The Case of Declining Beverage-on-Ground Performance

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Detailed modeling and measurements that validate the use of NEC help explain why over the course of two winter seasons the performance of the Beverage on the Ground (BOG) antenna dropped off dramatically as the antenna slowly sank into the ground.

In midsummer of 2013 I placed a 450 foot length of insulated wire in my pasture configured as a Beverage-on-the-Ground (BOG) receiving antenna. At the same time I erected a terminated loop receiving antenna — a triangle, 70 feet high by 30 feet on the base. I already had a 30 foot vertical working as a non-directional *E*-probe with an amplifier. Over the last 18 months I've been decoding WSPR transmissions — which provide S/N estimates — and comparing reports between the antennas in an attempt to quantify their relative performances.

Initially the BOG and the loop were clearly superior to the vertical, and throughout the 18 months the loop performance was very consistent. The BOG worked well at first. However, over time and especially during the two intervening winter wet seasons, I noticed the BOG signal amplitudes dropping off significantly (-15 dB) and the S/N improvement dropped to no better than the vertical. With the coming of the last summer's dry season the BOG improved somewhat but never really came back. This winter the BOG was not very useful. I checked the connections, feed lines and all associated hardware carefully but found no problems, so this rather radical decline in performance was a mystery!

Recently, I received an email from Al Christman, K3LC, relaying a question he received from Carl Luetzelschwab, K9LA, regarding the reliability of NEC modeling for wires close to, or on the surface, or buried in the soil. There has been some skepticism regarding the validity of NEC modeling in these situations. Over the years I've often compared my modeling predictions with finished antennas and generally found very good correlation. However, while modeling *E*-and *H*-fields for verticals close to the soil-air interface I saw some anomalies in the *H*-field calculations when using NEC4.1, which uses the GN2 ground code.

These problems have long been recognized but recently Jerry Burke modified the NEC code to NEC4.2 upgrading to GN3, improving modeling of the ground interaction. I've had a chance to try GN3 (incorporated into NEC4.2) and it did not generate the anomalies I'd seen with GN2. This prompted me to ask, "does NEC4.2 model antennas with wires close to and/or buried in soil well enough to explain why

the performance of my BOG was declining so badly?" To answer that question I felt I had to validate NEC4.2 modeling to my satisfaction before I could confidently move on to my BOG problem.

I decided to perform a series of field experiments to see how well NEC predictions would correlate with actual antennas having wires parallel to the soil at low heights or buried in the soil. I also wanted to investigate an antenna that employed a ground rod. Since my interest is in antennas for 80 m and 160 m, I used test frequencies ranging from 1 to 4 MHz. By no means do my examples cover all possibilities but they are representative. Here is what I found.

Modeling Software and Instrumentation

NEC solves for the currents on the wires. From these currents both the feed-point impedance and the radiation pattern are calculated. If the impedances from the NEC model agree with the values measured on the actual antenna over a wide range of frequencies you can be reasonably sure the modeling is reliable. In the case of my BOG it would also be helpful to see if NEC4.2 would predict the current distribution along the wire at a given frequency, for example 1.83 MHz.

For the modeling part of this experiment I used *EZNEC Pro4 v6*, courtesy of Roy Lewallen, W7EL.[1] That version of *EZNEC* uses NEC 4.2. I also used the latest version of *AutoEZ* from Dan Maguire, AC6LA.[2] *AutoEZ* is an Excel® spread sheet with macros that automate a wide range of modeling tasks using *EZNEC* as the engine. For impedance measurements I used a vector network analyzer (VNA), either the VNA2180 from W5BIG or a homebrew N2PK VNA. I've made it a point to display the raw measurements without any "corrections" to the data points. That is why you can see noise present on the graphs of VNA measurements at frequencies associated with my local broadcast stations and, in one case, coupling to nearby verticals. The soil electrical characteristics were calculated at the same frequencies as the impedance measurements. This ground data was then inserted into the model. *AutoEZ* makes it easy to blend this kind of data into a model.

The following discussion addresses only NEC4.2, since NEC2 does not allow buried wires and does not do a very good job when the wires are close to ground. It is very possible that GN3 was not required for all the comparisons. NEC4.1 might very well have returned very similar results. I didn't repeat the modeling with NEC4.1 (GN2).

Soil Surface

First let's clarify the nature of the ground surface. When modeling, we assume the air-ground interface is a distinct line with the properties of air above it and the soil below it. NEC in its present form cannot model a "transition" zone. It's important to recognize that with real antennas the soil-air interface is not smooth nor sharply defined. Unless carefully reworked, the soil surface will be lumpy with varying characteristics both vertically and horizontally. As we'll see later, the characteristics of an antenna close

to, or buried in, the soil are very sensitive to soil electrical characteristics so this "lumpiness" in the surface makes it difficult to get good correlation when modeling wires that are between one inch above and one inch below the surface. In effect there is no distinct soil-surface interface. What we do have in reality is a transition zone from air to soil, which we can model only approximately.

For example, in a pasture as you get closer to ground, first there is grass, then there is the body of grass plant, then there is the root system, and finally you reach actual soil. Even then you're still not home free. The moisture in the top few inches of soil varies quickly with rain and subsequent drying. If the antenna is installed in a forest, initially a surface wire will be lying on top of leaves or needles in various stages of decay, and other woody debris. In summer time this surface may be quite dry, so in effect the antenna is at a height of a few inches.

My experience, and that of others, as well as the modeling, show that this can provide a very good receiving antenna. However, with the arrival of fall, leaves and needles will drop down on the wire, burying it to some degree. Also it's likely that the forest floor will be quite wet or even frozen.

I had an interesting exchange with Don Johnson, N4DJ, about his work with BOG antennas in a forest. His results were very good, and he did not notice the severe degradation in performance that I had experienced. It appears that the degradation over time is highly variable and specific to a particular installation, so we want to be careful about drawing general conclusions. If you live in the desert you may be able to place a wire directly on the soil surface and have that remain relatively unchanged for an extended period of time.

