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Embedded Based Dielectric Constant Measurement System

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ABSTRACT

Measurement of AC Conductivity of solids is one of the important studies performed in electrical and electronic device manufacturing industries. Though different AC conductivity measuring techniques are available using AC bridge they require many components. The proposed technique exploits frequency measurement to determine the capacitance of the sample using astable multivibrator and embedded system to measure dielectric constant. The proposed work is an attempt to develop an inexpensive and easily available embedded board for the measurement of capacitance and dielectric constant of the solid sample under different physical conditions.

Keywords: Dielectric constant, Embedded system, Sensor, Astable--Multivibrator

1. INTRODUCTION

Measurement of dielectric constant (⍰) of a material is very important for both scientific research and practical applications. Dielectric constant is a property of an electrical insulation of a material, some solids and liquids can serve as good dielectric materials, having a special property of storing and dissipating electrical energy when subjected to electromagnetic fields. Dielectric measurements are useful for detecting explosives, plastic and metal weapons, drugs, chemical agents, and biological agents.

Dielectric constant of a material is defined as the degree to which the medium can resist the flow of electric charge and is represented by the equation

D = K⍰$_o$E -----------(1).

Where D is the electric displacement,
E is the applied electric field strength and
⍰$_o$ (=8.85 x 10^{-12} F/m) is the permittivity of the free space.

The dielectric constant (⍰) can also be defined as the ratio of the capacitance of a capacitor with dielectric (C) to the capacitance of a capacitor without dielectric (C_o) i.e., air filled capacitor.

⍰ = C / C_o ----------- (2)

Dielectric cell is generally used to find the dielectric constant of the material [1]. The dielectric cell consists of two parallel metallic plates which act as electrodes and are separated by sample under test. The sample acts as a dielectric medium while the cell acts as a capacitor. The present work is aimed to develop a practical and useful instrument which can measure capacitance and dielectric constant of the solid material with the help of 555 timer and Arduino microcontroller thus avoiding LCR bridge. From recent studies, it is known that enormous work is going on in designing and development of sensors. The proposed work will find its application in measuring physical quantities which changes dielectric constant of the material under test. Thus, allowing us to design sensors with simple circuits without going for AC complex impedance measurements.

Sensors based on permittivity measurements are classified into two types depending on output [2]. The first one monitors changes in the real part of the permittivity whereas the output of the second one is related to the complex permittivity. The real part of the permittivity measure changes in the capacitance of the sample. The dissipation factor (D or tanδ) relates these two quantities which is the ratio between the imaginary part and the real part of the complex permittivity. The real part of the permittivity can be measured using low cost electrodes [3] and very simple circuits such as bridges[4,5], resonant circuits[6], astable multivibrators [7]. In the present work 555 astable multivibrator is used to generate square wave and frequency is measured using Arduino microcontroller. Measurements made on certain CNT doped polymer samples using the developed instrument are presented[8].

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2. PRINCIPLE

In timing circuits and in oscillators generally a resistor and a capacitor are used[9]. The time taken to charge the capacitor to a certain percentage of the applied voltage depends on the RC time constant and this voltage is used to trigger a circuit to control the period of oscillation. The 555 integrated circuit is one such device. It can be used as an oscillator (astable multi-vibrator) to generate square waveforms[10]. The frequency is determined by the value of the R and C used in the circuit.

