Soil Resistivity Measurements

Introduction

First a bit of physics: Resistance can be defined through Ohm's law stated as

$$R=V / I$$

Where R is resistance (in ohms), V (in volts) is the voltage applied to the object being tested, and I (in amps) is the current that is driven through the object by the applied voltage. The more voltage it takes to drive a given current through the object, the higher resistance that object has. A hundred watt light bulb has a resistance of about 600 ohms and therefore will draw about 0.4 amps when connected to the 240 volt mains supply.

Soil Resistivity

For a thorough discussion see Tony Clark's book Seeing Beneath the Soil, Batsford, London, 1996 or Chris Geoffy and John Gater, Revealing the Buried Past, Tempus, Stroud, 2003. Resistivity is the property of a material that results in measurable resistance to the passage of current. The tungsten in the filament of the light bulb possesses a certain resistivity which, when shaped into the specific dimensions of the filament, will result in the resistance noted above. Make the filament thicker or shorter and this resistance will decrease. What would a 40 watt light filament look like compared to a 100 watt filament?

Resistivity and measured resistance are linked by the geometry of the measurement and the material. For soil one can in principle stick two electrodes in the ground, put a voltage across them and measure the current that results. Converting this resistance measurement into a value for soil resistivity requires quite a bit of geometry and theory. For most archaeology we do not need to know the precise value of soil resistivity at every point, just the local values relative to other measurements made close by.

By using a fixed measurement configuration (probe spacing, current) for measurements, we can use the recorded resistance to look for local changes caused by disturbances to the background soil resistivity. Ditches, walls, pipes, stone, masonry, and other subsurface features can produce small changes from the 'natural' background and are thus detectable by simply measuring the resistance at a number of points on the ground. The conversion from resistance to absolute resistivity is not usually important at the time of measurement but is used to compare very different sites or two different instruments. The conversion is a simple multiplying factor that depends on the geometry of the probes.

Reality

There are a number of reasons why a two electrode resistance measurement using a simple battery to supply the voltage and current doesn't work very well. Lots of electrochemistry happens at the soil-electrode surface when making a simple direct current (DC) measurement. Suffice to say that the soil and the electrodes conspire in a way that means that an alternating current (AC) source is needed and that it's better to push the current into the ground through one pair of electrodes and measure the voltage with another pair. The electrode spacing determines how far the current penetrates into the ground.

The depth of the penetration is about twice the electrode spacing if all four electrodes are equally spaced (the Wenner configuration). You can get a bit more penetration by separating the electrodes into two pairs, a probe set and a reference set (the dipole or twin-probe configuration). The dipole configuration is used normally over relatively small areas (30x30m) because of the trailing wire. The dipole resistance measurements must be corrected depending on the separation between the two pairs of electrodes. This correction will be small if the minimum probe to reference separation is at least ten times the electrode pair spacing. The Wenner four-electrode configuration is often used over large areas since there is no trailing lead but for only modest electrode spacing (30-50cm) the frame for the electrodes gets large and cumbersome.

Resistivity varies with soil type, rainfall, planting, geology, and disturbance. Some care is needed when comparing measurements done on the same site at different times. Corrections and normalisation will be necessary to compare measurements where considerable time passes or where different instrument configurations have been used.

Resistivity Surveys Using the M.M Instruments

Laying Out the Grid

Resistivity surveys can conveniently be done on a 30x30m grid at one metre intervals. Use two tapes on parallel sides and one movable line marked at one metre intervals to stretch between these. Survey the square grid onto the site and choose an origin to begin the measurements. Record the grid location, orientation, and origin carefully as these will be needed to map the resistivity features onto the exact location on the site. If you choose the origin as below in Fig 1, the data will be easier to manipulate using a spreadsheet.

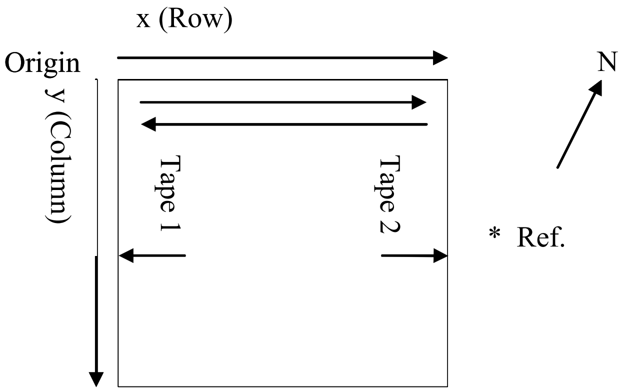

Figure 1

Dipole or Twin-Probe Resistivity Measurements

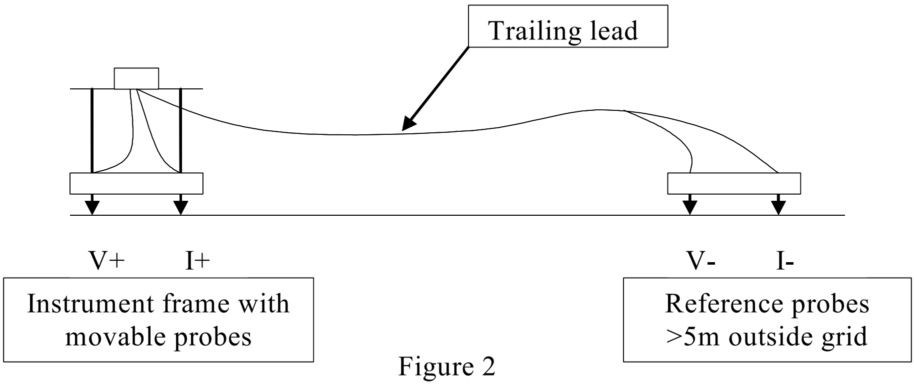

Figure 2

Setting up the Instrument

Choose one of the sides of the grid and place the reference electrodes 5 metres outside the grid on the centreline (i.e., at 15 metres, see asterisk in Fig 1) as per Figs 1 and 2. Record this location as it will be needed to correct the measurements if high accuracy is needed. With the instrument at the origin, plug in the reference trailing lead (not required for the Wenner configuration) and turn on the instrument. Set the controls as follows:

