Design and development of microcontroller based conductivity measurement system

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A real time microcontroller based conductivity measurement setup has been developed to measure conductivity by investigating ionic solutions using a modified AC Wheatstone bridge network. This instrument system permits recording of conductivity and temperature and send data to personal computer to enable the computer processing of such data. A dedicated 8031(8-bit) based microcontroller board was 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, Data acquisition system, Microcontroller, Electrolytic solutions, Ionic solutions, Current-carrying ions]

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1 Introduction

Rapid decrease in unit cost and increase of on-chip capabilities have enabled widespread 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 a study of the conductivity of an electrolyte solution, taking full advantage of the microcontroller facilities. Conductivity is an important property of the ionic solutions used for analytical purposes. 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 temperature by 1°C increases the conductivity by an average of 2-3%. A good conductometric measurement system should be capable of measuring of rapid changes in solution resistance.

Measurement of conductivity along with time and temperature possesses potential applications such as - estimating the hardness of water, detecting the extent of disease in plant leaves, in soil studies, manufacturing of paper and sugar, vat dyeing, etc. The most accurate methods of measurement of unknown impedance are the bridge methods where the 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. In the present work an operational amplifier based modified Wheatstone bridge network has been used to measure conductivity of a solution. A microcontroller based conductivity measurement setup is designed to measure the conductivity and temperature of rapidly changing solution with time.

2 Experimental Details

Figure 1 shows the block diagram of conductivity measurement set up. The block I consists of a commercial platinum cell having a cell constant 1.0 cm⁻¹ for the measurement of conductivity of ionic solutions. A modified AC Wheatstone bridge network is kept in the block II. The conductivity cell with electrolyte solution is connected to one arm of the bridge. The circuit is unbalanced due to conductivity of the given solution. The output of the bridge
network is rectified using precision rectifier, which is kept in block III. It is used to rectify small input signals (less than 0.7V)\(^{12}\). Block IV is a semiconductor temperature sensor AD590 and is used as a sensor to measure temperature of the solution. The block V consists of an instrumentation amplifier, which amplifies the voltage from semiconductor sensor.

Programmable Peripheral Interface (PPI) 8255A and A/D converter (ADC0808) is kept in block VI, which converts analogue conductivity or temperature into digital quantities. The IC0808 is a monolithic CMOS device with an 8 channels 8-bit analog to digital converter. IC0808 offers high speed, high accuracy, and repeatability. The 8-bit A/D converter uses successive approximation, which can make 100 conversions per microsecond \(^{13}\). Microcontroller 8031 is kept in the block VIII. It is a low power, high performance HMOS 8-bit microcontroller which processes the acquired input data. A solid-state controller with heater is kept in the block VII, which maintains the temperature of the sample at constant temperature. Block IX is a two-row 16 characters LCD display from Hitachi and is used to display the measured data and results. The ICL232 is a dual RS232 transmitter/receiver interface circuit that meets all EIA RS232 specification kept in the block X. It requires a single +5V power supply and features two onboard charge pump voltage converters, which generate +10V to –10V supplies from the 5V supply. The output ICL232 is connected to COM1 port of computer, which is kept in the block XI.

### 3 Circuit Description

A general AC Wheatstone’s bridge network is modified as shown in Fig. 2, where two very high gain operational amplifiers U11 and U12 are connected with the bridge network\(^{14}\) with a 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 which affects the stray capacitance exists between them and also among themselves and ground. This may be assumed to be minimized. If the sinusoidal input voltage, \(V_i = V_m \sin \omega t\), is applied to the bridge network consisting of \(Z_1, Z_2, Z_3\) and \(Z_4\), then the output of bridge network is given by

\[
V_0 = \frac{R_f}{Z_1Z_2Z_3} \left[ \frac{Z_3Z_5Z_7Z_4}{Z_1Z_4} \right] V_i \tag{1}
\]

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

\[
\frac{1}{Z_3} = G_C = \left[ \frac{V_0Z_1Z_4}{R_fV_i} + \frac{Z_1Z_4}{Z_2} \right]^{-1} \tag{2}
\]

*\(V_0 =\) Bridge output voltage

*\(V_i =\) Input excitation voltage

*\(Z_1, Z_3, Z_4 =\) Known resistances

*\(G_C =\) conductivity of a solution

The output of amplifier U12 is given to input of the precision rectifier constructed with operational amplifier U13 and U14 as shown in the Fig 2. To measure temperature of the sample the temperature sensor AD590 is used. It is a temperature dependent current source from Analog devices. The AD590 produces a current proportional to its temperature. A CA3140 amplifier (U15 & U16) amplifies the EMF generated by the temperature sensor (1mV/kelvin). The CA3140 device is a monolithic amplifier, which has very high input impedance, very low input current, and high-speed performance.