I think it is important to reiterate that modeling a wire lying on the ground surface is a special problem. My test antennas #1, #2, and #3 were modeled with the assumption that the air-soil interface was distinct, not fuzzy, and that seems to have worked well. In my case, the BOG wire (test antenna #4) was placed on the surface of a pasture in the summer time when the grass had been mowed and was very dry. The soil also was very dry, so the wire was effectively 1 to 3 inches above the soil. But over the period of 18 months the wire was swallowed up by the weeds, and by this winter it was buried in wet sod and tall grass. There really is no way to model this transition layer between air and the actual soil. What I've done is to compare a BOG antenna one inch above the soil to a BOG antenna one inch below the soil. There was good agreement between modeling and experiment.

Test antenna #1

The first test antenna was a center-fed dipole. I chose a length of 300 feet because that included both series (odd half-wave multiples) and parallel (even half-wave multiples) resonances within the test frequency range. This presented a wide range of impedance values at the feed point, from a few tens of ohms to several thousand ohms. I varied the height above ground from 48 inches down to 1 inch in the sequence 48, 24, 12, 6, 3 and 1 inch. A common mode choke was used for isolation. The feed-point

impedance was measured with a VNA. The VNA calibration plane was directly at the antenna terminals. Soil electrical characteristics were measured concurrently. The details of the soil measurements are given in articles on soil electrical characterization. [3]

Figure 1 shows a view along the length of test antenna #1. The #17 AWG aluminum electric fence wire was supported on 5-foot fiberglass wands with plastic wire clips. The clips were moved up and down to adjust wire height. The wands were spaced 10 to 20 feet apart and the wire was anchored at the ends to steel fence posts that were more than 6 feet away from the ends of the wire. Multiple support points and significant wire tension kept the droop to less than a quarter of an inch. I used high quality insulators and non-conducting Dacron line at the wire ends, and a Budwig center connecter. Figure 2 shows the Budwig connector and common-mode choke at the feed point.

Another view of the center connector is shown in Figure 3, which also shows a measurement of the shunt capacitance (C_p) across the feed point introduced by the Budwig and the cable shield. The center wire of the cable connecting the fitting to the choke was open-circuited so only the capacitance of the fitting and the outside of the cable was included. Shunt capacitance C_p turned out to be about 6 pF, which was added to the model as a capacitive load in parallel with the source. In the 1 to 4 MHz range a shunt capacitance of 6 pF would not seem to matter but, as seen in Figure 4, when added to the model, significantly improved the correlation around the high impedance point.

Figure 5 shows the measured impedance of the common mode choke. While the choke impedance is more than 2 kΩ, at some frequencies the feed-point impedance was even higher. For this reason the graphs show some reduction in measured compared to predicted impedance at the high impedance points.

The measured and computed comparisons of test antenna #1 resistance and reactance are shown in Figures 6 through 17 for heights of 48, 24, 12, 6, 3 and 1 inch above the soil. Note that there are glitches in the VNA measured data around 1.2 to 1.6 MHz on many of the figures. These correspond to local radio station transmissions. These spurious signals are obvious and can be ignored.

NEC4.2 based calculations appear to do a very good job of matching measurements down to 1 inch above ground. I didn't go lower because the soil surface had variations of more than a half inch, and despite weed-whacking closely, there were still grass lumps under the antenna. The zero reactance measurements of Figure 18 show how the resonant frequencies, both series (odd half wave multiple) and parallel (even half wave multiple), vary with height.

Figure 18 illustrates the important point that the resonant frequency goes down in frequency as the antenna comes closer to ground, and that the change is relatively slow until you get to very low heights (less than 3 inches) at which point the change is rapid.

Test antenna #2

The second test antenna was a 40 foot dipole using #26 AWG insulated wire buried 1 inch below ground surface. I wanted to have both series and parallel resonances like I had with the 300 foot dipole but that wasn't possible over the 1 to 4 MHz range so I settled for a 40 foot length that was resonant at about 2.5 MHz. The length of test antenna #2 is 1/9 the length test antenna #1 but we still have a series resonance frequency comparable to the 300 foot above-ground dipole. This observation reinforces the message in Figure 18, that placing the antenna close to or in the soil drastically and rapidly decreases the resonant frequency. As shown in Figure 19, I cut a slot in the soil with a lawn edger. I then inserted the antenna and backfilled the slot with compacted dirt.

After inserting the wire into the slot but before backfilling it, I measured the impedance. The result was very different from the NEC-based calculation for a buried antenna, and instead behaved as though the antenna were lying on the surface. However, as soon as I backfilled the soil slot and re-measured the impedance, I obtained the results shown in Figures 20 and 21. The good agreement in Figures 20 and 21 between measurements and calculations indicates the NEC model provides reasonable predictions.

I tried both a 19-inch monopole probe and a 12-inch open wire line probe (OWL) to measure the soil characteristics.[3,4,5] The monopole probe gives a good estimate of the average soil characteristics from the surface down to three feet or so. The OWL probe, on the other hand, measures a cylinder of soil just 12 inches from the surface. Figures 22 and 23 illustrate the differences in measurements between the two probes in the same soil.

I felt the OWL data was more appropriate for a wire buried only 1 inch deep. OWL measured values yielded better correlation with modeled values.

Because soil measurements are not perfect, I wondered just how sensitive the model was to variations in the soil characteristics. I reran the VNA measurement of the buried dipole nine days later after it had rained. A comparison between the two measurements is shown in Figures 24 and 25. After the rain, soil moisture was higher, which increased significantly in both conductivity and permittivity, and lowered the resonant frequency from 2.4 to 2.2 MHz.

