. No. U/8/67

DESIGN AND DEVELOPMENT OF A SIMPLE ELECTRICAL RESISTIVITY EQUIPMENT FOR GROUNDWATER INVESTIGATIONS AT SHALLOW DEPTHS

By

Dr. S.P. Mathur
WHO Consultant
Environmental Health Project

Prepared for

The Rural Water Supply Division
Department of Health
Royal Thai Government
Bangkok, Thailand.

October, 1980.

DESIGN AND DEVELOPMENT OF A SIMPLE ELECTRICAL RESISTIVITY EQUIPMENT FOR GROUNDWATER INVESTIGATIONS AT SHALLOW DEPTHS

Contents

Page No.

List of figures

List of Tables

....

Summary

In recent times electrical resistivity method has proved to be a very useful tool to a hydrogeologist (1-5) by supplementing more definite information of geophydrological conditions existing at depth in the investigated area. This information otherwise is extrapolated from surface or near surface information or from the data obtained from boreholes drilled in the area.

Electrical resistivity surveys are not used in this country as a part of routine groundwater investigations, eventhough its importance is well known. This method is thought to be sophisticated, time-consuming and expensive.

The equipment needed for electrical surveys is imported from abroad at high cost. Facilities for repair and maintenance do not exist with the departments engaged in ground water surveys. These factors limits the wide use of this method.

There is a great need for an indegeneous simple, easy to repair and maintain equipment suitable for shallow investigations needed in rural water supply programme.

A portable digital resistivity meter was designed and fabricated with the components available in the local market. This is a step further in the use of appropriate technology.

The total cost of the equipment designed is less than ฿ 3,000 (US.$ 150). Imported equipment of similar capabilities cost more than US.$ 1,500.

Fabrication of the equipment was done by the personnels of Rural Water Supply Division (RWSD).

The equipment was tested in laboratory and in field in Thanyaburi district, Pathumthani province and geohydrological information upto 250 m depth was obtained. The equipment and its operation is simple. Field procedures developed to suit local conditions, reduces the time of observation considerably.

Details of the equipment sufficient for duplication and its operations is given here.

1. Introduction.

One of the important aim of the Environmental Health Project (EH) is to select, to develop and field test suitable methods and technologies to provide safe drinking water supply to the rural population.

As a part of this important aim, suitable methodology using electrical resistivity method is developed for location of sites in problematic areas where geohydrological conditions are complex. A simple, easy to operate and indegeneously made equipment is developed and described here for purpose of duplication by the organizations engaged in such surveys.

The report was prepared by Dr. S.P. Mathur, WHO Consultant to the EH Project.

The report in section two describes the present status of the available equipment.

In section three, the basic principle of the equipment designed is described.

Section four gives the technical specifications of the equipment and section five describes the pannel controls.

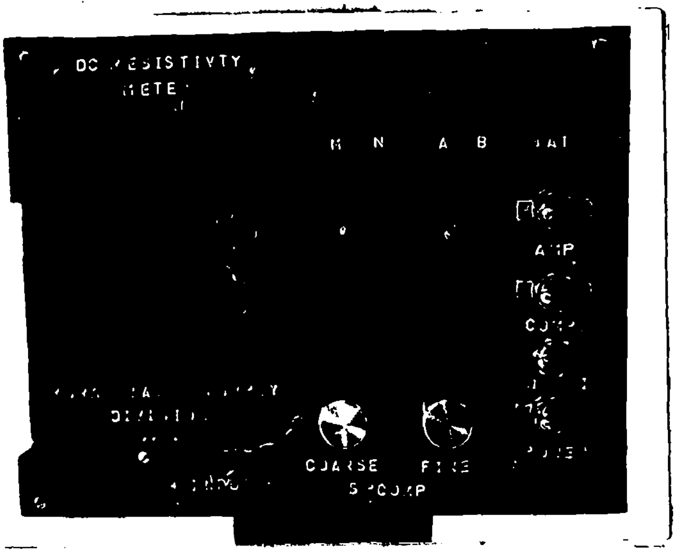
In section six operation procedures are given.

In section seven, results of laboratory and field testing is described and conclusions in section eight.

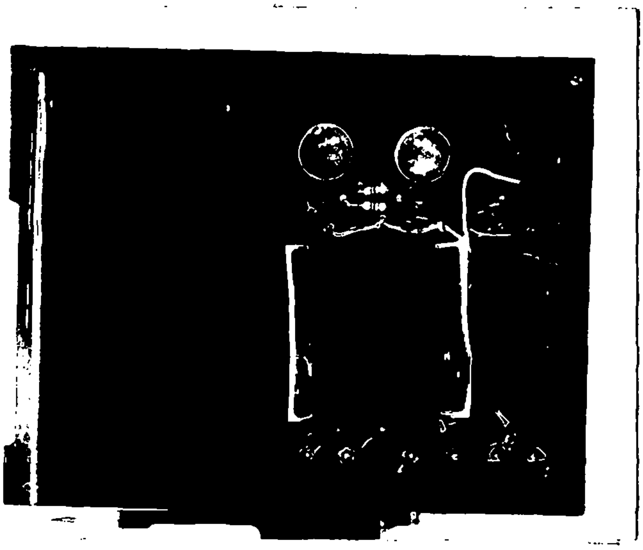
This report reflects the development work done by the author. The report is not approved by the Royal Thai Government, United Nations Development Programme and World Health Organization.

The author also retains sole responsibility for any errors which might have included in the report.

2. <u>Photographs</u>.