Current	1.0 mA
Gain	10
Display	2.0 V scale
Filter	‘Fast’ or ‘Medium’

The meter should indicate between 0.100 and 1.999 and the Fault led should be off if the soil conditions are ‘normal’. The Fault indicator will light if there is poor contact with the soil, one or more of the electrodes are not connected, or if the soil resistivity is too high for the normal settings above. If the reading is too low, try increasing the Gain before increasing the current to 10 mA. If the reading is too high or the Fault led is on, reduce the current to 0.1mA. Note that low current measurements may be noisy due to contact resistance and interference from electrical sources nearby. The ideal range for recording data is between 0.200 V and 1.999 V on the meter with a preference for higher numbers if possible.

Taking Measurements

Record which direction (the Row or *x* direction) you are intending take the measurements at one metre intervals. Normally a ‘stitch’ or ‘zig-zag’ pattern is used; along the Row, over one metre (in the Column or *y* direction), then return. With the one metre wide instrument frame this means the marked line only needs moving every two (up and back) passes. If some other scheme is used be sure to record how you took the measurements. The recorded data is simply a string of numbers (see the EOR function below) and needs to be properly interpreted when reconstructing the grid.

There are four buttons, three on the instrument and one on the frame (sample):

Start	start taking data (enables the other buttons)
Stop	stop taking data (disables all buttons except Start)
EOR	End of Row (marks the end of a row then Stops)
Sample	records the measurement (and beeps)

Manual Operation: Set the instrument on 'MAN' for manual control.

a) With the probes inserted at the origin, press Start. A short beep will sound and the green Ready led will light up indicating you can begin recording.

b) Press Sample. A beep indicates the button press and the Ready led will go out. <u>Wait for the pair of beeps that indicates the measurement has been recorded</u>. The green Ready led will also illuminate and you can move the probes to the next point and press Sample, etc, etc. The red Fault led will come on when you lift the probes but should go out as you insert the probes for the next data point. You cannot take a Sample if the Fault led is on.

c) After the last point in the Row, press EOR. A short beep acknowledges the button press and all buttons except Start are disabled. EOR writes a marker to the data file.

d) When you have moved to the start of the next Row, press Start then press Sample and continue until this Row is complete, press EOR, etc.

e) You can stop any time by pressing Stop. Press Start when you wish to continue.

f) You can place extra markers by pressing EOR then Start and repeating this for as many times as needed. This is most often used to indicate that the grid is complete but can also be used mark a change in the measurement pattern, a possible error in taking the measurement, or an event like a battery change, earthquake, etc.

g) Turn off the instrument when you have finished. You can turn off the instrument at any time but preferably after an EOR. When turned on again it will resume recording data where you stopped without overwriting any previous data. The memory can be cleared only after writing all the data to a file using the Reader box so there is no danger of losing data.

Automatic Operation: Set the instrument on 'AUTO' for automatic control.

Note: In automatic mode the instrument uses the Fault indicator to trigger the data recording process. The instrument waits for the measurement to settle before recording the data and it is slightly slower than the manual mode. The advantage is that the operator does not have to manually press the Sample button to take data. The operator must be quite decisive about inserting the probes because the recording process starts as soon as the Fault led goes off. *This mode is not recommended in rough terrain or where it is difficult to insert the probes.*

a) With the probes in the ground, press Start. The green Ready led will light.

b) Lift the probes out of the ground and the red Fault led will light. Place the probes back in the ground without moving forward and the Fault led should go out. <u>Wait for the (triple) beep and the green Ready led to come on</u>.

c) Lift the probes out of the ground and move to the next point, wait for the beeps and led, etc.

d) At the end of the row press EOR then move to the start of the return row and repeat a), etc.

e) e) to g) are the same as the Manual mode above. You can switch between the two modes at any time but take care how you record the sample at the point of the switch so as to not miss a sample or repeat one.

<u>Download the Data</u>

a) Plug the Reader unit into the Instrument Box and into the PC/Laptop RS232 port.

b) Launch the **M.M Logger** software on the PC. Enter the required information in the software window.

c) Set the Instrument Box to 'DATA XFR'. Turn 'ON' the Box and the Reader.

d) Click on Transfer Data. See detailed Software Operation instructions if download does not commence.

e) When download is complete, click Exit.

Process and Display the Data (See detailed software instructions)

a) Launch the spreadsheet program (MS Excel assumed here) and open the data file into the spreadsheet using default settings. Save the data spreadsheet using an appropriate name.

b) Open the data recording template, mark and copy the data columns from the data spreadsheet into the the appropriate place in the data recording template Worksheet.

c) Enter the appropriate information in the data record Worksheet cells. Click on the ‘Do It’ button. The data array should now be filled. (Errors in data taking will be evident, these should be corrected now)

d) Copy the array to the Data Worksheet.

e) See detailed software instructions and templates for graphics manipulation and display.