Report 7, 1987

GEOPHYSICAL INSTRUMENTATION AND DATA ACQUISITION IN ELECTRICAL RESISTIVITY PROSPECTING

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ABSTRACT

In this report the author attempts to look into the geophysical instruments and the associated data acquisition procedures in electrical resistivity prospecting. He also describes the instruments major components in terms of their functions in the instruments with respect to data acquisition. The field procedure based on Icelandic experience is also described and was used to obtain resistivity data in the Krísuvík area south west Iceland using the Schlumberger electrode configuration.
The limitations to electrical resistivity prospecting are also discussed in some details. Mention has been made on the tentative steps towards approaching a functional problem in the instruments in case of defects. The report is therefore laying emphasis on the fact that, for one to be able to obtain the best results from any geophysical work, worth meaningful interpretation, then he or she has to understand the equipments used in addition to being thoroughly conversant with data acquisition procedures and other related requirements to ensure a smooth and an almost un interrupted flow of the work during field operations.

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1. INTRODUCTION

Geophysics being an important, but expensive branch of Earth Science applied to investigate the physical properties under the earth mainly in exploring for oil, water, geothermal resources, minerals, etc, will demand that the application of any of its disciplines that include MT, AMT, EMT, Seismic, Gravity, Electrical resistivity surveys etc should give the best results possible and within the time scheduled to complete the survey program of the given project. This is important if the cost of running the project is to remain within the budget estimates. To be able to fulfil these requirements, instruments in excellent working conditions with qualified manpower having long time experience in instrumentation and the associated data acquisition procedures are the important underlying factors. This requirement is indispensible because it will help many countries especially the developing ones to be self sufficient hence reduce some of the technical mistakes that are made due to inability to make suitable choices of instruments with specification to meet the workload of the intended project, which when combined with lack of qualified personnel to use and maintain the instruments results in obtaining very poor and unreliable data whose interpretations cannot be of any scientific or economic significance.

2. DESCRIPTION OF THE INSTRUMENTS

In order to conduct a resistivity survey, the following instruments are required;

(i) Current transmitter.

(ii) Potential difference receiver.

(iii) Power source.

(iv) Electric cables.

(v) Current Electrodes.

(vi) Potential electrodes.

N.B In some resistivity instruments both the current transmitter and the potential difference receiver are built in a single case and are usually referred to as "All In One" resistivity instruments. There are those resistivity instruments that operate on the basis of either frequency or time domain. In the frequency domain instruments, the current input to the ground is a sine wave with frequency f, and time $T = 1/f$ and the resulting output voltage is also a sine wave whose amplitude A, and phase ϕ depend on the electrical properties of the earth. The output is delayed by; $\phi * T/2\pi$ relative to the transmitted current waveform, these waveforms are illustrated in Figure 1. In time domain the transmitted and received waveforms are illustrated in Figure 2. The received waveform is as a result of the transmitter current being periodically turned on and off and the output is the voltage measured when the transmitter current is off and R and I are the peak amplitudes of the in phase (real) output waveform and the quadrature (imaginary) component (Stanley H. Ward and William R. Sill, 1983).

The components and the role played by each instrument with respect to electrical resistivity prospecting is described in individual terms as follows:

2.1. Current Transmitter

This is the resistivity instrument that constitute the current circuits and used for transmitting the current into the ground during a resistivity survey (see schematic diagram in Figure 3). The major components and functions in the instrument are as follows;

(i) On/off switch - used for activating the circuits.

(ii) Power supply terminal - for connection with power supply unit.

(iii) Voltage converter - for stepping up the input voltage from power supply.

(iv) Voltmeter - for indicating voltage output.

(v) Amperemeter - for indicating the current output.

(vi) Current reversion mechanism (switch or automatic, optional) for reversion of direction of current flow during the sounding or profiling.

(vii) Commutation switch - for selecting the path of current flow in the instrument circuits.

(viii) Filters - for filtering off peak voltages.

(ix) Current output terminals - to connect the current transmitting cables.

(x) Voltage range adjusting switch - for selecting a desirable voltage output.

(xi) Voltage regulation switch - for adjusting the voltage output peaks to match the selected voltage output.

(xii) current regulation switch - for adjusting current output peaks to match the selected current output.

(xiii) Light indicator (L.E.D) - for showing that the circuits have been activated.

2.2. Potential Difference Receiver

This may be a digitally computerized microprocessor or may be a potentiometric strip chart recorder. The principal on which the two work is the same except for certain differences in efficiency and convenience. The principal parts of a potential measuring receiver as shown in Figure 4 are as follows;

(i) S.P (Spontaneous Potential) compensation module - for cancelling out the DC component of the parasitic currents from the input potential signal.

(ii) Filter module(the RC type) - for smoothing the signal by eliminating the high frequency component of the parasitic currents.

(iii) Amplifier module - for amplification of the potential difference signal.

(iv) Power supply module - for power supply.

(v) MN input terminals - for connecting the potential measuring cables.

(vi) On/Off switch - for activating the circuits.

2.3. Power Sources

The power supply used in resistivity surveys can be obtained from any of the following sources depending on the type the instrument is designed to use;

(i) A.C generator 50 Hz.

(ii) Transistor oscillator(low frequency) with a transformer power output to meet the power specifications of the instrument.

(iv) Motor driven alternator for high power requirements.

(v) a set of rechargeable batteries that can be connected in series to give a total of several tenths volts DC.

2.4. Electric Cables

These are usually copper or copper and steel insulated together, although the use of aluminum is also employed and has the advantage of being light. These are used for transmission of the current from the current transmitter to the current electrodes and also for transmitting the potential difference signal across the potential electrodes to the receiver. The following information must be looked for in the specifications when purchasing the cables; thus,

(i) Insulation temperature.

(ii) Resistance.

(iii) Diameter.

(iv) Density.

Note: The cables for potential measurement should be shielded or have a double core flex.

2.5. Reels

The reels are used for winding the cables on. They should be made of very light material, precisely aluminum to reduce the weight when the cables are wound onto them.

2.6. Current Electrodes

These are usually iron bars or spiral blades. The iron bars can be of diameter of one centimeter or less and a bout 50 centimeters long. They are used for conducting the current into the ground by being made to have contact with the ground by hammering or pushing them down into the ground depending on the condition of the ground and connecting them to the current cable. The spiral blades electrodes are better than the iron bars because they have a bigger surface area for contact with the ground but in dry surface conditions they are difficulty to drive down.

2.7. Potential Measuring Electrodes

These are usually porous pots that are actually ceramic vessels filled with a saturated solution of copper sulphate. The base is porous and a copper metal rod is made to have contact with the copper sulphate solution and is continuous to the outer surface through the cork and the potential cables are connected to its tip. Due to polarization potentials generated at the point of contact between a metallic conductor and an electrolytic conductor the use of metallic electrodes is not recommended although stainless steel can be used but has the disadvantage of being too expensive.

3. TECHNICAL SPECIFICATIONS

Technical specifications are the most important thing one should consider when making a choice of the instrument to use because it contains the strength of an instrument to measure a given parameter. The details concerning the following deserve considerations; thus,

(i) Maximum transmitter voltage and current outputs.

(ii) The following should be known about the receiver; thus,

(a) Input impedance(Mohms).

(b) Input voltage ranges(mV-V).

(c) Common Mode Rejection Ratio (CMRR)in decibel(dB)

(d) Accuracy(%) and precision.

(iii) Power source and its capacity.

(iv) Operating conditions e.g temperature and humidity.

(v) Weight(kg).

(vi) Dimensions W*L*H(mm).

As far as the technical specifications are concerned it is important to pay special attention to the accuracy and precision of the entire instrument. Accuracy can be defined as the maximum error in the measurement of a given physical quantity in terms of the output of a particular instrument and is usually given as a percentage of the instrument's full scale ie Absolute Error/Output of Full Scale * 100%. Accuracy in ideal situations represents the ability and the extent to which an instrument conforms to certain design conditions to produce results for the physical quantity being measured within the error limits given in the specifications, thus it is the measure of an instruments efficiency. If the instrument's output is compatible with the specifications given when it is employed practically in the field, then such an instrument can be considered suitable for the work with respect to its technical specifications. On the other hand an instrument may be operating well within the specified accuracy but while in the field the problem of precision is usually a major drawback towards the accuracy of the results measured using the instrument. Precision can be defined as the number of distinguishable alternatives from which a representative alternative is selected eg, if one made the following measurements, ie 150.1 mV, 150.4 mV, and 151.5 mV it might appear that the value 151.5 mV seems to have higher precision than the rest of the values, but it does not necessarily mean that it is more inaccurate or accurate than the rest. It is in such kind of situation that one may find it difficult to decide which among the three values was measured more accurately than the others. Precision may come as an effect of the interference of noise causing factors in geophysical surveys and affects the accuracy of the results by producing different results that do not necessarily reflect the accuracy of the instrument.

4. THEORY OF MEASUREMENT

The relationship for the potentials at the earths surface form the basis for understanding the quantities that are measured and the factors that define resistivity stratification in the subsurface. In this respect, the potential field at the surface set up by a single point source of current gives way to considering the actual case in which two current electrodes are used. The theoretical considerations given below form the basis for one dimensional interpretations and is as well important in two and three dimensional interpretations; thus

(a) The subsurface consists of finite number of layers separated from each other by horizontal boundary planes with the deepest layer extending to infinite whereas the upper layers have finite thickness.

(b) Each of these layers are considered electrically homogeneous as well as electrically isotropic.

(c) The field is generated by a point source of current located at the surface of the earth.

(d) The current emitted by the source is direct current.

