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REPUBLIC OF TURKEY

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PRECISION MEASUREMENT OF RESISTANCE WITH DIRECT MICROCONTROLLER CONNECTION

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AHMET HAKAN İNCE

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Prof. Nuran DOĞRU

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Ahmet Hakan İNCE

ABSTRACT

PRECISION MEASUREMENT OF RESISTANCE WITH DIRECT MICROCONTROLLER CONNECTION

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M.Sc. in Electrical and Electronics Engineering
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Today, many systems and sensors consist of different connection combinations of resistors. Many types of sensors, such as LDR light sensors, temperature sensors, platinum sensors, are examples of sensors consisting of resistance systems. They operate according to instantaneous change of resistance values depending on temperature and ambient conditions (as Luminous). For this reason, the correct measurement of the resistors is of great importance for the accuracy of the data to be received from the sensors. Many precision resistors and capacitive sensors measurement methods with microcontroller based on charging and discharging capacitor over resistors and calculating the elapsed time. In this thesis, measurement techniques which based on finding the value of unknown resistor by RC circuit analysis by charging the capacitor and calculating the discharging times of the capacitor over known resistors with microcontroller, then charging the capacitor again and estimating discharging time of the capacitor over the unknown resistor and then comparing the discharge times are studied. With the measurement methods, it is aimed to make more accurate measurement, by determining the errors which may occur in the measurements, minimizing these errors and value of unknown resistor is found in the most accurate way. By minimizing errors in resistance measurement, the data received from the sensors will be detected more accurately.

Key Words: Resistance Measurement Methods, Resistor Measurement with Microcontroller, Precision Measurement with Microcontroller,

ÖZET

DOĞRUDAN MİKRODENETLEYİCİ BAĞLANTISI İLE HASSAS DİRENÇ ÖLÇÜMÜ

İNCE, Ahmet Hakan
Yüksek Lisans Tezi, Elektrik ve Elektronik Mühendisliği
Danışman: Prof. Dr. Nuran DOĞRU
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60 Sayfa

Günümüzde birçok sistem ve sensorler dirençlerden oluşmaktadır. LDR ışık sensörü, sıcaklık sensörleri, platinyum sensörleri gibi bir çok sensör çeşidi direnç sisteminden oluşan sensörlere örnek olarak gösterilebilir. İçlerinde bulunan dirençlerin değerlerinin sıcaklık ve ortam koşullarının anlık değişmesine bağlı olarak çalışırlar. Bundan dolayı dirençlerin doğru ölçümü sensörlerden alınacak verilerin doğruluğu açısından büyük önem arz etmektedir. Bu tez de dirençlerin ölçümünü mikrokontroller kullanarak kapasitörü doldurup bilinen bir direnç üzerinden boşaltıp zamanı hesaplayarak daha sonra kapasitörü tekrar doldurup bilinmeyen (ölçümü yapılmak istenen) direnç üzerinden boşalma zamanlarını kıyaslayarak bilinmeyen direncin degerini RC devre analiziyle bulmaya dayalı ölçüm teknikleri araştırılmıştır. Bu ölçüm teknikleri ile daha hassas ölçüm yapmayı, yapılan ölçümlerde oluşabilecek hataları belirterek ve mevcut hataların minimize ederek direncin degerini en doğru şekilde bulunmasını amaçlamaktadır. Direnç ölçümünde oluşabilecek hatalar en düşük seviyeye getirildiğinde sensörlerden alınan veri daha dogru şekilde algılanmış olacaktır.

Anahtar Kelimeler: Direnç Ölçümü Methodları, Mikroişlemciler ile Direnç Ölçümü, Mikroişlemciler ile hassas ölçüm

''Dedicated to my family''

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I would like to express my love and gratitude to my all family for their support and always best wishes.

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LIST OF SYMBOLS

V_{tl}	Threshold voltage logic 1 to 0
V_{th}	Threshold voltage logic 0 to 1
R*	Estimated resistance
E_R	Calculated error
T	Time
Hz	Frequaency (Hertz)
K	Constant part of equation
R	Resistance
I	Current
Ln	Natural logarithm
V	Voltage
C	Capacitance
A	Alfa
β	Beta
Ω	Ohm
Π	Pi

LIST OF ABBREVIATIONS

A/D	Analog to Digital
LCD	Liquid Crystal Display
PIC	Type Of Microcontroller
D/A	Digital to Analog
DC	Direct Current
POT	Potentiometer Resistance
I/O	Input/Output
Kohm	Kilo-Ohm
Mohm	Mega-Ohm
MIR	Measurement Internal Resistance
MCV	Measurement Changing Voltage
MCR	Measurement Changing Resistance

CHAPTER I

INTRODUCTION

Many systems and sensors consist of resistor. LDR (Light Depend on Resistor) light sensors, temperature sensors, platinum sensors are just a few example of resistors which works with resistance [15-17]. Correct and precision Measurement of a resistance is important for all circuits and systems that uses resistive sensors as well as measuring the resistance of a circuit element. The new method which is called ”Proposed Method” in the thesis eliminates the amount of errors arising from the internal resistance value in the input port of the microcontroller in previous method [6]. Making more measurements with different circuit connection according to the previous method, measurements numbers and unknown numbers are synchronized and Internal resistance values is calculated accordingly sensor resistance. Thus, causing the measurement error which is arising from internal resistance is eliminated with numerical calculation with calculated discharging time with microcontroller. Since it uses only passive circuit elements instead of active circuit elements, it is accepted in measurement methods by direct microcontroller connection. Methods which are using active circuit element is disadvantageous in terms of power consumed by and cost. In the previous method, there are no measurements or calculation for the internal resistance affecting the margin of error [2,5]. The number of the measurement is not enough to calculate this value. In measurement using the circuits with microcontroller, C, VS, V_{TH} (or V_{TL}) values are need to find the sensor resistance. These values change with time and temperature. Because of these reasons, the margin of error is high in the measurement. Proposed calibration method is implemented to getting more accurate result by eliminating internal resistance of unit (pin).

CHAPTER II

ANALYSIS OF THE MEASUREMENT METHODS WITH MICROCONTROLLER

2.1 Basic Information About Measurement with Microcontroller

There are many methods that use a microcontroller connection to find resistance/capacitance values of sensors [1-14]. A/D converter based programmable measurement system in Figure 2.1, Oscillator based programmable measurement system in Figure 2.2 and Direct sensor (resistance/capacitance) to microcontroller system in Figure 2.3 are most usage example for resistive/capacitive sensor measurement with microcontroller methods. A/D converter based system is that Conversion of the measurement quantity into proportional electrical signal and use of an A/D converter and a microcontroller calculates signal value which comes from A/D. Oscillator based programmable measurement system method based on measurement of frequency, period or duty cycle and resistive/capacitive sensor value is estimated with a microcontroller by using frequency and duty cycle. One of the most important usage measurement method is Direct sensor (resistive/capacitive) to microcontroller system. Direct sensor (resistive/capacitive) to microcontroller system measurement method based on charge / discharge a capacitor over a know resistor and in this process, calculate elapsed time and then estimating unknown resistor value by comparing these elapsed times values.