We can get a feeling for the sensitivity of the modeling to variations in soil electrical characteristics by taking a soil measurement and varying the values ±10% as shown in Figure 26. This example illustrates why good soil measurements are needed to get reasonable correlation, at least for antennas with wires close to or buried in soil.

The sensitivity of modeled resistance calculations is shown in Figure 27 for variations of the insulation relative dielectric constant, and in Figure 28 for insulation thickness. The choices for insulation thicknesses in Figure 28 were not random. The wire used for the antenna had an insulation thickness of

0.008 inches marked on the reel label, however my actual measurements, using a micrometer, of the total outer diameter minus the wire diameter revealed that the actual thickness was 0.009 inches. Using the measured value in the model improved the correlation as shown in Figure 28. Figures 24 though 28 illustrate the sensitivity of resistance and reactance of buried wires to different variables, such as the effect of rain, ground constants, insulation permittivity and insulation thickness.

Test antenna #3

I wanted to test an antenna that incorporated a ground rod, and one that would have a radiation resistance comparable to the loss resistance associated with a rod to get a feeling of how well ground rods are modeled. I have a pair of tall support poles so I simply suspended a 77 foot length of #26 AWG insulated wire from the midpoint of a Dacron line stretched between the poles directly over the ground stake shown in Figure 29. One of the rules for NEC modeling is that a source cannot be on a segment directly adjacent to a wire-size discontinuity. In this case that would be the ground stake to the #26 AWG wire connection. In the model, the source must be in the center of three consecutive segments of the same length and wire diameter. To meet those requirements I used 3-inch segments in the model and placed the source at the center of the second segment (at 4.5 inches), which matched the actual feed point configuration of the test antenna. Using concurrent soil measurements, I got the results shown in Figures 30 for the resistance, and Figure 31 for the reactance.

The overall agreement between measurements and calculations is good, and the resonant frequency is particularly close. The noise introduced into the VNA from local AM broadcast stations picked up by the tall vertical is also obvious. There were other antennas and a metal building within 150 feet of the test vertical, which also introduced some spurious resonances. Unfortunately there's not much I can about the local AM signals. Their bandwidths are all narrow so I fit a 3rd order polynomial trend line (R^2=0.987) into the VNA data, which pretty well filtered out the noise. The NEC calculation is a good fit to the trend line.

Test antenna #4

This entire exercise had been prompted by a mystery concerning the declining performance of a BOG, and by questions regarding the validity of NEC modeling of BOGs so, appropriately, my final test antenna was a BOG.

Using the 450' BOG already in place I measured the feed point impedance from 400 kHz to 4.4 MHz. I also measured the current amplitude and phase along the wire at 1.83 MHz. I added the current measurements as a further confirmation of the NEC modeling predictions, that is, the rapid exponential decrease in current with distance along the wire. Figures 32 shows the BOG in relation to a measuring tape alongside the wire to locate the sampling points. Figure 33 shows the instrumentation

position. Figure 34 shows the probe for picking up the antenna currents. Figure 35 shows the excitation point at the base, and a current sampling example. For the current measurements, the VNA was in the transmission mode where the antenna was excited at the feed point and the transmission gain (S21) was sampled at several points along the wire using the oscilloscope current probe shown in Figure 34. S21 is a surrogate for the current.

The antenna was modeled one inch below the soil. Modeling results and comparisons to the VNA measurements are shown in Figure 36 (resistance), Figure 37 (reactance) and Figure 38 (current amplitude). The impedance and current distribution graphs show good correlation between NEC and the real antenna despite the uncertainties in the ground surface transition zone.

The rapid exponential decay of the antenna current was a surprise, but the field measurements confirmed it. This goes a long way towards explaining why the antenna performance was so poor. Functionally it behaves more like a short radial than an antenna! Disconnecting the ground rod at the far end had no effect on either the current distribution or feed point impedance, which was no surprise since there was very little current at the far end of the antenna.

Next, I modeled the BOG with the antenna wire one inch above and one inch below the soil to approximately represent the changes from the time it was first installed to the present. The radiation patterns are compared in Figure 39.

I think antenna patterns of Figure 39 solves the initial mystery! The larger pattern with receive directivity factor (RDF) of 12 dB and peak gain *Gp* of -21.47 dB represents the initial condition of the antenna. The smaller pattern with an RDF of 6 dB and *Gp* of -37.4 dB is the present condition of the BOG. These patterns make it clear just how severely the performance was declining as the BOG gradually sank into the sod and soil through two winters. At the time of the measurements spring had arrived and the grass was growing rapidly. The pattern differences shown in Figure 39 agree well with S/N comparisons made over the past 18 months.

Insulated wire

One of the small mysteries was the observation that placing the dipole loosely in the ground slot — which was quite narrow — without packing it with soil had much less affect on the antenna impedances than when the soil was packed around it. One way to explore this is to model a buried dipole as if it were inside a hollow pipe. We can do this with NEC by setting the insulation parameters $\sigma=0$ and $\varepsilon_r=1$, that is, air insulation. We can then vary the radius of the insulation from 0.001 to 3 inches as shown in Figure 40.

What we see is that even a very thin layer of air around the wire will rapidly increase the resonant frequency. In effect, laying test antenna #2 directly into the soil slot resulted in a layer of air around the wire except at a few points where it was resting on the soil. This also affects test antenna #4, the BOG.

The vegetation had grown up gradually around the wire so that it was embedded in the weeds and sod with very little air gap. The same wire BOG centered within a small diameter plastic pipe would behave quite differently. Buried Beverages in plastic pipes?

Conclusions

In the four examples, correlation between measurement and modeling was excellent. These do not by any means represent all the possibilities but the antennas chosen cover a range of practical examples using very low or buried wires.

