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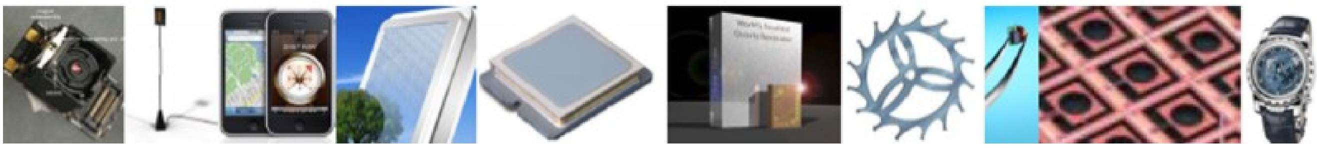

The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten, The Netherlands Antilles

Important deadlines:

Submission (full paper)	September 25, 2010
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- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
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C. Biotechnologies and biomanufacturing

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Design and Development of Embedded Based System for the Measurement of Dielectric Constant Spectroscopy for Liquids

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Abstract: An embedded based system for the measurement of dielectric constant spectroscopy (for frequencies 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz) for liquids has been designed and developed. It is based on the principle that the change in frequency of an MAX 038 function generator, when the liquid forms the dielectric medium of the dielectric cell, is measured with a microcontroller. Atmel's AT89LP6440 microcontroller is used in the present study. Further, an LCD module is interfaced with the microcontroller in 4-bit mode, which reduces the hardware complexity. Software is developed in C using Keil's C-cross compiler. The instrument system covers a wide range of dielectric constants for various liquids at various frequencies and at different temperatures. The system is quite successful in the measurement of dielectric constant in liquids with an accuracy of ± 0.01 %. The dielectric constant is very dependent on the frequency of their measurement. No one-measurement technique is available, however, that will give the frequency range needed to characterize the liquid sample. The paper deals with the hardware and software details. *Copyright © 2010 IFSA.*

Keywords: Dielectric constant spectroscopy, MAX 038 Function generator, Frequency measurement, C using Keil's C-cross compiler and AT89LP6440 microcontroller.

1. Introduction

A dielectric is a substance that can sustain an electric field and acts as an insulator. Some liquids and gases can serve as good dielectric materials, having a special property of storing and dissipating electrical energy when subjected to electromagnetic fields. Dry air is an excellent dielectric. Dielectric data also helps in gaining insight into the molecular structure of compounds. Dielectric studies have a long and distinguished history, the dielectric data is used to determine the electric dipole moments, which is not only significant as a refection of electronic structure of the molecule, but is also of prime importance in understanding of molecular interactions and it at least partly controls the transitions between the solid, liquid and gaseous states. Dielectric measurements are useful in detecting explosives, plastics and metal weapons, drugs, chemical agents and biological agents. Determination of dielectric constant plays an important role in the investigation of the molecular structure of a polar substance as its measurement is being widely used in the determination of conformation characteristics of macromolecules in solution. Methods developed in connection with the theories of liquids have had a great influence on the theories of situation and vice versa. The characterization of dielectrics includes the measurement of dielectric constant as a function of frequency at a given temperature or as a function of temperature at a given frequency. The measurement of dielectric constant over a wide frequency range gives the information regarding the conduction mechanism, interfacial polarization, molecular dynamics and relaxation behavior phenomena [1]. The dielectric data have also been used to estimate the amount of moisture in wood, sand, and agricultural products. It has been shown that dielectric data can also be used for an on-line determination of water content in crude oil flowing in a pipeline and thus is a tool for fundamental research. The dielectric constant ε of a liquid is defined as the ratio of the electrical capacitance of a cell when the liquid / solution forms the dielectric medium (C_s) to the capacitance of the cell when air forms the dielectric medium (C_0) at a given temperature, which is represented by the following equation

