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Experimental Determination of Ground System Performance for HF Verticals

Part 3

Comparisons Between Ground Surface and Elevated Radials

Experimental results from another of the author's antenna experiments.

Over the years there has been a great deal of discussion regarding the relative merits of a vertical antenna with a few elevated radials versus one with a large number of radials either lying on the ground or buried just below the surface. *NEC* modeling predicts that as few as four radials, a few feet above ground, will provide as efficient a ground system as a large number of on-ground radials. Whether this prediction is valid is a matter of some dispute. Resolving this issue is important for amateurs using HF vertical antennas.

The first segment of the experiment was a comparison of the performance of a ¼-wavelength vertical antenna with a large number of ground surface radials (64) to one with only four elevated radials. From the results in segment one it appeared that elevated radial systems for HF verticals have some merit. But there are a number of different ways to implement an elevated radial system. The purpose of the second segment of the experiment was to evaluate the relative performance of several different elevated radial schemes.

Segment One

All measurements were made at 7.2 MHz using a 33.5 foot tubular aluminum vertical antenna. The experiment began with sixty four, 33 foot no. 18 AWG insulated wire radials lying on the ground surface. The antenna was insulated from ground and used a common mode choke (balun) in the feed line. With a height of 33.5 feet and 64 radials, the vertical was close to resonance at 7.2 MHz.

During the experiment, |S21| (magnitude of the transmission gain, see Part I of this series)[1] and the input impedance at the feed point (Z_i) were measured and recorded as the radial system was changed. The experiment began with 64 radials lying on the ground surface. Without changing the height of the vertical, |S21| and Z_i were measured as the radial number was reduced in the following sequence: 64, 32, 16, 8, 4. The next step was to make a series of measurements, beginning with the four radials on the ground and then elevating the radials and the base of the vertical to 6 inches, 12 inches and finally 48 inches. At the 48 inch height, a measurement of the current division between the radials was made.

This entire sequence was repeated three times on different days. The results did not change significantly between test runs.

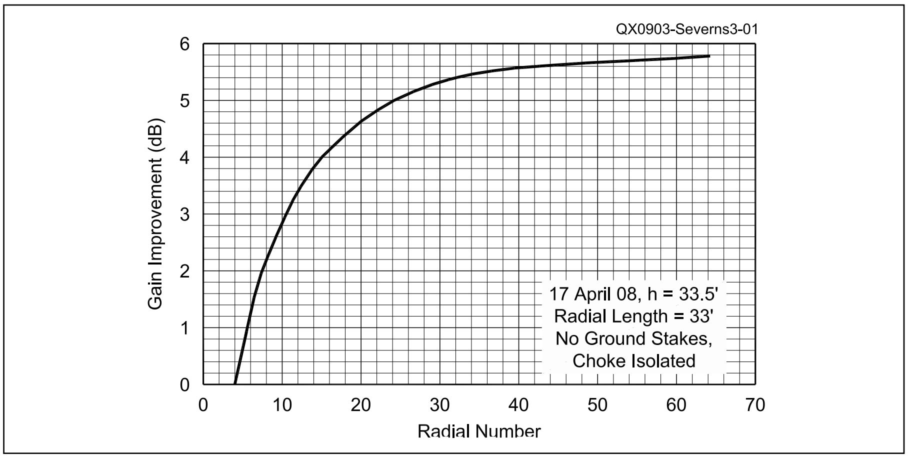

Figure 1 — |S21| as a function of radial number. All radials are lying on the ground surface.

[1] Notes appear on page 32.

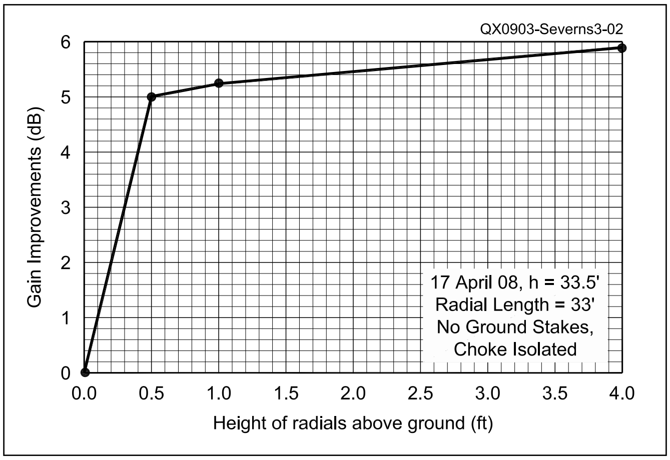

Figure 2 — |S21| with 4 radials and the antenna base at different heights.