Based on this work I believe that if we use NEC4.2, and follow the NEC modeling guidelines closely, make sure the model is dimensionally as close as possible to the actual antenna, and make careful soil measurements, then NEC modeling will give reliable results. The practical limitations of NEC4.2 modeling are not due to computational shortcomings in the NEC code. What limits us is our knowledge of the details of the actual antennas and the associated soil characteristics and our ability to replicate these in a model.

As a practical matter we can never be perfect, but modeling should get us close. I think we can use NEC to compare elevated radials and buried radials, both insulated and non-insulated, with reliable results.

There are many other questions we can ask, like what happens when interlaced elevated radials are used in vertical arrays. I think that NEC should give reliable results. The results for Beverage antennas, both elevated and buried with resistor and ground rod terminations should also be reliable.

In the case of the BOG the news is bit ambiguous. NEC modeling demonstrates that the BOG antenna can work very well, and from my experience I agree. However, your results may vary. High conductivity soil, for example, may result in very low signal levels. If the BOG is slowly being covered by whatever grows around it or falls from the sky, you may experience significant degradation in performance over time. As always, buyer beware!

Acknowledgements

I express my sincere appreciation to both Roy, W7EL, and Dan, AC6LA, for the use of their latest software. Without these tools the study would have been impractical. My thanks to Don, N4DJ; Greg, W8WWV, and Carl, K9LA, for reading and helpful comments on draft versions of this article.

Photos courtesy of the author.

Rudy Severns, N6LF, was first licensed as WN7AWG in 1954. He is a retired electrical engineer, an IEEE Fellow and ARRL Life Member.

Notes

[1]Several versions of *EZNEC* antenna modeling software are available from developer Roy Lewallen, W7EL, at **www.eznec.com**.

[2]*AutoEZ* automates use of *EZNEC*, see **www.ac6la.com**.

[3]Rudy Severns, N6LF, "Experimental Determination of Ground System Performance for HF Verticals", *QEX,* in seven parts, Jan/Feb 2009 pp 21-25 and pp 48-52, Mar/Apr 2009 pp 29-32, May/Jun 2009 pp 38-42, Jul/Aug 2009 pp 1-3, Nov/Dec 2009 pp 19-24, Jan/Feb 2101 pp 18-19.

[4]Rudy Severns, N6LF, "An Experimental Look at Ground Systems for HF Verticals", *QST* Mar 2010 pp 30-33.

[5]Rudy Severns, N6LF, "A Closer Look at Vertical Antennas With Elevated Ground Systems", *QEX*, Part 1 Mar/Apr 2012 pp 32-44, Part 2 May/Jun 2012 pp 24-33.

Figure 1 — Test antenna #1.

Figure 3 — Shunt capacitance measurement of the center fitting.

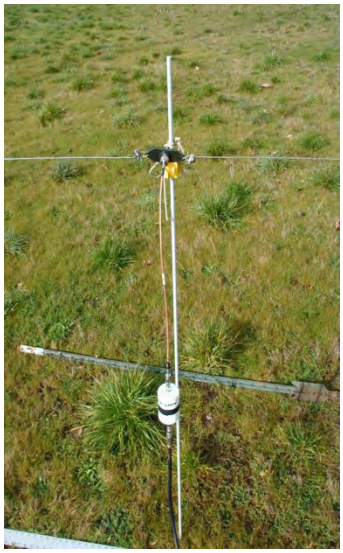

Figure 2 — Center connector, common mode choke and feed point support.

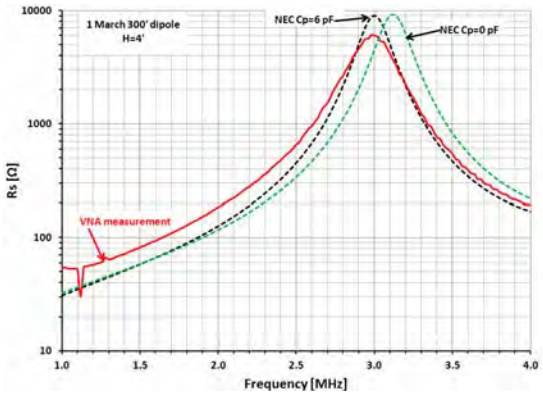

Figure 4 — Modeling with and without Cp.

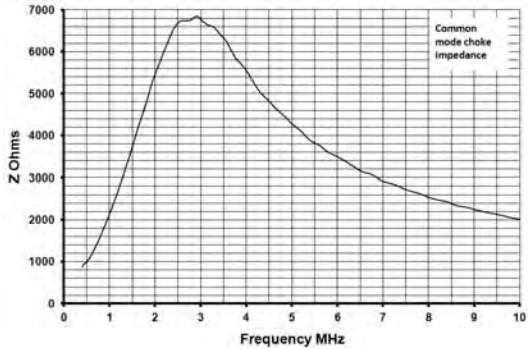

Figure 5 — Measured impedance of the common mode choke.

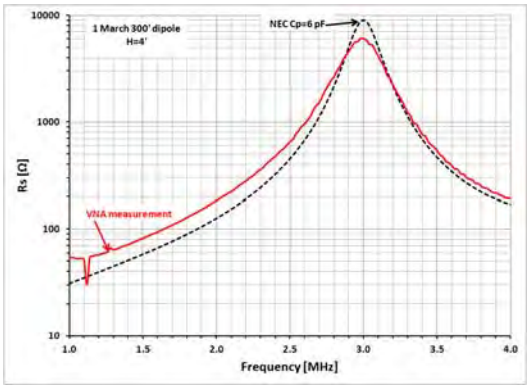

Figure 6 — Resistance measurement at antenna height of 48 inches.

