Measuring Soil Electrical Characteristics-An Update

N6LF February 2024

Introduction

To model antennas over ground values for the soil conductivity (σ) and relative permittivity (Er) are needed. A practical way to get these at a given QTH is to insert an OWL (Open Wire Line) probe into the soil and measure the impedance (Zi=Ri+jXi) between the two rods with a vector network analyzer (VNA). From the measurement of Zi it is possible to calculate values for σ and Er. Examples of a typical OWL probe and a field measurement are given in figure 1. Note, the plastic cross-bar near the bottom of the probe is a sliding spacer that helps to keep the rods parallel during insertion.

Figure 1A– Typical OWL probe and Zi measurement.

While this approach has been used for many years [1,2] there have been significant limits on the accuracy of the mathematical extraction of σ and Er from Zi and the instruments used to measure Zi have tended to be large (not exactly "portable") and/or not available to the average ham. As a result soil measurements have not become routine.

Figure 1B– Typical OWL probe and Zi measurement.

Fortunately these problems have recently been solved: small, inexpensive (the NanoVNA shown is <$100), self contained battery powered VNA's are now available as well as free software to convert Zi measurements to the desired σ and Er values. While working with the new software unappreciated problems (and solutions!) associated with the details of the probe and VNA physical arrangements during measurement have come to light. With all this it's time to take another look at soil measurements.

New software

The procedure for extracting σ and Er accurately from Zi can be mathematically complex. Unfortunately the equations in amateur literature [2] have generally been simple algebraic expressions, easy to use but only approximations useful at frequencies well below the self-resonant frequency of the probe. Even a 12" probe can be resonant below 30 MHz in some soils. An OWL is not just a simple length of transmission line, part of it is buried but there is another section above ground in air. In addition, to create a measuring point, there will be a cross-wire between the top the rods which introduces some inductance. When coaxial connectors, cable and an instrument are added things get complicated.

DL1GLH [3] and K6STI [4] have created software to perform the Zi to σ-Er conversion with much greater accuracy and convenience. DL1GLH's conversion is done on-line. Brian Beezley's (K6STI) software (GND) can be downloaded to a PC and takes account all of the above points using either touchstone (.sp1 or .sp2) or .csv files from a VNA.

OWL examples

Figure 2 shows a 12" (length in soil!) OWL probe with 3/8" Al rods spaced 3". The handle was made from schedule 80 PVC pipe and the connector mounting plate cut from a plastic kitchen cutting board. I also fabricated a second version of figure 2 using 24" rods with 4" spacing. Both probes could be made with simple hand tools: hacksaw, file and hand drill and they worked well but the large diameter of the rods made them hard to insert especially in my dry summer soil.

