Rudy Severns, N6LF

PO Box 589, Cottage Grove, OR 97424; n6lf@arrl.net

Experimental Determination of Ground System Performance for HF Verticals Part 6 Ground Systems for Multiband Verticals

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

The first five parts of this series have focused on ground systems for a single-band vertical (mostly on 40 m).[1, 2, 3, 4, 5] This part of the series will address multiband radial systems, and give us an opportunity to see if the performance equivalence shown earlier between a large number of radials lying on the ground and a few elevated radials will hold with a multiband radial system.

The experiments were performed in two phases. The first was for radials lying on the ground and the second was for elevated radials. These represent two typical scenarios for amateurs: in other words. "Do I put the antenna in the back yard or up on the roof?" These are quite different arrangements, so the discussion is divided into two parts, beginning with the radials lying on the ground surface and then moving on to elevated radials.

The Test Antenna

For this series of tests I used a SteppIR III vertical antenna. The SteppIR has the advantage that its height can be adjusted to be resonant anywhere between 40 m and 6 m. The height adjustment is motorized and controlled remotely, so it is very convenient for tests on multiple bands.

[1]Notes appear on page 24.

Test Frequencies

Most of the measurements were taken at spot frequencies of 7.2, 14.2, 21.2 or 28.5 MHz. I did make a limited number of measurements across each band, however, and some of those results will be discussed.

Radial System Configurations

For these experiments I made up four sets of thirty two ¼ λ radials, one set for each band (40, 20, 15 and 10 m). The radial lengths are given in Table 1 along with the corresponding free space ¼ λ. As is the usual practice, the radials are a few percent shorter than the free space ¼ λ. The radials were fabricated from AWG no. 18 stranded, insulated wire.

Table 1
Description of Radial Lengths

Frequency (MHz)	*Free-Space ¼ λ (Feet) / (Inches)*	*Radial Length (Feet)*
7.2	34.2 / 410	33
14.2	17.3 / 208	16.8
21.2	11.6 / 139	11.3
28.5	8.63 / 104	8.4

Table 2
Total Length of Wire in Each Configuration.

Configuration	*C1*	*C2 and C8*	*C3*	*C4*	*C5*	*C6*	*C7*
Total Wire (ft)	2240	280	560	1056	528	264	132

Table 3
Transmission Gain (S21) in dB for Each Configuration Relative to C2 (0 dB).

Frequency (MHz)	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
7.2	+0.9	0.0	+0.2	+0.9	+0.4	+0.1	–3.2
14.2	+0.8	0.0	+0.3	+1.0	+0.5	–0.6	–1.8
21.2	+0.3	0.0	+0.3	+0.8	+0.2	–1.1	–2.6
28.5	–0.6	0.0	0.0	+0.4	–0.5	–1.3	–3.8

During the experiments I used several different configurations:

C1) Sets of 32 single-band radials, one set at a time. In this way I had an optimized ¼ λ vertical over a ground system of thirty two ¼ λ radials on each band. These antennas were then measured individually on the appropriate single band.

C2) Four ¼ λ radials on each band (16 total radials), connected *all at the same time*.

C3) A repeat of C2 except using eight radials for each band (32 total radials) .

C4) Thirty two 33 foot radials.

C5) Sixteen 33 foot radials.

C6) Eight 33 foot radials.

C7) Four 33 foot radials.

C8) For some elevated radial tests, I used four ¼ λ radials on each band, *one set of radials at a time*. The set of four was chosen for the particular band.

C1 and C8 were used for comparison purposes in that they represent a monoband antenna on each band. Obviously with a multiband antenna you would not run out to the antenna and change the radials whenever you changed bands! But this can give us feeling for any compromise in going from monoband to multiband verticals.

C2 represents the most common multiband ground system in general use both for elevated and ground surface radial systems, and so it was an obvious choice. I could have chosen many other possible combinations but those I did choose are at least reasonable. In particular I wanted to show that a few long radials (C6 and C7) don't work very well whether on the ground or elevated. Table 2 shows the total length of wire in each configuration.