3. EXPERIMENTAL SETUP

The block diagram shown in Fig.1 depicts the experimental setup

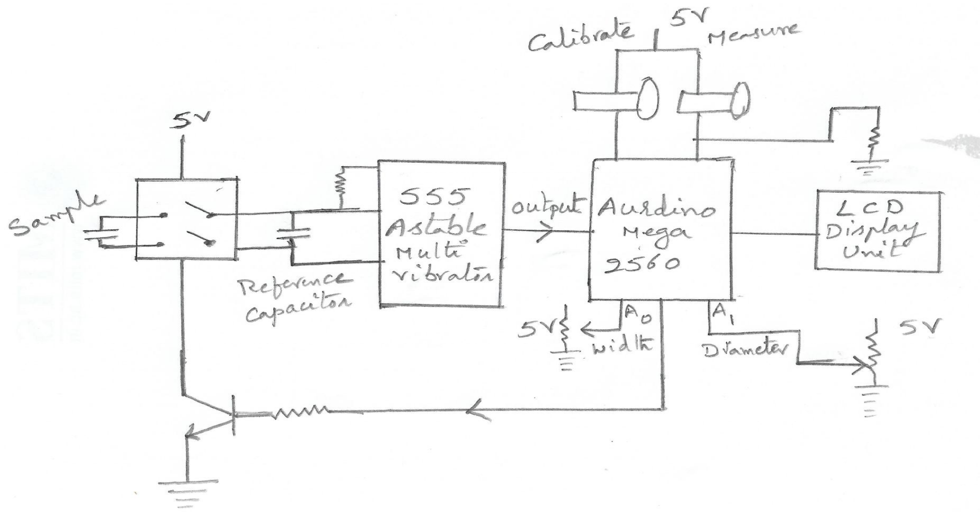

Fig.1 The block diagram

It essentially consists of

1. Sample holder
2. Astable Multivibrator
3. Arduino Mega Board
4. Relay Board
5. Electric Kettle

3.1 Sample Holder: The sample holder consists of two circular glass plates of diameter 5cm. Copper electrodes are designed on the glass plates and the sample which is in the form of a circular shape of 5cm diameter is placed in between the glass plates. The whole setup is placed in an electric kettle to transfer the temperature to the sample under test. The sample holder is represented in Fig.2

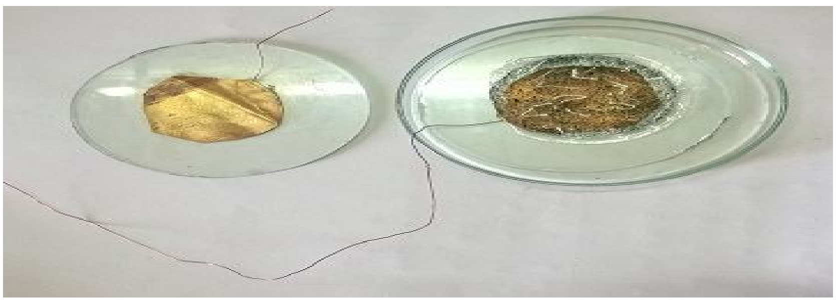

Fig. 2 : Sample holder

3.2 Astable Multi-vibrator:

A multi-vibrator circuit has been designed as shown in Fig.(3) incorporating resistors and capacitors[11]. In the astable circuit the '555' timer chip is the active component. When the circuit is connected as shown in the figure 3 it acts as

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free running multivibrator. Through R_1 and R_2 resistors the external capacitor gets charged. Thus, the duty cycle which can be determined from R_1 and R_2 may be precisely set by the ratio of these two resistors. In this mode of operation the capacitor charges and discharges between 1/3 Vcc and 2/3 Vcc . The charge and discharge times and the frequency is independent of the supply voltage.

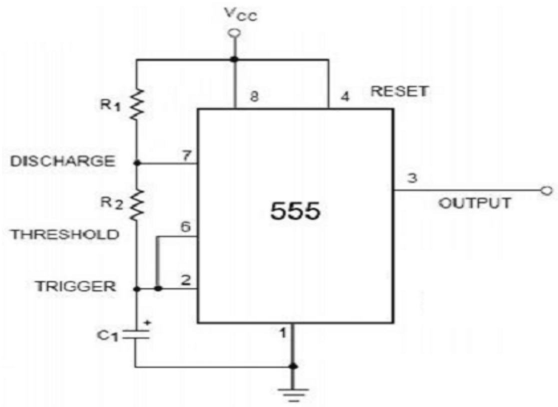

Fig.3: Astable Multivibrator circuit

The charge time is given by,

$$t_1 = 0.963\ (R_1 + R_2)\ C \quad \text{----------------------- (2)}$$

And the discharge time is given by

$$t_2 = 0.693\ (R_2)\ C \quad \text{----------------------- (3)}$$

Thus, the total period is given by,

$$T = t_1 + t_2 = 0.693\ (R_1 + 2R_2)\ C \quad \text{--------------------- (4)}$$

The frequency of oscillation is then $f = 1/T = 1.44 / ((R_1 + 2R_2) C$ --------------------- (5)

The sample is placed in sample holder and is connected in parallel to reference capacitor with the help of relay board controlled by Arduino mega Board.