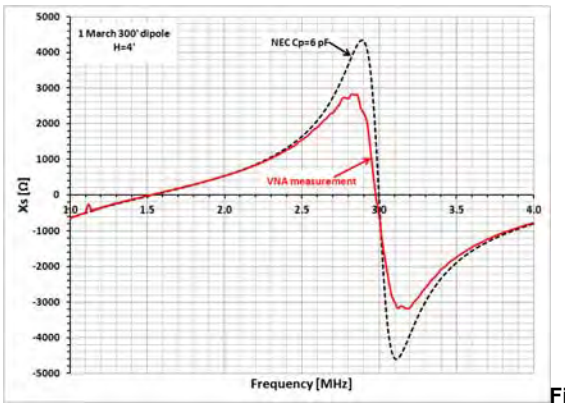

Figure 7 — Reactance measurement at antenna height of 48 inches.

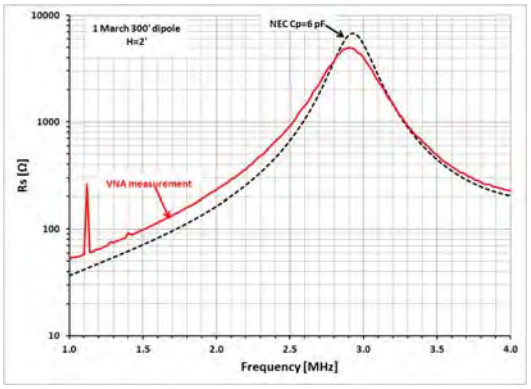

Figure 8 — Resistance measurement at antenna height of 24 inches.

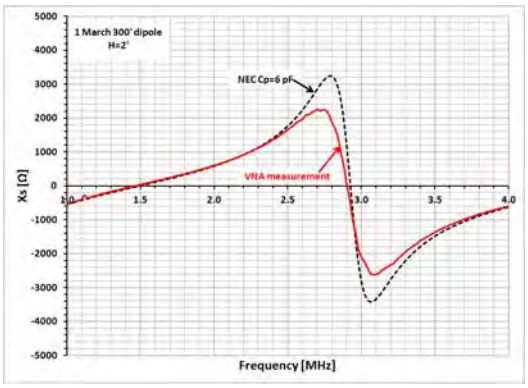

Figure 9 — Reactance measurement at antenna height of 24 inches.

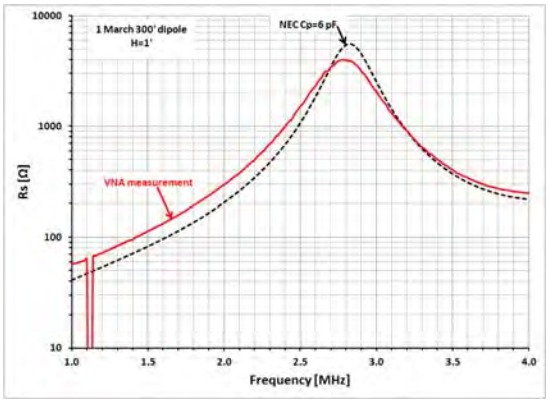

Figure 10 — Resistance measurement at antenna height of 12 inches.

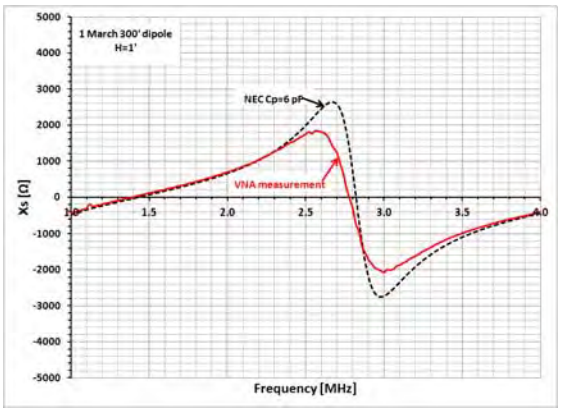

Figure 11 — Reactance measurement at antenna height of 12 inches.

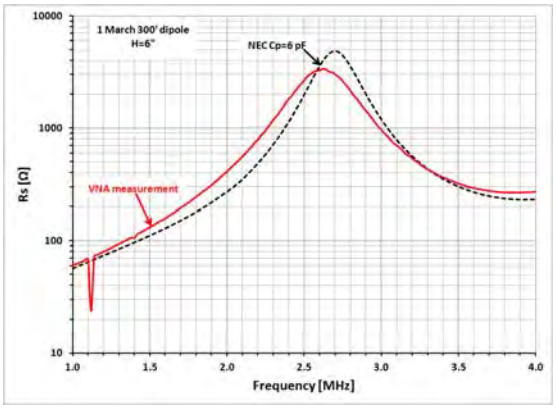

Figure 12 — Resistance measurement at antenna height of 6 inches.

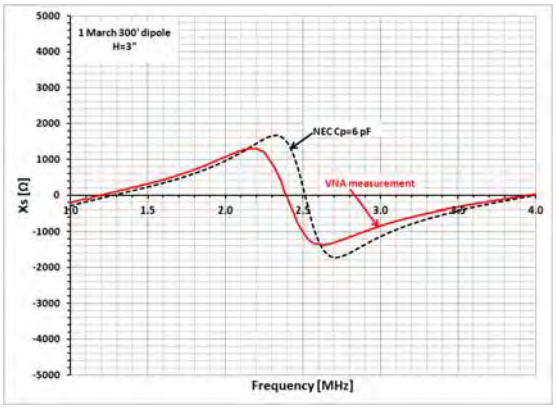

Figure 15 — Reactance measurement at antenna height of 3 inches.

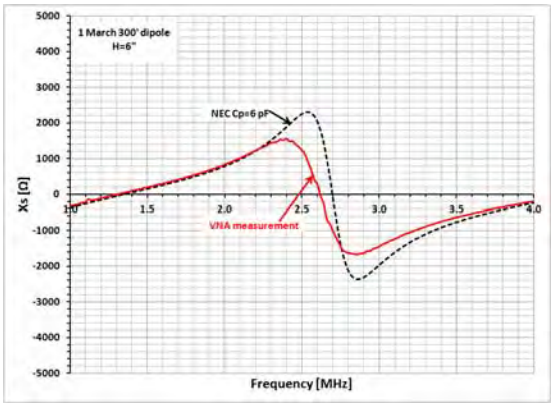

Figure 13 — Reactance measurement at antenna height of 6 inches.

