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Development of Digital Resistivity Meter

Mikailu A.[1*], Abdullahi I.[1], Sani M.G.[1] and Muhammad S.[2]
1. Physics Unit, Ahmadu Bello University, School of Basic and Remedial Studies, Funtua.
2. Department of Physics, Bayero University, Kano.
*abdulmikailu@gmail.com

Abstract
A digital resistivity meter was designed and constructed using microcontroller (PIC16F877A) and other carefully selected components. The meter was developed, using the state of the art technology, to measure the earth's electrical resistivity through application of direct current electrical resistivity method. It was designed as a system with various subunits implemented as modules, to help greatly in trouble shooting the system in case of system failure. This meter injected currents of 0.1mA, 1mA and 10mA and two, 6V batteries connected in series powered it. Its capability of accepting analog input and displaying digital output gives it advantage of minimizing errors associated with output display. Microcontroller operated using a configuration of hardware components and functional software written and burnt into the microcontroller's memory. The meter was tested with a specially designed test unit and the generated results were compared with the calculated values, the two agreed.
Keywords: Electrical resistivity, microcontroller, analog, digital

1. Introduction

Geophysical instruments vary in terms of complexity, size, field utilization and source nature but all are used to measure variation of physical properties in the field as well as in the laboratory. This measurement are made in order to reveal details about the underground conditions of site of investigation and follow up surface manifested features underneath. The geophysical methods depend on measuring physical properties, contrast between the object feature of interest and the surrounding environment (Milsom 1989).

There are many physical properties being exploited for geophysical investigations, few among them are seismic wave velocity, electrical conductivity, self-potential mass density, magnetic susceptibility (Milsom 1989). Consequently, there are many geophysical methods typically exploited to study these properties as gravity, magnetic, electrical and many others. This article is limited to electrical geophysical method with bias on direct current aspect of the method.

Soil resistivity is the key factor that determines what the resistance of a grounding electrode will be and to what depth it must be driven to obtain low ground resistance. All soils conduct electrical current, with some soils having good electrical conductivity while the majority has poor electrical conductivity. Resistivity or inverse of conductivity of the soil is obtained using resistivity meter (Igboama & Ugwu 2011). Electrical resistivity is a product of electrical resistance and geometrical factor. The later is concerned with ways the measuring electrodes are arranged at the site of measurement. Electrical resistance is measured using an instrument while the geometric factor can be handled, provided or pre-calculated by the operator or researcher or incorporated in the instrument, notwithstanding the operator has to key-in the value of geometrical parameters. This instrument is therefore designed in such a way to accept analog input and display digital output. The digital output is composed of injected current in milliampere (mA) and developed potential difference in Volt (V).

Analog meters give display of both injected current and the measured potential difference on non-linear scales. Readings obtained from such meters are prone to many serious errors that could conceal the desired information. Few of such errors are parallax, temperature, creep of the springs etc. Moreover, in the computation of resistance by analog meters, results are compromised by the compounded errors due to current and voltage readings.

In an effort to significantly reduce such errors, reduce cost and produce a user-friendly device it was resorted to develop a digital resistivity meter using the state of the art technology. This is an on-going new approach that combines software and hardware to produce a device that could be utilized for various purposes dictated by the use of peripherals and accustomed software, thereby reducing the amount of hardware requirements as most of the control is handled by the software. The software does most of the functions previously done by the hardware, thus, making the whole set up portable, cheaper, more rugged and easier to operate during field usage. The readings of the meter are given in digital format; therefore, errors due to parallax are highly minimized.

In this paper, a digital device capable of measuring the earth's electrical resistivity in situ has been designed, constructed and test run using state of the art technology.

2. Theory of Application

According to Telford et al. (1976), there are two basic assumptions underlying electrical method, these are

$$J = \sigma E \quad (1)$$

given by Ohms law, and

$$\nabla.\vec{J} = 0 \quad (2)$$

given by divergence theorem.
Where E is electric field intensity
J is the current density, and
σ is electric conductivity

The earth is considered homogenous and isotropic medium of resistivity ρ and conductivity σ. Suppose current is injected into the earth by means of a point source of current whose voltage is V, then the current density J and electric field intensity E developed in the earth is given by

$$\vec{J} = \sigma\vec{E} \quad (3)$$

$$\vec{E} = -\nabla V \quad (4)$$

Combining equation 4 and equation 3, we get

$$J = -\sigma\nabla V \quad (5)$$

When divergence theorem is applied to equation 5 it gives

$$-\sigma\nabla^2 V = 0 \quad (6)$$

or

$$\nabla^2 V = 0 \quad (7)$$

Equation 7 is a Laplace equation that can also be written in polar coordinate as

$$\frac{\partial}{\partial r}\left[r^2\frac{\partial V}{\partial r}\right] = 0 \quad (8)$$

