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Experimental Determination of Ground System Performance for HF Verticals Part 5 160 Meter Vertical Ground System

How much will the signal strength and feed point impedance change as radials are added?

This experiment was actually the first of the series of experiments on ground systems that have been the subject of this series of articles. The experiment involved measuring the change in signal strength as radials are added to the ground system of a vertical antenna, beginning with four radials and going up to 64 radials. The intent was to determine the additional gain in signal for each doubling of radial number, and to determine the point of vanishing returns. In addition, the changes in feed point impedance due to changing radial number were of interest.

While the results of this initial experiment were quite interesting, a more important result was an appreciation of the difficulties of making these measurements accurately. This experience led to a modification in the test procedure and a shift to 40 m verticals, which have been described earlier.

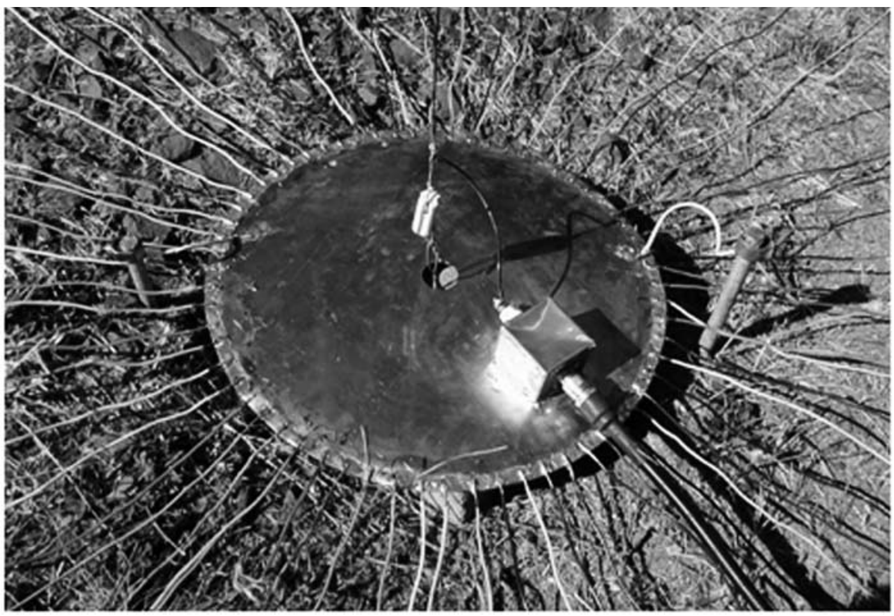

Figure 1 — This photo shows the antenna base with radials attached.

Test Antenna Description

The test frequency for this experiment was 1.800 to 2.000 MHz. The vertical was 125 feet of no. 12 AWG insulated copper wire suspended from a Dacron line hung between two 150 foot poles.

At the base of the antenna there was an 18 inch diameter copper disk, as shown in Figure 1. The inner ends of the radials and the shield of the coax feed line were attached to the disk. There were also two galvanized ⅝ inch × 4 foot ground stakes connected to the disk. The radials were 130 foot lengths of no. 12 insulated (THHW) wire lying on the ground surface. Radials were put down in the sequence of 4, 8, 16, 32 and 64.

The terrain around the antenna was not flat, but rather on a narrow ridge about 40 to 50 feet wide. The result is that many of the radials were in part bent down at about a 45° angle as they ran down the steep slope on either side. Along the ridge, however, the radials are more or less level.

The test antenna was erected 700 feet to the east of my house with a 50 foot deep gully in between. The ridge is in a Douglas fir forest with 100 plus foot trees within 50 feet of the test antenna at some points. The radial system ran along the ridge and also down the sides of the ridge into the forest.

To excite the test antenna, between the house and the antenna there was a 700 foot length of 1⅝ inch coax, with an additional 75 feet of ½ inch coax. Both were Andrews heliax.

