Measuring Ground Constants

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Ground conductivity and dielectric constant (relative permittivity) directly affect the performance of our antennas. When simulating an antenna, getting these values wrong will result in errors in the pattern and feed point impedance. This is especially true for designs that have elements close to the ground, such as radials, or any kind of low antenna. Results may be so far off as to turn you into a non-believer in simulation when you actually build and test your design.

Simulators like EZNEC include default parameters for various types of ground with names like "extremely poor" and "very good." The corresponding numeric values (also published in the ARRL Antenna Book) are derived from 1939 FCC measurements intended for use in the broadcast band. However, soil parameters vary quite a bit with frequency, thus guaranteeing errors when applied to the HF bands. But you can get better values from a webpage provided by Brian Beezley, K6STI. Brian assembled some charts and tables [Ref 1] that extrapolate those BC band data to the HF bands for much-improved accuracy. It's better to start with that information.

Then there is another matter: What kind of soil do you actually have? The FCC has a map of ground conductivity for the USA [Ref 2]. Once again it's for the BC band so the values need correction, and your particular location could be different due to all sorts of alterations to the local soil and of course moisture content. Also the map only shows conductivity but not permittivity. So this is again only a partial solution.

When in Doubt, Measure It

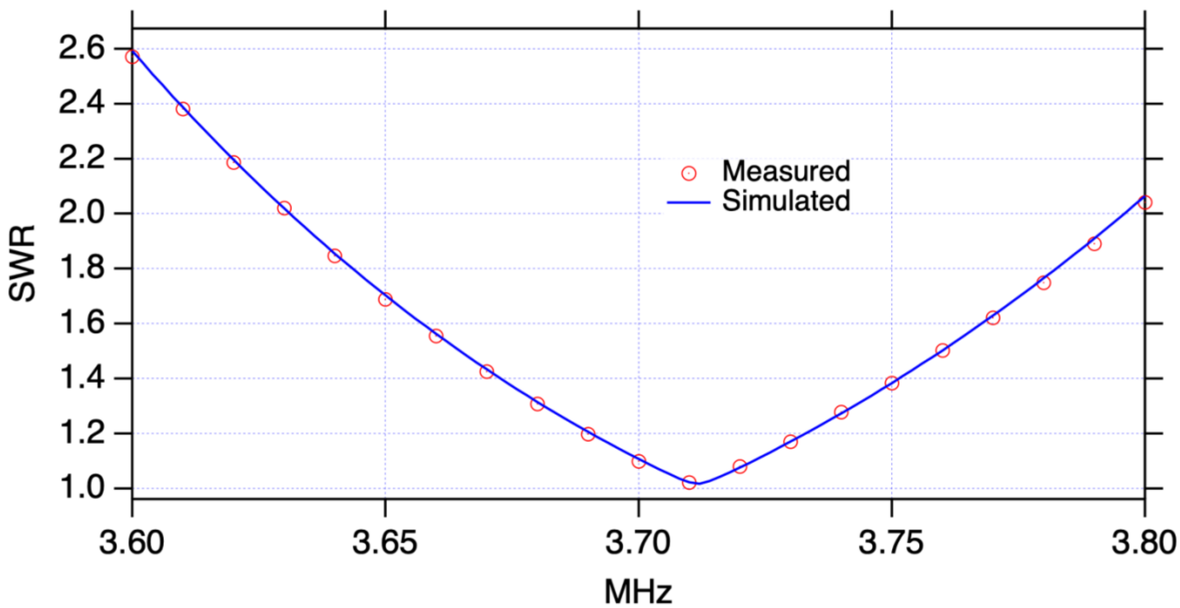
Yes, you can directly measure your local ground constants. There are at least two ways. One is to use a special dielectric probe that is inserted into the ground and connected to an impedance analyzer [Ref 3]. After applying a formula, reliable results are obtained. Of course you need to make the special probe and it only measures data at single points. But it's an excellent technique.

Another way to do the measurement is with a low dipole [Ref 4]. The beauty of a dipole is that it's easy to build and easy to simulate accurately. Basically you measure it's impedance and then in EZNEC you simulate the antenna geometry exactly and then adjust the ground parameters until the results match. The other advantage of this method is that it averages a large volume of soil. All you need is some wire, insulated supports, and enough space to string it up a few feet above the ground. Height is not important—3 to 5 feet is fine—as long as you *know* the height accurately. Also it will make simulation easier if you run it in a straight line. Finally, you will need a good common-mode choke at the feed point to prevent your (short length of) coax and equipment from becoming part of the antenna [Ref 5]. And of course you need a reliable impedance measurement device that displays complex impedance (R+jX). I used my Rig Expert AA-230 but a NanoVNA or many other instruments are fine.

Some Actual Results

My friend Greg, KK6PXT, has been considering purchase of some new property so I went along to do RFI measurements with portable antennas. While I was at it, I put up a full-length 80 m dipole at 4 ft off the ground. It was made from 18 AWG magnet wire and had a good choke at the feed point. When I measured it, resonance was at 3710 kHz and 49.2+j0 ohms. I also saved an SWR scan for later comparison.

The *exact* geometry (including the 3-foot feedline) was simulated in EZNEC using the NEC5 engine and a real/extended accuracy ground. (NEC 2 will be pretty close too; just be sure to use real/high-accuracy ground.) Ground properties were varied by guessing until results perfectly matched simulation; it took me about 15 runs. I was focused on matching the impedance at resonance and finally nailed it. The result was conductivity = .0232 S/m, dielectric constant = 41. In the graph below, SWR data from my antenna analyzer and from the simulation are overplotted. This is a great validation of simulation! If I did not do this measurement, and didn't know better, I'd use the default values for "poor rocky soil", .002/13. That's wayy off, with resonance appearing 6 kHz low and Z = 95+j0.



Now that we know the values on 80 m, we can use the information from Ref. 1 to extrapolate to other bands. It turns out that I could have taken data on other bands while using this same antenna and then run the simulation at those other frequencies, again looking for matching impedances. In that case you do have to watch out for extremely high or low impedances where your analyzer may exhibit large errors.

Conclusion

Don't trust the generic default values for ground constants. At the very least, use the estimates discussed here. Or dig into your junk box and put up a simple dipole, then spend some quality time with EZNEC. You may want to repeat the test in wet and dry conditions as well. At last, you will have accurate ground data for your property and future simulations will be much more accurate.

Additional Comments Regarding Accuracy

I had some discussion with Brian Beezley and he noted that like any metrology endeavors, the absolute accuracy of this measurement depends on more than just the wire geometry. First, the end insulators and even the small loops of wire have to be accounted for. Actually, minimizing them is probably the way to go. A miniscule insulator made from a small-diameter rod of low-loss polymer (e.g., polystyrene, Teflon, polyethylene) or fiberglass would be ideal. Then the loop of wire may also be negligibly small.

The other thing is your connection to the analyzer. Excess capacitance from cables and connectors must be included in the simulation or somehow minimized to a negligible level. Hand or ground capacitance is also a problem. Rudy found that his VNA had to be elevated off the ground with no hand contact, otherwise results would vary. My best solution is to solder the antenna wires directly into an N connector that's plugged into my Rig Expert analyzer. After pressing the start button, I can let go of it and walk away while it does its slow scan. Residual capacitance is very small, and there is essentially no feedline at all.

References

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