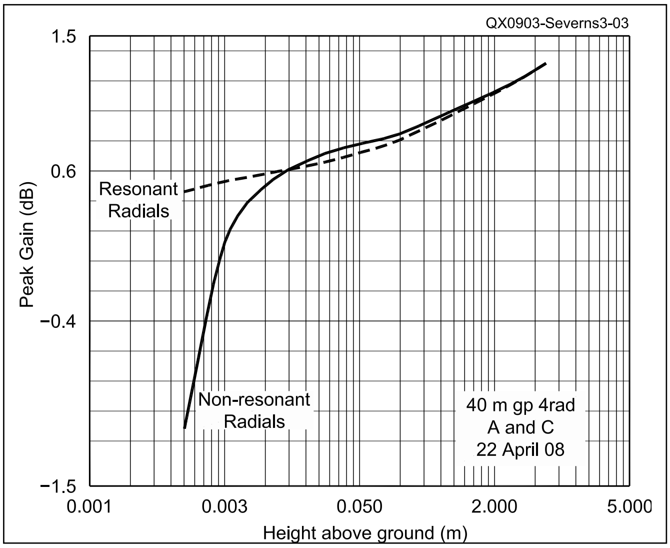

Figure 3— *NEC* prediction of peak gain versus radial height for 4 radials.

Table 1

Experimental Values for Feed Point Impedance.

Number of Radials	*Radial Height (Inches)*	*Z_i (Ω)*
64	0	39.7 – *j* 1.2
32	0	42.9 + *j* 2.1
16	0	56.1+ *j* 6.2
8	0	85.5 + *j* 8.0
4	0	137 + *j* 14.9
4	6	43 + *j* 6.4
4	12	40.6 + *j* 0.08
4	48	34.8 – *j* 9.7

Table 2

Current Distribution in the Radials When Elevated to 48 Inches.

Radial Number	*Relative Current (A)*
1	0.235
2	0.271
3	0.247
4	0.247

Table 3

Gain Comparisons With One and Four Radials.

Radial Number (dB)	*Azimuth (Degrees)*	*Peak Gain (dBi)*	*Elevation (Degrees)*	*Delta from 4 Radial Case (dB)*	*Delta from 4 Radial Case*
4	0	+1.15	21.4	0	X
4	0	–1.12	8	X	0
1	0	+0.38	22.8	–0.77	X
1	0	–2.04	8	X	–0.92
1	90	–0.36	22.8	–1.51	X
1	90	–2.79	8	X	–1.67
1	180	–2.19	19.8	–3.34	X
1	180	–4.59	8	X	–3.47

Experimental Results

The observed variations in |S21| as radial number and height were changed are shown in Figures 1 and 2. In the graphs, |S21| has been normalized (0 dB) to the value for 4 radials lying on the ground surface, so that the graphs show the *improvement* in dB as either the radial height or number were increased.

From Figure 1, we see that with 64 radials lying on the ground surface |S21| = +5.8 dB. From Figure 2, for four radials and the base of the antenna elevated 48 inches above ground, we see that |S21| = +5.9 dB. The difference is only 0.1 dB. For any practical purpose, the two ground systems are equivalent, which is in accord with *NEC* predictions.

The large change in |S21| with radial number in Figure 1, which is predicted by *NEC*, is mostly the result of additional loss caused by resonances present in sparse radial screens. This effect was discussed in Part 2 of this series.[2]

The very large change between 0 inches and 6 inches in elevation shown in Figure 2 was also predicted by *NEC*. A typical prediction from *NEC* of peak gain versus radial height is shown in Figure 3.

The data line labeled "nonresonant radials" corresponds to constant length (33 feet) radials, which are not shortened to compensate for the effect of the soil characteristics on the radial resonant frequency. The other data line shows the effect of adjusting the length of the radials to re-resonate the antenna as the height above ground is altered.

Typical measured values for Z_i during the experiment are given in Table 1.

The measured current division between the radials, normalized to 1 A of total base current, is given in Table 2.

The radial current asymmetry was small

enough to not have any meaningful effect on |S21|. Earlier measurements on radial systems with 64 radials, lying on the ground surface, also showed little asymmetry in the current division.

