HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF ELECTRICAL AND ELECTRONICS

REPORT PROJECT I

Topic: Temperature and Humidity Circuit using PT100, HS1101 and Microcontroller 8051

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INTRODUCTION

In the realm of modern engineering and the rapidly evolving technological landscape, especially in the fields of measurement and environmental monitoring, the creation of compact, highly accurate temperature and humidity sensing devices that operate reliably and seamlessly interface with monitoring and data collection systems is of utmost importance. Furthermore, the ability to gather essential data demands that such devices possess data transmission and computer communication capabilities. It is for these reasons that we have chosen the topic: "Temperature and Humidity Sensing Circuit Using PT100, HS1101 Sensors, and 8051 Microcontroller".

This report consists of five main chapters:

- Chapter 1: Temperature and Humidity Measurement Methods.
- Chapter 2: Overview of ICs and Microcontrollers.
- Chapter 3: Calculation and Design Circuit.
- Chapter 4: Programming Microcontroller 8051.
- Chapter 5: Real Circuit and Measurement Results.

During the execution of this project, we have not only consolidated and acquired new knowledge about temperature sensing technologies but have also learned and honed our working methods. We have become more proactive and flexible in our research approach, particularly in teamwork.

ACKNOWLEDGMENTS

Throughout the duration of this project, we have received valuable assistance, insightful contributions, and enthusiastic guidance from Ms. Nguyen Thi Hue, our instructor from the Department of Measurement and Industrial Computer Engineering. We extend our heartfelt gratitude to her for her patient guidance and support throughout the entirety of our project.

TABLE OF CONTENTS

IMAGE INDEX

TABLE INDEX

CHAPTER 1. TEMPERATURE AND HUMIDITY MEASUREMENT METHODS

1.1. Thermometers

1.1.1. Bimetallic Thermometers

The Bimetallic Thermometers is based on two simple principles:

- Metals change in volume in response to a change in temperature.
- The coefficient of change is different for all metals.

If two dissimilar metal strips are bonded/joined together and then heated, the resultant strip tends to bend in the direction of the metal with the lower coefficient of linear expansion. The degree of deflection is directly proportional to the change in temperature.

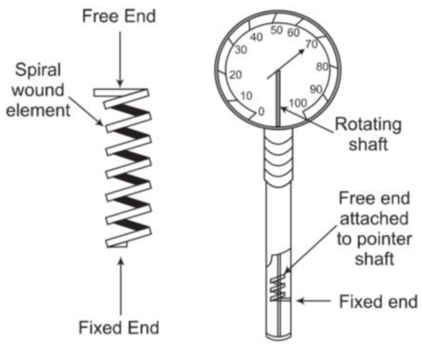

Figure 1. Bimetallic Thermometers

The advantage of Bimetallic Thermometer is being much more resistant to breakage than the glass thermometer.

However, its drawbacks are subject to change in calibration when handled roughly and the overall accuracy is not good as the glass thermometer.

1.1.2. Quartz Crystal Thermometers

Temperature measurements using a quartz are based on the resonant frequency of a given crystal changing in response to change in temperature. This technology is capable of sensitivities of the order of 0.0003°F in laboratory conditions.

The quartz crystal is typically hermetically sealed in a stainless-steel cylinder similar to a thermocouple or RTD sheath although somewhat larger.

Figure 2. Quartz Crystal Thermometers

Since the quartz crystal converts temperature into a frequency, there are no lead resistance or noise problems to deal with. They provide good accuracy and response time and excellent stability.

The quartz crystal technology is expensive as compared to other methods and accuracy is not quite like that of an RTD.

1.2. Thermocouple

a) Construction:

A thermocouple is a thermoelectric temperature-measuring device. It is formed by welding, soldering, or merely pressing two dissimilar metals together. The welded point is called the "working end," and the other two ends are referred to as "free ends."

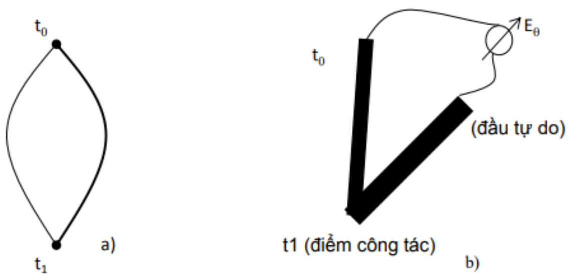

Figure 3. The simple construction of Thermocouple

Similar to RTDs, the Thermocouple is widely used in industry, often in the form of thermal probes.

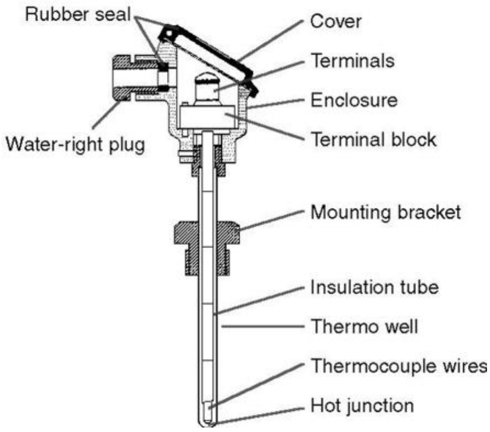

Figure 4. Construction of Thermocouple

b) *Working principle*

The Thermocouple works on the principle of Seebeck effect. The operating principle of a thermocouple is based on the Seebeck effect. Specifically, when two different metal rods are joined together at one end (Measuring junction), it creates an electromotive force (EMF) or voltage. This principle can be illustrated using the following diagram:

- The junction point between the two metal rods (Measuring point) is in contact with a higher temperature - (1) hot junction.
- The other two ends of the wires, marked as (-) and (+), are not fixed and are designated as (2) cold junction.
- In this setup, there is a temperature difference between (1) and (2), causing the movement of conducting electrons, which generates an EMF across the two wire ends.
- As a result, the two metal rods are joined at the hot junction, which is used for temperature measurement. When the temperature at the hot junction increases, the voltage at the cold junction also increases (not in a linear manner). Therefore, measuring the voltage at the cold end accurately determines the temperature at the hot end.

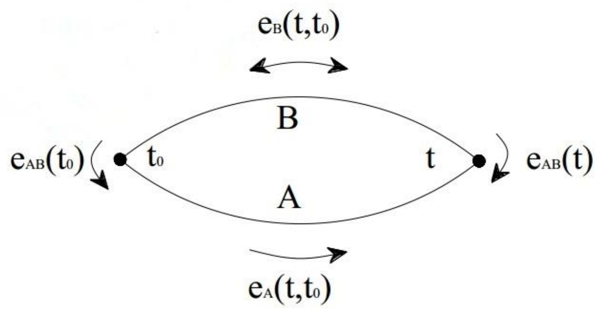

Figure 5. Describe the formation of electromotive force within loop a-b.

The figure below describes the formation of electromotive force within loop a-b under the condition that the number of free electrons in wire a (n_a) greater than the number of free electrons in wire b (n_b), and simultaneously the temperature of one contact end is t while the other end is at t_o, with $t > t_o$ According to Kirchhoff's law, the electromotive force within the loop is determined as:

$$e = e_{AB}(t) - e_A(t, t_o) - e_{AB}(t_o) + e_B(t, t_o)$$

This electromotive force has generated a current flowing within the loop. In reality, the value $e_A(t, t_o)$ and $t_B(t, t_o)$ are much smaller than $e_{AB}(t)$ and $e_{AB}(t_o)$. So the formula above can be transformed into the form:

$$e = e_{AB}(t) - e_{AB}(t_o)$$

Based on experimental foundations:

$$E_T = K_T(t_1 - t_o)$$

where K_T = the thermoelectric effect coefficient

t_1 = temperature of the hot junction

t_o = temperature of the cold junction

If t_o remains constant and t_1 depends on environment, we have:

$$E_T = K_T(t_1) - C$$

where C = constant

E_T = depends on t_1, t_o and the materials composing the metal strips.

Some thermocouples are commonly used:

Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

Table 1. Some common thermocouples

c) *Measurement Circuit*

The measurement circuit uses a millivolt meter. If the potentials at both ends 2 and b are equal, then the electromotive force is essentially the electromotive force of the thermocouple pair.

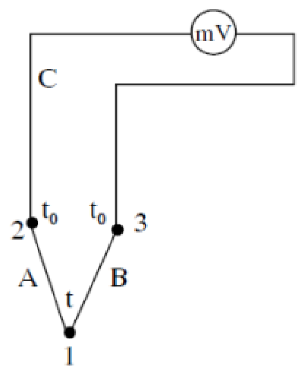

Figure 6. Measurement circuit of Thermocouple

1.3. Thermistor

Thermistor is the change corresponding to its temperature change: $R_T = f(t^o)$, by measuring R_T , we can deduce the temperature. They are also considered to be resistance thermometers.

There are two main types of thermistor sensors:

- Metal Thermistor
- Semiconductor Thermistor

1.3.1. Resistance Temperature Detector

Resistance Temperature Detector (RTD) is an electrical sensor used to measure the temperature of the environment by measuring the change in electrical resistance of a metallic wire.

The metallic wire is referred to the temperature sensor whose resistance varies with the temperature. The resistance is measured using any other device to translate into temperature. It has high accuracy and linear characteristics as compared to other temperature sensors.

a) Construction

An RTD's construction is described as the figure below:

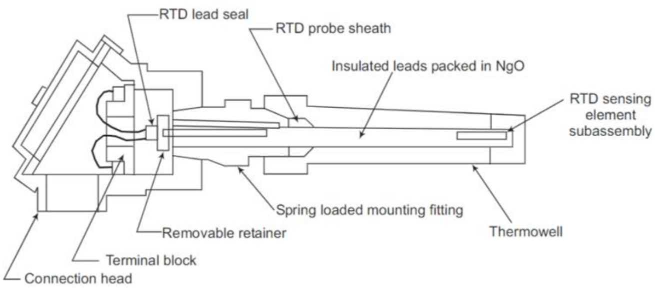

Figure 7. Construction of RTD

The construction is typically such that the small diameter wire element is wound in a bifilar manner onto a cylindrical mandrel, usually ceramic. Lead wires run axially through the tube and are connected to the element wire. The tube assembly is usually covered with a coating or glaze to protect the element wire.

In industrial, the wires from measuring leads of these thermos must have a wide length, which leads to loss of resistance on the wires, this value is unstable and causes a large error for measurement. To compensate for temperature errors, manufactures will create 3 or 4 probe RTDs as shown below:

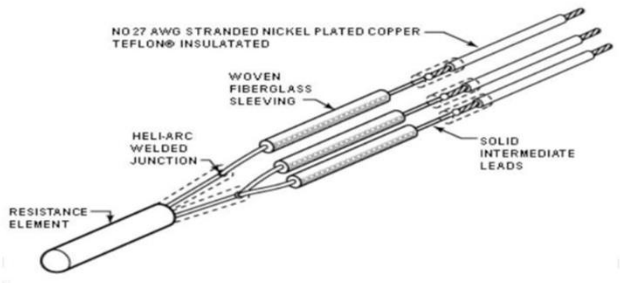

Figure 8. 3-probe RTD

In addition to the wire wound RTD, there is a thin film RTD. A thin layer of platinum is applied to the porcelain base. The advantage of this type of sensor is its low cost and low thermal mass, quick response, and easy placement in narrow locations, but it is not as stable as the wire wound type.

Figure 9. Film thin RTD

b) *Working principle*

RTD works on the following principle: The resistance of metals changes with changing temperature. For pure metals, the characteristic relationship the governs resistance thermometry is given:

$$R_T = R_o(1 + \alpha t + \beta t^2 + \gamma t^3 + \cdots)$$

where $R_o = resistance\ at\ ref\ temperature\ (0^oC)$

$R_t = \ resistance\ at\ temperature\ t$

$\alpha = \ temperature\ coefficient\ of\ resistance/(^oC)$

$\beta, \gamma = \ coefficients\ calculated\ on\ the\ two\ or\ more\ than\ known$

$resistance - \ temperature\ (Calibration)\ points$

The coefficients depend on the materials using in manufacturing RTD, the table below are shown the parameters of different materials:

Parameters	Cu	Ni	Pt	W
T_f (°C)	1083	1453	1769	3380
c $(J°C^{-1}kg^{-1})$	400	450	135	125
λ $(W°C^{-1}m^{-1})$	400	90	73	120
α_1 $x10^6$ (°C)	16,7	12,8	8,9	6
ρ $x10^8$ (Ωm)	1,72	10	10,6	5,52
α $x10^3$ $(°C^{-1})$	3,9	4,7	3,9	4,5

Table 2. Parameter of materials manufacturing RTD

According to the table, we can see that:

- RTD Platinum has the highest Melting Temperature, followed by Nikel and Copper. Moreover, Platinum is chemically inert, has high crystal structure stability, so it can be used in harsh environments with high temperature and many chemical impurities.

- Platinum has the lowest specific heat of the three metals, so the sensitivity and thermistor coefficient are also lower, which slows down the response time of RTD.

- Platinum has a lower coefficient of thermal resistance, so the linearity between temperature and resistance of platinum is the lowest.

In addition to the above technical characteristics, there are also some problems with economics and manufacturing methods. RTDs made from Platinum are more expensive than RTDs of Nickel or Copper. Moreover, RTDs of Nickel and Copper are easier to fabricate. However, choosing which RTD to use should depend mainly on the technical requirements and efficiency of the given problem.

c) *Circuit*

There are two types of measured circuit that usually use:

- Measuring circuit using current source

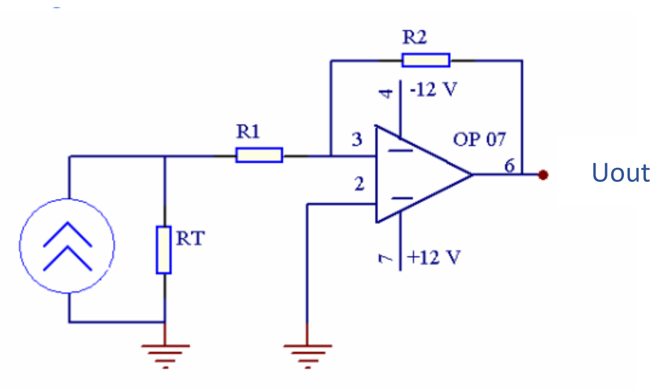

Figure 10. Measuring circuit using current source

RTD is connected in series with a standard current source, $U_{out} = U_{RT} \times \frac{R_2}{R_1} = I \times R_{RT} \times \frac{R_2}{R_1}$ is linear with temperature. From the received voltage signal, we can give converters to display the measured temperature value.

- Measuring circuit using voltage source

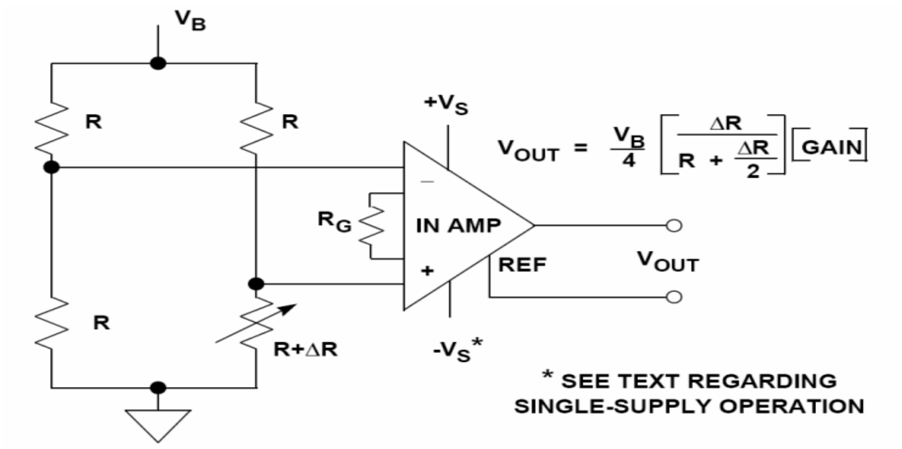

Figure 11. Measuring circuit using bridge circuit

RTD is connected to a bridge circuit as the figure above, the difference between two voltage bridges is calculated through the subtractor using OpAmp. At $0^oC, \Delta R = 0$ so the bridge is balanced, the output voltage is 0V.

1.3.2. Semiconductor Thermistor

a) Construction

Semiconductors Thermistor are made from specific mixtures of pure oxides of nickel, manganese, copper, cobalt, magnesium, and other metals sintered at very high temperatures.

