

EM38
GROUND CONDUCTIVITY METER
OPERATING MANUAL

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INTRODUCTION

This manual supplies users of the EM38 with operating information and some theoretical results to assist in the planning and interpretation of geophysical surveys. Additional information can be found in Geonics Technical Note TN-5, which outlines the factors affecting soil and rock conductivity, and Technical Note TN-6, which describes the general theory of terrain conductivity mapping using inductive electromagnetic techniques.

1. EM38 OPERATING INSTRUCTIONS - Simplified Method

(Operator should follow the steps outlined below **or** as an alternative, and more theoretical procedure follow Sections 2.2 to 2.5)

1.1 Battery Test

The battery test should be carried out at the beginning of each day or when the battery voltage is suspected of being low. Check the battery voltage as follows: with the range switch in the 1,000 mS/m position set the battery test switch to BATT. The absolute value of the displayed reading will be over 720 for a good battery and under 720 for a bad one.

To remove the battery, undo the two screws holding the cover of the battery compartment at the top rear of the instrument frame. A Mallory MN1604 9-volt Alkaline battery or equivalent gives about 30 hours of continuous operation. For longer service (about 55 hours) we recommend a Mallory TR146X 9-volt Mercury battery.

The following steps are used to prepare the EM38 for survey operation.

1.2 Calibration Method for Phasing and Instrument Zero

This calibration should be carried out at least 3 to 4 times per day unless the ground is very resistive in which case you would repeat it more often.

IMPORTANT! Because of the high sensitivity of the EM38 it is advisable to remove all metal objects from wrists, fingers, neck and pockets during the calibration procedure. Sensitivity to metal objects, which is discussed in Section 2 is greatest near the coils at either end of the instrument.

Turn instrument on by setting the ON/OFF/BATT switch to "ON" and follow proceeding steps.

Step 1

With the EM38 on the ground, mode switch set to Q/P, and the instrument in the vertical dipole mode of operation (see Fig. 1) set the Quad phase (Q/P) reading to zero using the Q/P zero control knob.

Step 2

Set the mode switch to Inphase (I/P) and set the Inphase reading to zero using the I/P coarse and fine controls. Go back and make sure that the Q/P still reads zero.

Step 3

With the mode switch in Q/P, set Q/P to 50 mS/m, using the Q/P zero control knob.

Step 4

Set the mode switch back to I/P and raise the I/P reading to 50 mS/m by using the coarse and fine I/P controls.

Step 5

Return mode switch back to Q/P and make sure it reads 50 mS/m. If the Q/P reading is not 50 mS/m then adjust the Phase control so that the Q/P reading is 50 mS/m (+/-1 mS/m).

Step 6

Bring both readings of Q/P and I/P to zero once again, as described in steps 1 and 2.

Now lift the EM38 to a height of about 1.5 Meters (5 feet).

Step 7

With the instrument in the air and in the horizontal dipole mode of operation (Fig. 1), set the Q/P and I/P readings to zero as was done in steps 1 and 2.

Step 8

Now with the mode switch in the Q/P position adjust the Q/P zero control so that an arbitrary value (i.e $H=10$ mS/m) appears on the display. Rotate the EM38 to the vertical dipole mode and note the reading (hypothetically $V=16$ mS/m). Subtract the horizontal dipole reading from the vertical ($V-H=6$ mS/m).

Step 9

Finally, with the mode switch still in the Q/P position and instrument still in the horizontal dipole mode, rotate the Q/P zero control until the display reads the value calculated in step 8. In this example it

would be 6 mS/m. Now when you rotate the EM38 to the vertical dipole mode the reading should be 12 mS/m.

With instrument at least 1.5 meters above ground or higher, the Q/P reading or conductivity should always satisfy the following equation:

$$V=2H$$

where V = vertical dipole mode reading

and

H = horizontal dipole mode reading

Fig. 1

2. EM38 OPERATING INSTRUCTIONS - Expanded Method

The following procedures are used to prepare the EM38 for survey operation. The suggested time interval between the various procedures are typical values; under adverse conditions they may have to be carried out more often and under good conditions less often, as dictated by survey experience.

