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PC Based Instrument for the Measurement of Dielectric Constant of Liquids

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Abstract: A PC based instrument for the measurement of dielectric constant in liquids has been developed. It is based on the technique that utilizes frequency measurement for determination of capacitance using the personal computer as a tool. The change in frequency of XR–2206 function generator, when the liquid forms the dielectric medium of the dielectric cell, is measured with a personal computer. The programmable interval timer 8254 available in the DIOT card is used to measure the frequency, which in turn determines the capacitance of the cell and dielectric constant. The necessary software is developed in C language. The instrument system covers a wide range of dielectric constant for various liquids. The system is reasonably successful in measuring dielectric constant with an accuracy of ± 0.5 %. The paper deals with the hardware and software details. *Copyright © 2010 IFSA.*

Keywords: Dielectric constant; XR–2206 function generator; Frequency measurement and Computer based system

1. Introduction

The dielectrics have a special property of storing and dissipating electrical energy when subjected to electromagnetic fields. The dielectric constant of a material is a measure of the ability to hold charge. 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 benzene as the standard liquid. 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. The dielectric constant of materials contains detailed information about physical and chemical composition and structure [1]. 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, A.C. bridge techniques, etc. Kalyanaraman and Vasuhi [2] developed a simple apparatus for the measurement of dielectric constant using 555 timers with limited accuracy. Using frequency measurement principle, Prasad [3] 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 microcomputers 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 personal computer (PC) as a tool while the most of the conventional techniques measure the capacitance using the bridge methods.

2. Principle

The IC XR–2206 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 which varies with dielectric medium. Consequently the frequency of the oscillator also changes. The measurement of frequency of the oscillator enables one to measure the value of capacitance of the cell and thus the dielectric constant of the medium. In the present study, with suitable interface of the oscillator circuit with a personal computer, the frequency of the oscillator is measured and displayed on the monitor of the personal computer.

3. Instrumentation

3.1. Hardware Design

The block diagram and the schematic diagram of the PC based instrument for the measurement of dielectric constant in liquids is shown in Figs. 1 and 2 respectively. It consists of the functional units: (i) Dielectric Cell (ii) Function generator and (iii) Personal computer with DIOT card.

3.2. Dielectric Cell

The dielectric cell consists of two circular discs or plates (25 mm diameter) of brass metal separated by a distance of about 1 mm. The faces of the circular discs are well machined and later polished with fine emery. The two conducting plates are positioned parallel to each other at close proximity by two brass leads which are connected to a thick circular hylam sheet. The length of leads is kept as small as possible (2.5 cm). These leads form interconnections between BNC (SRF – 10 recepticle of 50 Ω impedance) and the two conducting circular plates of the capacitor. It offers a capacitance of 25 pF approximately. The design of dielectric cell for use with solutions is made such that the structure of the cell is rigid so that the variation of its capacitance due to strain is negligible and also it is less fragile.

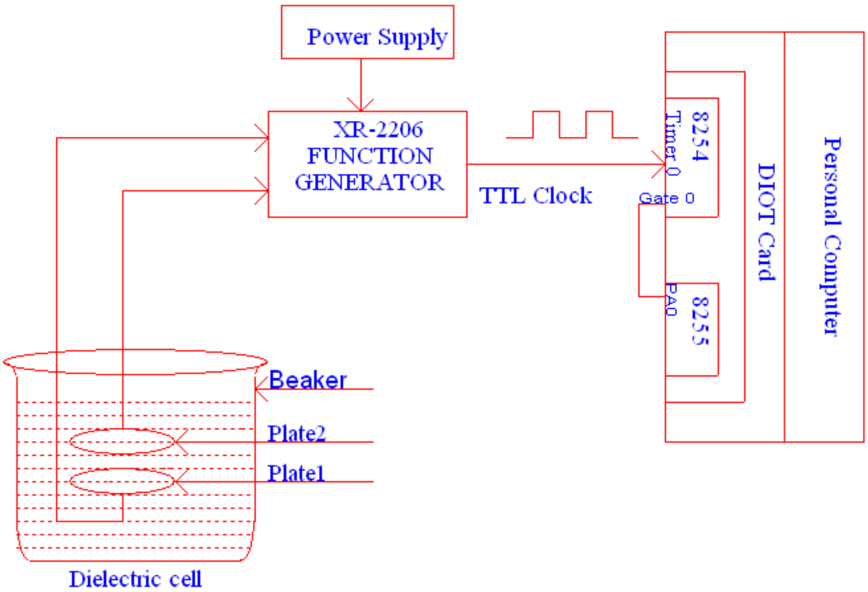

Fig. 1. Block diagram of PC based instrument for the measurement of dielectric constant for liquids.