If we consider Ay as an element of surface and J the current density in Amp/m^2 per square meter, we can say the current flowing through the element surface Ay is J*Ay. The current density J and the electric field E can be related according to Ohms law as follows for flow of electric currents in extended media as;

$$J = \sigma E = 1/\sigma * E \qquad (1)$$

where J = current density Amps\square meter

σ = conductivity of the medium

E = electric field volt per meter

Electric field E is a gradient for a scalar potential, thus,

$$E = -\nabla V \qquad (2)$$

hence equation 1 can be rewritten as,

$$J = -\sigma \nabla V \qquad (3)$$

In the event of a charge being conserved; thus no current sources or sinks with a volume enclosed by a surface A, then,

$$\int_A J dA = 0 \qquad (4)$$

According to Gauss' Theorem which states that the volume integral of the divergence of a current throughout a given region is equal to the total charge enclosed,

$$\int_V \nabla J dV = 0 \qquad (5)$$

hence if dV is an infinitesimal volume enclosing a given point then we have,

$$\nabla \bullet J = - \nabla^2 (\sigma V) = 0 \qquad (6)$$

and

$$\nabla \sigma \bullet \nabla V + \sigma \nabla^2 V = 0 \qquad (7)$$

with c constant throughout, we have Laplace equation as

$$\nabla^2 V = 0 \qquad (8)$$

Therefore the electric potential distribution for the D.C current flowing in a homogeneous isotropic medium satisfies the Laplace equation. For a current, I, injected into an infinite homogeneous medium, for a single current electrode at depth, the current circuit is completed through another electrode but so far away that the influence from it is negligible. In which case the potential will be a function of r only where r is the distance from the first electrode hence the Laplace equation in spherical conditions can be given by;

$$\nabla^2 V = d^2V/dr^2 + 1/2 * dV/dr = 0 \qquad (9)$$

and multiplying by r^2 and integrating we have;

$$dV/dr = A/r^2 \tag{10}$$

which when integrated further it gives;

$$V = - A/r + B \tag{11}$$

where A and B are constants and for the boundary conditions we shall have V = 0 when r is infinite, B = 0, hence the current flows radially outward in all directions from the point electrode (Telford et al, 1976). The total current through a spherical surface will be given by;

$$I = 4\pi r^2 * J = - \pi r^2 * \sigma dV/dr =$$
$$-4\pi\sigma A = -4\pi * 1/\rho * A$$

hence,

$$A = - I\rho/4\pi \tag{12}$$

From equation (11), V = - A/r + B, and from equation (12),

$$A = -I\rho/4\pi,$$

hence

$$V = (I\rho/4\pi) * 1/r + 0$$

Therefore for a homogeneous surface,

$$V = (I\rho/4\pi) * 1/r \tag{13}$$

hence

$$\rho = 4\pi * r * V/I \tag{14}$$

but for half space eg the earth, we shall have

$$A = I\rho/2\pi \tag{15}$$

and

$$V = (I\rho/2\pi) * 1/r \tag{16}$$

and

$$\rho = 2\pi * r * V/I \tag{17}$$

In the event two current electrodes with a source at r_1 and a sink at r_2, the potential difference across the potential electrodes will be given as,

$$\delta V = VM - VN = I\rho/2\pi \ 1/_{r1} - 1/r_2) \qquad (18)$$

and apparent resistivity

$$\rho a = \delta V/I * 2\pi(1/(1/r_1 - 1/r_2)) \qquad (19)$$

hence,

$$\rho a = \delta V/I * K \qquad (20)$$

where K is a geometrical factor depending on the electrode configuration.

5. PRE-FIELDWORK PLANNING

This is important in the sense that it ensures a smooth flow of the field operations by focussing on the major requirements and the possible obstacles to the fieldwork hence curbs wasting invaluable time on the site. The major factors to consider are as follows;

(i) Estimation of the total prospect area.

(ii) The site geophycisist should physically visit the prospect area.

(iii) The type of instruments and their cost.

(iv) The manpower required and the cost of employing them.

(v) Assessment of the accommodation situation and transport costs.

(vi) Estimation of the maximum period the survey is to last i.e rate of work to be done per day.

(vii) Drawing a budget that will reflect the overall cost of the project in terms of the surveying period, analysis and interpretation of acquired data and the subsequent reporting of the results.

(viii) choosing of appropriate sites prior to the actual resistivity survey.

(ix) Others;

(a) Have the correct number of reels and prepare the current and potential measuring cables according to the maximum spacing current electrode distance AB/2. It is advisable to mark the AB/2 and MN/2 cables using different color codings. Ensure that the cables are properly insulated.

(b) Ensure that the current transmitter and the potential measuring receiver are in good working condition by calibrating according to prescriptions in the users' manual.

(c) Power sources should be in order e.g ensure that the batteries have full charge if not charge them. In case of generator check for the plugs and if carbon coated clean them using sandy paper and make new ones available, check the fuel and oil and ensure you have reserve.

(d) Ensure that you have the walkie-talkies and their batteries are fully charged.

(e) Have a multitestor, compass preferably the prismatic or Silva type, ranging rods, measuring tapes.

(f) Have tools kits for instruments and vehicles

(g) Have field vehicles serviced

(h) Have all the equipments assembled in one place and while loading ensure that the most sensitive instruments e.g the transmitter and receiver are kept in appropriate containers fitted with soft spongy material for absorbing shocks due to vibrations during transportation.

6. FIELD PROCEDURE

In resistivity prospecting the field procedure depends on the type of electrode configuration adopted i.e whether Wenner, Schlumberger, Lee method, Dipole-Dipole etc. In this report the procedure adopted is based on the Schulumberger array of four electrode configuration as Figure 5 where A, B are the current electrode and 2S the distance between them and M and N are potential electrodes and Figure 6 is a general four electrode configuration. We used this in the Krísuvík area in south west Iceland in the active tectonic zone. The instrument used was designed and assembled in Iceland. The array is arranged at a pre-selected site in such away that;

(a) The current transmitter and the potential receiver are at the center of the AB line

(b) The trend of the AB resistivity line is determined from the center using a compass (Prismatic or Silva)

(c) The MN (potential measuring) cable is laid a long the main resistivity line AB but is usually shorter than the AB line. In this case MN cable was 200 m long marked with six different MN/2 spacings of 2.5 m, 10 m, 25 m, 50 m, 75 m, and 100 m.

(d) The free ends of the current cables are connected to the current output terminals of the transmitter and whereas the potential cable ends are connected to the input terminals of the receiver

(e) The potential measuring electrodes are connected at the shortest MN/2 distance whereas two people one on either side of the AB line hammers or pushes down into the ground the current electrodes at the shortest distance of AB/2 spacing ie 10 m and connects them to the current cables. This is done by connecting crocodile clips to the electrodes and a cable leading from its handles is connected into a socket in the reel in contact with the current cable wound onto the same reel. The AB line was 3560 meters long thus AB/2 was 1780 meters long.

(f) The power source of 24 volts d.c from two rechargeable batteries 12 volts each is connected to current transmitter

power supply terminals.
(g) The optical fibre is connected from the transmitter to the receiver
(h) The micro-computer is plugged into the receiver and respective AB/2 and MN/2 values selected according to the computer program.
(i) The date, resistivity station number, location of the resistivity area and name and the operator's name and those assisting are written down on the table of results and the double log paper.
With above procedure accomplished, the operator will select convenient voltage output range on the transmitter as wells a voltage input range on the receiver using the respective switches already described. After that he communicates to the two people handling the current electrodes using a walkie - talkie to confirm from them whether they have done the connections in the correct positions preferably referring to the type of color code at the expected position. If they confirm it the operator then alerts them about the current in the cable and electrodes before the current is released. Then the current is released using the respective switch and a measurement taken at a particular electrode spacing. The results are digitally displayed on the computer terminal screen and the corresponding apparent resistivity calculated and plotted against the AB/2 spacing distance and if the resulting curve is satisfactory the operator advises the current electrodes people to move the electrodes outward to the next point. There are two major concepts underlying the outward movement of the current electrodes and the potential measuring electrodes; thus, the current electrodes are moved outward in order to increase the depth of penetration of the current into the ground, as illustrated in Figure 7 on the other hand the potential measuring electrodes are moved outward to magnify the signal received across them because as the ratio (eccentricity) of the electrode distance and the potential electrodes increases, the signal of the potential difference across them becomes too small too be measured.

7. THE PROCESS OF DATA ACQUISITION

This description is based on a typical resistivity instrument to give the reader a simplified picture of how the process of data acquisition takes place with respect to instrument circuits and how such data is treated to achieve the whole aim of resistivity surveys. Thus when the on/off switch A, is switched to the on position as in Figure 3, it causes a current to flow through a relay B, that in turn closes the connection C, between the positive pole of the battery D, and the input of the converter T. This convertor is responsible for stepping up the 24 volts from the battery B, to 1000 volts D.C being the total voltage output of the current transmitter. This total voltage output can be adjusted in four discrete steps of 250 volts each using the respective selecting switch. The resulting voltage output can be monitored by a voltmeter F, whereas the resulting current output can be monitored by the amperemeter G, this monitoring is important because it ensures that the selected voltage and current outputs do not increase beyond the selected values during measurements otherwise the data acquired will be full of errors due to fluctuations in current intensity hence the current density in the ground. However the path of current flow in the instrument will be controlled by the commutation switch H, in which case if it is connected over the relay I, the current path will be such that the negative output terminal of the converter is connected to the current terminal and/or electrode J, whereas the positive terminal will be connected over the amperemeter G, to the current terminal and/or electrode K and if the commutation switch is over the relay L then the current flow will be the reverse of the previous one thereby the negative terminal of the converter being connected to the current terminal and/or the current electrode K and the positive terminal of the converter will be connected over the amperemeter to the electrode and/or current terminal J. This current is what goes to ground and creates equipotentials that are measured by the receiver indicated in Figure 4. The equipotentials are received at the potential electrodes and the potential difference across them signaled to the receiver via the MN input terminals T in Figure 4. This potential difference signal is channelled to the measuring pre amplifier Q via an SP compensation circuit consisting of a potentiometer P, two dry cells S, the variable resistors U. This circuit is important because it cancels out the DC component of the noise bearing parasitic currents that will be discussed later under limitations to resistivity surveys. This signal is channelled across high input impedance consisting of resistors V, and to an RC type lowpass filter circuit, that consists of a resistor R and the two capacitors W. Here the potential difference signal is smoothed by the elimination of the AC component of the parasitic currents. The smoothing out of the signal is done by the filter operating within a given cut off frequency which can be defined according to the formula;

$$f_co = 1/2\pi*RC;$$

where RC is a time constant consisting the resistor of resistance R in ohms and a capacitor of capacitance C in farads. Cut off frequency phenomena at the filter circuit allows only the signals at frequencies much lower than the cut off frequency (f_co) to pass and appear at the output with the amplitude unchanged where as those at higher frequencies are cut off or filtered out and appear at the output with the amplitude greatly changed. The cut off frequency or half the power point is defined such that its amplitude ratio

$$V_out/V_in = 1/\sqrt{2} = 0.707$$

and roughly divides the passband at frequencies less than cut off from the stopband at frequencies more than cut off. The curve in Figure 8 illustrates this phenomena graphically and was computed from theoretical data in which the amplitude ratio V_out/V_in was computed using the formula;

$$A = 1/\sqrt{1 + (2\pi fRC)^2}$$

where, f, is the selected frequencies from 1 H_z - 10 000 H_z, with 1 000 H_z as the cut off frequency, and R and C representing the resistance of the resistor and capacitance of the capacitor, respectively in the theoretical filter circuit. The amplitude ratio was then plotted against the corresponding frequencies on a semi - logarithmic scale with amplitude on the linear axis and frequencies on the logarithmic axis. The region under the flat part of the curve represents the passband for signals at frequencies much below the cut off frequency hence constant amplitude for input and output signals.