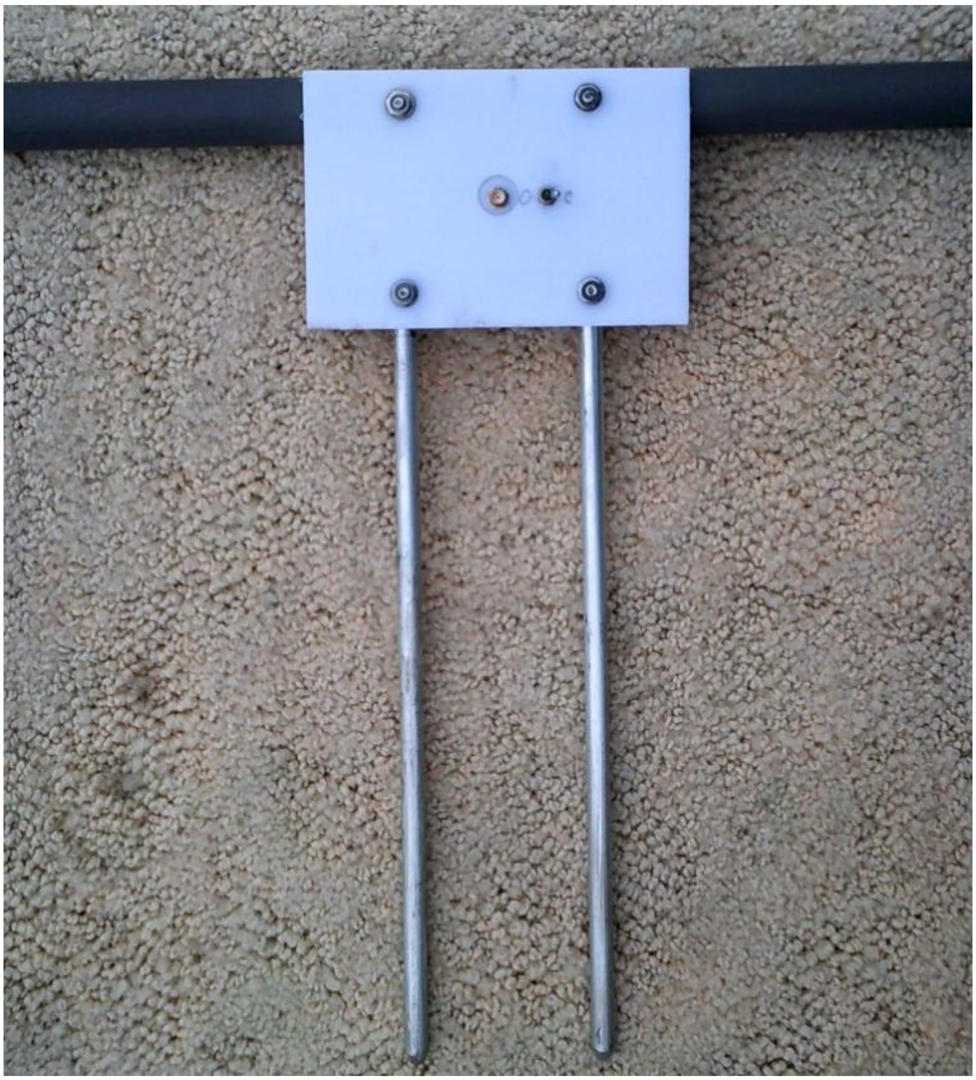

Figure 2A – front

Figure 2B – back

The small switch next to the SMA connector was used to improve CM rejection. This optional as described in the GND readme file.

Figures 1 and 3 show a probe with 0.250" 316 stainless steel (SS) rods spaced 3".

Figure 3- back side of figure 1.

Note the sliding spacing guide shown in figure 1. The rods were about 14" long with 11.5" inserted into the soil. There is 2" of 1/4-20 thread at the top of each rod. I placed a nut at the bottom of the threaded sections, slipped the 3/4" pipe pieces over the threaded sections adding nuts on the top to clamp everything together. The longer upper pipe is spaced from the soil surface by the shorter lower pipe so I could get my knuckles around the handle. The white plastic on which the SMA in mounted is piece of cutting board. This was as simple an arrangement as I could think of but was a bit more difficult to assemble because it required a die and die holder to create the threaded upper section one each rod. Dies and holders are usually available at hardware stores. When purchasing these you should also buy a small can of cutting fluid suitable for the metal being threaded.

During the wet season at my QTH and probably at other QTHs year around the probe in figure 3 should be fine but in summer it was not usable at my QTH. That probe wasn't robust enough to be hammered into the my very hard soil. I had to go to less convenient but much more robust design.

Figure 4 - components for a hammer inserted OWL probe.

Figure 4 shows the parts for a probe intended to be hammered in. The rods were 3/8" 316 SS, about 14" long with 12" inserted into the soil and the rod spacing was 3". The length of 2" PVC pipe is a guide for inserting the rods. The short piece of insulated perforated board mounts the SMA connector and the cross-wire between the rod ends. The first step is to lay the guide on the soil surface. Next the 2" long 3/8" coupling nuts (with a short bolt in one end to make a surface to hammer on) are screwed onto the rod ends. Then the rods are inserted into the guide one at time and hammered home. The coupling nuts are then removed and the SMA mounting plate installed. This may seem like a lot of trouble but in practice it works well in hard soils. I can quickly make measurements not possible with the lighter probe. Figure 5 shows the "hammer" probe installed.