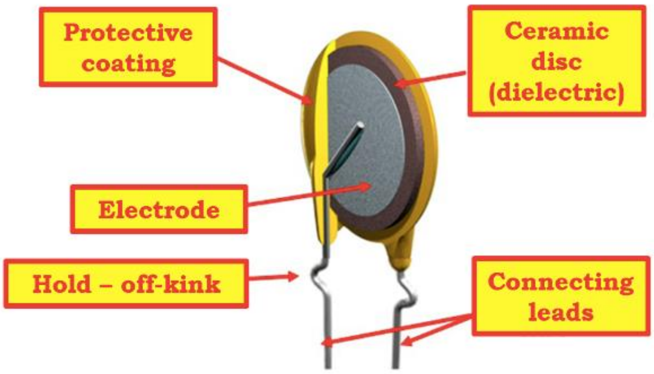

Figure 12. Construction of Thermistor

b) *Characteristics*

A thermistor is constructed from a mixture of oxide powders. These powders are blended in specific proportions and masses, then compacted and fired at high temperatures. The electrical conductivity of this mixture will change as the temperature varies.

There are two types of thermistors: Positive Temperature Coefficient (PTC) - the resistance increases with temperature; Negative Temperature Coefficient (NTC) - the resistance decreases with temperature. The NTC type is the most used.

Thermistors are linear only within a certain temperature range, typically 50 - 150°C, which is why they are less commonly used as temperature sensors.

The resistance-temperature relationship for a thermistor is given by the formula:

$$R_T = A \times e^{\beta/T}$$

A = a constant dependent on the physical properties of the semiconductor, size, and shape of the resistor.

β: a constant dependent on the physical properties of the semiconductor.

The negative temperature coefficient of a semiconductor thermistor is significantly larger (6 to 10 times) than that of a metal resistor. This property makes it suitable for temperature control circuits or temperature measurement within a narrow range.

c) Measuring circuit

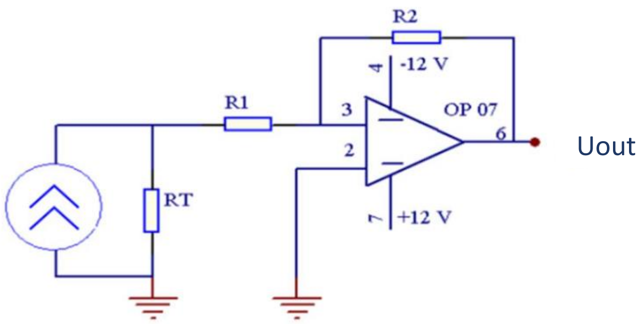

Figure 13. Measuring circuit with semiconductor thermistor

The output voltage: $U_{out} = U_{RT} \times \frac{R_1}{R_2} = I \times R_T \times \frac{R_1}{R_2}$

1.4. Pyrometer

1.4.1. Construction and Working principles

In industrial applications where high temperatures (above 1600°C) need to be measured, pyrometers are used. Pyrometers are divided into three types:

- Radiation Pyrometer
- Optical Pyrometer
- Color Pyrometer

1.4.2. Radiation Pyrometer

Typically, there are two types: radiation pyrometers with converging lenses and radiation pyrometers with reflective glass.

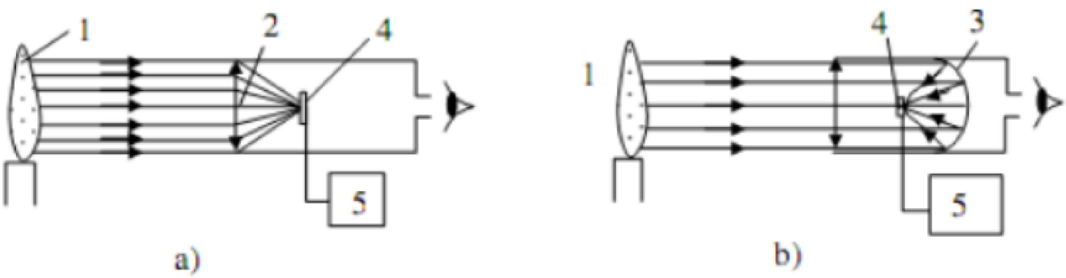

Figure 14 Radiation pyrometry functionality

1) Radiation source 2) Converging lens 3) Reflective mirror
4) Energy receiver 5) Secondary measuring device

The energy receiver can be a resistance thermometer or a combination of thermocouples. They must satisfy the following requirements:

- Can operate normally within the temperature range of 100 - 150°C.
- Must have minimal and stable thermal inertia after 3 - 5 seconds.
- Small enough in size to focus radiation energy onto the measurement point.

When measuring temperature using a radiative pyrometer, the error usually does not exceed 27°C under the following conditions:

- The object being measured must have an approximate emissivity of 1.
- The ratio of the diameter of the radiating object to the measuring distance (D/L) is not less than 1/16. In reality, the emissivity of the measuring object e < 1, and then

$$T_{do} = \sqrt[4]{\frac{1}{\varepsilon}} \times T_{doc}$$

Normally, it is determined by following formula: $T_{do} = T_{doc} + \Delta T$

1.4.3. Infrared Optics

Figure 15. Infrared temperature measuring device

Radiation energy:

$$E_T = K_T \times E_{bx} = K_T \sigma T^4$$

1.5. Humidity Meter

Air humidity is the water vapor (moisture) present in the air or gas. There are two concepts of humidity:

- Absolute Humidity (AH): is the ratio of the mass of water vapor to the volume of air, expressed in grams per cubic meter. Absolute humidity can be calculated from relative humidity, air temperature, or measured directly.
- Relative Humidity (RH): is the amount of moisture in the air compared to the moisture level at the same temperature and pressure needed for saturation, expressed as a percentage. Most humidity sensors work using the RH principle because of the high accuracy, dependability, and low cost.

Generally, humidity sensors work on the principle that the water vapor is absorbed and changes the properties of the sensor component, thereby changing the electrical characteristics that we can measure and infer the humidity.

Figure 16. Some sensors commonly integrate both temperature and humidity measurements.

1.5.1. Capacitive Humidity Sensors:

Capacitive Humidity Sensors consists of two metal electrode layers between a dielectric (non-conductive) material, typically a polymer film with a dielectric constant of around 2-15. The dielectric film inside the capacitive humidity sensor attracts and absorbs moisture from the surrounding air. Once the moisture contacts the electrodes, a voltage change occurs.

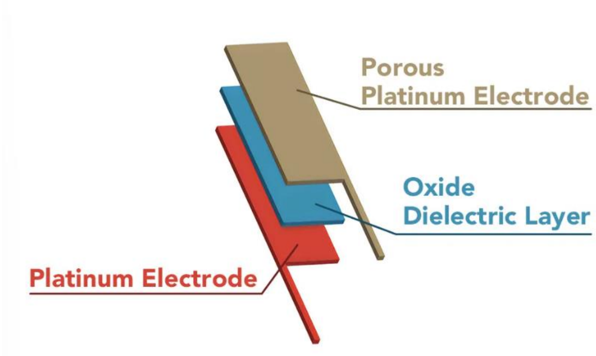

Figure 17. Construction of inside of capacitive humidity sensor

When moisture is absent, the capacitance is determined by the geometry of the capacitor and the dielectric constant (relative permittivity) of the dielectric material; As the humidity changes in the surrounding air, the dielectric polymer absorbs and releases water vapor, therefore the electrical capacitance of the sensor changes.

In capacitive humidity sensors, there is a direct relationship between the RH of the surrounding air, the amount of moisture in the dielectric material, and the capacitance (dielectric constant) of the humidity sensor. The change in the dielectric constant is directly proportional to the RH, therefore, by measuring the dielectric constant, the RH can be calculated.

1.5.2. Resistive Humidity Sensors

Resistive humidity sensors, also known as electrical conductivity sensors, measure the change in resistivity between two electrodes inside a humidity probe (connected to the sensor) to establish relative humidity (RH).

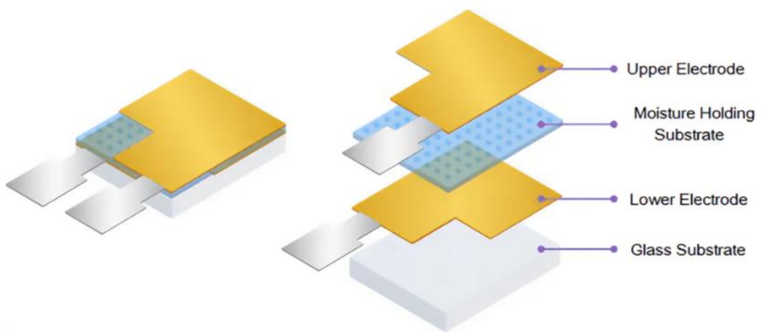

Figure 18. Construction of inside a resistive humidity sensor

Resistive humidity sensor has a similar principle to capacitive sensor; an electrical change is measured, producing an RH value. However, resistive humidity sensors use a moisture – absorbing (hygroscopic) material, so their operation principle is slightly different.

Inside a resistive humidity sensor, the hygroscopic conductive layer (typically a conductive polymer, salt, or treated substrate) acts as a polymer humidity sensing film, which contains comb-like electrodes. The electrodes typically come from noble metals like gold, silver, or platinum, and are arranged in interdigitated patterns to increase the contact surface area between the electrodes and the hygroscopic layer. The output voltage has an inverse exponential relationship to RH. As more water vapor is absorbed, the resistivity decreases due to an increase in the non-metallic conductivity material's conductivity.

1.5.3. Thermal Conductivity Sensors

Thermal conductivity sensors have different operating principles compared to capacitive and resistive humidity sensors. These types of sensors measure the absolute humidity (AH) of the surrounding air/environment by calculating the difference between thermal conductivity in dry air vs humid air.

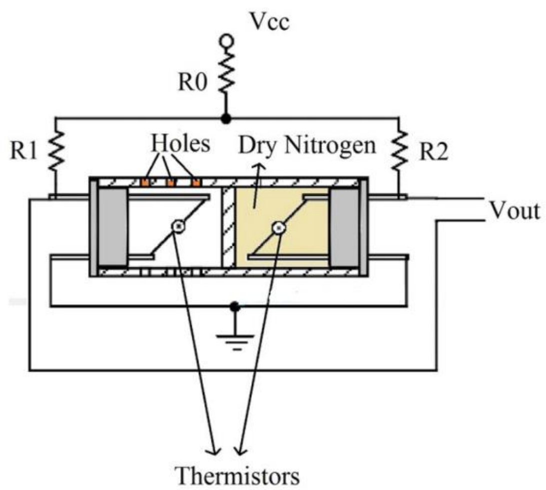

Figure 19. Circuit and Construction of Thermal Conductivity Sensor

A Thermal Conductivity humidity sensor consists of two matched negative temperature coefficient (NTC) thermistor elements, suspended by thin wires, in a bridge circuit. One thermistor is located in an exposed chamber via several ventilation holes, exposing it to the surrounding environment. The second is hermetically encapsulated in dry nitrogen and located in a different section within the humidity sensor.

An electrical circuit passes a current between the two thermistors, resulting in the thermistors self-heating; resistive heating increases the sensor's temperature. When one of the thermistors is exposed to humid air, the conductivity changes. The difference in resistance between the two thermistors (bridge circuit) is directly proportional to AH.

1.6. Problems Analysis and Components Selection

From analyzing the methods above and the requirement of measuring temperature and humidity, a possible solution that we choose is using PT100 and HS1101. These are two popular types of temperature and humidity sensor, which are easy to buy, reasonable cost, and high accuracy.

In order to calculate the measured values from PT100 and HS1101, we decided to choose a icroprocessor that meets the requirements such as ubiquitous, easy approach and low cost. Hence, Microcontroller AT89S52 of the 8051 Microcontroller is selected. In addition, to work with PT100 and HS1101, an ADC (Analog to Digital), calculating an Amplifier Algorithm and Pulse generator are also applied.

In summary, the ICs and Microcontroller that are used in this problem are listed below:

- Microcontroller AT89S52
- IC ADC0804
- IC TLC555
- IC LM
- LCD 1602
- RTD PT100 (Temperature Sensor)
- HS1101 (Humidity Sensor)

Besides, about the software, we decide to use these following procedures:

- C programming language

- Simulation on Proteus
- Design Schematic and PCB on Altium

CHAPTER 2. OVERVIEW OF ICS AND MICROCONTROLLER

2.1. Overview of PT100

2.1.1. Overview

PT (Platinum – Resistance Thermometer) is a thermistor made from Platinum. Due to platinum's excellent characteristic of resistance variation with temperature, it is widely used in resistance thermometers. PT100 is a temperature sensing probe with its core made of platinum. It is encased in multiple protective layers on the outside to safeguard the inner core while maintaining good heat conduction.

2.1.2. Construction

PT100 sensor consists of four main components, namely sheath, a resistance element, lead wire, and the terminator (the connector). The resistance element is the element that senses the change in the temperature and gives the result in the form of resistance. It is made from Platinum. The resistance element is in contact with the lead wire (head support). The lead wire extends from the sensing element to the connector. The sheath is the outer protective layer of the sensor. It protects the resistance element and the lead wire from the external environment and moisture. It also helps to stabilize and immobilize the sensor. The terminator connects the RTD to the control circuit. It can consist of two, three, or four wires.

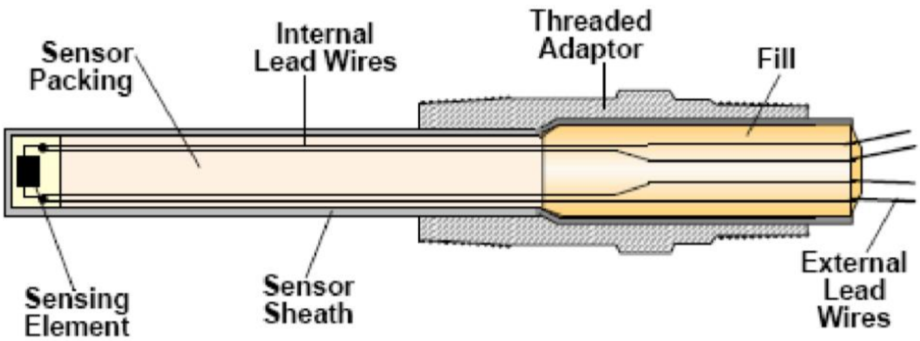

Figure 20. Construction of PT100 probe

2.1.3. Working principle

The working principle of PT100 is based on resistance measurement principles. When the temperature increases, the resistance element also increases. According to manufacturing standards, at 0^oC, the resistance value is 100Ω.

2.1.4. Characteristics

The linearization equation of PT100:

$$R_T = R_o(1 + \alpha t + \beta t^2 + \gamma(t - 100)t^3)$$

where: $\alpha = 3.9083 \times 10^{-3}K^{-1}$

$\beta = -5.775 \times 10^{-7}K^{-2}$

$\gamma = -4.183 \times 10^{-2}K^{-4}$

Some of the characteristics that make PT100 widely used include:

- It can be manufactured with high purity (99.99%), thereby increasing the accuracy of its electrical properties.
- It has excellent chemical inertness and high structural stability, ensuring high stability in electrical conductivity during usage.
- The temperature coefficient of resistance at 0^oC is approximately $3.9 \times 10^{-3}\Omega/^oC$.
- The resistance at 100^oC is approximately 138.5Ω.
- It has a relatively wide operating temperature range from -200^oC to 1000^oC.
- There is a nearly linear relationship between resistance and temperature, and the temperature coefficient of resistance is significant enough to facilitate easy measurement of results.