However after the signal has been smoothed out at the filter circuit, it is then channelled through an integrated circuit amplifier (IC) I, that works in conjunction with a set of resistors R_x that constitute the amplification factor of the amplifier. The amplifier has a feedback mechanism consisting of the resistors above and a wire connection Y which is connected to its input as to control the potential difference from either becoming too positive or too negative. The resulting potential difference δV, is signalled across a low impedance output resistor Ro and can be read directly from a voltmeter indicated in Figure 4 as Z or can be recorded on a strip chart by a potentiometric recorder or can digitally be processed by a computerized micro processor designed in the receiver and finally displayed on the computer terminal screen.

The receiver we used in the Krísuvík area is a computerized micro processor which operates on the logic digital concept such that it logically calculates and displays digitally the final potential difference signal which is an average of about 20 different signals at the same potential electrode spacing distance as well as at same current electrode spacing. It calculates the corresponding apparent resistivity, the standard deviation, and displays them on the computer screen. The current is signaled from the transmitter to the receiver through a none electronics optical fibre in the Icelandic resistivity instrument.

If a potentiometric strip chart recorder is used it would mean that all the calculations have to be done manually. This of course will involve measuring the length of signal waveform drawn by the recorder pen deflecting from one end to the other. This is done on the basis that the strip chart has a scale calibrated either in volts or millivolts, such that one centimeter is an equivalent of one volt or millivolt respectively. If for example the strip chart full scale is R mV and the selected voltage range on the recorder is T mV and after a potential difference signal is sent in, the length of the signal drawn as a result the recorder pen deflections is measured to be L cm, then the resulting potential difference δV, will be calculated from the formula;

$$\delta V = (T*L\backslash R) mV$$

e.g let R, T, and L be 12 mV, 200 mV, 10 cm respectively the

$$\delta V = 200*10/12 = 166.7 \text{ mV}$$

and the apparent resistivity ρa will calculated according to the formula;

$$\rho a = (\delta V*K/I)$$

where δV is the calculated potential difference in mV, I is the current used in mA, and K is a geometrical factor depending on the electrode configuration used, in this case the Schlumberger electrode configuration applies and can be calculated according to the formula;

$$K = \pi((S^2 - P^2)/2P)$$

where S, and P are the distances of the current and potential electrodes, AB/2 and MN/2 respectively with respect to the center. In this case assuming S is 15 m, P is 2.5 m and 2P is 5 m, then K will be;

$$3.14((225 - 6.25)/5) = 137.4$$

What can be deduced from comparing the digital computerized receiver used in Iceland by the National Energy Authority (Orkustofnun) and the conventional strip chart recorders is that the digitally computerized receiver is most suitable for conducting resistivity surveys due to the following reasons;
(i) It saves time hence speeds up the daily progress in work since all the calculations are done by the computer unlike in the analog recorders where all the calculations have to be carried out manually.
(ii) Its design (local) makes it handy to take more than one measurement simultaneously at different potential electrode spacing and at the same current electrode spacing.
(iii) The accuracy of the data obtained is higher as result of a final reading being digitally displayed as average of several values stacked together after being processed through at least 20 cycles.
(iv) It reduces the problem of having to deal with several strip charts which are sometimes monotonously several meters long and cumbersome to deal with especially when measuring in order to calculate the resulting potential difference.
(iv) The quality of the data can easily and quickly be judged and necessary remedies effected immediately in the field in case of poor quality data because the values can be monitored digitally as the measurement continues. Noland S. Maceda (1983) has made a detailed description on the application and adaptation of digital computers.

8. LIMITATIONS TO DATA ACQUISITION

Like the other geophysical surveys, resistivity surveys are also exposed to various drawbacks that affect the ultimate accuracy of the data. Some of these are due to the following factors;

(i) Telluric and cultural currents
(ii) Near surface lateral inhomogeneities
(iii) Skin effect
(iv) Topographic effects
(v) Anisotropy
(vi) Overburden
(vii) Electric coupling
(viii) Poor cable insulations
(ix) Poor electrode to ground contacts
(x) Human effects
(xi) Instrumental effects

The causes of each of these, effects and possible remedies for most of them are therefore discussed as follows;

8.1. Telluric and Cultural currents

The resistivity surveys are conducted on assumption that the potential difference measured are as a result of the current injected into the ground at the two current electrodes on the surface. However this is not the case as there are other stray currents that exist in the ground either naturally or due to man made structures. Telluric currents constitute the naturally occurring parasitic currents that come about as a result of the interactions of fields and particles from the sun with the earths' magnetic fields and their magnitude depend on the solar activity. The occurrence of thunder storms especially in tropical climates contribute highly to telluric noise (Stanley H. Ward and William Sill, 1983), (Nicholous Marita, 1986)

The cultural currents are another branch of the parasitic currents that cause noise in resistivity surveys. They are as a result of man made features such as power transmission lines, telephone lines, electric railway lines, water pipes due to electric currents for cathodic protection electric wire fences especially those supported by metallic posts etc. Both the telluric and cultural currents cause noise in geophysics by disturbing the potential difference to be measured by making them non symmetrical. The effects of the parasitic currents can be remedied by the use of the a spontaneous potential compensating circuit that cancels out the DC component of the parasitic currents and a lowpass (RC type) filter circuit that smoothes the potential difference signal by eliminating the AC component of the parasitic currents. However the instrument must have a current reversion mechanism which can be operating automatically or can be operated manually by the use of a reversion switch. In this procedure the measurement is carried out in both directions of current flow. Thus between consecutive measurements at the same electrode spacing the direction of the current flow between the current electrodes and the direction in which the potential difference is measured must be reversed simultaneously. Since the direction of the parasitic currents is not reversed by this procedure, the parasitic potential difference cancels out when the average of the of the potential difference in the two consecutive measurements is determined. Otto Koefoed (1979) has described the method of current reversion using the Deppermann (1968) method which explains that a current sent into ground must be automatically reversed in direction at fixed intervals and the direction in which the potential difference is measured is reversed automatically with the current and the resulting potential difference integrated with respect to time over an integer number of periods. The integration can be done automatically in the instrument or the resulting potential difference recorded on magnetic tapes and the integration done in the office computer. This method is known to eliminate the DC component of the parasitic voltages and considerably eliminates the AC voltages to some extent. The diagrammatic illustration of the procedure can be seen in Figure 9 in which Deppermann showed that when a current is reversed the voltage value does not reach its final value immediately but does so asymptotically and the integration should be done using the flat portion semi period parts indicated by the braces in Figure 9. Deppermann shows that the time in which the voltage difference requires to be approximately close to its value can be given by the equation;

$$t_e = 4.12*10^{-7} s^2 / (\rho e^{1}.5)$$

where;

t_e = time approximated
e = relative difference between the actual and final voltage difference
ρ_e = ground resistivity or ρ_a in case of apparent resistivity
s = AB/2 distance of the current electrodes

Hoogervorst (1975) has also given a description on field experiments concerning parasitic currents carried out in different areas the results of which indicated that although the strength of the parasitic currents changes considerably with time, their time is considerably constant. In this procedure two potential electrodes are displaced from each other in a direction perpendicular to the measuring configuration.

8.2. Near Surface Lateral Inhomogeneities

These are features at or close to the surface of the earth eg roads, ditches, fissures, pipes, wire fences, thin lens of the earth below the surface etc. These features can affect the pattern of current flow by distorting it and hence the final potential difference to be measured. This will depend on the position of both the potential measuring electrodes and the current measuring electrodes relative to the inhomogeneities. The inhomogeneities are considered small if their effects are reduced with the increase in the distance between the current electrodes from them thus if the dimension of the inhomogeneity is small in such circumstances, and if the potential electrodes are kept in the same position when the current electrodes are shifted then the relative error in the measured potential will remain constant and a correction is possible in the Schlumberger measurements. However if the distance between the current electrodes and the inhomogeneity is small eg carrying out a measurement parallel to the inhomogeneity eg a pipe, the relative error will be too big to correct due too a large part of the current being channelled a way along the pipe hence the pipe distorts the pattern of normal current flow to the ground (Otto Koefoed, 1979). Locating the potential measuring electrodes close to an inhomogeneity or above thin lens shaped inhomogeneity will cause errors in the potential difference measured and the final apparent resistivity. The remedy for this is to try and choose appropriate sites and avoid locating the potential electrodes on or close to the inhomogeneity eg in Figure 10 situating the potential electrodes M_1 N_1 above the portion indicated will have a very big difference in the potential difference measured and the resulting apparent resistivity compared to that due to the position of potential electrodes M_2 N_2.

8.3. Skin Effect

This is a phenomenon in which the current tends to concentrate at the surface of the earth. This happens when the AC current sources are used. Hochstein et al., (1982) has explained that soundings made with AC frequency sources with a frequency of about 0.1 Hz produces unusually steep upturns of at least 45 degrees in the resistivity sounding curves at spacings of AB/2 100 m if the soundings were made over prospects with low resistivity rocks at shallower depth of 100 - 200 m. Figure 11 illustrates the skin effect. In this phenomenon the A.C current density decreases exponentially with depth yet the use of D.C current would have had a homogeneous current field hence current density (Otto Koefoed, 1979). In this regard it follows that the use of D.C current sources in resistivity prospecting can eliminate skin effect problem.

8.4. Topographic Effects

If a resistivity profile is sited perpendicular to the axis of a valley and the potential electrodes positioned on the steep part of the valley the measured potential will be erratically smaller than if the they were situated in a free flat surface because the equipotentials are perpendicular to the free surface and if the profile is sited over a ridge the results will be the reverse.

8.5. Apparent Anisotropy

This is due to dipping layers or steeper resistivity discontinuities beneath a sounding spread AB/2 which cause an inhomogeneous current density J, beneath the potential electrodes. These are not easy to deal with but for minor anisotropy i.e less than 10 degrees it is possible for the interpretation of sounding curves to be done by the principle of a horizontally layered earth but for larger anisotropies interpretation using a two dimensional method by finite difference or finite element method can be applied (Hochstein et al., 1982), (Keller et al., 1970) showed that if resistivity is measured with an array parallel to the bedding planes the measured resistivity is higher than the longitudinal one by a ratio, α.

8.6. Overburden

Conductive overburden inform of alluvium or weathered bed rock, prevents the current from penetrating to the more resistive bed rock and this makes it uncertain to detect the more resistive bedrock.