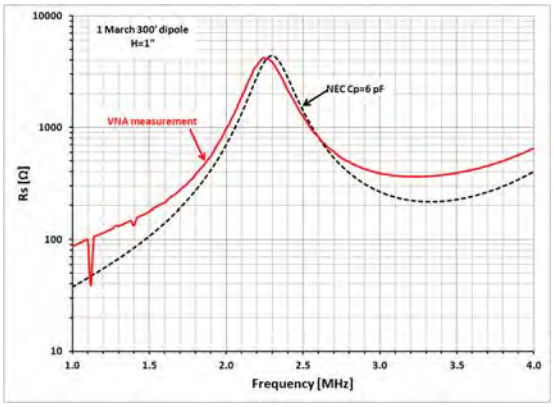

Figure 16 — Resistance measurement at antenna height of 1 inches.

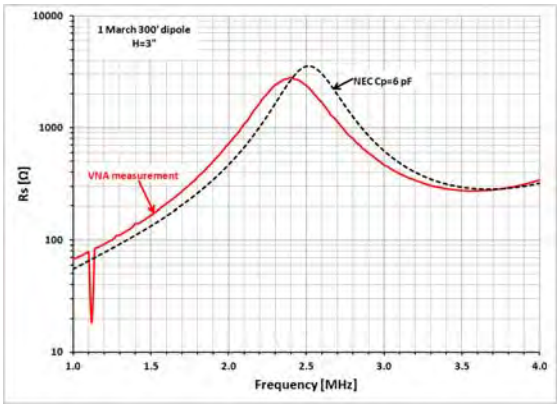

Figure 14 — Resistance measurement at antenna height of 3 inches.

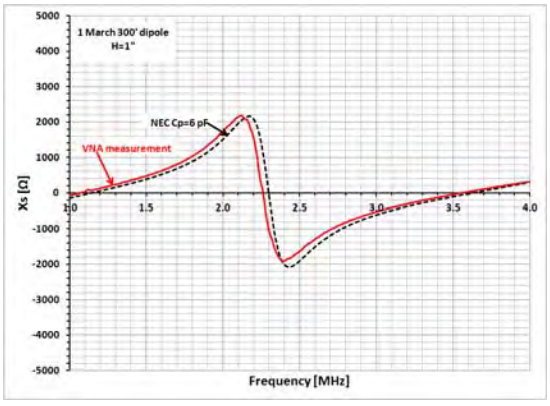

Figure 17 — Reactance measurement at antenna height of 1 inches.

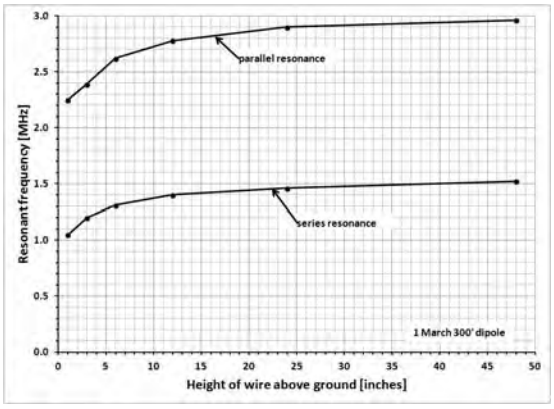

Figure 18 — Resonance variation with height for the 300 foot dipole.

Figure 19 — Cutting a slot in the soil for the 40 foot buried dipole.

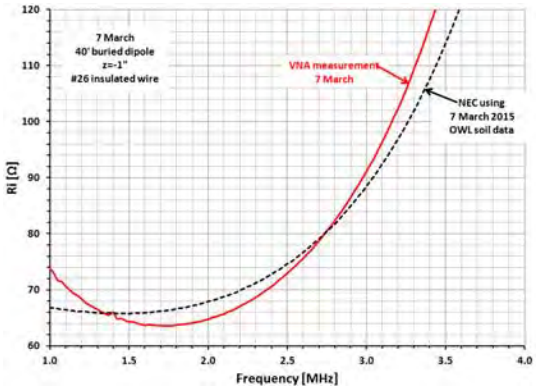

Figure 20 — Resistance measurement of the 40 foot dipole buried 1 inch.

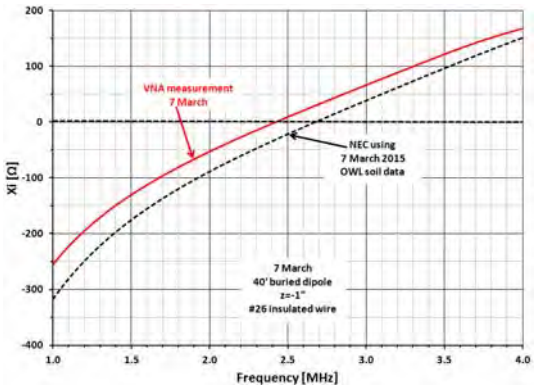

Figure 21 — Reactance measurement of the 40 foot dipole buried 1 inch.

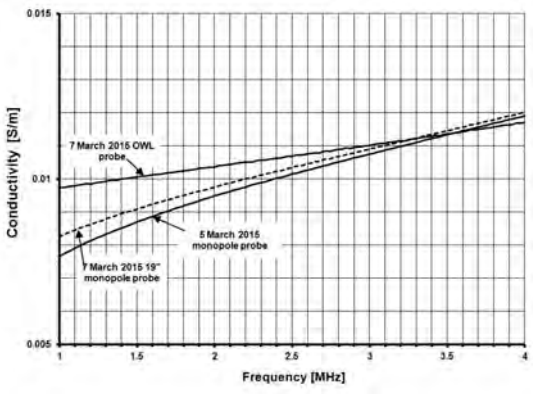

Figure 22 — Soil conductivity measurements.

