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Microcontroller Based Dielectric Constant Measurement

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Abstract A dielectric constant measurement setup has been developed to measure dielectric constant of liquids using AT89C55WD microcontroller. A modified operational amplifier based AC Schering Bridge network is used to compute capacitance and hence calculate dielectric constant of liquids. This instrument system permits recording of dielectric constant of liquids at various concentrations and temperature and sends data to a computer to enable the computer processing of such data. A dedicated AT89C55WD (8-bit) based microcontroller and its associated peripherals are employed for the hardware. The details of its interface to measure dielectric constant of liquids, temperature and to control the temperature at desired range and evaluate results are explained in this paper.

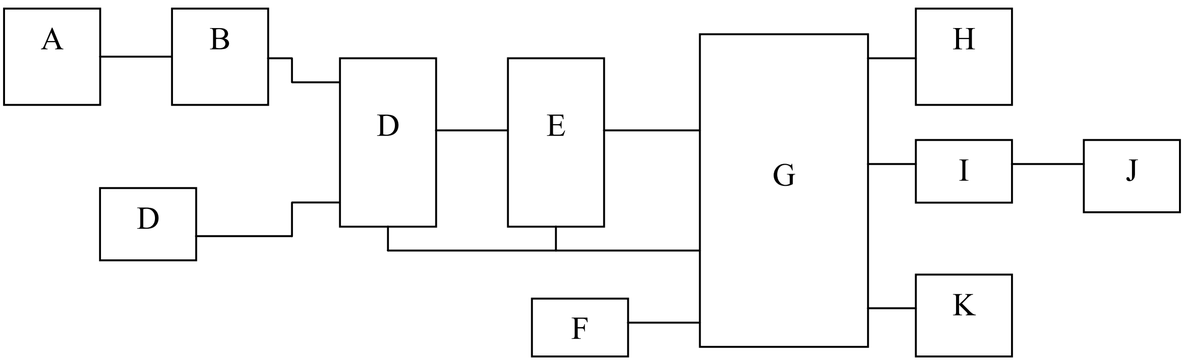
Keywords: AC Shering Bridge, dielectric constant, temperature measurement, microcontroller

1. Introduction

Dielectrics are basically insulator materials having a special property of storing and dissipating electrical energy when subjected to electromagnetic fields. The dielectric constant of materials contains detailed information about physical and chemical composition and structure [1]. Studies of these materials particularly in ac fields provide an insight of the electrical nature of the molecular or atomic species, which constitute the dielectric materials. The decrease in unit cost and the increase of on-chip capabilities have enabled the use of single chip microcontroller in instrumentation and measurement technology. This development system enabled use of compensation, calibration and linearization techniques and application of Microcontrollers in system control and data acquisition and processing. This paper presents measurement of dielectric constant of liquids, which takes full advantage of the microcontroller facilities. In the present work an operational amplifier based modified AC Shering bridge network have been used to measure dielectric constant of liquids.

2. Experimental

Figure 1 shows the block diagram of dielectric constant measurement set up. The capacitance cell is connected to one arm of a modified AC Shering bridge network is kept in the block A. The cylindrical cell is immersed in a beaker containing liquids. The circuit is unbalanced depends upon the dielectric constant of a liquids. The output of the bridge network is rectified using precision rectifier, which is kept in block B. Block C consists of an AD590 is used as a sensor to measure temperature of the solution and instrumentation amplifier, which amplifies the signal from temperature sensor. The block D is a multiplexer (IC 4051), which is used to select dielectric constant or temperature. The output of multiplexer is given to the analog to digital converter (IC MCP3201), which is kept in the block E. The Microchip Technology Inc. MCP 3201 is a successive approximation 12- bit (A/D) converter with the device is done using a simple serial interface compatible with the SPI protocol. The device is capable of sample rates of up to 100ksps at a clock rate 1.6 MHz. The MCP3201 operates over a broad voltage range (2.7V-5.5V). It is used to convert the analog dielectric constant and temperature into digital values. Block G is an AT89C55WD microcontroller from *Atmel* Company, is a low power, high performance CMOS 8-bit microcontroller with 20KB of flash programmable and erasable memory and 256 bytes of RAM. It has four parallel ports, three 16-bit timers/counters, eight interrupt sources, one programmable serial port, low power ideal and power down modes and it has the facility of three level program memory lock. Two of its Port 1 and Port 2 are being employed as input port and another Port 0 as an output port. The solid-state power controller with heater, which is kept in the block F, is used to heat the furnace. The rate of heating is controlled at any temperature by proper commands from the microcontroller. Block H is a two-row 16 characters LCD display from *Hitachi* is interfaced with microcontroller through Port1 to display the measured data and results. Block I consists IC MAX232 is a dual RS232 transmitter/receiver interface circuit that meets all EIA RS232 specification. It requires a single +5V supply. The output MAX232 is connected to COM1 port of computer, which is kept in the block J. A keyboard is connected kept in block K for getting inputs.



