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Determination of Soil Electrical Characteristics Using a Low Dipole

N6LF shows how to create a universal chart showing antenna impedance values for a wide range of soils that map to the average values of σ and Er for the soil over which the antenna is installed.

Rick Karlquist, N6RK, asked on the top-band reflector about placing a dipole on the ground surface to derive soil electrical characteristics — conductivity (σ) and relative dielectric constant (*Er*) — from impedance measurements of the dipole. A short discussion of this technique has appeared in the last few editions of *The ARRL Antenna Book*.[1] For some years I've used the ground probe approach[2] to measure soil characteristics so I hadn't paid much attention, but in some situations this method may have advantages over the soil probes and is worth considering. The probe approach gives the values for a small volume of soil around the probe, down to a depth of 3 ft or so. If you want to map the properties of a large area you need to make multiple measurements at different locations. The low-dipole approach on the other hand intrinsically averages the properties of a much larger area below the antenna and for a couple of skin depths down into the soil. The *ARRL Antenna Book* discussion was pretty limited so I decided to expand on it using antenna modeling software combined with a spreadsheet.

If you have a program that accurately models the soil-antenna interaction (such as NEC4) then you can use the antenna of your choice at whatever frequency you are interested in, see Example 2. Most amateurs don't have this software but the technique can still be used. With some prompting from Rick, N6RK, I realized that if the antenna dimensions — length, height, wire size, etc. — and measurement frequency are predefined then it is possible to create a universal chart with contours showing values of *Ri* and *Xi* for a wide range of soils. If the antenna is fabricated as specified, and impedance is measured at the specified frequency, the measured impedance can be plotted directly on the graph yielding a good estimate of the average values of σ and *Er* for the soil over which the antenna is installed. As a practical matter the reference antenna needs to be something easy and inexpensive to build. For that purpose a low dipole works well, and details of a suggested design are given in Example 1. From a practical point of view it is necessary to have a predefined antenna for each band. In this article I've chosen 80 m for demonstration purposes.

What frequency, lengths and heights?

The height above ground *z* and test antenna length *L* will depend on the frequency of interest. At what frequency within the band should we make the measurement or do we need to measure across the band? Figures 1 and 2 show examples of actual measured values for σ and *Er* at my home site using soil probes.

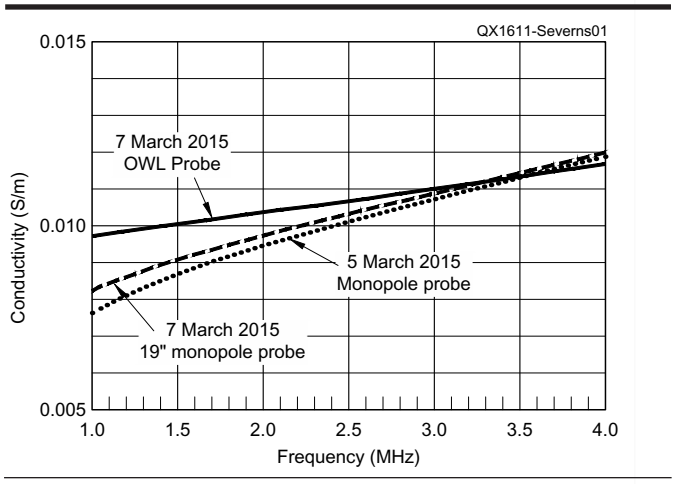

Figure 1 — Soil conductivity σ at N6LF.

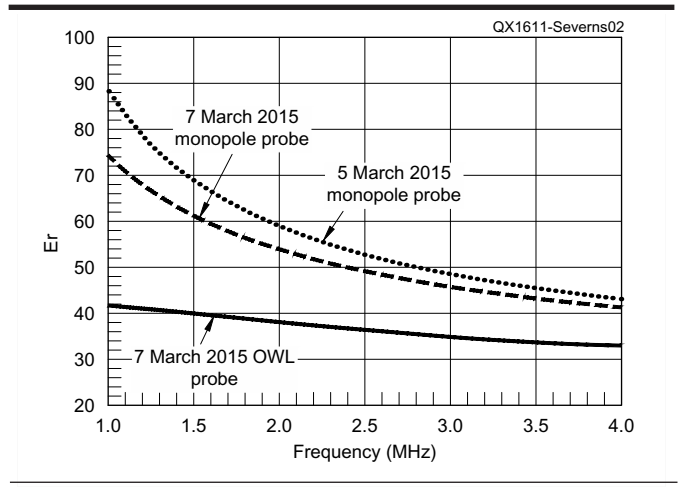

Figure 2 — Soil relative permittivity *Er* at N6LF.