Effect Of Radial Current Division Asymmetry

As shown by Weber, it is very common for the current division between the radials in an elevated radial system to be unequal, especially if there are only a few radials.[3] This asymmetry can affect the radiation pattern, and may possibly explain some of the variation in earlier comparisons. For this reason, I was very careful to minimize that asymmetry.

To get worst case estimates of the effect of current asymmetry on the pattern, I did some *NEC* modeling. Two models, the first with four radials and the second with one radial, are shown in Figures 4 and 5.

Comparisons between the peak gain and the gain at 8° elevation are given in Table 3. I have shown the peak gain and its associated angle, and also the gain at 8°, which corresponds to the angle to the test range receive antenna. As Table 3 shows, that makes little difference in the magnitude of the pattern distortion.

The worst case signal reduction from the four-radial case is at the 180° azimuth, with one radial. If all the current were in the radial pointing away from the receive antenna, the signal strength would be a bit over –3 dB from the case where all four radials had the same current. I examined models with 1, 2, 3 and 4 radials, but the worst case is for a single radial. That is hardly surprising.

Segment 2

The "standard" elevated radial scheme has four or more radials elevated above ground by 4 feet to 10 feet, with the base of the vertical antenna also elevated so that the radial fan is essentially flat. For a variety of practical reasons, however, somewhat different radial configurations are often used and it is of some interest to see what effect these variations have on the performance of the antenna.

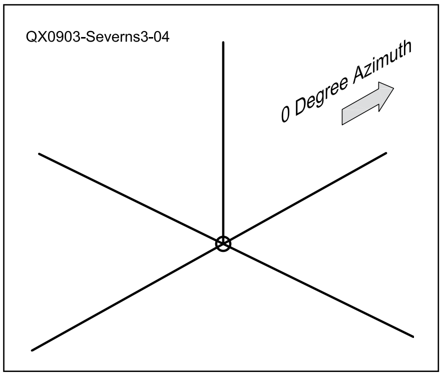

Figure 4 — Four elevated radials, 48 inches above 0.015/30 soil.

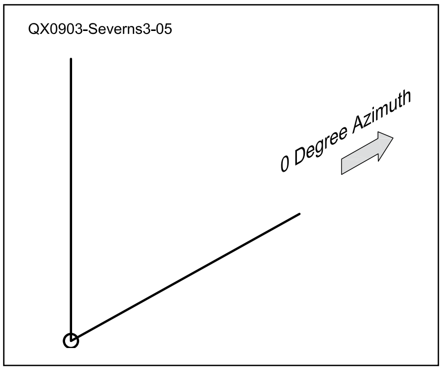

Figure 5 — One elevated radial, 48 inches above 0.015/30 soil.

Description of the Experiment

All the experimental runs were done with four 35 foot radials (except as noted), the length of the vertical set to 34 feet and a test frequency of 7.2 MHz. The antenna, including radials, was isolated from ground with a common mode choke (balun) in the feed line. Measurements of |S21| and Z_i were made for each test configuration.

The following configurations were tested:

1) Radials and antenna base elevated at 48 inches above ground.

2) The far end of the radials at 48 inches sloping down to the base at ground level.

3) A "gullwing" configuration as suggested by Dean Straw, N6BV, and later extensively modeled by Al Christman, K3LC.[4] The base was at ground level with the radials rising from the base at a 45° angle until they reached 48 inches above ground. The rest of the radials beyond this point were kept at 48 inches above ground from this point out to the far ends.

4) Radial lengths cut to 17.5 feet (≈ ⅛-wavelength). Radial and base height set to 48 inches. Antenna resonated with a 2.2 μH inductor.

5) For reference purposes, a run was made with the radials lying on the ground surface and the antenna base at ground level. This was done as a check because segment one of this experiment had been done earlier and ground conditions at the site had changed. Also a slightly different radial length was used (35 feet versus 33.5 feet).

Experimental results

The experimental results are summarized in Table 4. The values for |S21| were normalized by setting the value for configuration 1 to 0 dB and the rest to the difference between them and configuration 1. A line of data from an earlier experiment has been added for comparison. (See Note 2.)

As a check, for configuration 1, the current division between the radials was measured. Those results are summarized in Table 5.

Comments on Segment Two

The most important observation is that radically changing the radial geometry does not seem to have a major impact on performance (|S21|).

Table 5

Measured current division between radials, normalized to 1A total base current.