A= Modified operational amplifier based AC Shering bridge
C= AD590 Temperature sensor & Signal conditioning circuit
E = 12-bit Serial A/D converter (MCP3201)
G= AT89C55WD Microcontroller
J=PC

B=Precision Rectifier
D= Multiplexer
F= Solid state controller with heater
H= LCD I= MAX232
K= Keyboard

Fig.1 *Block Diagram of AT89C55WD Microcontroller Based Dielectric Constant of Liquids Measurement Setup*

3. Circuit Description

A general AC Shering bridge network is modified as shown in figure 2, where two very high gain operational amplifiers U1 and U2 are connected with the bridge network [2] with the non-inverting terminal connected to the circuit ground. This enables the bridge output nodal points B and D to be almost at the same potentials with respect to the ground and hence the effect of stray capacitance that will exist between them and also between them and ground, may be assumed to be minimized. Since B and D are at virtual ground, so for the sinusoidal supply voltage $Vi=V_m \sin\omega t$, the currents through the bridge impedances Z_1, Z_2, Z_3 and Z_4 are respectively given by

$$I_1 = \frac{V}{Z_1} \quad I_2 = \frac{V}{Z_2} \quad I_3 = \frac{V_1}{Z_3} \quad I_4 = \frac{V_4}{Z_4}, \tag{1}$$

where V_1 is the output voltage of the operational amplifier U1. If V_0 is the output voltage of the operational amplifier U2 then the current through its feedback resistance is given by

$$I_f = \frac{V_0}{R_f}$$

Applying Kirchhoff's current law

$$I_1 + I_3 = 0 \tag{2}$$

and

$$I_2 + I_4 + I_f = 0 \tag{3}$$

The equation (1) and (2) give

$$\frac{V_i}{Z_1} + \frac{V_1}{Z_3} = 0$$

$$V_1 = -\frac{Z_3}{Z_1} \cdot V_i \tag{4}$$

The equations (1) and (3) give

$$\frac{V_i}{Z_2} + \frac{V_1}{Z_4} + \frac{V_0}{R_f} = 0 \tag{5}$$

The equations (4) and (5) give

$$V_0 = \frac{R_f}{Z_1 Z_2 Z_3} \cdot (Z_2 Z_3 - Z_1 Z_4) \cdot V_i \tag{6}$$

At balance condition of the bridge, $V_0 = 0$, which is identical with the conventional bridge network. For the modified AC Shering bridge circuit

$$Z_1 = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$Z_3 = \frac{R_3}{1 + j\omega C_3 R_3}$$

$$Z_4 = \frac{1}{1 + j\omega(C_0 + \Delta C)}$$

Hence, from the equation (6), the bridge output voltage is given as

$$V_0 = \frac{j\omega R_f}{R_1(1 + j\omega C_3 R_3)}[(R_3 C_x - C_2 R_1) + j\omega R_1 R_3 (C_1 C_x - C_2 C_3)]V_i$$

If the bridge is balanced at the minimum value of the process variable for which the capacitance of a transducer is C_0, then $V_0=0$ for $C_X=C_0$, also, $R_3C_0-C_2R_1 = 0$ and $C_1C_0-C_2C_3 = 0$.