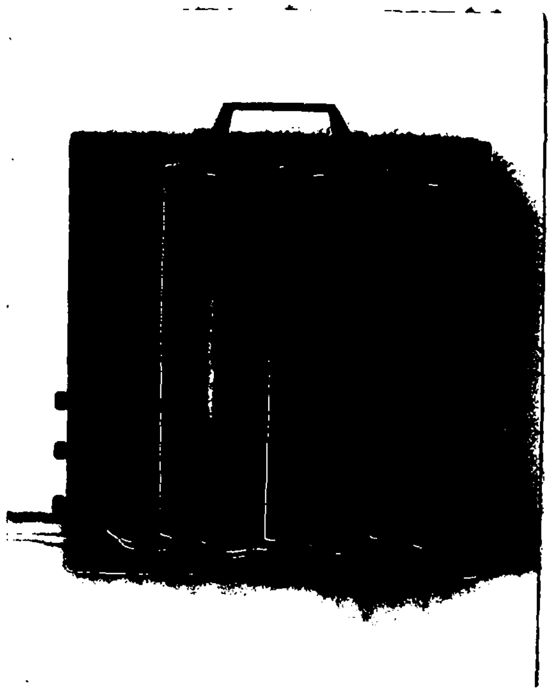


The equipment is very compact and portable (23 cm x 18 cm x 5 cm). With only six pannel controls, the operation of the equipment is easy and time taken for each observation is considerably small. A large 3½ digital display makes the reading of measured values easily and accurately.

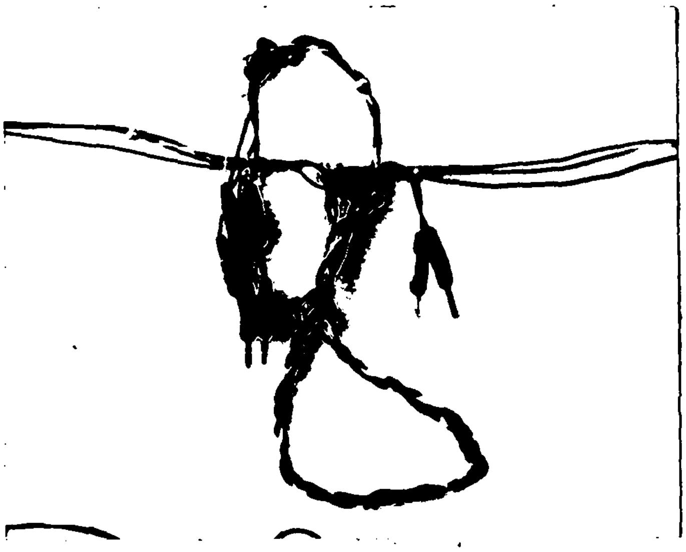


Use of few components (available locally) makes the assembling of the equipment very easy and can be done by low level technicians. Repair and maintenance is easy. The digital multimeter (seen on right) is used as a part of the measuring system and also used in the routine checks during the survey.

2. Photographs - cont'd.



Power for energization of formation is drawn from a specially designed battery pack (90 volts) which forms an accessory. The battery pack uses the 1.5 volts dry torch cells which are commonly available even in rural areas for replacements. Life of such battery pack is much larger than the compact battery which is expensive and commonly not available.



Design of special cable for connecting potential measuring electrodes reduces the time of observation considerably. Also, the helpers needed to conduct the survey is reduced from three (sometimes four) to two only. This reduces the cost of survey.

3. Present status and need for a simple equipment.

There are many makes and types of equipment available abroad. These equipment vary in its complexity depending on the depth of investigations, i.e. the power required for energization and the accuracy of measurement of signals. All types of equipments available, based on the type of current employed to energize the formation, can be grouped broadly into :

(a) Alternating current (AC) equipment
(b) Direct current (DC) equipment.

In alternating current or AC type of equipment, the current (I) used to energize the formation is a low frequency alternating current converted from a direct current source. The potentials (U_{MN}) measured are also AC potentials. These potentials are converted into DC potentials before they are measured.

In the DC equipment, direct current (I) is used to energize the formations. The measured potentials (U_{MN}) are also DC potentials.

In such type of AC and DC equipment, measurement of current (I) and potentials (U_{MN}) is done seperately. From these values the resistivity is computed.

In some of the equipment (mostly AC type), the energizing current is kept constant at 10 milliampere for varying load conditions i.e., for the changes in the resistance of the formations. Hence, in such equipment there is only need to measure the potentials.

The potentials (U_{MN}) can be measured directly on millivoltmeters or microvoltmeters or can be measured by null method making use of potentiometric circuits. In the null method, sensitive centre zero galvanometers are used to detect the null point.

The complexity of the equipment increases with the depth of investigations. The larger the depth of investigation, the larger is the power required to produce sufficiently large potentials that can be measured accurately. Hence, we have a range of equipment, from small and portable to big which are fitted in one or two trucks.

Most of the boreholes drilled for the rural water supply programme are shallow at 30 to 70 meters. Geohydrological information upto such shallow depths can be obtained easily by a equipment using small power for energizing the formations. The voltages developed will also be of the order of millivolts. Hence, the equipment needed for such conditions can be simple, compact and very portable.

A very simple method of measuring the current is to use a direct current milliammeter. For currents larger than its basic range, an attenuater is used. Voltage can be measured by the null method. A low gain differential amplifier in the measuring circuit is used to increase the sensitivity. However this method has the following defects :

3. Present status and need for a simple equipment - cont'd.

(a) Low sensitivity.

(b) Mechanical damage resulting in periodic replacement of galvanometers and milliammeter.

(c) Measuring procedure by comparision rather cumbersome and time consuming.

(d) Human errors involved in the anolouge readout systems. Such errors can sometimes be large, especially in the multirange systems where the actual reading is obtained by a scale multiplying factor.