Since there is a single source of current, then there is symmetry of current in θ and ψ direction, hence their derivatives become zero.
Integrating equation 8 twice, we get

$$V = -\frac{c}{r} \quad (9)$$

where c is the constant of integration.
The current flowing through the hemispherical equipotential surface developed in the earth is given by

$$I = \int_s J ds \quad (10)$$

Substituting equation 3 in equation 10, we get,

$$I = \int_s \sigma E ds \quad (11)$$

$$\therefore I = \frac{1}{\rho}\int_s E ds \quad (12)$$

Also

$$E = -\frac{\partial v}{\partial r} = -\frac{\partial}{\partial r}\left[-\frac{c}{r}\right] = \frac{c}{r^2} \quad (13)$$

Putting equation 13 in equation 12,

$$I = \frac{1}{\rho}\int_s \frac{c}{r^2} ds \quad (14)$$

From equation 10, 12 and 14, we get

$$V = \frac{I\rho}{2\pi r} \quad (15)$$

If current is injected into the earth through two current electrodes C_1 and C_2 then the potential difference measured between the electrodes P_1 and P_2 is given by

$$\Delta V = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right] \quad (16)$$

$$\rho = \frac{\Delta V}{I}\left[\frac{2\pi}{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}}\right] \quad 17$$

$$\rho = \frac{\Delta v k}{I} \quad 18$$

where

$$k = \frac{2\pi}{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}}$$

k is known as `geometric factor. The geometric factor depends on the kind of electrode arrangement used for resistivity survey.

3. Materials and methods.

The meter was constructed based on the Wenner four-point electrode array. Method of four-electrode profiling has been used in soil practices since 1931 for evaluating soil water content and salinity under field conditions (Rhoades & Ingvalson 1971).

The meter, cased in a box of plastic sheet with dimension 60cm by 40cm by 30cm, was conceived as a system with various subunits implemented as modules. This greatly helps in troubleshooting the system in case of system failure. The subunits are the square wave oscillator, constant current generator, current level detector, differential amplifier, synchronous rectifier, DC gain amplifier and microcontroller.

Square wave oscillator was used to generate an AC current for injection into the soil. This is essential because injecting DC current into the soil would present two problems; response to "battery effect" by the meter usually caused by the chemical interaction between measurement probes due to acids and alkalis that naturally occur in the soil, and the electrolytic effect of the current passing through the soil. In the designing of square wave oscillator, frequency considerations must be taken good care of, that, it must neither be too low nor be too high to guard against electrolytic effect and ground inductive effects respectively. It should also not be a multiple of 50 Hz (supply line) or the probes will pick noise from the supply line

The constant current generator provided current that was injected into the soil. The design requirements for the current generator are predetermined with current ranges of 0.1mA, 1mA and 10mA and a symmetrically polarized current output.

Current level detector circuit ensured that the supply voltage drove the current required for injection. When voltage drop across the current output exceeds a predetermined value, the circuit's lamp switches on as an indicator that the voltage read might be erroneous.

Differential Amplifier was designed based on a set of three LM741 operational amplifiers, with two configured as buffer and the other as a difference amplifier. For the Werner method, the digital resistivity meter has been designed such that the potential probes are configured to pick a floating voltage - a voltage that is neither of the two probes is at the supply's 0 Volt potential. This necessitated the use of a differential amplifier, since none of the two inputs of the amplifier must be connected to the 0 Volt line.

A synchronous rectifier is a discriminating circuit, used to select a waveform that has some specific characteristics of frequency or phase from a complex signal, made of many superimposed waveforms, and then rectify it. To achieve synchronous rectification, there was need for a reference signal, which was tapped from the main source of the target signal and then fed into the circuit to control its operation.

In the resistivity meter, a synchronous rectifier was employed to ensure that only voltage due to the injected current was allowed to pass to the final stage of the meter, by blocking noise from the mains. For this, output of the square wave generator circuit was used as the reference signal, thereby locking the two circuits together.

The DC gain amplifier was required to compensate for attenuation in signal amplitude due to non-linearity and impedance of the various subunits that made up the meter. The combination of a resistor and a capacitor form a low pass filter, which converted the rectified voltage from the synchronous rectifier into a pure DC voltage.