ΔC is the change in capacitance for a given change of the process variable above this minimum value. The capacitance cell is connected instead of ΔC.

The capacitance of a liquid is determined by the given equation

$$\Delta C = \left(\frac{R_1(1 + j\omega C_3 R_3)}{j\omega R_f R_3 (1 + j\omega C_1 R_1) V_i} \right) \cdot V_0$$

$$\Delta C = \left(\frac{R_1(1 + 2\pi f C_3 R_3)}{j2\pi f R_f R_3 (1 + j2\pi f C_1 R_1) V_i} \right) \cdot V_0, \qquad (7)$$

where V_0 is the bridge output voltage; V_i is the input excitation voltage; R_f is the feedback resistance; f is the AC excitation frequency; ΔC is the capacitance of a solution.

A dielectric constant of liquid:

$$(\varepsilon_r) = \frac{\Delta C_{medium}}{\Delta C_{air}}, \qquad (8)$$

where ΔC_{medium} is the capacitance when the cell filled with a dielectric liquid; ΔC_{air} is the capacitance in air.

Figure 2 shows the circuit diagram for the modified AC Shering Bridge with a precision rectifier. The precision rectifier (U3 & U4) is implemented with the operational amplifier. The temperature transducer is also presented in Figure2, includes an integrated circuit temperature sensor AD590, which delivers a current proportional to the temperature and a signal conditioning circuit, which converts the current to a voltage. The temperature sensor is almost insensitive to line voltage drops due to its high output impedance and its high interference rejection results from the output being current rather than a voltage. The output current from AD590 flows through a 1KΩ resistance, thereby developing a voltage of 1mV/ ºK. The output of the 2.5V dc reference voltage obtained from a voltage regulator is divided down by resistors to provide an offset of 273 mV required to have ºC as the reference temperature. This offset is subtracted from the voltage across 1KΩ resistor and amplified by a second amplifier (U5&U6).