Radial number	*Normalized Current (A)*
1	0.249
2	0.269
3	0.260
4	0.221

Table 4

Experimental Results

Configuration Number	*|S21| Normalized (dB)*	*Z_i (Ω)*	*Test Configuration*
1	0	39 + *j* 6.3	Base and 4 radials elevated at 48 inches
2	–0.47	36 + *j* 6.2	Base at ground level, radials ends at 48 inches
3	–0.65	29 – *j* 11	Gullwing, base at ground level radial ends at 48 inches
4	–0.36	39 + *j* 0.9	Base and radials at 48 inches radial length = 17.5 feet 2.2 μH inductor to resonate
5	–5.19	132 + *j* 22	Base and radials on ground surface, four 35 foot radials
Earlier Experiment (See Part 2)	–1.79	51 + *j* 1	Base and radials on ground surface, Four 21 Foot Radials

Cutting the radial lengths in half (configuration 4) and adding a small loading inductor reduced the gain by only –0.4 dB. The use of shorter radials has been suggested by Weber (see Note 3) and Moxon to either make the radial screen footprint smaller and/or reduce asymmetry in the current division between radials.[5]

I was surprised to see that the gain reduction for the gullwing configuration (configuration 3) was slightly worse than simply running the radials straight up to the far end (configuration 2). It may have something to do with the higher feed point impedance in configuration 2. In the case of the gullwing, the radials rise close to the vertical element, resulting in some cancellation between the vertical element and radial currents depressing the feed-point resistance. We see a similar effect in top-loaded antennas with sloping wires. From the standpoint of keeping the radials above head height for safety reasons, the gullwing is more attractive than just sloping up the radials.

It would seem that anything done to get the radial wires away from ground makes a great improvement as you can see from configuration 5, where the radials are lying directly on the ground surface. Even using shorter, resonant radials on the ground surface is not as effective as simply elevating the radials. Modeling and experimental work shows that you don't have to get very high to make a substantial improvement but greater heights are used for safety reasons to keep the radials above head height.

One thing missing from this experiment was the use of more than four radials. An earlier experiment which compared four elevated radials to eight in configuration 1, showed very little difference in $|S21|$ (about + 0.2 dB). The advantage of more radials is not so much improved efficiency but rather reduced chances for radial current asymmetry and a lower Q, which can improve the SWR match bandwidth.

Summary

The experiments seem to show that a few elevated radials can work well as a replacement for a large number of ground radials. The experiments also show that alternate elevated radial geometries can work nearly as well as the "standard" and may have practical advantages.

Certainly this set of experiments does *not* completely resolve the debate regarding a large number of ground radials versus a few elevated radials, but it does lend some credence to the *NEC* modeling. To finally resolve these questions we need other experimenters to repeat these and/or similar experiments. We should also recognize that these experiments were done at a particular site, which has good to very-good soil. Repeating the tests over other soils, particularly poor ones, would be of considerable interest. It is at least possible that larger differences between the ground surface and elevated radials might be seen.

Even if these tests and *NEC* modeling are in fact correct and a few elevated radials can, in principle, provide equivalent performance to a large number of ground radials, this does not mean we should dash out and convert all our ground systems to four elevated radials. Because of their much higher Q, elevated radial systems are subject to a number of ills. They are very sensitive to details of layout, soil characteristics, nearby conductors, coupling to feed lines, and other factors. Like ground radials, elevated radial systems work much better if the screen is not too sparse: in other words, try to use 12 or more radials. You will be much happier.

Notes

[1] Rudy Severns, N6LF, "Experimental Determination of Ground System Performance for HF Verticals, Part 1," *QEX,* Jan/Feb 09, pp 21 - 25.

[2] Rudy Severns, N6LF, "Experimental Determination of Ground System Performance for HF Verticals, Part 2," *QEX* Jan/Feb 09, pp 48 - 52.

[3] Dick Weber, K5IU, "Optimum Elevated Radial Vertical Antennas," *Communication Quarterly*, Spring 1997, pp 9 - 27.

[4] R. Dean Straw, N6BV, "Antennas Here Are Some Verticals On The Beach," *ARRL Antenna Compendium, Vol 6*, pp 216 - 225.

[5] L. Moxon, G6XN, "Ground Planes, Radial Systems and Asymmetric Dipoles," *ARRL Antenna Compendium Vol 3*, pp 19- 27.

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