Radials Lying on the Ground

The experimental results for radials lying on the ground are shown in Tables 3, 4 and 5. In Table 3 the values for S21 are in dB *relative* to the measured S21 value for C2 (0 dB). This was done to make it easier to compare each configuration to the de facto standard (C2).

The results for C7 show the same problem when used with a multiband vertical as shown earlier for a single band vertical — the ground loss is very high. Increasing the radial number from 4 to 32 (from C7 to C4) shows improvement.

C2 is our "standard" ground system (at least in practice) and we can see that its performance in comparison to the other configurations is quite good. It is true that individual sets of 32 radials on each band (C1) are somewhat better (except on 10 m, for which I have no explanation!) but the compromise is less than 1 dB. Even though C2 has only four radials cut for 40 m, the other twelve shorter radials seem to take up most of the slack, and we do not see the very poor performance that four radials by themselves displayed. By doubling the number of radials in C2 to eight for each band (C3), we see some improvement over C2, although it's only a fraction of a dB.

The best performer is C4, which is 0.4 to 1 dB better than C2, depending upon the band. C4, however, requires almost four times as much wire. If we cut the amount of wire in half (C5) we still have some improvement over C2 (with the exception of 10 m). C3 and C5, which use approximately the same amount of wire, behave very similarly.

In the final analysis it appears that the standard ground system (C2) works just

Figure 1 — Here is a view of the vertical with elevated radials.

Table 4
Physical Height of the Vertical for Each Frequency and Ground System Configuration.

Configuration Frequency (MHz) (Inches)	*Free Space ¼ λ (Inches)*	*C1 (Inches)*	*C2 (Inches)*	*C3 (Inches)*	*C4 (Inches)*	*C5 (Inches)*	*C6 (Inches)*	*C7*
7.2	410	391	406	394	391	386	371	369
14.2	208	201	202	201	198	199	200	201
21.2	139	137	137	137	137	137	137	138
28.5	104	103	102	102	102	102	103	104

Table 5
Measured Feed Point Impedances With the Vertical Height Adjusted for Resonance at the Test Frequency.

Configuration Frequency (MHz)	*C1 (Ohms)*	*C2 (Ohms)*	*C3 (Ohms)*	*C4 (Ohms)*	*C5 (Ohms)*	*C6 (Ohms)*	*C7 (Ohms)*
7.2	40.0	54.4	51.7	40.0	43.5	56.3	92.4
14.2	35.1	50.0	44.5	42.7	51.2	62.4	85.8
21.2	36.0	40.5	38.4	42.0	48.9	66.3	102.9
28.5	34.4	48.2	39.3	43.8	51.6	67.8	105.6

fine. You can add more wire and get some improvement but whether that improvement is worthwhile depends on the user.

As shown in Tables 4 and 5, there is some interaction between the tuning or resonant height of the vertical and the individual ground system configurations. We've seen this effect in earlier experiments. The heights shown are a bit of an approximation. The control unit display for the SteppIR gives the length of the tape (the vertical conductor) above a certain point but between that point and the actual ground radial plate there is approximately another 12 inches of wire. The wire is bent within the base housing so you can't assign an accurate additional length. I have used 12 inches as a reasonable approximation.

The measured feed point impedances are given in Table 5.

Elevated Radials

Having four sets of 32 radials (one set on each band) on hand from the ground surface tests I decided to use these same radials for the elevated radial tests. With the exception of C1and C3, I used the same configurations (C2, C4-C7) for the elevated tests. In the elevated radial testing, I used C8 in place of C1. Like C1, C8 is not practical, being a series of monoband verticals, but it serves as a reference against which to judge the compromise from using a multiband radial system. For comparisons between elevated and ground surface radials I have added a column (C1) to Tables 7 and 9 for the *on-the-ground* data associated with C1. We will use these when we discuss elevated versus ground radials.

A photograph of the experimental arrangement for the elevated radial tests is shown in Figure 1.