8.7. Electric Coupling Effect

This is an electromagnetic interference that occurs between the potential measuring circuits and the current circuits. This is as a result of electric current leakages. This will therefore require that care to be taken to avoid it and this can be done by isolating the two circuits eg the current carrying cables should be kept at least five meters away from the potential measuring cables and the two should NEVER cross one another. This effect can be reduced by using shielded potential cables. The optical fibre used to signal the current to the receiver in the Icelandic resistivity equipment helps to decouple out the effect.

8.8. Insulation Effects

If both the current and potential measuring cables are poorly insulated then this will form the points from which the current leaks to the ground in case of the current cables. This will introduce errors into the final data because the interpretation done is based on the principle that the current is introduced into the ground at the two current electrodes only and if it leaks to the ground from other points along its cable then the electric field and the current density in the ground will no longer be evenly distributed as for the assumption, hence the errors. In fact the worst problem of current leakages is experienced when the current cables have to be cut at every point of connecting it to the current electrodes and reconnecting it after the measurements and insulating the reconnected parts by an insulation tape. This practice increases the errors due to current leakages because the insulation tape is easily removed either due to increase in atmospheric temperature or due to friction with the ground surface especially when the cables are pulled hence leaving the points of reconnection in direct contact with the ground such that during the transmission of the current part or most of it is introduced to the ground at such points other than at the two current electrodes thereby affecting the current density into the ground by distorting it. The practice of cutting the cables should strictly be discouraged and all cable connections should be made directly from the reels so that instead of cutting the cable, the reels are moved to the next AB/2 points with the cable on it intact and the connection made into the reel socket using suitable connectors. As for the potential electrode cables, interference from ground potentials will be introduced into the potential to be measured making them non symmetrical. Apart from the cables reels can also be causes of leakages especially on rainy days by diverting down part of the current destined for the current electrodes especially when they are left on the ground connected to the cable from the next reel. It is therefore important to keep them in plastic bags to avoid contact with the ground. This procedure is strictly adhered to in Iceland.

8.9. Electrode Contact Effects

When electrodes are in poor contact with the ground the current flow to the ground will be poor and this may affect the final resistivity value, therefore to avoid this the electrodes should be made to penetrate deep into the ground and if the ground is too dry the conductivity can be increased by adding some water to the ground.

8.10. Human Effects

This can be divided into the following categories;
(i) Misreading the meters; this happens when the operator is reading the meters from an oblique position such that a value like 81 can be seen and misread as 18 or vice versa. To avoid this the operator of the instrument should sit in a such position that the meters are always directly before the eyes and in the right position for reading correctly.
(ii) Misbooking; this may come as result of two people helping one another at the center such that one does the

operation and reads it out to the next one for recording. It is during such an exercise that the wrong data values are booked because the operator may read a value correctly e.g 90 mV and this can be misheard as 19 mV so to avoid this it is important always to stick to the rule of reading in individual digits more than once eg 90 should be read as nine, zero and let the person booking repeat it for assurance of the correct booking.

(iii) Negligence; this comes out of taking things for grunted e.g the operator or the entire field crew may consist of individuals who do not value the outcome of the work being done as such they may do things which they know are wrong but they may do nothing to correct them e.g the operator may be asking the electrode people to move yet he himself is not remembering to change the position of the potential electrodes on the instrument only to realize later but do nothing to repeat the measurements and he decides to insert imaginary values by guessing where those values could have fallen on the curve produced from other correct measurements as if the curve is standard for all measurements made at that particular station. Definitely such data cannot be relied on for interpretation purposes. On the other hand one of the electrode people may for one reason or the other confuse the electrode positions and hesitates to inform the operator and the data collected is computed using the wrong electrode separation. This introduces non symmetrical data in the overall data results that give the wrong idea about the resistivity pattern in the given field simply because the electrode configuration was not kept to the principle of moving them outward symmetrically as is required by the procedure. This can only be controlled if qualified personnel who have an understanding of the importance of the data from the scientific point of view are used in the field operations.

In line with these limitations, Risk (1982) has discussed the methods used by DSIR Geophysical Division in New Zealand to monitor human errors and errors due to current leakages in the field. In this method four current electrodes A, B, C, and D are used in line with one set of potential electrodes M, N, as illustrated in Figure 12. Using the correct length of cable and appropriate switch box four measurements can be made using the following combinations; AC, AD, BC, BD and the corresponding values of the potential difference across MN recorded eg,

AC = δV_w,

AD = δV_x,

BC = δV_y,

BD = δV_z,

the corresponding apparent resistivity values are such that those corresponding to measurements at AD and BC are symmetrical i.e ρ_{ax} and ρ_{ay} respectively and the others at AC and BD are non symmetrical i.e ρ_{ax} and ρ_{az}. This method helps in monitoring human errors in the field and can help to detect apparent anisotropy near steep boundaries. Checking for current leakages is done on assumption that a current source is operated at a constant voltage and the contact resistance between the current electrodes and the ground remains the same so that;

$$(1/Ix) + (1/Iy) = (1/Iz) + (1/Iw)$$

where Ix, Iy, Iw, and Iz are current readings during the measurement of the potential difference at the corresponding current electrode setting.

8.11. Instrumental Effects

This may be a design problem in which the potential receiver has a very low input impedance such that the potential resistance R1 exceed its input resistance R2 hence creating errors in the potential difference measured, in such circumstances it is necessary for the corrective measures to be applied using the formula given as;

$$\delta V_t = \delta V_m(1 + R1/R2)$$

where δV_t is the true potential difference and δV_m is the incorrect potential difference measured at the receiver. However other problems that can affect the data are as a result of certain functional defects within the instrument which can be noticed by showing any of these symptoms;

(A) the entire instrument not showing any response even when the circuits have been activated

(B) One of the meters not indicating

(C) The instrument or one of its parts stopping to function temporarily etc

(A) If the first case applies one should try to check the power input fuse using a multitestor and if there are no deflections in the multitestor then this implies that the fuse has been damaged and should be replaced. If no change is observed after replacing the fuse then possibly check whether the power supply has the correct power output and if it is okay then check if the cables connecting it to the instrument are loosely connected and also check whether the same cables are disconnected internally.

If all these attempts do not show any tangible results then it is an indication of a more complicated problem which will then require that the individual module be checked. This can be attempted using a multitestor to check for the voltage or current that is rated for each module. A Cathode Ray Oscilloscope (C.R.O) can also be used particularly to monitor the waveforms in certain modules. The way to go about checking the various modules with respect to its role in the circuits can be attempted as for the guidelines outlined below;

(i) One must have the following;

(a) The users' manual with part list information, overlay and schematic diagrams.

(b) An electrical parts databook

(iii) Relevant instruments ie an appropriate toolkit, multitestor, color coding chart for some electronic components eg resistors, capacitors etc, and a C.R.O etc

The procedure is as follows;

(i) Open the instrument as may be outlined in the manual and

use the correct instruments to open
(ii) Using the manual part list, one can select the part within a given module. This should have the base index number eg UA741 which may be either a resistor or an IC amplifier etc.
(iii) Using the base index number one can then go to the electrical parts databook for detailed information regarding the particular function and properties of the part.
(iv) After that one can then go to the overlay diagram which shows the actual location of the part in the instrument or if this is not available the schematic diagram will serve the purpose because it indicates how the part is connected to the circuits.
(v) Then carry out the testing eg rated current through it or voltage across it etc using a multitestor set in the corresponding scale or by using a C.R.O.
(B) If one of the meters is or any other moveable part within the equipment is not working normally then you may check if there's any mechanical disconnection along its line in the instrument system and if determined to be okay then try to apply the method outlined in A
(C) If the instrument is coming on and off temporarily then check for any mechanical disconnections as well as checking the capacity of the power source to see if it is fluctuating. Also check the cables connecting the power source to the instrument to see if there are any loose connections or disconnections.
NOTE: (i) If any part or the whole module needs replacement make sure that you replace them according to specifications because there exist several parts bearing the same name but its application may vary with different manufacturers' specifications and if the replacement is done using a part with different specifications the instrument will still not work.
(ii) When doing the testing take care not to cause a short circuit between two independent circuits. This can easily happen accidentally by a metallic object eg screw driver dropping into the equipment with activated circuits or it may

be as a result of whoever is carrying out the test holding the multitestor probe horizontally while testing.
It is also important that you avoid touching the parts because apart from dangerous electric shocks some parts in the circuitry eg semiconductors can be completely damaged due to the static electric charges within human bodies and as such it might require that one discharges himself or herself before handling the instrument circuitry. Hence have a grounded conductor at the testing desk.
(iii) One should NEVER attempt to open and repair an instrument if he or she does not have any idea about the circuits and worse still if he or she does not know the particulars of what to look for because this may end up making the instrument to be worse off than before by introducing another complicated problem which he or she is incapable of even detecting or repairing.
(iv) When opening the equipment make sure that you remove one part at a time and be sure of where each part was removed from or less you end up messing the instrument by confusing the actual positions from where the parts were removed. And always keep the parts in containers to avoid loosing them.
N.B: If all these methods have been employed both in the field and lab but still the instrument is causing problems then consult the manufacturers.

9. RECORDING AND STORING OF DATA

Both the original(raw) and derived data must be properly recorded, organized and stored for future use.
This is vital because every data obtained is done so at a cost and it will be very costly if one was to go to the field a fresh to collect new data from an area that has already been covered in the exploration programs. This problem is therefore solved by recording and the subsequent storage of the data. There are three major methods by which recording and storing of the data can be done; namely, recording the data manually on data tables in the field and organizing it in a manner legible to others and keeping the same in the normal office paper files with labels to make their identity easy when required later, or the data can be recorded as above but if computer facilities are available, the data can be transferred to the office and fed into the computer and stored in computer files by saving it under different file names using a given program for storing such data. The third alternative includes recording the data directly on magnetic tapes if the instrument being used is computerized and transferring it to the office so that it can be copied onto the main computer hard disk and stored among other files but under a different program so as to make it possible to retrieve it when required later. The data that we collected in the Krísuvík area was recorded and stored as described in the second procedure using the Ellipse program. It should however be noted that when the data is recorded and stored onto diskette files it is important to make a back - up copy of each file so that in case something happens to the computer and the files are destroyed then the back up copy will be used as an alternative and save a situation which could have compelled one to go to the field again and collect other data which of course is costly. In view of this it will as well be safe if the data recorded on magnetic tapes is printed out on ordinary paper and stored in the office paper files. The availability of computer files has become very handy in as far as the storage of the data is concerned be

cause it has helped ease out the problem of having big piles of paper files over crowding in the shelves, some of which could easily be misplaced or lost completely thereby causing a gap in the data collected in very costly projects. Note that it is important for care to be taken so as not to mix different data during storage.