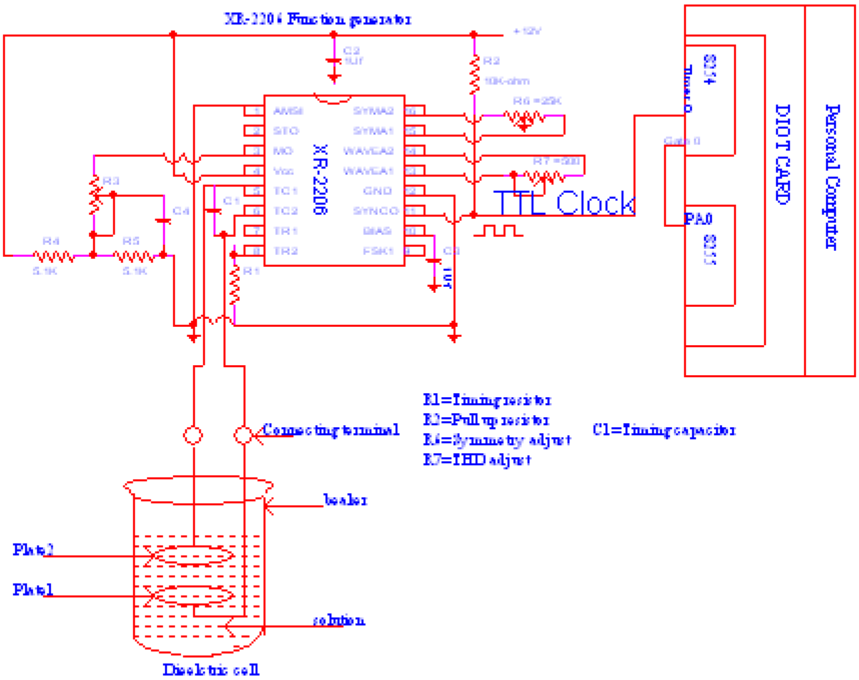

Fig. 2. Schematic diagram of PC based instrument for the measurement of dielectric constant for liquids.

3.3. Function Generator

The XR – 2206 is a monolithic function generator integrated circuit capable of producing high quality sine, square, triangle, ramp, and pulse waveforms of high-stability and accuracy. It acts as an RC oscillator [4]. The output waveforms can be both amplitude and frequency modulated by an external voltage. The frequency of operation can be selected over a range of 0.01 Hz to 1 MHz linearly using the external resistor / capacitance combinations. The output is suitable over a wide range of temperatures and power supply variations. The total power dissipation is 750 mW. The symmetry of all waveforms can be adjusted with external timing resistors.

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 either pin7 or 8. The frequency is given as:

$$f_0 = 1 / R^* C$$
$$C = 1 / R^* f \tag{3}$$

It can be adjusted by varying either R or C.

In the present study, the timing resistor R is kept constant. Since the timing capacitor C is to be maintained at a minimum of 100 pF, a capacitor of value 100 pF is connected in parallel with the dielectric cell. The designed cell is connected between pins 5 and 6 of XR-2206 using BNC connector. The dielectric cell acts as a capacitor C whose capacitance can be measured in terms of frequency. The square wave output (pin11) is a open collector and hence it needs a pull up resistor to V_{cc}. Connecting a 10 kΩ resistor between pin 11 and V_{cc}, it makes the square wave output to be TTL compatible (Fig. 2). In the present study, the frequency of oscillation is chosen as 1 MHz with air as dielectric medium.

3.4. Personal Computer with DIOT Card

To measure the frequency of the output of XR-2206 function generator, it is to be interfaced with a personal computer. It requires one counter and one port. The DIOT card provides these requirements. This card is very useful especially when the PC has to be interfaced with the outside world. In the present study, the DIOT card of Advanced Electronic Systems Associates Pvt. Ltd, Bangalore is used. This card provides 48 TTL compatible I/O lines (8255X2) and three channels of 16 bit Timer / counters using 8254 [5]. This card is inserted in one of the available PCI slots.

3.5. Interfacing of the Oscillator with Personal Computer

The output of the RC oscillator is given to the clock input of Timer 0 of the IC 8254, which is available on the DIOT Card (Fig. 2). The counter counts the clock pulses that are given from the RC oscillator over an interval of 1 sec that gives the frequency of the oscillator. The 1second delay is generated internally through the software. The PA_0 of 8255 is given to the gate of Timer 0 for switching ON/OFF the counter for 1second interval.