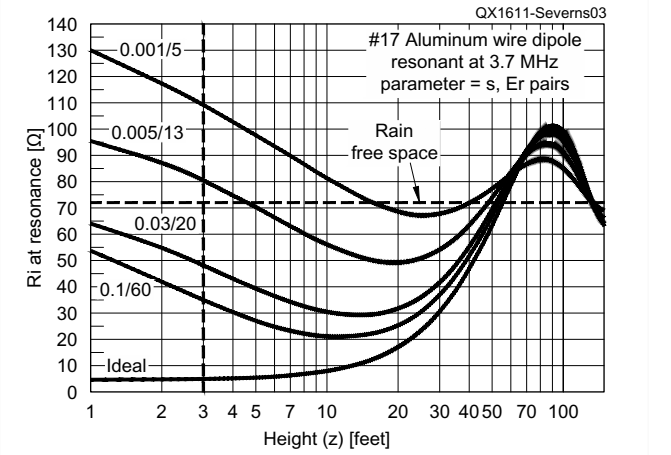

Figure 3 — *Ri* at resonance versus *z* for typical σ, *Er* pairs.

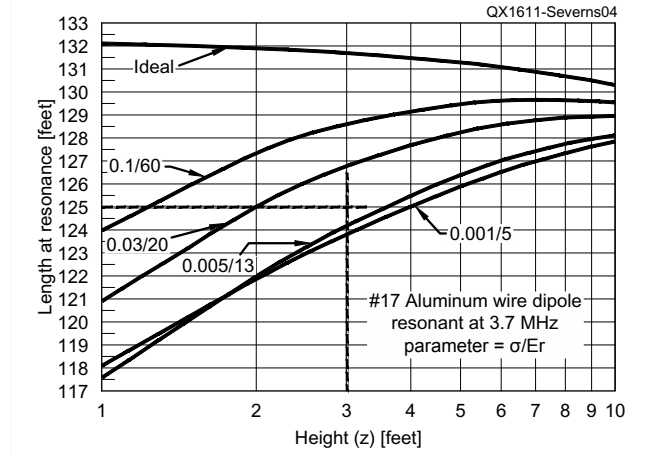

Figure 4 — Effect of height and ground constants on resonant length at 3.7 MHz.

