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Development of Low Cost Terrameter

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Abstract- The research work was based on development of low-cost terrameter instrument to measure ground resistivity and conductivity using schlumberger electrodes array method. The terrameter consists of inverter circuit, voltage multiplier, and current limiting network, induced voltage measuring circuit, analog-to-digital converter, liquid crystal display, keypad and microcontroller. The system has four electrodes array in schlumberger was tested on various soil type and different moisture level in the tropical terrain. The current and voltage measuring unit were calibrated using secondary standard method with available Mastech MS8210 meter. The keypad provided was used to enter space between the electrode at each measurement on the instrument to obtain the soil resistivity and the soil conductivity automatically. The instrument can measure in both dry and wet soil. At wet soil the resolution is about is 0.01 Ω. The range is 0.1 Ω to 1 MΩ. The mean deviation from available terrameter or wet soil is ±0.1 and for dry soil is ±1.02.

Indexed Terms- Conductivity, Resistivity, Induced Voltage, Terrameter, Schlumberger Array

I. INTRODUCTION

All resistivity methods of measurement employ a source of current such as wet cell battery, which is introduced into the ground through point electrodes or long line contacts; the latter arrangement is rarely used nowadays. The procedure is used to measure the electric potentials near the current flow. The fact that the current is measured as well, makes it is possible to determine the effective resistivity of the subsurface. In this regard, the resistivity technique is superior at least theoretically, to all the other electrical methods, because quantitative results are obtained by using a controlled source of specific dimensions. So resistivity is the resistance of unit length of material of unit cross sectional area. It decreases with increase in moisture content of the material until its minimum value is obtained. This minimum resistivity value is the resistivity of the material practically, as in other geophysical methods, the maximum potentialities of resistivity method are never realized. The chief drawback is its high sensitivity to minor variations in conductivity near the surface; that is the noise level is high. An electrical cell used to measure electrical conductivity of soil samples, pastes, and suspensions, was also developed based on four electrode principle. Researcher developed and introduced a compact low-cost four-electrode salinity sensor into routine agricultural practices. Also, worked on the design of earth resistivity meter suitable for locating archaeological objects, to assist in finding conditions favourable for alluvial gold or gemstones and for determining where to locate a septic tank. A special soil salinity probe, which utilized the same four-electrode principle, was also designed for bore-hole measurements and/or for permanent installations in soils for infiltration and salinity monitoring designed a resistivity meter that is analogue and also sensitive to wet soil only because of its low sensitivity. Another Scientist designed a resistivity meter with constant current of 500 mA using Wenner method.

The measurement of ground electrical conductivity is important to many branches of engineering, communication, geophysics, hydrological and mineral exploration. Electrical installations, earthling of transformers in the electric power networks, the detection of different types of minerals and rocks present in the earth's crust are some of the uses to which we put the measurement of ground electrical conductivity. Electrical resistivity method is the most suitable for foundation studies of ground water exploration. It is easy to employ and the equipment is convenient to transport from place to place. Information about aquifers, water tables, salinities, impermeable formations, bedrock etc can be obtained from resistivity survey.

II. BASIC TARAMETER BLOCK PRINCIPLE

The design of the resistivity is based on the electrical resistivity method. The theory of design employed is based on the principle that the measurement of current can be measured directly and being divided by induced voltage from the ground. This method is a modified to previous techniques using a constant, either by a regulator or manually fixing it during probing. A basic circuit block diagram is shown in Figure 1. The basic block diagram comprises of the potential measuring circuit, the current measuring circuit and the arduino microcontroller controlled display circuit to give the various measurements like the current and voltage sent to the ground. These values were used by the tarrameter is made to calculate the soil resistivity and the soil conductance automatically. The block diagram of the design of the terrameter is shown in Figure 1. It comprises of the followings:

a) Transmitting and Receiving Electrode
b) High Voltage DC circuit consists of
 i. The inverter circuit
 ii. The voltage multiplier circuit
c) ADS1116 has differential inputs
 i. Current measuring circuit
 ii. Induced Voltage circuit
d) The microcontroller and display unit

