start with the simple vertical wire I first put up. It consisted of a 60-foot length of no. 12 wire suspended from an insulator attached to the limb of a tree. The top of this antenna was 65 feet above ground.

ground losses

All antenna literature states that a good ground system is necessary for a base-excited ¼-wave vertical. Therefore I laid out 24 radials around the antenna base. Each radial was no. 12 wire 66 feet long. But is this a good ground system for 80 meters? I thought so, and friend W2LV agreed it was the best I could do under my circumstances. However, W2LV kept mentioning ground losses and finally provided the information in **table 1.** This data doesn't exactly fit my case, but it is representative and based on a vertical radiator of 0.2 wavelength. The data goes back to the 1930s when broadcasters were interested in standards for antennas with vertical propagation angles.

The interesting thing about the data is that if the radials are too short, say 0.15 wavelength, they don't do much good.

impedance matching

Using a GR 916A rf bridge, I made measurements between the antenna and ground system. Antenna characteristics are shown in **fig. 1.** A pure resistance of 57 ohms appears at 3.65 MHz. I wanted the antenna to resonate at 3.8 MHz, but at this frequency the impedance was 63 + j36 ohms, which is equivalent to an swr of 2. This indicated that some kind of matching arrangement was necessary.

The series-resonant circuit shown in **fig. 2A** was constructed and installed in a plywood box, then mounted on a short post at the bottom of the antenna wire. The 50-ohm tap point for the coax cable was determined using a homemade bridge.[1] A point on the coil producing a zero indication could not be found, so the arrangement of **fig. 2B** was used. The tap and capacitors were carefully adjusted to give a null. (Incidentally, I found from experience that it's prudent to check an impedance bridge with a carbon composition resistor to make sure everything is working properly.)

The transmission line was connected, and the transmitter was fired up. An swr of 1.2 (at 3.8 MHz) was obtained at the transmitter end with an swr bridge.

fig. 1. Measurements of the initial 80-meter ¼-wave vertical suspended from a tree limb. Desired resonant frequency was 3.8 MHz.

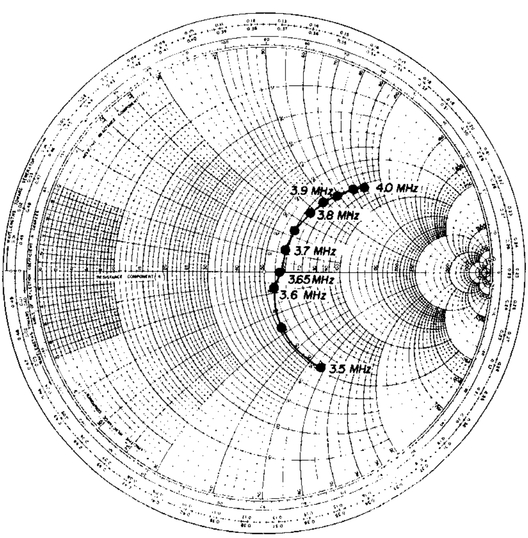

table 1. Ground loss in radials for vertical antennas.

no. radials	radial wavelength	percent ground loss
30	0.4	23
30	0.15	41
60	0.4	10
60	0.15	38
120	0.4	2
120	0.15	35

Results were interesting. Close-in signals (200-300 miles) were weak on the vertical compared to a horizontal antenna. Signals further away were about equal in amplitude on either antenna. DX signals (Europe, Hawaii) were stronger on

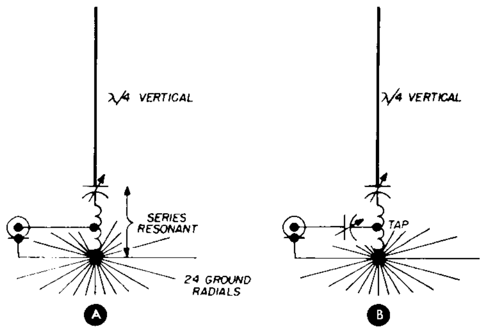

fig. 2. Tuned circuits for resonating the initial version of the vertical. Circuit at B produced an swr of 1.2 at the desired operating frequency.

the vertical. I worked 23 countries on 80-meter phone in the 1969 ARRL DX test with the vertical.

top loading

Flushed with success, my next objective was to improve the efficiency of the vertical by moving the current loop away from ground. Top loading seemed to be the answer.