Because of the need for easy access to the radial base plate to make the many changes in radial configuration, I had to place the base of the antenna only 6 feet above ground.

Six feet high for the base is a bit low if we want to improve the feed point match by sloping the radials downward. In free space the input impedance of a 4-radial ground-plane antenna is about 22 Ω. As we bring the antenna closer to the ground, the impedance will vary around this number but in general is well below 50 Ω. Often the SWR will be high. One common means to improve the match is to slope the radials downward from the base, which raises the feed point impedance and lowers the SWR. Because of the limited height at the center, I could only lower the outer ends of the radials a small amount. Keep this in mind when we look at the measured impedances and SWR plots.

Experimental results are given in Tables 6, 7 and 8. A few of the columns have blanks. These are cases where that configuration, on that band, performed so poorly as to be unac-

Table 6
Transmission Gain (S21) in dB for Each Configuration Relative to C2 (0 dB).

Frequency (MHz)	*C2 (dB)*	*C4 (dB)*	*C5 (dB)*	*C6 (dB)*	*C7 (dB)*	*C8 (dB)*
7.2	0.0	–-0.1	–0.2	–0.2	0.0	0.0
14.2	0.0	+0.2	–0.8	–4.0	—	+0.2
21.2	0.0	+0.4	+0.2	+0.2	—	+0.4
28.5	0.0	+1.1	+1.8	+0.7	—	+0.2

Table 7
Physical Height of the Vertical for Each Frequency and Configuration.

Configuration Frequency (MHz)	*Free Space ¼ λ (Inches)*	*C1 (Inches)*	*C2 (Inches)*	*C4 (Inches)*	*C5 (Inches)*	*C6 (Inches)*	*C7 (Inches)*	*C8 (Inches)*
7.2	410	391	403	397	397	400	403	403
14.2	208	201	208	190	180	150	—	208
21.2	139	137	143	142	143	145	—	142
28.5	104	103	104	100	97	88	—	104

Table 8
Measured Feed Point Impedances with the Vertical Height Adjusted for Resonance.

Configuration Frequency (MHz)	*C2 (Ohms)*	*C4 (Ohms)*	*C5 (Ohms)*	*C6 (Ohms)*	*C7 (Ohms)*	*C8 (Ohms)*
7.2	43.4	42	41.0	42.1	43.0	43.0
14.2	34.2	38.9	41.1	83.9	—	33.9
21.2	36.8	52.3	49.5	48.4	—	31.4
28.5	23.9	34.8	38.3	73.2	—	24.5