The figures below gives the circuit diagram of the fabricated components of the meter

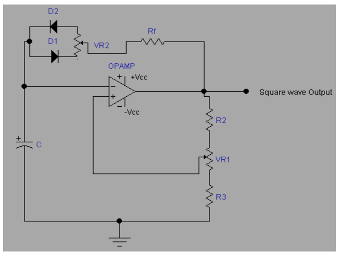

Fig 1: Square Wave Oscillator

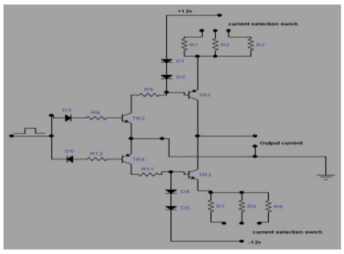

Fig 2: Constant Current

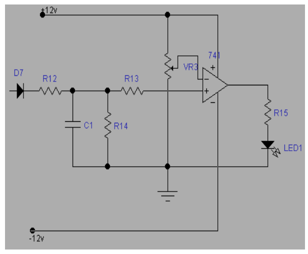

Fig 3: Current Level Detector

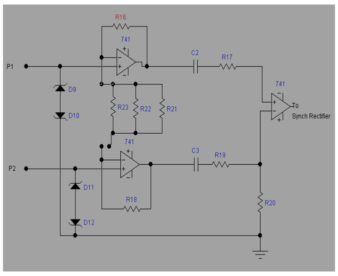

Fig 4: Differential Amplifier

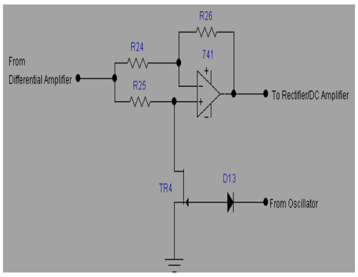

Fig 5: Synchronous Rectifier

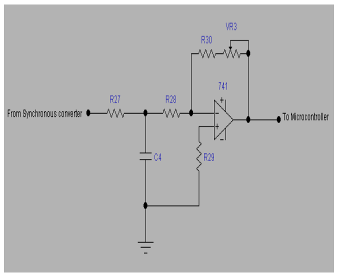

Fig 6: DC Gain Amplifier

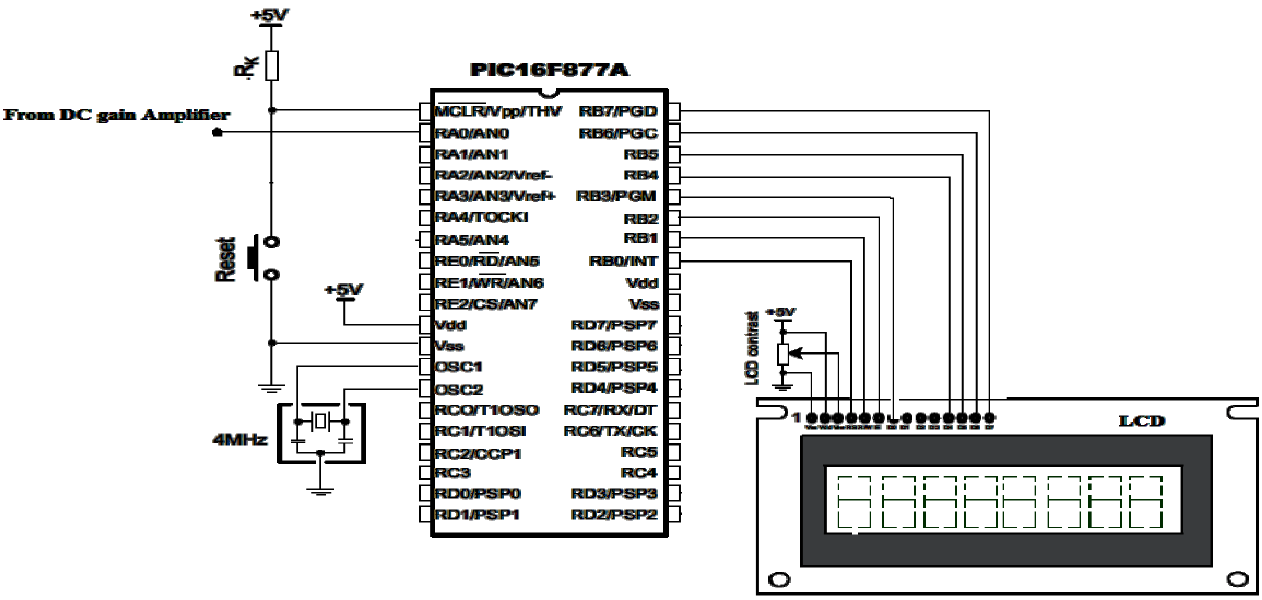

Fig 7 : The Microcontroller and the LCD

4. Results and Discussion

An earth resistivity meter can be used to identify the composition of various earths' strata and the depth at which each stratum occurs and by detecting changes in earth composition, to point to the existence of buried objects.