4. Software

The necessary software for the operation of the system is developed in C language [6]. The main role of the software in the present study is to govern the following activities.

1. To generate 1 second delay.
2. To measure the frequency of the oscillator in which dielectric cell is a part of the oscillator system.
3. To compute capacitance value using the formula C = 1 / R* f where R-value is kept constant.
4. Clean the dielectric cell, dry it and keep it in a beaker containing air.
5. Connect the cell to the circuit as shown in Fig.2.
6. Switch on the system and activate the software.
7. The system measures and displays the frequency and in turns the capacitance of the cell using the equation (3). Note down the values.
8. Keep the reference liquid (benzene in the present study) in the cell.
9. Repeat the steps from (5) to (8).
10. Keep the unknown liquid in the cell.
11. Repeat the steps from (5) to (8).
12. Then calculate the dielectric constant of unknown liquid using the equation (2).
13. To display and store the dielectric constant of unknown liquids.

The flow chart of the program is presented Fig. 3. The necessary software for the operation of the system is developed in C language.

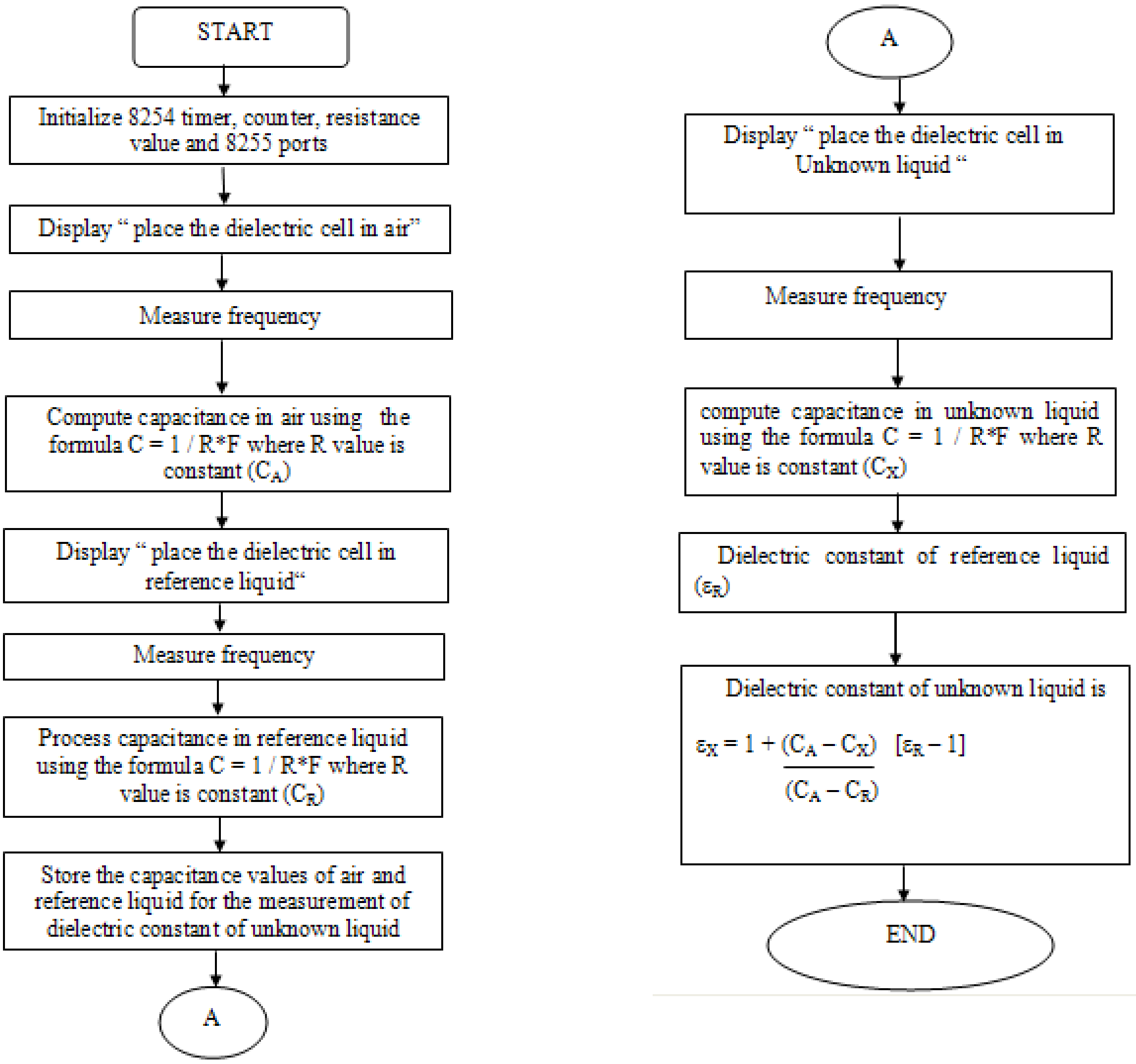

Fig. 3. Flow chart for PC based instrument for the measurement of dielectric constant for liquids.

5. 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.2.
3. Switch on the system and activate the software.
4. The system measures and displays the frequency and in turn the capacitance of the cell using the equation (3). Note down the values.
5. Keep the reference liquid (benzene in the present study) in the cell.
6. Repeat the steps from (2) to (4).
7. Keep the sample whose dielectric constant is not known.
8. Repeat the steps from (2) to (4).
9. Then determine the dielectric constant of the sample using the equation (2).
10. From other samples repeat the steps from (2) to (9).

6. Results and Discussion

After making the appropriate adjustments both in hardware and software and also following the calibration procedure, the instrument is tested with – Toulene, Chlorobenzene, Cyclohexanone, Acetone and Nitrobenzene at 30°C. The results are presented in Table 1. The recorded data of frequencies and capacitance for the samples using equation (3) is also presented in Table 2.