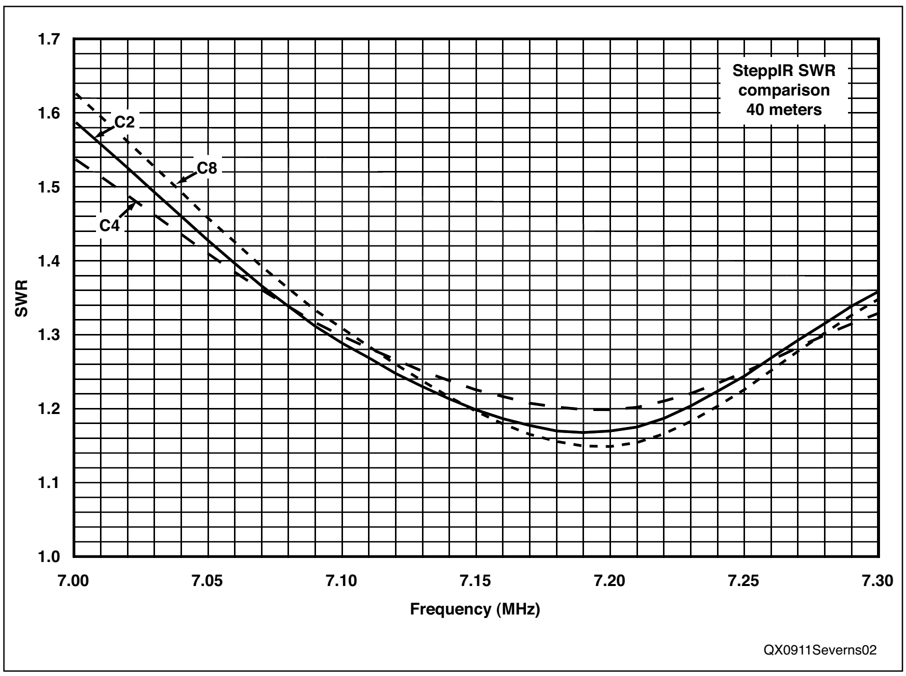

Figure 2 — Feed point SWR comparison on 40 m.

ceptable and I didn't see any point in recording that information.

From the data in Table 6, the standard multiband radial system (C2) appears to work very nearly as well as C4 and it takes only a quarter as much wire! The only band on which C4 appears to have a significant advantage is 10 m. C2 is also very close to C8 so there is very little compromise from the monoband case. As we move to fewer long radials (C5-C7) we see there is an immediate problem on 20 m, where the gain starts to fall quickly. From Table 7 we see that on 20 m the resonant height of the vertical starts to change radically as we go to fewer long radials, so clearly there is some funny business going on. This is related to the fact that ¼ λ radials on 40 m are close to ½ λ long on 20 m. Except on 20 m, C5 and C6 seem to be okay on 15 and 10 m, but by the time we get to C7 (four 33 foot radials) the performance was so poor I haven't even entered the data. The four long radials don't even work well on 15 m, where they are close to ¾ λ long.

From a loss point of view there appears to be little advantage to using anything other than the standard four radials cut for each band (C2). There is, however, the question if there is any matching (SWR) improvement from using more wire — for example C4 instead of C2. Figures 2 through 5 show a comparison of the feed point SWR between C2, C4 and C8 on the four bands.

On 40 m the differences are insignificant. On the higher bands we see little difference between C2 and C8. C2 is behaving pretty much as we would expect. However, C4 does seem to offer some improvement above 40 m. It is especially noticeable on 15 m, where the 32 radials are all near ¾ λ resonance. From some of my earlier work I was not surprised that increasing the number of radials beyond four did not give much improvement in S21, but I was expecting to see much flatter SWR curves. This just doesn't seem to happen on 40 m but does appear on 15 m with ¾ λ radials.

We should keep in mind that the feed point impedances and associated SWR will be affected by the height above ground, which in this case is very low. For well

Modifying the Ground Radial Connections on the SteppIR

Before conducting the experiments, I modified the ground radial connection on the standard SteppIR and also made up a special feed line choke that would have an impedance greater than 1000 Ω on all bands.

As the SteppIR comes from the manufacturer, it has a single no. 12 brass machine screw to which the ground radials can be attached. I felt this was not adequate and certainly not very convenient for the many radial changes necessary during the experiments. I changed the single brass no. 12 screw to a pair of ¼-20 machine screws spaced about 6 inches apart, as shown in Figure 1A.

I then fabricated an aluminum disk with fifteen ¼-20 bolts with wing-nuts around its perimeter. The disk was attached to the base of the SteppIR housing as shown in Figure 2A.

For all the measurements in the experiments, but particularly for the elevated radial measurements, I wanted to have a common mode choke (balun) in the feed line and the cabling at the base of the antenna. The choke I used is shown in Figure 3A. The choke has 6 turns of RG8X coaxial cable wound on two stacked type 43 cores (Fair-Rite #2643803802, available from Mouser Electronics). Also shown in the picture is the probe from the HP4815A vector impedance meter used for impedance measurements. The measured shunt impedance was between 2 and 3 kΩ from 7 through 30 MHz.

Figure 4A shows both the chokes installed at the base of the antenna.