After reading the early articles [2, 3, 4] the installation shown in **fig. 3** evolved. Although top loading can be accomplished with a ball, cylinder, or disk, the latter seemed the easiest to build. A chart[2] of capacitance vs. disk diameter showed that a disk six feet in diameter would give a capacitance of 61 pF. The only reason I picked six feet was that it was a nice number and I felt the bigger the better. I had reason to regret this decision, which I'll now explain. You'll notice from **fig. 3** that a pulley arrangement is used to raise and lower the antenna. Such a method is convenient and saves climbing during tuning adjustments. However, be sure the vertical path is free of obstructions for the whole diameter of the disk! I had a fearful journey up the tree cutting down branches which criss-crossed the six foot imaginary cylinder through which the disk has to pass. There were times when I wished that a 1-foot-diameter disk had been used.

capacitive hat

The disk was made by using two six-foot lengths of 1 x 2 inch wood in the form of a cross. A circle of ¼-inch copper tubing was supported on standoff insulators at the ends of the cross; and 24 no. 12 wires were connected from the outside to the center of the disk (**fig. 4**).

loading inductance

Knowledge of the disk capacitance is necessary to obtain a ball-park figure for the loading-coil inductance. An inductance of 29 μH was required to resonate the system at 3.8 MHz with the 61-pF disk.

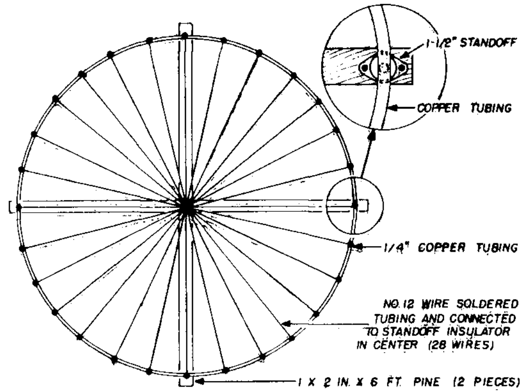

fig. 4. Construction details of the capacitive hat. The copper tubing is flattened and attached to a standoff insulator as shown in the inset.

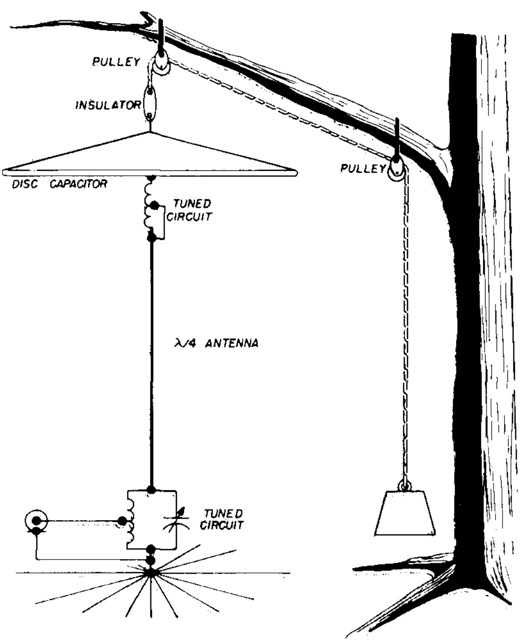

fig. 3. The antenna with a capacitive hat for top loading. The disk was six feet in diameter, but a smaller disk could have been used with a larger tuning inductance.

The coil was from some surplus equipment. It has a 3-inch-diameter ceramic form with 33½ turns of no. 12 wire spaced the diameter of the wire, with an overall inductance of 44 μH. This coil, with provisions for shorting out turns, was mounted as shown in **fig. 3** and the whole thing hoisted in the air.

Now, how do you tune the coil to bring the antenna into resonance at the desired operating frequency? The old QST articles stated that the field strength of the antenna should be monitored at a distance greater than 300 feet. A point is reached when decreasing the coil inductance causes the field strength to drop off. You then go back a few turns and there you are.

Such a method works but it doesn't seem very scientific. Since I had an impedance bridge available I decided to do it properly.

