Development of a simple conductivity meter for testing ground materials

Thesis submitted in partial fulfilment of the requirements for the degree

of

Bachelor of Technology

in

Electronics and Instrumentation Engineering

By
Himanshu Mishra
111EI0452

Department of Electronics & Communication Engineering
National Institute of Technology
Rourkela

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Under the guidance of
Prof. Subrata Maiti

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Dedicated to My Family

Declaration

I hereby declare that this thesis is my own work and effort. Throughout this documentation wherever contributions of others are involved, every endeavour was made to acknowledge this clearly with due reference to literature. This work is being submitted for meeting the partial fulfilment for the degree of Bachelor of Technology in Electronics and Instrumentation Engineering at National Institute Of Technology, Rourkela for the academic session 2011 – 2015.

Himanshu Mishra

111EI0452

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis **entitled**, "**Development of a simple conductivity meter for testing ground materials**" submitted by **Himanshu Mishra(111EI0452)** for the award of **Bachelor Of Technology** degree in **Electronics and Instrumentation Engineering** during session 2011-2015 at National Institute of Technology, Rourkela is under my supervision and guidance.

Date :

Place : Rourkela

Prof. Subrata Maiti

Dept. of Electronics & Communication Engineering

National Institute of Technology, Rourkela

Acknowledgement

I would like to express my appreciation to my guide Prof. Subrata Maiti for his understanding, immense knowledge , inspiration and steady backing. His direction has helped me throughout my project work and in composing my thesis at NIT Rourkela.

Besides my guide, I would like to thank Prof. S.K. Kar, Prof. T.K. Dan, Prof. U.C. Pati, Prof. M.N. Islam, Prof. S.Meher and Prof. D. P. Acharya for their encouragement and insightful comments.

I would like to thank all faculty individuals and staff of the Department of Electronics and Communication Engineering, N.I.T. Rourkela for their liberal help in different routes for the consummation of this thesis.

I would like to thank my friends Sahil Suhag, Rudrendra Kashyap, Soumya Prakash Mishra and Jalaj Chaturvedi and Ayushi Khetan without the support of whom this thesis could not have been completed.

I am especially indebted to my family for their love, sacrifice, and support. My full commitment to the work would have not been conceivable without their support and good backing. This thesis is a devotion to them.

Himanshu Mishra

Roll No. 111EI0452

Dept. of Electronics & Communication Engineering

National Institute of Technology

Rourkela

Contents

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The main object of this project is to calculate the electrical conductivity of different samples of water and study the electrical properties of soil. The device Vector Network Analyser has been discussed which is used to measure complex impedance like the soil impedance which is a function of soil conductivity and soil permittivity. The electrical model equivalent to soil has been discussed. The measurement of dielectric constant has been discussed through the use of capacitive sensor technique and phase delay measurements. A conductance measurement circuit is discussed which takes in to the use of a conductance sensor. Also a novel technique for calculating conductivity of different water samples have been discussed using two metallic plates as electrodes which act as our conductivity sensor. Results also have been obtained using the same.

Chapter 1

Review of Soil Measurement Techniques

1.1 Introduction

1.1.1 Electrical conductivity

Electrical conductivity is the measure of a material's capacity to accommodate the transport of an electric charge. It is also defined as the inverse of electrical resistivity and is the ratio of the current density to the electric field strength. Its SI derived unit is Siemens per metre or Sm^{-1}.

1.1.2 Dielectric constant

The dielectric constant is the ratio of the permittivity of a substance to the permittivity of vacuum. It is also known as relative permittivity. It tells us the degree to which a material concentrates electric flux, and is also regarded as the electrical equivalent of relative magnetic permeability.