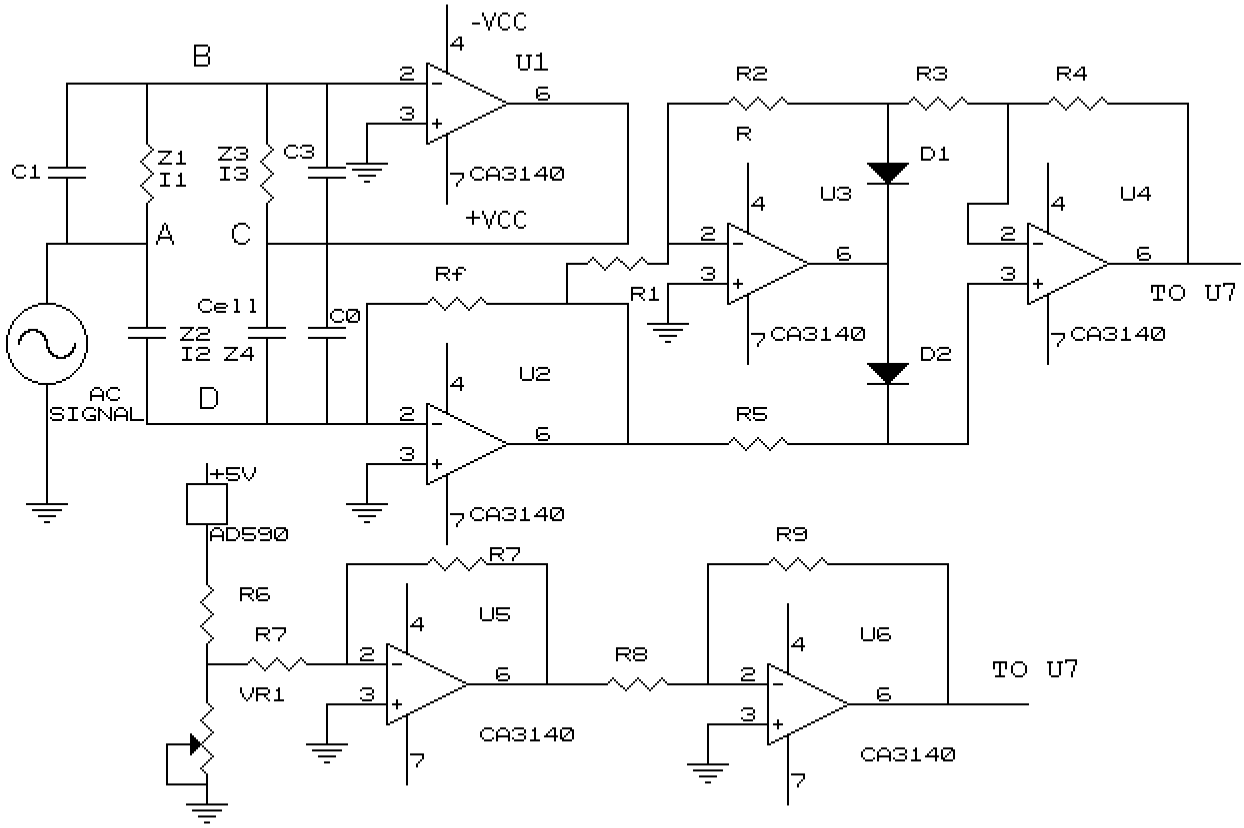


Fig. 2 *Modified AC Shering Bridge and Temperature Measurement Circuit*

The circuit diagram of ADC interface with microcontroller is shown in Figure 3. It consists of AT89C55WD microcontroller (U9), ADC MCP3201 (U8) and MAX232 and LCD. P0.0, P0.1 and P0.2 are connected to CS, D_{OUT} and CLK signals of MCP 3201 12 bit serial A/D converter. LCD is connected to Port1 of microcontroller. P2.3 and P2.4 bits of Port 2 are used to select either dielectric constant or temperature using the multiplexer 4051(U7).

Figure 4 shows solid-state power controller, which is used to control the power to the heater. The power controller is establishing a variable duty cycle switch with zero cross over switching. The circuit is built around IC 555 timers, triac driver (MOC 3041), triac (BT136). U10 wired as a variable duty cycle oscillator with a constant time period of around 0.1 second. Duty cycle can be varied from 0 to 100% using the resistance R1 to R7, which are selected by the multiplexer (U12). The duty cycle can be changed by proper words from the microcontroller to pin 9,10 and 11 of 4051. U11 wired as comparator with hysteresis (i.e.) Schmitt trigger. The transformer T1 with rectifying diodes D1 and D2 delivers unidirectional. The low AC voltage is given to pin 2 and 6 of U11. The output of U8 from pin3 is connected to pin2 of triac driver as shown in the figure. MOC 3041, which incorporates a zero voltage crossing bilateral triac driver providing low power dc control of power triac, is used to drive the triac. By outputting 0 to 7 to port 2 of microcontroller the duty cycle of oscillator of an U10 can be changed and hence the power to the heater can be varied.