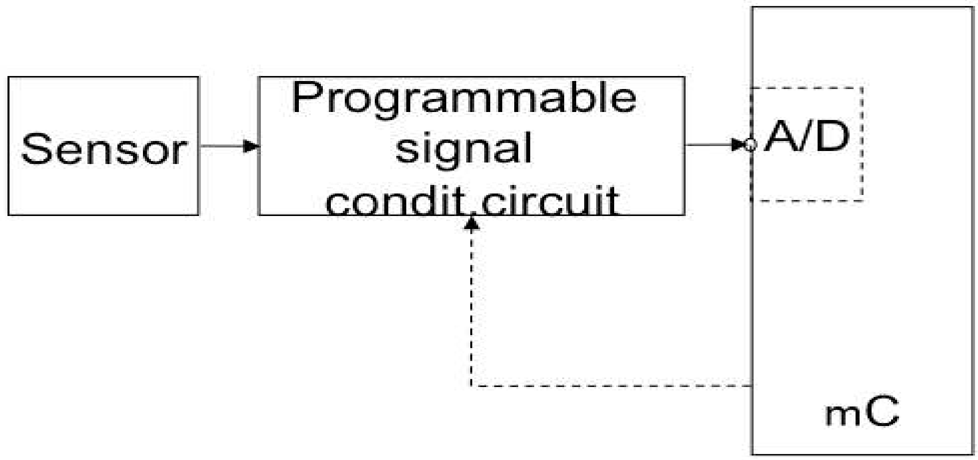


Figure 2.1 A/D converter based programmable measurement system

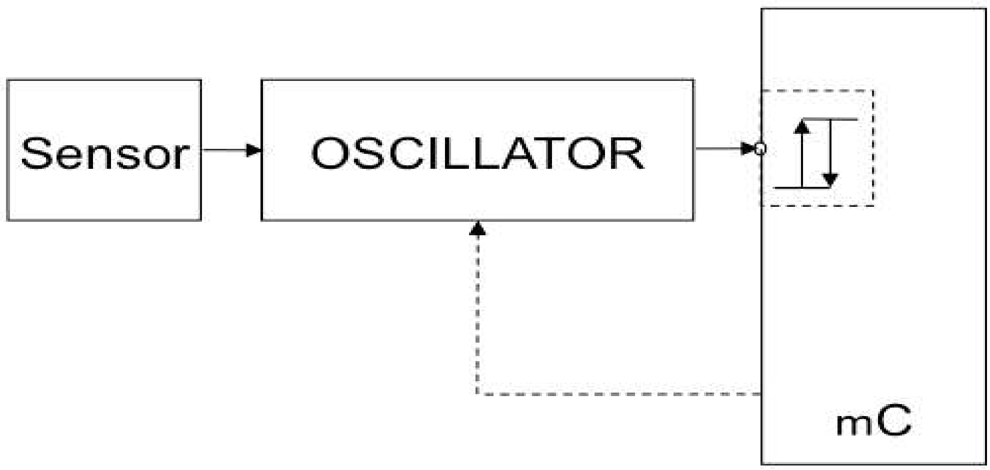


Figure 2.2 Oscillator based programmable measurement system

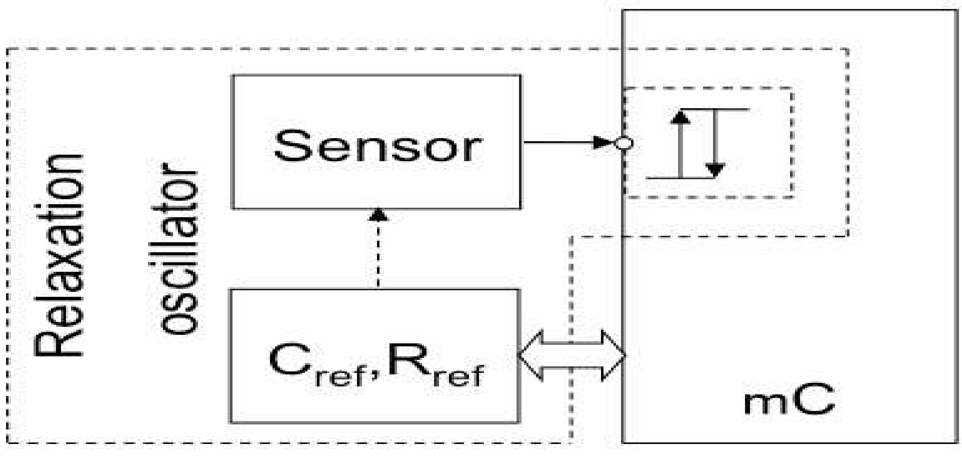


Figure 2.3 Direct sensor (resistance/capacitance) to microcontroller system

2.2 Direct Sensor (Resistive/Capacitive) to Microcontroller System

Direct Sensor (Resistive/Capacitive) to Microcontroller method is tackled in this thesis. Advantages of this method which are difference from the other methods are that use only passive component in the system and cheaper. So usage of passive component in the system provides less consuming energy. Disadvantage of Direct Sensor to microcontroller method is internal resistance of units (pins) which is used in the measurement. The internal resistance affects the measurement and resistor value. Existing measurement methods with microcontroller is analyzed in detail and internal resistance of pin (unit) of a microcontroller is removed with a new (proposed) method by improving previous methods.

Direct Sensor (Resistive/Capacitive) to Microcontroller method based on calculating the charge or discharge time of the capacitor in an RC circuit with microcontroller. In order to perform these charging / discharging operations, phase (input or output) and voltage values (0V or 5V) of the input-output units of the microcontroller are changed with code. The input phase units contain very high internal resistance value [6], so the amount of current entering input unit reaches negligible values. The input phase is used to prevent current flowing through this unit and determine that if the circuit voltage connected to the unit is below or above upper threshold level (V_{TH}) or lower threshold level (V_{TL}). If the unit is in the output phase, it has a lower internal resistance than input phase. In this phase, two different logic levels can be selected as digital 0 or 1. Switching the logic level to 1 which supplies the unit to become a 5V voltage source that can provide an average current of 20 mA. If the logic level is 0, it provides ground connection via internal resistance. Selecting the output and logic level 1 of an input-output unit will be expressed as output-1, and the output and logic level being 0 will be expressed as output-0.

Since the input-output units of non-advanced and inexpensive microcontrollers (such as PIC16F84A) are all digital, the charging or discharging times in direct connections can only be understood when certain thresholds are exceeded [6, 7]. In the previous methods, measurement is carried out in an interface circuit as shown in Figure 2.4 (a) using input / output units 1 and 2. The unit number 2 is determined as output-0 in the first level of measurement and the capacitor is discharged completely over the internal resistance of RIN2 is waited for at least five times the time coefficient. At this time, unit 1 can be specified as input or output-0

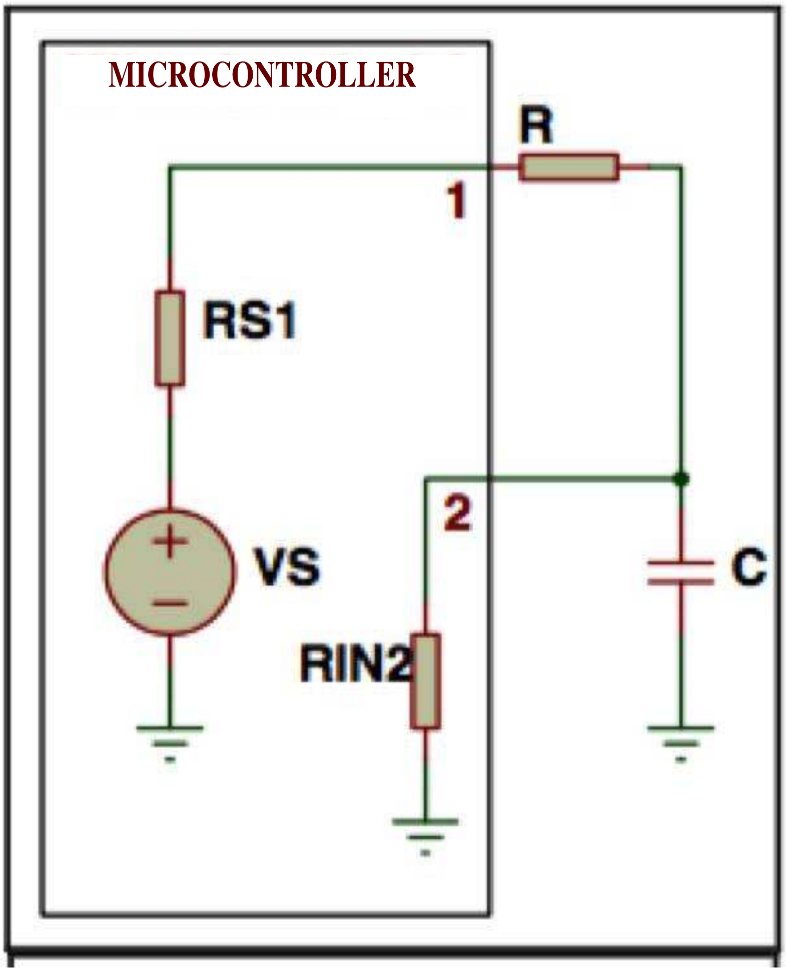


Figure 2.4 (a) Basic microcontroller interfaces capacitor charging

In the second stage, the empty capacitor is charged on the resistor which is represented by the resistor R in figure 2.4 (a). In order to charge the capacitor, unit 2 is selected as input and unit 1 is selected as output-1. While charging the capacitor, a timer in the microcontroller starts counting. While unit 1 is charging the capacitor, unit 2 checks whether the capacitor voltage exceeds a certain threshold (V_{TH}). The resistance R is estimated using the following relationship (2.1) with charging time (T) between 0V to the V_{TH} threshold.

$$R = \frac{T}{C\ln\left(\frac{vs}{vs \quad v_{TH}}\right)} \quad RS1 \tag{2.1}$$

VS in Equation (2.1) represents the voltage value of output-1 phase (approximately 5v) and RS1 is the internal resistance of pin-1 in the phase. If the time T obtained using the timer of the microcontroller and if values of the circuit elements used in the interface in Figure 2.4 (a) are known, the resistance R can be estimated with Equation (2.1). The capacitor is charged on the RS2 in the first stage and discharged on the R in the second stage in Figure 2.4 (b) and the approximate value of the resistor R is calculated by estimating the time which is required to change the logic level 1 to 0 in the input-output unit.

In Schmitt triggered input-output units, due to hysteresis (HTH), changing input pin logic level from 0 to 1 occur when charging capacitor voltage exceeds the V_{TH} threshold value, and changing logic level from 1 to 0 occur when the capacitor voltage falls below the V_{TL} threshold values. Since the noise level at the V_{TH} value is higher than V_{TL}, the calculations made by the discharge of the capacitor (measurement of the voltage level below the V_{TL}) give more accurate results.

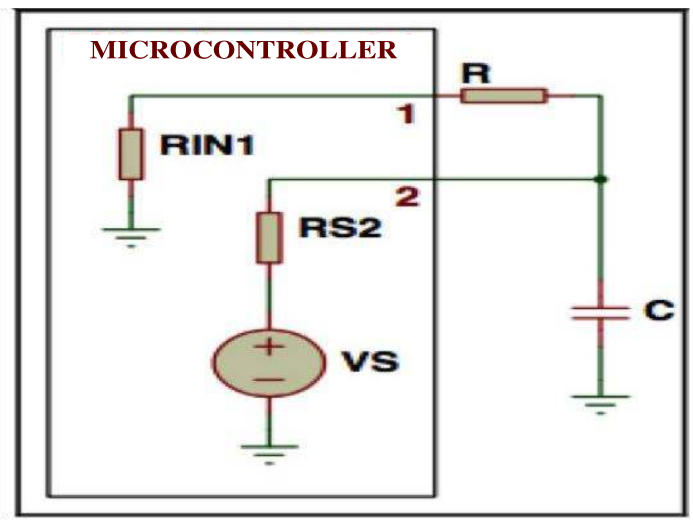


Figure 2.4 (b) Basic microcontroller interfaces capacitor discharging

2.3 One Calibration Resistor Method

In measurements by using the circuits on Figure 2.4 (a) and (b), C, VS, V_{TH} (or V_{TL}) values are needed to find the sensor resistance R. As these values change with ambient temperature and time, uncertainty and error margin in measurement is high. In order to obtain clearer results, a single resistance calibration method is applied [2]. In the single resistance calibration method (see Figure 2.5), the filled capacitor is first discharged on a well known calibration resistor (R_X) and then through the sensor (R). The elapsed times (T_X and T, respectively) for both resistor R_X and R are calculated using the timer of the microcontroller. Resistance (R) of Sensor can be estimated from the ratio of times by using the following Formula (2.2).

$$R = \frac{T}{T_X} R_X \tag{2.2}$$

$$e_R = \left| \frac{RIN2}{RX + RIN2} + \frac{RX.RIN1}{R.(RX + RIN2)} \right| \tag{2.3}$$

C, VS, V_{TH}, (or V_{TL}) values do not require to calculate and do not effect to value of a measurement in one calibration method. So uncertainty and error margin in measurement is lower than the previous basic method in Chapter 2.2. The margin of error of the one resistance calibration method can be calculated using Formula (2.3) [2, 3, 4]. In the Equation (2.3), RIN1 and RIN2 are the internal resistances of the input-output units 1 and 2 in the output-0 phase in which the capacitor is discharged. Since these values (even if the same brand and model) are different in each microcontroller, the error amount has random value for each microcontroller.