1.2 Vector Network Analyser

The Vector Network Analyzer (VNA) has turned into an progressively valuable piece of equipment for the research facility portrayal of soil electromagnetic properties, for example, apparent permittivity and conductivity. The network analyser discharges a sinusoidal signal which falls incident on the device under test and the reflected and transmitted voltages are resolved in respect to the incident signal (frequently spoke to in decibels). The expression "vector" in VNA speaks to the way that the phase angle difference between incident and reflected/transmitted signals is additionally decided[4]. VNA tests where just reflected signals are measured are known as one-port frameworks, and those additionally measuring transmission are known as two-port. VNA estimations can be utilized, for occurrence, to focus the complex impedance of probes, or coaxial cells, for figuring soil electromagnetic properties. With a suitable recieving wire, or antennas in two-port estimations, the VNA can likewise be utilized as a GPR framework.

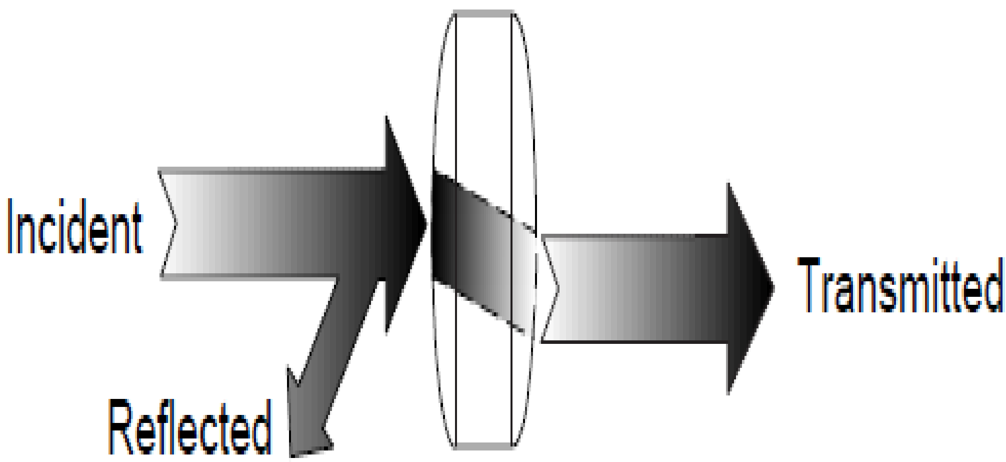


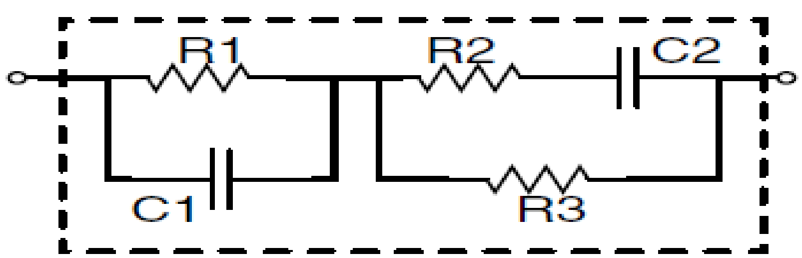
FIGURE 1.1 Signals as measured by a VNA

1.3 Impedance Analyser

To develop the electrical model of soil, frequency response of the soil is measured using a high frequency impedance analyser. The measurement is performed using an impedance cell consisting of two stainless steel metallic parallel plates acting as electrodes and and fixed at opposite ends of a cubic container[3]. The soil sample is placed in between the electrodes and its impedance is measured at various frequencies using impedance analyser. This is used to produce different graphs of real and imaginary part of the impedance versus frequency.

1.3.1 Electrical model equivalent to soil

Soil is a complex material and its conduct can't be modelled by any straightforward circuit with settled values of resistances and capacitances. We give an estimated equivalent circuit of the soil to EIS tool. EIS tool utilizes distinctive sorts of curve fitting algorithm like Nelder-Mead algorithm, Powell Algorithm, Levenberg- Marquard Algorithm and Newton Algorithm[3]. Then the frequency response of the circuit is contrasted with the real frequency response of soil sample. After trying with many equivalent models the model which satisfies all types of soil samples vend for a relatively wide frequency range can be obtained.