2.1 Battery Test

The battery test should be carried out at the beginning of each day or when the battery voltage is suspected of being low. Check the battery voltage as follows: with the range switch in the 1,000 mS/m position set the battery test switch to BATT. In the case of a good battery the meter will read over -720 units. If the meter reads below -720 units replace the battery. To remove the battery, undo the two screws holding the cover of the battery compartment at the top rear of the instrument frame. A Mallory MN1604 9-volt Alkaline battery or equivalent gives about 30 hours of continuous operation. For longer service (about 55 hours) we recommend a Mallory TR146X 9-volt Mercury battery.

2.2 Initial Inphase Nulling

The initial inphase nulling should be carried out at the beginning of the day at the first survey station. As described in Technical Note TN-6 the EM38 measures ground conductivity by inducing very small electrical "eddy" currents in the ground and measuring the magnetic field that these currents generate. A small transmitter coil located at the rear of the EM38 is used to generate the time-varying primary magnetic field which induces the eddy currents in the ground, and a small receiver coil located at the front end measures both this strong primary magnetic field and the much smaller secondary magnetic field arising from the eddy currents in the ground.

It is the task of the receiver electronics to measure the very small signal from the eddy currents in the presence of the much larger signal arising from the primary magnetic field. To facilitate this measurement an internally generated signal is used to cancel or "null" the large primary signal so that it does not overload the electronic circuitry, particularly on the most sensitive range scale (100 mS/m). Because of the high sensitivity of the EM38 it is advisable to remove all metal objects from wrists, fingers, neck and pockets when making this adjustment (sensitivity to metal objects, which is discussed further in Section 2. is greatest near the coils at either end of the instrument).

To null the EM38, set the I/P range switch to the 1,000 mS/m range. Lift the instrument to a height of about 1.5 meters (5 feet) above the ground and place in the horizontal dipole mode of operation (Fig. 1). Set the Mode switch to the I/P position and null the meter to indicate zero by first adjusting the I/P coarse zero control and then the I/P fine zero control. Repeat the procedure on the 100 mS/m range, re-adjusting the Zero controls if necessary. The EM38 is satisfactorily nulled when, with the Mode switch in the I/P position and the instrument at a height of 1.5 meters the meter reads approximately zero (± 10 mS/m) on the 100 mS/m position.

2.3 Instrument Zero

This adjustment should be carried out at the beginning of each day at the first survey station and should be checked thereafter three or four times a day or more often when making measurements over ground of low conductivity. As referred to earlier, this adjustment is used to accurately set the instrument zero so that if the unit were taken to a great height above the earth (so as to no longer respond to terrain conductivity) it would actually read zero. As with all measurements, it is carried out with the long axis of the instrument horizontal as shown in Fig. 1.

The Mode switch is now in the normal Q/P position. Lift the instrument to a height of approximately 1.5 meters (5 feet) above the ground. The exact height is not critical but this height should be reasonably accurately maintained (± 5 cm or 2 inches) throughout the zeroing procedure. With the instrument in the horizontal dipole mode of operation (Fig.1) and the Q/P range switch set to 100 mS/m adjust the Q/P Zero control so that the Q/P meter reads approximately 50 mS/m. Note the meter reading in mS/m which we shall call H. Now without changing the instrument height, rotate the instrument about the long axis to the vertical dipole mode (Fig. 1) and once again read the Q/P meter. Note the new reading which we shall call V (over highly conductive ground it may be necessary to adjust the range switch to a higher range to obtain an on-scale reading). Now it can be shown that, regardless of any layering in the earth, with the instrument at a height of 1.5 meters V should equal twice H; conversely if V is not equal to twice H we know that the zero is incorrectly set.