In the last few years, portable digital battery operated pannelmeters with liquid crystal display are available. This recent trend in the instrumentation technology has proved to be a better subsititute for the anolouge measuring systems. Taking advantage of this, the author designed and fabricated a direct current electrical resistivitymeter(5). This equipment is designed to read the potentials directly instead of the conventional null method without loosing resolution and accuracy of the null method.' Since then, this equipment was tested rigrously under different geological and hydrogeological conditions. From the experience of working with this equipment, it was felt by the author that a new equipment could be designed in which

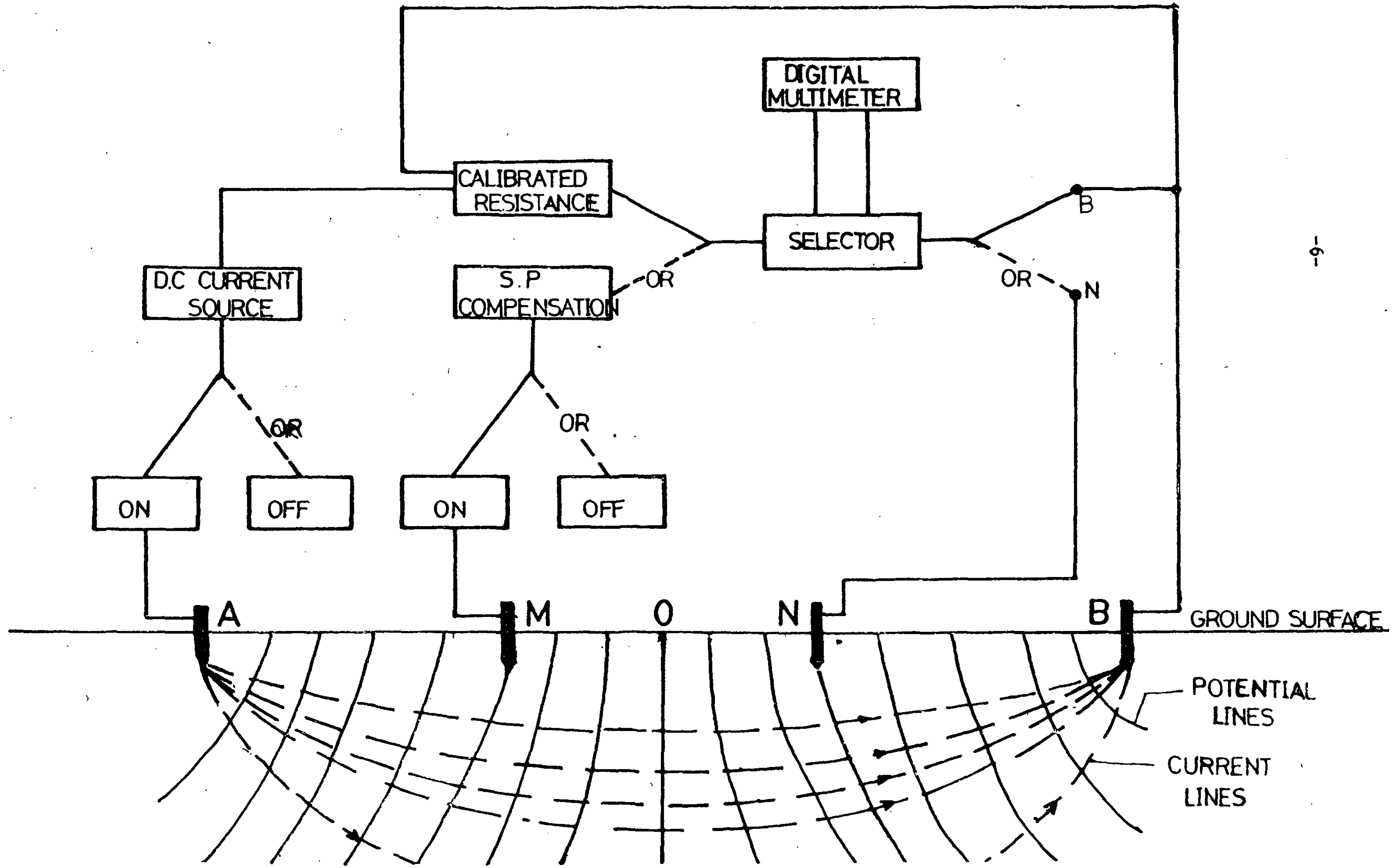
(a) It is possible to make the measuring procedure more simple by reducing the number of controls on the pannel and thus save time considerably on each measurement.

(b) The equipment is made more portable and also reduce the overall cost considerably by using the newly introduced portable battery operated digital multimeter instead of pannelmeters. In corporating these features, the equipment described here is designed and fabricated.

4. Basic principle of the equipment designed.

Block diagram explaining the principle of the direct current digital resistivitymeter is shown in fig.1 and the actual circuit diagram is shown in fig.2. Power is drawn from a 90 volts battery source box (each box contains 60 numbers of 1.5 volts dry cell batteries connected in series) and when higher voltage sources are required two or more battery source boxes are connected in series. A ON-OFF switch controls the flow of current to the electrodes A and B. A calibrated standard resistance of 1 ohm (1 watt, tolerance of 1% or less) is connected in series in current circuit. The strength of the current (I) is measured by measuring the voltage drop across the 1 ohm resistance. Digital multimeter operating in DC voltage mode and by choosing a proper range (200 mv or 2 volts) can measure this voltage drop accurately. The reading on the digital multimeter indicates directly the current flowing into the ground as voltage drop measured is across a calibrated 1 ohm resistance.