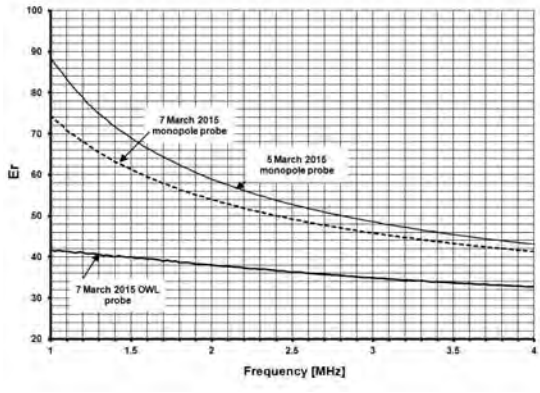

Figure 23 — Soil relative permittivity measurements.

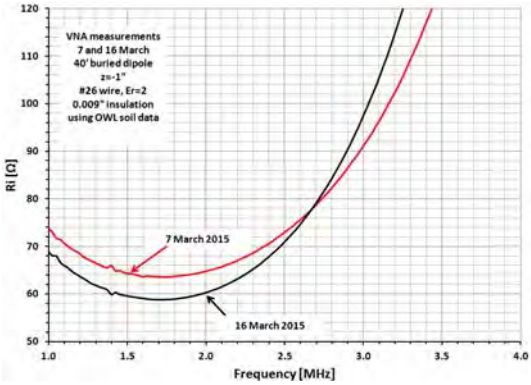

Figure 24 — Resistance measurement of the buried 40 foot dipole on March 7, and on March 16 following rain.

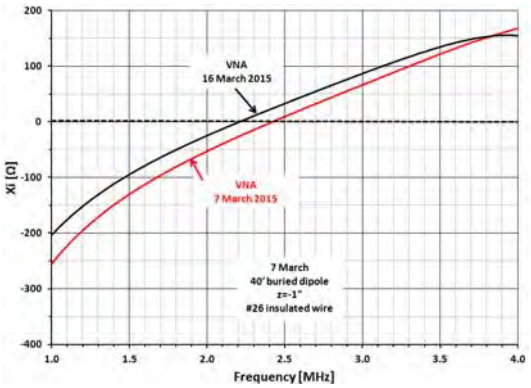

Figure 25 — Reactance measurement of the buried 40 foot dipole on March 7, and on March 16 following rain.

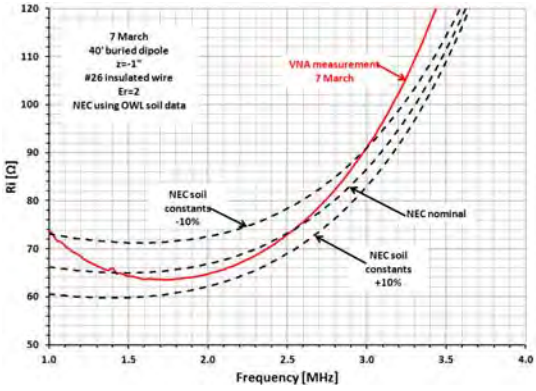

Figure 26 — Variations in modeled resistance for different ground constants.

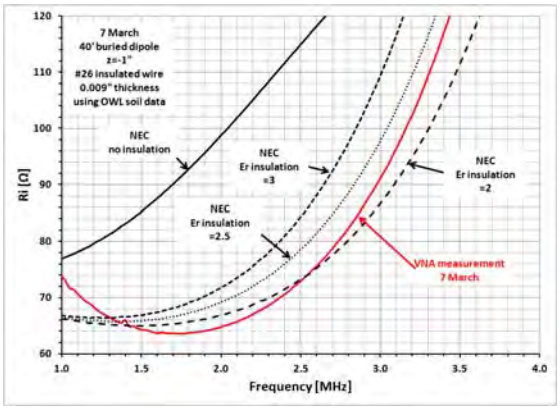

Figure 27 — Effect of wire insulation relative dielectric constant.

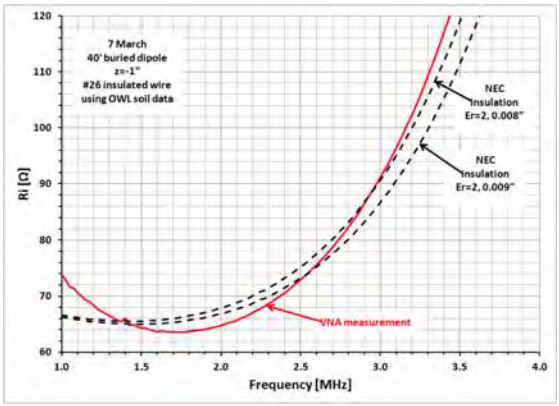

Figure 28 — Effect of insulation thickness.

Figure 29 — Feed point and ground rod of test antenna #3.

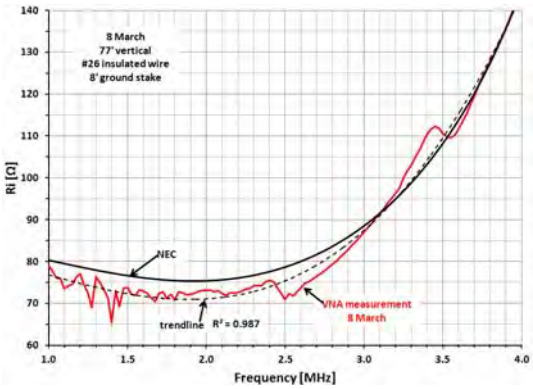

Figure 30 — Measured and computed resistance of the 77 foot vertical with a single ground stake.