We can alter the instrument zero arbitrarily by adjusting the Q/P Zero Control. However we know that we must adjust this control by an amount such that when we repeat the vertical and horizontal dipole measurements after the adjustment (again at 1.5 meters) the new Q/P meter readings, which we shall call V_N and H_N , must satisfy $V_N = 2H_N$. Let C be the amount by which we alter the meter reading by adjusting the Q/P zero Control. How much should C be? If V and H are the readings before the adjustment and V_N and H_N are the readings after, then, since the correction C affects both V and H equally, $V_N = V + C$ and $H_N = H + C$. But C has been chosen so that $V_N = 2H_N$ and therefore

$$\frac{V}{H} = \frac{V + C}{H + C} = 2$$

which can be re-arranged to give C as

$$C = V - 2H$$

Thus having obtained V and H, the initial meter readings in the vertical and horizontal dipole modes respectively, to set the zero correctly we first calculate $C=V-2H$, and then with the instrument in either position we adjust the Q/P Zero Control so as to alter the meter reading by the amount C (in the direction of higher conductivity if C is positive, lower conductivity if C is negative). Repeating the vertical and horizontal dipole measurements should now give $V=2H$ and the zero is correctly set.

An example will help to illustrate this procedure. Suppose that with the instrument at 1.5 m height the meter reads 12 mS/m in the horizontal dipole mode and 35 mS/m in the vertical dipole mode.

Then $H = 12 \text{ mS/m}$
 $V = 35 \text{ mS/m}$

and we calculate $C = 35 - 2 \times 12 = +11 \text{ mS/m}$

With the instrument at 1.5 meters and in the horizontal dipole mode (and thus still reading 12 mS/m) we now adjust the Q/P Zero to increase the meter reading by 11 mS/m and thus make the new reading $H_N = H + C = 12 + 11 = 23 \text{ mS/m}$. If we rotate the instrument to the vertical dipole mode it will now read 46 mS/m (which is twice 23) since the 35 mS/m has also been increased by 11 mS/m. The zero is correctly set.

Again, suppose that the readings are

$H = 14 \text{ mS/m}$
 $V = 16 \text{ mS/m}$

we calculate $C = 16 - 2 \times 14 = -12$

and with the instrument at 1.5 meters height and in the horizontal dipole mode we now adjust the Q/P Zero so as to reduce the horizontal dipole reading by 12 i.e., from 14 to 2, whereupon when we rotate the instrument to the vertical dipole mode it will read $16 - 12 = 4$, which is twice 2. Again the zero is correctly set.

It was stated at the introduction to this section that this adjustment should be carried out at the first survey station at the start of each day. Suppose that this site happens to be a region of very high conductivity, say 1,000 mS/m to take an extreme example. If the conductivity is uniform with depth at an instrument height of 1.5 meters it can be shown that the correct value of V will be 312 mS/m and of H 156 mS/m. The accuracy of the zero setting will be of the order of 10 mS/m. This is perfectly adequate for regions where the ground conductivity is 1,000 mS/m but if the conductivity falls to a few tens of mS/m an error of 10 mS/m in the zero setting would become very serious. The answer is, of course, that if regions where the conductivity falls to low values are encountered during the progress of the survey, we should reset the zero in these areas at the 100 mS/m scale. A small change in the zero

setting will have negligible effect on the accuracy of the previous high conductivity readings and will greatly improve the accuracy in low conductivity areas.

In setting the zero the operator will occasionally find that, on rotating the EM38 from the horizontal dipole position where he got H to the vertical dipole mode to get V the meter reading does not change, i.e., $V=H$. The answer to this puzzle is that he is standing over ground that is so resistive that at 1.5 meters height the EM38 no longer responds to the conductivity. The procedure outlined above still works however; now $C=V-2H = -H$, so that he will adjust the Q/P zero control to reduce the meter reading by H which, of course, adjusts it to read $H_N=0$. Rotating the instrument will give $V_N=0$ as well.

Particularly over resistive ground the operator must ensure that, when setting the instrument zero he is not near fences, cars or other large metallic objects. The reason for this is that the theory wherein $V_N=2H_N$ applies only for a uniform or a horizontally layered earth. The presence of large metallic objects will usually affect H more than V, and will thus give an error in the zero setting. The operator must also make sure that the ground is laterally uniform for a few meters on either side of the site where he is setting the zero. He must not, for example, attempt to set the zero in an abandoned landfill site where there are probably buried metallic objects, without first making sure that the surrounding area is reasonably uniform by carrying out a quick preliminary EM38 survey.