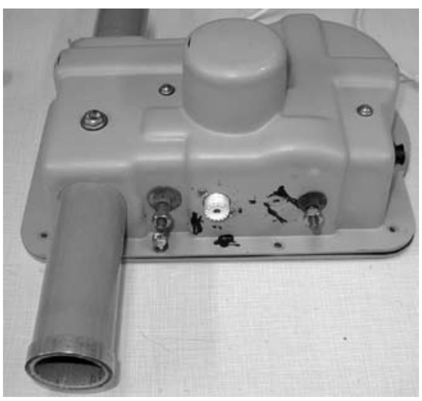

Figure 1A — Modified radial attachment scheme for the SteppIR.

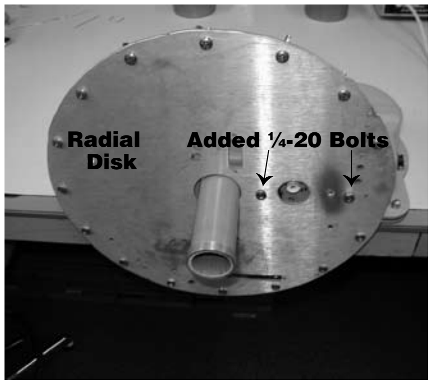

Figure 2A — SteppIR with radial disk attached.

Figure 3A — Common mode choke for the feed line.

Figure 4A — Chokes installed in the feed line and control cables at the base of the antenna.

elevated radials, where the slope can be adjusted to provide a better match, the results may be much better than shown here.

Elevated Versus Ground Radials

Another key question is "How do the elevated radial systems compare to a large number of radials on the ground on each band?" Table 9 makes that comparison using the results from this series of experiments. C1 is used as the reference (0.0 dB).

C1 uses radials lying on the ground surface and C2, C4 and C8 are elevated. When we compare the signals for C1 to those for C8, which is a direct comparison between four elevated radials against 32 ground surface radials, one band at a time, we see only small differences: four elevated radials seem to perform much the same as large numbers of ground surface radials. This is in keeping with what we saw in Part 3, only now extended to bands from 40 through 10 meters.

C4 (which is thirty two elevated 33 foot radials) is also only marginally different from C1 and C2 except on 10 m, where the difference is 1.4 dB. Considering it has four times the wire, I doubt it's justified.

Some Final Comments

In summary, I don't see any compelling reason to use more than four radials on each band for a multiband vertical. The "standard" system (C2) does in fact seem to work well. If you want to lay out or hang up more wire, you can get some small improvement but generally the maximum improvement seems to be on the order of 1 dB or less, although the improvement might be somewhat higher over poorer soil than mine. In a way, this was a bit of a disappointment. It would have been nice to discover some magic new ground system for multiband verticals, but that was not to be. All I've really accomplished is to show that the old standard works just fine, and it appears that a few elevated radials can work as well as a large number of on-the-ground radials! Be careful, however! As I pointed out earlier in the series, elevated monoband radial systems with only a few radials are very susceptible to local effects that can cause unequal radial currents, which can degrade performance.

Keep in mind when comparing the data in this part with some of the data reported in earlier parts of this series, that this set of measurements were made in mid-summer when the temperature had been 85° and 108° F over the preceding month. The soil will have dried out considerably compared to that for most of the earlier experiments. This can cause the impedance and S21 measurements to vary substantially between seemingly identical experiments. This is why I emphasized in Part 1 the need to do all com-

Table 9
Transmission Gain (S21) in dB for Each Configuration Relative to C1 (0 dB).

Frequency (MHz)	*C1 (dB)*	*C2 (dB)*	*C4 (dB)*	*C8 (dB)*
7.2	0.0	+0.2	+0.1	+0.1
14.2	0.0	+0.1	+0.3	+0.3
21.2	0.0	–0.5	+0.4	–0.1
28.5	0.0	–0.3	+1.1	–0.1