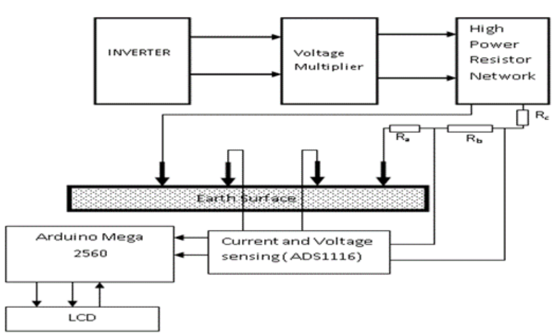

Figure 1: Block Diagram of a terrameter

2.1 Wenner Electrode Arrangement Probing Method

The current and potential electrodes using schlumberger array, shown in Figure 2, was used to obtain the apparent resistivity (ρ) and r_1, r_2, r_3 and $r_4$are electrode spacing. The apparent resistivity is given as

$$\rho = \frac{2\pi\Delta V}{I\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]} \quad (1)$$

$$= \left(\frac{2\pi\Delta V}{I}\right)p$$

Where $p = \frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}$, which has to do with the electrode geometry.

ΔV is the receivers' voltage from potential electrode (P1, P2) and I is current sent to ground through the current electrode (C1, C2).

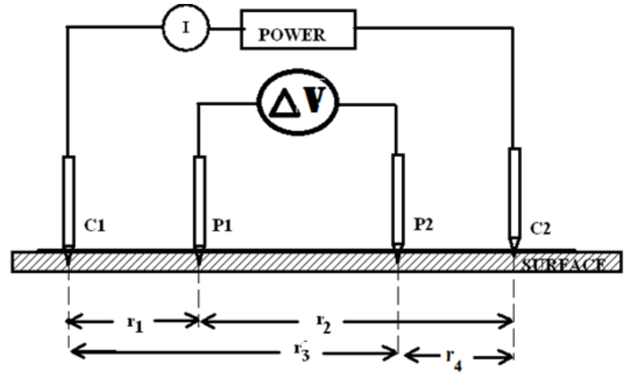

Figure 2: Schlumberger array of Electrodes

By measuring ΔV and I and knowing the electrode configuration, the resistivity, ρ , can be obtain over a homogenous isotropic ground. This resistivity will be constant for any current and electrode arrangement. If the ground is inhomogeneous, however, and the electrode spacing is varied, or the spacing remains fixed while the whole array is moved, then the ratio (ΔV/I) will, in general, change. This results in a different value of ρ , for each measurement. The magnitude is intimately related to the arrangement of electrodes. This measured quantity is known as the apparent resistivity, ρ , although it is diagnostic, to some extent, of the actual resistivity of a zone in the vicinity of the electrode array. The apparent resistivity is definitely not an average value and only in the case of homogeneous grounds is it equal to the actual resistivity.

Another term that is frequently found in the literature is the so-called surface resistivity. This is the value of ρ_a, obtained with small electrode spacing. Obviously, it is equal to the true surface resistivity only when the ground is uniform over a volume roughly of the dimensions of the electrode separation. When the electrodes are uniformly spaced in a line and setting $r_1 = r_4 = a$ and $r_2 = r_3 = 2a$, the apparent resistivity of equation 1 becomes.

$$\rho_a = 2\pi a \, \Delta V/1 \qquad (2)$$

2.2 High DC Voltage Circuit

The high dc voltage circuit comprised an inverter circuit, voltage multiplier and high power resistor was used as current source.

