LOW COST DIGITAL PH METER

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Abstract- In this paper we have proposed an idea to design and implement a low cost digital pH meter for biological samples. Conventional pH meters use the ISFET (ion-selective field-effect transistor) model, which is most commonly used for biological samples and has several issues while troubleshooting, especially with regards to reference electrode. In place of the ISFET electrode, we have used a regular pH glass electrode and have overcome these limitations. We have also used the TL081 to provide as a high impedance buffer in place of the costlier LMP77xx series. The analog millivolt signals from the glass electrode are conditioned and are displayed as a digital pH value by use of an LCD, controlled by the ATMEGA16 microcontroller.

Keywords- pH meters, Analog-digital conversion, Biological, TL081.

I. INTRODUCTION

The term pH refers to the measurement of hydrogen ions concentration in a solution. It is the measure of acidity or alkalinity of a solution. Our internal metabolic process cannot bear an imbalanced pH level. Our body depends on a healthy alkaline environment through pH balance. A slight deviation from standard blood pH value can prove fatal; an over-acidified body produces toxins and weakens the body's ability to produce enzymes and hormones that leads to central nervous system depression it can also lead to a coma and even death, it also affect; electrophysiological activity of brains, escalates alteration in shape of enzymes that aggravates key and lock mechanism between enzyme and substrate resulting in mal-function of metabolic activities. Maintenance of a moderate pH in biological body is essential for condition of homeostasis. Any variation in pH of biological fluids accounts for a change in the treatment method or the diagnosing plan for the patient; therefore it is of great significance for doctors to have pH values of patient beforehand [1].

Whether something is perceived as acidic or alkaline depends on the hydrogen ion ( ) concentration in the solution. The pH value is defined, by the Sorensen Equation, as the negative logarithm of the ion concentration in a given solution. In other words, at a high concentration, e.g. 1 mol/L, pH = 0 (acidic) and at a low concentration, e.g. 10^-14 mol/L, pH = 14 (alkaline). Hence, different substances are objectively compared with each other, where pH 0 is extremely acidic, pH 14 extremely alkaline, and pH 7 neutral. In the last few years the measuring of pH has gained in importance. In the control and regulation of chemical and biological processes, it has become indispensable to monitor the pH values [2].

A pH meter is an electronic device used for measuring the pH of a liquid. A typical pH meter consists of an electrode, connected to an electronic meter that measures and displays the pH reading. The glass electrode has a very high impedance. To feed the signal from the glass electrode to the microcontroller thus needs an amplifier with very low input bias current. The analog-to-digital converter (ADC) converts analog voltage to digital data. The microcontroller reads the digital data, performs digital filtering and converts it to pH scale using Nernst equation. It is given by

$$E = E_o + 2.3 \frac{RT}{nF} \log[H^+]$$

Where, \(E\) represents voltage signal from the electrode, \(E_o\) is the cell potential, \(R\) is the gas constant, \(T\) is temperature of the sample. \(F\) is the Faraday constant, and \(n\) is the ionic charge. Automatic temperature compensation (ATC) is generally used in laboratories, except when both calibration and pH measurement occur at a constant temperature. If the sample temperature does differ from calibration temperature by more than 10 °C, lack of appropriate temperature compensation will result in a measuring error of 0.15 pH units or more (between pH 3 and 11). The pH range (0-14) is determined through the ion product of the water. Water dissociates to a small extent into \(H^+\) and OH- ions. \(I = [H^+] [OH^-] = 10^{-14}\) molar (at 25°C). The ion product I is strongly dependant on temperature. The temperature influences the pH measurement through four factors:

i. Temperature coefficient of the measured solution
ii. Temperature dependence of the slope given by the Nernst Equation mentioned above in (1)
iii. Position of the isothermal intersection
iv. Differing response time of the electrode (caused by temperature changes)

The pH readings will then be displayed by the LCD.

II. OVERVIEW

The proposed design is shown in Fig.1. One input to the meter is the millivolt signal from the glass electrode. This lies within the range of ±414 millivolts. The glass electrode has an impedance of 900MΩ. Hence, its output has to be passed through a
high precision amplifier such as the TL081 which has a very low input bias current of 50pA. The other input is from the Pt100 RTD (Resistance Temperature Detector), which is the output of the temperature measurement circuitry.

The ATMEGA16 microcontroller performs the analog-to-digital conversions for both the temperature and pH signals, translates the obtained voltage into a pH value and displays the value on a 16×2 LCD. It also carries out the required calibration that needs to be done prior to measuring the pH of a substance. The frequency of calibration varies with use.