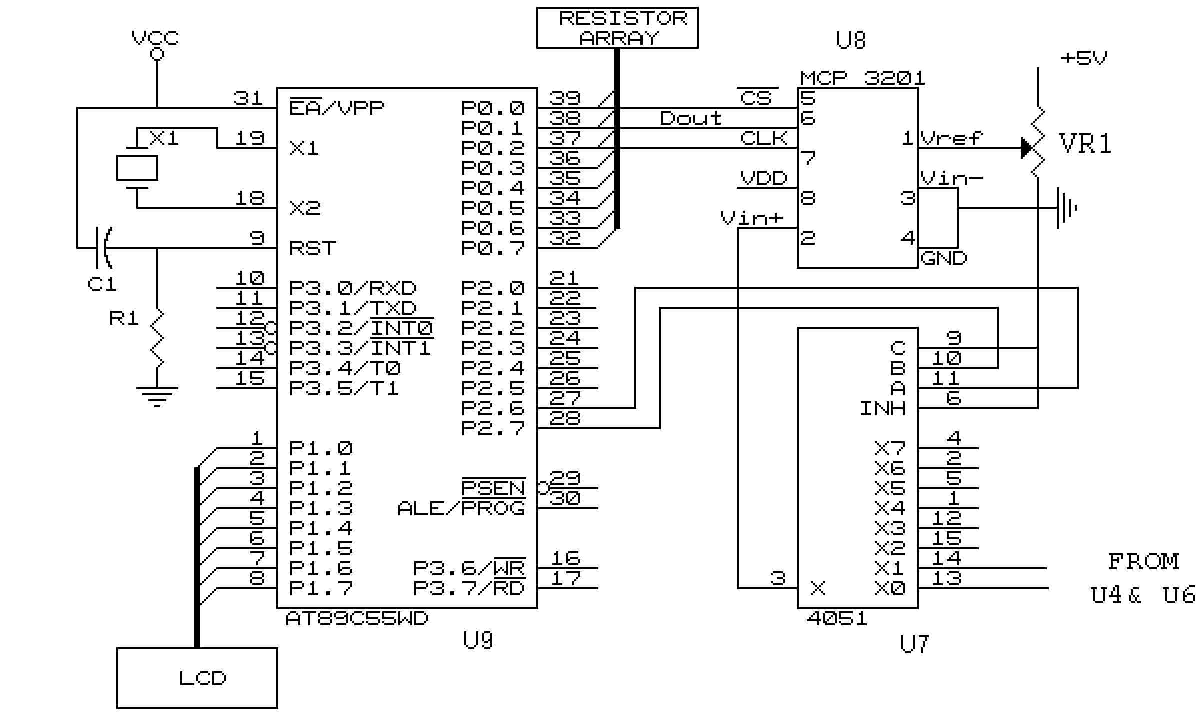


Fig. 3 *Circuit Diagram of Microcontroller and12-bit serial A/D Converter*

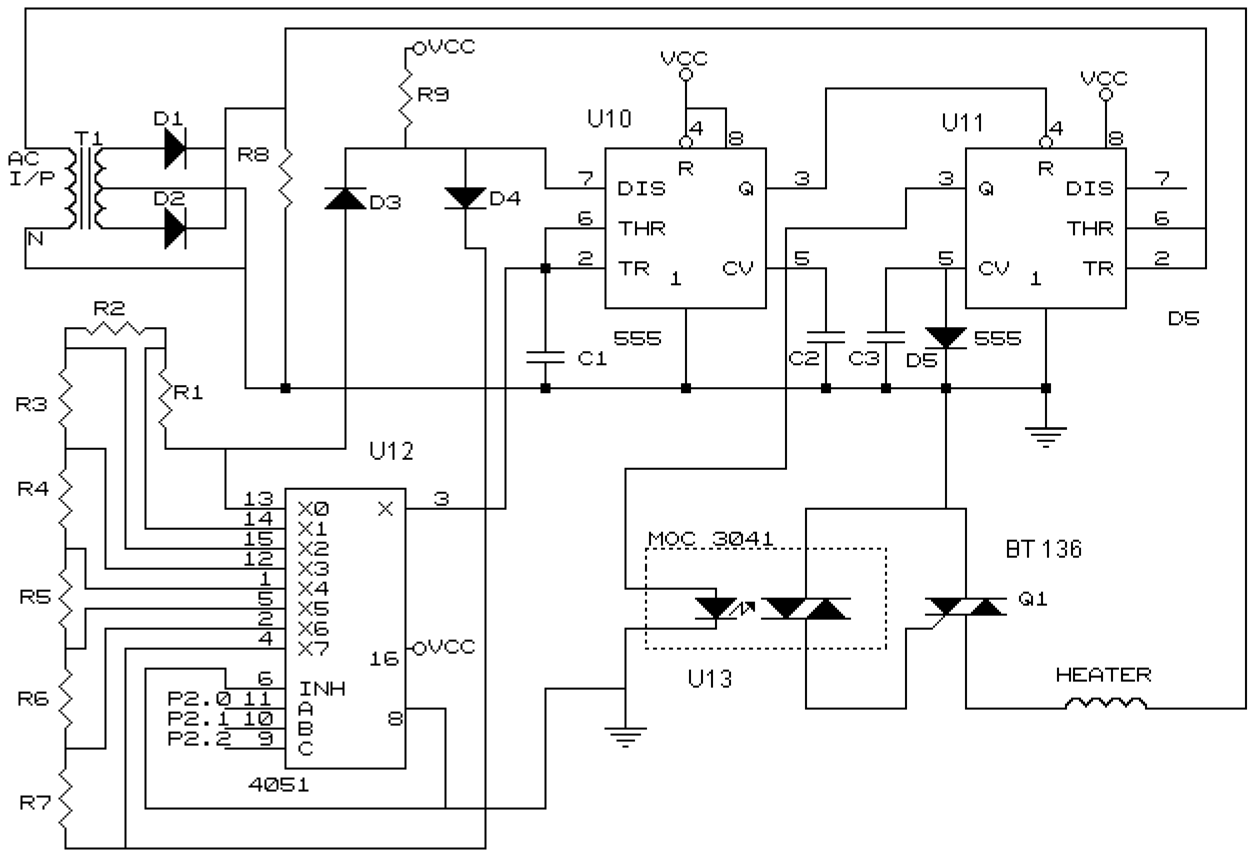


Fig. 4 *Circuit Diagram for Solid Sate Power Controller*

4. Measurement and Details of Software

A fixed sinusoidal excitation voltage of 2V is applied to the bridge. The dielectric constant were measured at 1KHz using a water circulating arrangement in the temperature is maintained at desired temperatures by giving data to microcontroller through the keyboard. The dielectric constant is also measured for various concentrations.

Software is developed in assembly language and C language to initialize LCD display, serial port, selection of temperature or dielectric constant (capacitance) by multiplexer, to select 3201 A/D converter, to receive 12 bit data serially from the data output pin, measure the dielectric constant of the sample from equation (9), temperature of the sample, data computation for acquired data, storage of data for dielectric constant and temperature, and to send data to PC. To transmit data to PC, software is written to select UART mode, to select timer1 for non gated auto reload, to set 4800 baud rate, to start timer1 to send data to transmit buffer, so that a PC can read data through COM1 port. For the development of hardware and software 80C535-microcontroller kit, which has six parallel ports is used. After development the codes are stored in the program memory (flash EPROM) of the AT89C55WD microcontroller and program is executed.

The flowchart for performing the above tasks is shown in Figure 5. Software is also developed to initialize COM1 port in the PC, to receive data from the microcontroller, to store data in a file and to send commands to microcontroller.

5. Results and Discussion

The performance of the microcontroller-based instrument is measuring dielectric constant of liquids, is investigated by comparing its response with result by other methods [3-4]. The instrument is calibrated prior to the actual sample measurement with AR grade pure organic solvents like benzene, carbon tetra chloride, acetic acid etc., whose dielectric constants are precisely known from the literature [5].

Table 1 shows dielectric constant for various liquids. The results of dielectric constant measurement using this instrument are compared with the Digital capacitance meter (Vasavi Electronics, India) to check the accuracy of the instrument and it is found that both results agree and hence this instrument can be used to measure dielectric constant.

The Figure 6 shows the dielectric constant of diethanolamine +1, 4 dioxan, cyclohexylamine + benzene and triethylenetertramine + benzene for various concentrations at 30ºC. The range of the instrument is used to measure the dielectric constant up to 10.The error in measurement is found to be less then 1%. The variation of dielectric constant of the solutions for various temperatures is given in the Figure 7. 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 control functions in addition to data acquisition, 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.