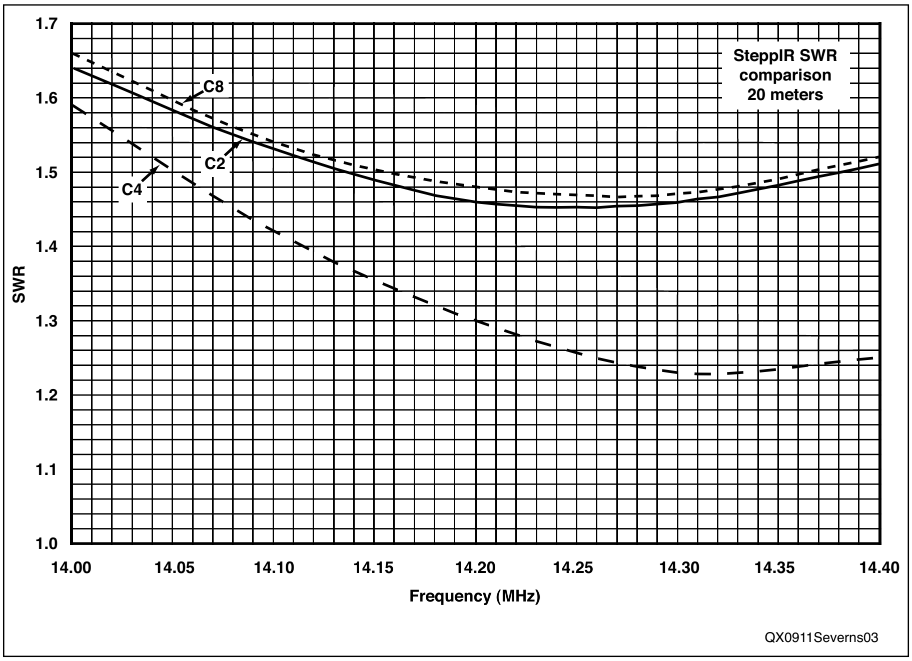

Figure 3 — Feed point SWR comparison on 20 m.

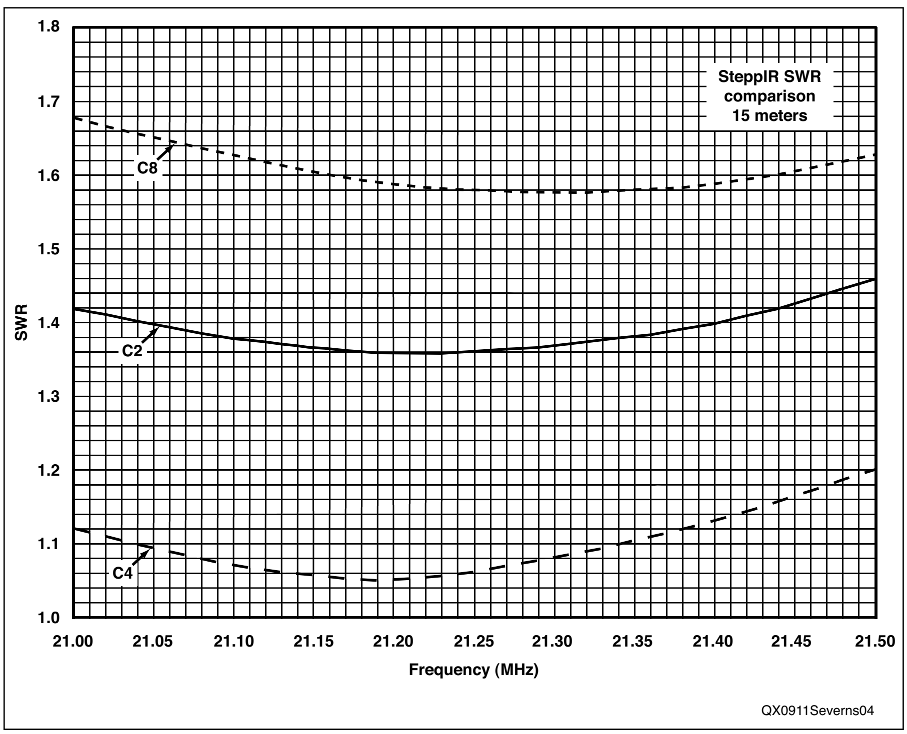

Figure 4 — Feed point SWR comparison on 15 m.