Measurement Equipment

The signal source was a Yaesu FT1000MP transceiver with two Bird Model 43 wattmeters on the output (forward and reflected power). The wattmeters were used to set the forward power to a constant 50 W and also to measure reflected power to calculate SWR. The SWR measurement is needed to correct for the power reflected from the antenna and not radiated. This correction was applied to the received signal amplitude.

The receiving antenna was a 10 foot vertical wire driven against a 4 foot ground stake, next to my house. The receiver was an HP3585A spectrum analyzer. The amplitude resolution was about ± 0.1 dB.

Base impedance measurements were made at the antenna using an N2PK vector network analyzer (VNA). The impedance measurements were accurate to better than 1%.

The test procedure was very straightforward. For each number of radials, the FT1000MP output was adjusted to 50 W and received signal strength on the spectrum analyzer recorded along with the SWR for that measurement and the input impedance at the base of the antenna.

Test Results

Three complete runs were made to verify repeatability of the measurements. Each run included a complete stepping through the number of radials in the sequence, 4, 8, 16, 32 and 64. Typical received (and corrected for SWR) signal strengths versus radial number are given in Table 1. This data is graphed in Figure 2.

The data in Figure 2 has one obvious oddity. You would expect that the incremental difference as the radial numbers are doubled would be monotonically decreasing as the radial number rises. The step between 16 and 32 radials does not do this and it appears that the value for 16 radials is too small. This anomaly was noted during the experiment, however, and checked carefully as the radial count was redone three times. The anomaly was there in all three cases. I have no explanation for this other than the irregularity of

Table 1
Typical Test Data for Received Signal Strength with P_o = 50 W.

Number of Radials	*Corrected Signal Strength*	*Relative Signal Strength*
4	–30.1 dBm	0.0 dBm
8	–29.3 dBm	0.8 dBm
16	–28.9 dBm	1.2 dBm
32	–28.0 dBm	2.1 dBm
64	–27.7 dBm	2.4 dBm

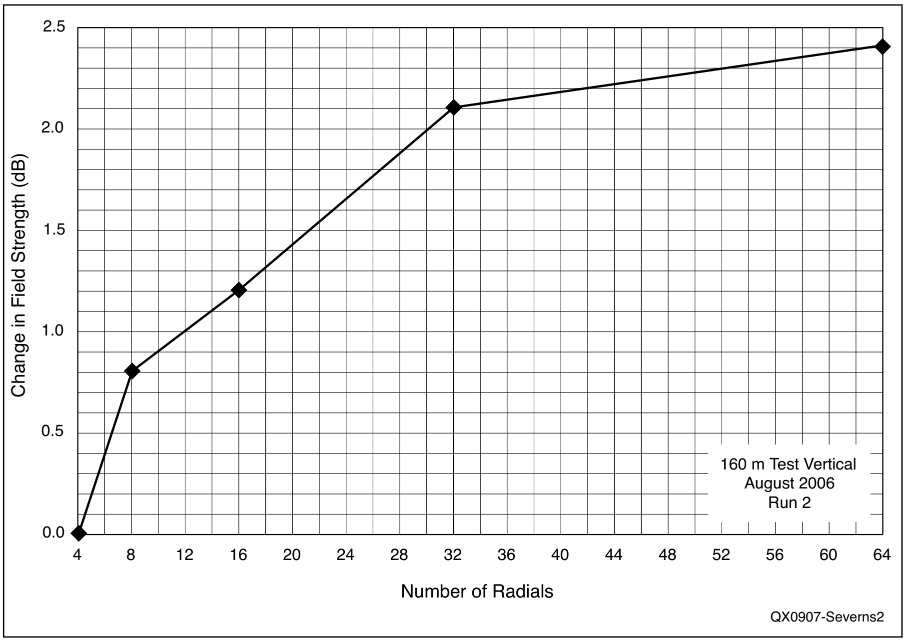

Figure 2 — Here is a graph of the typical signal strength change with radial number.