It should be noted that if the operator does not want to use the Q/P zero to physically alter the zero setting during the survey, he should take readings of V and H (with the instrument at 1.5 meters every so often during the day. Then, when he is doing the data plotting he should calculate C, using the above quotation and add or subtract the value of C to the survey readings to correct them using linear interpretation as necessary. In the first example given above, 11 mS/m would be added to the readings, and in the second example 12 mS/m would be subtracted from them.

2.4 Final Inphase Nulling

It was stated above that the inphase nulling was required in order to cancel or null the large primary signal from the transmitter so that it does not overload the electronic circuitry, particularly on the most sensitive scale; thus the nulling procedure was carried out before setting the instrument zero, as described above. Unfortunately the magnetic susceptibility of soils causes an additional signal to be picked up by the receiver coil when the EM38 is located close to or is lying on the surface of the ground. Fortunately this signal decreases rapidly with the instrument height above the ground and is negligible at a height of 1.5 meters.

The additional signal is dealt with in one of two ways. If the survey is to be carried out in only the vertical or horizontal dipole mode the instrument is simply placed on the ground in the appropriate position and the residual signal arising from the magnetic susceptibility is nulled out exactly as described in Section 2.2 (except that the instrument is on the ground).

In the event that the zero level is to be checked during the survey the nulling procedure should be repeated with the instrument at 1.5 meters before the zero check is carried out, and again when the instrument is placed back on the ground for further conductivity measurements. The magnetic susceptibility of the soil generally varies relatively slowly with location so that checking the null on the ground every half hour or so is usually sufficient.

More commonly, surveys are carried out in both the vertical and horizontal dipole configurations in order to obtain information about the layering, as described later in this note. Unfortunately, the signal from the susceptibility causes a positive meter deflection in the vertical dipole mode (when the Mode switch is in the I/P position) and a negative meter deflection in the horizontal dipole mode, so that even though the instrument is correctly nulled for a vertical dipole measurement, re-nulling is necessary for the horizontal mode measurement, significantly slowing survey speed. However, this procedure must be followed when making accurate measurements in both the vertical and horizontal dipole modes on low conductivity ground having significant magnetic susceptibility. On some occasions it may be quicker to perform the survey twice, first in one mode and then in the other.

There is another solution to this problem which is often quite satisfactory. In this approach the procedures described in Sections 2.2 and 2.3 for Initial Inphase Nulling and Instrument Zero setting are carried out as indicated at a height of 1.5 meters. The range switch is then set to the 1000 mS/m position, the Mode switch to the I/P position, and the EM38 is laid on the ground in the vertical dipole mode. If the I/P reading is less than 150 mS/m, then the 100 mS/m position for the range switch can be used for all subsequent ground conductivity (Q/P) measurements in either the vertical or horizontal dipole mode. If the I/P reading is greater than 150 mS/m, the 1,000 mS/m position for the range switch must be used for conductivity measurements. If minimal effect from any susceptibility variations is desired (for example in archaeological applications) then the inphase nulling procedure described above must be carried out before every measurement and the faster way is probably to perform the survey twice, once in each dipole.

Finally if it is observed that the values of conductivity do not repeat from one range switch setting to another susceptibility signal has become too large and the EM38 must be re-nulled.

2.5 Equipment Functional Checks

These checks need be carried out only at the start of a new survey. To check the phasing and the sensitivity of the instrument, first set the inphase null as described in section 2.2. To check the phasing, lift the instrument to 1.5 meters in the horizontal dipole position and set the range switch to 1,000 mS/m. With the Mode switch in the Q/P position, note the conductivity reading on the meter. Rotate the I/P coarse zero control clockwise one step, note whether the reading changes, and return the I/P coarse zero to its original position (one step counter-clockwise). If the reading changed, adjust the phase control a small amount in one direction, note the new meter reading, again rotate the I/P coarse zero to its original position. If the meter change was less than for the original position of the phase control, re-

adjust the phase control farther in the same direction, and repeat the procedure, until rotating the I/P coarse zero to one step clockwise produces no significant change in the meter reading. The phase control is now correctly set. If at any time the meter change becomes greater, the phase control should be adjusted in the opposite direction. Check that the I/P coarse zero control has been left in its original position by checking the null of the instrument (Section 2.2).