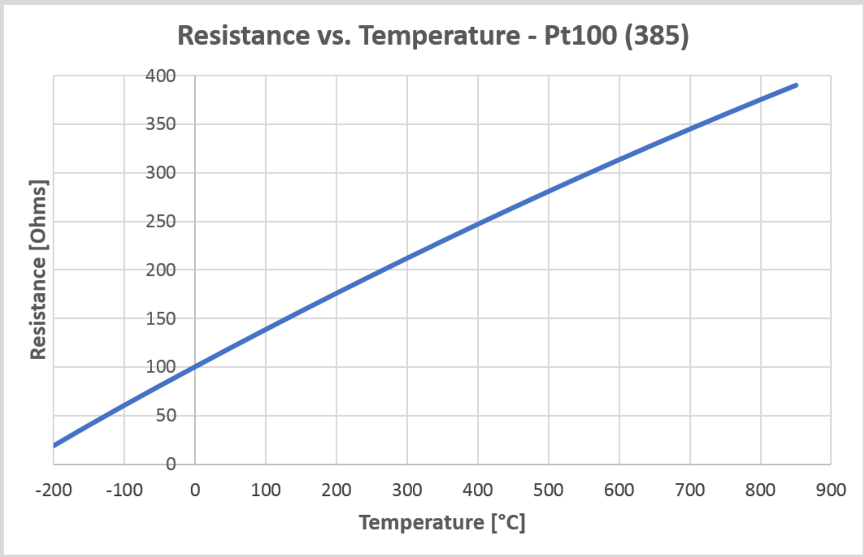

Figure 21. Figure of a nearly linear relationship between resistance and temperature

°C	Ω	°C	Ω	°C	Ω	°C	Ω	°C	Ω	°C	Ω
-200	18,49	0	100,00	200	175,84	400	247,04	600	313,59	800	375,51
-190	22,80	10	103,90	210	179,51	410	250,48	610	316,80	810	378,48
-180	27,08	20	107,79	220	183,17	420	253,90	620	319,99	820	381,45
-170	31,32	30	111,67	230	186,82	430	257,32	630	323,18	830	384,40
-160	35,53	40	115,54	240	190,45	440	260,72	640	326,35	840	387,34
-150	39,71	50	119,40	250	194,07	450	264,11	650	329,51	850	390,26
-140	43,87	60	123,24	260	197,69	460	267,49	660	332,66		
-130	48,00	70	127,07	270	201,29	470	270,86	670	335,79		
-120	52,11	80	130,89	280	204,88	480	274,22	680	338,92		
-110	56,19	90	134,70	290	208,45	490	277,56	690	342,03		
-100	60,25	100	138,50	300	212,02	500	280,90	700	345,13		
- 90	64,30	110	142,29	310	215,57	510	284,22	710	348,22		
- 80	68,33	120	146,06	320	219,12	520	287,53	720	351,30		
- 70	72,33	130	149,82	330	222,65	530	290,83	730	354,37		
- 60	76,33	140	153,58	340	226,17	540	294,11	740	357,42		
- 50	80,31	150	157,31	350	229,67	550	297,39	750	360,47		
- 40	84,27	160	161,04	360	233,17	560	300,65	760	363,50		
- 30	88,22	170	164,76	370	236,65	570	303,91	770	366,52		
- 20	92,16	180	168,46	380	240,13	580	307,15	780	369,53		
- 10	96,09	190	172,16	390	243,59	590	310,38	790	372,52		

Figure 22. Table of Resistance Values of PT100 at Various Defined Temperature Values

Observing that the resistance value of PT100 changes approximately by 4Ω/10K, it is possible to linearly approximate the resistance with respect to temperature within each range to accurately measure the temperature.

In this project, the temperature sensor used is a 3-wire PT100 sensor. It has an accuracy of $\pm 1^o C$ and a measurement range from $-50^o C$ to $200^o C$, as specified in the manufacturer's datasheet.

2.2. Overview of HS1101

2.2.1. Overview

The humidity sensor HS1101 is a capacitive humidity sensor used to measure relative humidity (RH%). HS1101 is widely utilized and often paired with an oscillation circuit generator like the IC555. The structure of HS1101 consists of a capacitor cell with capacitance ranging from approximately 163pF to 202pF, varying depending on the temperature. The external part is protected by a plastic frame with perforations for air circulation.

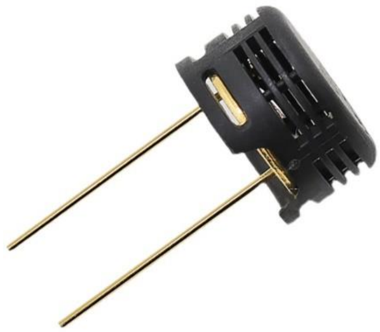

Figure 23. HS1101

2.2.2. Working principle

The working principle of HS1101 is based on a unique capacitive cell. When air containing humidity enters between the two plates of the capacitor, it carries moisture which alters the dielectric constant of the air layer between the plates, consequently changing the capacitance. This capacitance value can influence the oscillation circuit that can be easily counted using a counter and the timing of a Microcontroller. By measuring the output frequency, the capacitance of the HS1101 is measured. When the humidity increases, the capacitance also increases.

2.2.3. Characteristics

The capacitive value of HS1101 is given by the following equation:

$$C = C_o \times (1.25.10^{-7} RH^3 - 1.36.10^{-5} RH^2 + 2.19.10^{-3} RH + 0.9)$$

where $C\ (pF)$ = The capacitance at the desired relative humidity (RH)

C_o = The capacitance at a reference humidity ($RH = 55\%$)

RH = The relative humidity that to be measured

HS1101 has a fast response time with a wide operating temperatures and frequencies range ($-40^oC \div 100^oC$ and $5kHz \div 100kHz$). At 55% relative humidity (RH) and 25°C, the capacitance of the capacitor is 180pF.

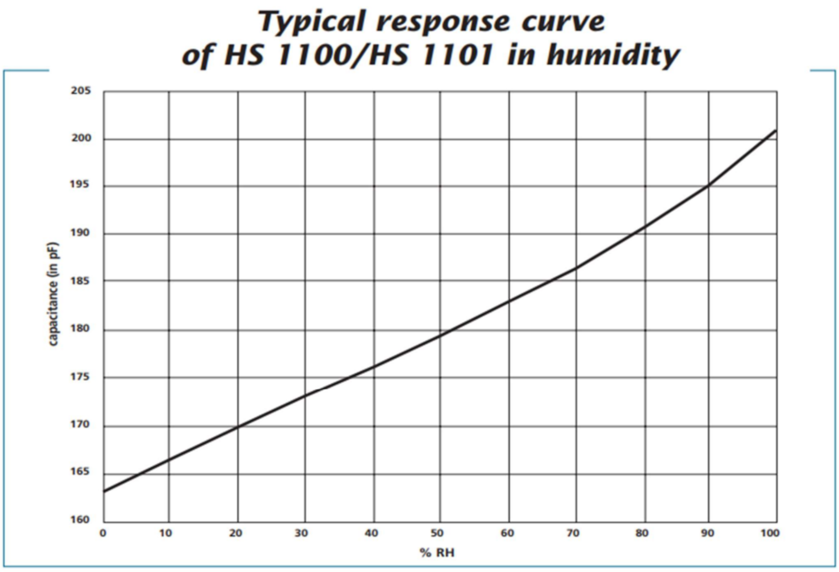

Figure 24. The graph of the capacitance - humidity dependency

It's observed that the graph is relatively linear, with an average sensitivity of 0.34pF/%RH.

According to datasheet, the frequency values when combining HS1101 with TLC55 oscillator circuit are provided in the following table (Table 2.2):

Typical Characteristics for Frequency Output Circuits

REFERENCE POINT AT 6660Hz FOR 55%RH / 25°C

RH	0	10	20	30	40	50	60	70	80	90	100
Frequency	7351	7224	7100	6976	6853	6728	6600	6468	6330	6186	6033

Typical for a 555 Cmos type. TLC555 (RH : Relative Humidity in %, F : Frequency in Hz)

Table 3. The frequency value from TLC555 integrated HS1101

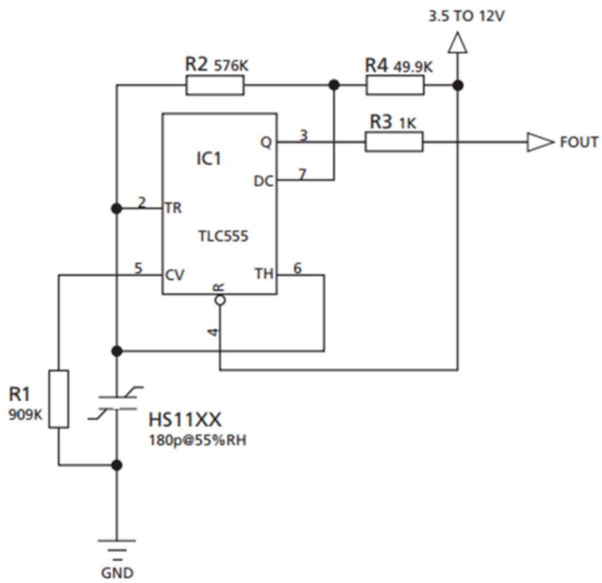

Figure 25. The Schematic of HS1101 from datasheet

2.3. Overview of Microcontroller AT89S52

2.3.1. Construction of MCS-51

The MCS-51 is a microcontroller family produced by Intel. The notable members of this family are 8031, 8051, 8951, and so on. While there are some differences in the main characteristics and operational principles among these microcontroller families, mastering one type of microcontroller can facilitate the adaptation to and understanding of other microcontroller families. Therefore, to gain specific knowledge about different microcontroller families and to serve the purpose of this project, we delved into the study of the widely used MCS-51 family, with AT89S52 being a representative example.

The AT89S52 is a popular microcontroller series manufactured by Atmel. It is an enhanced version of AT89C52 with several new improvements, notably including a user-friendly serial programming mode. The AT89S52 is based on Intel's MCS-51 microcontroller family, but it comes with significant enhancements. Some of the specific features of the AT89S52 include:

- 8KB internal ROM (4KB with 8051).
- 256 bytes of internal RAM (128 bytes with 8051).
- 4 ports of 8-bit input/output (I/O).
- Serial communication.

- 64KB external ROM memory space.
- 64KB external RAM memory space.
- Boolean processing (operating on single bits).
- 3 Timer/Counter modules (2 with 8051).
- 2 external interrupts.
- Operating frequency up to 24MHz.

	8051	8052	80C320	E5
Clocks per instruction cycle (fewer is better)	12	12	4	4
Timers	2	3	3	3 plus using CSL
Watchdog Timer	No	No	Yes	Yes
UARTs/serial ports	1	1	2	1 plus using CSL
Internal DATA RAM bytes	128	256	256	256
Internal XDATA RAM bytes	0	0	0	8K to 40K, depending on device
Maximum program size without external logic	64K	64K	64K	2M 16M with effort
Wait-state support	No	No	Some capability with variable-speed MOVX instruction	Yes
DMA channels	0	0	0	2
Maximum PIO port pins	32	32	16	Up to 150, depending on package
Debug without emulator	No	No	No	Yes, uses embedded JTAG port
Number of interrupts	Fixed	Fixed	Fixed	Expandable via CSL

Table 4. The difference between ICs in MCS-51 family

2.3.2. Construction and function of Microcontroller 8051

The pin configuration of the 8051 Microcontroller (AT89S52, which is similar) is as follows:

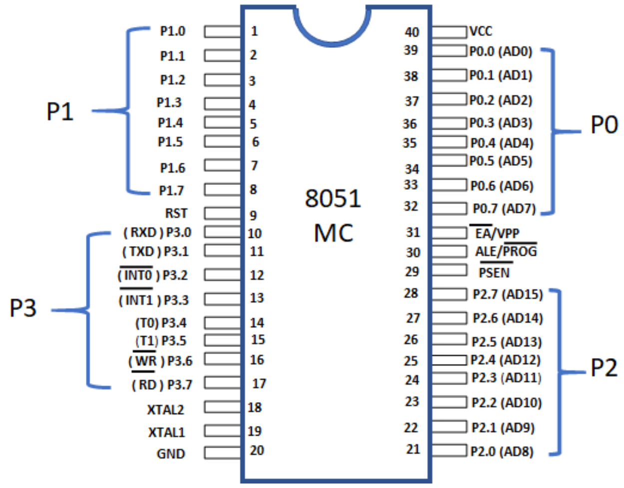

Figure 26. Pin Configuration of the 8051 Microcontroller

The 8051 microcontroller has a total of 40 pins. The functions of each pin (Port) are summarized as follows:

- Pins 1 to 8 (Port 1, P1.0 to P1.7) are used as input/output ports for external communication.

- Pin 9 (RST) is the RESET pin used to restart the 8051. Normally, these pins are at a low level. When this signal is brought to a high level for at least 2 machine cycles, the internal registers of the 8051 are loaded with appropriate values to restart the system.

- Pins 10 to 17 (Port 3, P3.0 to P3.7) have two purposes: they can be used as input/output ports or for specific functions, such as:

- Pin P3.0 (RXD) is the received data pin for serial communication.
- Pin P3.1 (TXD) is the transmit data pin for serial communication.
- Pin P3.2 (INT0) is the external interrupt 0 pin.
- Pin P3.3 (INT1) is the external interrupt 1 pin.
- Pin P3.4 (T0) is the timer 0 pin.
- Pin P3.5 (T1) is the timer 1 pin.
- Pin P3.6 (WR) is the write strobe signal for writing data to external memory.
- Pin P3.7 (RD) is the read strobe signal for reading data from external memory.

- Pins 18 and 19 (XTAL) are connected to an external quartz oscillator to generate the on-chip clock signal (CLK) and are typically accompanied by two capacitors of around 33pF for oscillator stability.

- Pin 20 (Vss) is the ground connection (0V).

- Pins 21 to 28 (Port 2, P2.0 to P2.7) serve as input/output ports or as the high byte of the address bus when using external EPROM and RAM memory up to 64KB.

- Pin 29 (PSEN) is the program store enable signal, used to select external program memory and connected to the Output Enable (OE) pin of external EPROM to enable program memory reading.

-Pin 30 (ALE – Address Latch Enable) is used to enable the address latch between the address bus and the data bus of Port 0.

- Pin 31 (EA – External Access) is set low to enable external program memory for the 8031 microcontrollers. For the 8051, a high EA selects internal ROM, a low EA selects external ROM, and a voltage of 21V allows programming of internal EPROM.

- Pins 32 to 39 (Port 0, P0.0 to P0.7) serve as input/output ports or as the low byte of the address bus.

- Pin 40 (Vcc) is the power supply input (5V).

2.3.3. The memory organization

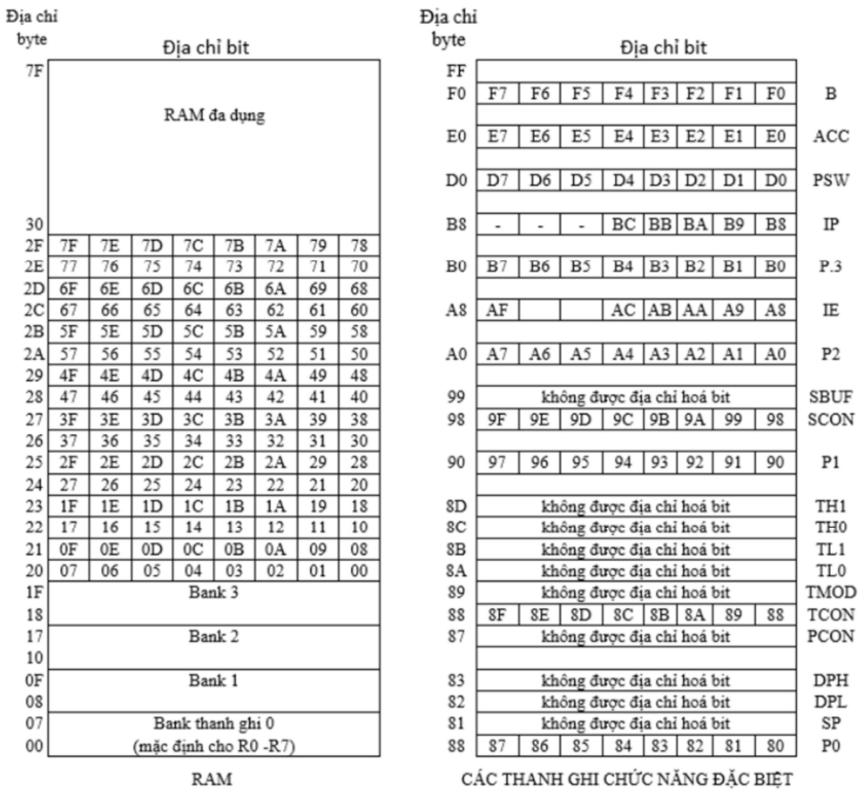

Figure 27. Memory organization of 8051

There are several register banks and special function registers (SFRs) with specific functions, such as:

- Register Banks: These are the 32 memory locations located at the end of the memory range, spanning from address byte 00H÷1FH. The instruction set of 8051 provides 8 registers from R0 to R7 at addresses byte 00H÷ 07H.
- Special Function Registers (SFRs): These are 21 registers located at the top of the memory space, each with a designated name and address, responsible for various functions of the microcontroller, including counting, processing, serial communication, and more.

