

Vertical Antenna Ground System experiment 2

Rudy Severns, N6LF

The purpose of this experiment was to quantify the effect of varying the number of radials in the ground systems of several different vertical antennas. Of particular interest was how much was actually gained as the radial numbers were made larger and the point of vanishing returns.

Description of the experiment

The measurements were made between 7.0 and 7.3 MHz, with most at 7.2 MHz. The details of the instrumentation, test procedures and test range are given in a separate document associated with this series of test reports.

I used five different antennas:

- A 1/4-wave, 1" aluminum tubing vertical, adjusted to resonate at 7.2 MHz.
- An 1/8-wave, 1" aluminum tubing vertical with three top loading wires, disposed symmetrically (120 degrees between them) around the top, sloping at roughly 45 degrees, resonated at 7.2 MHz.
- An 1/8-wave, 1" aluminum tubing vertical with no top loading but resonated to 7.2 MHz with a base inductor (5 uH).
- A 40 m Hamstick mobile whip adjusted for resonance at 7.2 MHz.
- A Cushcraft R7000 vertical.

The minimum conceivable ground system for a vertical would be a single ground stake with a coaxial feedline back to the shack. The feedline acts as a single random length radial. For this experiment I adopted this as the "zero radial" ground system where the stake was a 4' copper-clad steel rod. A common mode choke (balun) was not used in the feedline.

The ground system was improved progressively by adding 33', #18, insulated wire radials in the progression: 0, 4, 8, 16, 32, 64. This was repeated for each antenna. 33' is close to a 1/4-wave in free space at 7.2 MHz. However, the

electrical length changes when we place the radials close to the soil which shows up as a shift in resonant frequency with radial number.

The soil characteristics under the radial system were measured using a technique given in QEX^[1]. The average soil constants in the test field were: conductivity, $\sigma=0.02$ S/m and relative dielectric constant, $\epsilon_r=30$.

For each number of radials and each antenna, two measurements were made: the input impedance and the value for S21 (transmission gain) at a point 1.8 wavelengths away from the test antenna, at an elevation angle of about 5 degrees. Because the number of radials effects the resonant frequency, each antenna was re-resonated by adjusting its height as the number of radials was changed. All of the measurements were repeated several times to as a check.

Experimental results

When we compare the results for different numbers of radials on a given antenna, the change in relative signal strength directly answers the question of how much signal improvement we get by adding radials. Typical test results are shown in Figure 1.