Unfortunately the impedance bridge

measured only to about 1200 ohms, and the base of a properly tuned top-loaded vertical is probably several thousand ohms. It was necessary to have some means of using the bridge while adjusting the coil turns to produce a pure resistance at the base of the antenna, which would be in the range of the rf bridge. If

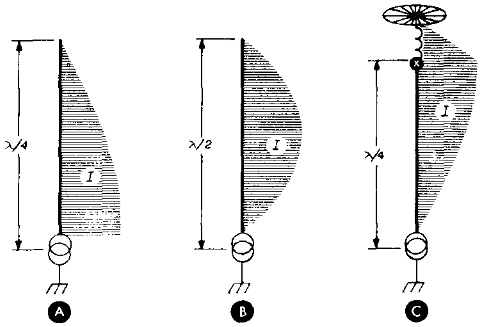

fig. 5. Current distribution on three vertical antennas. The tuned circuit at C simulates ¼ wavelength.

a pure resistance is obtained at the antenna base, the antenna is in resonance.

measurements

Let's pause a minute to look at the problem. **Fig. 5** shows several conditions of current distribution. A is that of the quarter-wave vertical, B a half wave vertical, and C a top-loaded quarter-wave vertical to simulate a half wavelength. If we could put our measuring equipment at the top of the antenna, a low-impedance point would be available at point X; not very practical.

W2KXD pointed out that the same objective could be accomplished at ground level by using a quarter-wave extension as shown in **fig. 6.** The quarter-wave coax will translate the high impedance at the antenna end to a very low impedance at the bridge end of the coax. The bridge measurement will show a pure resistance when the antenna is at resonance. I believe this method of tuning the coil of the top-loaded vertical is novel.

Don't let the mention of a General Radio rf bridge scare you off if you don't have one available. The rf bridge described in Reference 5 will work very well. The quarter-wave coax length was determined by measuring its input with the output open circuited, and cutting until a pure resistance input was obtained. Before connecting the antenna, I took the precaution of inserting a 50-ohm carbon composition resistor across the bridge. It read 49.5 ohms, so I knew my setup was correct. With the total coil in use, a reading was taken at 3.5 and 4.0 MHz with the following results:

3.5 MHz Z = 1.0 + j0 ohms

4.0 MHz Z = 1.5 + j 12.1 ohms

The pure resistance at 3.5 MHz indicated that the antenna was resonating at that frequency, but 3.8 MHz was desired.

The antenna was lowered and eleven turns shorted out on the coil. After pulling the antenna back into place, the measurements then became:

freq (MHz)	impedance (ohms)
3.5	1 – j7.1
3.6	1.3 – j4.2
3.7	1.3 – j2.7
3.8	1.7 – j0
3.9	1.7 + j2.7
4.0	1.5 + j5.0

Resonance is indicated at 3.8 MHz, just where I wanted it. To further test the procedure, 23 turns were shorted out with the following results:

freq (MHz)	impedance (ohms)
3.5	2.5 – j11.4
3.6	2.0 – j9.7
3.7	2.2 – j4.0
3.8	2.3 – j2.6
3.9	2.2 – j2.0
4.00	2.2 – j1.2

It can be seen that resonance is above 4.0 MHz. Therefore the 11-turn tap point was correct.

Since there was now a high impedance at the base of the antenna, a parallel-tuned circuit was used as shown in **fig. 7** and adjusted as previously described.

After reconnecting everything, the transmitter was fired up. The swr bridge at the transmitter end showed the following readings:

frequency (MHz)	swr
3.5	almost full scale
3.6	3.3
3.7	1.4
3.8	1.2
3.9	1.5
4.0	3.0

A check on the receiver showed that locals were way down compared to those on the half-wave horizontal, and equal signal strength between the two antennas appeared to be at about 1000 miles. The vertical was used on 80 meters during the 1969 phone CQ DX contest with good results. I had the intuitive feeling, however, that I could work DX stations just as well with the half-wave horizontal, because received signal strengths seemed to be the same. It was not working the way I had hoped it would, and I wanted to do some more testing.

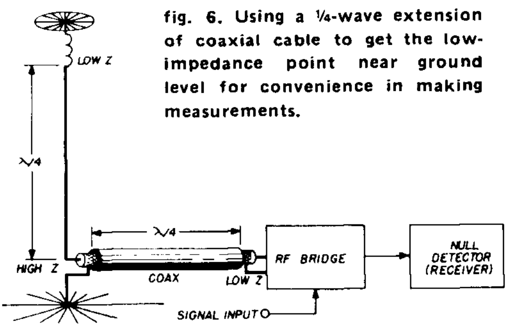

fig. 6. Using a ¼-wave extension of coaxial cable to get the low-impedance point near ground level for convenience in making measurements.