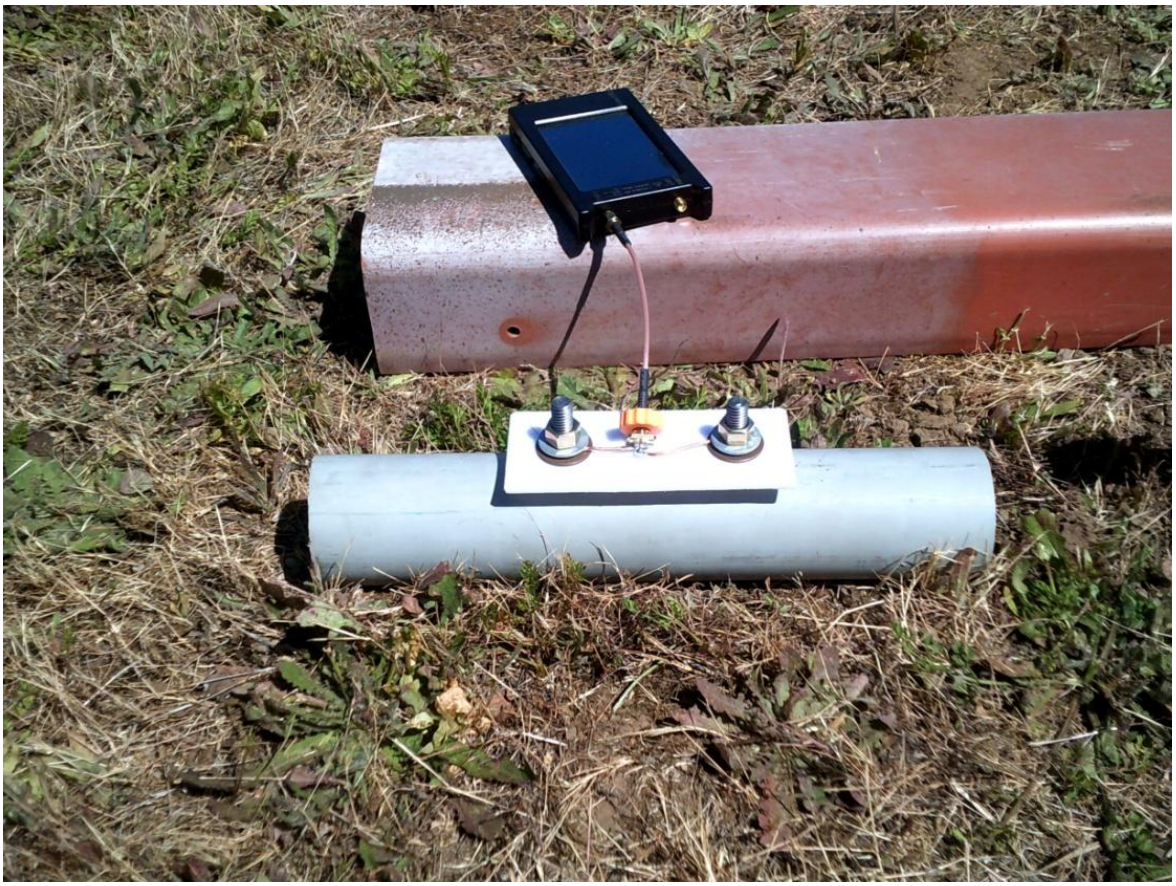

Figure 5 - Hammer probe installed.

There is one final step: extracting the rods after you've hammered them in. That can be frustrating without some preplanning. Figure 6 shows my extraction tool: a coupling nut with a 4" carriage bolt and a handle. Remove the SMA mounting board and use this tool to extract one rod a time. Rotating the rod with the handle while pulling helps a lot!

Figure 6 – Rod extraction tool.