3.3 Arduino Mega Board

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560.
It has 54 digital input/output pins
14 can be used as PWM outputs
16 analog inputs,
4 UARTs (hardware serial ports),
Operates at 16 MHz
a USB connection

In present work Arduino mega board is used to measure the frequency of 555 Astable multivibrator. At first the frequency of Astable multivibrator is measured with reference capacitor connected to the circuit and then with combination of sample and reference capacitors. The variation of frequency is measured and from the frequency difference capacitance of the sample is calculated and the dielectric constant of the sample is determined. Arduino software is used to develop code for the application. Temperature sensor is also interfaced to the microcontroller to measure the temperature of the sample under test and to display it on LCD along with dielectric constant, Capacitance of the sample.

3.4 Relay Board

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Fig. 4: Relay board

A two channel Relay Board as shown in Fig.4 is used to connect reference capacitor and sample under test to astable multivibrator circuit under the control of microcontroller. It acts as double pole double through switch in connecting sample and reference capacitor. GPIO pins of microcontroller are used to control relay board.

3.5 Electric Kettle

A 500 watt electric kettle is used to maintain temperature of sample holder.

Fig. 5: Electric kettle

The sample is sandwiched between two similar copper electrodes which are attached to the glass plates of almost same diameter. The whole assembly was placed in an electric kettle where a temperature sensor is used. This arrangement was used to increase the temperature of the samples automatically. Sufficient amount of coconut oil is placed into the kettle and then the sample arrangement was made so that the temperature is recorded by the sensor and the same temperature is transported to the sample arrangement. The temperature is monitored with the help of temperature sensor connected to the system. LCD display is interfaced with microcontroller to show the instantaneous temperature and dielectric constant for every 0.5°C temperature difference.

4 Dielectric constant measurement using PC:

Though the embedded module can work in standalone mode, a MATLAB program is developed to read instantaneous values of temperature, Capacitance, dielectric constant of the samples through USB port of the PC from the embedded module for real time graphical visualization and recoding of data.

5 EXPERIMENTAL PROCEDURE:

Different samples of different concentrations by weight percentages (pure PVA, 0.5% CNT + PVA, 1%CNT + PVA, 2% CNT + PVA) and of thickness 60 micron were prepared by solution casting method [12]. These samples are of diameters 5cm. These samples are sandwiched between two similar copper electrodes which are attached to the glass plates of almost same diameter. The whole assembly was placed in an electric kettle where a temperature sensor is used. This arrangement was used to increase the temperature of the samples automatically. Sufficient amount of coconut oil is placed into the kettle and then the sample arrangement was made so that the temperature is recorded by the sensor and the same temperature is transported to the sample arrangement. The temperature is monitored by the system we have arranged. It consists of a monitor to show the instantaneous temperature and dielectric constant for every 0.5^{o}c temperature difference. Here we have investigated the dielectric constant of the above said samples by placing weights like 50g, 100g, 150g, 200g, 250g, 300g, 350g and 400g on the samples and increasing the temperature from 30°c to 80°c to the above said samples at a constant frequency of 1 KHz.

Fig 5(a), 5(b) and 5(c) represent the graphs between temperature and dielectric constant of Pure PVA, PVA + 0.5 % CNT, and PVA + 1% CNT at constant frequency are represented above.

