A Theoretical and Experimental Study of the Effects of Very Large Ground Screens on 20 meter Verticals

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INTRODUCTION:

It seems to be well-known in ham radio circles that the typical ham vertical antennas radiates equally poorly in all directions, as the saying goes. On the other hand, there have been numerous reports of spectacular performance of verticals over salt water when used by DXpeditions on the proverbial desert island. I have been curious for a long time about whether a salt water ground could be simulated by a sufficiently large and dense ground screen, and if so, what is "sufficient." I investigated this problem from three perspectives: analytical theory, computer simulations, and physical construction and measurement.

GOALS:

What I, as a radio amateur, wanted to know is what effects various ground schemes would have on my signal when working DX. That is, at the typical angle of arrival of DX, what the gain of the antenna would be. If this were pure science, not a hobby, it would be interesting to know both the angle and the antennas pattern. But the bottom line is whether a really ambitious ground screen system provides enough bang per buck to justify the effort to build it. I was looking for a consistent, substantial advantage, not just something that is slightly better once in a while.

ANALYTICAL THEORY:

I reviewed a bunch of papers from the 50's and 60's that pre-dated finite element computer analysis. In these papers, large ground screens were studied using nothing but Maxwell's equations and vector calculus. The consensus of these papers was that a very large ground screen, such as 50 to 100 wavelengths long, would be necessary to get a big improvement at low angles where the vertical was typically 10 dB down from perfect ground values. The papers in most cases didn't address the issue of how dense the radial screen had to be.

COMPUTER SIMULATIONS:

Jerry Burke at LLNL was nice enough to provide me with a special version of NEC that takes advantage of the circular symmetry of a monopole over a radial ground screen to drastically reduce the number of calculations needed for N identical radials. Basically, it just calculates the current for one radial and repeats it N times. This allowed me to simulate systems as large as 1000 radials 8 wavelengths long, which took only 1 ½ hours to run on a 150 MHz Pentium system. This showed that the predicted field strength was still improving with longer and more numerous radials, even at the 1000 radial 8 WL long mark. With that configuration, NEC predicted that FS was 1 to 2 dB down from a perfect ground down to an angle of 10 degrees. At 5 degrees, it was a lot better than a "small" radial system like the canonical 120 half wave radials, but still had a long way to go compared to a perfect ground. It seemed like for angles below 10 degrees, the size of the ground screen would have to grow to enormous proportions to have desert island properties. Probably beyond what I could even simulate, let alone build. However, I still had the hope that NEC might be in error because of the well known difficulties involving wires near ground. There was also the fact that I did not know the angle of arrival of typical DX signals, so there was uncertainty how to interpret the NEC results, even if they were without error.

EXPERIMENTAL METHOD:

A total of six antennas were built and tested. The procedure was to measure antennas in pairs while receiving DX signals, using an A/B switch located in the shack. The A and B antennas were mounted 800 feet apart to avoid mutual coupling. A control test was run initially with identical antennas at locations A and B to assure that there wasn't a detectable difference in ground conductivity, etc between the sites, which were both within a 20 acre pasture. The antennas were carefully matched, using matching transformers where necessary. The insertion losses of the transformers and the coax cables connecting the antennas were measured using a good signal generator and a thermistor type power meter. The antennas were then equalized with attenuators in the shack. An attenuator was used between the A/B switch and the receiver, to eliminate mismatch errors. While receiving a signal, the attenuator was varied if necessary to get equal signals from both antennas, as judged by both S-meter equivalency and by ear. Note that this procedure does not rely on the S-meter to be calibrated and the answer is in dB, not "S-units", whatever they are. Also note that absolute signal strength, not signal to noise ratio, was the criterion. This is why these tests should generalize by way of reciprocity to transmit mode. These tests were done on 20 meters during the summer of 1998 when signals from Europe and VK/ZL could be heard reliably on the west coast most nights.

DESCRIPTION OF ANTENNAS:

NOTE: ALL REFERENCES BELOW TO WAVELENGTHS REFER TO FREE SPACE WAVELENGTH, I.E. 20 METERS. This is to avoid any arguments about the velocity of propagation along radials laying on the ground, which the author does not claim is the same as in free space.

Antenna 1: A ground mounted ¼ wave vertical, with 32 radials, ¼ wave long, laying on top of the ground.

Antenna 2: A ground mounted ¼ wave vertical, with 32 radials, ¼ wave long, plus 60 radials 4 wavelengths long, laying on top of the ground. The 60 long radials were laid out over a 45 degree octant from 0 degrees (North) to 45 degrees (Northeast), which basically "points to Europe" from W6. The tips of the long radials were 3 feet apart.

Antenna 3: A ground mounted ½ wave vertical, with 4 radials 4 feet long. Matching to the vertical was done with an L/C step up circuit.

Antenna 4: Antenna as in #3, ground system as in #1.

Antenna 5: Antenna as in #3, ground system as in #2.

Antenna 6: Rotatable half-wave horizontal dipole, ½ wave high.

EXPERIMENTAL RESULTS:

Other than for exceptions noted below, ALL ANTENNAS HAD THE SAME PERFORMANCE, within a threshold of about 2 dB minimum detectable difference.

EXCEPTION 1: Antenna #5 had a 2 to 3 dB advantage from Europe, but not elsewhere.

EXCEPTION 2: Antenna #6 had a 5 to 10 dB advantage on short skip (W0 to W6, etc.)

Other interesting things to note are that on signals with severe QSB, the fading on two identical antennas 800 feet apart was not in unison, so diversity reception could be successfully applied. On local signals, there was a lot of polarization discrimination if the dipole was used to receive a vertically polarized signal or if the vertical was used to receive a signal from a Yagi. This held even 50 miles away over a range of mountains. Clearly, on skywave, signals must become circularly polarized since it didn't matter what the transmitting station was using for an antenna.

CONCLUSIONS:

The artificial ground plane failed to replicate the desert island QTH performance. This would seem to indicate that the angle of arrival of signals from Europe was very low, such as 3 to 5 degrees.

Evidentally, the ground screen was not big enough to work at these extreme low angles, yet it was so big as to be nearly impracticable. If the angle of arrival had been somewhat higher, it might have helped, but at higher angles, the horizontally polarized dipole at 30 feet high is better than even the desert island QTH. My heuristic explanation of what is going on with the ground screen is as follows: the signal initially propagates as a ground wave hugging the ground screen as well as a radial sky wave. When the ground wave signal reaches the edge of the ground plane, it diffracts from the discontinuity and reverses phase. This ground signal interferes with the sky wave in the same way as the signal reflected from the ground interferes with the sky wave from an elevated antenna. Therefore, the net result is that the antenna behaves as if it were a vertical dipole elevated above the ground at a height corresponding to the height of the sky wave at the ground screen radius. For example, for a take off angle of 5.9 degrees (a 10% grade), the sky wave is .4 WL high at the radius of 4 WL. Not surprisingly, a vertical dipole at .4 WL is no better than a horizontal one at .5 WL.

The ground screen did help with the ½ wave vertical because its center is ¼ wave above ground, and the reflection for a 5 degree takeoff angle occurs within the 4 WL radius. So with a small conventional ground screen, the ½ wave vertical has no gain over the ¼ wave vertical, but with the big ground screen, it attains the 2 dB theoretical gain that is has over a perfect ground plane.

WHAT’S NEXT AT N6RK:

Verticals (except on 160, 80, and maybe 40) are out. Rhombics also don’t look too promising because the pattern is much more narrow than for a Yagi of the same gain. We will probably try to get a four square for 80 going and some kind of vertical on 160.