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Measurement of conductivity of liquids using AT89C55WD microcontroller

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Abstract

A conductivity measurement setup has been developed to measure conductivity of ionic solutions using a microcontroller. A modified AC Wheatstone Bridge network is used to measure conductivity. This instrument system permits recording of conductivity 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 conductivity, temperature and to control the temperature and evaluate results are explained in this paper.

Keywords: Conductivity measurement; Temperature measurement; Microcontroller

1. Introduction

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 to use of compensation, calibration and linearization techniques [1,2] and application of microcontrollers in system control and data acquisition and processing [3,4]. The advantages of the microcontroller-based system are small, programmable, simple, reliable, and low cost. The entire circuit can be built in a single board, which reduces the noise level during it's operation. This paper presents the conductivity study of an electrolyte solution, which takes full advantage of the microcontroller facilities. The conductivity is an important property of the ionic solutions used for analytical purposes. The conductance of a solution depends on its concentration, the nature of the electrolyte, the rate of movement of the current-carrying ions and temperature. Raising the temperature by 1 °C increases the conductivity by an average of 2–3% [5,6]. A good conductometric measurement system should be capable of measuring of rapid changes in solution resistance. The measurement of conductivity along with time and temperature possesses potential applications including in estimating the hardness of water, in detecting the extent of disease in plant leaves, in

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soil studies, in the manufacture of paper and sugar, in vat dyeing [7]. The most accurate methods of measurement of unknown impedance are the bridge methods [8], whose accuracy is basically limited only by the accuracy of the known values of the various elements constituting the bridge. A modified approach of the balancing techniques of AC Wheatstone's bridge network has been reported to achieve high accuracy in measurement [9,10]. In the present work an operational amplifier based modified Wheatstone bridge network have been used to measure conductivity of a solution. A microcontroller based conductivity measurement setup is designed to measure the conductivity and temperature of rapid changing solution resistance with time.

2. Experimental

The Fig. 1 shows the block diagram of conductivity measurement set up. The platinum cell having a cell constant 1.0 cm^{-1} is connected to one arm of a modified Wheatstone bridge network kept in the block A. The conductivity cell is immersed in a beaker containing electrolyte solution. The unbalanced output voltage of the bridge circuit depends upon the conductivity of ionic solution. The output of the bridge network is rectified using precision rectifier which is kept in block B. Block D is a K type chromel–alumel thermocouple is used as a sensor to measure temperature of the solution. The block E consists of an instrumentation amplifier, which amplifies the thermo emf from thermocouple. The block C is a multiplexer (IC 4051), which is used to select conductivity or temperature. The output of multiplexer is given to the analog to digital converter (IC 7109), which is kept in the block F. The 7109 A/D converter is a low power integrating device which provides the user with high accuracy, low noise, low drift, versatile and economical A/D converter of the dual slope integrating 12 bit A/D converter which can make 30 conversions per second. It is used to convert the analog conductivity and temperature into digital values. Block H is an AT89C55WD microcontroller from Atmel Company, a low power, high performance CMOS 8-bit microcontroller with 20 KB 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 G, is used to heat the furnace. The rate of heating is controlled at any temperature by proper commands from the microcontroller. Block I is a two-row 16 characters LCD display from Hitachi is interfaced with microcontroller through Port 1 to display the measured data and results. Block J consists IC MAX232 is a dual RS232 transmitter/receiver interface circuit that meets all EIA RS232 specification. It requires a single +5 V supply. The output MAX232 is connected to COM1 port of computer, which is kept in the block K.

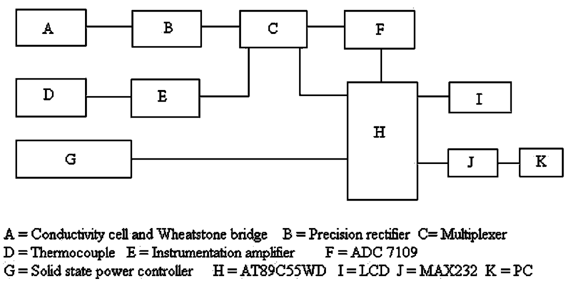

Fig. 1. Block diagram of conductivity measurement system.

3. Circuit description

A general AC Wheatstone's bridge network is modified as shown in Fig. 2, where two very high gain operational amplifiers U1 and U2 are connected with the bridge network 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 [11]. Since B and D are at virtual

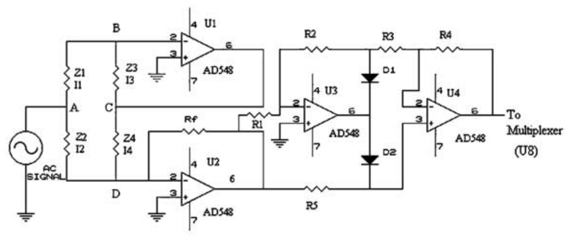

Fig. 2. AC modified Wheatstone bridge network with precision rectifier.