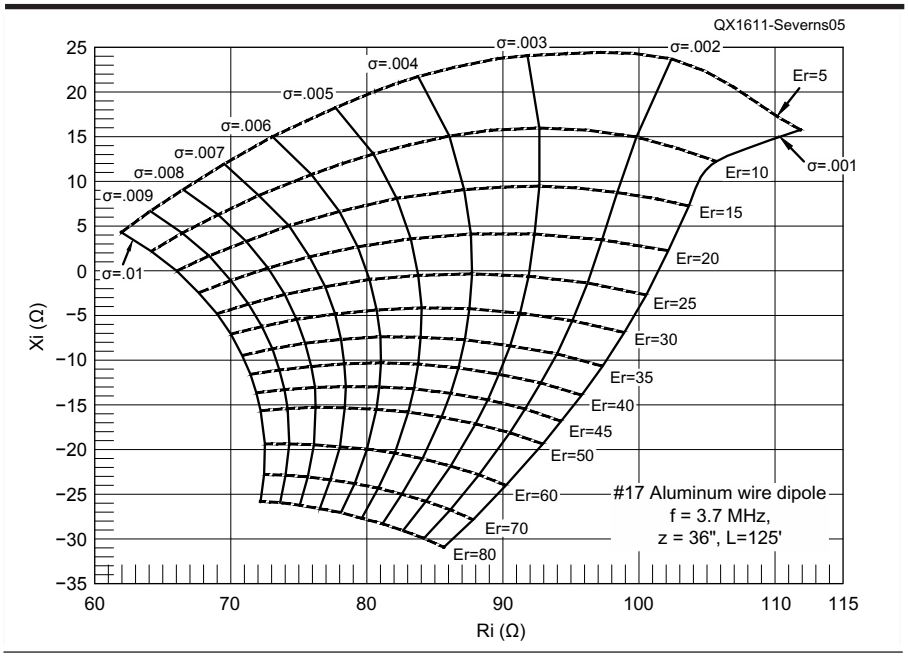

Figure 5 — *Xi* versus *Ri* for 0.001<σ<0.01 and 5<*Er*<80.

Over the 80 m band (3.5-4.0 MHz), conductivity is 0.011<σ<0.0.012 S/m and relative permittivity is 41<*Er*<43. This is a pretty small range and a measurement near mid-band, say 3.7 MHz, should be more than accurate enough. Remember, we are not trying for 1% accuracy, ±20% will do just fine. The modest change of values shown over the 80 m band is typical of most soils. Other bands are much narrower in percentage of center frequency so the changes are even smaller. A single frequency measurement is adequate for each band.

Strictly speaking, the test antenna does not have to be resonant but there are practical measurement advantages to not being too far from resonance. As you move away from resonance the values for *Ri* and *Xi* will begin to change fairly rapidly. Many of the instruments used to measure impedance don't handle very well impedances less than 10 Ω or greater than a few hundred ohms. The impedance values are smaller close to series resonance.

The next question is "how high"? Figure 3 shows the effect of various soils (typical σ and *Er* pairs) at a range of heights when the antenna is tuned to resonance at each point. For heights between 1 and 10 ft the contours are well separated, promising reasonable resolution for variations in σ and *Er*. However, at greater heights the contours begin to tighten up making resolution a problem. It looks like any height *z* between 1 and 10 ft should work. I chose 36 in because it's a very convenient working height. Since standard electric fence hardware is well suited for this kind of field measurement, 36 in corresponds to a standard insulated electric fence post — a practical detail passed to me by N6RK.

For a given height and resonant frequency, the resonant length will depend on the values for the ground constants as shown in Figure 4. For calculations at 3.7 MHz with *z*=36 in, *L*=125 ft is a reasonable compromise.

A universal graph for 80 m

If we have a physical description of the antenna in terms of height above ground *z*, length *L*, wire size, etc., we can model the antenna at a single frequency *f* using a wide range of values for σ and *Er*. This will give us values for the feed-point impedance *Zi=Ri+jXi* at a given frequency for each pair of σ and *Er* values. Using a spreadsheet we can then graph *Ri* versus *Xi* — which are the quantities we can actually measure on a test antenna — as functions of σ and *Er*, with *Ri* on the *x*-axis and *Xi* on the *y*-axis, where σ and *Er* are parameters defining the contours. After measuring the feed-point impedance at *f* we can plot the measured *Ri* and *Xi* pair as a point on the graph. I used *EZNEC pro*[3] with NEC4.2 and an *Excel*® spreadsheet software, *AutoEZ*[4], to automate the calculations and graph them. From earlier work I did on verifying the accuracy of NEC4 for wires close to ground I found that the fitting at the feed point has a shunt capacitance of about 6 pF. This has been added to the model.