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

Sample	Present work	Literature	Reference
Toulene	2.43	2.40	7
Chlorobenzene	5.94	5.91 5.90	8 7
Cyclohexanone	17.92	18.2	7
Acetone	20.30	20.35	7
Nitrobenzene	34.85	34.81 34.80	10 9

Table 2. Frequency and capacitance of pure liquids at 30 °C.

S. No	Sample	Frequency (kHz)	Capacitance (pF)
1	Toulene	962.8	103.8
2	Chlorobenzene	923.2	108.3
3	Cyclohexanone	639.8	156.3
4	Acetone	483.1	206.9
5	Nitrobenzene	123.7	808.4

The samples are selected to cover the wide range. The results of the present study are in good agreement with the literature values. The instrument is also tested by determining the dielectric constant of the binary mixture: benzene + nitrobenzene at 30 °C and at various concentrations. The results are graphically represented in Fig. 4.

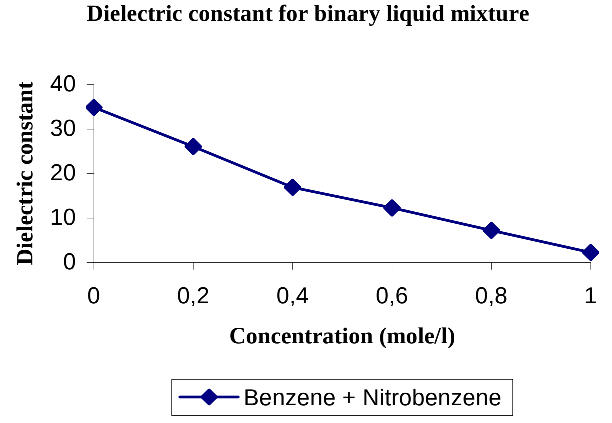

Fig. 4. Concentration versus dielectric constant for binary liquid mixture.

7. Conclusion

The hardware and software features of a PC based instrument for the measurement of dielectric constant in liquids are described. The necessary software is developed in C language. The system is quite successful for the measurement of dielectric constant in liquids (Carbon tetrachloride, Cyclohexane, Hexane, Heptane, Cyclopentane, Ethyl Acetate, Acetonitrile, Methanol, etc.) and for binary liquid mixtures with an accuracy of ± 0.5 % and capacitance of whole construction and stability of generator's frequency is around 10 pF. In the present study, the dielectric constants are measured at a fixed frequency of 1 MHz. The readings are observed for the time duration of 10 minutes; there is no change in the reading. The IC AD774X is also tested for this purpose but found the following constraints.

1. The excitation frequency is only 32 kHz and hence it cannot cover the wide range of dielectric constant.
2. This IC requires double conversion for dielectric constant measurement.
3. Its cost is very high when compared to the IC used in the present study.

The measurement of dielectric constant in a wide range is a special feature of the present study.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
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