$$\varepsilon = (C_s) / (C_0) \tag{1}$$

The dielectric cell consists of two parallel metallic plates which act as electrodes. The cell acts as a capacitor, while the liquid acts as a dielectric medium. The cell has to be first standardized to measure the dielectric constant of unknown solutions. This is accomplished by considering a pure liquid such as chlorobenzene as the standard liquid for frequencies 1 kHz, 10 kHz and 100 kHz. The dielectric constant of an unknown liquid (ε_x) can be determined by measuring the capacitance of the cell in air (C_0), the capacitance of cell in reference liquid (C_r) such as benzene and the capacitance of the cell in liquid whose dielectric constant has to be measured (C_x) using the relation

$$\varepsilon_x = 1 + [(C_0 – C_x) / (C_0 – C_r)] \times (\varepsilon_r – 1), \tag{2}$$

where ε_r is the dielectric constant of the reference liquid. By considering another pure liquid such as acetone as the standard liquid for frequencies 1 MHz and 10 MHz. Here we chosen two liquids for cell standardization, because for getting good accuracy for the dielectric constant spectroscopy. The dielectric constant of a material contains detailed information about the physical and chemical composition and structure [2]. Several attempts have been made for measurement of dielectric constant in liquids which are based on Hetrodyne beat method, Wheatstone bridge, Schering bridge, microwave bridge, resonance method, micrometer method, AC bridge techniques, etc. Kalyanaraman and Vasuhi [3] developed a simple apparatus for the measurement of dielectric constant using 555 timers with limited accuracy. Using frequency measurement principle, Prasad [4] developed a simple apparatus for the measurement of dielectric constant using IC-555 Timer for limited accuracy. However, these techniques are conventional and they have their own limitations. The advent of microcontrollers has opened up the new possibilities in the area of instrumentation for measurement of dielectric constant in liquids. In the present study, the technique utilizes frequency measurement for determination of capacitance using the microcontroller as a tool, while the most of the conventional techniques measure the capacitance using the bridge methods. The present paper is continuous of our previous work [5]. It is fair to say that a strong existing interest in the design of dielectric constant spectroscopy is primarily a consequence of the recent developments in instrumentation capable of performing frequency ranges. A literature survey shows that the instruments most widely used by the research community are impedance analyzer and LCR meters for the measurement of dielectric constant. In the present study we design and developed embedded based dielectric constant spectroscopy for the measurement of dielectric constant for liquids is the instrument that can measure dielectric constant directly with frequency.

2. Experimental

2.1. Principle

The IC MAX 038 is a function generator chip. It acts as an RC oscillator. The frequency of oscillations depends on the values of timing resistor R and timing capacitor C. The value of R is kept constant. The dielectric cell acts as a capacitor C that varies with the dielectric medium. Consequently, the frequency of the oscillator also changes. The measurement of the frequency of the oscillator enables one to measure the values of the capacitance of the cell and, thus the dielectric constant of the medium. In the present study, with suitable interface of the oscillator circuit with an AT89LP6440 microcontroller, the frequency of the oscillator is measured. The dielectric constant of the medium is computed using Equation (2) and is displayed on the LCD and HyperTerminal of the personal computer.

2.2. Dielectric Cell

The dielectric cell consists of two circular discs (25 mm diameter) of brass metal C, whose faces are well machined and later polished with fine emery separated by a distance as shown in Fig. 1.

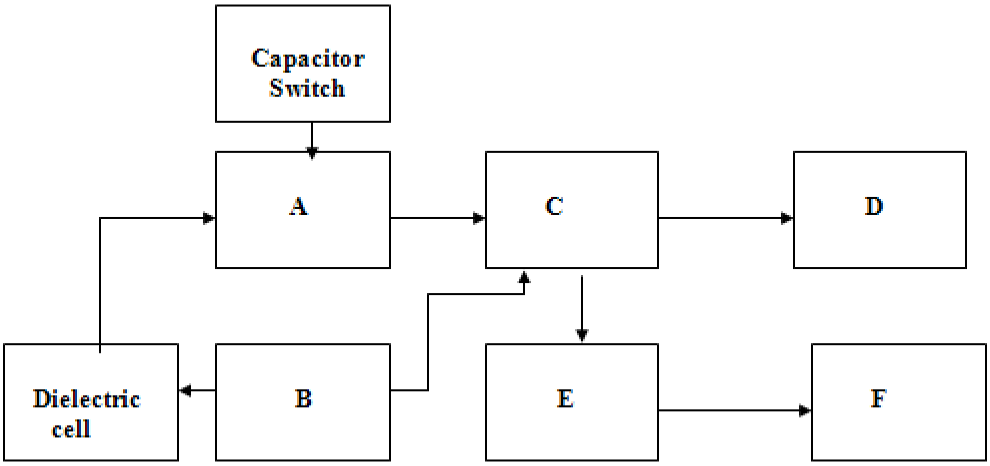
Fig. 1. Dielectric cell for an embedded based system for the measurement of dielectric constant spectroscopy for liquids.