Fig. 1. BLOCK DIAGRAM OF DIRECT CURRENT RESISTIVITY METER



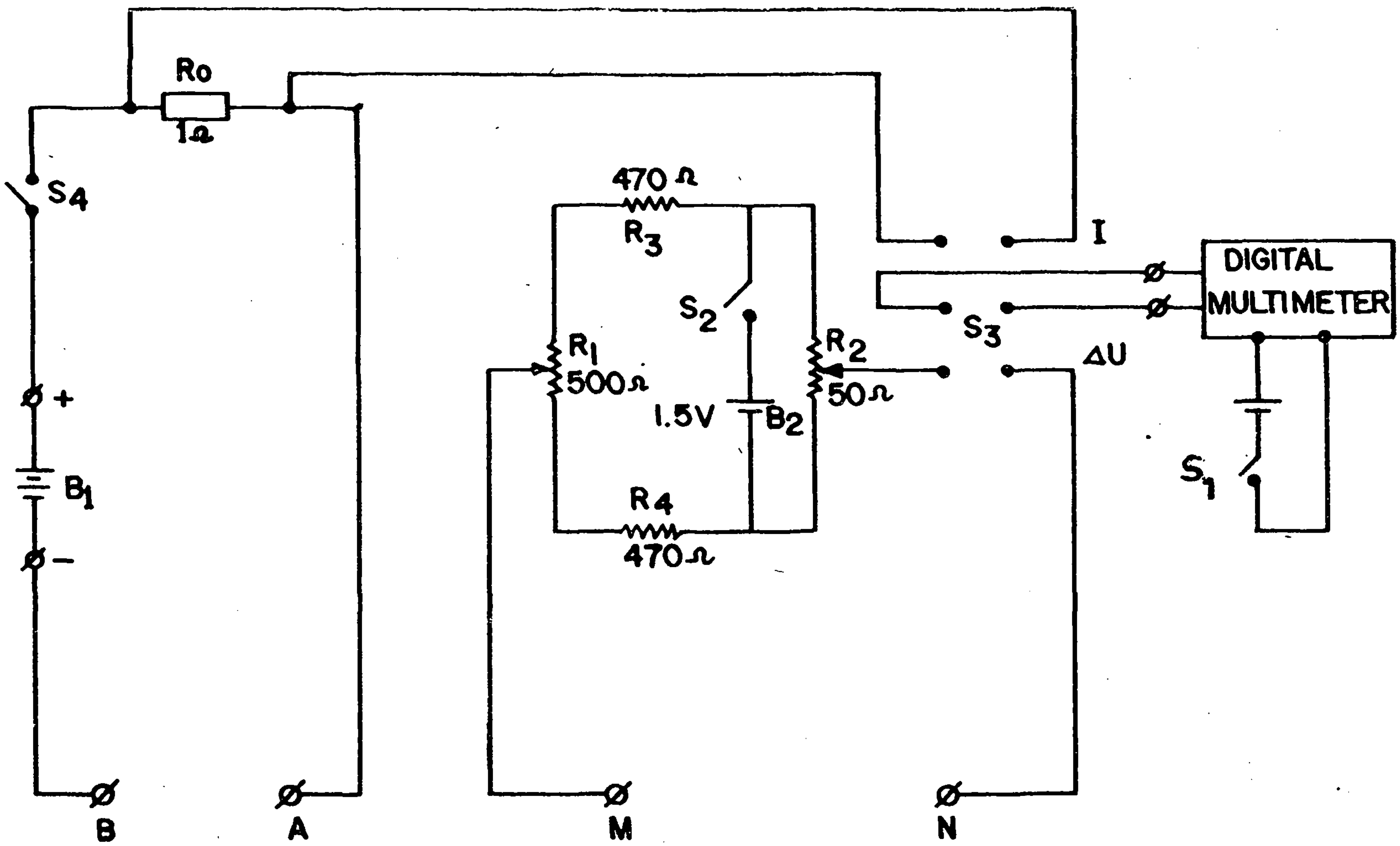


FIG: 2 CIRCUIT DIAGRAM OF DIRECT CURRENT DIGITAL RESISTIVITY METER

RURAL WATER SUPPLY DIVISION
DEPARTMENT OF HEALTH

DESIGN BY: S P MATHUR
DATE: NOVEMBER 1980

4. Basic principle of the equipment designed - cont'd.

By the flow of direct current into the ground loop, an artifical electrical field is developed which behaves the laws governing the flow of direct current in a media. The voltage drop of this artifical field is measured at two other electrodes M and N. This voltage will be a DC voltage and this can be measured on the digital multimeter operating in DC voltage mode. But, it is known that in formations we have the flow of natural direct currents which gives rise to a natural electric field. At M and N electrode we can also measure the potential drop of this electric field. These potentials are called the self potentials or in short S.P. Sometimes these potentials are quite significant and has to be compensated before we measure the voltage drop of the artifical direct current field.

For compensating the S.P potentials, a voltage of opposite polarity is fed to the electrodes M and N. This compensating voltage is drawn from a S.P compensator. The S.P compensator which is a bridge type of a circuit can provide variable voltage of $\pm$ 600 mv. with a coarse and a fine control. The fine control provides a smooth varying voltage of $\pm$ 50 mv.; while the coarse control provide $\pm$ 550 mv. S.P compensator is connected in series with the MN circuit. The power to this circuit is drawn from 1.5 volt dry cell battery. A ON-OFF switch controls the supply of power to this circuit.

The selector is a double pole double way switch. It can connect the inputs of the digital multimeter either to the MN circuit for measuring U_{MN} or across the standard resistance to measure the current I by actually measuring the voltage drop across it.