To approximately check the sensitivity of the instrument, with the range switch at 1,000 mS/m and the instrument at 1.5 meters in the horizontal dipole position set the Mode switch to the I/P mark and rotate the I/P coarse zero control clockwise one step. Meter should change between 100 and 200 mS/m. Make sure that the I/P coarse zero control is reset to its original position.

3. SURVEY PROCEDURES

To carry out a survey with the EM38, one simply lays the instrument on the ground to take a reading. This can be done either in the vertical dipole mode or in the horizontal dipole mode, with important differences in the depth response to be described later in this manual.

The EM38 yields good spatial resolution and measurement stations should be as close as a meter apart if maximum resolution is to be employed. The decision as to the correct station spacing will be based on an estimate of the lateral dimensions of the anticipated conductivity anomalies. Since measurements can be made very quickly it is better to have too many measurements with good spatial resolution rather than too few.

This instrument is a sensitive detector of small changes in ground conductivity and, particularly when set to the most sensitive scale (100 mS/m), is responsive to metal objects either in or on the ground or on the operator. Metal chains around the neck or wrist, metal wristwatch straps, metal framed glasses, steel supports in boots, coins, keys, or knives in pockets can be offenders when they are located close to the coils (which are at either end of the instrument) either when on survey or when the null or zero is being set. To check whether a metal object is giving a detectable response simply move the object a few meters away from the instrument and note whether the reading changes. No change -- no problem.

How near can the operator approach a conductive object such as a pipe, fence, etc., and still ensure that the readings are accurate? In a laterally uniform ground the EM38 should read the same regardless of the azimuth of the long axis (i.e., whether it is pointing north/south or east/west). Any significant difference in the reading in two directions at right angles is an indication of a significant lateral disturbance. To check whether a pipe or fence is producing an erroneous reading make two measurements of the ground conductivity, one reading with the long axis pointing to the object and a second reading at right angles. If the two readings differ by more than 10% a significant disturbance is being felt and the measurement point must be located further away from the object.

It should be noted when traversing a pipe on a survey line perpendicular to the pipe direction in the vertical dipole mode that the reading over the pipe may decrease and attempt to go negative. If the goal is to locate the pipe one should again rotate the instrument 90° so that the long axis is parallel to the pipe in which case the apparent conductivity reading becomes a maximum when (a) the instrument is directly over the pipe and (b) also pointing in the same direction as the pipe. These remarks apply in the vertical dipole mode, which should be used for the detection of pipes since the exploration depth is greatest. It is, of course, assumed that the pipe is conductive i.e., is made of iron, steel or copper.

4. ELECTRICAL INTERFERENCE

Occasionally electrical interference will be encountered, either from cultural sources (50/60 Hz power lines, industrial noise) or from atmospheric electricity (spherics). Noise from cultural sources will often manifest itself as slow or rapid semi-periodic oscillations of the output meter reading which must be averaged out by the operator. The amplitude of these excursions may be a function of the coil orientation and will also be largest on the most sensitive (low conductivity) range.

In regions where intense cultural noise is suspected (near large power lines, etc.) and the range setting is on the 100 mS/m position it is often a good idea to check for instrumental overload by increasing the range setting and checking that the indicated conductivity still reads the same. To give an example: suppose we are working on the 100 mS/m scale and the instrument reads 20 mS/m near a power line. If the reading is not 20 mS/m on the 1,000 mS/m scale, overload is present and readings must be taken at 1,000 mS/m range. Suppose however that at this location the instrument reads 20 mS/m on both the 100 and 1,000 mS/m scales. The overload is not present and high sensitivity range 100 mS/m can be used in the vicinity of the interference.