The two conducting plates are positioned parallel to each other at close proximity by two brass leads (d) of about 3 mm diameter which are connected to a thick circular hylam sheet of diameter 50 mm. The length of leads is kept as small as possible (2.5 cm). These leads form interconnections between BNC, SRF-10 recepticle (e) of 50 Ohms impedance and the two conducting circular plates of the cell. The cell acts as a parallel plate capacitor with a liquid being dielectric whose dielectric constant is to be measured. The dielectric cell is designed such that it is rigid and fragile which avoids capacitance variations. The filling and emptying of the cell is made as easily as possible.

2.3. Instrumentation

2.3.1. Hardware Design

The block diagram and the schematic diagram of the design and development of embedded based system for the measurement of dielectric constant spectroscopy for liquids are shown in Figs. 2 and 3 respectively.



A - MAX 038 Function Generator
B - LM 35 Temperature Sensor
C - AT89LP6440 Microcontroller
D - LCD Display
E - MAX 232 for serial communication
F - PC (Personal Computer)

Fig. 2. Block diagram for an embedded based system for the measurement of dielectric constant spectroscopy for liquids.

The designed cell is connected between pins 5 and 6 of the MAX 038 using a BNC connector. The dielectric cell acts as a capacitor C whose capacitance can be measured in terms of frequency. The block A of Fig. 3 consists of the MAX 038 function generator [6].

In the present study, the MAX 038 function generator generally operates at 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz frequencies. The output of the RC oscillator is directly given to the external timer input of the microcontroller, which is available on the microcontroller (P1.1). The microcontroller counts the clock pulses that are given from the MAX 038 over an interval of 1 sec, which gives the frequency of the oscillator. Block B of Fig. 3 consists of an LM 35, which is used as a sensor to measure the temperature of the solution [7]. The output of the LM 35 is given to the analog-to-digital converter, which is available in the microcontroller inbuilt. It is used to convert the analog temperature into digital values. Block C of Fig. 3 is an AT89LP6440 microcontroller from the Atmel company [8]. It is a low power, high-performance 8-bit microcontroller with 64 K bytes In-system programmable flash, 8 K bytes of flash data memory, three 16bit timers/counters, 8 general purpose interrupt sources, two 8 bit PWM outputs, 8-channel 10-bit ADC / DAC, up to 38 programmable I/O lines, etc,. Four ports are used, port 0 is used for LCD display, LM 35 (4 lines for data, 3 lines for enable, RS and RW, one line for ADC), port 1 is used for frequency measurement, serial programming (P1.1 for frequency measurement and P1.2, P1.3 for SDA and SCL), port 3 is used for serial communication (P3.0 for RXD and P3.1 for TXD) and port 4 is used for crystal (P4.0 and P4.1). Block D of Fig. 3 is a two-row 16 characters LCD display from LAMPEX [9]; it is interfaced with the microcontroller through port) to display the measured data and results. The Block E of Fig. 3 is an MAX 232 [10] for serial communication from microcontroller to personal computer. The results from the instrument are directly display on hyper terminal of the personal computer using the Block E. The Block F of Fig. 3 is personal computer. It is used for data storage.

2.3.2. Interfacing of the Oscillator with the Microcontroller

The frequency of oscillation f_0 is determined by the external timing capacitor C across pin 5 and 6, and by the timing resistor R, connected to pin1 and 10. The frequency is given as

$$f_0 = (2\times2.1) / (R\times C) \tag{3}$$

It can be adjusted by varying either R or C.