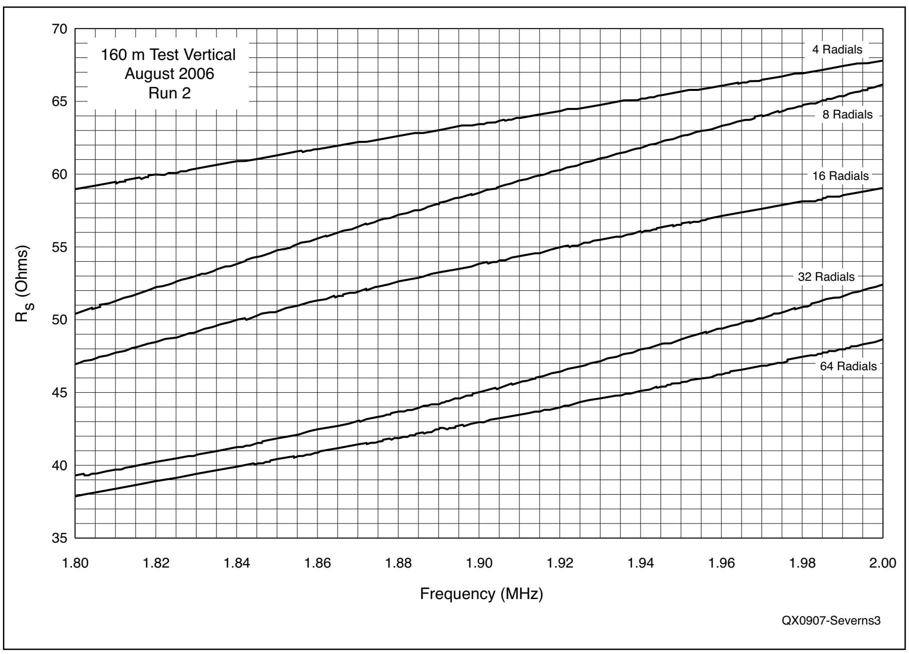

Figure 3— This graph gives the resistive part of the base impedance over the 160 m band for different radial numbers.

the site, which forced the radial layout to be far from flat or level. Later experiments with more regular radial systems on other antennas all showed the expected monotonic decrease in improvement with increasing radial number.

In any case, it's pretty clear that 32 radials do a good job and by 64 radials you are well into the region of vanishing returns. I certainly could not justify doubling the radial count to 128!

The results of feed-point impedance measurements are given in Figures 3, 4 and 5.

As discussed in Part 2 of this series, we would expect the resonant frequency to vary with the number of radials, due to the shift in radial resonance because of soil loading. The 40 m experimental work was done over an essentially flat pasture and the resonant frequency change was regular and monotonic. The gross irregularity of the ground surface in this earlier experiment, however, resulted in the erratic frequency changes shown in Figure 5. This problem was a primary reason for moving the experimental site from the narrow ridge to a pasture. Unfortunately, the 150 foot support poles were not available in the pasture so it was necessary to change the experimental frequency to 40 m to make the vertical height manageable.

Summary

This initial experiment helped me to understand the problems inherent in making accurate comparisons between different ground systems. I had to change the site, the test frequency, the test instrumentation and the test methodology to get to the point where I could have confidence in the test results and draw conclusions from them.

This experiment was by no means a failure, however. We can see that the change in signal strength is very much in line with what we saw in the 40 m work. It also supports the conclusion that we should use at least 16 radials, but when we use more than 32 radials we are definitely reaching the point of vanishing returns. For most amateur installations the Standard Broadcast ground system of one hundred twenty 0.4-wavelength radials could not be justified by any useful increase in signal strength.

Rudy Severns, N6LF, was first licensed as WN7WAG in 1954 and has held an Extra class license since 1959. He is a consultant in the design of power electronics, magnetic components and power-conversion equipment. Rudy holds a BSE degree from the University of California at Los Angeles. He is the author of two books and over 80 technical papers. Rudy is an ARRL Member, and also an IEEE Fellow.