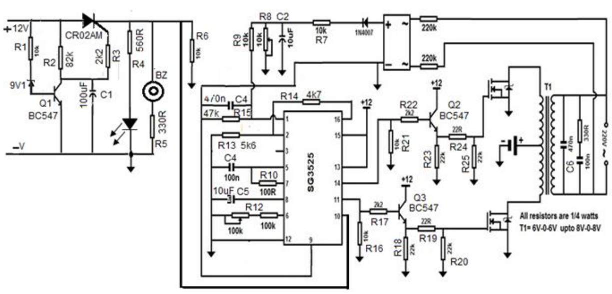

Figure 3: Inverter Circuit Using SG3525

The Figure 3 shows the diagram of inverter that was developed using pulse width modulation (PWM) integrated circuit, SG3525 in which the pulse width modulation frequency is determined by passive components connected at pin 5, 6 and 7 which are C_4, R_{10} and R_{12} and are related by

$$f = \frac{1}{C_4\left(0.7R_{10} + 3R_{12}\right)}$$

1

Where C_4 is in µF, R_{10} and R_{12} are in Ω.

For a required drive signal of 50 Hz, the oscillator frequency using the above formula is 100 Hz which will be divided into two by the internal flip-flop circuit to give two alternating 50 Hz signals at the output. At pin 9 to pin 1, R_{15} and C_3 provide the needed compensation to avoid fluctuations of the output voltage due to loading effect. Also, R_{10} (10 µF) provides about 3.33 ms dead time on the pulse train to imitate the zero crossing as in sine waves. This is necessary because most equipment are very sensitive to pure square wave and will not operate properly. To control the output voltage, the internal error amplifier of SG3525 is utilized with a feedback from the final output. R_{13} and R_{14} provide a reference voltage of about 2.0 V to the non-inverting input of the error amplifier. The rectified feedback from the output voltage by two 220 kΩ resistors and the bridge rectifier is further brought down by voltage divider combinations of R_8 and R_9 to the inverting input (pin 1), which is set a little above 2 V by R_8. Thus, R_8 is used to set the final output voltage at 230 V_{ac}. Other features of the PWM are the soft startup at power on and the shutdown (pin 10). The soft startup increases gradually from zero percent duty cycle to the required duty cycle after startup which is made possible by C_5 at pin 8. Capacitor C_6 at the output serves as a filter with the transformer inductance to remove upper harmonics. Shutdown at low battery cut-off and overloading conditions is possible at pin 10 when it goes positive at around 1 V and above.

Pins 11 and 14 are the totem pole transistor outputs of the internal flip-flops that provide two alternating drive signals of 50 Hz to the transformer power driving transistors (the MOSFET). These totem pole outputs are fed to the bases of transistors Q_2 and Q_3 which now drive the MOSFETs. This is to provide protection for the MOSFETs. R_{19}, R_{20}, R_{24} and R_{25} are placed very close to the power transistors driving each primary side of the transformer. T_1 is a 12 V centre tap transformer, which is 6V-0V-6V. Other values up to 9V-0V-9V can be used to provide more power.

To protect the 12 V battery from over discharge, a low voltage battery detector circuit is include to provide both audible and visual indication. This is achieved with a 9.1 V zener diode at the base of Q_1 which grounds the gate of CR02AM thyristor under normal battery operation. When the battery voltage falls to around 9.7 V under load condition, Q_1 stops conducting and the gate of CR02AM thyristor goes high in about 5 seconds and latch. Thus, light emitting diode LED1 and the buzzer become active and at the same time, pin 10 of SG3525 goes positive and shuts down the whole inverter system. When this happens, the battery voltage rises back to about 10.5 V which is still good enough to be recharged.

The half-wave voltage doubler in Figure 4, is a multiple of the peak input voltage, the peak input voltage from a supply transformer of rating only V_s max, and each diode in the circuit of PIV rating 2 V_s max. If load is small and the capacitors have little leakage, extremely high dc voltages can be obtained from such a circuit using many sections to step-up the dc voltage. In operation capacitor C_1 is charged through diode D_l to a peak value of transformer secondary voltage, V_s max during first positive half-cycle of the ac input voltage. During the negative half cycle capacitor C_2 is charged to twice the peak voltage 2 V_s developed by the sum of voltages across capacitor C_1 and the transformer secondary.