10. CHOICE OF INSTRUMENT

The choice of instrument depends on a number of factors that include the following;

(i) The extent of vertical resolution.

(ii) Instrument specifications.

(iii) The cost of the instrument.

(iii) The type of terrain and manpower.

The factors outlined above are inter related and dependent on each other in one way or another, thus, one has to know the type of prospecting for which the instrument is required thus if it is aimed at delineating resistivity changes with depth then he has to choose an instrument with high vertical resolution power. This means that the instrument has to have the appropriate technical specification to be able to have the current penetrate deep into the ground and will therefore require that the current transmitter should have a specification of at least 1000 volts total voltage output and a total current output of a at least 500 mA and the receiver has to have a high input impedance so as to stop the incidence of the potential resistance exceeding it hence introducing errors in the final result. It should also have a high signal to noise rejection ratio. This of course will depend on the cost of the instrument and the availability of funds to purchase or hire it. The type of terrain in which the instrument is going to be used will detect the weight of the instrument and the manpower available. Thus if the terrain is rugged and the instruments to be used are heavy then it will require big manpower to be able to carry a heavy generator and other equipments up and down the terrain. Though this can be overcome by using portable power sources e.g rechargeable batteries and possibly using an All In One instrument with adequate specifications.

However if the purpose of the resistivity survey is to delineate resistivity changes due to lateral extent the same equipment above can be used or one with a lower power output can be used because the delineation is only done at intermediate depth and the manpower will still depend on terrain and weight of the equipment.

11. FIELD PRECAUTIONS

Given that electrical prospecting methods employ the use of high voltages and currents that could cause serious field accidents in form of electric shocks and even electrocutions it is vital to strictly observe the following;

(i) An effective communication system must be established between the center of operations and those handling the current electrodes. This is usually done by the use of walkie - talkies or a telephone wire system designed within some field instruments.

(ii) Those handling the current electrodes should be cautioned NEVER to touch or connect the electrodes to the current line unless they are advised to do so by the operator at the center.

(iii) Those handling the current electrodes must wear plastic gloves on their hands and be advised to be staying away from the current electrodes during the transmission of the current to the ground.

(iv) The operator at the center should always confirm that all those handling the current electrodes have heard him before he switches on the current, hence ambiguous communication should be avoided at all costs.

(v) Others; carrying on with fieldwork involves some uncertainties which in common practice tend to be ignored yet they can equally halt the progress of any project irrespective of the availability of the best instruments and qualified manpower with experience, if not considered seriously in the initial stages of project planning. Some of the most common are as follows;

(a) Injuries eg cuts, sprains and fractures, bites etc

(b) Vehicle tire punctures, running out of fuel and getting stuck

(c) Unpredictable weather conditions

(d) Delays in the field etc

All these uncertainties should be addressed to before any field work commences; thus,

(i) A first aid kit with full contents should be carried to the field always so that in case any of the members of the of the field crew is suffering an injury, first aid measures can be applied immediately before the victim is rushed to hospital if the injury is a serious one.

(ii) Given that most if not all geothermal fields are situated in rugged and remote areas away from business centers it will be very necessary for certain precautionary measures to be taken to avoid inconveniences that can be detrimental to the progress of a day's work and the project as a whole. These can come as a result of encountering a vehicle tire puncture, getting stuck in the mud or ditch, or running out of fuel. To this effect it is important that spare tires, tubes, extra fuel in special motto towed tanks, ropes or chains, tools kit etc should always be transported together with other equipments.

(iii) The weather sometimes is very unpredictable as such it will be necessary for the field crew to be reminded to carry the appropriate weather gears i.e, sweaters in case it gets cold or rain coats in case it rains.

(iv) Sometimes if the data collected is having too many errors that need be corrected, it might occur that the field crew can be delayed in the field up to very late in the day as such, it is important that they are always cautioned to carry enough packed lunch so as to give them the energy to continue with the work in the extra hours, remember the truth is, no one can work effectively on an empty stomach.

NOTE: None of these factors mentioned is of any direct scientific significance to geophysical surveys as far as the quality of the data required is concerned, but any one of them is capable of frustrating every effort towards obtaining such data as per the project schedule hence need be considered if the project is intended to run smoothly.

12. DISCUSSION

As already seen the quality of data in resistivity surveys is determined by the instruments used in addition to qualified personnel to use them. The major factor that should be remembered is that the instrument should have the correct technical specifications so as to meet the projected workload. In this regard in electrical sounding one will need a current transmitter with very high power output to enable the current to penetrate deep in order to be able to delineate the resistivity changes with depth. An instrument with a maximum voltage output of 1000 V and maximum current output of at least 500 mA will be quite ideal for vertical electrical soundings. With such an instrument it is possible to carry out a sounding whose maximum current electrode spacing AB/2 is at least 2500 m and obtain very good results out of it without overloading the instrument. But on the other hand if an instrument with maximum power output half the one specified above is used for the same current electrode spacing ie 2500 m it is no doubt that the results obtained will by far not depict the same resistivity changes with depth as in the first case, but it can perform well in delineating resistivity changes due to lateral extent since this is only done at intermediate depth. The qualities of a good current transmitter of course have to go hand in hand with a powerful potential difference measuring receiver precisely computerized and should have very high input impedance of at least 50 Mohms minimum so that even if the potential resistance increases it will not affect the potential difference to be measured. The receiver should have a high noise rejection ratio to reduce the disturbances caused in the potential to be measured as a result of the interference from stray underground currents so as to ensure that the potential difference measured is to a bigger extent as a result of the current injected into the ground from the transmitter than from such noise. In this case the common mode rejection ratio should be at least 100 decibels(dB) and above. These factors combined with a reliable power source with an appropriate energy capacity to complete a day's sounding without the possibility of being overloaded or drained during the measurement, will assure one of very reliable, hence interpretable data.

The more compact an instrument is the easier to carry and work with it. The instrument used in Iceland is very conducive to field conditions ie the current transmitter has a maximum voltage output of 1000 V and a maximum current of 500 mA and its power is from a set of two batteries of 12 volts each arranged and connected in series to produce a total of 24 volts which is stepped up to 1000 V. The receiver is computerized and makes the work easy by making at least three measurements of the potential difference at three different potential electrodes simultaneously at the same electrode spacing and calculates the resulting apparent resistivity and the standard deviation and displays all on the computer terminal screen and the only work left for the operator is to plot apparent resistivity against the electrode spacing distance AB/2. This in addition to very light and very portable field equipments makes the progress of a day's work to be relatively easy going, i.e during the resistivity survey that we carried out in the Krísuvík area south west Iceland, it only required a total labor force of four people, two of whom remained at the center to do the operations and plotting of the resistivity curves whereas the other two were responsible for moving the current electrodes a long the main AB line of AB/2 1780 m with three reels each in the rack sack and a cable about 600 m long wound on them and it took the four of us at least five hours despite rugged terrain to complete a job that in some countries is done by about 30 - 40 people. This was made possible due to the fact that the cables and reels were made of very light aluminum material unlike the heavy copper or steel cables that need several laborers to help each other and the versatility and the compactability of the main resistivity instruments was an added advantage to making the survey to be completed in such a short time.

For the instruments to be able to perform with maximum efficiency they have to be well maintained by being calibrated, serviced, and faulty parts have to be detected, checked and repaired. The cables have to be checked for poor insulations so as to eliminate errors due to current leakages in the current cables and stop the interference of ground potential that creep into the potential difference to be measured thereby distorting it. For all this to be possible it will mean that qualified manpower with experience in instrumentation and data acquisition together with fully equipped electronics laboratory are all indispensible for pursuing any given geophysical surveys effectively because in case of any faulty instrument the same will be checked in the available electronics laboratories. This will cause only minimum delays in the field operations unlike when such instruments are to be taken abroad even for very minor faults and this ends up causing untold damage to the project. Iceland under the auspices of the National Energy Authority has the situation under control due to the availability of a well equipped modern electronics laboratory with the highly qualified personnel to man it.

The success of resistivity surveys will demand that the site geophycisist or any other qualified person in that category should pay a visit to the project and inspect the prospect on foot so as to be conversant with the various problems ranging from administrative to technical factors that can affect the smooth flow of the data acquisition procedures.

In the light of this and by virtue of its vast geothermal potential and many years experience in geothermal exploration and exploitation technic, together with the availability of all the technical requirements for effective geothermal exploration and exploitation, Iceland can be of great international technical assistance especially to developing countries like Kenya, the author's motherland.

13. CONCLUSIONS

1. Always make sure that you choose and use an instrument with the correct specifications to suit the workload of the given prospecting i.e vertical electrical sounding to delineate resistivity changes with depth or profiling to delineate resistivity changes due to lateral extent etc with emphasis on its accuracy and precision that should be compatible with given technical specifications of the instrument as a whole.

2. Never use or continue to use defective instruments, keep them well maintained, have them repaired by qualified personnel only and ensure that the cables are always checked for leakages before and after the fieldwork.

3. For effective maintenance and repairs, a well equipped electronics laboratory is indispensible.

4. Planning before field operations should strictly be observed to ensure a smooth flow of the survey and attention should be paid to the major uncertainties that can halt the progress of the geophysical survey.

5. The project geophysicists or any other qualified person in the same category should visit the project area and carry out a physical inspection of the prospect on foot to acquaint himself with the various possible social and administrative problems and use the same opportunity to study the technical limitations to the survey.

6. Record and store both the original (raw) and derived data using the most convenient method available precisely the computer facilities and ensure that the same is recorded and stored in an orderly manner. Be careful in this exercise to avoid mixing different data.

ACKNOWLEDGEMENTS

I would like to extend my sincere thanks to the UNU staff particularly the Director of the institution Jón-Steinar Guðmundsson for the distinguished manner in which he runs the institution. His guidance, advice, and continuous encouragements, together with his exceptional humorous character provided me and I hope the rest of the fellows with a very conducive atmosphere towards achieving the goal of the training. I would also like to express my appreciation to the National Energy Authority (Orkustofnun) for its invaluable contributions to the fellows in terms of providing introductory lectures, seminars, and above all the provision of the other technical facilities for our practicals and project work.