These register banks and SFRs play crucial roles in the operation and functionality of the microcontroller, facilitating tasks such as data storage, arithmetic operations, and control of peripherals and communication interfaces. They allow the microcontroller to interact with the external environment and perform specific tasks based on the program instructions executed by the central processing unit (CPU).

2.4. Overview of ADC0804

The ADC0804 is an 8-bit Analog-to-Digital Converter (ADC) that converts analog signals into digital values.

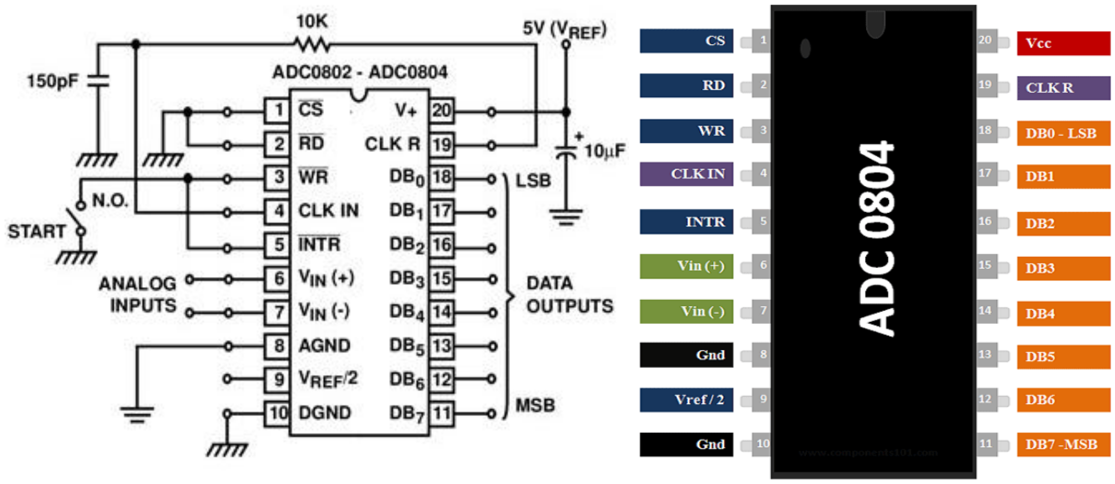

Figure 28. Circuit diagram and Pins of ADC0804

Here is some information about the ADC0804 and its specifications:

- The ADC0804 has 20 pins and is available in a DIP-20 package.
- It has an 8-bit resolution, which means it can convert analog signals into 8-bit digital values (ranging from 0 to 255).
- The conversion time is approximately 100 microseconds (μs).
- The supply voltage (Vcc) is +5V, and the maximum supply current is 2.5mA.
- The reference voltage (Vref) can be adjusted and connected to the Vref/2 pin.
- Other pin functions of the ADC0804 are as follows:
    - Chip Select (CS) Pin: This pin is used to select the chip. It is active low, meaning it is activated when brought to a low voltage level.
    - Read (RD) Pin: This pin is used to receive the data input signal. When the microcontroller wants to read data from the ADC, it provides a pulse to this pin.
    - Write (WR) Pin: This pin is used to initiate the conversion process. It is active low.
    - Interrupt (INTR) Pin: This pin is an output that goes low when the conversion is complete. It can be checked to read the value from the ADC.

- Vin+ and Vin- Pins: These are the two differential analog input pins. The analog voltage to be converted is applied to these pins.
- Vcc Pin: This pin is connected to the +5V power supply.
- Vref/2 Pin: This is the reference voltage input. The reference voltage corresponds to the maximum ADC value (255).
- CLK IN and CLK R Pins: These pins are connected to an external RC oscillator to generate the timing clock for the conversion process. The internal ADC0804 also has its own clock generator. To use an external RC oscillator, the recommended values are R = 10kΩ and C = 150pF.

CHAPTER 3. CALCULATION AND DESIGN CIRCUIT

3.1. Block diagram

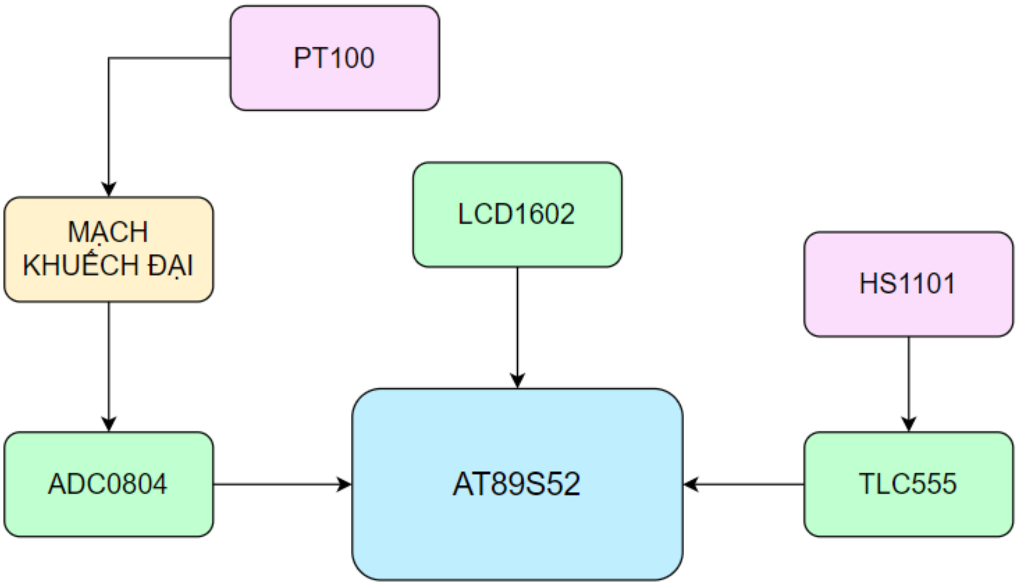

Figure 29. Block Diagram

Overview of the block diagram will include the following components:

- Central processing unit block
- Temperature measurement block: The temperature from the PT100 sensor will pass through a differential amplifier block to be fed into an Analog-to-Digital converter (ADC0804), which will then send the signal to the processing microcontroller.
- Humidity measurement block: The signal from the HS1101 sensor will be fed into a pulse generator using TLC555 to provide input to the processing microcontroller for humidity calculation.
- Display block: An LCD1602 display will show the temperature and humidity values on the screen.

3.2. Circuit design calculations

3.2.1. Overview of the measurement circuit

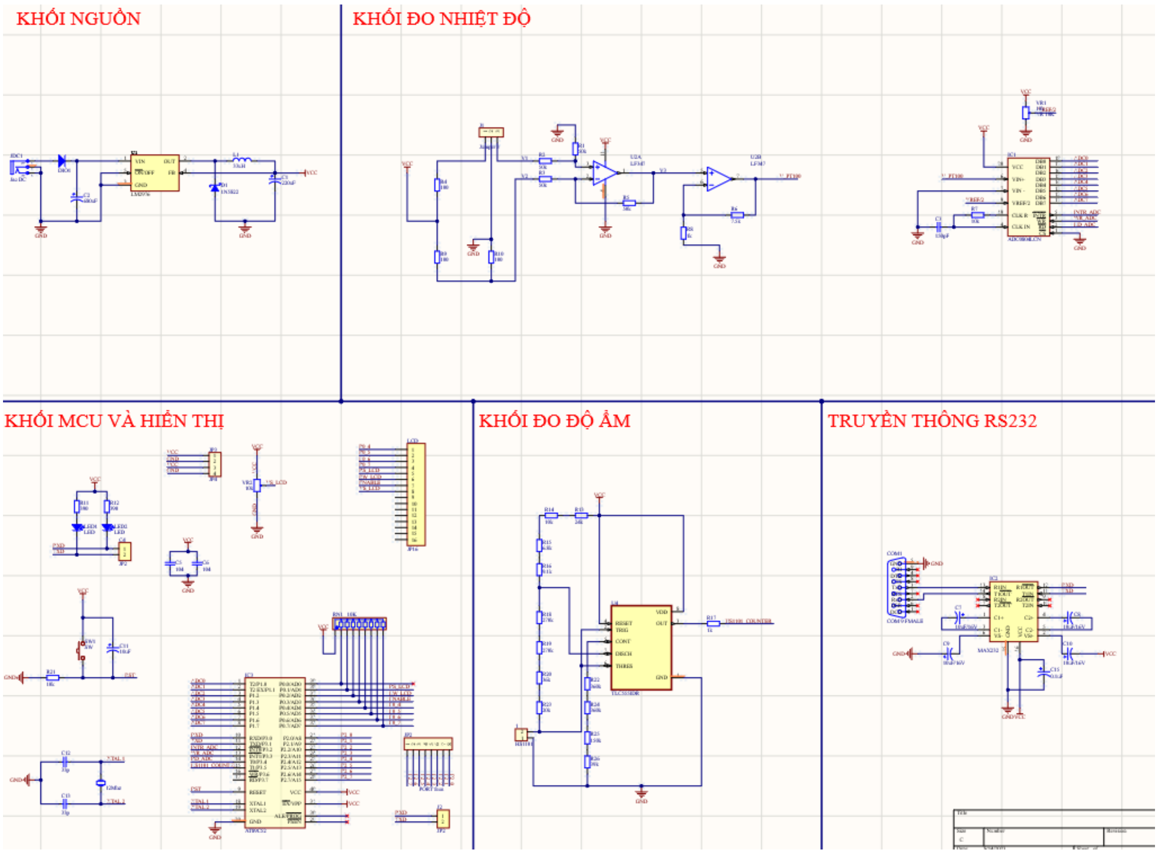

Figure 30. Schematic of measurement circuit

We utilize Altium software for designing the schematic and 3D PCB layout based on the overall structure depicted in the diagram above. The detailed explanation of each block will be provided below.

3.2.2. Power supply

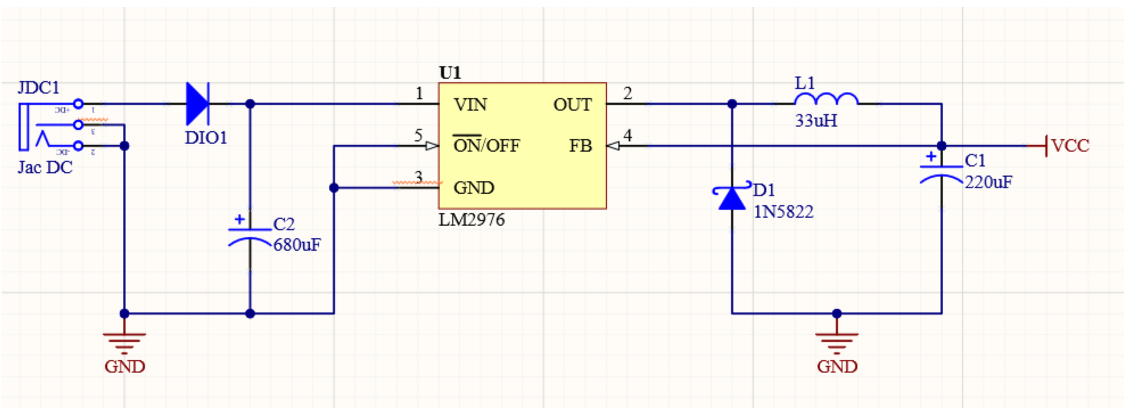

Figure 31. Power supply

Due to the fact that the input voltage for all components is 5V, we are utilizing the LM2596 IC to step down from 12V to 5V. The schematic diagram is depicted in the image above, and the input voltage ranging from 9V to 12V is sourced from the adapter.

CONDITIONS			INDUCTOR		OUTPUT CAPACITOR			
					THROUGH-HOLE ELECTROLYTIC		SURFACE-MOUNT TANTALUM	
OUTPUT VOLTAGE (V)	LOAD CURRENT (A)	MAX INPUT VOLTAGE (V)	INDUCTANCE (µH)	INDUCTOR (#)	PANASONIC HFQ SERIES (µF/V)	NICHICON PL SERIES (µF/V)	AVX TPS SERIES (µF/V)	SPRAGUE 595D SERIES (µF/V)
3.3	3	5	22	L41	470/25	560/16	330/6.3	390/6.3
		7	22	L41	560/35	560/35	330/6.3	390/6.3
		10	22	L41	680/35	680/35	330/6.3	390/6.3
		40	33	L40	560/35	470/35	330/6.3	390/6.3
		6	22	L33	470/25	470/35	330/6.3	390/6.3
	2	10	33	L32	330/35	330/35	330/6.3	390/6.3
		40	47	L39	330/35	270/50	220/10	330/10
5	3	8	22	L41	470/25	560/16	220/10	330/10
		10	22	L41	560/25	560/25	220/10	330/10
		15	33	L40	330/35	330/35	220/10	330/10
		40	47	L39	330/35	270/35	220/10	330/10
		9	22	L33	470/25	560/16	220/10	330/10
	2	20	68	L38	180/35	180/35	100/10	270/10
		40	68	L38	180/35	180/35	100/10	270/10
12	3	15	22	L41	470/25	470/25	100/16	180/16
		18	33	L40	330/25	330/25	100/16	180/16
		30	68	L44	180/25	180/25	100/16	120/20
		40	68	L44	180/35	180/35	100/16	120/20
		15	33	L32	330/25	330/25	100/16	180/16
	2	20	68	L38	180/25	180/25	100/16	120/20
		40	150	L42	82/25	82/25	68/20	68/25

Table 5. Parameters from Datasheet of LM2596

The selection of components such as inductors and capacitors is based on the specifications provided in the manufacturer's datasheet.

Additionally, the circuit employs a diode to prevent reverse current that could damage the components, and a Zener diode is used to regulate the output voltage.

3.2.3. Temperature measurement and Amplifier circuit

a) Measurment circuit

Utilizing Wheastone bridge circuit for PT100

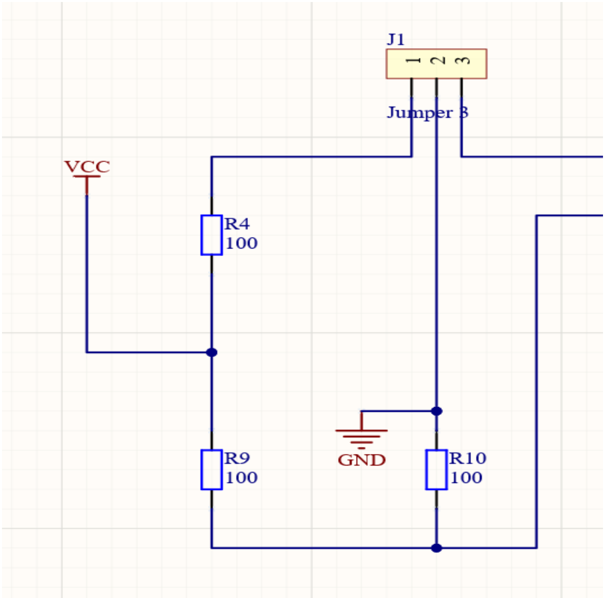

Figure 32. Wheastone bridge circuit for PT100

When temperature (t) changes, the resistance (R_t) changes. From the formula, we can calculate:

- The voltage deviation a function of the temperature change (relative to 0°C, which is the temperature being measured).
- Using a 3-wire compensated PT100.
- The bridge circuit has the following values: $R_4 = R_9 = R_{10} = 100\Omega$, the supply voltage $V_{cc} = 5V$.

At 0°C, the resistance of the PT100 is 100Ω, V_ra = 0V.

At 100°C, the resistance of the PT100 follows the formula:

- $R_t = R_o(1 + \alpha t)$ with $\alpha = 3.0 \times 10^{-3}$

Hence,

$$V_{out} = \frac{V_{cc}}{4} \times \frac{R_t}{R_t + \frac{\Delta R}{2}}$$

b) Differential Amplification Circuit

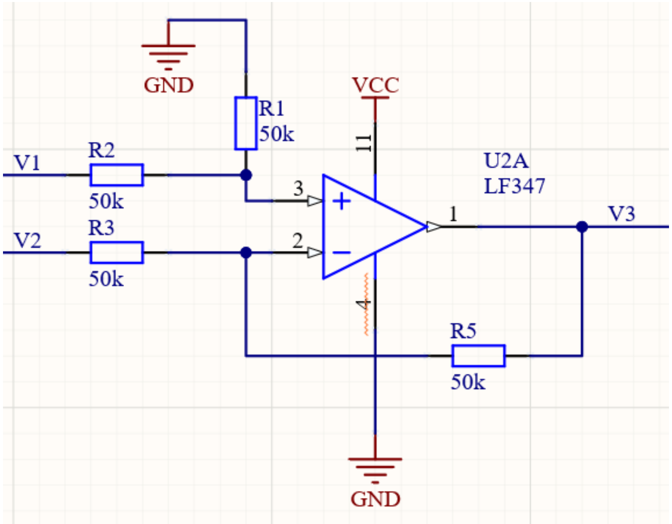

Figure 33. Differential Amplification Circuit

The outputs V1 and V2 of the measurement circuit will be connected to the differential amplification circuit to reduce the influence of the preceding blocks on the measurement circuit and increase the output impedance of the signal. We use four resistors, where $R_1 = R_2 = R_3 = R_5 = 50k\ \Omega$.