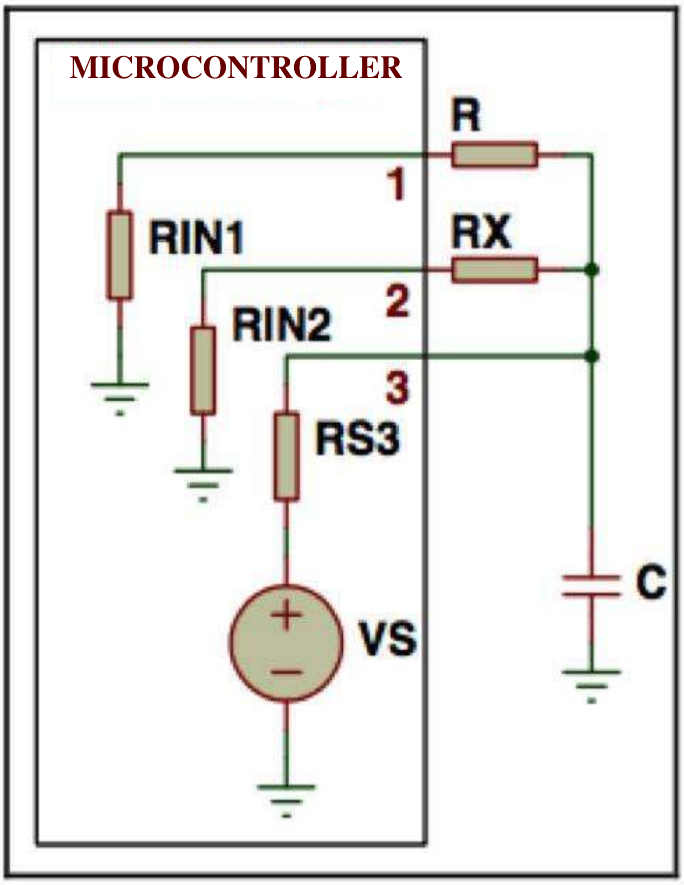


Figure 2.5 One calibration resistor circuit with microcontroller

2.4 Two Calibration Resistors Method

To reduce the amount of error of the previous methods in Chapter (2.2) and (2.3), two calibration resistors method (see Figure 2.6) is presented [2, 3]. In this method, the capacitors which are discharged over two resistors (RX1 and RX2) whose exact values are known, are then discharged with the resistor (R) and the elapsed times (T1, T2 and T respectively) are calculated with timer in microcontroller. In this method R resistance can be calculated using Equation (2.4) below.

$$R = \frac{T - T_1}{T_2 - T_1}(RX2 - RX1) + RX1 \tag{2.4}$$

Error margin of the method can be calculated with Equation (2.5).

$$R_{ij} = RIN_i \quad RIN_j, i, j = 1,2,3$$

$$e_R = \left| \frac{R_{32}}{RX2 \quad RX1 + \quad R_{32}} + \frac{1}{R} \frac{RX1 \quad R_{31} \quad RX2 \quad R_{21}}{RX2 \quad RX1 + \quad R_{32}} \right| \tag{2.5}$$

Error margin of the method is expecting lower than previous the method in Chapter (2.2) and (2.3) [2-4]. Three signal methods are obtained by selecting a zero value of the RX2 value in the two calibration resistors method and adding a series, small value resistor to the capacitor [18]. The error margin of this method can also be found when the value RX2 = 0 is substituted in (2.5). The error margins both the two calibration resistors and three signal methods vary according to the internal resistance of the input-output units. This can also be said as a disadvantage of the methods.

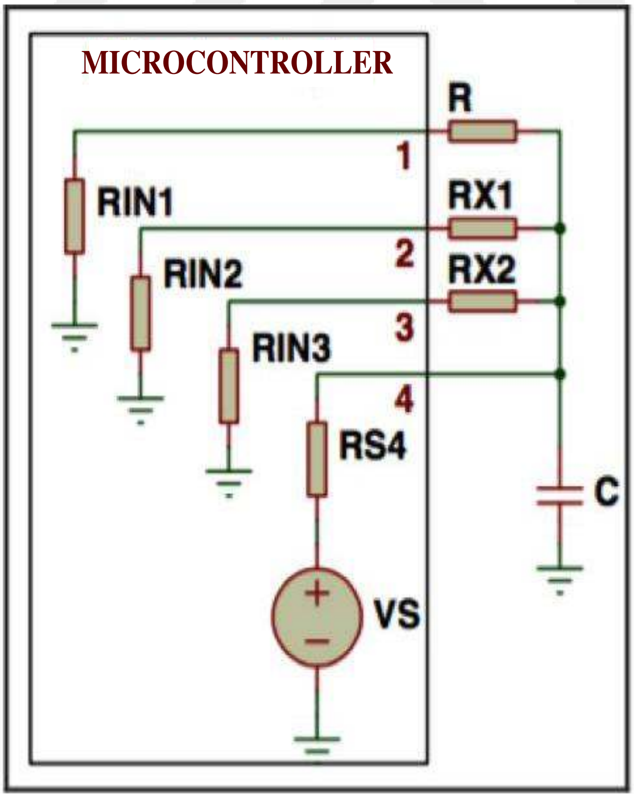


Figure 2.6 Two calibration resistors circuit with microcontroller

2.5 Proposed Method (New Method)

In previous methods in Chapter (2.2), (2.3) and (2.4) [2-4], measurements are not made to find the internal resistance affecting the margin of error. Only count of measurements is not sufficient to calculate internal resistance values of each pins. For example, in the one calibration resistor method, the capacitor is discharged once through the calibration resistance and once through the sensor resistance, and the elapsed times are calculated. In fact, each measurement gives us one equation in terms of unknown variables in the circuit. Therefore, a total of two equations are obtained in the one calibration resistor method. However, the sensor's own resistance and the internal resistances of the input-output units connected to the resistors give us a total of three unknowns. Two measurements are not sufficient to find three unknown values. Similarly, in the two resistances calibration method, three measurements and four unknown variables are obtained, again the count of measurements is not enough to solve unknowns. Therefore, assumptions such as zero or equal internal resistance are used in these methods and these assumptions cause error in measurements.

Measurement with the proposed method eliminates the amount of error which comes from the internal resistance values and internal resistance differences in the input ports of a microcontroller in the previous methods. The differences from the previous methods [2-4], more measurements are made with different circuit connections, the unknown values and the count of measurements are equalized, the internal resistance values of pins is estimated and the sensor resistance are calculated accordingly. In this way, error which comes from internal resistance of a pin is eliminated by using the measured numerical values in the proposed method.

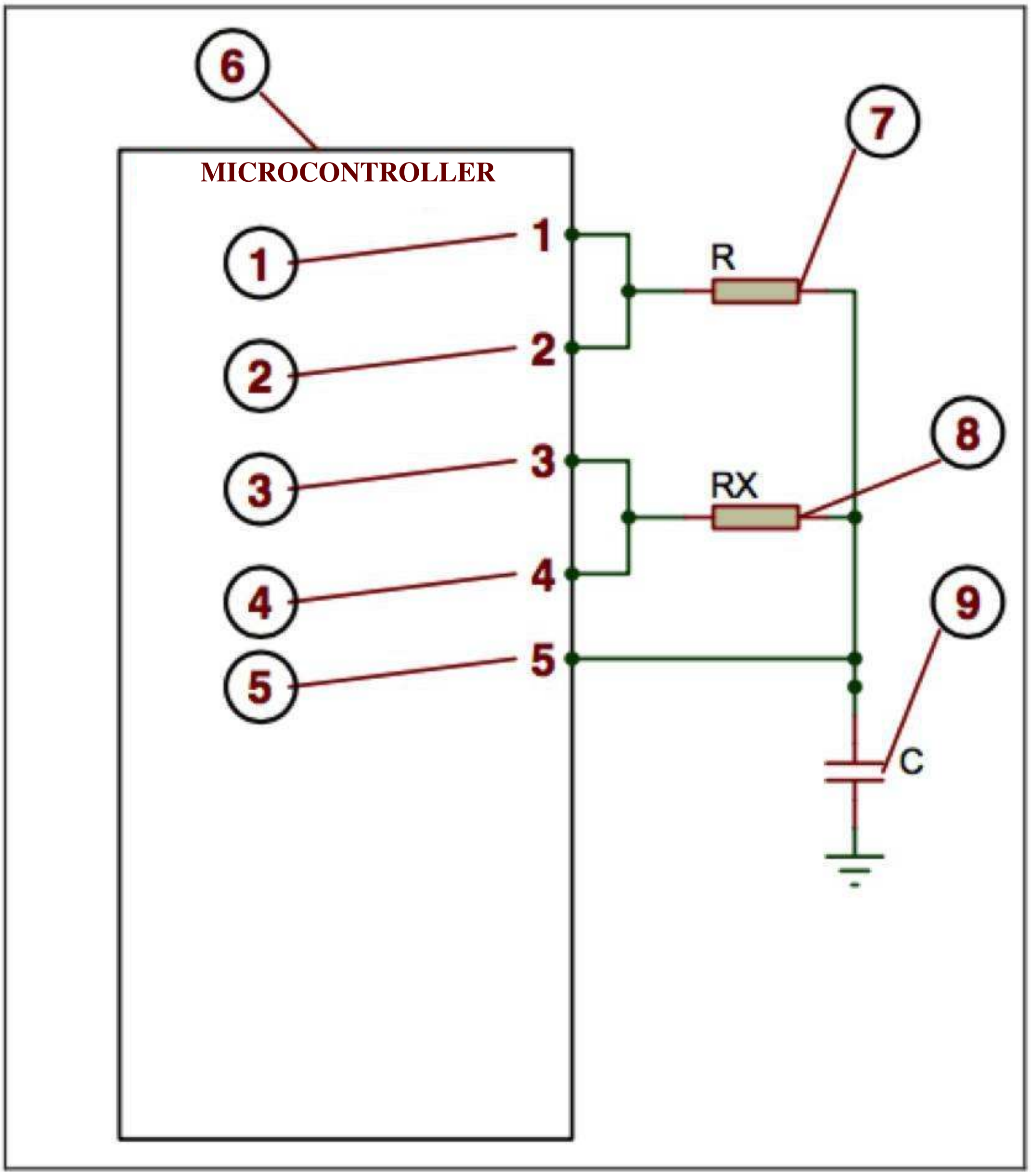


Figure 2.7 Proposed (new) method structure

The measurement method outlined in the circuit and process steps given in Figure 2.7 is used to measure the value of the resistive sensor / resistor(R)-7 shown in the circuit. In this circuit, the microcontroller (6) provides the input-output units (pins) (1, 2, 3, 4, 5) to be operated in the input or output phase. Thus charging and discharging the capacitor (9) is provided. The charged capacitor (9) is discharged through the input-output units (pins) (1, 2, 3, 4) 1, 2, 1 and 2 - 3 - 4- 3 and 4, respectively until it reaches a voltage low enough to be detected at the logic-0 level by the microcontroller. This is done by selecting the output-0V to be discharged from the capacitor (9) and the unit (output-0V) shows low internal resistance. During the discharge operation of the capacitor (9), the other input-output units are operated in the input phase and show high internal resistance and the current flowing over them is negligible amounts. Discharge times on the input-output units ((1, 2, 3, 4, 5) (pins) of the full capacitor (9) are calculated and recorded by the microcontroller (6) .