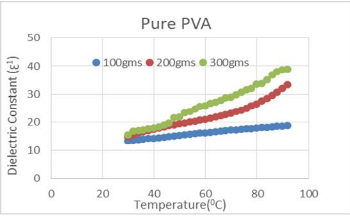

Fig 5(a)

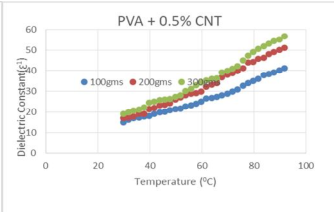

Fig 5(b)

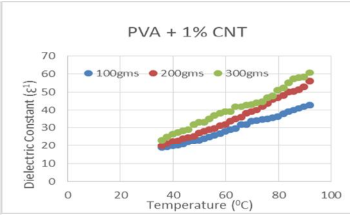

Fig 5(c)

It was observed from Fig. 5(a), Fig. 5(b), and Fig. 5(c) that for 60 micron nanocomposite samples, as the temperature of the samples increases, the dielectric constant is increasing gradually [13]. And at the same time, the dielectric constant is also increasing as the weight on the samples increases. And also observed that the dielectric constant is more for 1.0% CNT doped PVA sample when compared with other samples. It may be due to the amount of increased interstitial dopant in the sample. This may be attributed to the increase of electronic, ionic and orientation polarizability. Based on preliminary results, it is evident that all the samples are functional and variation in molecular mass. PVA powder yielded changes to the capacitance as well as to the dielectric constant.

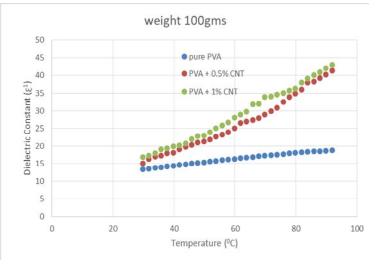

Fig.6(a)

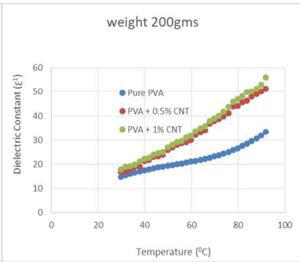

Fig.6(b)

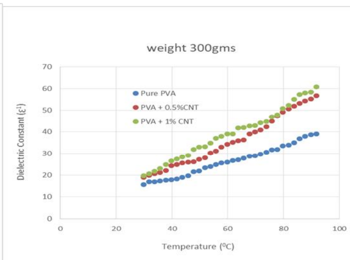

Fig.6(c)

Fig 6(a), 6(b) and 6(c) represent the graphs between temperature and dielectric constant of Pure PVA, PVA + 0.5 % CNT, and PVA + 1% CNT at constant weight and at constant frequency for different concentrations. We have studied the variation of dielectric constant with concentration of CNT maintaining weight/stress constant at different temperatures.

From figures 6(a), 6(b) and 6 (c), we have observed that, the dielectric constant is increasing as the concentration of the samples increases. These variations are observed for constant weights of 100g, 200g and 300g. Because of hopping mechanism of the charge carriers to a new site, MWCNT dopants added to PVA has increased the dielectric constant which can be endorsed to the amount of the interstitial dopant being deposited in the nanocomposites.

6 Results and Discussion: PVA/MWCNT samples were prepared by solution casting method. We have studied the dielectric constant of these nanocomposites. It is observed that the dielectric constant will enhance by adding a small amount of MWCNT to the PVA polymer. Moreover, the dielectric constant was increasing by increasing the weights on the samples. These observations were done at different temperatures ranging from 30°c to100°c and at constant frequency of 1 KHz. Additionally, highly doped MWCNT combined with PVA nanocomposites showed the highest dielectric constant when compared to other samples. This study reveals that the relaxation process at high CNT content is due to the ionic conductivity relaxation. The results obtained were found to be in good agreement with the literature values.

7 Conclusion:

Hardware and software were developed in the present study for the measurement of capacitance and dielectric constant at different temperatures. The data logging was done under the control of a pc. The good agreement between the values evaluated in the present study and that of literature values has paved path for the measurements made on new polymer samples.

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