ground, so for the sinusoidal supply voltage $V = V_m \sin \omega t$, the currents through the bridge impedances Z_1, Z_2, Z_3 and Z_4 are respectively given by,

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

Where V_1 is the output voltage of the operational amplifier U1. If V_0 be 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 Eqs. (1) and (2) give

$$\frac{V}{Z_1} + \frac{V_1}{Z_3} = 0, \qquad V_1 = -\frac{Z_3}{Z_1} V \tag{4}$$

The Eqs. (1) and (3) give,

$$\frac{V}{Z_2} + \frac{V_1}{Z_4} + \frac{V_0}{R_f} \tag{5}$$

The Eqs. (4) and (5) give

$$V_0 = \frac{R_f}{Z_1 Z_2 Z_3}[Z_2 Z_3 - Z_1 Z_4] V \tag{6}$$

At balance condition of the bridge, $V_0 = 0$, which is identical with the conventional bridge network. The conductivity cell is connected instead of Z_3. The conductivity of a solution is determined by the given equation

$$Z_3 = \left(\frac{V_0 Z_1 Z_4}{R_f V_i} + \frac{Z_1 Z_4}{Z_2} \right) \tag{7}$$

$$\frac{1}{Z_3} = G_c = \left(\frac{Z_1 Z_4}{R_f V_i} + \frac{V_0 Z_1 Z_4}{Z_2} \right)^{-1} \tag{8}$$

V_0 = bridge output voltage, V_i = input excitation voltage, Z_2, Z_3, Z_4 = known resistances, G_c = conductivity of a solution.

The output of amplifier U2 is given to input of the precision rectifier constructed with operational amplifier U3 and U4 as shown in the figure.

The chromel–alumel thermocouple is used to measure the temperature of the sample. An AD548 (U6 and U7) amplifier amplifies the EMF generated by the thermocouple. The AD548 is a low power, precision monolithic amplifier. It has low input offset voltage and drift, low bias current and low $1/f$ noise reduces output errors. Cold junction compensation is provided using AD590 from analog devices as shown in Fig. 3. The AD590 produces a current proportional to its temperature. An AD548 amplifier (U5) amplifies the voltage generated by the temperature sensor (1 mV/K).

An ADC interface with microcontroller is used to acquire data for temperature and conductivity of sample. This board is fabricated using AT89C55WD microcontroller, ADC 7109, MAX232, and LCD. The output of operational amplifier (U4 and U7) is connected to pin 13 and 14 of multiplexer 4051 (U8). The output from the multiplexer (U8) is given to pin 35 of ADC 7109 to convert analog values into digital

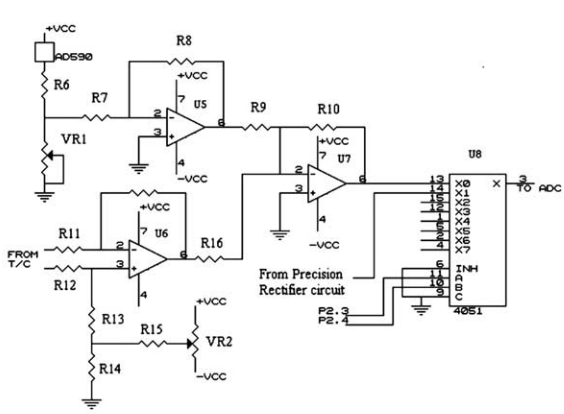

Fig. 3. Temperature measurement circuit and multiplexer.

values. LCD is interfaced to Port 1 of microcontroller. A solid-state power controller is used to control the power to the heater. This power controller is constructed with optocoupler MC2TE, UJT 2N2646 and Triac [12].

4. Measurement and details of software

A fixed sinusoidal excitation voltage of 1 V is applied to the bridge. A modified AC Wheatstone network, which is formed by connecting the conductivity cell at one arm of the bridge and selecting the resistance value Z_1 (100 Ω or 1 kΩ), Z_2 (1 kΩ), and Z_4 (1 kΩ). By keeping the temperature bath at various temperatures the conductivity is measured. The conductivity is also measured for various concentrations. The preset VR1 is adjusted for calibration of temperature. The potential over the cell is alternated, avoiding polarization of the electrode.

Software is developed in assembly language and C language to initialize LCD display, serial port, selection of temperature or light intensity by multiplexer, to start ADC conversion, to check end of conversion, to read higher and lower bytes of ADC by enabling LBEN and HBEN signal, measure the conductivity of the sample from Eq. (8), temperature of the sample, indication of over range and sign of data, data computation for acquired data, storage of data for conductivity and temperature, and to send data to PC. To transmit data to PC, software is written to select UART mode, to select timer 1 for nongated auto-reload, to set 4800 baud rate, to start timer 1 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 given in Fig. 4. 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.