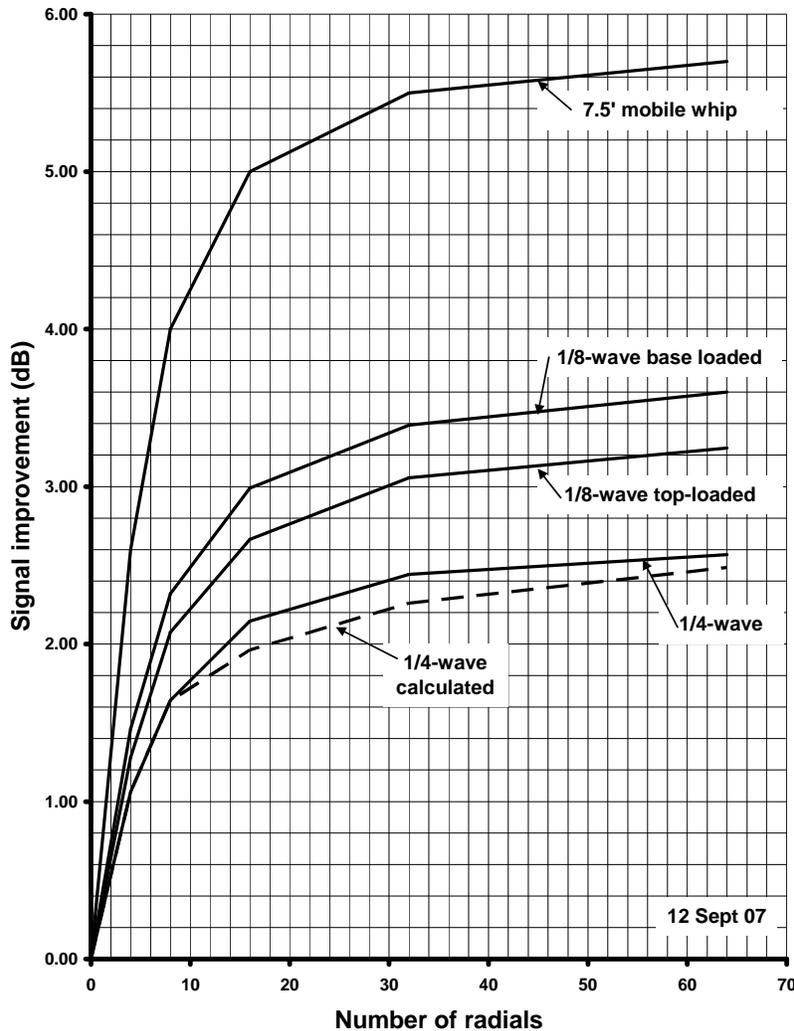


Figure 1 - Typical improvement in signal as 1/4-wave radials are added to the basic ground system(a single ground stake).

Note, the graph is in terms of the *improvement* in signal over the single ground stake with no radials for *each* antenna. The graph does *not* compare the relative worth of each antenna. Obviously the short, lossy mobile whip will yield much less signal (-10 dB or worse!) than the 1/4-wave vertical.

The effect of radial number on input resistance (R_s) is shown in Figure 2.