Hence, $V3 = V1 - V2$. Substituting the calculation formula, we get:

At t = 0°C $V3 = 0$V

t = 100°C $V3 = 0.41$V

c) Voltage Amplification Circuit

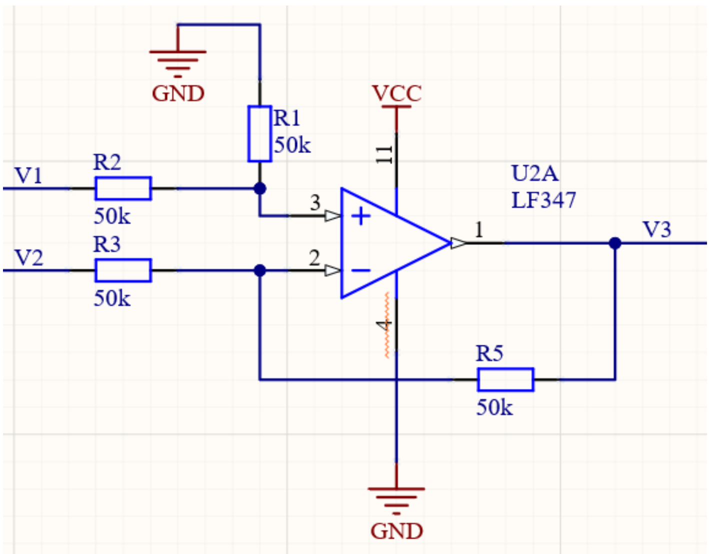

Figure 34. Voltage Amplification Circuit

To obtain a voltage range of 0-5V to feed into the ADC0804, we have used the LM358 IC to amplify the voltage V3.

By choosing $R_6 = 9.1k\Omega$ and $R_8 = 1k\Omega$ for the non-inverting amplifier stage, we get:

$$V_{PT100} = V_3\left(1 + \frac{R_6}{R_8}\right)$$

As a result, $V_{PT100}max = 4.12V$ at t = 100°C < 5V and within the voltage reference range. The chosen resistor values are readily available in the market and are entirely reasonable.

3.2.4. Humidity Measurement and Pulse Generation Circuit

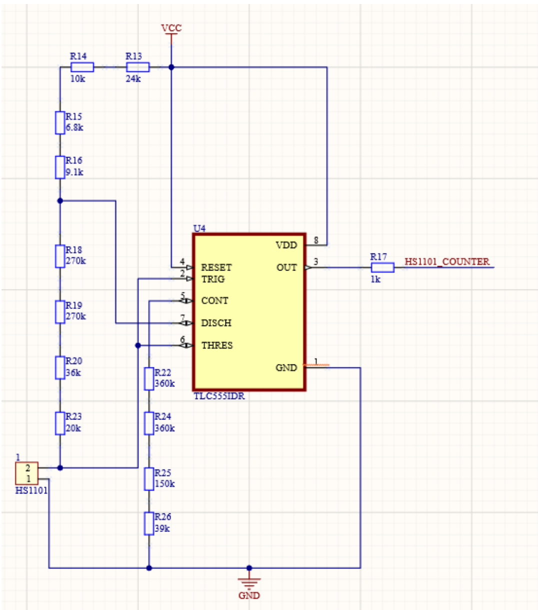

Figure 35. Pulse Generation Circuit

Due to the nature of the HS1101 humidity sensor as a capacitive cell that changes with humidity, the pulse generation circuit takes advantage of this characteristic to convert capacitance changes into frequency variations. The IC TLC555 is utilized according to the manufacturer's datasheet, and resistor values are determined as shown in the diagram.

The output frequency can be calculated using the following formula from the datasheet:

$$f_{out} = \frac{1}{C@\%RH\left(R_x + 2R_y\right) \times ln2}$$

where $R_x = 49.9k\Omega, R_y = 576k\Omega$, to minimize errors, smaller resistors are used to achieve the desired total resistance.

The generated pulses will have values ranging from 6000 to 7400Hz, which is suitable for the operating frequency of the HS1101. These pulses will be fed into Timer 1 of the 8051 microcontroller (Pin P3.5). The microcontroller will count the number of pulses using the counter and provide the relative humidity value.

3.2.5. LCD Display Module

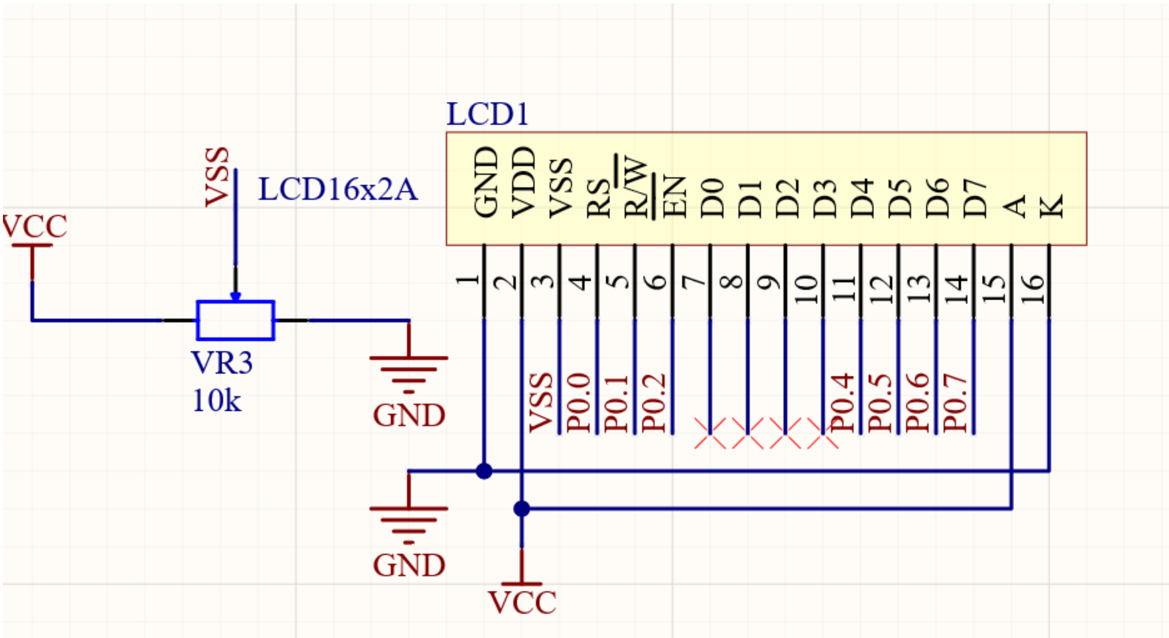

Figure 36. LCD Display Module

Using the LCD1602 (HD44780) in 4-bit mode as shown in the diagram, the microcontroller can display the calculated values on the screen for the user. The VEE pin can be utilized to adjust contrast and is connected to a 10kΩ variable resistor. The RS, RW, E pins, and the data pins are connected to Port 0 of the microcontroller. The signal pins should be pulled up to define the logic level for Port 0.

3.2.6. Microcontroller 8051 Module

a) Central Microcontroller

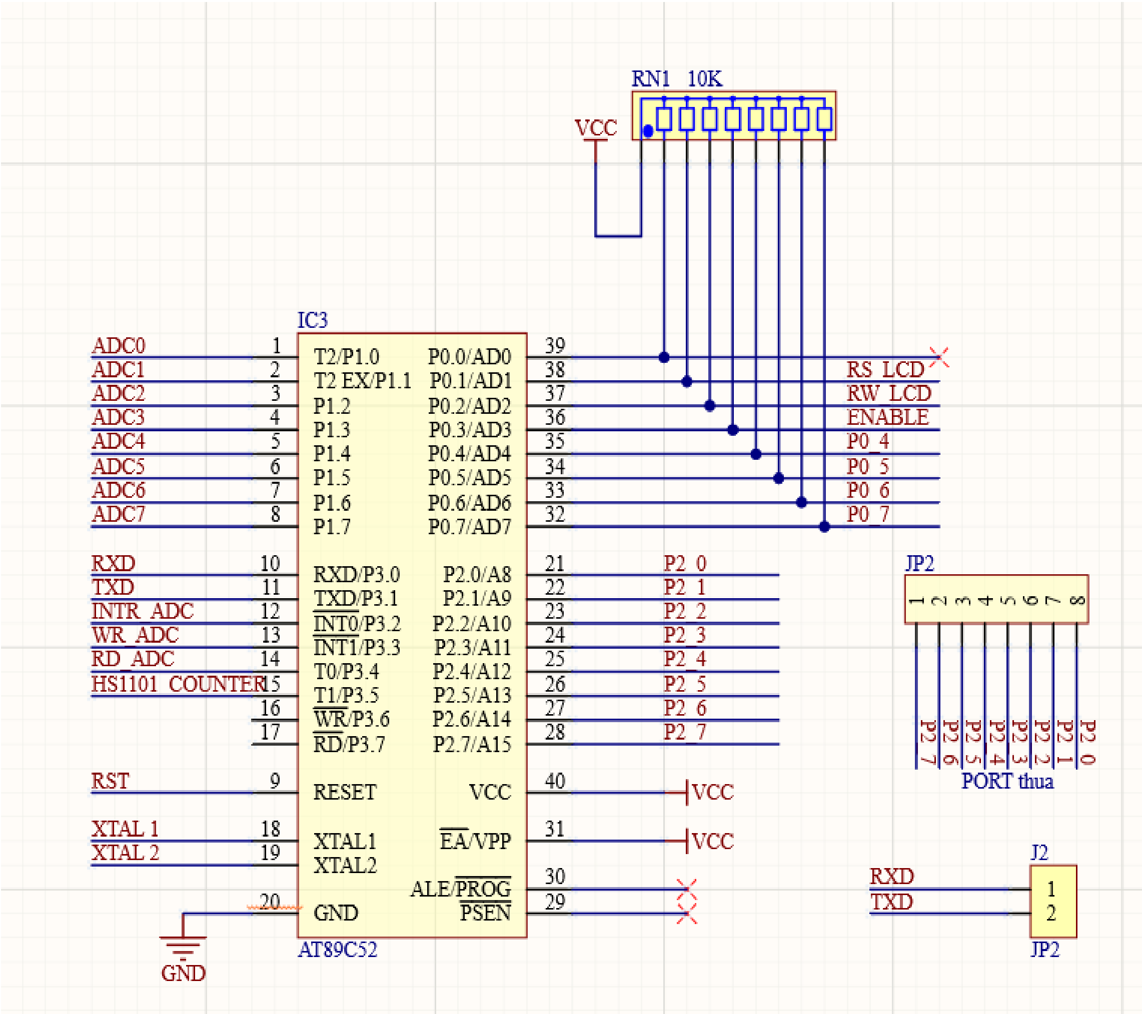

Figure 37. Microcontroller Module

We are utilizing the AT80S52 microcontroller from the 8051 series, with Netlabels to connect to peripherals. A $10k\Omega$ pull-up resistor is employed for Port 0, and extra ports are available for system expansion.

b) Pulse Generation

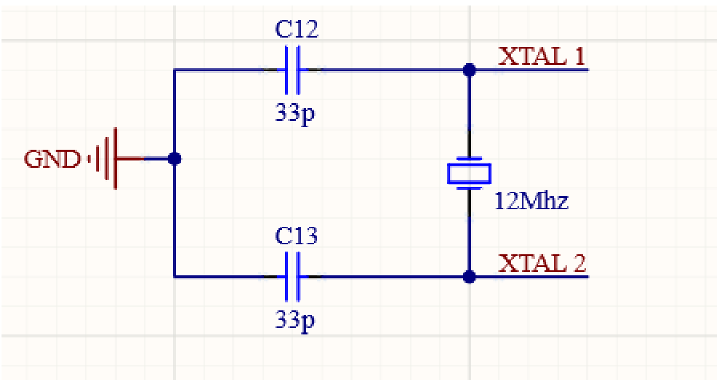

Figure 38. Pulse Generation

We are using an 11.0592MHz quartz crystal oscillator to generate the clock signal for the microcontroller. The oscillator circuit includes two 33pF ceramic capacitors to provide shock resistance and improve the accuracy of the quartz crystal oscillator.

c) *Reset block*

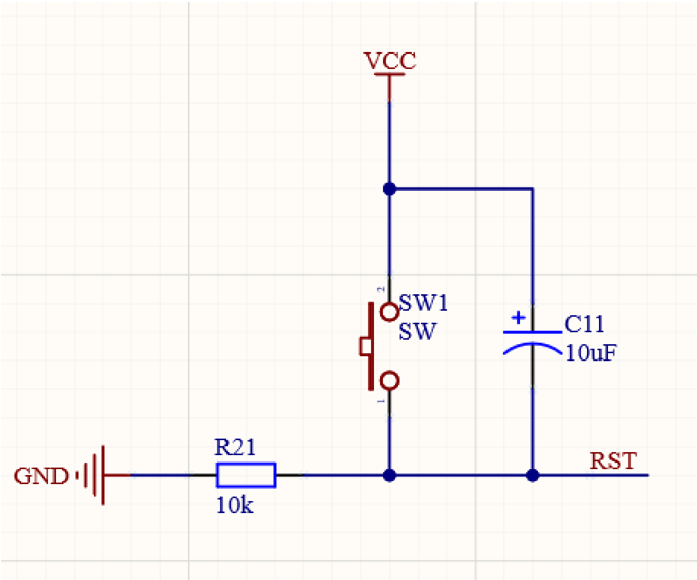

Figure 39. Reset block

The push-button will be connected to the RST pin of the microcontroller to initiate a system restart in case of errors. A 10μF electrolytic capacitor is added to prevent switch bounce, and a 10kΩ resistor is used to prevent short-circuiting when the Reset button is pressed.

3.3. Simulation on Proteus

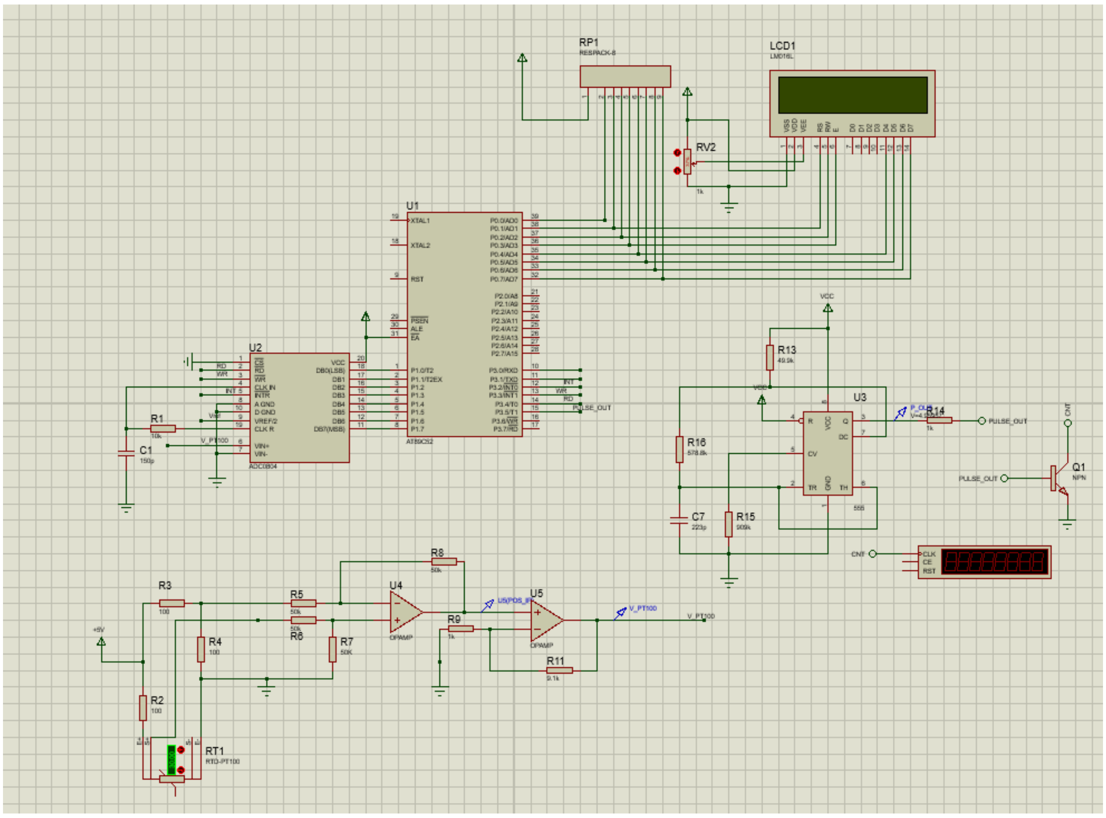

Figure 40. Simulation on Proteus

Based on the schematic, we will program the functionality using Keil C software and simulate the measurement circuit in Proteus. Simulating the circuit in Proteus beforehand provides a partial understanding of how the circuit operates and allows us to verify whether the programming functions correctly. This step also enables us to make adjustments and corrections to match the real-world behavior of the circuit.