In an RC circuit, if R is the resistance value, C is the capacitance value, V_r is used when the capacitor is discharged voltage, V_t is the limiting voltage between logic 1-0 and V_0 is the first voltage of the capacitor,

V_0 to V_t the discharge time of the capacitor is expressed by the Equation (6) below.

$$t = \quad RC\ln\frac{V_r \quad V_t}{V_r \quad V_0} \tag{2.6}$$

If constant part of the equation above is defined as ‘k’.

$$k = \quad C\ln\frac{V_r \quad V_t}{V_r \quad V_0} \tag{2.7}$$

Discharging time of the capacitor can be expressed

$$t = kR \tag{2.8}$$

In the other methods, the discharge of the capacitor (9) is carried out only once on an input-output unit. Since the internal resistance of this unit is unknown, the error rate due to the internal resistance of the measurement is uncertain. In this method, unlike the others, each of the resistors (7) and (8) is first discharged via two different input-output units and then discharged over the two units together. The internal resistances of these two units are parallel to each other due to the connections in Figure 2.7 in the discharges provided by both input-output units. Thus, three different measurements are made depending on the internal resistance of these two input-output units. The first measurement measures the internal resistance of the first input-output unit, the second only to the second unit's internal resistance, and the third measurement measures the internal resistance of both units in parallel.

If Rin, i, i is the internal resistance of the input-output unit, the values from the first two measurements are $t_1 = k(R + R_{in1})$ and $t_2 = k(R + R_{in2})$, respectively. The last measurement value is
$t_p = k(R + R_{in1} \| R_{in2})$

From these three measurements

$$R = (t_p \quad \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)}) / k \tag{2.9}$$

The Equation (2.9) is obtanined.
Similarly, The next three measurement on Rx by microcontroller (6) are t_{x1}, t_{x2}, t_{xp}, respectively. The calibration resistor value as other variables can be express in the Equation (2.10)

$$R_x = (t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})}) / k \tag{2.10}$$

From resistive Equations (2.9) and (2.10) sensors,

$$R = RX \frac{(t_p \quad \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)})}{(t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})})} \tag{2.11}$$

Resistance value R Can be estimated with Equation (2.11) above. Since exact value of calibration resistance RX is known by the microcontroller (6) and other parameters are again measured by the microcontroller (6), the microcontroller (6) can calculate the resistor (7) value R by using the Equation (2.11).

Similarly, Internal Resistance of the units (pins) (1, 2, 3, 4) can be estimated with Equation (2.12), (2.13), (2.14), (2.15) respectively.

$$R_{in,1} = RX\frac{(t_1 \quad t_p + \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)})}{(t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})})} \tag{2.12}$$

$$R_{in,2} = RX\frac{(t_2 \quad t_p + \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)})}{(t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})})} \tag{2.13}$$

$$R_{in,3} = RX\frac{(t_{x1} \quad t_p + \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)})}{(t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})})} \tag{2.14}$$

$$R_{in,4} = RX\frac{(t_{x2} \quad t_p + \sqrt{(t_1 \quad t_p)(t_2 \quad t_p)})}{(t_{xp} \quad \sqrt{(t_{x1} \quad t_{xp})(t_{x2} \quad t_{xp})})} \tag{2.15}$$

CHAPTER III

METARIALS

3.1 PIC16F84A

It is used in all calibration and measurement types in the thesis. PIC 16F84A has 68 bytes data memory (RAM) and 64 bytes EEPROM. It also has 13 I/O units (pins) which are user-configured on a unit-to-unit basis. Some pins are multiplexed with other device functions. These functions include: External interrupt, change on PORTB interrupt, Timer0 clock input. PIC16F84A has two memory blocks which are program memory and the data memory. Each of them has its own bus, so that access to each block (memory) can eventuate during the same oscillator cycle [19].

(Absolute Maximum Ratings)

Ambient temperature under bias...-55°C to +125°C

Storage temperature ....-65°C to +150°C

Voltage on any pin with respect to VSS (except VDD, MCLR, and RA4) ....

-0.3V to (VDD + 0.3V)

Voltage on VDD with respect to VSS ....-0.3 to +7.5V

Voltage on MCLR with...-0.3 to +14V

Voltage on RA4 with respect to VSS Total ....800 mW

Maximum current out of VSS pin ....150 mA

Maximum current into VDD pin ....100 mA

Input clamp current, IIK (VI < 0 or VI > VDD)...± 20 mA

Output clamp current, IOK (VO < 0 or VO > VDD) ....± 20 mA

Maximum output current sunk by any I/O pin...25 mA

Maximum output current sourced by any I/O pin ....25 mA

Maximum current sunk by PORTA ....80 mA

Maximum current sourced by PORTA..50 mA

Maximum current sunk by PORTB..150 mA

Maximum current sourced by PORTB ....100 mA

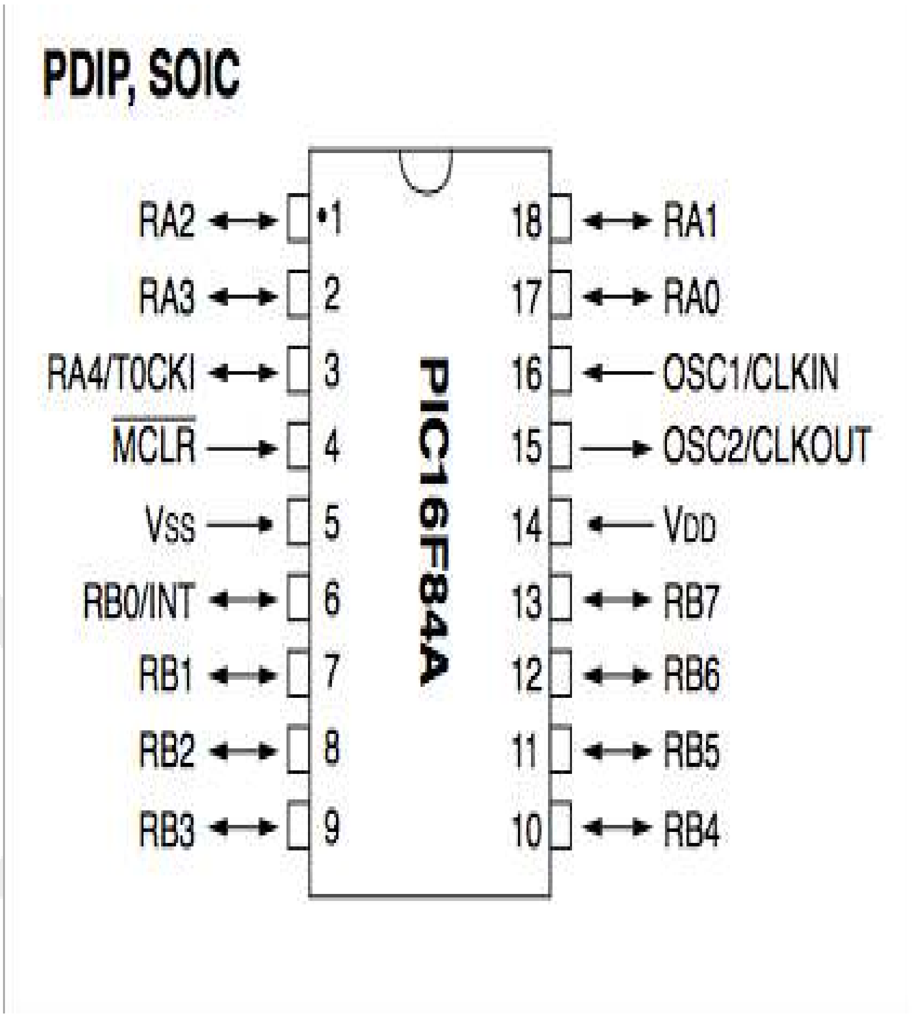


Figure 3.1 PIC16F84A pin diagram [19]

3.2 PIC16F877

The PIC16F87X devices have a 13-bit program counter capable of addressing an 8K x 14 program memory space. There are have 8K x 14 words of FLASH program memory in PIC16F877 device, and 4K x 14 in PIC16F873/874 devices. It is defference between PIC16F7.. series. Accessing a location above the physically implemented address will cause a wraparound [20].

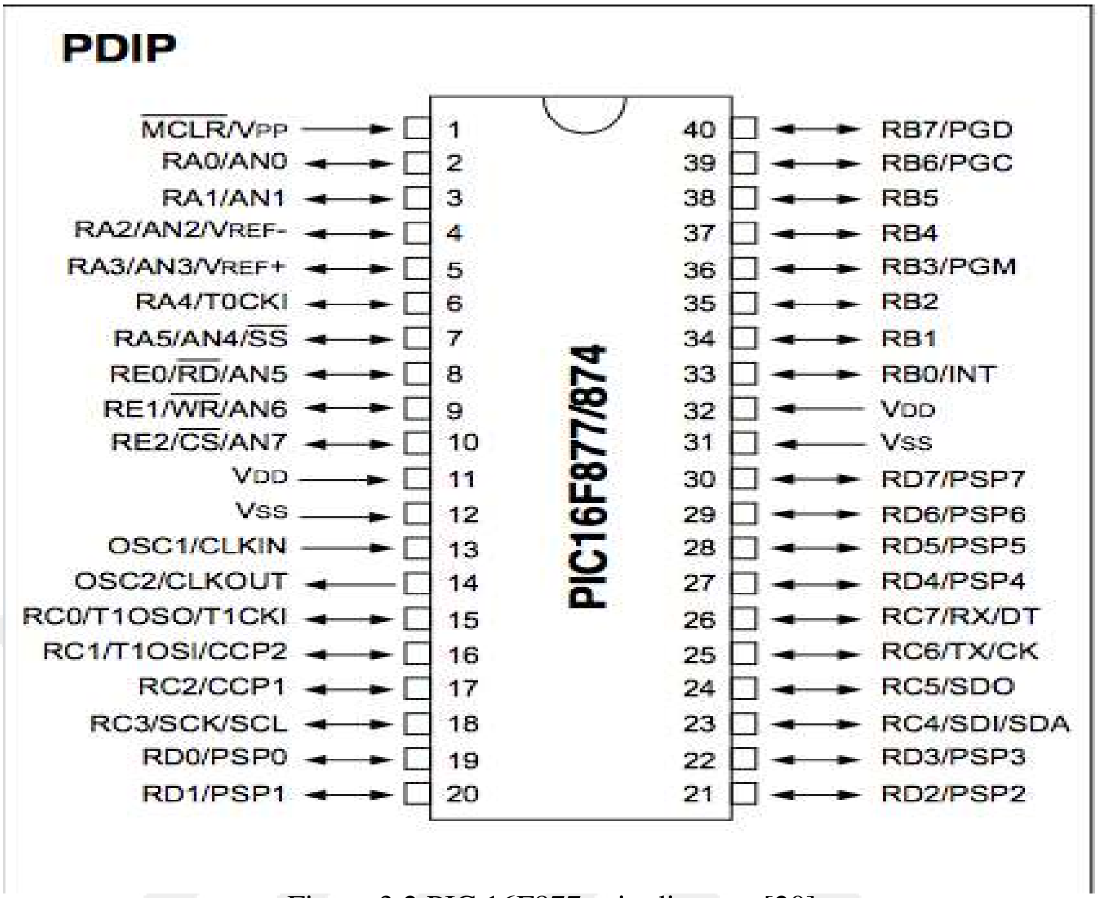


Figure 3.2 PIC 16F877- pin diagram [20]

3.3 LCD

LCD means **l**iquid **c**rystal **d**isplay, it is a type of display which is used in digital watches and many computer types. LCD displays utilize two sheets of polarizing material with a liquid crystal solution between them. Monochrome LCD images usually appear as blue or dark gray images on top of a grayish-white background. Color LCD displays use two basic techniques for producing color: Passive matrix is the less expensive of the two technologies.