Special thanks go to Brynjólfur Eyjólfsson who was my course advisor for his tireless efforts and concern in giving me the necessary technical guidelines and clues to what was expected of me all of which gave me the initiative to pursue and complete my course successfully. Along the same line I am indebted to Reynir Sigurðsson for his good instructions and guidance during my practicals in the electronics laboratory and I commend him for his style of approach, patience and the concern all of which gave me the confidence in my undertakings. Einar the Electrical Engineer in charge of the electronics laboratory and Sverrir deserve credits for their general assistance to me during the same time.

Thanks to Ómar Bjarki for his well organized administrative role and the most commendable active role he played in taking care of our welfare for the rest of our course period. Thanks to Anna Maria for her assistance in providing us with the necessary stationery for our notes etc.

It would be incomplete without extending my very deep appreciation to the UNDP particularly the Chief Technical Advisor in my Ministry, Gestur Gíslason for nominating and giving me the opportunity to attend this important course in Iceland. I also thank J. K Kinyariro for his recommendation that made it possible for the training arrangements to sail through. Thanks to the entire Kenya Government for giving the authority for me to leave the country and attend this course.

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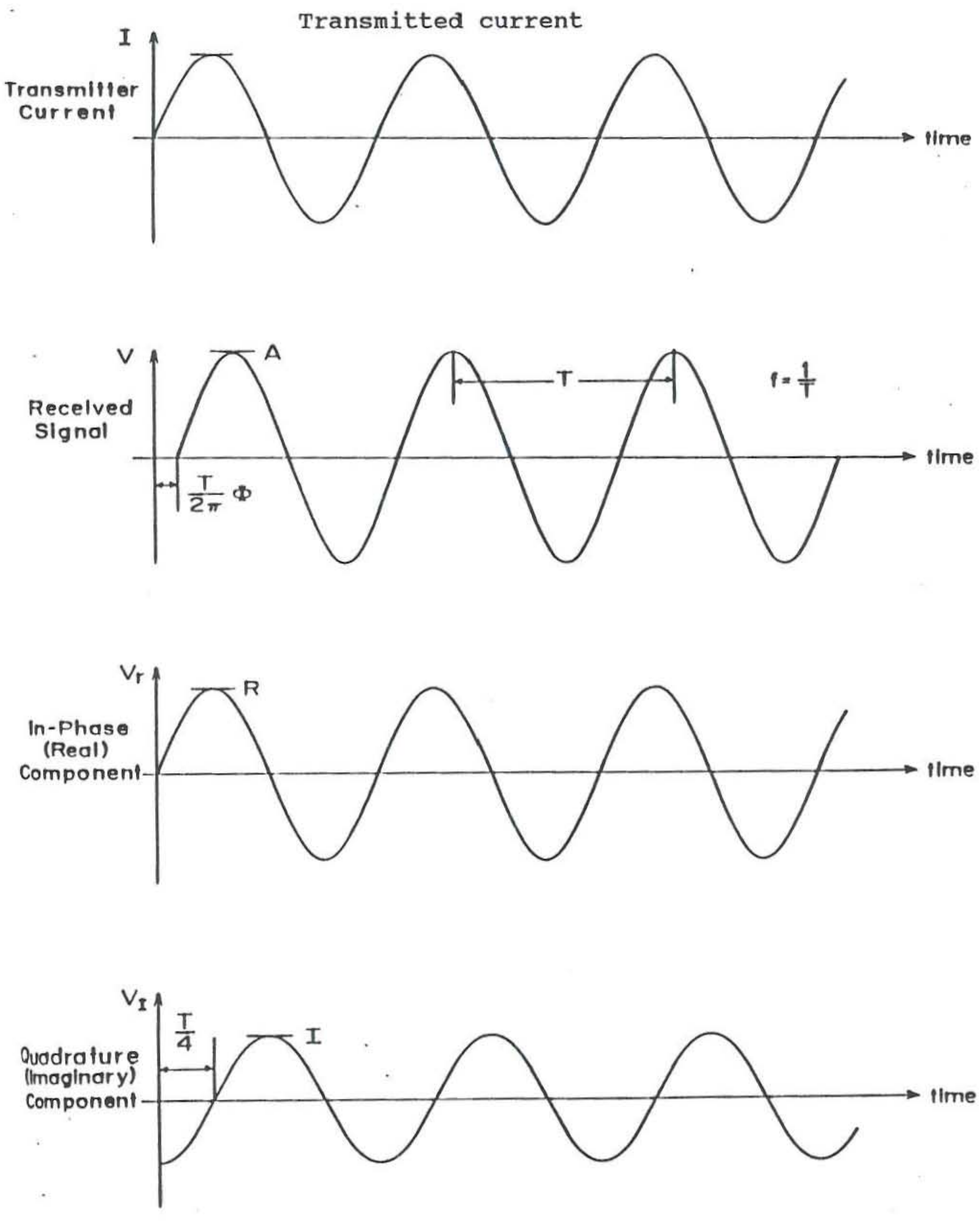


Figure 1. Transmitted and received waveforms in frequency domain (after Hohmann and Ward, 1981)

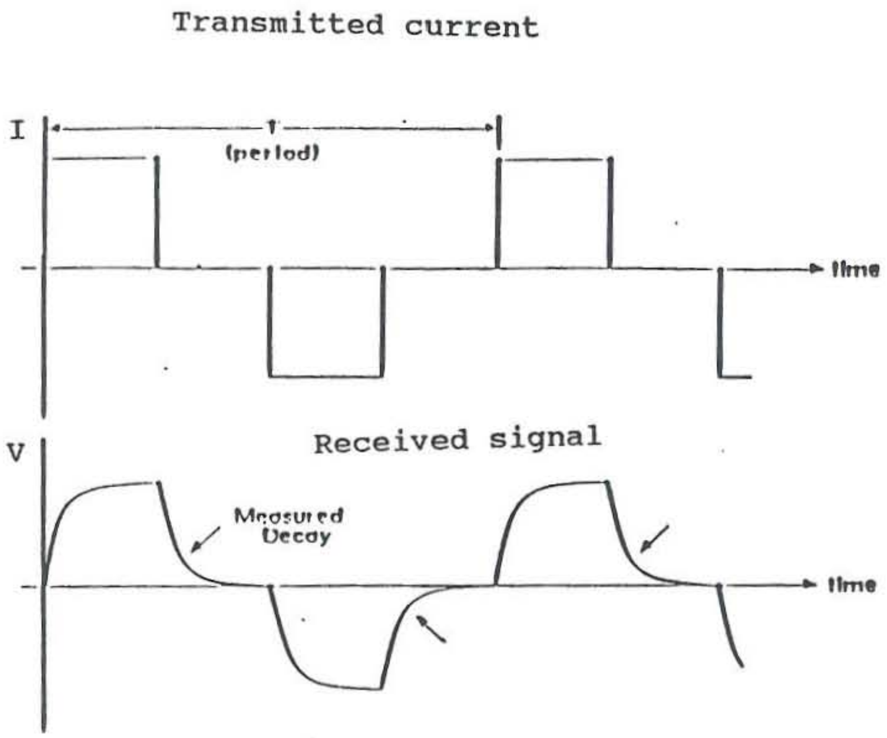


Figure 2. Transmitted and received waveforms intime domain (after Hohmann and Ward)