With *L*=125 ft, *z*=36 in and *f*=3.7 MHz we graph *Xi* versus *Ri* as functions of σ and *Er* (Figures 5 and 6). The dashed contours represent 5<*Er*<80 and the solid contours represent 0.001<σ<0.01 S/m (Figure 5), and 0.01<σ<0.03 S/m (Figure 6). This range of values should cover most common soils that amateurs are likely to encounter. If this doesn't work for your site then you can use the

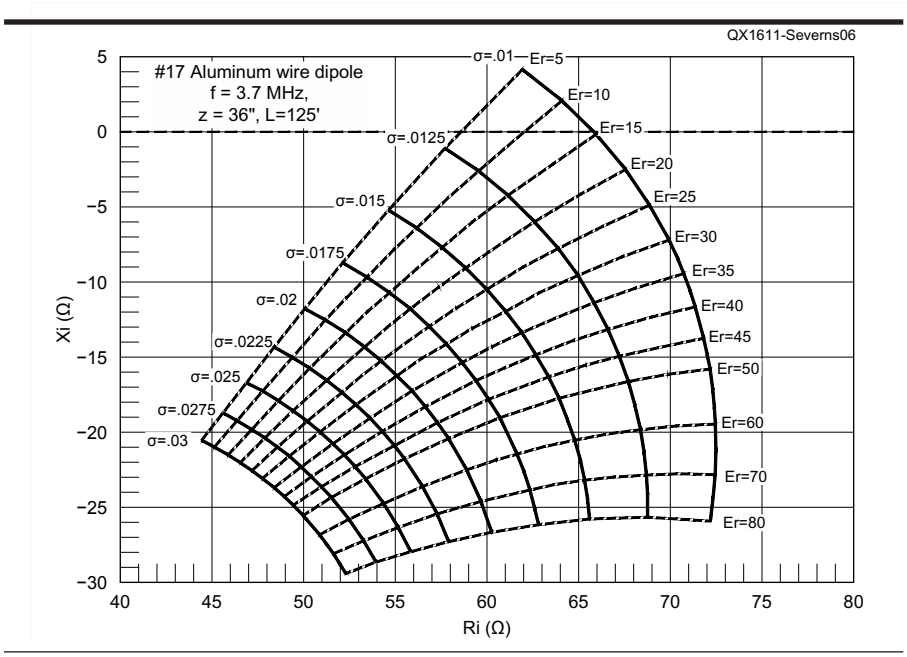

Figure 6 — *Xi* versus *Ri* for 0.01<σ<0.03 and 5<*Er*<80.

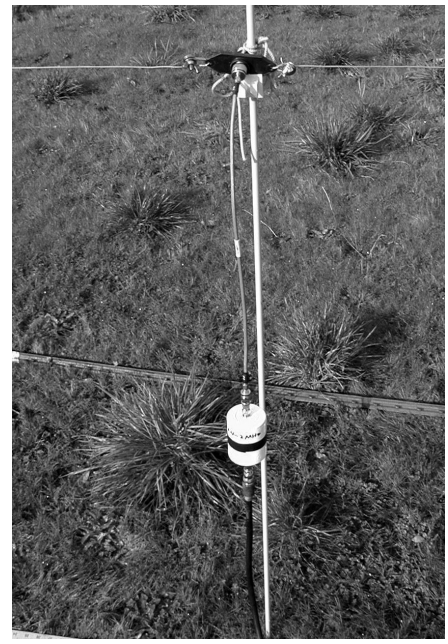

Figure 7 — Center connector and feed-point support. [Rudy Severns, N6LF, photo.]

procedure described in Example 2 to generate your own graph using NEC4 software.

Note that I've cut Figure 6 off for σ greater than 0.03 S/m. As the conductivity increases the scale compresses rapidly. In fact if we push σ all the way to infinity (perfectly conducting soil) *Zi* converges to a single point at *Zi*=4.2-*j*76.5 Ω. Most amateurs are not blessed with soil of this high conductivity so this limitation is not that serious. For higher conductivity soils ground probe measurements are probably a better method.

Example 1

Figures 7 and 8 are photos of the mechanical arrangements for typical test antenna using standard #17 AWG aluminum electric fence wire and hardware widely available in hardware and farm stores. The electric fence wire is suspended at 36 in on fiberglass (F/G) wands, with yellow plastic wire clips that slide up/down the wands for height adjustment. The wands were spaced 10 to 20 ft apart and the wire is anchored at the ends to steel fence posts 6 to 10 ft away from the ends of the wire. Multiple support points and significant wire tension kept the droop to less than 0.25 in. High quality insulators and non-conducting Dacron line were used at the wire ends. Figure 7 shows the Budwig center connecter and the common mode choke (balun) at the feed-point. The center connector and choke introduce approximately 6 pF of shunt capacitance across the feed point, which must be added to the model. The steel fence post at the midpoint shown in Figure 8 was replaced with the F/G wand shown in Figure 7.

