Is There A Relationship Between Vertical Height

And Optimum Radial Length?

Rudy Severns N6LF

November 2009

The suggestion that the length of radials in a vertical ground system is related to the height of the vertical, has long been part of amateur antenna lore. The idea is that with a 1/4-wave antenna you use 1/-4wave radials and with an 1/8-wave vertical 1/8-wave radials, etc. While you can make arguments why this might be, I thought it would be interesting to conduct a modeling study using NEC (EZNEC Pro 5.0 w/NEC 4) to see if I could find any support for this idea.

I modeled 1/4-wave and 1/8-wave verticals at 1.8 MHz over average soil (0.005 S/m, Er=13). The radial lengths were stepped in the sequence 1/8, 1/4, 3/8, 1/2-wavelength. The number of radials was stepped in the sequence 4, 8, 16, 32, 64 and 128. At each point I recorded the average gain (Ga) and used this as a measure of relative efficiency between different radial configurations. The radials were buried 3" below the ground surface.

The results are shown in figures 1 and 2. Note that the vertical axis is "improvement" in dB when going from four 1/8-wave radials to more and/or longer radials. The gain for four 1/8-wave radials was used as the reference and set to 0 dB. I did this because it nicely illustrates what you might "gain" by adding more wire, in different ways, to the radial fan.

 Note that the solid lines represent constant radial numbers of different lengths. The dashed lines connect points of common total radial wire length: 1, 2, 4, 8 and 16 wavelengths. For example, 4 radials 1/2-wave long represent a wire total of 2-wavelengths.   Eight 1/4-wave and sixteen 1/8-wave radials also total 2-wavelengths, etc.   16 wavelengths at 1.8 MHz is almost 9,000' of wire, which is a substantial ground system (64 1/4-wave radials).

These graphs show that how you add wire to the radial system matters as well as how much wire you add. As we can see from the graphs when only a few radials are used (4 to 8 radials), making them longer is waste. You gain little or nothing. In fact as was shown in my QEX article[1] you can actually lose in the case of ground surface radials. I am by no means the first to look into optimum radial lengths, Stanley[2], Sommer[3] and Christman[4] have all written on this subject but most of that work was for 1/4-wave verticals.
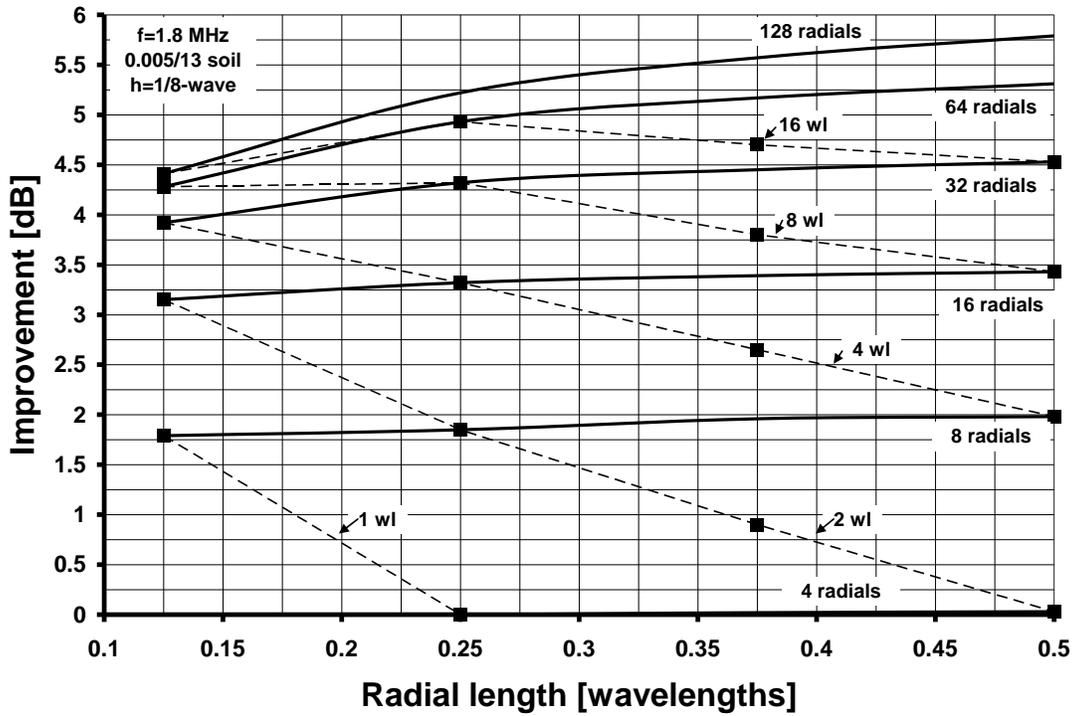
Figure 1, Signal improvement for various radial configurations: 1/8-wave vertical.
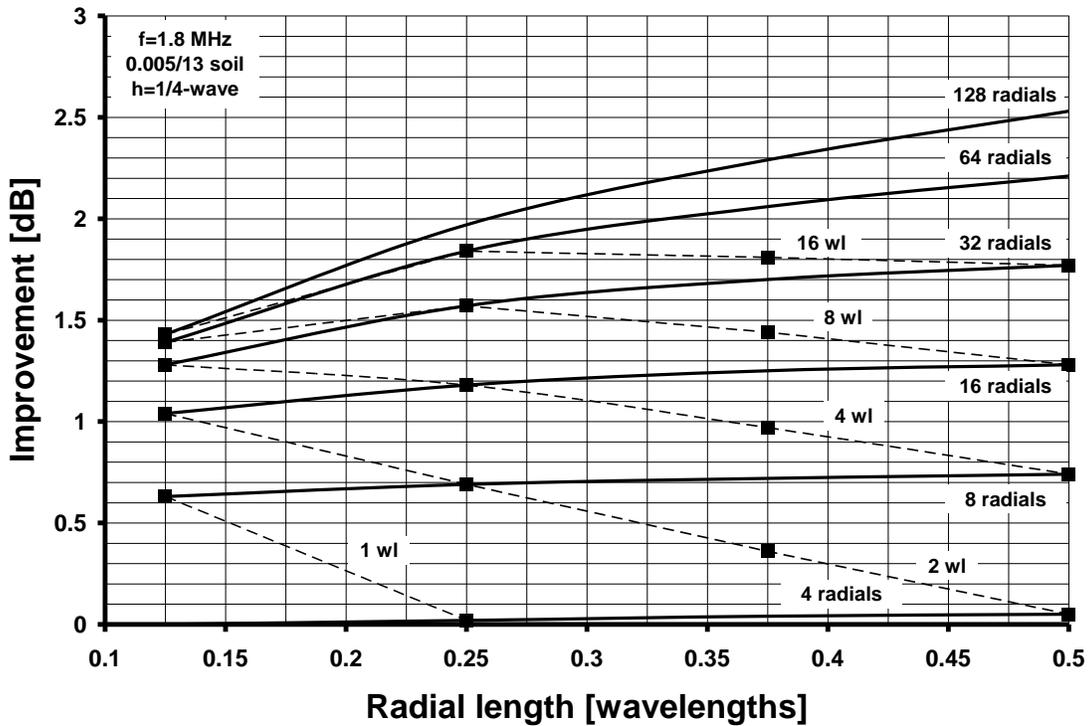