Temperture	Vout	V_ADC	K	ADC_Value
0	0.0005	0.0053	10.01	0.3
10	0.0473	0.4783	10.11	24
20	0.0928	0.937	10.1	48
30	0.1363	1.3775	10.11	70
40	0.1783	1.801	10.1	92
50	0.2187	2.2089	10.1	113
60	0.2576	2.6014	10.1	133
70	0.295	2.9796	10.1	152
80	0.3311	3.3443	10.1	171

90	0.366	3.6962	10.1	189
100	0.403	4.07	10.1	208

Table 6. ADC and Temperature Value in Simulation

We can observe that the OpAmp operates quite accurately within the measurement ranges, and the ADC values show good linearity with simulated temperature. To enhance the accuracy of the circuit, we have decided to use interpolation to calculate temperature values with the highest precision.

The interpolation formula within the temperature range (t_1; t_2) is:

$$D = \frac{D(t_2) - D(t_1)}{t_2 - t_1} \times (t - t_1) + D(t_1)$$

Regarding the pulse generation circuit, due to the use of Timer0 delay function with 'for()' loops in the software, it introduces longer delays than anticipated, resulting in a delay of several machine cycles. This inaccuracy affects the pulse counting. By reducing the delay time of the timer, we can easily compensate for this error.

This compensation will be implemented in the software, and the actual circuit will be tested and adjusted using a frequency meter to ensure that the timer accurately counts pulses.

Please note that while I've provided a general understanding of your description, the actual implementation and debugging process might require careful consideration and adjustments based on the specific characteristics of your hardware and software.

CHAPTER 4. PROGRAMMING MICROCONTROLLER 8051

4.1. Flow chart of delay function

- Name function: delay();
- Purpose: takes a parameter that specifies the delay time in milliseconds (ms).

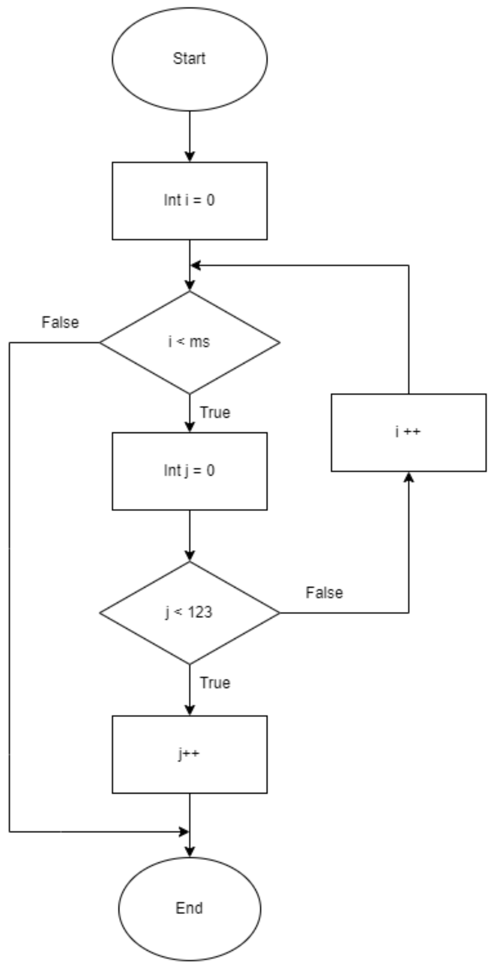

Figure 41. Flow chart of delay function

4.2. Flow chart of LCD display

4.2.1. Send High Nibble and Send Low Nibble

a) Send High Nibble

- Name function: sendHigh();
- Purpose: Send the upper 4 bits of 4-bit mode

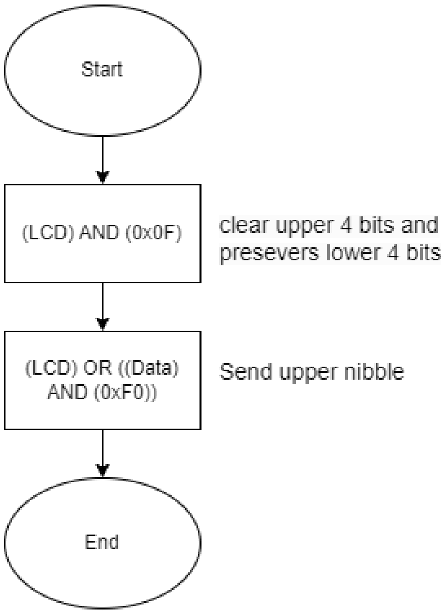

Figure 42. Flow chart of send High nibble function.

b) Send Low Nibble

- Name function: sendLow();
- Purpose: Send the lower 4 bits of 4-bit mode

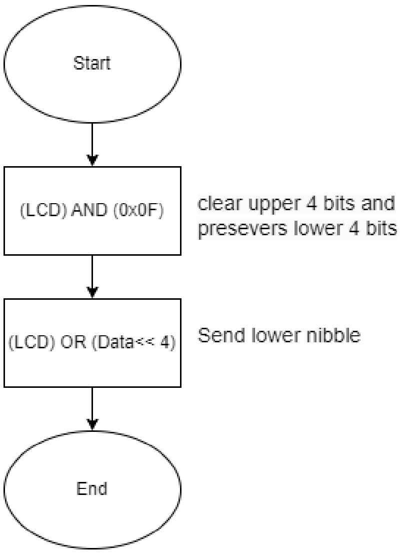

Figure 43. Flow chart of send Low nibble function.

4.2.2. Data Transmission on LCD

a) Enable LCD

- Name function: LCD_Enable();

- Purpose: Control the Enable (EN) signal of the LCD display. The Enable signal is used to trigger data or command transmission to the LCD module.

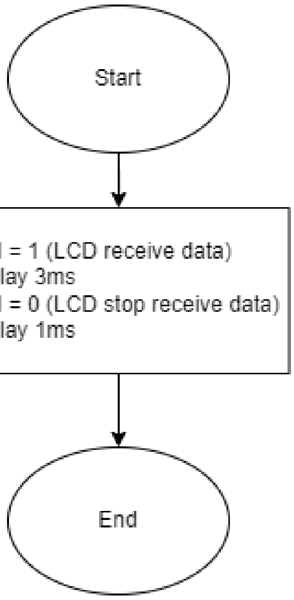

Figure 44. Flow chart of Enable LCD

b) Send Command to LCD

- Name function: sendCMD();
- Purpose: Send Command to LCD

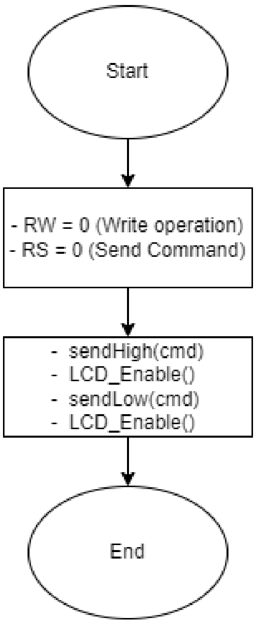

Figure 45. Flow chart of Send command to LCD

c) Send Data to LCD

- Name function: sendData();
- Purpose: Send Data to LCD

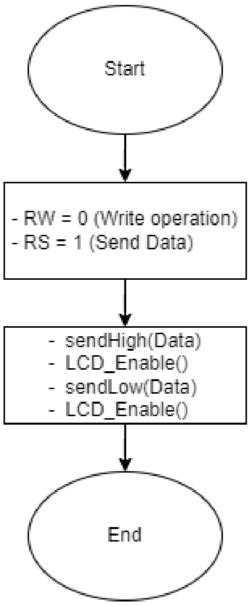

Figure 46. Flow chart of Send Data to LCD

4.2.3. Print Character and Print String on LCD

- Name function: printChar(); and printString

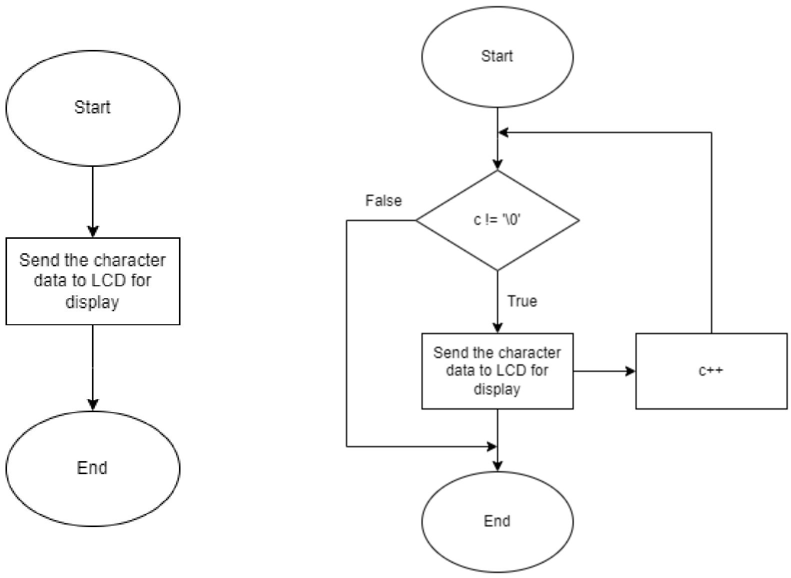

Figure 47. Flow chart of print character (Right) and string (Left) to LCD

4.2.4. Initialization LCD

- LCD_Init() function to initialize the LCD
- Set_Cursor() to set the cursor position

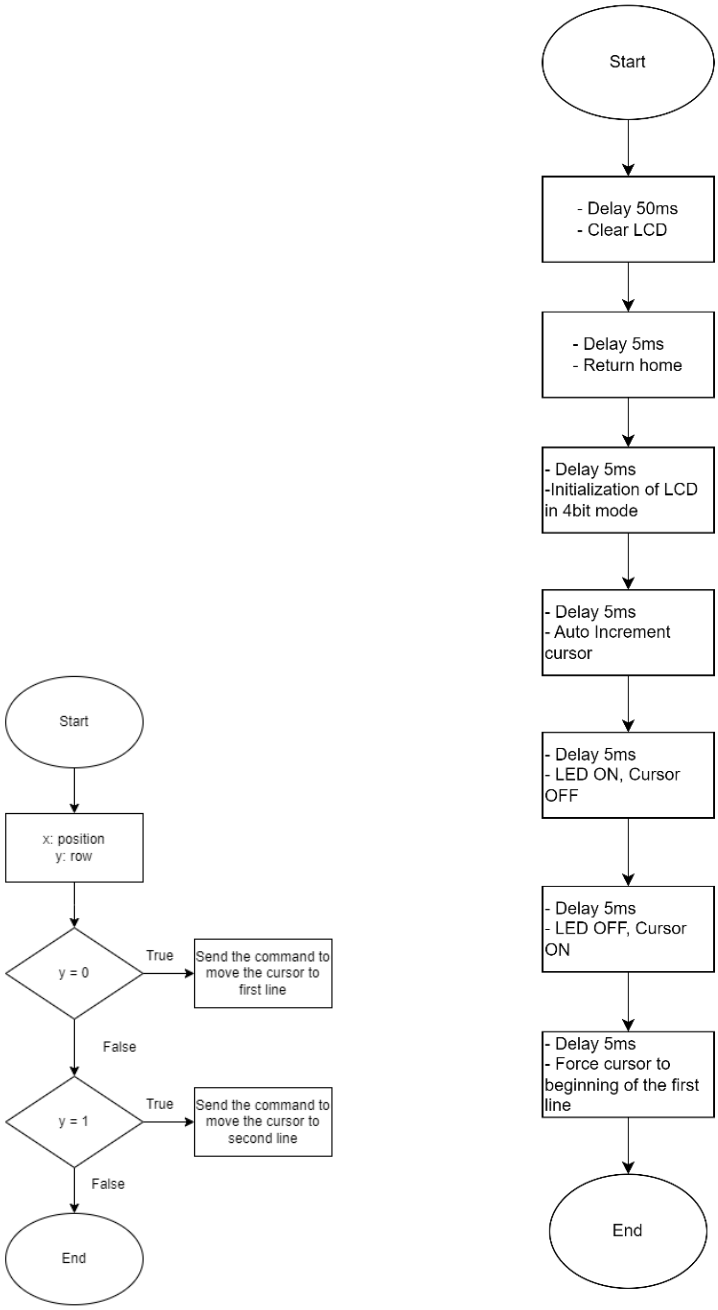

Figure 48. Flow chart of Set Cursor (Right) and Initialization LCD1602 (Left)

4.3. Temperature (Main Program)

4.3.1. Calculate Temperature

- Name function: Cal_Temp();

- Purpose: Taking the ADC input value and substituting it into the interpolation formula within the temperature range (t1; t2) allows you to calculate the desired temperature value.

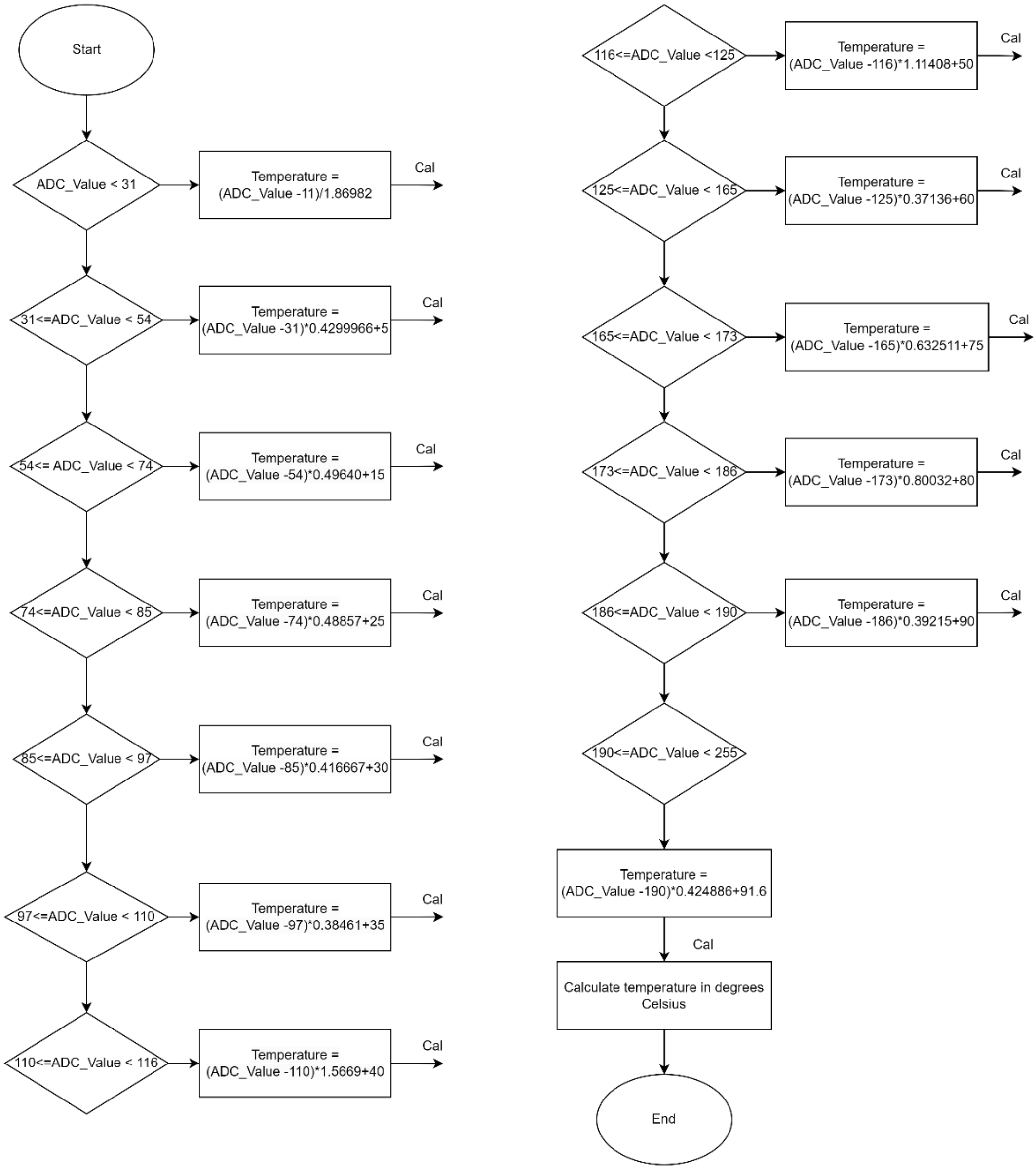

Figure 49. Flow chart of calculating Temperature

4.3.2. Read ADC0804

- Name function: ADC0804_Read();
- Purpose: Convert the values that have been read from Vin+ to digital value that can be fed into the Microcontroller 8051.