Hence, the temperature sensor should be capable of sensing temperature at the above mentioned range. A Pt100 RTD is used for this purpose. Also, the RTD must be of immersion type so that it can measure the temperature of solution. A typical Pt100 has a change in resistance of 0.385Ω/°C where at 0°C, its resistance is 100Ω. Hence at 0°C, resistance of RTD will be 100Ω and at 100°C, the resistance of RTD will be 138.5Ω. The resistance can be determined by measuring the voltage across the RTD. To accomplish this, the current flowing through the RTD must remain constant. Hence, the RTD is excited by using a Howland current source. Also, the current value should be chosen in such a way that it does not cause self-heating of the RTD. The voltage output across the RTD should be in the range detectable by the ADC module.

C. Design of Current Source
A Howland Current Pump with grounded load is shown in Fig.3. It is used to convert voltage to current, independent of the load. The output current \( I_o \) is the current through \( R_{load} \) and is equal to \( V_o/R_o \). \( V_o \) is the input voltage given to the pump. The condition to be satisfied is \( R_1 = R_3 / R_4 \).

The Howland current pump was designed to produce 5.6mA current. The current source was excited using a Zener diode with a reverse voltage of 5.7V. The Characteristics of obtained current source is shown in Fig.4. The Voltage compliance was found to be 7.6V with a power supply of ±12V.
D. Electrode Output Voltage Follower

The voltage output of the glass electrode cannot be directly connected to the ADC of the microcontroller. The Glass electrode has an impedance of around 900MΩ. The signal is sent via voltage follower operational amplifier to the next stage. This operational amplifier should have very low input bias current. Even few Nano amperes of input bias current will cause a lot of change in the output voltage of the electrode. The operational amplifier must have input bias current in Pico amperes range or even lesser to ensure minimal error. TL081 operational amplifier is used for this purpose. The TL081 has a very low input bias current of 50pA [4]. Since operational amplifiers have low output impedance, the detector sees a low impedance input. Hence, loading is avoided. The voltage follower is as shown in Fig.5.

![Fig. 5. TL081 Voltage Follower](image)

E. DC Level Shifter Using Summing Amplifier

The Glass electrode output voltage follows the Nernst equation. According to the equation, the output voltage of the electrode, lies between -414mV to 414mV at 25°C. This range increases to -518mV to 518mV at 100°C. Microcontrollers can process only voltages which are positive. Hence, the Glass electrode output voltage is shifted by adding a DC voltage of 625mV to it. This ensures that the voltage which goes to the microcontroller is always positive. LM317 is capable of providing a voltage reference of 1.25V (see Fig. 6). This output is given to a voltage divider circuit which divides the voltage to 625mV (see Fig.7). The voltage divider output is taken to the next stage using a voltage follower.

![Fig. 6. 1.25V Voltage reference](image)

The voltage follower is designed using OP07 operational amplifier (see Fig.6). The reason behind using OP07 is that it has very low offset voltage. It has a typical offset voltage of 30µV and a maximum of 75µV at 25°C [5]. This helps in reducing the error. In order to shift the electrode voltage output to positive value, the voltage output must be added with the 615mV. This is done using the Summing Amplifier. The summing amplifier is designed for a gain of 1 as we do not need any amplification of the signal. The output of the summing amplifier will be a level shifted pH signal from the electrode. A non-inverting summing amplifier is used for this purpose and is shown in Fig. 8.

![Fig. 7. Voltage divider with voltage follower](image)

![Fig. 8. Summing Amplifier](image)

IV. CALIBRATION

The calibration procedure used is 3-point calibration. The best fit linear curve is obtained using linear regression technique. The meter is calibrated with buffer solutions of values 4, 7 and 9.2. The linear regression equation obtained is,

\[ Y = 1.023373(x) - 0.209348 \]  

(2)

This equation is used in the program to display the pH value after calibration.
V. MICROCONTROLLER

A 40 pin ATmega16 microcontroller from Atmel is used for ADC (Analog to Digital Conversion) and 16x2 LCD (Liquid Crystal Display) interfacing. The microcontroller is programmed to perform two simultaneous ADC to sample the voltage signals of current temperature and the pH of the solution. The microcontroller power supply is given using IC 7805-5V voltage regulator. It is also provided with an external clock of 4MHz using a crystal oscillator. The pin0 and pin2 of port-A are used for the analog to digital conversion. The pin0 samples temperature signal and pin2 samples pH signal. Also, the microcontroller is provided with an external reference of 1.25V. Since, the pH signal and temperature signal are less than 1.25V; this reference will give a good resolution for analog to digital conversion. The ADC module functions at pre-scalar of 64 bit [6]. The Nernst equation is used in the program to find the pH of the solution at the given temperature. The calculated pH is simultaneously displayed onto an LCD screen. The flowchart algorithm is shown in the Fig.9.

![Flowchart](image)

REFERENCES