The measured impedance of the common mode choke is shown in Figure 9. The choke comprises two Fair-Rite 2631665702 type 31 cores taped together to form a binocular core. The winding is six turns of RG174/U 50 Ω mini-coax.

Example 2

If NEC4 based software is available then you can create your own charts using your choice of antenna, as follows. We assume a horizontal center-fed dipole made with #17 AWG aluminum wire at a height *z* of 36 in. After tuning to resonance at 3.5 MHz the length *L* is 131.11 ft. The measured feed-point impedance *Zi* at 3.5 MHz is 80.26+*j*0 Ω. From this we can determine the values for σ and *Er* at 3.5 MHz. First create the NEC4 model using #17 AWG aluminum wire 131.11 ft long and 36 in above ground. Since we do not know the values for σ or *Er*, we'll run the model repeatedly with a range of possible values for σ and *Er*. If we're too far off in our choice of values the process should point the way to go. In this case the trial values will be 0.001<σ<.0.01 S/m and 1<*Er*<50. Running the model repeatedly, we can determine *Zi* for a matrix of σ and *Er* values. A spreadsheet, sample included in the *QEXfiles*, is a good way to keep track of results.[5]

Using the spreadsheet we can graph a more restricted set shown in Figure 10. The measured value of *Zi* for the antenna at 3.5 MHz is 80.26+*j*0 Ω. A dot with a label has been placed at that value on the graph. We see our matrix of values has bracketed this value nicely. The σ=0.005 S/m line passes right through *Zi*. Also, *Zi* lies between the *Er*=10 and *Er*=15 lines, right around *Er*=13. We could repeat the process for multiple values of *Er* around 13 to refine the answer further, but from a practical point of view we're already close enough. With σ=0.005 S/m and *Er*=13, we have average soil.

Figure 8 — Test antenna supported with F/G wands. [Rudy Severns, N6LF, photo.]

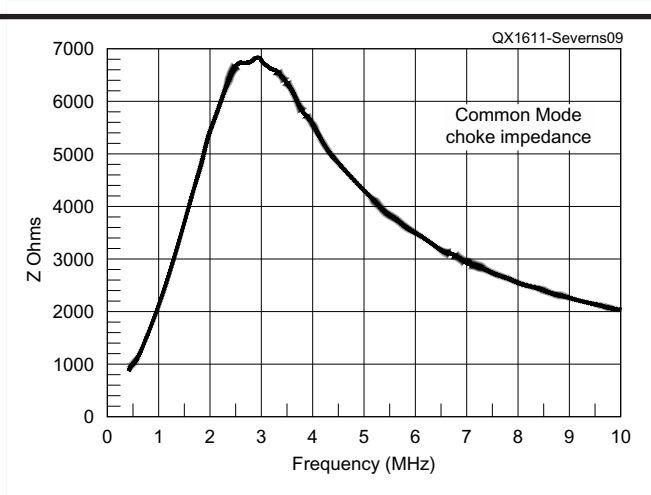

Figure 9 — Common mode choke impedance.