Some comments on probes

The probes shown above are what I've been using but there's nothing sacred about them. A wide variety of dimensions, materials and mechanical construction could be used. I used materials I happened to have on hand or could easily procure at a local hardware store. Rod spacing's of 3" and 4" are shown but anything in the range of 2-6" should work. The in-the-ground length of the rods is not critical anything between 12" and 24" can be used but there are some trade-offs when choosing the length. The values for σ and Er are for a cylinder of soil roughly the diameter of the rod spacing down to a depth a little more than the rod length. The soil may be stratified and the characteristics can vary widely with moisture content. Typically the upper layer of soil will be wetter than at greater depths while raining and drier after a few days without rain. As a result a shallow surface probe measurement may not exactly reflect characteristics deeper in the soil. You might think all you needed to do was to use longer rods. The problem with that is longer rods are much harder to insert (and extract!). It's also much harder to keep the rods parallel which the calculations assume. There is another problem with longer rods: self-resonance of the probe. When inserted in soil even a 12" probe can be self resonant below 30 MHz and 24" probe below 15 MHz. Measurements near a self resonance point can be a problem. Rod lengths of 12"-18" seem to be the most practical.

The metal used for the rods can brass, aluminum or stainless steel (SS), the choice makes very little difference in the final measurement but common carbon steel is not acceptable. Common and stainless steels have much higher resistivity than Al or brass but that's not the killer. The problem with common steel is its relative permeability. At a given frequency skin depth in a conductor decreases with the inverse square root of resistivity and permeability. The relative permeability of SS is very close to 1 but approaches 100 for common steels. Because the skin depth is reduced by a factor of ten there is a ten-fold increase in resistance in steel which is enough to affect measurements.

Mechanically Al and brass are the easiest to work with but SS makes for the most robust probes. To make rod insertion easier the rod tips should be shaped with a file or a grinder to approximate a bullet tip.

Initially I used 3/8" aluminum rod which I had. It worked well but I found inserting the rods not all that easy. After some prompting from Brian to use smaller diameter rods I tried 1/4" Al rod which I also had but that was a bit too easy to bend distorting the probe. So I bought 1/4" diameter brass and 316 SS rods (EBay was the cheapest source I could find) and built the probe shown in figures 1 and 3 using SS rod. This worked well being relatively easy to insert in my wet season soil which is river sediment with lots of clay and small stones but in summer my soil is a very close approximation to concrete and that probe couldn't be inserted without hammering which bent it out of shape. Since relatively hard soils are common and I wanted to measure my own soil in summer I built the hammer probe.

There are many other possibilities. For example, OE1CGS [5] has a very nice probe handle fabricated on a three dimensional printer which is well worth considering if such a printer is available.

Some tips on taking measurements

When Brian first sent me his software I used a VNA (VNA2180) located in the shack with a coaxial cable running out to the probe inserted in the field outside. The VNA calibration was done with the OSL loads at the far end of the cable right at the probe. The idea was to remove the cable effects from the measurements. Unfortunately many of the initial graphs had features clearly not right for any for real soil. In time it was realized that the problem was common mode stray capacitance and perhaps even cable shield resonance with the long cable. An OWL probe is a balanced line but the connection to the probe was an unbalanced cable. To cure this problem I initially tried low capacitance isolation transformers and then common mode chokes (CM). These helped some but were not ideal solutions. Part of the problem was I was trying to characterize the soil over a wide band (0.1-100 MHz). CM chokes generally have high impedance over a narrow range around the choke self-resonant frequency so this approach works only over a limited band. K9YC's CM choke cookbook [6] is a very good reference on these chokes.

The simplest and by far most effective solution was a small battery powered VNA (like the NanoVNA shown in figures 1B and 5) carefully spaced away from the ground surface. Some VNAs however, require an associated PC. In the field a battery powered laptop can be used but care is needed. Figure 7 shows a common arrangement often seen where the VNA is attached to a laptop lying directly on the ground. This is a really bad arrangement! The stray capacitance will affect measurements especially at HF. If this is the only type of VNA available it should be elevated away from ground as shown in figure 8. In addition the CM choke shown should be used. If the soil characteristics are needed on only a single band then the turns on the choke can be adjusted to place the self-resonant frequency near the band of interest [6].