Atmospheric noise will usually show itself as sporadic changes of the meter reading, usually most severe in the horizontal dipole mode. In this case the receiver operator must again average out the noise, or restrict himself to the vertical dipole mode of operation, or wait until the spherics have decreased.

5. NOTES ON SURVEY INTERPRETATION

5.1 Linearity of Response

The indicated apparent conductivity measured with the EM38 is accurate over the full range of the instrument.

5.2 Relative Response with Depth

TN-6 discusses in detail the fact that it is possible to calculate the relative response from material at different depths for both the vertical and horizontal dipole mode coil configurations. The results for the EM38 are shown in Fig. 2 where the function ϕ gives the fractional response to the meter reading from a thin horizontal sheet of thickness dz buried at a depth z . We see that in the vertical dipole mode the relative sensitivity to near surface material is very low (being zero

right at the surface), that the sensitivity increases with depth, becomes a maximum at about 0.4 meters and decreases slowly thereafter. On the other hand in the horizontal dipole mode of operation the relative sensitivity is greatest to material at the surface, and decreases thereafter with depth. The large difference in the response to near surface material in the two coil configurations is important; the horizontal dipole mode will be relatively sensitive to variations in the near surface whereas the vertical dipole mode will be insensitive.

This difference in sensitivity allows a quick method for determining whether the near surface material is more or less conductive than material at depth. One simply places the instrument on the ground in the vertical dipole mode, notes the reading, rotates the instrument to the horizontal dipole mode and again notes the reading. If the second reading is greater than the first, the near surface material is the more conductive and vice versa. If both readings are essentially the same then the conductivity of the ground is essentially uniform to a depth of about 1.5 meter, the effective depth of exploration for the EM38.

5.3 Multi-Layer Calculations

The functions $R_v(z/s)$ and $R_h(z/s)$ referred to in TN-6 are illustrated in Fig.3. It will be recalled that these curves give the fractional response arising from all material below depth z for both the vertical and horizontal dipole modes (the curves in TN-6 refer to the depth normalized with respect to the intercoil spacing which for the EM38 is one meter so the curves apply directly). These curves, when used with the techniques outlined in TN-6, allow simple calculation of the instrument response in either coil configuration to a multi-layered horizontally stratified earth.

5.3.1 Variation of EM38 Response with Height

The curves of Fig. 3 also give the decrease of the apparent conductivity reading when the instrument is lifted above a uniformly conductive earth, since in general for a two-layered earth

$$\sigma_a = \sigma_1 [1 + R(z_1)] + \sigma_2 R(z_1)$$

and if the first medium is air, with conductivity $\sigma_1=0$

$$\sigma_a = \sigma_2 R(z_1)$$

where z_1 is now the instrument height above the ground.

Examination of the curves shows that in the vertical dipole mode an increase of elevation from 0 to 20

cm results in a reduction of apparent conductivity reading to 92.5% of the surface reading, whereas in the horizontal dipole mode the reading is reduced to 68%. We thus see that the instrument reading in the horizontal dipole mode is more sensitive to instrument height or conversely that in regions where the surface topography varies rapidly on the order of 10-20 cm we can expect some scatter in the horizontal dipole readings.

In the event that the earth is two-layered it is possible to resolve this geometry by lifting the EM38 above the ground and making a sequence of measurements at various heights in both the horizontal and vertical dipole mode. The curves shown in Figs. 4 and 5 illustrate the fall-off with height of the apparent conductivity for a variety of two-layered configurations; to employ them one simply plots the measured apparent conductivity with height on a piece of transparent paper to the same scale as the figures and translates the plot vertically or horizontally across the various figures until a match is obtained. The various layer parameters are then calculated as in the following example, using the measured values of apparent conductivity from Table 1.

TABLE 1
Apparent Conductivity (mS/m)

h (m)	Vertical <u>Dipole</u>	Horizontal <u>Dipole</u>
0.0	93	77
0.5	62	36
1.0	41	23
1.5	29	16
2.0	23	12

By translating this data as described above on top of the various curves of Fig. 4 we see that good agreement is achieved for $t=0.3$ m and $k=\sigma_2/\sigma_1=2$. Furthermore we note that, in the vertical dipole mode $\sigma_a/\sigma_1=1.85$ when $\sigma_a=93$ mS/m. Therefore $\sigma_1=\sigma_a/1.85=50$ mS/m, $\sigma_2=2\sigma_1=100$ mS/m, and $t=0.3$ m, fully resolving the two-layered geometry.

