Estimating the soil conductivity for GPR surveys

By Reinaldo Alvarez Cabrera

The results of the Ground Penetrating Radar survey depend on many factors. In order to get useful data and good penetration, one of the conditions is that the conductivity of the ground is not too high. The conductivity of the material, the operating frequency and the dielectric constant allow us to calculate the loss factor that is used to roughly estimate the theoretical penetration.

There are many ways for estimating the bulk relative dielectric constant, one of them with the radar itself. By using some reflection from an object at a known depth and a velocity analysis tool like the one in the GPRSoft PRO software package we can accurately find out the layer's relative dielectric permittivity or RDP.

It is however, a little bit more difficult to estimate the conductivity of the soil if one doesn't have a resistivity meter or a similar measuring instrument. Since this is quite an important parameter I'll try to explain here a simple, yet effective method to estimate the conductivity of the soil under survey.

A little bit of theory first

A while ago, almost one hundred years soon, Mr. F. Wenner suggested that a linear array of four equally spaced electrodes would make all the problems they had at that time with soil-electrode contact go away. Ever since most of the resistivity measurements are carried out using the four electrodes principle.

If we insert four electrodes into the ground, as shown in Figure 1., and apply the current between the electrodes A and B then the electrical potential will appear between the electrodes M and N.

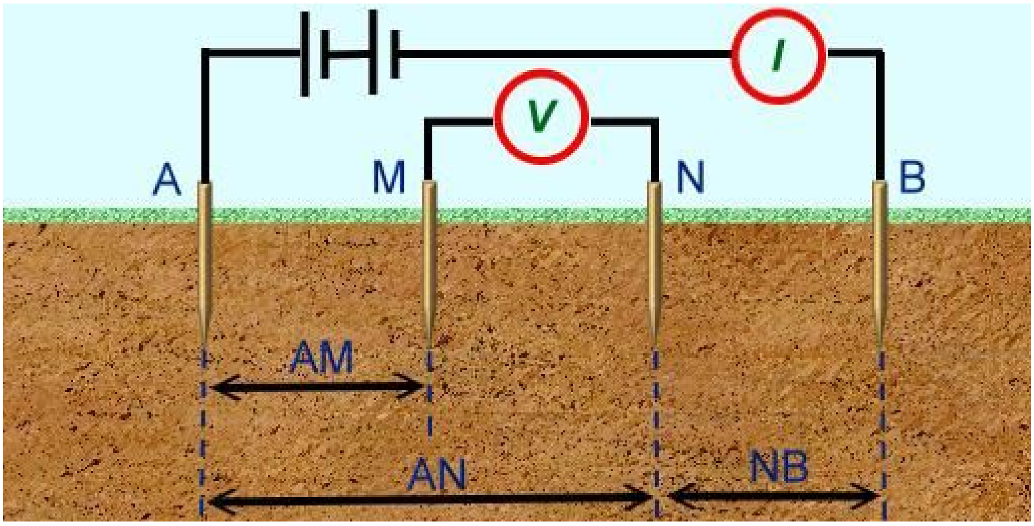

Fig. 1 Four electrodes resistivity measurement setup.

The theory also says that the electrical resistivity of any material is equal to the electrical potential that appears over a length of material L with a cross sectional area A.

$$Rho = \frac{A \cdot dV}{L \cdot I} \quad (1)$$

where:

Rho – is the electrical resistivity of the material ,

A – is the cross sectional area,

L- is the length of the uniform conductor,

dV – is the potential over the length of the uniform conductor, and

I – is the current flowing through the uniform conductor.

If we substitute the ratio of the cross sectional area to the length of the conductor with some coefficient K we obtain:

$$Rho = \frac{K \cdot dV}{I} \quad (2)$$

This coefficient K is found to be a geometric factor that can be calculated based on the distance among the electrodes A, M, N, and B. For linear arrays like the one shown in Figure 1. this coefficient is calculated as follows:

$$K = \frac{Pi \cdot [AM] \cdot [AN]}{[MN]} \quad (3)$$

It is not difficult to see that if all the distances between adjacent electrodes are equal then the coefficient simplifies to:

$$K = 2 \cdot Pi \cdot s \quad (4)$$

where:

s = [AM] = [MN] = [NB], all the electrode are equidistant from adjacent ones.

Now we can put the expression for K from equation 4 into equation 2 and get the formula for the resistivity in Ohms per meter.

$$Rho = \frac{2 \cdot Pi \cdot s \cdot dV}{I} \quad (5)$$

where:

Rho – is the electrical resistivity in Ohms per meter

Pi – is a mathematical constant, 3.14159...

s – is the distance between the electrodes in meters

I – is the applied current in Amperes.