In the present study, the timing resistor R is kept constant as 10 kΩ for all frequency ranges. The dielectric cell acts as a capacitor C whose capacitance can be measured in terms of frequency. Since the timing capacitor C is to be maintained at a minimum values (42 pF, 420 pF, 4.2 nF, 42 nF and 420 nF for frequencies 10 MHz, 1 MHz, 100 kHz, 10 kHz and 1 kHz) is connected in parallel with the dielectric cell. The minimum capacitors are arranged to capacitor switch. Using that switch we can select frequency for our requirement. The designed cell is connected between pins 5 and 6 of MAX038 using BNC connector. The dielectric cell acts as a capacitor C whose capacitance can be measured in terms of frequency using the following equation:

$$C = (2\times2.1) / (R \times f_0) \tag{4}$$

2.3.3. Software

Software is developed in C using Keil’s C-cross compiler to initialize the LCD display and measure the frequency, capacitance, dielectric constant and temperature. After development, the codes are stored in the program memory (flash) of the microcontroller and the program is executed. The flow chart of the program is presented in Fig. 4.

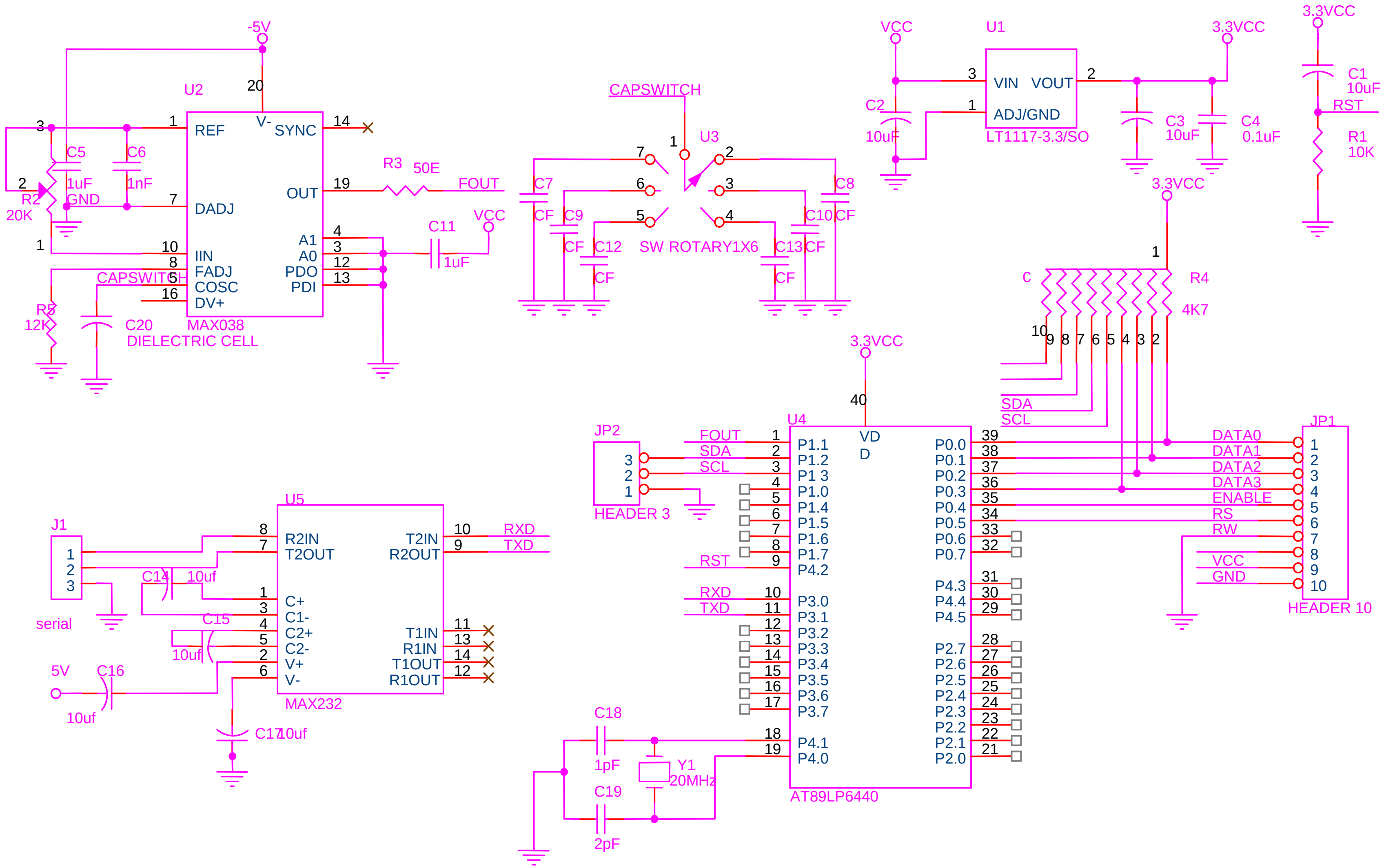


Fig. 3. Schematic diagram for an embedded based system for the measurement of dielectric constant spectroscopy for liquids.

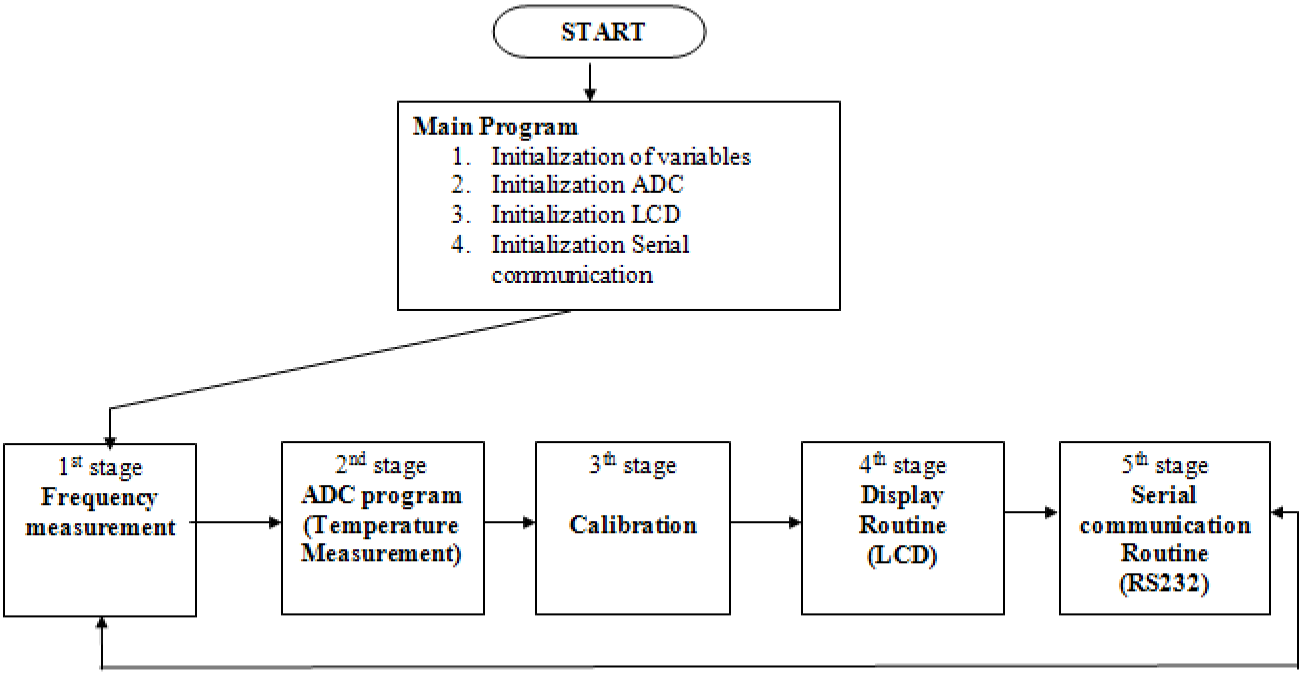


Fig. 4. Flow chart for an embedded based system for the measurement of dielectric constant spectroscopy for liquids.

2.3.4. Calibration and Measurement

The instrument is calibrated and measured following the procedure mentioned below.