If additional diodes (each diode of PIV rating 2 V_s max) and capacitors (each capacitor of voltage rating 2 V_s max) are used, each capacitor will be charged to 2 V_s max. Measuring from the top of the transformer secondary winding will give odd multiples of V_g max at the output, while measuring from the bottom of inverter transformer primary winding will give even multiples of the peak voltage, V_s max.

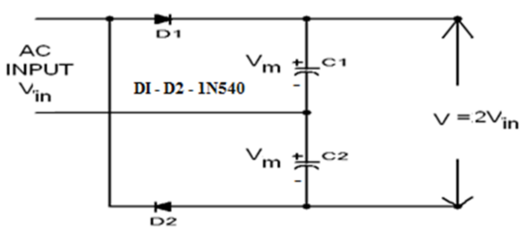

Figure 4: Voltage Multiplier

2.3 The Current Sensing Circuit and the Induced Voltage (ΔV)

The current sensing circuit uses a differential amplifier that measure potential drop across 100 ohms choke resistor through which signals from the high voltage was sent to the ground was connect input of AN0 and AN1. Also, for the induced voltage probe of Figure 2 was connected the ADS1116 second differential input of AN2 and AN3. The potential drop on the resistors 100 ohms connected between two inputs of a differential amplifier of ADS1116 analog to digital converter output was lead microcontroller for the computation of the corresponding current sent likewise the second differential input of the ADS. It has programmable gain amplifier (PGA) is implemented before the ΔΣ core of the ADS1116. The PGA can be set to gains of 2/3, 1, 2, 4, 8, and 16. Table 1 shows the corresponding full-scale (FS) ranges. The ADS1116 communicate through an I2C interface. The I2C bus consists of two lines, SDA and SCL. SDA carries data; SCL provides the clock. All data are transmitted across the I2C bus in groups of eight bits.

Table 1. PGA Gain Full-Scale Range

PGA Setting	FS(V)
2/3	±6.144 V
1	±4.096 V
2	±2.048 V
4	±1.024 V
8	±0.512 V
16	±0.256 V

III. MICROCONTROLLER

Microcontroller is small size computer on a single IC containing processor core, memory and programmable input-output peripheral. Microcontrollers are designed for the use of embedded applications, in contrast with microprocessor which are used for personal computers and other general purpose applications. Atmega2560 is a low power, high performance; CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. Atmega2560 provides 256 Kbytes with 8 Kbyte RAM of in-system self-programmable memory with read while write capability and 2 Kbyte EPROM.

IV. MICROSD CARD MODULE

It interfaced with microcontroller with SPI (Serial Peripheral interface) standard. The module is designed for dual voltage power supply. The interface module can be used with two logic level i.e. CMOS 3.3V or TTL 5V.

V. LIQUID CRYSTAL DISPLAY

LCD is used to display the depth and hip formation during tillage operation and horizontal distance move at the instant. A Dig chip make 20 character × 4 lines JHD162A liquid crystal display was used in the system developed. The display is a 16 pin which works with maximum power supply of 5.0 V and the data can be sent in either 4 bit, 2 operations or 8-bit, 1 operation so that it can be interfaced to 8-bit Microcontroller. Here we used 4 bits, 2 operation system

Figure. 5: Picture of Tested Constructed Terramete

VI. TESTING, CALIBRATION AND EVALUATION

The constructed terrameter (see Figure 5) and the standard terrameter were installed side by side with the same current, electrode spacing. An analog ammeter is connected in series with potential probe and corresponding output voltage drop measure by differential input of ADS1116 linked to microcontroller with display was recorded for standardization of current measuring unit (see Table 2). The induced voltage between the two mid probes were measured using high input impedance meter (mastech) and second differential of ADS1116 the value are shown on Table 2. After calibration is done, data were collected at various sites within FUTA to represent wet, moist and dry soil conditions and alongside with available terrameter. The instrument was to collect data that was used to examine it performance at the three soil types, moist, wet and dry with current electrode spacing using Wenner's method, in Figure 2. The data collected are shown in Table 3 to 5.