[3]

FIGURE 1.2 An approximate model circuit for soil impedance

1.4 Capacitive Sensor Technique

Various strategies are accessible which depend on dielectric constant of the soil water matrix for the moisture estimation, capacitive sensing is one of these systems. It comprises of the pair of electrodes embedded in the soil as a piece of an oscillator circuit. The soil around the electrodes frames the dielectric of the capacitor. The capacitor acts as a piece of resonating circuit of an oscillator. Dielectric of water changes the dielectric of soil. This change gets reflected as change in the oscillation frequency and thus moisture substance can be measured [3]. Oscillator system helps in measuring bound water in fine molecule soil. Bound water is firmly connected to the surface of the soil molecule, which constitute almost 10% of the soil moisture & can't be resolved successfully by different strategies. The repeatability, affectability & minimal effort estimation are the preference over different procedures. The soil water mixture is not purely capacitive so the oscillator based technique might fail for large levels of moisture content if impact of change in the conductivity is not taken into consideration while designing the oscillator.[3] Hence emphasis should be laid on low power oscillators with minimum complexity to test the developed electrical model of soil.

1.4.1 Oscillator design

LC oscillators are one category of oscillators used for the measurement of moisture.

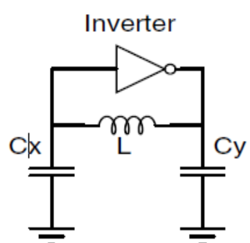


FIGURE 1.3 A LC Oscillator

The oscillation frequency for the above oscillator is given as

$$\omega_{osc} = \frac{1}{\sqrt{L\left(\frac{C_x C_y}{C_x + C_y}\right)}}$$ [3]

As the figure presented above shows that there are only two nodes in the circuit and by analysing the expression of oscillation frequency, we have two ways of using soil sample in the circuit shown below.

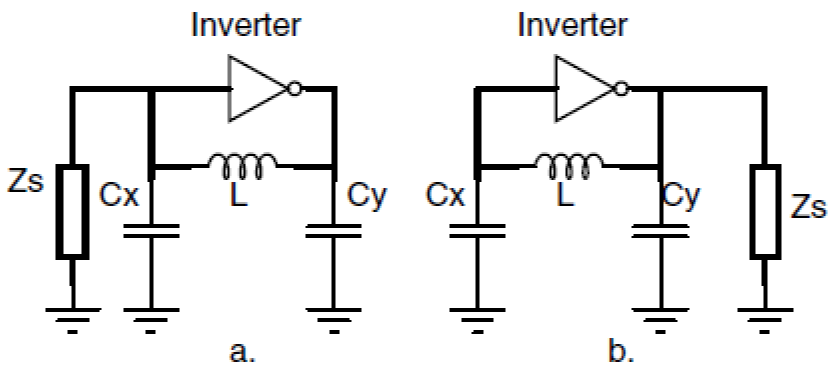


FIGURE 1.4 Embedding soil sample in the oscillator

By analysing the possible configurations shown above in the figure one can notice that using soil sample at the input of the inverter will change the feedback factor as well as feedback phase shift from 180 degrees which will then not satisfy the required condition for oscillations. The configuration shown in part b of the figure uses soil sample at the output of inverter and is stronger as compared to the other configuration[3]. But as the mixture of soil and water is not purely capacitive its conductivity will affect the measurable range of moisture content.

Z(s)=Rs – jXs is the impedance of soil at the output of the inverter where

Rs is the real part of the soil impedance and contains information regarding conductivity of soil

Xs is the imaginary part and contains information egarding the capacitance of the soil.