Figure 3.3 2x16 LCD

3.4 DMM 4040 Digital Precision Multi-meter

As the circuits in embedded system designs become more sophisticated with tighter tolerances, you must measure a multitude of different parameters with a high rate of accuracy to validate your design. The DMM 4040 6.5 digit bench multi-meters pack many different functions and analysis into one instrument, all with exceptional precision and performance. Typical multi-meter measurements- volts, ohms, and amps – are made with basic VDC accuracy of up to 0.0024 %, and resolution of 100pA and 10 μΩ, ensuring you have the performance you need for today's demanding designs [21].

Figure 3.4 DMM 4040 precision multi-meter

3.5 Potentiometer

A potentiometer has three terminal which is sliding or rotating on the three-terminal resistor. Only two terminals are used, one of them called 'end' and the other 'wiper', it behaves as a variable . It has maximum and minumum range.it can only be adjustable value between maximum and minumum range. It also has streght value againist current. When choosing potentiometer type for any system, maximum-mininumum values and power strenght of potentiometer should be considered.

Figure 3. 5 Potentiometer which is used on the lab

CHAPTER IV

MEASUREMENTS EXPERIMENTS

4.1 Measurement of Threshold Voltage of PIC16F84A and 16F887 for all Pins

Threshold voltage V_{TH}, (or V_{TL}) is a voltage level that changing pin logic level 1 to 0 (V_{TH}) or changing logic level 0 to 1 (V_{TL}). Measurement of threshold voltage of the pins (units) is one of the most considerable things for precision measurement because the threshold voltage level is used to calculate discharging time of capacitor by using Equation (4.1) below. V_0 is initial capacitor voltage, V_r is capacitor voltage and V_{th} is threshold voltage of the unit (pin).So firstly All units of the PIC 'except the pin to be measured' threshold voltage are made as input . The pin which is measured threshold voltage is made as output pin. The threshold voltage of all pins of PIC16F84A and 16F887 are founded by using DMM4040 and same model but different PIC values are measured and the results are compared with each other .The all data which is obtained from the measurement is indicated in a chart in the Chapter 5 of the thesis.

$$T = \quad RC \ln \frac{V_r \quad V_{th}}{V_r \quad V_0} \tag{4.1}$$

4.2 Measurement Internal Resistance in RA0 Pin of PIC16F84A

The next observation is that effects of current on internal resistance of the pin (RA0) of the PIC16F84A. First step, a potentiometer which has maximum 1Mohm is connected to RA0 pin of 16f84A and the Vin supplied voltage is adjusted constant 5v. Instant resistance of pot, the current which enter in the RA0 and the pot voltage is measured by changing resistance of the pot and then Rin(internal resistance of RA0) is estimated with Equation (4.2). After measurement current-Rin and Rpot-Rin graph is created by using matlab for better analysis.

$$\frac{V_{in}}{I} \quad R_{pot} = R_{in} \tag{4.2}$$

The another important thing that voltage effect on internal resistance R_{in}. Again a potentiometer is connected to pin RA0 and set it a constant resistance value after that measure the current by changing voltage (V_{in}) and calculated the internal resistance of RA0 (R_{in}) by using Equation (4.2).

4.3 Calculate Discharging Time of a Capacitor by using PIC16F887

In this process, a code is composed to calculate discharging time of a capacitor. Discharging time value of a capacitor is used to calculate the resistor which is unknown with Equation (4.3). The code is composed in C and MikroC pro .In thıs code, TMR0 interrupt and pin change interrupt is used to calculate discharging time of the capacitor during the pin level 1 to 0. V_R is calculated by using the capacitor discharging time in the Equation (4.3).

$$V_R(t) = V * e^{\frac{t}{RC}} \tag{4.3}$$

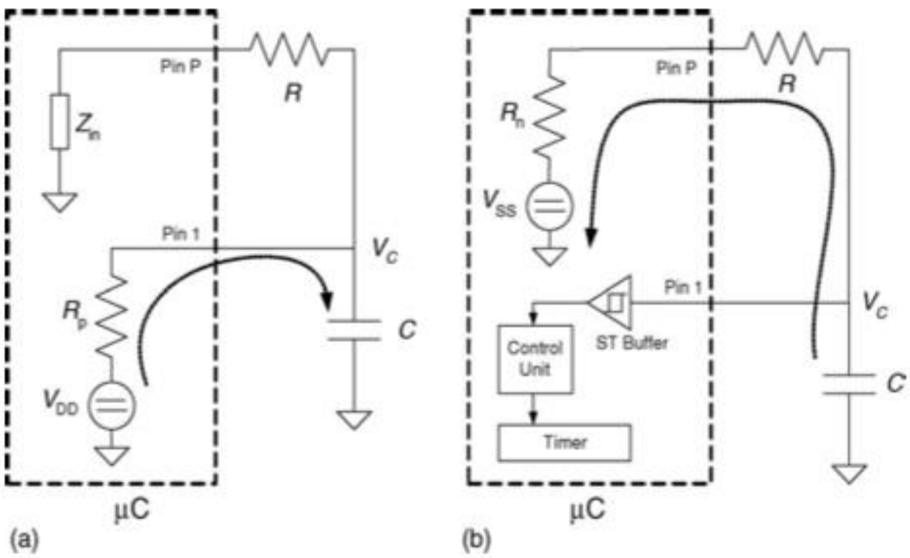


Figure 4. 1 Charging (a) and discharging (b) diagram [2]

4.4 Design One Calibration Resistor Method

In this process, one calibration resistor system is designed on a breadboard to measure a resistor which is unknown. In the system, one calibration resistor which exact value is known is used to eliminate error which comes from calculating threshold values. First, a code is written in MicroC pro to calculate discharging time of the capacitor on the R1(unknown resistor) and Rc(calibration resistor). In the code, first step R1 pin and Rc are as input pin and RB0 is as output pin and 5v to charge the capacitor in full. After charge the capacitor full in, the code makes RB0 as input, Rx as input, Rc as output pins and 0 volt. Then, the capacitor discharge on Rc pins and meanwhile, discharging time of the capacitor is estimated by timer in the code by microcontroller and then again the process is made to charge the capacitor in full and the code make RB0 and Rc pins as input and Rx pin as output and 0 volt and then discharge the capacitor on the Rx pin and meanwhile, the discharging time is estimated by using TMR0 interrupt function in the code. Finally, after calculation of the discharging time on R1 and Rc pins. By using the discharging times in the Equation (4.4) , the unknown resistor is calculated. Nx is the discharging time on the Rx pin and Nc is the discharging time on the calibration Rc.