1. Clean the dielectric cell, dry it, and keep it in a beaker containing air.
2. Connect the cell to the circuit as shown in Fig. 3.
3. Switch on the system and activate the software.
4. The system measures and displays the frequency, along with temperature and, in turn, the capacitance of the cell using Equation (2). Make a note of the values.
5. Keep the reference liquid (chlorobenzene in the present study for 1 kHz, 10 kHz and 100 kHz frequencies) in the cell.
6. Press the 1 kHz frequency switch.
7. Repeat the steps from (2) to (4).
8. Repeat the process for 10 kHz and 100 kHz frequencies.
9. Keep the reference liquid (acetone in the present study for some frequencies) in the cell.
10. Press the 1 MHz frequency switch.
11. Repeat the steps from (2) to (4).
12. Repeat the process for 10 MHz frequency
13. Place the unknown liquid in the cell.
14. Repeat the steps from (2) to (4).
15. Measure the unknown liquid for all frequencies.
16. Then calculate the dielectric constant of the unknown liquid using equation (2) for all frequencies.
17. Note the readings of the dielectric constant of unknown liquids along with frequency and temperature.

3. Results and Discussion

The performance of the embedded based system for the measurement of dielectric constant spectroscopy for liquids are tested with some liquids at 30°C. The samples are selected to cover a wide range. The results are presented in Table 1. The results of the present study are in good agreement with the literature values.

Table 1. Dielectric constants of pure liquids at 30°C.

S.No	Samples	Present work					Literature	References
		Dielectric constant at 1 kHz	Dielectric constant at 10 kHz	Dielectric constant at 100 kHz	Dielectric constant at 1 MHz	Dielectric constant at 10 MHz		
1	Toulene	2.399	2.391	2.384	2.379	2.371	2.40	15
2	Carbon tetrachloride	2.197	2.190	2.185	2.180	2.172	2.20	15
3	Cyclohexanone	18.380	18.257	18.198	18.156	18.108	18.2	15
4	Methanol	32.921	32.879	32.756	32.465	32.273	32.6	15
5	Nitrobenzene	35.154	34.957	34.681	34.582	34.461	34.81	12
6	Ethyl alcohol	25.541	25.489	25.372	25.198	24.053	24.3	12 & 13
7	Acetonitrile	35.359	35.125	34.991	34.712	34.651	35-37.5	12&13
8	DMSO	47.476	47.251	46.991	46.785	46.529	47.0	11& 14

4. Conclusions

The hardware and software features of an embedded based system for the measurement of dielectric constant spectroscopy for liquids is designed and developed. The necessary software is developed in C, using Keil's C-cross compiler. The system is quite successful for the measurement of dielectric constants in liquids with an accuracy of ± 0.01 % and capacitance of whole construction and stability of generator's frequency is around 5 pF. In the present study, the dielectric constants are measured at spectroscopy (1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz frequencies). The readings are observed for the time duration of 30 minutes; there is no change in the reading for entire spectroscopy. The measurement of dielectric constant spectroscopy, over a wide range, is a special feature of the present study.

The measurement system was tested with different samples to check the reproducibility. One common feature of the system is that the microcontroller can handle the process of dielectric constant, temperature measurement and send the data to the personal computer to data storage, data manipulation, displaying and decision making operations. Moreover, the system is easily operated and does not require any programming expertise. In this instrument the manual supervision involved is little. The system is highly reliable, low cost, and portable. There are good reasons for the current surge of interest in the fundamental and applied aspects of dielectric constant spectroscopy for liquids. Fundamental investigations of the dielectric response yield a wealth of information about different molecular motions and relaxation processes. A unique characteristic of dielectric constant spectroscopy is the frequency range (1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz frequencies). The remarkable breadth is the key feature that enables one to relate the observed dielectric response to slow and/or fast molecular events and a chemical and/or physical change as a result of chemical reaction, crystallization, vitrification, and phase separation, etc. polarization due to charge migration and polarization due to orientation of permanent dipoles are studied using dielectric constant spectroscopy. Based on these reasons/applications we design and developed an embedded based system for the measurement of dielectric constant spectroscopy for liquids.

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