An earth resistivity meter may be used to locate archaeological objects to assist in finding conditions favourable for alluvial gold or gemstones, or even for such prosaic duties as determining where to locate a septic tank. (John Stanley 1981)

The developed digital meter was tested using a test circuit of fig. 8. The plugs PL1 and PL2 of the test circuit were connected to the current probes of the digital resistivity meter while the plugs PL3 and PL4 were connected to the potential probes of the resistivity meter. Values obtained when different resistances were selected are shown in Table 1. In the table, some entries were missing or ignored this indicated that the amplifier was saturated following too high input voltage.

Comparing the values in Table 1, obtained from the meter, with the calculated values using Ohms law in Table 2, it was concluded that the two sets of values are almost the same. This, in turns certified that the constructed digital resistivity meter can be used conveniently in the field to obtain potential difference as well as resistivity.

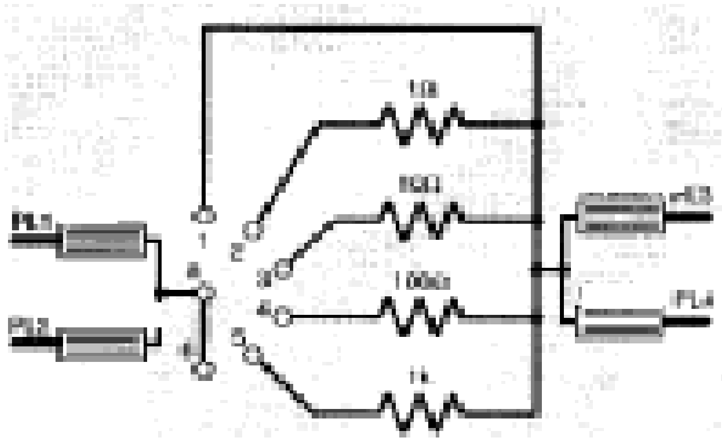

Fig 8: Schematic diagram of the simple test circuitocontroller and the LCD

Table 1: Results obtained using simple test circuit.

Test unit resistor (Ω)	Output Current (mA)	Volts output (mV).		
		Amp gain X 10	Amp gain X 100	Amp gain X1000
0	0.1	0	0	0
1	0.1	1	10	100
100	0.1	98	980	-
1000	0.1	999	9990	-
0	1	0	0	0
1	1	10	100	1000
100	1	992	9920	-
1000	1	10000	-	-
0	10	0	0	0
1	10	100	1000	10000
100	10	97	970	-

Table 2: Calculated values

Test unit resistor (Ω)	Output Current (mA)	Resistor Volts (mV)	Volts output (mV).		
			Amp gain X 10	Amp gain X 100	Amp gain X1000
0	0.1	0	0	0	0
1	0.1	0.1	1	10	100
100	0.1	10	100	1000	10000
1000	0.1	100	1000	10000	100000
0	1	0	0	0	0
1	1	1	10	100	1000
100	1	100	1000	10000	1000000
1000	1	1000	10000	100000	1000000
0	10	0	0	0	0
1	10	10	100	1000	10000
100	10	1000	10000	1000000	10000000
1000	10	10000	100000	1000000	10000000

5. Conclusion

In conclusion, state of the art technology was used in the design and construction of the digital resistivity meter. The developed meter minimizes errors, being user friendly and it accepts an analog input and provides a digital output. It was tested using simple test circuit and the values obtained were in agreement with calculated values.

References

Milsom, J. (1989), "Field guide series" (third edition), John Willey and sons Ltd, London.

Igboma, W.N. & Ugwu, N.U. (2011), "Fabrication of resistivity meter and its evaluation", American Journal of Scientific Research Volume 2 No 5 PP 713-717.

Randy, S.G. (2002), "Tab Electronics Guide to understanding of electricity and magnetism" (second edition), Mc Graw Hill, New York.

Rhodes, J.D. & Ingvalson, R.D. (1971), "Determining salinity in the field soil with soil resistance measurement", Soil Sci.Soc.Am.proc. Vol 35 PP 54-60.

Stanley, J. (1981), "How to build gold and treasure detectors - Earth resistivity meter", Geo-tech journal.

Telford, W.M., Geldart, L.P., Sheriff, K.E. & Keys, D.A. (1976), "Applied geophysics", Cambridge university press, Cambridge.

Walter, B., John, W.H., Horst, S. & Holger, L. (2002), ":Hand book of physics", Springer – Verlag Inc, New York.

Byte craft Limited, [Online] Available: www.bytecraft.com (2002), "First step with embedded systems".