current distribution

One nice thing about having a project and friends is the interesting discussions one can get into. W2LV suggested that I get rid of the coil and just use the disk,

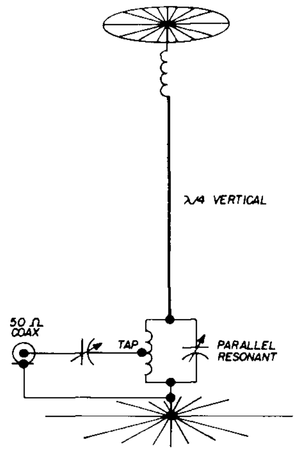

fig. 7. Parallel-resonant circuit for tuning the final configuration.

his feeling being that the coil is a loss unless it's wound with ¼-inch copper tubing, silver plated.

W2LL suggested that I solder a bunch of Christmas tree lights along the antenna and see if the current distribution was correct, then I could leave them up for the holiday season.

One never knows quite when to believe W2LL, but his suggestion fired my imagination. A dozen 2-volt, 60-mA bulbs were purchased and spaced every five feet along the 60-foot wire. There was some discussion on how far to tap the bulbs across the wire, but little objection to my suggestion of 5 inches. Having the antenna on the pulley made it easy to lower it, disconnect it, roll it up, and take it indoors to work on. The next evening, with the bulbs in place, the antenna was reconnected and hauled into position. It took 1 kW of power to light the lamps to proper brilliancy.

final adjustments

I looked at the lights from all angles and several distances, trying to figure out a way to record their brilliance quantitatively. How do I get at a point equally distant from each light? Can I photograph them?

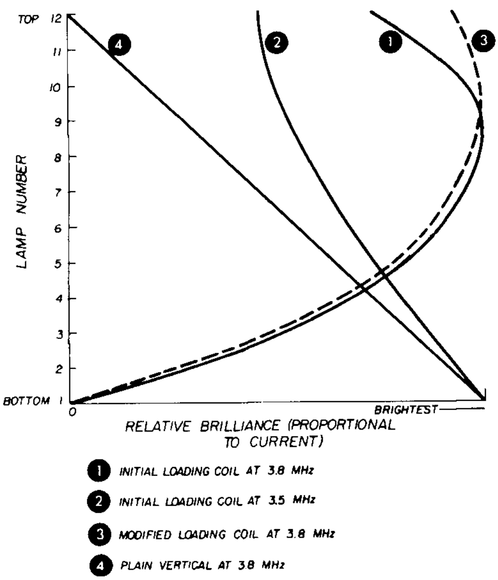

fig. 8. Results of tests using small lamps to determine current distribution.

The final solution was to pick out the brightest lamps, and those above and below that point were grouped as to equal brilliance. Very crude of course; but if you are there, you know what's happening. A plot of what I saw of the current distribution on the top-loaded ¼-wave vertical antenna is shown in **fig. 8** for 3.8 MHz. The lamps at 1 show a current loop about ¾ of the way to the top of the antenna. The transmitting frequency was increased to 4.0 MHz with results approximately the same. The transmitter frequency was then reduced to 3.5 MHz, and the lamps assumed a relative brilliance as shown by 2.

The next step was to lower the antenna, short out the total loading coil, and pull up the antenna. With the transmitting frequency returned to 3.8 MHz, the relative current distribution appeared to be as at 2.

The light presentations for the different displays agree with theory except for the 1 readings; the maximum brilliance should be at the top.

Down came the antenna, and coil removed. The coil Q measured 290 and had an inductance of 23 μH. (The same coil with the shorted turns unshorted had a Q of 400 and an inductance of 44 μH.)

Turns were removed from the coil to return its inductance to 23 μH. This not only improved the Q of the coil by eliminating the shorted turns, but improved its form factor as well. The final Q of the coil at 3.8 MHz was 480; a 165% improvement over the original value.

The coil was reinstalled in the antenna and the lights inspected. The dashed line, 3, of **fig. 8** shows the improvement in the current distribution. I have no doubt that W2LV is correct in suggesting the use of ¼-inch copper tubing for the coil — or better yet eliminating it — but the improvement one way or the other seemed marginal.

conclusions

I've attempted to pass along my experiences and some ideas on the evolution and design of an 80-meter top-loaded vertical antenna. You might say that my results were inconclusive since top loading gave no better results than base loading. However, top loading does get the current loop at the highest point of the antenna. If that's what you want, now you know how to do it.

references

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ham radio