Figure 2, signal improvement for various radial combinations: 1/4-wave vertical.

Referring to figure 1 (the 1/8-wave vertical), if your total wire length is limited to four wavelengths, the gain improvement goes from 2 dB with 8 radials to 3.3 dB with 16 radials and 3.9 dB with 32 radials. Obviously you're much better off to using thirty two 1/8-wave radials as apposed to a smaller number of longer radials. When you increase the wire length to 8 wavelengths then it's a wash whether you use either thirty two 1/4-wave or sixty four 1/8-wave radials. The choice becomes one of convenience in laying out the radial field. If you don't have room for the 1/4-wave radials then the larger number of 1/8-wave radials will work just as well. When you go up to 16 wavelengths of wire then sixty four 1/4-wave radials will give you about 0.6 dB improvement over 128 1/8-wave radials.

When we look at the gain improvement in figure 2 (the 1/4-wave vertical), we see similar behavior except that when we are using 8 wavelengths of wire there is a clear advantage to go from 1/8-wave to 1/4-wave radial lengths. 1/4-wave radials also work best when 16 wavelengths of wire are available. If we go up to 32 wavelengths of wire (about 18,000'!) then radial lengths of 3/8-wavelength are best.

These graphs shed some light on a long standing rule of thumb: "the radials should be the same length as the height of the vertical". In the case of the 1/8-wave vertical this seems to be true up to at least 8 wavelengths of total radial wire. Beyond this, longer radials become a more effective use of the wire. In the case of the 1/4-wave vertical, for small amounts of wire, 1/8-wave radials are best but as we make more wire available the 1/4-wave radials are superior. The break point in radial number where you shift from 1/8-wave to 1/4-wave lengths is lower for the 1/4-wave vertical than the 1/8-wave vertical.

The physics of this seem fairly clear. Once you have greatly reduced the losses near the base of the antenna, adding more close in copper doesn't buy much. At that point it's time to put the copper further out and reduce more distant losses, which may be small but are still significant. The difference in break point (in terms of radial number) between the two antennas stems from differences in the field intensities around the two antennas. For the same power, the fields near the base of the 1/8-wave vertical will be much higher than those for the 1/4-wave vertical[5] so we need to put more effort into reducing the close-in power losses. This means more radials close in.

Summary

From this brief study it would appear that the rule of thumb has some validity, at least until we go to 16 or more wavelengths of wire. Keep in mind that the numbers will probably change somewhat for different soil characteristics but I think the general trends will be similar because you still have a large difference in field

intensity near the base of the vertical as you vary the height so you still have to work harder close the base to reduce losses with shorter antennas.

References

[1] R. Severns, N6LF, Experimental Determination of Ground System Performance - Part 2, QEX magazine, January/February 2009, pp. 48-52

[2] J. Stanley, "Optimum Ground Systems for Vertical Antennas," *QST*, Dec 1976

[3] R. Sommer, N4UU, "Optimum Radial Ground Systems", QST August 2003, pp. 39-43

[4] Al Christman, K3LC, "Maximum-Gain Radial Ground Systems For Vertical Antennas", NCJ magazine, March/April 2004, pp. 5-10

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