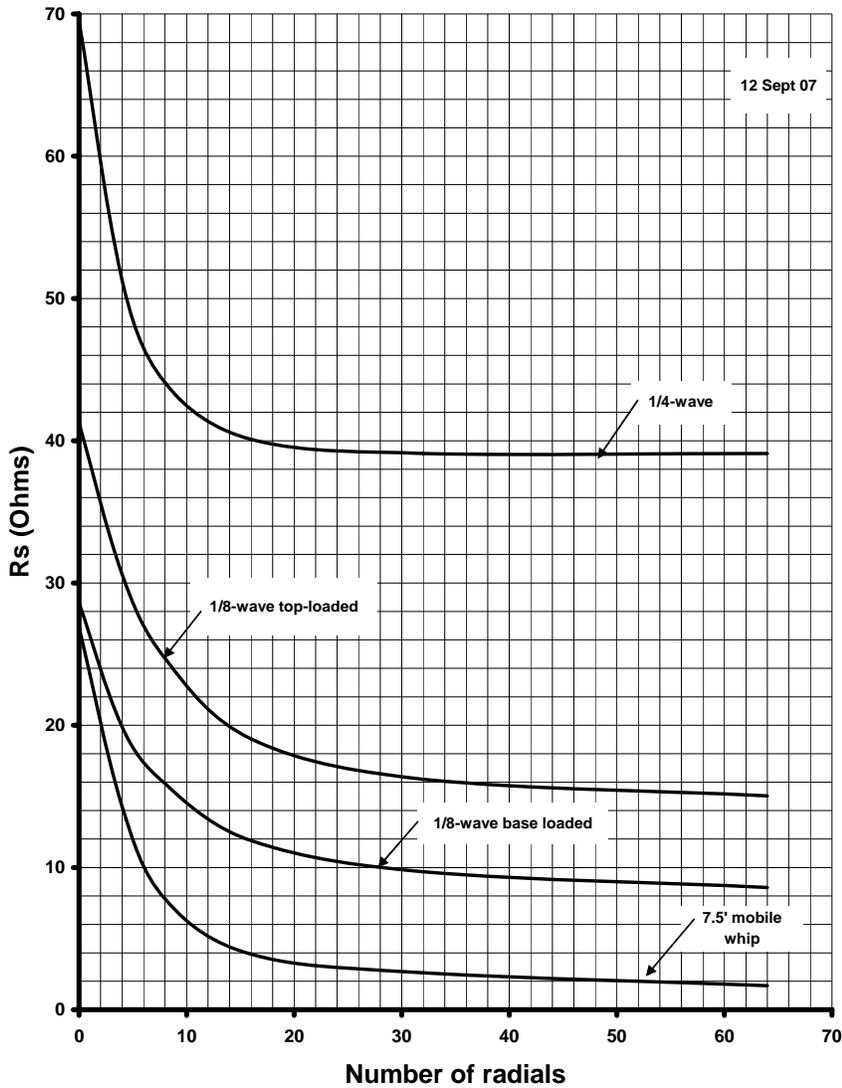


Figure 4- Measured input resistance (R_s) as a function of radial number.

In the case of the Hamstick mobile whip, I have subtracted the loss resistance due to the loading from the measured input resistance because it has a fixed value independent of radial number. We can see that as we add larger numbers of radials the values for R_s begin to level out and approximate the idealized values.

During the experiments I found that changing the number of radials changed the resonant frequencies of all the antennas except the R7000. For example, using the 1/4-wave vertical, I laid down 64 radials and adjusted the height of the vertical so that it was resonant at 7.2 MHz. I then started removing radials (but not changing the height), measuring the resonant frequency as I went down to zero radials. The results are shown in Figure 3.

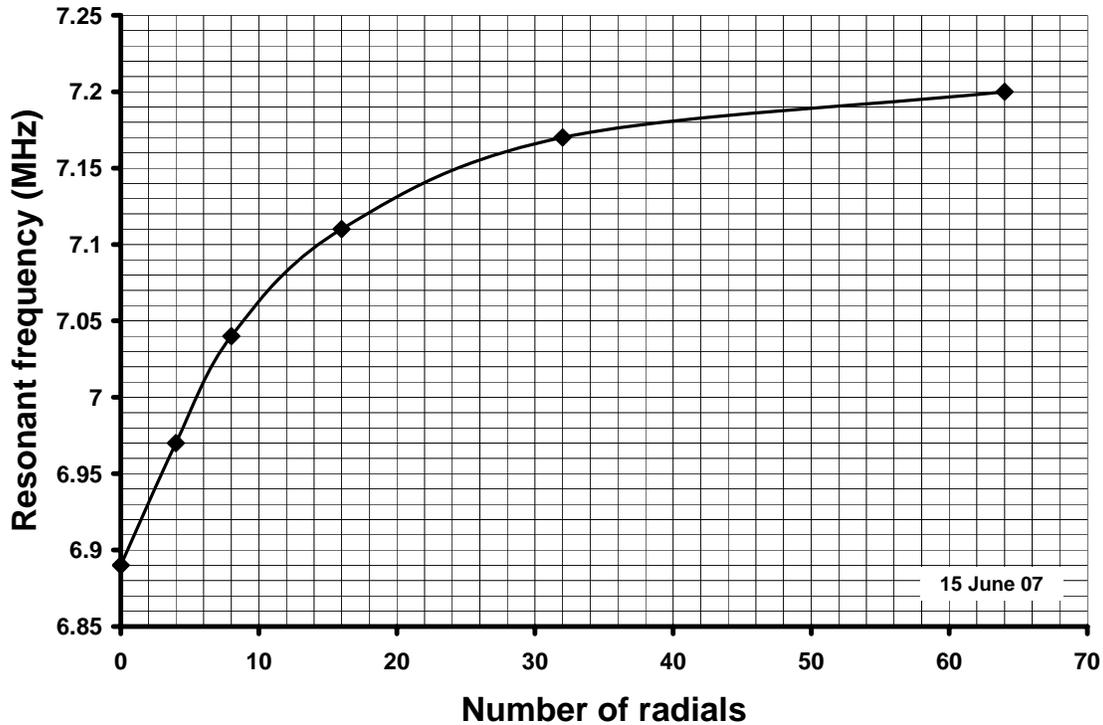


Figure 5 - Resonant frequency of a vertical resonated at 7.2 MHz with sixty four 33' radials as a function of the number of radials.