1.4.2 Dielectric constant measurement

The dielectric constant of soils can be calculated by using phase delay measurements between transfer function measurement of transmitter and receiver antennas. The phase delay gives us the time delay in seconds which is experienced by every component of the input signal. So, the phase delay is given by the expression below. Here

$\theta(\omega)$ is the phase response of transfer function measurement

ω is the radial frequency and $\tau(\omega)$ is the phase delay of the transfer function measurement[2].

$$\tau(\omega) = -\ \theta(\omega)/\omega$$

Chapter 2

Electrical conductance and Electrical conductivity measurements

2.1 Introduction

In industrial environments water conductivity estimations are by and large used to gauge the amassing of ionized chemicals in water. For water quality appraisal conductivity estimation can be non-particular in the sense that it doesn't recognize singular convergences of diverse ionic chemicals blended in water. In any case, conductivity estimations are of foremost significance in water quality evaluation frameworks since high or low conductivity levels moderately to its ostensible worth can be utilized to distinguish environment changes and contamination occasions[1]. By and large high conductivity levels originate from modern contamination or urban spill over. Expanded dry periods furthermore, low stream conditions likewise add to build conductivity levels.

2.2 Types of conductivity sensors

2.2.1 Two electrode sensors

They are for the most part built in a basic manner and are suited for estimations in clean arrangements. Burden is that they can without much of a stretch get defiled which influences the estimation.[1]

2.2.2 Four electrode sensors

Four electrode sensors involve two current and two voltage electrodes. Between the two current electrodes there is a predictable electric current. With the two voltage electrodes a voltage drop is measured over the sample. The voltage drop depends on upon the conductivity of the sample. In light of this estimation govern, four electrode sensors have an a great deal more broad straight estimation run furthermore, are not fragile to tainting.[1]

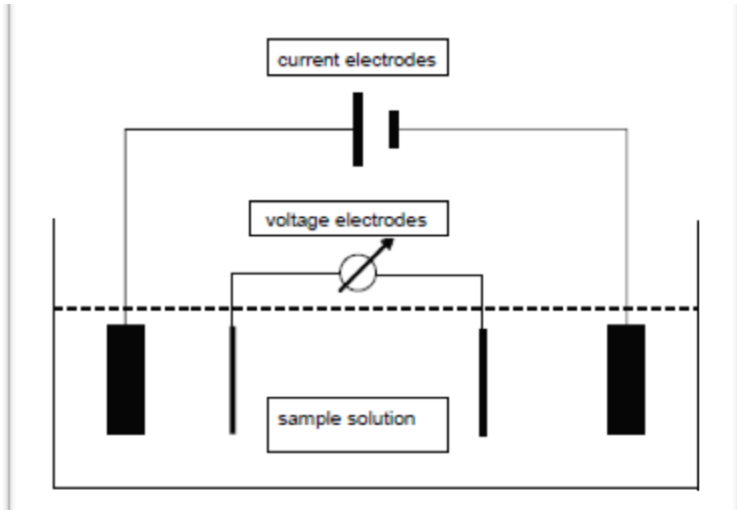


FIGURE 2.1 Scheme of a four electrode conductivity cell

2.2.3 Toroidal sensors

They are the non-contacting kind of sensors which oppose corrosion and fouling. They are perfect for utilization in corrosive liquids or liquids containing abnormal amounts of suspended particles that would somehow consume or foul metal electrode sensors. They are likewise suited for measuring exceedingly conductive electrolyte arrangements.

2.3 Making a conductance sensor and measurement circuit

1. Use scissors to cut a 5 cm. piece from a drinking straw.
2. Cut two pieces of copper wire each about 12 cm. long.
3. Wrap one piece of wire around the 5 cm. straw piece near one end a few times leaving a trail of 5 cm. wire.
4. The wire should be wrapped snuggly around the straw cause if the wire on the conductance sensor moves while taking the measurement then they might be inaccurate.
5. Wrap the second piece of wire around the other end of the straw a few times leaving a 5 cm. tail of wire.