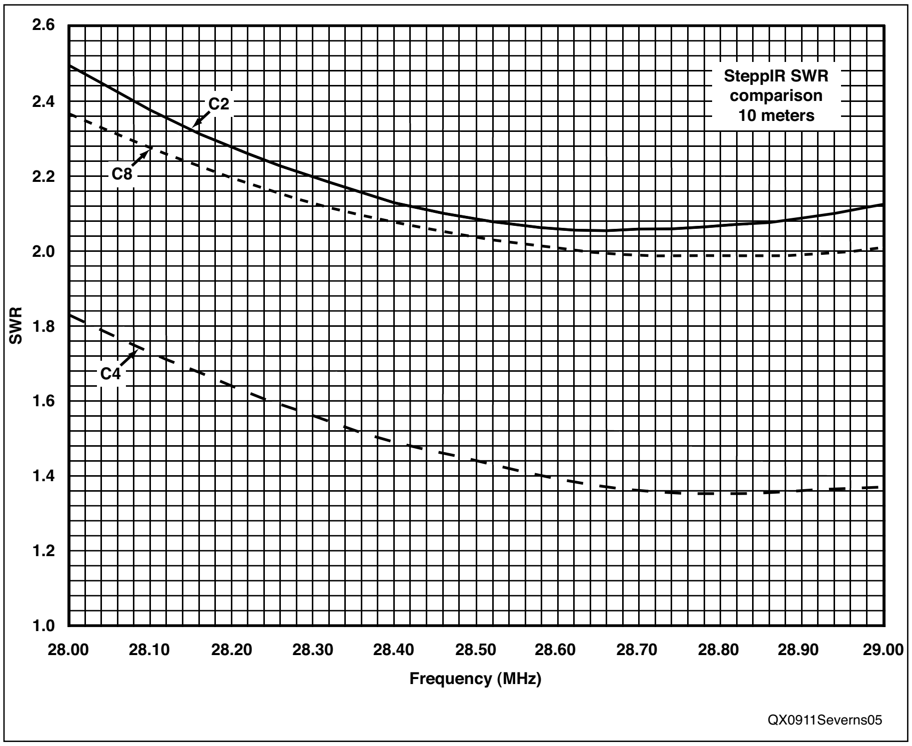

Figure 5 — Feed point SWR comparison on 10 m.

parison experiments in as short a time interval as possible. This sensitivity to changes in ground characteristics is also the reason I have emphasized that the specific numbers derived from these experiments must *not* be taken as absolutes. They are intended only to show the trends in performance between different ground systems. In addition, the frequency range in this series of tests goes much higher than those for the earlier experiments. The soil characteristics at a given location and time will vary with frequency.[6] In other words, your mileage may vary!

Despite the extensive experimental work reported in this series there will still be many unanswered questions regarding ground systems for verticals. Answers will have to be deferred to future experiments and computer modeling. Hopefully, others will be inclined to join in this effort making their own contributions. Of course not all questions have to be answered experimentally. As some of this work has indicated, *NEC* modeling can shed a lot of light on many questions, although in the end it's always more convincing if there is at least some experimental confirmation.

Acknowledgement

I would like to express my appreciation to Mike Mertel, K7IR, for the loan of the SteppIR vertical antenna used in these experiments. That antenna made the experiments much easier. I would also like to thank Mark Perrin, N7MQ, for his help at some key points in the experiments, when another hand was really helpful.

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.

Notes

[1]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance - Part 1," *QEX*, Jan/Feb 2009, pp 21-25.

[2]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance - Part 2," *QEX*, Jan/Feb 2009, pp 48-52.

[3]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance - Part 3," *QEX*, Mar/Apr 2009, pp 29-32.

[4]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance - Part 4," *QEX*, May/June 2009, pp 38-42.

[5]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance - Part 5," *QEX*, Jul/Aug 2009, pp 15-17.

[6]Rudy Severns, N6LF, "Measurement of Soil electrical Parameters at HF," *QEX*, Nov/Dec 2006, pp 3-9.

QEX