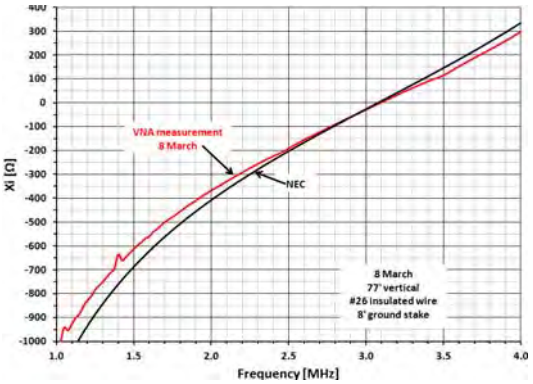

Figure 31 — Measured and computed reactance of the 77 foot vertical with a single ground stake.

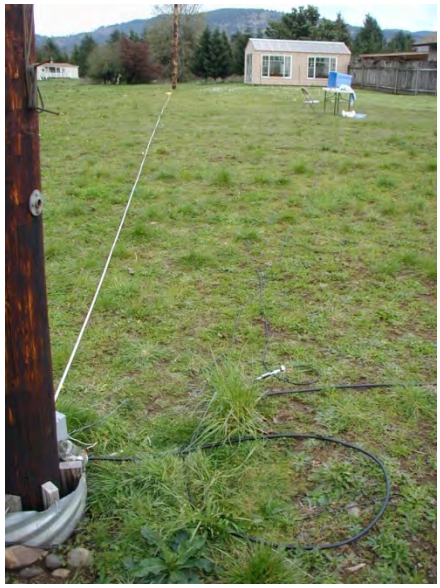

Figure 32 — View of the BOG with measuring tape.

Figure 33 — Instrumentation position.

Figure 34 — Scope probe used for current pickup.

Figure 35 — Base excitation and current sampling example.

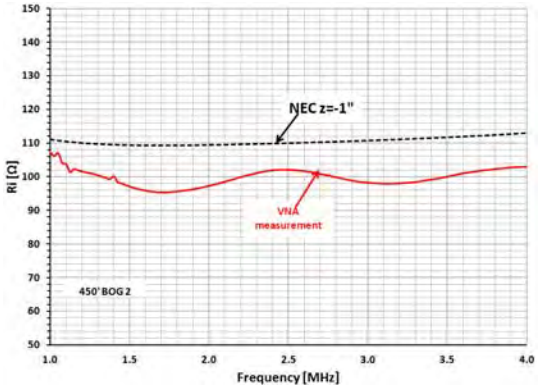

Figure 36 — Measured and computed BOG resistance.

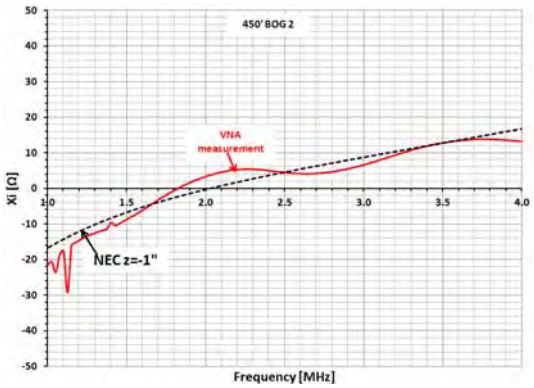

Figure 37 — Measured and computed BOG reactance.

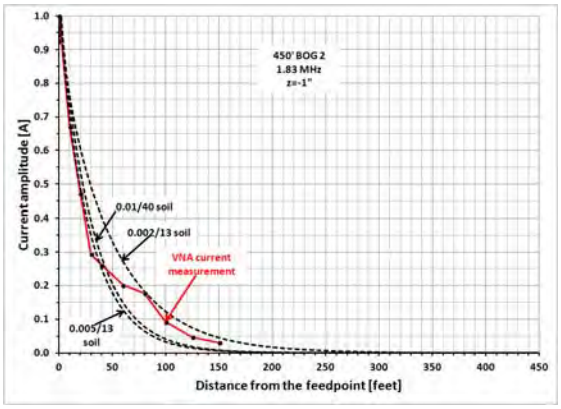

Figure 38 — Measured and computed BOG current amplitude.

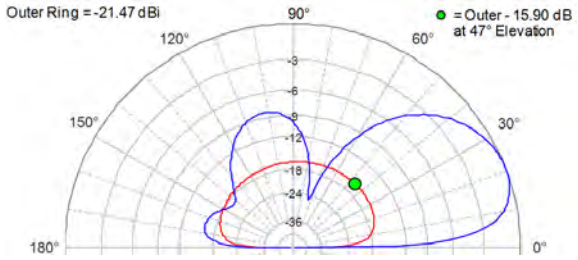

Figure 39 — Computed elevation antenna patterns for the BOG one inch above and one inch below ground.

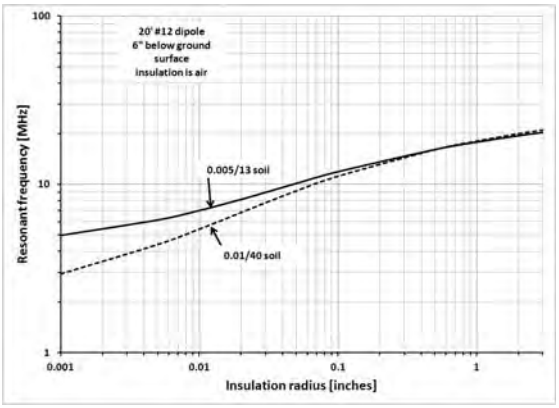

Figure 40 — Resonance frequency in two different soils for different air insulation thickness.