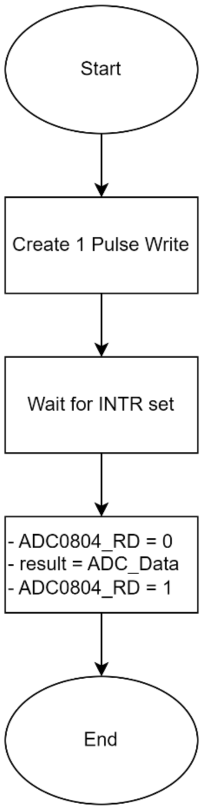

Figure 50. Flow chart of read ADC value.

4.4. Humidity (Main Program)

4.4.1. Get Frequency

- Name function: Freq();
- Purpose: Count pulses from a 555 timer and HS1101 sensor. It uses Timer1 in counting mode. The pulses will be counted over a 100ms period and multiplied by 10 to determine the frequency.

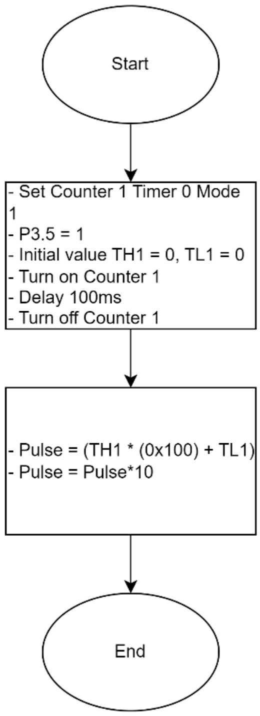

Figure 51. Flow chart of getting frequency from IC555

4.4.2. Get Humidity

- Name function: Humd();
- Purpose: The frequency getting from 'Freq();' function is then passed as a parameter to the "Humd()" function, where it is compared with values in the manufacturer's frequency table to calculate the humidity value, which is defined by 'HS1101[101]' array.
- HS1101[101] = {
  7351, 7338, 7325, 7312, 7299, 7286, 7273, 7260, 7247, 7234,
  7221, 7208, 7195, 7182, 7169, 7156, 7143, 7130, 7117, 7104,
  7091, 7078, 7065, 7052, 7039, 7026, 7013, 7000, 6987, 6974,
  6961, 6948, 6935, 6922, 6909, 6896, 6883, 6870, 6857, 6844,
  6831, 6818, 6805, 6792, 6779, 6766, 6753, 6740, 6727, 6714,
  6701, 6688, 6675, 6662, 6649, 6636, 6623, 6610, 6597, 6584,
  6571, 6558, 6545, 6532, 6519, 6506, 6493, 6480, 6467, 6454,
  6441, 6428, 6415, 6402, 6389, 6376, 6363, 6350, 6337, 6324,
  6311, 6298, 6285, 6272, 6259, 6246, 6233, 6220, 6207, 6194,
  6181, 6168, 6155, 6142, 6129, 6116, 6103, 6090, 6077, 6064, 6051
  };

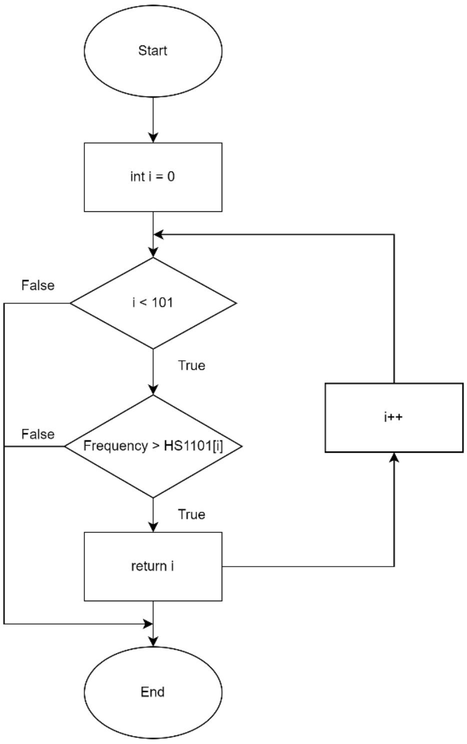

Figure 52. Flow chart of getting humidity

4.5. Main function

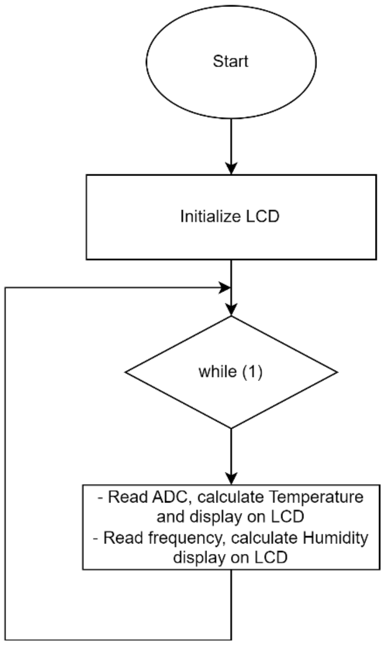

Figure 53. Flow chart of main function

The program is written and compiled using Keil C V4 software. The program is structured into subroutines (functions) and is invoked within the main program.

CHAPTER 5. REAL CIRCUIT AND MEASUREMENT RESULTS

5.1. Printed Circuit Board (PCB)

The PCB design is created using Altium Designer 20 software.

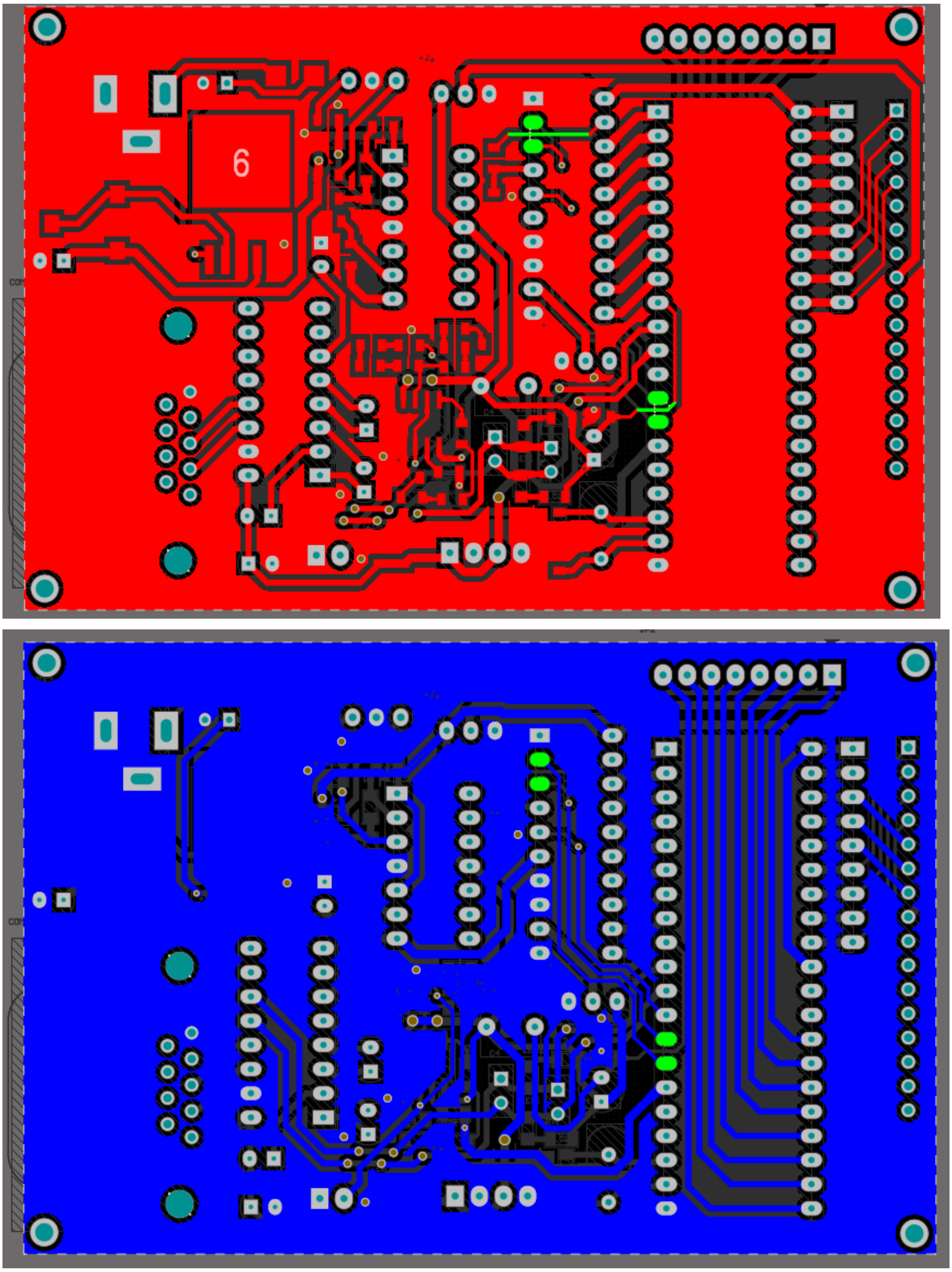

Figure 54. PCB 2 layers

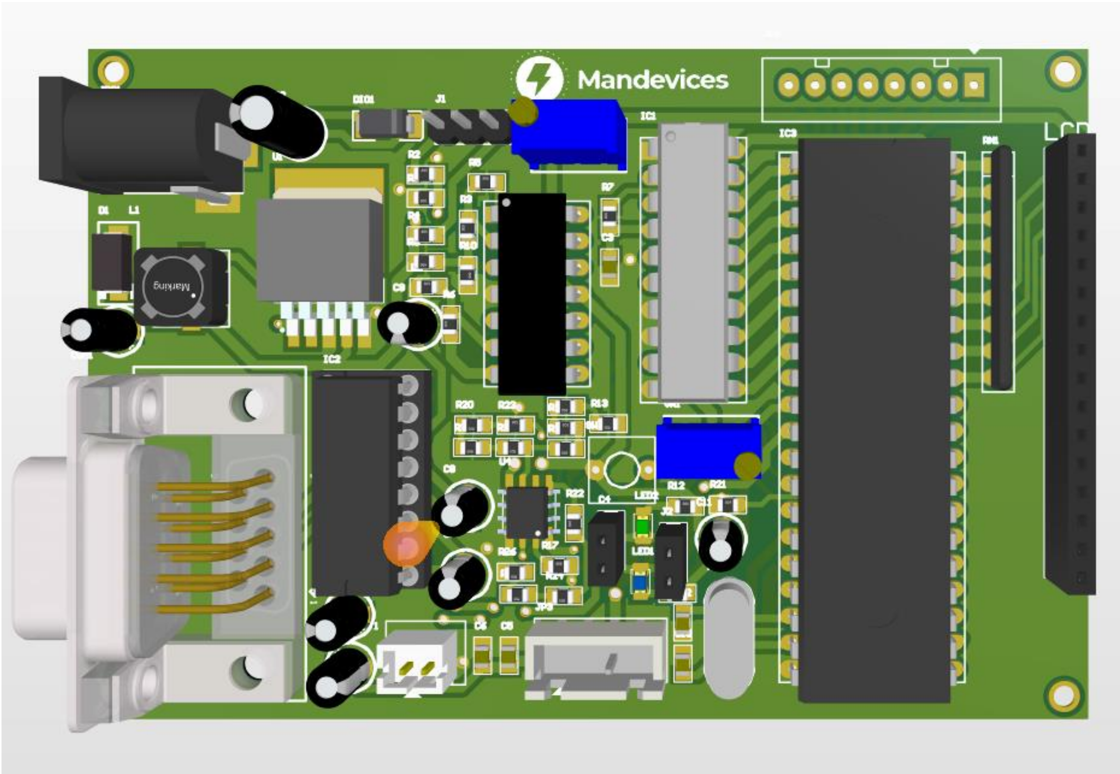

Figure 55. 3D Simulation of the Top Layer of the PCB

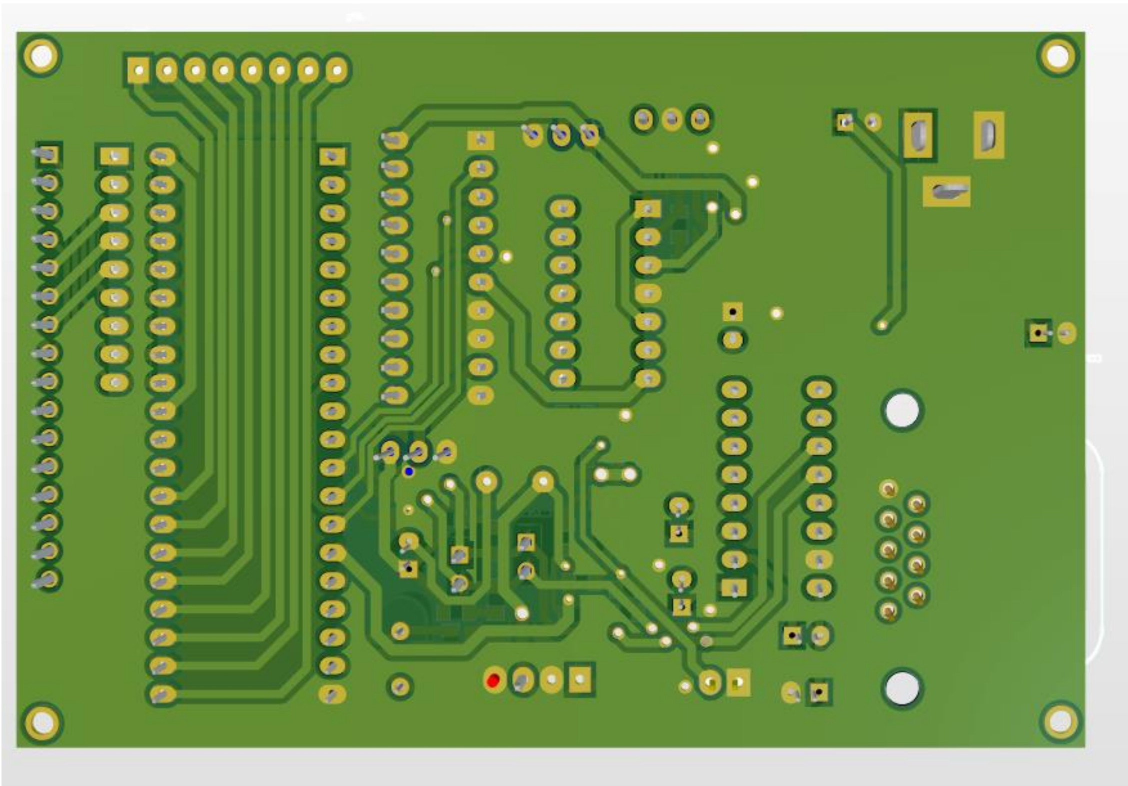

Figure 56. 3D Simulation of the Bottom Layer of the PCB

5.2. Real circuit

The actual circuit board has been manufactured in China through the company CXT, using a 2-layer PCB design. The LCD module will be mounted on the board for a compact and space-efficient layout. However, due to certain issues, external connections are needed. A detailed list of components has been prepared in advance, and the estimated cost for the circuit is around 500,000 VND. The components have been distributed among the team members for soldering.