The circuit diagram for ADC IC 0808 and 8255A Programmable Peripheral Interface is shown in Fig 3. The 8255A has three programmable ports, Port A,
Port B and Port C which can be programmed either as an input or output port. The ADC output D7-D0 are connected to Port A of 8255. The output from the amplifier U16 (temperature) and U14 (conductivity) are given to the input pins 26 and 27 of ADC 0808. The SOC signal, EOC signal and channel select signals of A/D converter are connected Port B and C of 8255 as shown in the Fig.3. The IC7414 is used as an oscillator for the clock (300 kHz) to the A/D converter.

The circuit diagram of 8031 microcontroller and its associated peripherals is shown in Fig. 4. The 8031 chip has a 16-bit address whose low order lines (A0-A7) are multiplexed with the data bus as AD0–AD7 lines. The address line A0 to A7 from the IC 74373 is connected to the address lines EPROM IC 2764 and RAM IC 6264. The address line A8 to A12 of EPROM and RAM are connected to P2.0 to P2.4 (higher order address bus) of microcontroller. The data lines of EPROM and RAM are connected to Port 0 of microcontroller. The address lines A15, A14 and A13 of microcontroller are connected to the input C, B and A of the decoder IC 74138. The address decoder 74LS138 is used to select memory devices and peripherals. The pins 17 and 29 are NANDed and then used to select RAM. A crystal oscillator of frequency 12 MHz is connected between 18th and 19th pins of 8031. The RC network is connected to pin 9 (RESET pin), which is used to power on reset. A solid-state power controller is used to control the power to the heater. This power controller is constructed with optocoupler MC2TE, UJT2N2646 and Triac.
4 Measurement and Details of Software

The experiments were done by connecting the conductivity cell at one arm of the unmodified Wheatstone network and selecting the resistance value $Z_1$ ($100\,\Omega$ or $1\,K\,\Omega$), $Z_2$ ($1\,K\,\Omega$) and $Z_4$ ($1\,K\,\Omega$). A fixed sinusoidal excitation voltage of 1V is applied to the bridge input. 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.
Fig. 5 — Flow chart for conductivity measurement system
Software is developed in assembly language and C language to initialize LCD display, serial port, selection of conductivity or temperature by multiplexer, to start ADC conversion, to check end of conversion, to read acquired data, process the conductivity of the sample from Eq. (2), temperature of the sample, data computation for acquired data, to display and storage of data for conductivity and temperature. 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. The flowchart for performing the above tasks is given in Fig. 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 measuring conductivity of samples is investigated by comparing its response with result by other methods\textsuperscript{16}. The instrument fabricated is used to study the conductivity of KCl, NaOH, NaCl and CuSO\textsubscript{4} 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\textsuperscript{17} of specific conductivities are known.

Fig.6 shows analytical curves for concentration versus conductivity for KCl, NaCl solutions. The results of conductivity measurement using this instrument are compared with the systronics 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. The error in measurement is found to be less then 2%. The variation of conductivity of the solutions KCl, NaOH, and NaCl for various temperatures is given in Fig.7. It is observed that conductivity increases with temperature. Use of standard resistance of high accuracy will reduce the error component due to it. Using 12-bit A/D converter the accuracy can be increased. The measurement system was tested with different samples to check the reproducibility. In this instrument the manual supervision involved is little. The system is highly reliable, less expensive, and portable.

References

5 Sharpio S & Gurvich Y, \textit{Analytical chemistry} (MIR publishers, Moscow) 1972,437.
7 Sheehan W F, Physical Chemistry (Prentice Hall of India), 1966, 412.