Thus by measuring U_{MN} and I, the resistance of the formations can be computed. Multiplying the resistance with the geometric constant (K) of the AMNB set up, we obtain the resistivity of the formations in ohm.m.

$$P = K \frac{U_{MN}}{I} \text{ ohm.m.}$$

where,

$$K = \frac{AM.AN}{MN} \text{ measured in meters}$$

5. Technical specification.

1) Current Measurement :

a) Range:	200, 2000, 20,000 mA
b) Readout:	3½ digits LCD display
c) Resolution:	0.10 mA in 200 mA range 1 mA in 2000 mA range

2) Potential :

a) Range:	200, 2000, 20,000 mV
b) Readout:	3½ digits LCD display
c) Resolution:	0.10 mV in 200 mV range 1 mV in 2000 mV range

4. Basic principle of the equipment designed - cont'd.

By the flow of direct current into the ground loop, an artifical electrical field is developed which behaves the laws governing the flow of direct current in a media. The voltage drop of this artifical field is measured at two other electrodes M and N. This voltage will be a DC voltage and this can be measured on the digital multimeter operating in DC voltage mode. But, it is known that in formations we have the flow of natural direct currents which gives rise to a natural electric field. At M and N electrode we can also measure the potential drop of this electric field. These potentials are called the self potentials or in short S.P. Sometimes these potentials are quite significant and has to be compensated before we measure the voltage drop of the artifical direct current field.

- For compensating the S.P potentials, a voltage of opposite polarity is fed to the electrodes M and N. This compensating voltage is drawn from a S.P compensator. The S.P compensator which is a bridge type of a circuit can provide variable voltage of ± 600 mv. with a coarse and a fine control. The fine control provides a smooth varying voltage of ± 50 mv.; while the coarse control provide ± 550 mv. S.P compensator is connected in series with the MN circuit. The power to this circuit is drawn from 1.5 volt dry cell battery. A ON-OFF switch controls the supply of power to this circuit.

The selector is a double pole double way switch. It can connect the inputs of the digital multimeter either to the MN circuit for measuring U_{MN} or across the standard resistance to measure the current I by actually measuring the voltage drop across it.

Thus by measuring U_{MN} and I, the resistance of the formations can be computed. Multiplying the resistance with the geometric constant (K) of the AMNB set up, we obtain the resistivity of the formations in ohm.m.

$$P = K \frac{U_{MN}}{I} \text{ ohm.m.}$$

where,

$$K = \frac{AM.AN}{MN} \text{ measured in meters}$$

5. Technical specification.

1) Current Measurement :

a) Range:	200, 2000, 20,000 mA
b) Readout:	3½ digits LCD display
c) Resolution:	0.10 mA in 200 mA range 1 mA in 2000 mA range

2) Potential :

a) Range:	200, 2000, 20,000 mV
b) Readout:	3½ digits LCD display
c) Resolution:	0.10 mV in 200 mV range 1 mV in 2000 mV range

5. Technical specification - cont'd.

3) Accuracy : $\pm$ 0.5%

4) Power supply :

a) internal: 9 volts eveready cell.
1.5 volt eveready cell.

b) external: power packs 90 v.

5) Diamensions : 230 mm x 180 mm x 50 mm

6) Weight : Less than 1kg.

7) Accessories : 2 battery pack, 2 winches with cable, 8 electrodes, 3 hammers, MN Cable, 2 rubber mats.

6. Pannel controls.

The equipment has a single pannel control of dimensions 23 cm x 18 cm (shown in fig.3)

There are in all 9 controls with one display. These controls as marked in the figure are :

(1) - Input terminals A and B for connecting the current electrodes.
(2) - Input terminals M and N for connecting the potential electrodes.
(3) - Input terminals + ve and - ve for connecting the external battery source box.
(4) - ON-OFF power switch (S1) for the amplifier.
(5) - ON-OFF power switch (S2) for the S.P compensator circuit.
(6) - Selector switch (S4) either to measure the potentials U_{MN} (U) or the current I.
(7) - ON-OFF power switch (S3) for controlling the flow of current to the electrodes A and B.
(8) - Coarse and Fine controls for self potential compensation.
(9) - Mode and range selector of the digital multimeter for measuring DC potentials.
(10) - Digital readout for potentials (U) or current (I).

7. Operation procedures.

1) Peg the four electrodes, A, M, N and B symmetrically in the earth along a line at predetermined distances marked on the MN cable. The distances are measured from the centre 'O' of the spread AMNB. Connect the end of the cables to the electrodes.

2) Connect the input terminals of the equipment A, B (1) and M, N (2) to the respective winches carrying the cable with connectors. (controls (1) and (2) on the pannel).