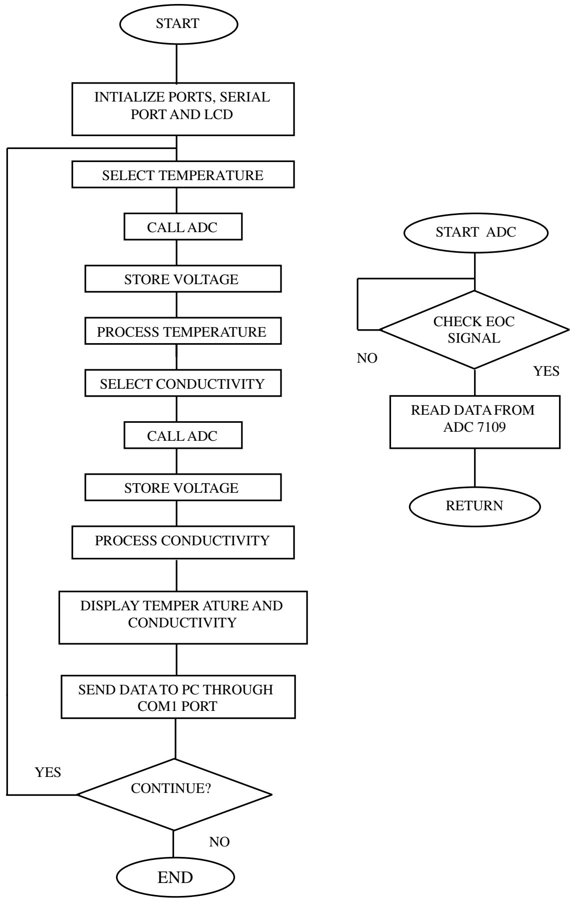

Fig. 4. Flow chart for performing conductivity measurement system.

5. Results and discussion

The microcontroller-based instrument's performance in measuring conductivity of samples is investigated by comparing its response with results by other methods [13,14]. The instrument fabricated has been used to study the conductivity of KCl, NaOH, and NaCl solutions and the variation of specific conductivity with temperature. The conductivity cell is dipped and conductivity is measured for various liquids to check accuracy and reproducibility of the instrument. With the circuit set for calibration the conductivity cell is dipped into KCl solutions, maintained at the required temperature, for which the literature values [14] of specific conductivities are known.

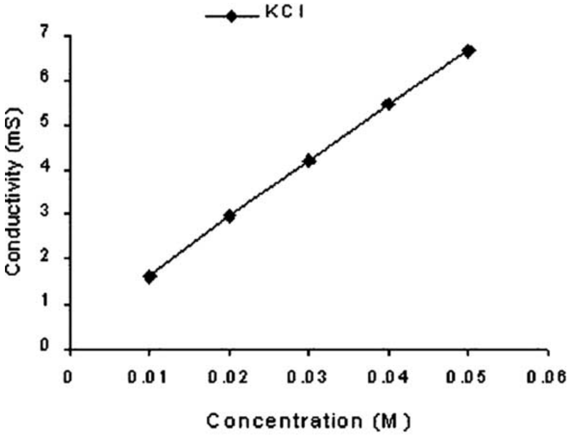

Fig. 5. Analytical curves for concentration versus conductivity.

The microcontroller measures the resulting output voltage and the conductivity of solution is displayed after processing. The Fig. 5 shows analytical curves for concentration versus conductivity. The results of conductivity measurement using this instrument are compared with the Phillips mode conductivity meter to check the accuracy of the instrument and it is found that both results agree and hence this instrument can be used to measure conductivity. Least square curve fitting method is used for error analysis. The error in measurement is found to be less then 3%. The variation of conductivity of the solutions KCl,

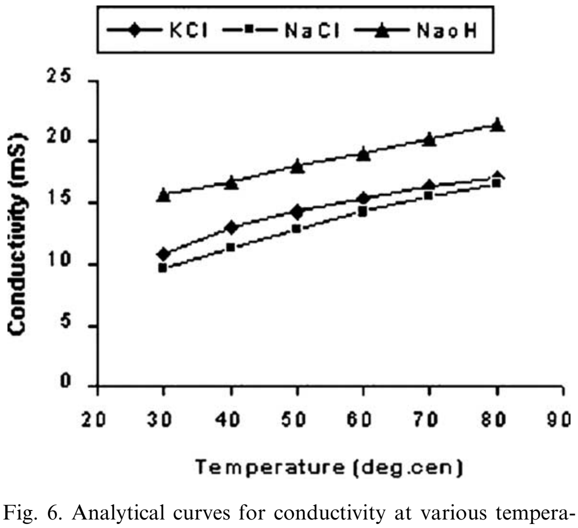

Fig. 6. Analytical curves for conductivity at various temperatures.

NaOH, and NaCl for various temperatures is given in the Fig. 6. It is observed that conductivity increases with temperature. Use of standard resistance of high accuracy will reduce the error component due to it. Accuracy can be increased using a 16-bit A/D converter. The measurement system was tested with different samples to check the reproducibility. In this instrument the manual supervision involved is little.

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