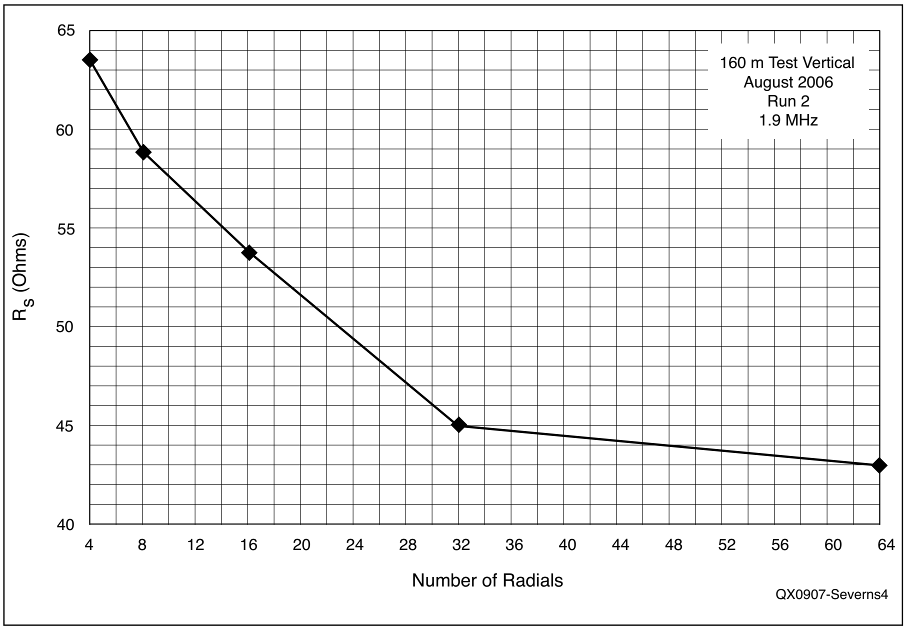

Figure 4 —This graph shows the base resistive component versus radial number at 1.9 MHz.

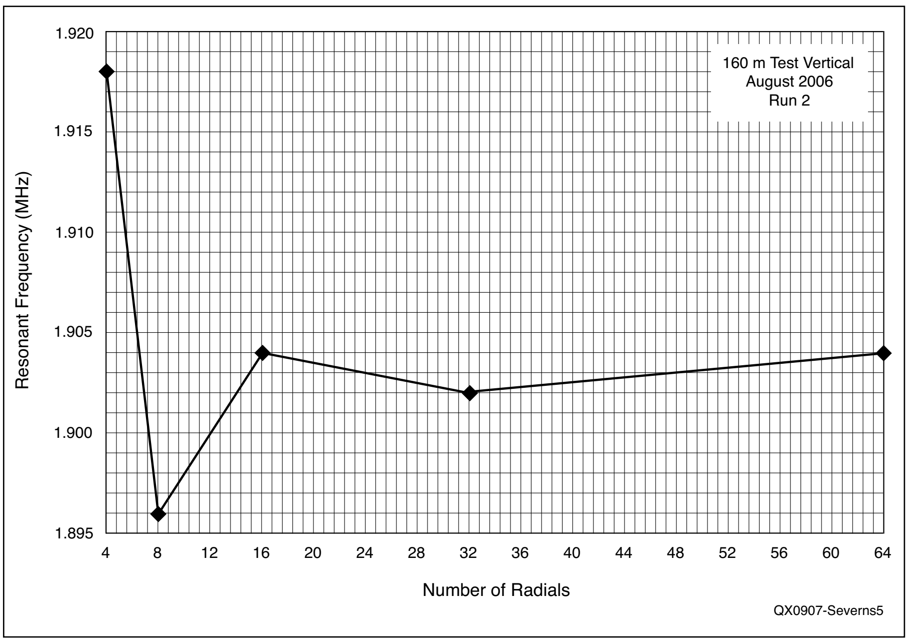

Figure 5 — This graph shows the antenna resonant frequency for different numbers of radials.