It should be noted that these curves are also useful for a three-layered earth geometry where the upper layer is relatively resistive compared with the other two, as illustrated in Fig. 6. In this case we simply assume that $\sigma_1=0$ and that this layer effectively prevents us from laying the instrument on the more conductive second layer. The fall-off with height of the apparent conductivity over such a geometry will still be as shown in Figs. 4 and 5 except that when a good match to one of these curves has been obtained it will be found that at a measured instrument height of zero meters the appropriate curve will still indicate a finite height, the value of which is the actual thickness of the upper resistive layer.

The user is cautioned that, to the accuracy with which the measurements can be made, more than one set of the curves shown in Figs. 4 and 5 may match the field data, in which case he must rely on other factors (such as knowledge of the probable geology) to decide which model is more appropriate.

5.3.2. Simplified Two-layered Earth Interpretation

In general, a two-layered earth has three unknown quantities, σ_1 , σ_2 , and t , whereas measurements made with the EM38 on the ground produce only two measured quantities, σ_{av} (the apparent conductivity in the vertical dipole mode) and σ_{ah} (the apparent conductivity in the horizontal dipole mode). If one of the two unknown conductivities is much greater than the other and we may assume that the smaller conductivity is zero we are left with only two unknowns and the problem is fully resolved. If $\sigma_1 \gg \sigma_2$ we obtain the conductivity and the thickness of the upper (conductive) layer; if $\sigma_2 \gg \sigma_1$ we obtain the depth to and the conductivity of the lower (conductive) layer.

Given σ_{ah} and σ_{av} the procedure is as follows: if $\sigma_{av} > \sigma_{ah}$ calculate the ratio $\sigma_{ah} / \sigma_{av}$ and with this ratio use curve (1) Fig. 7 to determine z , the depth to the conductive substrate. Given z , use Fig. 3 to obtain either $R_h(z)$ or $R_v(z)$ whence

$$\sigma_2 = \frac{\sigma_{ah}}{R_h(z)} = \frac{\sigma_{av}}{R_v(z)}$$

and the problem is solved.

If on the other hand $\sigma_{ah} > \sigma_{av}$, calculate $\sigma_{av} / \sigma_{ah}$ and with this ratio use curve (2) in Fig. 7 to determine z , the thickness of the conductive upper layer. Given z use Fig. 3 to obtain either $R_h(z)$ or $R_v(z)$ whence

$$\sigma_1 = \frac{\sigma_{ah}}{1 + R_h(z)} = \frac{\sigma_{av}}{1 + R_v(z)}$$

Note that in the event that neither $\sigma_1 \gg \sigma_2$ or $\sigma_2 \gg \sigma_1$ it is still possible to use this procedure to define an apparent conductivity and an apparent thickness (or depth) which should be reasonably valid as long as a reasonable conductivity contrast exists. If the earth has more than two layers this procedure defines the equivalent two layered earth.

6. MEASURING SOIL MAGNETIC SUSCEPTIBILITY

It is a simple matter to measure the magnetic susceptibility of the upper half meter of the soil using the EM38 in the vertical dipole mode. Set the Mode switch to the I/P position so that the instrument is measuring the inphase component from the ground and lift the instrument to a height of approximately 1.5 meters above the ground. On the 100 mS/m scale set the meter reading to approximately 50 mS/m using the I/P coarse and fine zero controls and note the apparent conductivity reading at this height. With the Mode switch still in the I/P position, lower the instrument to the surface and again measure the apparent conductivity. It will be observed that as the instrument is lowered, the meter reading initially swings to lower conductivity, then returns to the conductivity which was indicated at the height of 1.5 meters and finally increases to a larger apparent conductivity. This is entirely normal. If the meter goes over 100 mS/m when the instrument is lowered to the ground the range switch is adjusted to the 1,000 mS/m scale.