Obviously the resonant frequency is affected by the radials. You can of course re-resonate the antenna by changing its height or loading. During the experiment, except for the run shown in figure 1, I adjusted the height to restore resonance at 7.2 MHz. With 64 radials resonance at 7.2 MHz was obtained with $h=33' 7''$. With no radials the 7.2 MHz resonant height was $32' 11''$.

What's going on? Because the radials are lying right on the ground surface, the soil characteristics load or detune the radials, so that they are resonant well below 7.2 MHz. This has a direct impact on the feedpoint impedance. This effect is explored in more detail in the report for experiment 4.

Comments

Figures 1 and 2 have a lot of information in them. One of the interesting things about Figure 1 is that it shows that *the shorter and more heavily loaded the antenna, the more you have to "gain" from an aggressive ground system.* For example, the improvement for the 1/4-wave vertical, going from 0 to 64 radials, is about 2.6 db, certainly worthwhile but for the 1/8-wave base loaded vertical it's more like 3.4 dB, and for the mobile whip, nearly 6 dB.

What's going on here? As I pointed out in my July 2000 QST article on ground systems^[2], when we shorten an antenna but keep the input power the same, both the magnetic and electric field intensities in the immediate vicinity of the antenna increase dramatically. This translates to much higher ground losses. What we see in Figure 1 is that adding the radial system reduces these losses but since the losses are higher to start with for the shorter antennas, the improvement is greater. No mystery!

From Figure 1 we can see that for all the test antennas, most of the improvement comes with the first 16 radials. As we add more radials beyond 16 there is still improvement but it is proportionately much smaller. You gain perhaps another fraction of a dB going to 32 radials but by the time you reach 64 radials there isn't much change.

We have to be careful in drawing conclusions from these graphs. They represent experimental results over my particular soil, at one frequency. The soil under the test antennas was very good. More radials than shown above may be useful in poorer soils but I doubt that 120 radials are justified for amateur applications.

For the case of the 1/4-wave vertical with 4 radials I measured the current division between the radials. This is shown in table 1.

Table 1, current ratios between radials on the 1/4-wave vertical.

Radial	Current ratio
1	1.0
2	1.4
3	1.2
4	1.1

This radial current asymmetry is very similar to Dick Weber's (K5IU) measurements^[3]. In this case the radials are much closer to ground and the effect is muted. Even still, the radials are behaving very much like elevated radials. As more radials are added the asymmetry quickly goes down.

I made some measurements on an R7000, at 7.2 MHz, with and without an external ground system, which showed that adding a 64 radial ground system had almost no effect on signal strength (+0.1 dB). This surprised me until I had an e-mail conversation with Joe Reisert, W1JR, the original designer. The antenna was designed to work without a ground system and although the antenna is physically less than a quarter-wave on 40 m (25'), the loading is arranged so that it

behaves more like a 3/8-wave. There are a set of 48" radials at the base which are isolated from ground. The current maximum is well up into the antenna and the base is a high impedance point. The conventional wisdom, to which I have been a subscriber, is that even with a 1/2-wave vertical, adding an extensive ground system will improve performance. I did not see that here.

Bibliography

[1] R. Severns, N6LF, MEASUREMENT OF SOIL ELECTRICAL PARAMETERS AT HF, QEX magazine, Nov/Dec 2006, pp. 3-9

[2] R. Severns, N6LF, "Verticals, Ground Systems and Some History," QST, Jul 2000, pp 38-44

[3] D. Weber, K5IU, "Optimal Elevated Radial Vertical Antennas", Communications Quarterly magazine, Spring 1997, pp. 9-27