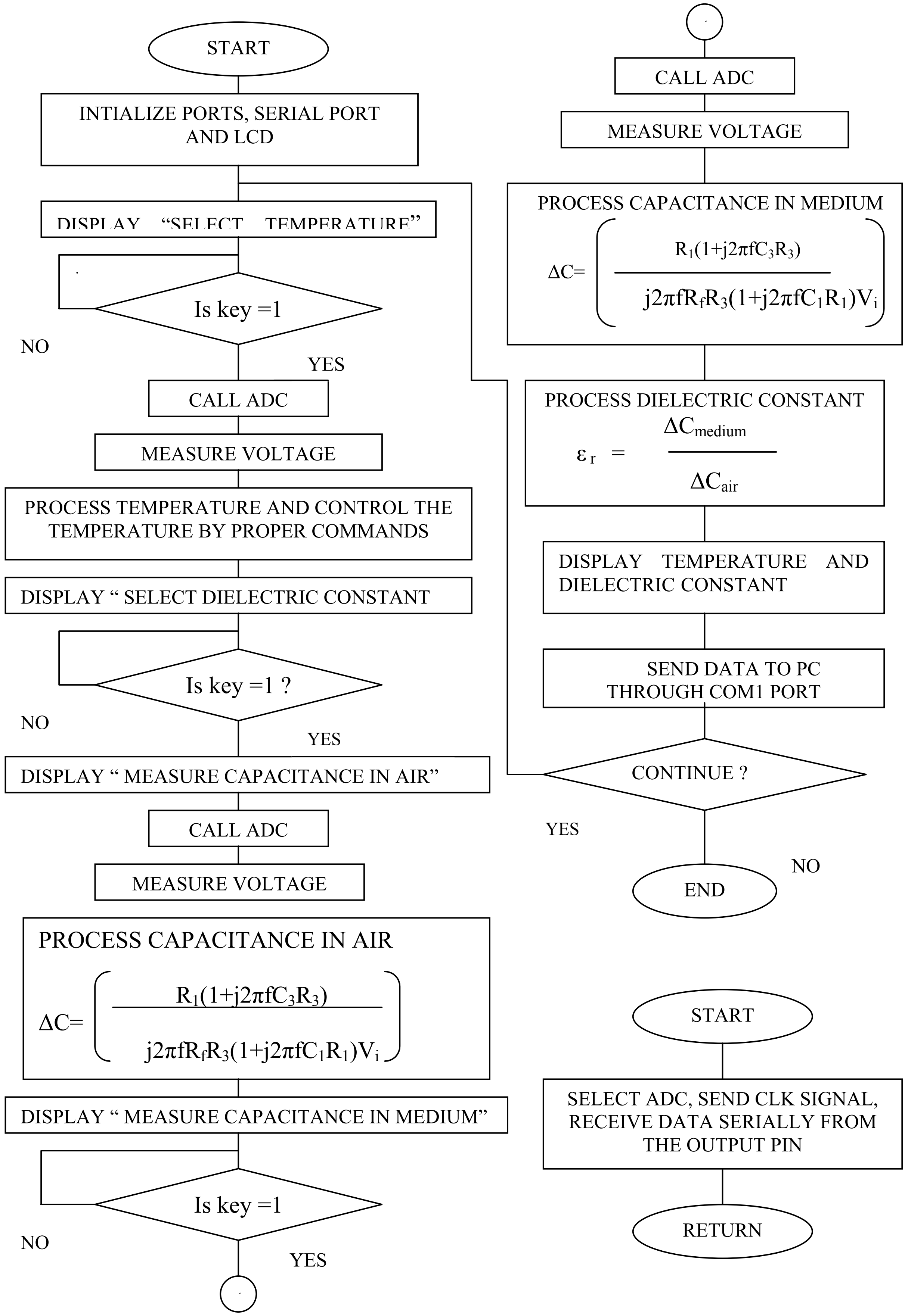
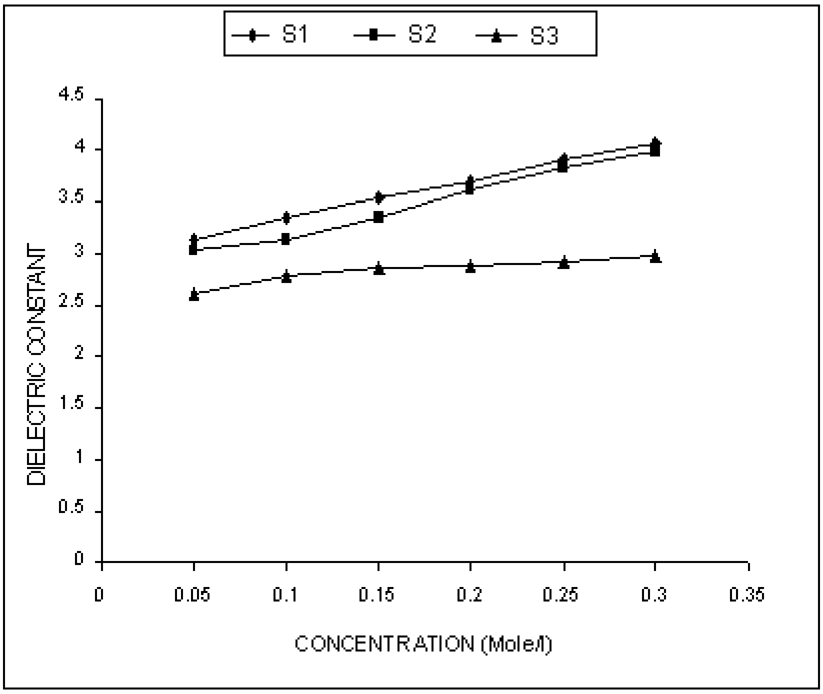