The magnetic susceptibility (in RMKS units) is then given by

$$K = 58 \times 10^6 \Delta \sigma_a \text{ (mS/m)}$$

or in CGS units by

$$K = \frac{58 \times 10^6}{4\pi} \Delta \sigma_a \text{ (mS/m)}$$

where $\Delta \sigma_a$ is the difference in the apparent conductivity measured when the instrument is on the ground and elevated to 1.5 meters.

7. OUTPUT UNITS

The EM38 is calibrated so that under the low induction number approximation the quadrature component output (Q/P) reads directly in apparent conductivity (σ_a). The inphase component output (I/P) on the EM38 also reads in units of mS/m; where 29 ppt of the secondary field relative to the primary field corresponds to 1,000 mS/m.

The following relation can be used to convert mS/m to ppm: 1 mS/m / 29 ppt

$$\text{where 1 ppm (parts per million) = } \frac{1}{1000} \text{ ppt (parts per thousand)}$$

When the instrument is used with a digital data logger (DL720) or computer the I/P readings in mS/m are automatically converted to ppt.

8. CONCLUDING REMARKS

It is hoped that the material given in this manual will assist in survey interpretation. It should be borne in mind that the strength of the EM38 lies in the speed and accuracy with which a reconnaissance conductivity survey can be carried out. While the instrument was not designed for detailed sounding of conductivity with depth it gives very useful results when the earth can be approximated by a two-layer mode.

9. EM38 INSTRUMENT SPECIFICATIONS

Measured Quantity	:	Apparent conductivity of the ground in millisiemens per meter (mS/m)
	:	Inphase response in parts per thousand (ppt) of secondary to primary magnetic field
Conductivity Ranges	:	100, 1,000 mS/m (4 digit digital meter)
Measurement Precision	:	$\pm 0.1\%$ of full scale deflection
Primary Field Source	:	Self-contained dipole transmitter
Sensor	:	Self-contained dipole receiver
Intercoil Spacing	:	1 meter
Operating Frequency	:	14.6 kHz (40.4 kHz optional)
Temperature Range	:	-30°C to +50°C
Power Supply	:	9V Transistor radio battery (e.g. Mallory MN1604)
Battery Life	:	30 hours continuous for MN1604

WEIGHT AND DIMENSIONS

Instrument	:	3.0 kg	106x15x3.6 cm
Shipping	:	10.0 kg	117x19x13 cm

March 1999

10. APPENDIX

- (i) Schematic Diagram of Vertical and Horizontal Dipole Positions
- (ii) Relative Response Curves
- (iii) Gain Calibration Using Test Coil

(iii) EM38 GAIN CALIBRATION PROCEDURE

For units operating 14.6 kHz - standard

The following is the gain calibration procedure for EM38 using the test coil and test jig:

POSITION 1

1. Set the phasing of the instrument as described in section 2.5 of EM38 operating instructions.
2. Set EM38 in the jig with the Q coil in position #1. Make sure that the Q coil is switched off.
3. Turn EM38 on to 100 mS/m range and adjust I/P and Q/P components to zero.
4. Turn Q coil on. The EM38 should read approximately 90 mS/m with Mode switch in Q/P position and $90 \text{ mS/m} \pm 10 \text{ mS/m}$ with Mode switch in I/P position. Next adjust I/P to zero and Q/P should read $90 \text{ mS/m} \pm 1 \text{ mS/m}$. If not, adjust Gain pot #R14 (inside the instrument) until Q/P reads 90 mS/m.

POSITION 2

1. Place Q coil in position #2, making sure that Q coil is turned off.
2. Set EM38 to 100 mS/m range and adjust I/P and Q/P component to zero.
3. Turn Q coil on. The EM38 should read approximately 24 mS/m with Mode switch in Q/P position and $23 \text{ mS/m} \pm 5$ with Mode switch in I/P position. Adjust I/P to zero and Q/P should read $24.5 \text{ mS/m} \pm 1 \text{ mS/m}$.

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