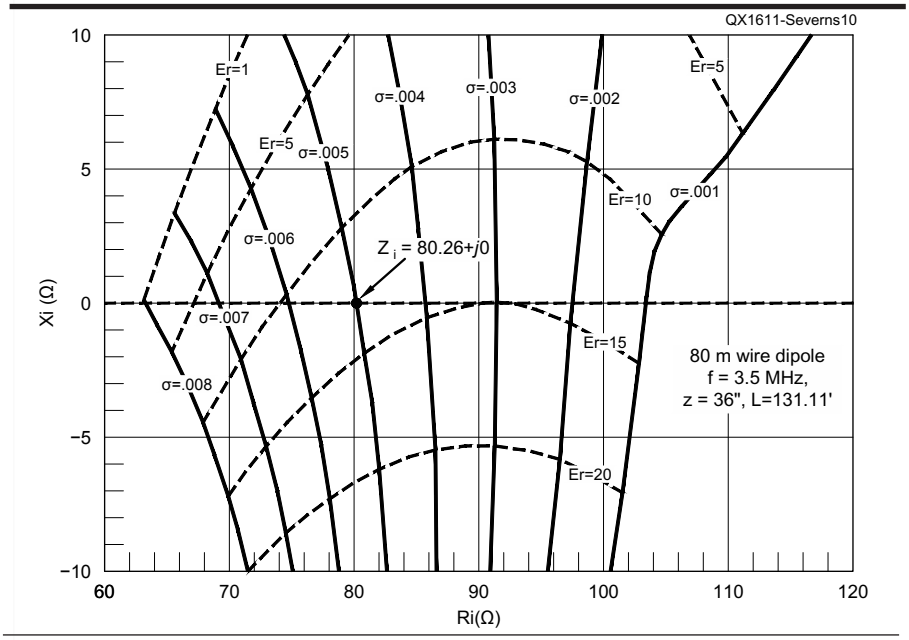

Figure 10 — Graph of *Ri* versus *Xi* for a range of σ and *Er* values at 3.5 MHz.

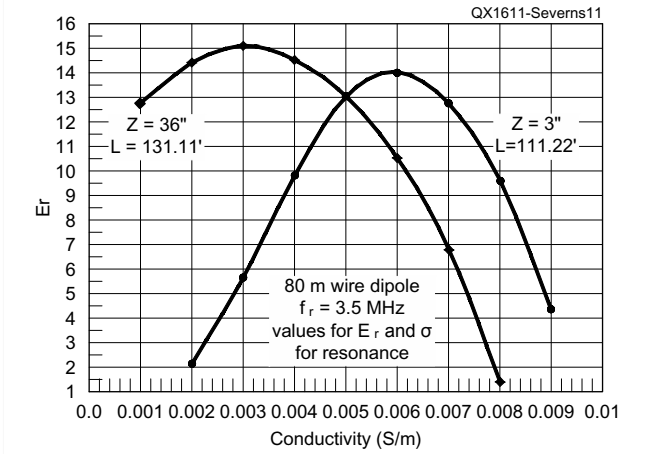

Figure 11 — Values for σ and *Er* that result in the resonant lengths shown at 3.5 MHz.

Example 3

If you have the requisite modeling software but not the impedance measuring equipment it is possible to determine σ and *Er* by resonating the antenna at a given frequency at two different heights and then, modeling these two configurations — trying different *L* and *z* — and graphing the values for σ and *Er* that correspond to the same resonant frequency. Figure 11 shows the procedure. Here *f*=3.5 MHz, and at *z*=3 in length *L*=111.11 ft, while at *z*=36 in *L*=131.11 ft. The two curves intersect at σ=0.005 S/m and *Er*=13.

Summary

There are several ways to use a low dipole to determine soil electrical characteristics. However, you will need either NEC4 software or a good impedance measuring instrument or both to do this. The ground probe method does not rely on modeling but it does require a reasonably good impedance measuring instrument capable of showing *R* and *X* as well as the sign of *X*. Low dipole measurements have the advantage of giving a realistic average of the soil characteristics over a substantial area and down a few skin depths into the soil. Ground probe measurements generally give the characteristics over a small volume of soil, and multiple measurements are required to cover a large area. Each has advantages and limitations but both will work.

Acknowledgements

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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]Pages 3-31 to 3-33 in, *The ARRL Antenna Book*, 22nd edition, 2011. Available from your ARRL dealer or the ARRL Bookstore, ARRL item no. 6948. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

[2]R. Severns, N6LF, "Measurement of Soil Electrical Parameters at HF", *QEX* Nov/Dec 2006, pp 3-9. Available at **www.antennasbyn6lf.com**.

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

[4]*AutoEZ* for *EZNEC*, see **www.ac6la.com**.

[5]See **www.arrl.org/qexfiles**.