$$R_x = \frac{N_x}{N_c} * R_c \quad (4.4)$$

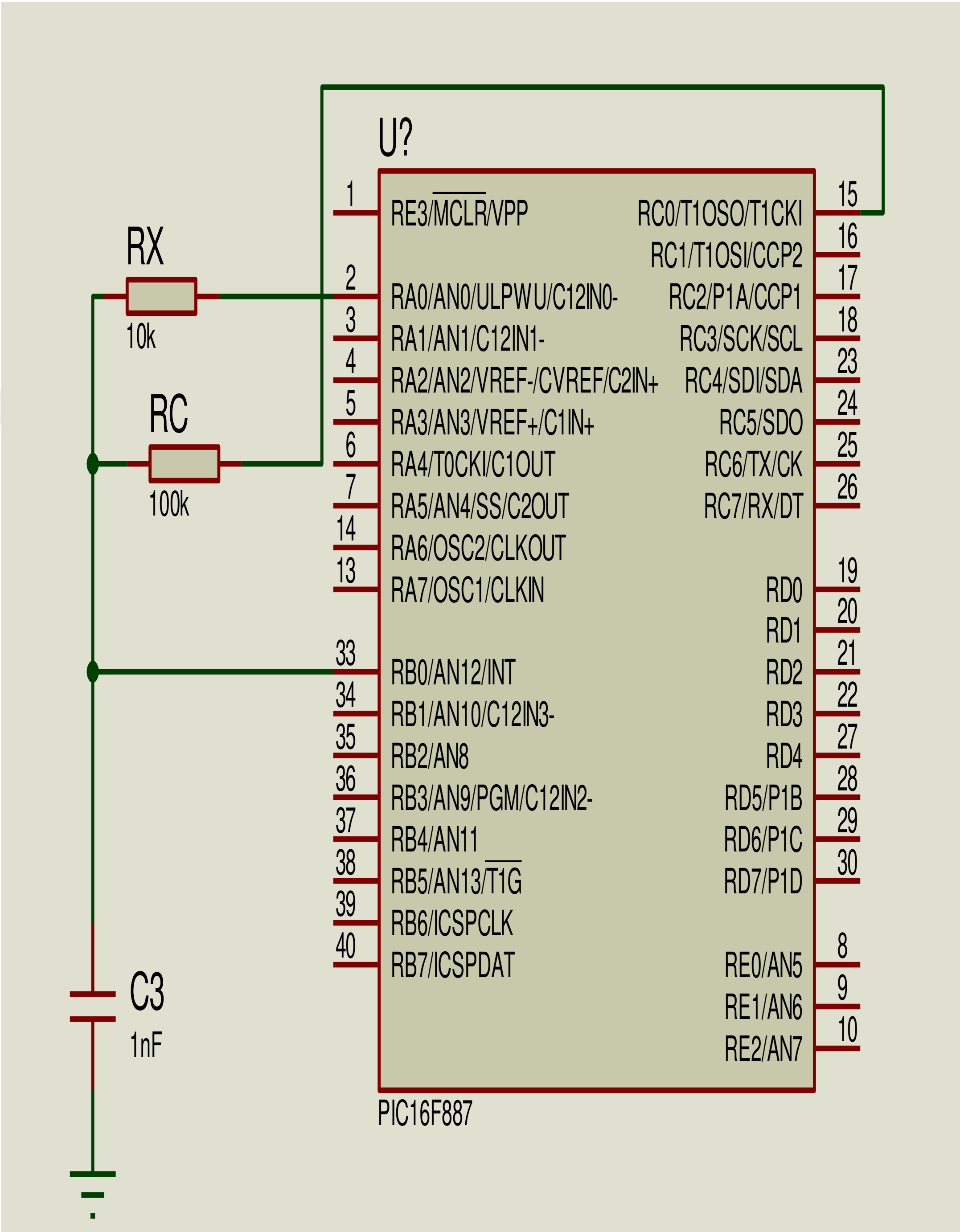


Figure 4.2 One calibration method proteous diagram

4.5 Design Two Calibration Resistors Method

In this step, two calibration resistors which are known very well are used and represented respectively R1, R2 and the resistor which is unknown is represented Rx. The advantage of this method is to eliminate error which comes from internal resistance of the capacitor. Firstly, the capacitor is charged in full by making RB0 output 5 volt and Rc1, Rc2, Rx are as input. After capacitor is full, discharge the capacitor on the Rc1 and the discharging time is Nc1 and then again charge the capacitor in full and then discharge on the Rc2 and the discharging time is Nc2.The other process is that again charge the capacitor in full and then discharge on the Rx and the discharging time is Nx. Rx is calculated with all discharging time of the capacitors on Rc1,Rc2,Rx by using Equation (4.5).

$$R_x = \left(\frac{N_x \quad N_{c1}}{N_{c2} \quad N_{c1}}\right) * (R_{c2} \quad R_{c1}) + R_{c1} \qquad (4.5)$$

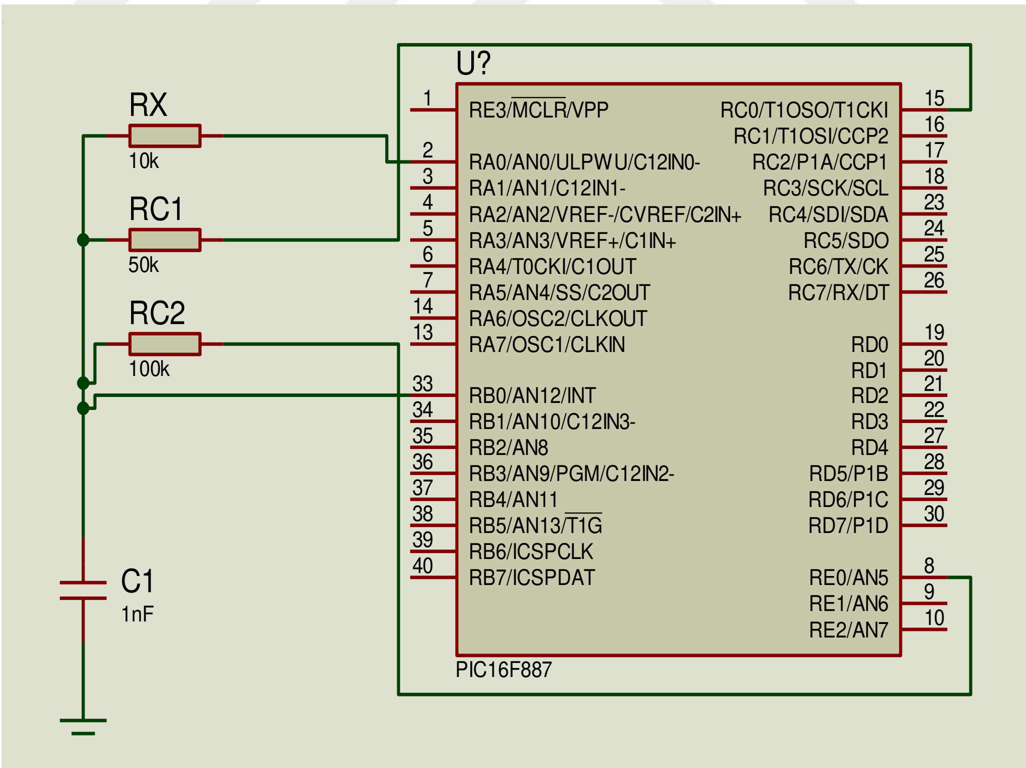


Figure 4. 3 Two calibration resistors method with PIC16F887 proteous diagram

CHAPTER V

MEASUREMENT IMPLEMENTATION AND RESULTS

5.1 Measurement of Rin (RA0)

In this part, a potantiometer which has maximum 1 Mohm is used .The pot is connected to unit RA0 of a PIC16F877. RA0 pin is made as output (0v) pin with code and supplied voltage is 5v. The internal resistance of RA0 is calculated by changing the pot resistance. Voltage on the pot is measured and calculated Rin by using Equation 4.2. (Voltage in the chart below is Rin voltage)

Table 5.1 Internal resistance of PIC16F877

Resistance	Voltage (Rin)	Rin
87.0 kΩ	0.26 V	4.772 kΩ
86.9 kΩ	0.260 V	4.766 kΩ
77.0 kΩ	0.291 V	4.758 kΩ
70.8 kΩ	0.316 V	4.776 kΩ
61.7 kΩ	0.358 V	4.758 kΩ
56.22 kΩ	0.390 V	4.756 kΩ
53.12 kΩ	0.411 V	4.757 kΩ
49.76 kΩ	0.437 V	4.7655 kΩ
40.53 kΩ	0.526 V	4.7650 kΩ
34.43 kΩ	0.608 V	4.780 kΩ
25.89 kΩ	0.779 V	4.778 kΩ
21.23 kΩ	0.919 V	4.780 kΩ
13.96 kΩ	1.276 V	4.783 kΩ
8.07 kΩ	1.697 V	4.146 kΩ
4.479 kΩ	1.830 V	2.585 kΩ
3.437 kΩ	1.890 V	2.088 kΩ
2.268 kΩ	2.007 V	1.521 kΩ
43.2 Ω	4.554 V	441 Ω
34.4 Ω	4.671 V	487.6 Ω
3.6 Ω	5.030 V	167.6 Ω
3.3 Ω	5.035 V	474.2 Ω
3.2 Ω	5.037 V	435.6 Ω

5.2 Measurement of Threshold Values

In this part, threshold voltage of different microcontroller types, different pins of a PIC, same model PIC and same pins are measured and showed below. PIC18F887 and PIC16F84A are used for this measurement.

Table 5.2 Threshold values of PIC16F887 and 16F84A

Measurement	PIC NUMBER	PORT	Threshold	Lower
Same PIC 2 different Ports				
	16F84A	A,0	1.2	
	16F84A	B,0	1.3	
Same PIC model 3 same pin number				
	16F84A	A,0	1.2	
	16F84A	A,0	1.1	
	16F84A	A,0	1.2	
RA4 measurement				
	16F84A	RA4	2.7	1.5
Same PIC 4 different ports				
	16F887	A,3	1	
	16F887	B,3	1	
	16F887	C,3	2.7	
	16F887	D,3	1	
Different PIC(same model)same Port measurement(I)(PIC 1 values)				
	16F887	A,3	1	
	16F887	B,3	1	
	16F887	C,3	2.6	
	16F887	D,3	1	
Different PIC(same model)same Port measurement (II)(PIC 2 values)				

	16F887	A,3	1	
	16F887	B,3	1	
	16F887	C,3	2.7	
	16F887	D,3	1.1	
Different PIC (same model) same Port measurement (III)(PIC 3 values)				
	16F887	A,3	1.1	
	16F887	B,3	1.2	
	16F887	C,3	2.7	
	16F887	D,3	1	
Different PIC(same model)same Port measurement (IV)				
	16F887	A,3	1	
	16F887	B,3	1	
	16F887	C,3	2.7	
	16F887	D,3	1	
Pin RA4 measurement				
	16F887	RA4	1	
Measurement of all PORT C pins				
	16F887	RC1	2.7	
	16F887	RC2	2.7	
	16F887	RC3	2.7	
	16F887	RC4	2.8	
	16F887	RC5	2.7	
	16F887	RC6	2.7	
	16F887	RC7	2.7	
	16F887	RC0	2.7	
Lower bound of RC				
	16F887	RC		1.4

5.3 Different Crystal Effects (Calibration Resistance is 10Kohm)

Different crystal effects is tried to find with one calibration technique in this part. 4,8,20 MHz crystals and 10 Kohm calibration resistor are used in order. A potantiometer resistance (Max value 1Mohm) value is measured with LCD by using PIC16F84A and with DMM 4040 precision measurement device gradually. Measurement with DMM 4040 is accepted correct value of the pot resistance and the error margin is estimated.

Table 5.3 Error calculation with 4 MHz crystal (Rc = 10 Kohm)

Crystal 4MHz

Measurement with LCD (kohm)	Measurement with DMM4040 (kohm)	Error	% Margin of Error
1,0459	1,014761	0,031139	3,068604331
3,2278	3,227005	0,000795	0,024635847
5,4731	5,522838	0,049738	0,900587705
6,8125	6,874852	0,062352	0,906957706
9,8949	9,989765	0,094865	0,949621938
11,861	11,99891	0,13791	1,1493544
12,742	12,92667	0,18467	1,428596847
14,964	15,17941	0,21541	1,419093364
21,999	21,93877	0,06023	0,274536813
33,46	32,96966	0,49034	1,487246153
39,814	39,15521	0,65879	1,682509173
52,381	51,2405	1,1405	2,225778437

Table 5.4 Error calculation results with 8 MHz crystal (Rc = 10 Kohm)

Crystal 8 MHz

Measurement with LCD (kohm)	**Measurement with DMM4040 (kohm)**	**Error**	**% Margin of Error**
1,0192	1,017004	0,002196	0,215928354
3,1733	3,238052	0,064752	1,99972082
5,3451	5,504029	0,158929	2,887502955
6,6446	6,845586	0,200986	2,935994084
9,8588	9,993848	0,135048	1,351311327
10,03	10,15365	0,12365	1,217788677
11,932	12,00214	0,07014	0,584395783
12,838	12,90879	0,07079	0,548386022
15,152	15,15536	0,00336	0,022170374
22,077	21,9457	0,1313	0,598294882

Table 5.5 Error calculation results with 20 MHz crystal (Rc = 10 Kohm)

Crystal 20 MHz

Measurement with LCD (kohm)	Measurement with DMM4040 (kohm)	Error	% Margin of Error
0,98516	1,016468	0,031308	3,080077287
3,226601	3,0985	0,128101	4,134290786
5,521726	5,3955	0,126226	2,339468075
6,872187	6,7434	0,128787	1,909822938
9,986765	9,876	0,110765	1,121557311
11,98821	11,868	0,12021	1,01289181
12,92037	12,779	0,14137	1,106268096
15,15934	15,035	0,12434	0,827003658
21,91442	21,725	0,18942	0,871898734
32,658	32,9561	0,2981	0,904536641
38,757	39,12399	0,36699	0,938017825
51,17809	50,496	0,68209	1,35078026

5.4 Different Crystal Effects (Calibration Resistance is 1Kohm)

Aim of this part is that to see different crystal effect on measurement of any resistance and calculate margin of error. One calibration resistance technique is applied in this part . Pot which has max 1 Mohm and 4,8,20 MHz crystals are used. Pot Resistance is measured with PIC16F84A and Dmm 4040. The Measurement value with PIC16F84A is displayed on a LCD. The pot resistance measurement with Dmm 4040 is accepted correct value of the pot resistance (reference value). Error is estimated with LCD and Dmm 4040 values.