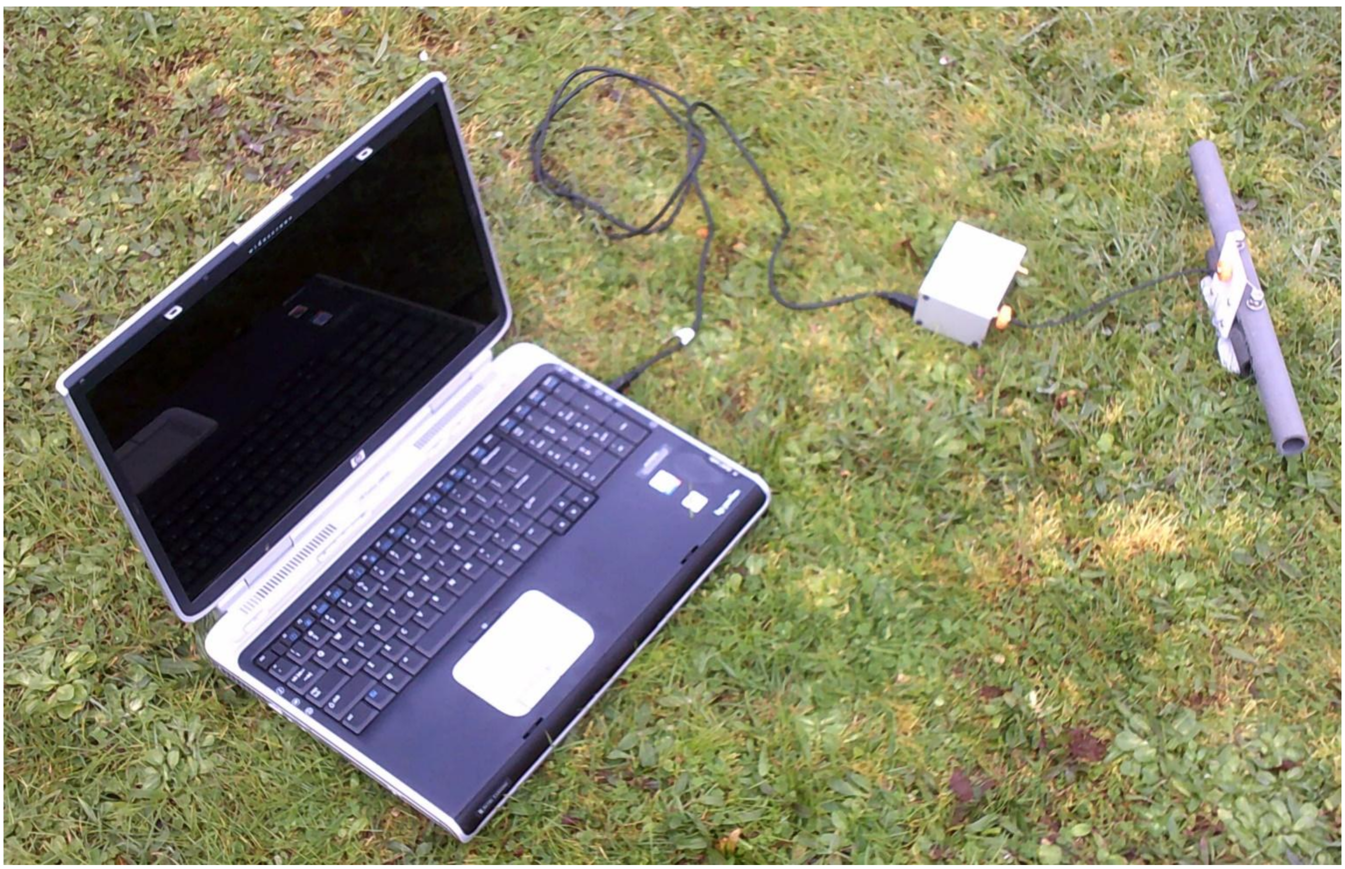

Figure 7 – Laptop and VNA on the ground.

Figure 8 –VNA and laptop spaced away from ground with a choke.

References

[1] ARRL Antenna Book, chapter 3

[2] Severns R. Measurement of Soil Electrical Parameters at HF, QEX Nov /Dec 2006, pp. 3-9

[3] DL1GLH, www.dl1glh.de/gc.html

[4] Brian Beezley K6STI, http://ham-radio.com/k6sti/gnd.htm

[5] OE1CGS, https://www.oe1cgs.at/bodenparameter-mit-owl-sonde-messen

[6] http://k9yc.com/2018Cookbook.pdf