VII. RESULT AND CONCLUSION

The evaluation of the data collected shows that the correlation to that of the constructed terrameter is 98% in agreement with the imported terrameter, Figure 6 shows the comparison of all the three soil types showing that the dry soil type has the highest resistance, followed by moist soil and wet soil respectively. The deviation from the mean, shows that wet soil and moist soil has the same deviation of ±0.1Ω because it is difficult to differentiate moist soil from wet soil. In addition, the dry soil has the highest mean deviation of ±1Ω (Tables, 3, 4 and 5)

Table 3: Sample Data with Error Analysis for Wet Soil Condition

Current Electrode Spacing(L(m))	Potential Electrode Spacing(l(m))	Standard terrameter(Ohms)	Constructed Terrameter(Ohms)	MEAN DEVIATION
1	0.20	2.58	2.350	0.23
2	0.25	0.93	0.850	0.08
3	0.25	0.73	0.630	0.10
5	0.25	0.61	0.450	0.16
8	0.25	0.34	0.300	0.04
10	0.25	0.30	0.250	0.05
10	0.50	0.48	0.320	0.16
13	0.50	0.44	0.400	0.04
15	0.50	0.40	0.250	0.15
20	0.50	0.34	0.260	0.08
20	1.00	0.46	0.420	0.04

25	1.00	0.40	0.310	0.09
30	1.00	0.31	0.270	0.04
40	1.00	0.44	0.400	0.04
40	2.00	0.36	0.250	0.11
50	2.00	0.32	0.290	0.03
70	2.00	0.22	0.100	0.12
				0.10

Table 5: Sample Data with Error Analysis for Dry Soil Condition

Current Electrode Spacing(L(m))	Potential Electrode Spacing(l(m))	Standard Terrameter(Ohms)	Constructed Terrameter(Ohms)	MEAN DEVIATION
1	0.20	93.00	83.700	9.30
2	0.25	23.10	20.790	2.31
3	0.25	19.00	17.000	2.00
5	0.25	5.65	5.090	0.56
8	0.25	2.74	2.470	0.27
10	0.25	1.98	1.780	0.20
10	0.50	4.40	3.960	0.44
13	0.50	2.77	2.000	0.77
15	0.50	2.09	1.880	0.21
20	0.50	1.26	1.130	0.13
20	1.00	1.25	1.130	0.12
25	1.00	2.24	1.800	0.44
30	1.00	1.44	1.200	0.24
40	1.00	1.10	0.900	0.20
40	2.00	0.74	0.670	0.07
50	2.00	0.40	0.360	0.04
70	2.00	1.11	1.000	0.11
				1.02

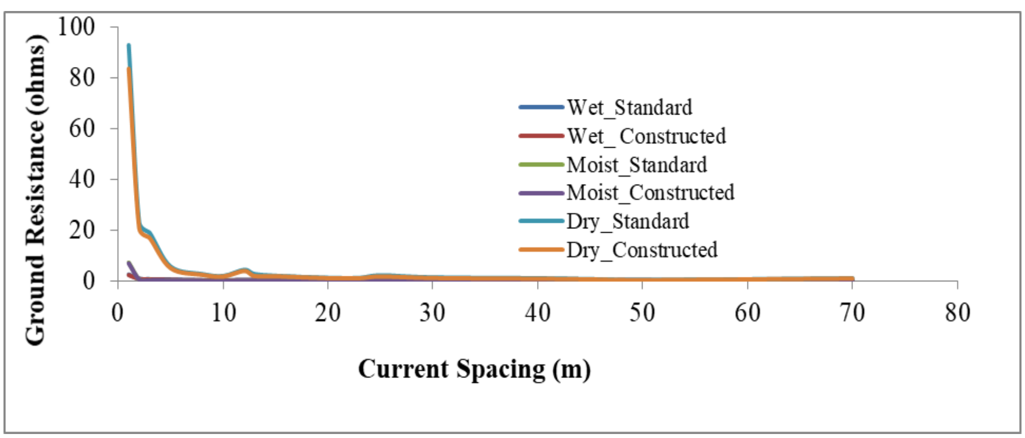

Figure 6: The Comparison of All the Three Soil Types

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