Table 5.6 Error calculation results with 4 MHz crystal (Rc = 1 Kohm)

Crystal 4MHz

Measurement with LCD (kohm)	Measurement with DMM4040 (kohm)	Error	% Margin of Error
0,96922	1,014686	0,045466	4,480795044
11,805	12,92845	1,12345	8,689750125
10,437	11,99674	1,55974	13,00136537
8,7757	10,07607	1,30037	12,90552765
48,695	51,22614	2,53114	4,941110144
4,8483	5,521857	0,673557	12,19801599
2,8563	3,22667	0,37037	11,47839723
8,7019	9,988485	1,286585	12,88068211
13,249	15,17375	1,92475	12,68473515
20,439	21,93504	1,49604	6,820320364
6,02	6,872445	0,852445	12,40380971
37,01	39,13711	2,12711	5,435020624

Table 5.7 Error calculation results with 8 MHz crystal (Rc = 1 Kohm)

Crystal 8 MHz

Measurement with LCD (kohm)	Measurement with DMM4040 (kohm)	Error	% Margin of Error
1,0192	1,017004	0,002196	0,215928354
3,1733	3,238052	0,064752	1,99972082
5,3451	5,504029	0,158929	2,887502955
6,6446	6,845586	0,200986	2,935994084
9,8588	9,993848	0,135048	1,351311327
10,03	10,15365	0,12365	1,217788677
11,932	12,00214	0,07014	0,584395783
12,838	12,90879	0,07079	0,548386022
15,152	15,15536	0,00336	0,022170374
22,077	21,9457	0,1313	0,598294882

Table 5.8 Error calculation results with 20 MHz crystal (Rc = 1 Kohm)

Crystal 20 MHz

Measurement with LCD (kohm)	Measurement with DMM4040 (kohm)	Error	% Margin of Error
0,98516	1,016468	0,031308	3,080077287
3,226601	3,0985	0,128101	4,134290786
5,521726	5,3955	0,126226	2,339468075
6,872187	6,7434	0,128787	1,909822938
9,986765	9,876	0,110765	1,121557311
11,98821	11,868	0,12021	1,01289181
12,92037	12,779	0,14137	1,106268096
15,15934	15,035	0,12434	0,827003658
21,91442	21,725	0,18942	0,871898734
32,658	32,9561	0,2981	0,904536641
38,757	39,12399	0,36699	0,938017825
51,17809	50,496	0,68209	1,35078026

5.5 MCR Effect on RA0 Pin (RA0 is as Input)

In this part, the internal resistance of RA0 pin is calculated by measuring pot resistance with Dmm 4040 precision multi-meter when RA0 is as input pin. Pot which has max 1 Mohm and PIC16F84A are used. The Supplied voltage approximately constant 5v and RA0 pin is made as input pin with code. RA0 pin (unit) is measured by changing resistance value of the pot. Aim of this part is that to see changing resistance effect on internal resistance of a pin of a microcontroller.

Table 5.9 MCR effect on internal resistance of input pin measurement results

	Vin	VRA0	R(pot)(kohm)	RA0(kohm)	I(mA)
Min Value	5,026273 V	1,461101 V	970,8059K		
Max Value	5,029827 V	1,461210 V	970,8957K		
Average Value	5.028925	1,461186 V	970.8757	397.627	0.003674764
Standart Deviation	574,055 u	17,6463 u	10.5022		
Samples	# 100	# 100	# 100		
Min Value		1,474774 V	879,8764 K		
Max Value		1,474871 V	879,9705K		
Average Value		1,474841 V	879.9165	365.139	0.004039117
Standart Deviation		15,4785 u	12.4469		
Samples		# 100	# 100		
Min Value		1,722683 V	780,3647K		
Max Value		1,722876 V	780,4787K		
Average Value		1,722839 V	780.4465	406.6995	0.004236147
Standart Deviation		43,5294 u	23.3635		
Samples		# 100	# 100		
Min Value		1,739210 V	714,5506K		
Max Value		1,739365 V	714,7124K		
Average Value		1,739321 V	714.6403	377.853	0.004603163
Standart Deviation		26,3765 u	18.2964		
Samples		# 100	# 100		
Min Value		1,762999 V	630,9077K		
Max Value		1,763507 V	630,9425K		
Average Value		1,763379 V	630.9272	340.697	0.005175792
Standart Deviation		128,338 u	5.09754		
Samples		# 100	# 100		
Min Value		1,778458 V	584,0270 K		
Max Value		1,779052 V	584,0872 K		
Average Value		1,778918 V	584.0526	319.685	0.005564585
Standart Deviation		141,149 u	6.96032		
Samples		# 100	# 100		
Min Value		1,821696 V	476,7304K		
Min Value		1,822666 V	476,8095K		
Average Value		1,822541 V	476.7422	271	0.006725615
Standart Deviation		233,921 u	10.8647		
Samples		# 100	# 100		
Min Value		1,867223 V	391,8585k		
Max Value		1,868148 V	391,8883k		
Average Value		1,868051 V	391.8696	231.591	0.008066147
Standart Deviation		198,523 u	5.10783		
Samples		# 100	# 100		
Min Value		1,927713 V	306,9435K		
Min Value		1,929381 V	307,0306K		
Average Value		1,929167 V	307.0121	191.072	0.010096538
Standart Deviation		372,197u	15.2904		
Samples		# 100	# 100		
Min Value		2,311316 V	225,2975K		
Max Value		2,328440 V	225,4681K		
Average Value		2,312354 V	225.4257	191.883	0.012050851
Standart Deviation		2,26861 m	33.8189		
Samples		# 100	# 100		
Min Value		2,388234 V	145,7307 K		
Max Value		2,432740 V	145,8341K		
Average Value		2,422402 V	145.7635	135.467	0.017881862
Standart Deviation		11,6335 m	21.3749		
Samples		# 100	# 100		
Min Value		2,534732 V	81,11372 K		
Max Value		2,596132 V	81,15210K		
Average Value		2,580250 V	81.13916	85.499	0.030178712
Standart Deviation		13,7589 m	12.6475		
Samples		# 100	# 100		
Min Value		2,755770 V	33,79967 K		
Max Value		2,839766 V	33,98595 K		
Average Value		2,835790 V	33.8734	43.799	0.064745328
Standart Deviation		13,6893 m	45.3586		
Samples		# 100	# 100		
Min Value		4,886636 V	61,40600 ohm		
Max Value		4,918682 V	63,17700 ohm		
Average Value		4,917639 V	0.06226587	2.7514	1.787321321
Standart Deviation		4,63654 m	277,482 m		
Samples		# 100	# 100		

5.6 MCV Effect on RA0 (RA0 is as Input Pin)

Aim of this part is that to see changing voltage effect on internal resistance of a pin of a microcontroller. Pot which has max 1 Mohm and PIC16F84A are used. The pot resistance is constant 523.891 Kohm and RA0 pin is made as input pin with code. Internal resistance of RA0 pin is measured by changing supplied voltage.

Table 5.10 MCV effect on internal resistance of input pin measurement results

	R kohm	Vin	VRA0	RA0 (Kohm)	I (mA)
Min Value	523,7368 Kohm	5,031447 V	1,799918 V		
Max Value	523,9556 Kohm	5,031540 V	1,799986 V		
Average Value	523.891	5.031481	1.799959	291.807489	0.00616831
Standart Deviation	39.4754	31.5855	15.2173		
Samples	#100				
Min Value		4.558984	1.767105		
Max Value		4,559193 V	1,767183 V		
Average Value		4.559125	1.767157	331.5932159	0.005329292
Standart Deviation		46,5544 u	12,8478 u		
Samples	#100				
Min Value		4,018563 V	1,725792 V		
Max Value		4,018625 V	1,726386 V		
Average Value		4.018593	1.726348	394.5556344	0.004375424
Standart Deviation		13,2218u	62,1307 u		
Samples	#100				
Min Value		3,493986 V	1,688533 V		
Max Value		3,494687 V	1,6911889 V		
Average Value		3.494237	1.690672	491.0983772	0.003442634
Standart Deviation		148,837 u	237,879u		
Samples	#100				
Min Value		3,056907 V	1,623839 V		
Max Value		3,056994 V	1,623905 V		
Average Value		3.056947	1.623873	593.6416751	0.002735443
Standart Deviation		19,1119u	13,1447u		
Samples	#100				
Min Value		2,555362 V	1.579431		
Max Value		2,556042 V	1.579548		
Average Value		2.555675	1.579509	847.6945002	0.0018633
Standart Deviation		153,540u	18,3077u		
Samples	#100				
Min Value		1,994725 V	1.486348		
Min Value		1,995507 V	1.487128		
Average Value		1.995175	1.486835	1532.319855	0.000970316
Standart Deviation		207,277u	254,579u		
Samples	#100				
Min Value		1,550957 V	1.358447		
Max Value		1,551348 V	1.358987		
Average Value		1.551135	1.358681	3698.550032	0.000367355
Standart Deviation		75,3804u	78,8065u		
Samples	#100				
Min Value		1,078104 V	1.013259		
Min Value		1,079888 V	1.017664		
Average Value		1.079076	1.015971	8434.483213	0.000120454
Standart Deviation		440,711u	936,196u		

5. 7 MCR Effect on RA0 Pin (RA0 is Output (0 V))

Aim of this part is that to measure internal resistance of an output pin of a microcontroller by changing the pot resistance gradually. PIC16F84A and pot which has maximum 1Kohm are used in this measurement. Supplied voltage is constant approximately 5v. RA0 pin is made as output pin and 0 volt with code. Internal resistance of RA0 pin is measured by changing the pot resistance gradually.