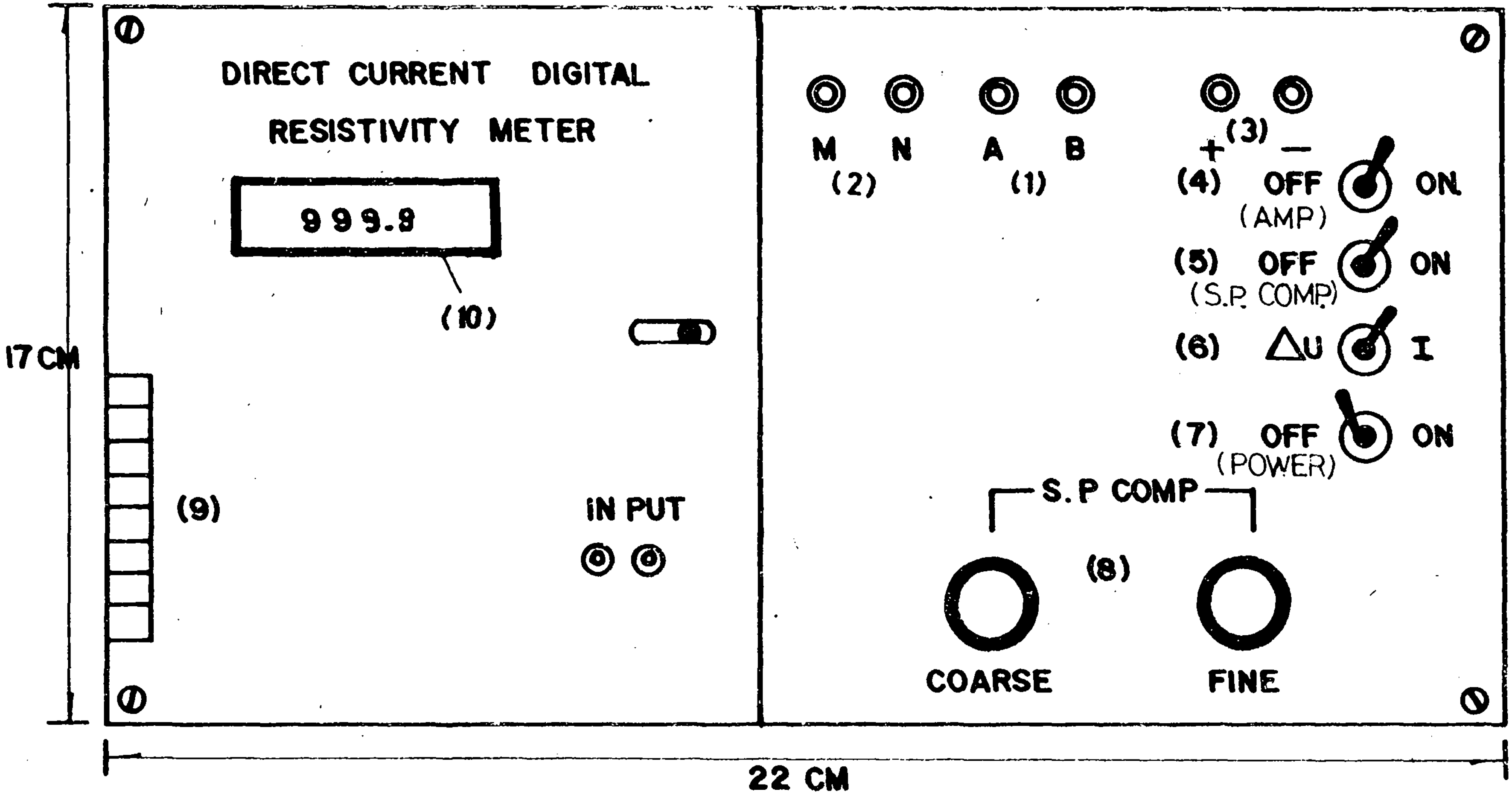


FIG:3 CONTROL PANNEL OF DIRECT CURRENT DIGITAL RESISTIVITY METER

RURAL WATER SUPPLY DIVISION
DEPARTMENT OF HEALTH

DESIGN BY : S. P MATHUR
DATE : NOVEMBER 1980

7. Operation procedures - cont'd.

3) Connect the + ve and - ve of the external 90 volt battery pack source to the + ve and - ve input power terminals (3) with the help of a connector with Bannana pins or jacks at either ends.

4) Switch 'ON' the power (4) supplied to the amplifier of the digital multimeter.

5) Switch 'ON' the power (5) to the S.P compensation circuit.

6) Select U mode on U-I switch (6).

7) Select the function switch (9) to DC volts and range switch to 200 mv or to 2 volts if the voltages expected are large.

8) S.P potentials appear with its polarity sign on the digital display. Monitoring the digital display (10), operate the coarse S.P compensation control knob (8), till the S.P potentials become small (around 10 - 20 mv). Then operate the fine control knob till the S.P potentials are compensated which is indicated by the zero reading on the digital display (10).

9) Switch 'ON' the power source (7) to the electrodes for energizing the formations. Potentials develop at MN electrodes.

10) Read the potentials developed at MN electrodes (U_{MN}) which appear on the digital display (10) and record it in the standard proforma for the AMNB configuration (Table 2).

11) Change the selector switch (6) position to I and read the current I on the digital display and record it in the standard proforma (Table 2).

12) Switch 'OFF' all the power supply controls (4, 5 and 6).

13) Calculate the apparent resistivity (Pa) of the formations using the value of 'K' for the AMNB seperation adopted.

14) Plot the value of Pa for the AB/2 seperation on a double log paper of modulus 6.25 (2 x 3 cycles). Shown in fig.4.

15) Expand the AB electrode seperation to the next predetermined distance which is marked on the cables and listed in VES data sheet. Repeat steps 4 to 14 detailed above. Check the accuracy of measurement by repeating the observations. The difference between the two observations should not be more than 10%.

16) By repeating steps 4 to 14 for all the AB/2 seperations listed in the data sheet, obtain a smooth VES curve.