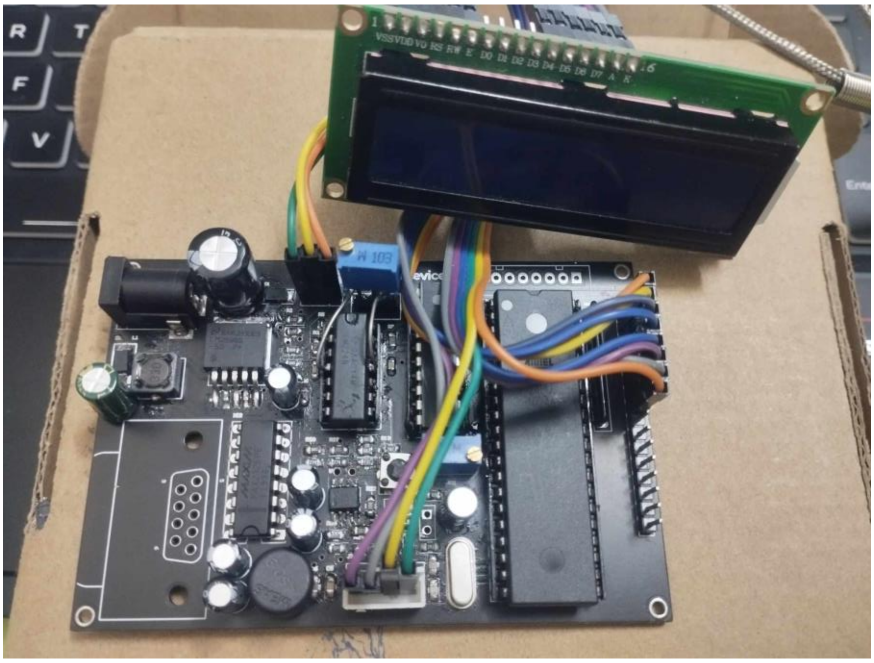

Figure 57. Real circuit

5.3. Measurement result

❖ 5V Power supply

Figure 58. A 5V voltage is supplied to the entire circuit

❖ Pulse generation circuit

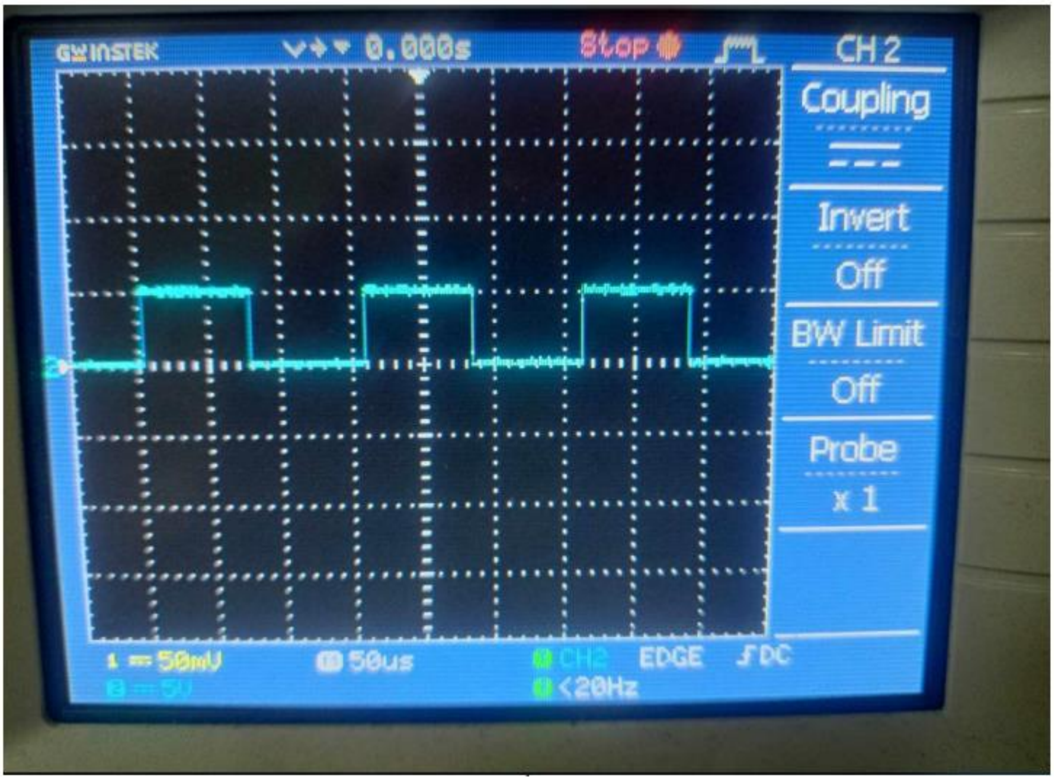

Figure 59. The output of TLC555

❖ Temperature and Humidity Value

We are using an electronic infrared temperature measurement device to measure the actual temperature. For low temperatures ranging from 0 - 20°C, we are measuring the temperature by placing the device close to a glass of ice water, allowing it to gradually melt. For higher temperature ranges, we are using a high-speed kettle to boil water and slowly adding cold water to achieve the corresponding temperatures. The actual data obtained is recorded in the following table:

Temperture	Vout	V_ADC	K	ADC_Value
0	0.0005	0.0053	9.6777	0
5	0.0628	0.615	9.78883	31
15	0.107	1.071	10.0126	55
25	0.1452	1.466	10.0933	75
30	0.1629	1.65	10.1262	84
35	0.1782	1.802	10.1108	92

40	0.193	1.962	10.1676	100
50	0.2241	2.282	10.1822	116
60	0.2212	2.648	10.1516	135
75	0.3214	3.25	10.1122	166
80	0.3355	3.405	10.1502	174
90	0.3833	3.65	9.5235	186
100	0.4137	3.73	9.0156	190

Table 7. Actual Measurement Results of PT100

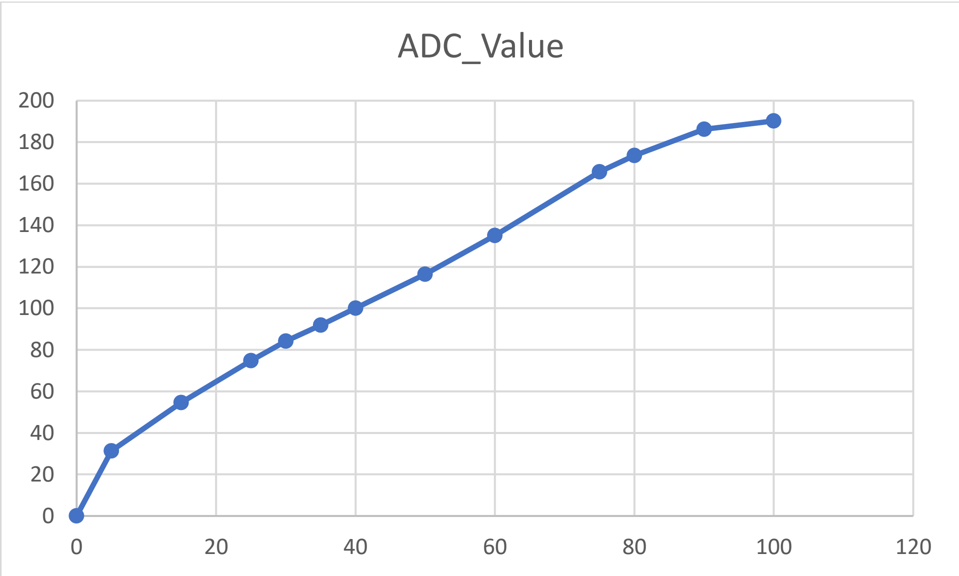

Figure 60. The graph of ADC value vs Temperature

With the requirement to measure temperature and humidity, we linearly calibrated the temperature range from 25 - 40°C with 5°C intervals to achieve the most accurate measurement results. It can be observed from the graph that the linear range is clear within the measurement range below 80°C. However, for higher values, the voltage of the comparator is not as desired. Additionally, we noticed discrepancies in the comparator's performance when the temperature drops below 10°C, which is attributed to the LM324. The values from the electronic thermometer and the calculated values have an error of no more than ±1.5°C. This error is acceptable as we are using an 8-bit ADC with relatively high resolution. Moreover, it takes into account errors from resistor values, comparator and amplification inaccuracies.

For the HS1101 sensor, we used a rotating hygrometer to cross-check the results and a digital multimeter to measure the current environmental parameters. The measured values had an error of less than 5% compared to the hygrometer readings.

Below are some images of the circuit in action, measuring temperature from ice water, hot water, room temperature, and observing humidity changes as vapor interacts with the HS1101 sensor.

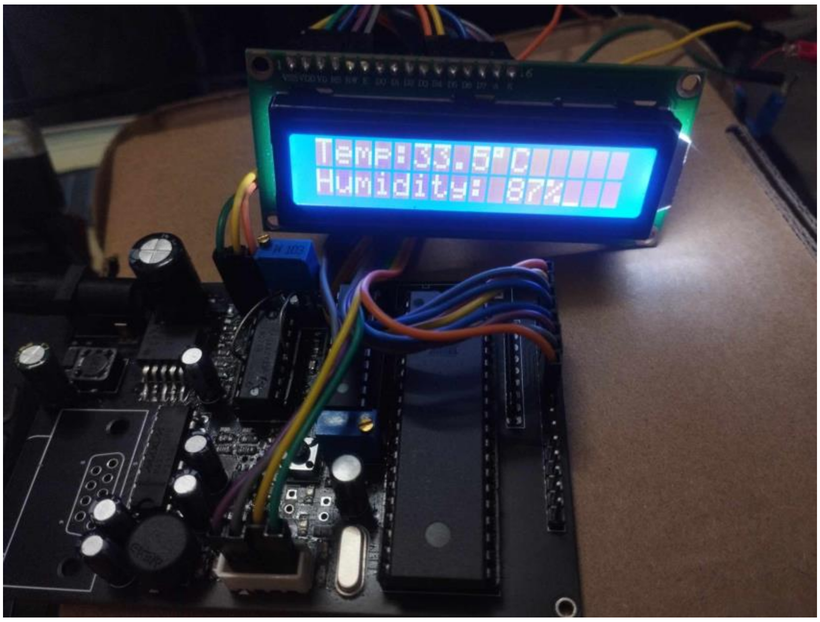

Figure 61. Temperature and Humidity in Environment Condition

Figure 62. When steam interacts with the HS1101 sensor

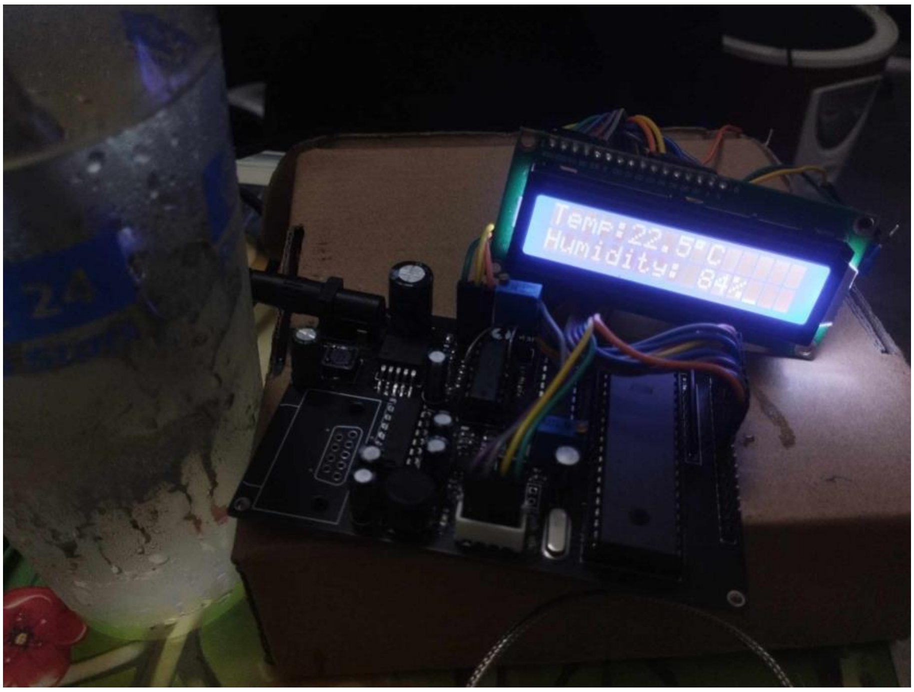

Figure 63. When placing the PT100 sensor in ice water

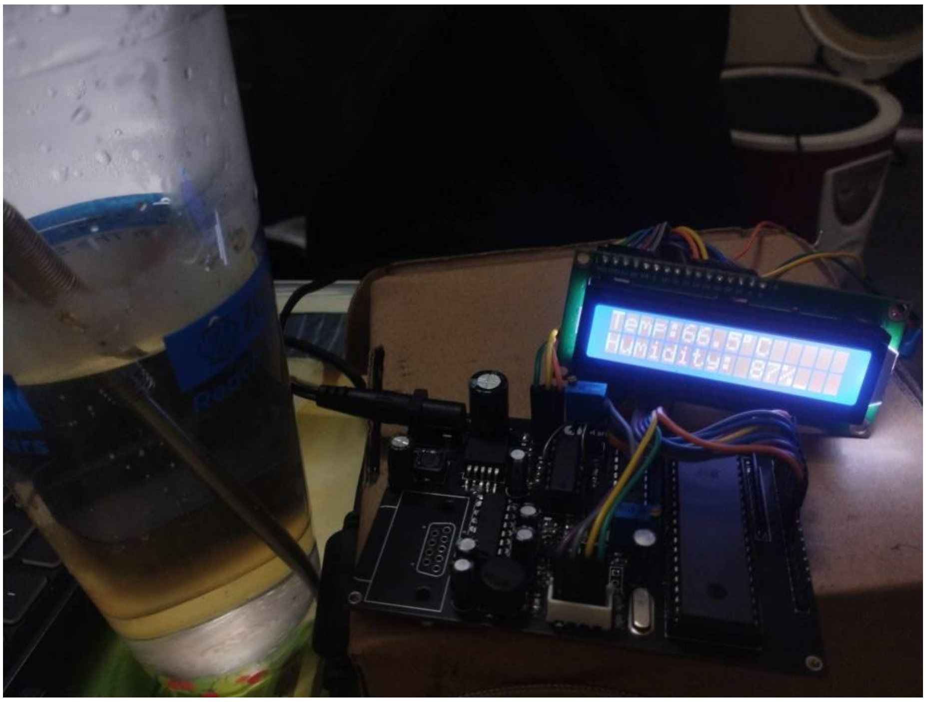

Figure 64. When placing the PT100 sensor in hot water

5.4. Conclusion and Product Enhancement

<u>Conclusion of Product:</u>

Our product has successfully met the specified requirements of measuring temperature and humidity in the environment with a 5% margin of error. However, our product does have some shortcomings, including:

- Lack of communication interface with a computer.
- Measurement values not reaching 100% accuracy due to device and component errors, environmental conditions, and some design flaws that impact aesthetics.

We propose new directions for project development, including:

- Expanding communication interfaces with computers and creating integrated apps for electronic devices such as phones, computers, smartwatches, etc.
- Creating a network of multiple similar devices interconnected to manage temperature and humidity over a wider range.
- Addressing and improving issues related to PCB design, components, and other aspects.

In particular, we extend sincere gratitude to our supervisor, Ms. Nguyen Thi Hue, for her dedicated teaching, guidance, and assistance in helping us achieve the best possible outcome. We eagerly welcome feedback and comments highlighting any deficiencies or limitations in the product, which will aid our ongoing development and research in the future.

Summary:

Following the completion of this project, we have gained valuable experience and new knowledge, including:

- Learning how to organize and execute a project effectively.
- Gaining insights into various methods and types of sensors for temperature and humidity measurement.
- Enhancing our understanding of the architecture of the 8051 Microcontrollers, its interaction with peripherals.
- Acquiring knowledge about the principles of circuit design, PCB design, and proficiently using software such as Altium, Proteus, and Keil C.

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