6. There should be no contact between the wires and they should be wrapped tightly enough so they will not slide off the tube.
7. The two wires should not touch otherwise it will blow the fuse of the multimeter.
8. Start assembling the conductance necessary circuit by attaching the battery clip to a 9V battery.
9. Plug the multimeter test levels into the multimeter.
10. Use one pair of alligator clips to connect the positive wire of 9V battery clip to the positive multimeter probe.
11. One wire of the sensor is connected to the negative part of the battery whereas the other is connected to the negative probe of the multimeter.

After the voltage is applied, a current is produced from which we cancalculate the resistance and in turn calculate the conductance as it is the reciprocal of resistance.

2.3.1 Observations

Sample	**Current measured (in mA)**	**Conductance measured (in mS)**
Tap water	**8.19**	**0.91**
Butter milk	**1.00**	**0.11**
Minute Maid drink	**27.53**	**3.05**

TABLE 2.1 Measured conductance of different liquid samples

2.4 Measuring Electrical Conductivity

2.4.1 Introduction

Electrical conductivity of an solution is the measure of its capacity to convey is an electric current, the more dissolved ionic solutes in water the more prominent its electrical conductivity. It is expressed in units of mS/m. It can be viewed as an unrefined indicator of water quality for numerous reasons since it is identified with the total of every ionized solute or total dissolved solid(TDS) content. The relationship between conductivity and TDS is not linear however since the conductive mobility of ionic species is variable. Univalent cations, for example, Na+ are mobile than multivalent cations, for example, Ca+2 or Al+3. Essentially univalent anions, for example, Cl- are more versatile than multivalent particles for example, the sulfate particles which are thusly more mobile than charged homic substances. As a rough approximation the relationship between EC and TDS commonly used is

$$TDS(mg/l)=EC(uS/cm) * 0.67$$

Since the movement of ions under an electrostatic potential increments with expanding temperature, EC qualities relies on the temperature. Most EC information are revised to 25 degrees Celsius and the qualities then are in fact alluded as specific electrical conductivity. An arbitrary constant is ordinarily utilized for the remuneration of temperature under the supposition that relationship in the middle of EC and temperature is linear in nature. For instance a 2% increment in EC for a degree ascend in temperature.

2.4.2 Conductivity measurement principle

For conductive measurements the sensor consists of two electrodes in direct contact with water. Between these electrodes, a potential is applied. This causes all charged particles in the water to move giving rise to a current as a function of the number and velocity of ions. The water with its ions behaves like a resistance and the conductivity is the reciprocal expression of the said resistance. Current also depends on the dimensions of the electrodes.

Here the conductivity measurements assume that the two electrodes are two parallel electrical plates of area A in water at a distance L apart. If a voltage V is applied across the plates and the current flow I is measured then the conductivity is given by

$$K=(I/V) * (L/A)$$

Or

$$K=L/R*A$$

where R is the resistance.

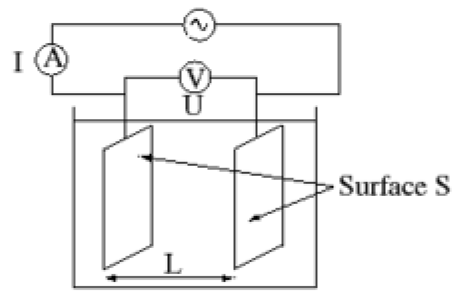


FIGURE 2.2 Principle circuit for measuring conductivity

2.5 Results

Sample	Current measured(in mA)	Conductivity measured(in uS/cm)
Tap water	0.72	223.70
RO water	0.74	165.58