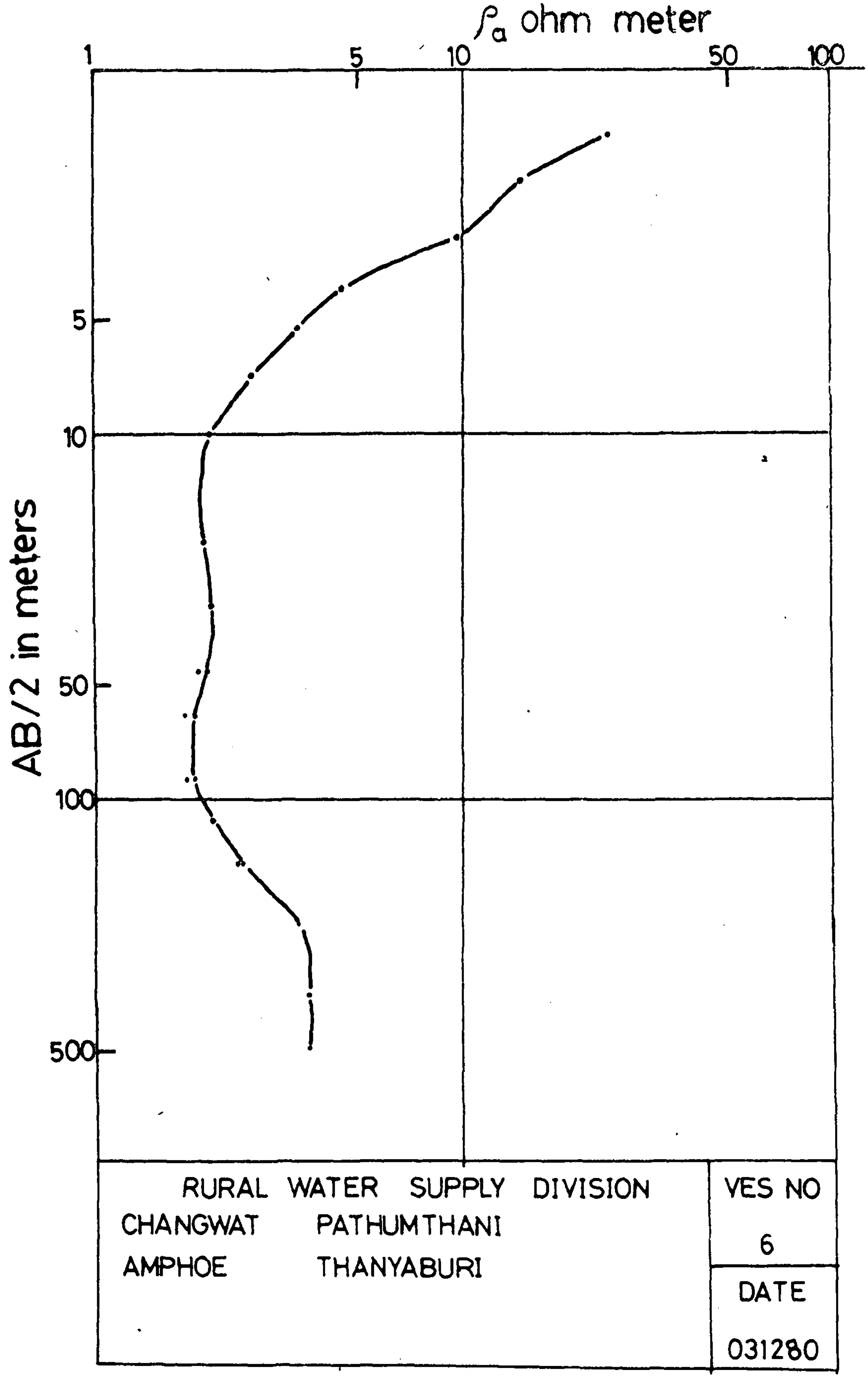


Fig: 4 VES curve obtained with the equipment designed

8. Results of laboratory and field testing.

The equipment testing was conducted initially in laboratory using standard resistances representing the formation resistances. The accuracy of measurement was better than 1% (see Table 1).

Later the equipment was field tested for short seperations (AB/2 = 20 meters) in the premises of the Ministry of Health. Field testing of the equipment indicated that the R-C filter, designed to cut the 50 cycle AC mains or its harmonics, had made the measuring system rather sluggish. The parameters of the filter were adjusted.

Detailed field testing of the equipment was then conducted at Amphoe Thanyaburi, Changwat Pathumthani for AB seperations as large as 960 meters. The area of testing is characterised by a geoelectrical section with low resistivities (2 to 6 ohm.m). In such geoelectrical sections, skin effects will be large.

Results of testing indicated the following :

a) The equipment designed could be used successfully up to 960 meters of AB seperation. Testing for AB seperations longer than this was not attempted. One of the VES curves obtained is shown in figure 4 and the measured data is shown in Table 2.

b) The repeatability errors in the measured value of apparent resistivity is around 5-7% for low values of resistivity and AB/2 seperations while for larger seperations it is less than 10%. However these errors which are mostly due to other factors relating to geometry, disposition and electrode resistances etc, can be reduced further. Even then, such small errors when plotted on log scale are not noticeable. The obtained curve would appear smooth.

c) The measuring procedure proved to be very simple and less time consuming. A VES curve upto 960 meters of AB seperation was completed with untrained workers in 90 minutes. This could be considerably reduced in future with the training of personnels.

d) The measured values could be read quickly and accurately because of the digital display. However, sometimes, in the most sensitive range, the last digit representing a part of millivolt keeps floating or changing ($\pm$ 0.1 or $\pm$ 0.2 mv. about a mean value). This feature, though present in anolouge systems, are subdued and are not seen because of low accuracy of measuring systems. However, in very sensitive equipment (microvoltmeters) this feature is seen.