Fig.5 *Flow Chart for Performing Dielectric Constant Measurement System*

Table 1. Dielectric constants for various liquids

Samples	**Dielectric constant (ε_r)**	
	Present work	**Reference**
Benzyl chloride	6.976	7.000
Chloro benzene	5.586	5.621
CCl_4	2.185	2.238
Benzene	2.236	2.284
Toluene	2.341	2.380
Acetic Acid	6.201	6.150



S1=Triethanolamine (A) +2 Methoxy Ethanol in Benzene (B= 1.04 mole/l)
S2=Diphenylamine (A) +2 Methoxy Ethanol in Benzene (B= 1.00 mole/l)
S3=Diphenylamine (A) +2 Methyl 1 Propanol in Benzene (B= 1.04 mole/l

Fig. 6 *Curves for Dielectric Constant of Liquids at Various Concentrations*

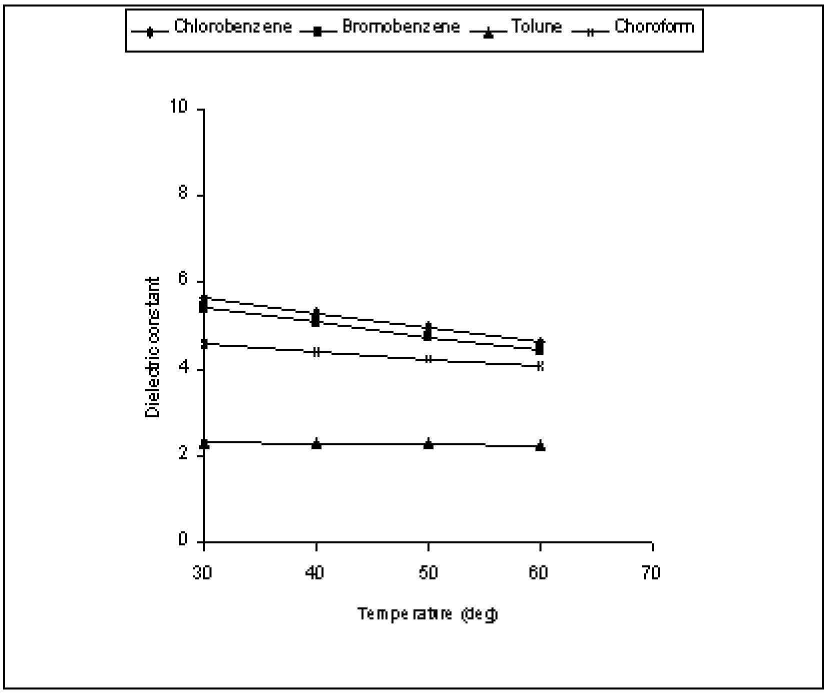


Fig. 7 *The Dielectric Constant of Liquids at Various Temperatures*

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