TABLE 2.2 Conductivity measured of two different water samples

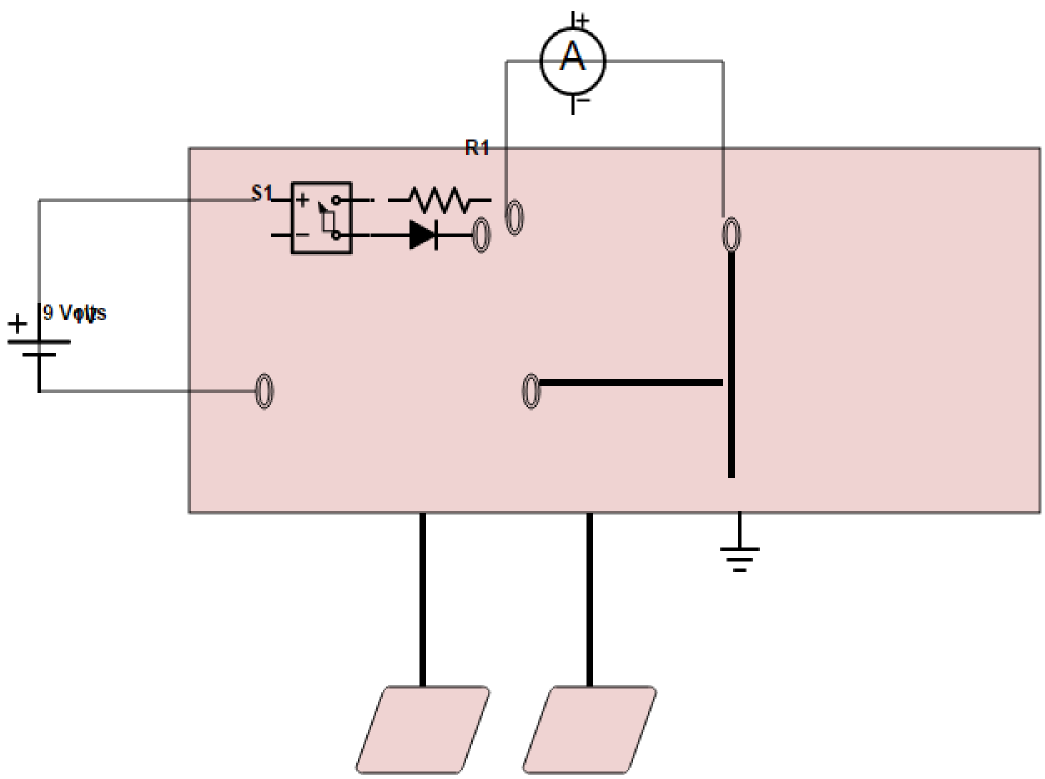


FIGURE 2.3 Final executed circuit on PCB

Chapter 3

Applications of conductivity measurement

3.1 Environmental significance of conductivity measurements

1. Electrical conductivity measurements are often employed to monitor desalination in plants.
2. It is useful to assess the source of pollution.
3. In coastal regions, conductivity data can be used to decide the extent of intrusion of sea water into ground water.
4. Conductivity data is useful in determining the suitability of water and wastewater for disposal on land. Irrigation waters up to 2 mS/cm conductance have been found to be suitable for irrigation depending on soils and climatic characteristics.
5. It is also used indirectly to fine out inorganic dissolved solids.
6. It is widely used to quickly estimate the ionic or soluble salt concentration in soils water supply, fertilizer solutions and chemical solutions.

3.2 Electrical conductivity of different samples of water

Sample	Conductivity(in uS/cm)
Totally pure water	0.055
Typical DI water	0.1
Distilled water	0.5
RO water	50-100
Domestic tap water	500-800
Potable water(max)	1055
Sea water	56,000
Brackish water	100,000
Melted snow	2-42
Freshwater streams	100-2000

Table 3.1 Electrical conductivity of different forms of water

Chapter 4

Conclusion

Conclusion

Various techniques to study the properties of soil were discussed such as obtaining an equivalent electrical model for a soil sample using the soil impedance various curve fitting algorithms who provide the circuit with specific values of resistances and capacitances. Two experiments were performed to measure the conductance and conductivity of sample solutions and samples of water respectively. For the latter one the conductivity measured for Tap water was more than the RO water concluding the presence of dissolved salts in the tap water and the purity of RO water.

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