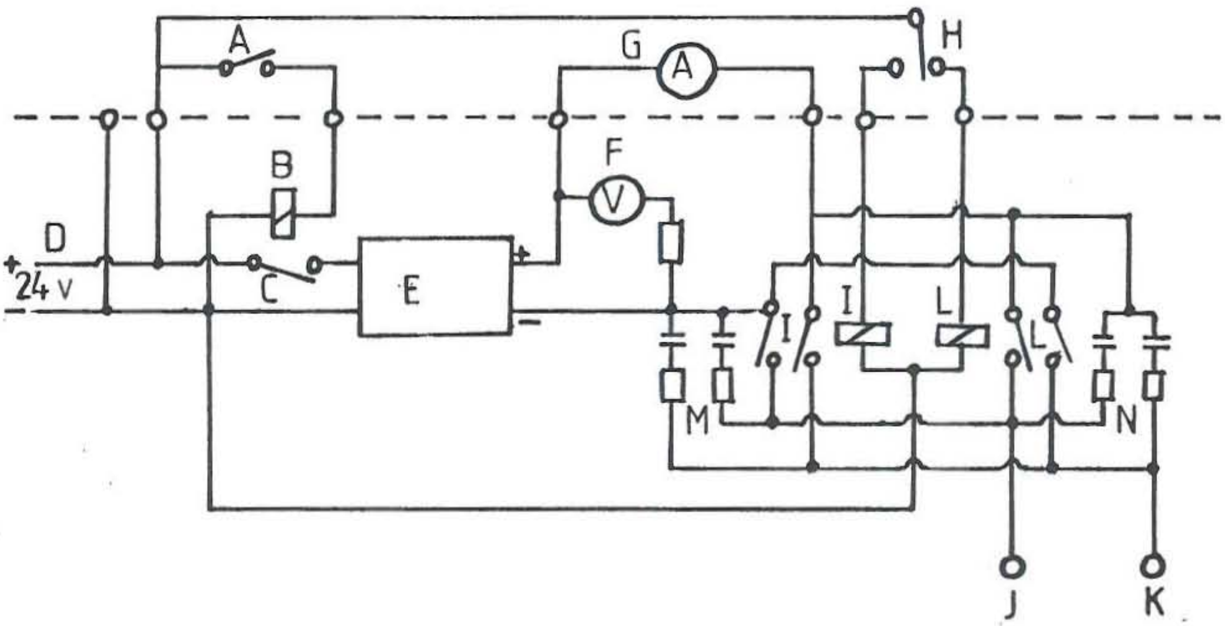


Figure 3. Schematic diagram of a current transmitter

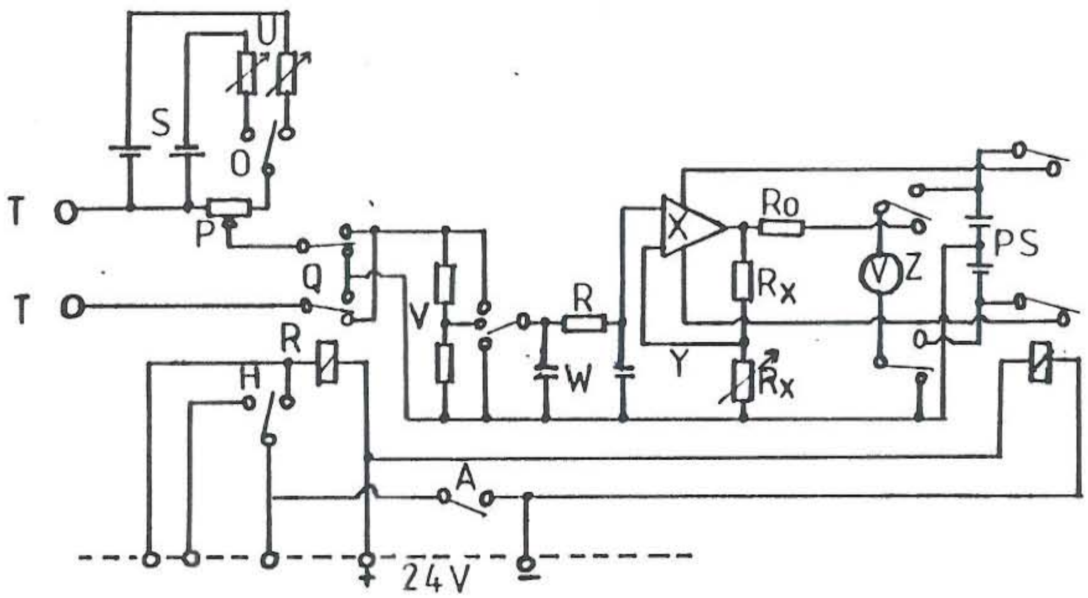


Figure 4. Schematic diagram for potential difference receiver

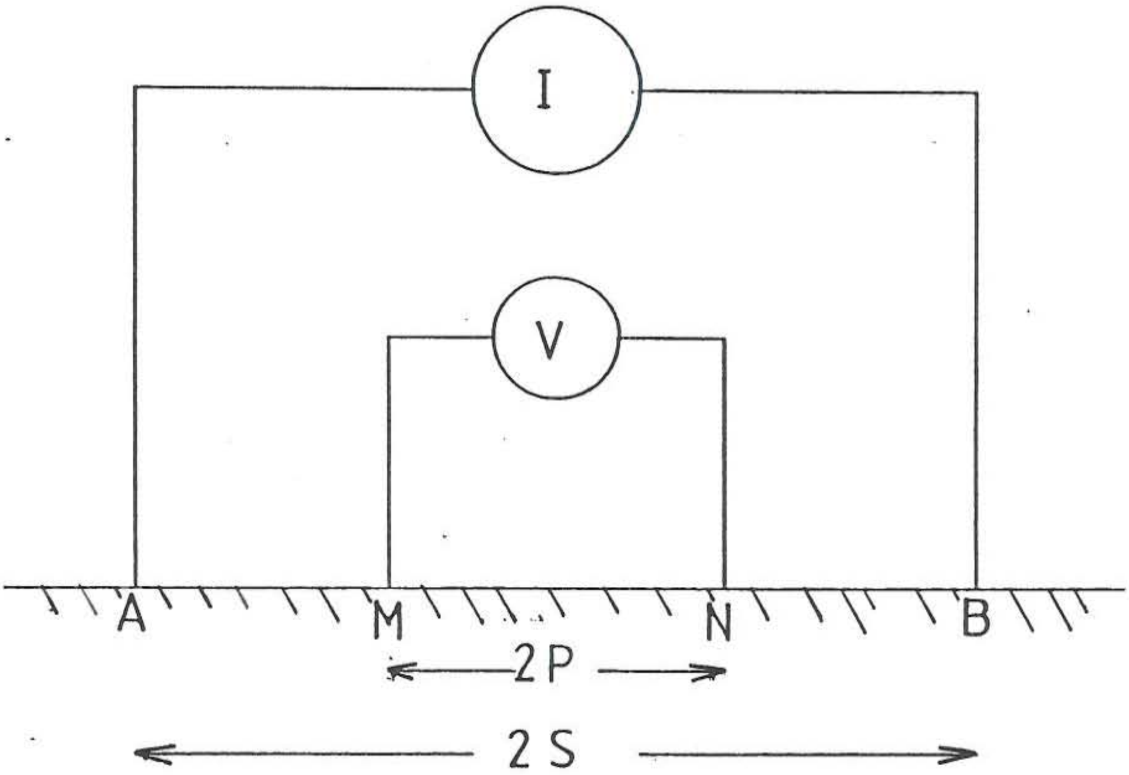


Figure 5. Schlumberger four electrode configuration array

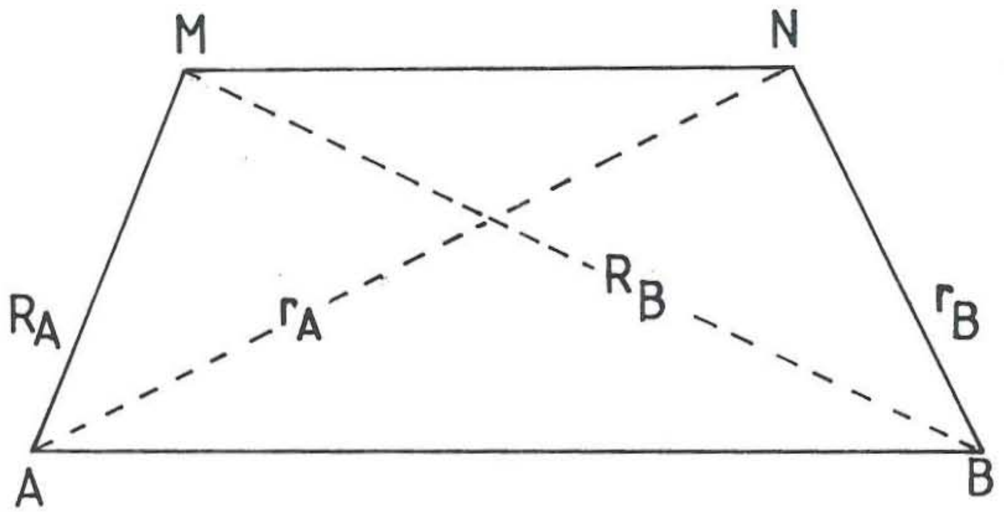


Figure 6. Generalized diagram for four electrode configuration

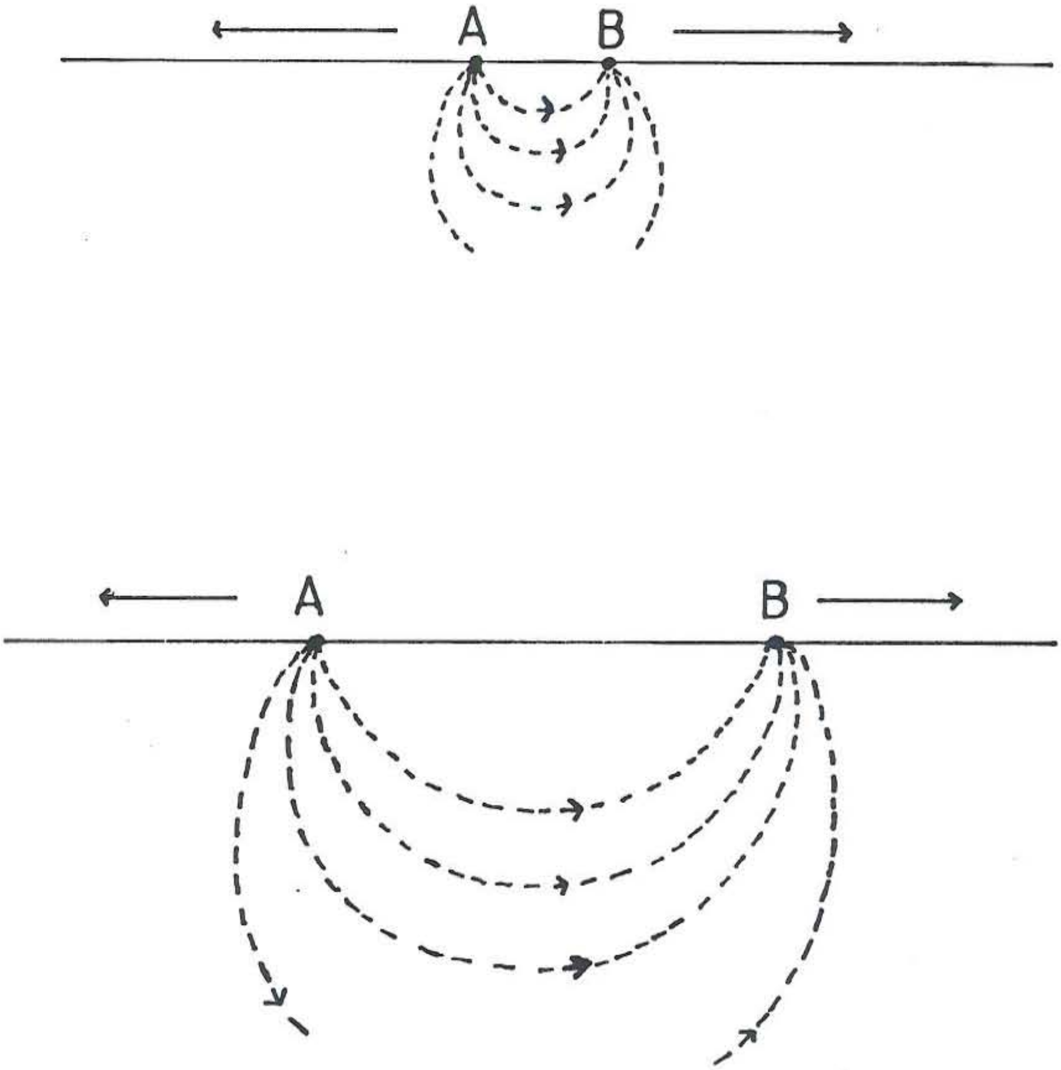


Figure 7. Illustration of current penetration as a function of moving current electrode soutward