The conductivity, which we are interested in, is calculated simply by taking the inverse of the resistivity. It's that simple.

$$S=\frac{1}{Rho} \quad (6)$$

The conductivity is measured in Siemens per meter and sometimes old timers like myself call it Mho which is Ohm reversed. However, Siemens is the international standard unit and it should be used always.

Enough theory, let's measure!

We are going to slightly modify our previous setup so we can get some meaningful and easier measurements. For the four electrodes needed, we can use any metallic rods with the same length and diameter. It would be a good idea to sharpen them in one end so it is easy to insert them into the ground. We are also going to need some sort of a current generator. Any voltage source with 20 to 50 volts and a high watt resistor (for instance 20 Ohms, 5 Watt) will do the job just fine. Finally, we need a good multimeter to measure the electrical potential between our M and N electrodes. Pick a multimeter with high input impedance to alleviate the effects of the measurement device on the results of the measurement.

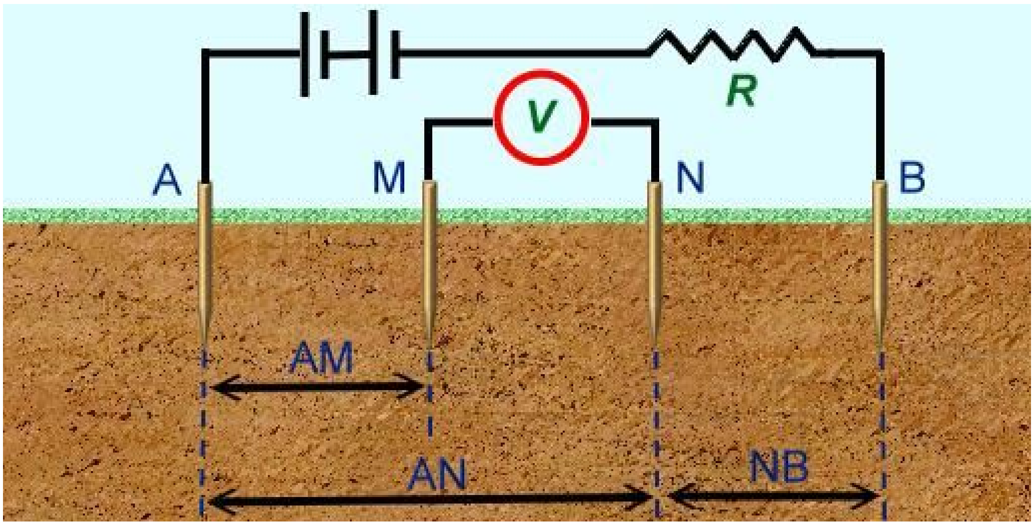

Fig. 2 Modified setup for resistivity measurement.

Insert the electrodes into the ground along an imaginary line and make sure the distance between them is the same. For electrodes 0.5 meters long, I'd insert them 0.4 meters apart and around 0.3 meters into the ground. Connect one end of the resistor to electrode B like in the figure 2 and the other end to one of the terminals of your voltage source. Connect the other terminal of the voltage source to the electrode A.

Now measure with your multimeter the voltage over the resistor and take note of that value, calling it V2. Then measure the voltage between the electrodes M and N and take note of that value, calling it V1. This voltages are depending on the conductivity of the soil you are measuring and the output voltage of your voltage source, so it is meaningless to give some exact figures here. For instance I get around 2 and 0.65 volts with 60 Volts in my yard.

Now it is rather easy to calculate the value we need. The conductivity of the soil you are measuring should be equal to:

$$S=\frac{1}{2\cdot Pi\cdot R\cdot s}\cdot\frac{V2}{V1} \quad (7)$$

where:

S – is the conductivity in Siemens per meter S/m

R – is the resistance of the resistor in Ohms

V1 – is the voltage between electrodes M and N, and

V2 – is the voltage drop over the resistor R

Conclusions

We have presented a simple and easy to follow method for measuring the bulk conductivity of the soil for ground penetrating radar applications. Of course, a more correct way to do this would be to take some samples and send them to a laboratory for analysis. Since that is not a viable solution all the time and most of the time we need only a fair estimate of the conductivity of the soil, I consider this method to be accessible, affordable and easy to do. However, there are many affordable soil resistivity meters available and if you can afford to buy one, then by all means do it.

References

1. *John M. Reynolds, An introduction to Applied and Environmental Geophysics, John Wiley and Sons, ISBN 0-471-96802-1*
2. *H. Robert Burger, Anne F. Sheehan and Craig H. Jones, Introduction to Applied Geophysics, W.W. Norton & Company, ISBN 0-393-92637-0*
3. *Arcone S.A., Lawson D.E., Delaney A.J., Strasser J.C. And Strasser J.D., "Ground penetrating radar reflection profiling of groundwater and bedrock in an area of discontinuous permafrost", Geophysics 63, 1573- 1584, 1998.*