TABLE NO. 1

Laboratory testing of direct current digical resistivitymeter

S.No.	Standard resistance in ohms	Current in mA.	Voltage U in mV	Resistance calculated in ohms	error in 100%
1	2	23.0	45.8	1.99	0.80
2	5	12.0	59.8	4.98	0.50
3	10	3.4	33.8	9.94	0.60
4	20	36.1	717.7	19.88	0.57
5	27	32.3	867.3	26.85	0.50
6	47	18.8	880.9	46.85	0.30
7	68	12.2	826.3	67.73	0.40
8	100	7.2	717.8	99.70	0.30
9	470	19.1	8,954.6	468.83	0.25
10	1,000	9.3	9,281.4	998.0	0.20

TABLE NO. 2

VES. DATA SHEET SHOWING THE REPEATABILITY ERROR

VES DATA SHEET RURAL WATER SUPPLY DIVISION DEPARTMENT OF HEALTH	CHANGWAT : PRATHUMTHANI AMPHOE : THANYABURI TAMBON : - MOO BAN : -
OBSERVER : DR. S.P. MATHUR RECORDER : MR. BANTHURNG INSTRUMENT : D.C.P.	DATE : 1.2.80 VES NO. 3 TIME : 13.00pm AZIMUTH : E-W

S NO.	AB/2 in mts.	MN/2 in mts.	K	Δ U in mV.	I in mA.	P1 a in ohm.m	Δ U in mV.	I in mA.	P2 a in ohm.m	Error in 100%
1	1.5	0.5	6.3	385	493	4.92	386	493	4.93	1.26
2	2.0	0.5	11.8	64	178	4.24	68	197.6	4.06	4.20
3	3.0	0.5	27.5	36	249	3.97	34.9	250	3.84	3.20
4	4.5	0.5	62.8	24	442	3.41	23.2	443	3.29	3.50
5	7.0	0.5	153.1	7	371	2.89	6.7	372	2.76	4.30
6	7.0	2.0	35.3	30	371	2.85	28.7	373	2.72	4.5
7	10.0	0.5	313.3	2.9	368	2.47	2.9	369	2.45	4.2
8	10.0	2.0	75.4	12.0	367	2.46	11.3	360	2.37	3.2
9	20.0	2.0	311.0	1.6	202	2.46	1.5	202	2.38	3.1
10	20.0	6.0	95.3	13.8	517	2.13	11.5	518	2.12	1.0
11	30.0	6.0	226.2	6.4	608	2.38	6.2	607	2.31	7.0
12	45.0	6.0	520.6	1.9	406	2.43	1.8	405	2.36	7.0
13	45.0	10.0	302.3	3.4	386	2.66	3.5	387	2.72	6.0
14	60.0	10.0	549.7	3.0	692	2.38	2.9	6.92	2.30	8.0
15	60.0	20.0	251.3	5.7	669	2.14	5.8	665	2.2	6.0
16	90.0	20.0	604.6	2.3	514	2.70	2.3	510	2.75	5.0
17	90.0	30.0	376.9	3.2	512	2.35	3.1	514	2.30	5.0
18	150.0	30.0	1,130.7	1.1	330	3.76	1.14	331	3.80	4.0
19	150.0	50.0	628.2	3.2	350	5.74	3.2	348	5.80	6.0
20	225.0	30.0	760.9	-	-	-	-	-	-	-
21	225.0	50.0	1,511.6	1.5	644	3.52	1.5	648	3.60	8.0
22	350.0	50.0	3,769.2	1.3	1,143	4.28	1.3	1,136	4.31	3.0
23	480.0	50.0	7,158.0	0.8	1,195	4.7	0.7	1,067	4.69	1.0

9. Conclusions.

The results of testing indicated that :

a) The equipment designed can be used very effectively in the location of favourable sites for drilling of boreholes as deep as 250 meters. The effectiveness and accuracy of this equipment is all the more high for shallow boreholes (Upto 40-60 meters) drilled in a rural water supply programme.

b) The equipment and measuring procedure is so simple that even a technician with little field training can operate and maintain the equipment.

c) The assembling of the present equipment was done by the technician of the department. Duplication of the equipment can be done very easily as all the components needed are locally available. The main part of the equipment which is a digital multimeter is also available locally.

d) Total cost of the equipment is less than ฿ 3,000 (US.$ 150) which is very cheap compared to imported equipment.

10. Acknowledgements.

The author wishes to thank for the assistance rendered by Mr. Banthurang Bunchan, Mrs. Devarugsa Kruerklai and Mr. Udom Kasetravetin, personals of the Department of Rural Water Supply Division, Ministry of Public Health, for the help extended during the development of the equipment. Special thanks to Mr. Banthurang who did the final assembly and for preparing the accessory equipment needed for the survey.

A deep appreciation is rendered to Mr. Chetpan Karnkaew, Director, Rural Water Supply Division, Health Department, Ministry of Public Health, and Mr. B.J. Kukielka, team leader, UNDP project for showing great interest in this work.

Lastly my special thanks to Miss Luckanawadee Buaseemuang for typing out this report.

11. List of references.

1) Ogilvi, A.A. 1967, Geophysical prospecting for groundwater in Soviet Union: Mining and Groundwater Geophysics, Canadian Geo. Surv. Econ. Geol. Bull 26.

2) Patangay, N.S. 1973, Application of electrical resistivity method for solving certain hydrogeological problems in Minjur - Ponneri area, Chingalpet district, Tamilnadu. Ph.D. thesis, Osmania University, Hyderabad.

3) Volkar, A and Dijkstra, 1955, Determination of Salanity of Groundwater beneath the Zuiderzee by geophysical exploration. Geop. pros. vol 3, P 11-125.

4) Vam Dam, J; and J. Meulenkamp, 1967, some results of the geo-electrical resistivity method in groundwater investigations in Netherlands. Geophysical prospecting, V15, P 92-115.

5) Mathur, S.P, 1978, Integrated Geophysical investigations for groundwater in parts of Chagalnadu Basin, west Godavari district, Andhrapradesh; Ph.D. Thesis, Osmania University, Hyderabad.

6) Mathur, S.P, etal: 1980; Report on the groundwater investigations for Augmentation of water supply in the Metropolis of Hyderabad, Andhrapradesh.

7) Koefoed, O, 1972., error propagation and uncertainity in the interpretation of resistivity sounding data. Geophys. prospect.; 24; 31-48.

....