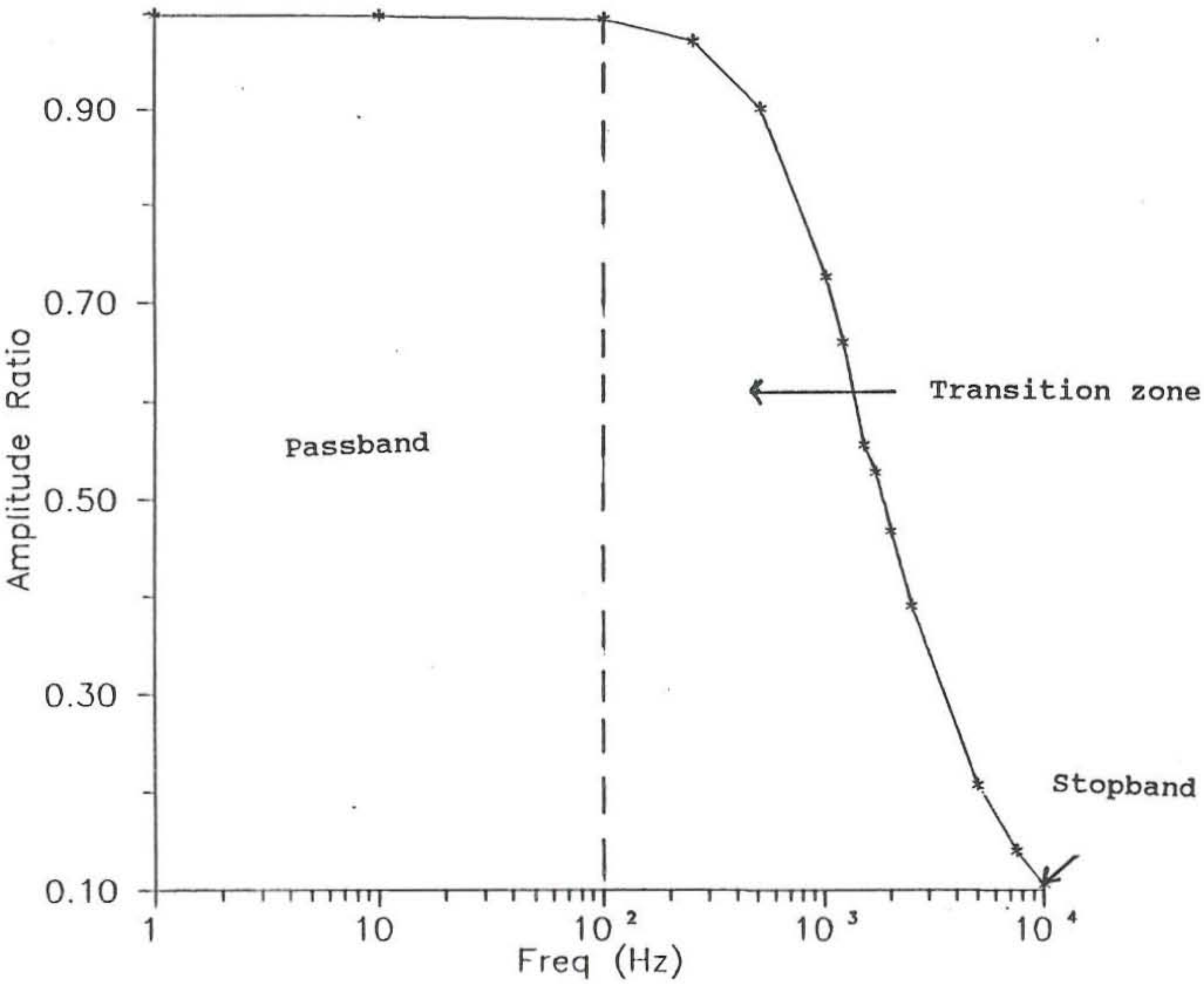


Figure 8. Illustration of the cut of frequency phenomena by a lowpass filter circuit

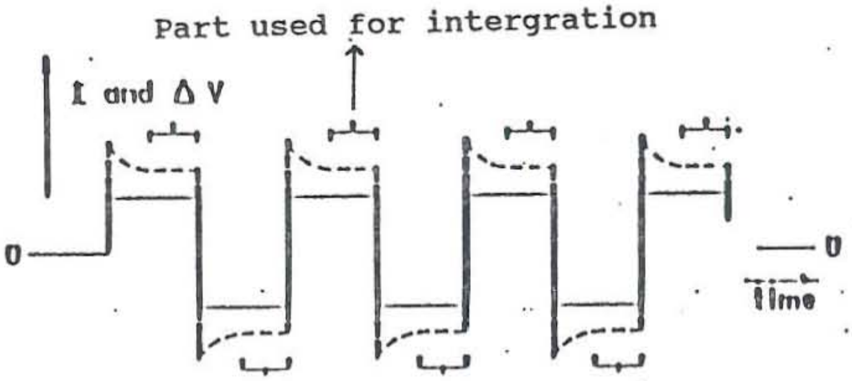


Figure 9. Deppermann's diagram for reversion of current flow

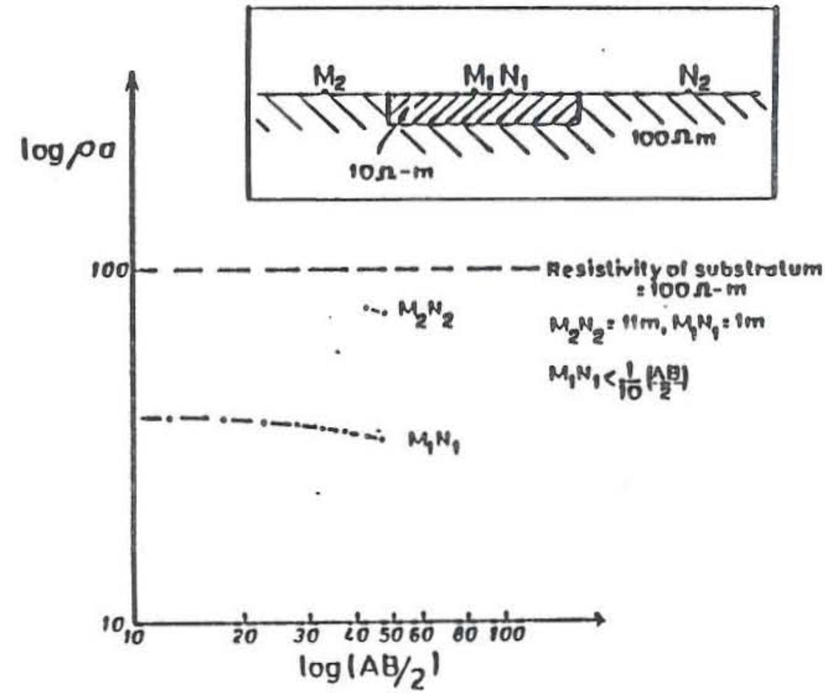
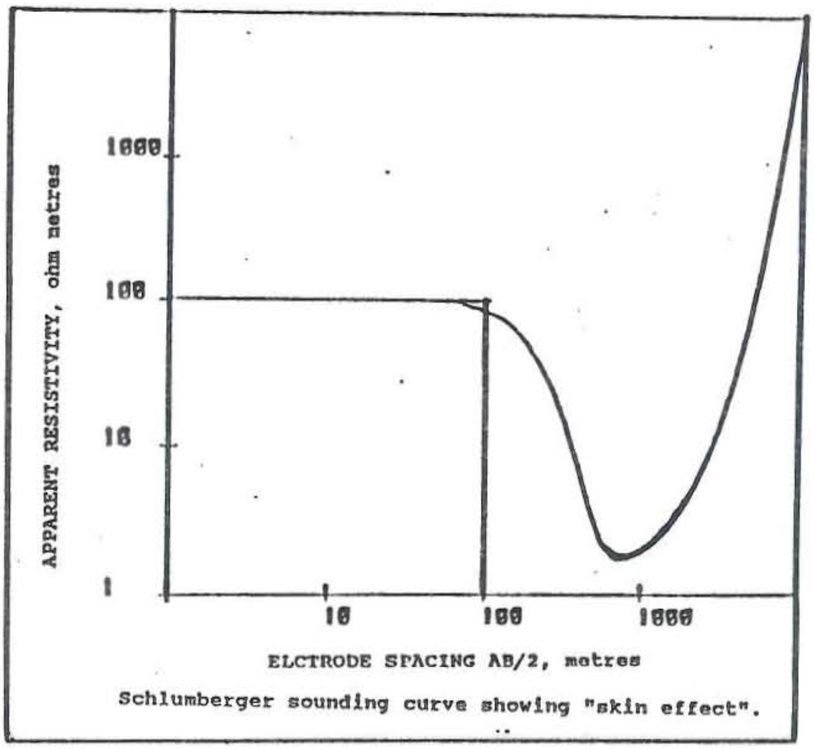


Figure 10. Illustration of near surface inhomogeneities (from Hochstein et al., 1982)



Schlumberger sounding curve showing "skin effect".

Figure 11. Theoretical "skin effect" phenomena due to AC sources in a two layer resistivity curve (from Hochstein et al, 1982)

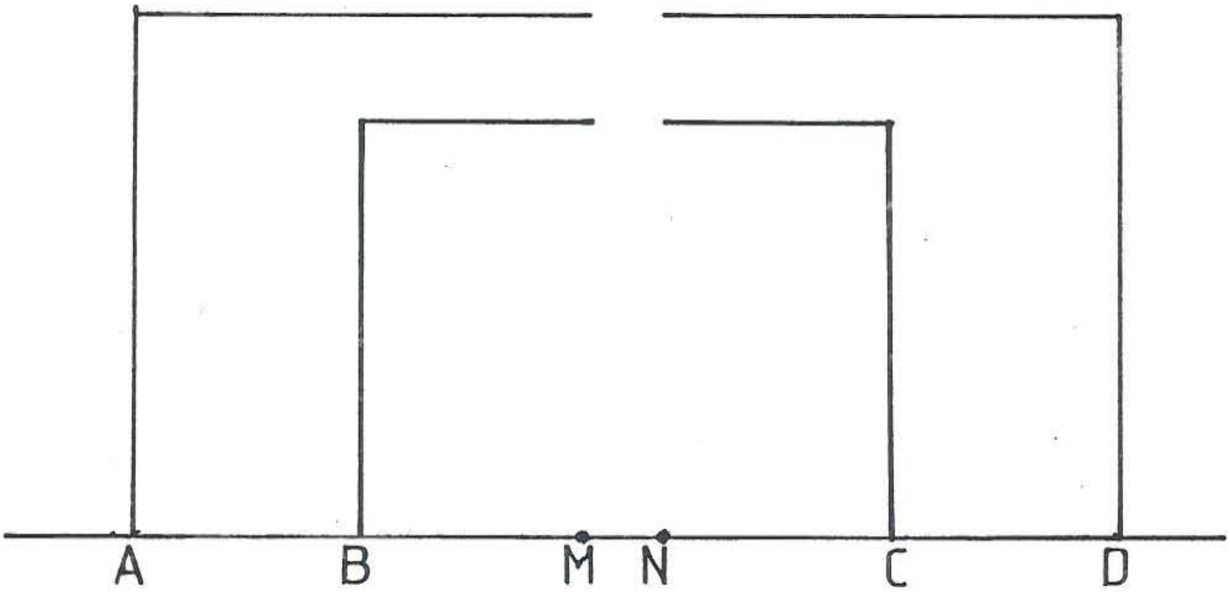


Figure 12. Electrode arrangement for field error monitoring