Table 5.11 MCR effect on internal resistance of output pin measurement results

	Vin(V)	VRA0(V)	R(ohm)	RA0(ohm)	I(A)
Min Value	5	5.065847	1.54609		
Max Value	5.072113	5.065953	1.57371		
Average Value	5.072017	5.065909	1.563792	1296.992136	0.00390589
Standart Deviation	58,7261 u	23,8288u	4,58711m		
Samples	# 100	# 100	# 100		
Min Value		3.488388	55.17909	121.5474555	0.028699803
Max Value		3.490366	55.20108	121.8169955	0.028652537
Average Value		3.489479	55.18797	121.6888709	0.028675416
Standart Deviation		602,883u	5,89681m		
Samples		# 100	# 100		
Min Value		2.986243	105.7491	151.4030329	0.019723799
Max Value		2.987063	105.8417	151.6368351	0.019698795
Average Value		2.98671	105.7905	151.5199173	0.019711666
Standart Deviation		237,973u	27,1662m		
Samples		# 100	# 100		
Min Value		2.654665	170.7382	187.4996789	0.014158238
Max Value		2.654835	170.8769	187.6772104	0.014145751
Average Value		2.654751	170.7902	187.5695328	0.014153423
Standart Deviation		45,4528u	40,7357m		
Samples		# 100	# 100		
Min Value		2.368524	267.9291	234.7320683	0.01009033
Max Value		2.368941	267.9984	234.8703469	0.010086165
Average Value		2.368725	267.9671	234.8027401	0.010088149
Standart Deviation		99,7872u	18,2102m		
Samples		# 100	# 100		
Min Value		2.236372	336.6489	265.5029716	0.008423152
Max Value		2.241597	336.96	266.8609341	0.008399869
Average Value		2.238379	336.7595	266.0168281	0.008414426
Standart Deviation		792,616 u	81,9820m		
Samples		# 100	# 100		
Min Value		2.177237	377.7656	284.1270292	0.0076629
Min Value		2.180376	377.8205	284.8869381	0.007653478
Average Value		2.177674	377.7933	284.2478057	0.007661181
Standart Deviation		509,918u	15,7166m		
Samples		# 100	# 100		
Min Value		2.080658	462.9802	322.0287023	0.006461095
Max Value		2.080745	463.2416	322.2333653	0.006457261
Average Value		2.080701	463.092	322.1177527	0.006459442
Standart Deviation		23,6846u	76,2509m		
Samples		# 100	# 100		
Min Value		2.017897	536.7243	354.6207598	0.005690296
Min Value		2.019929	536.7982	355.2631023	0.005685727
Average Value		2.01808	536.7568	354.6956479	0.00568961
Standart Deviation		353,335u	15,9530m		
Samples		# 100	# 100		
Min Value		1.966885	612.3635	387.8896558	0.005070733
Max Value		1.966913	612.5124	387.9929955	0.005069455
Average Value		1.966898	612.4028	387.9187376	0.005070387
Standart Deviation		5,56331u	38,7267m		
Samples		# 100	# 100		
Min Value		1.9262	684.0928	418.8735554	0.004598524
Max Value		1.926298	684.3653	419.0747834	0.00459655
Average Value		1.92625	684.2089	418.9621779	0.00459767
Standart Deviation		21,9353u	79,2061m		
Samples		# 100	# 100		
Min Value		1.905495	724.358	435.8916651	0.004371488
Max Value		1.906089	724.4385	436.1578204	0.004370182
Average Value		1.90559	724.4079	435.9565056	0.004371055
Standart Deviation		74,0755u	22,7271m		
Samples		# 100	# 100		
Min Value		1.86958	806.6851	470.9420761	0.003969873
Max Value		1.869696	806.7121	471.0041206	0.003969596
Average Value		1.869599	806.6994	470.9580047	0.003969779
Standart Deviation		16,6901u	7,88941m		
Samples		# 100	# 100		
Min Value		1.827777	919.6775	518.1384182	0.003527584
Max Value		1.827887	919.7507	518.2284149	0.003527184
Average Value		1.827837	919.7006	518.1780251	0.003527431
Standart Deviation		26,8688u	20,7850m		
Samples		# 100	# 100		
Min Value		1.815487	957.9234	534.0339194	0.003399572
Max Value		1.815615	958.0412	534.1582438	0.003399021
Average Value		1.815559	957.0663	533.5890512	0.003402542
Standart Deviation		28,1238u	32,0459m		
Samples		# 100	# 100		

5.8 MCV Effect on RA0 Pin (RA0 is Output (0 V))

In this part, Internal resistance of RA0 pin is measured by changing supplied voltage gradually. Purpose of this part is to see changing voltage effect on internal resistance of a pin of a PIC. This experiment is created with Pot which has max 1 Kohm and PIC16F84A. The pot resistance is constant 522.0382 ohm and RA0 is made output pin (0 volt) with code.

Table 5.12 MCV effect on internal resistance of output pin measurement results

	Rohm	Vin	VRA0	RA0 (ohm)	I (A)
Min Value	521.8926	5.070442	4.457993		0.009712814
Max Value	522.2715	5.070499	4.458031		
Average Value	522.0382	5.07046	4.458011	3799.911565	0.001173188
Standart Deviation	104,182m	14,9674u	9,79122u		
Samples	#100	#100	#100		
Min Value		4.507907	1.952039	398.7056162	0.011306354
Max Value		4.508424	1.952129	398.6573965	0.011309019
Average Value		4.508314	1.95207	398.6533011	0.011308859
Standart Deviation		138,800u	18,2049u		
Samples	#100	#100	#100		
Min Value		4.033742	1.883674	457.3575275	0.008819669
Max Value		4.033867	1.883738	457.3600909	0.008819893
Average Value		4.033786	1.883708	457.3636555	0.008819647
Standart Deviation		26,3537u	12,9828u		
Samples	#100	#100	#100		
Min Value		3.511594	1.803832	551.4054127	0.006368443
Max Value		3.51182	1.803941	551.4009555	0.006368904
Average Value		3.511722	1.803884	551.3967697	0.006368775
Standart Deviation		47,1631u	21,1661u		
Samples	#100	#100	#100		
Min Value		2.989197	1.708405	696.3290457	0.004292794
Max Value		2.989352	1.714364	701.9387608	0.004258708
Average Value		2.989276	1.713109	700.7768879	0.00426566
Standart Deviation		31,7690u	1,66968m		
Samples	#100	#100	#100		
Min Value		2.521731	1.636243	964.6447501	0.002614155
Max Value		2.538259	1.637382	948.8264791	0.002675156
Average Value		2.532557	1.636863	954.0144449	0.002654632
Standart Deviation		4,74997m	319,034u		
Samples	#100	#100	#100		
Min Value		2.004035	1.512201	1605.067336	0.001248568
Max Value		2.004121	1.512338	1605.379217	0.001248379
Average Value		2.004066	1.512254	1605.195392	0.001248487
Standart Deviation		18,2897u	28.4632		
Samples	#100	#100	#100		
Min Value		1.558108	1.557384	1122947.431	1.38752E-06
Max Value		1.558175	1.557426	1085495.148	1.43545E-06
Average Value		1.558139	1.557405	1107663.355	1.40603E-06
Standart Deviation		14,7632u	10,0098u		
Samples	#100	#100	#100		

CHAPTER VI

MEASUREMENT GRAPHICS

6.1 MCR Effect Graphs (Rin as Output Pin)

In this part, Analysis to changing resistor effect on internal resistance of RA0 pin (Rin), supplied voltage is constant and approximately 5v. RA0 is as output pin and Pot which has max 1 Kohm is used. Rpot-Rin and Current-Rin graphs are created by using measurement values.

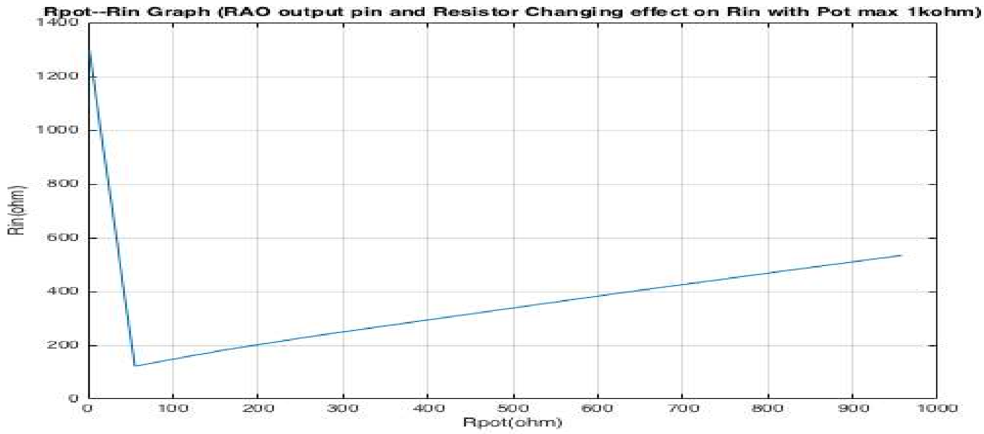


Figure 6.1 Rpot – Rin graph (Rin is output, constant voltage)

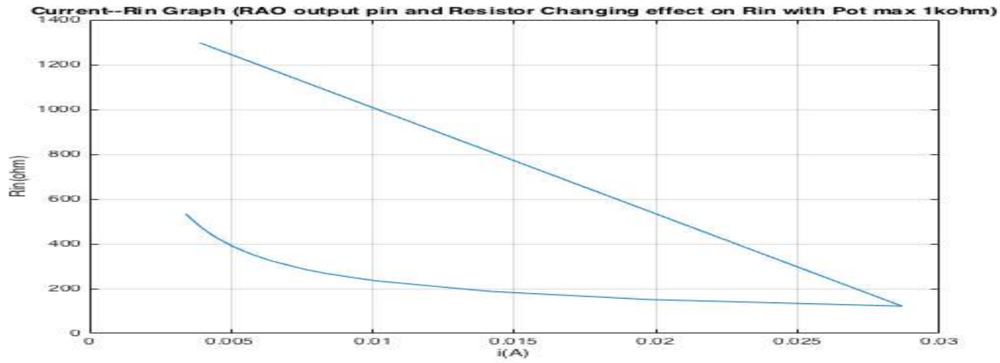


Figure 6.2 Current - Rin graph (Rin is Output, constant voltage)

6. 2 MCV Effect Graphs (Rin as Output Pin)

In this part, Analysis to changing supplied voltage effect when Rpot resistance is constant 522.0382 ohm and RA0 (Rin) is as output pin. Voltage-Rin and Current-Rin graphs are created by using measurement values.

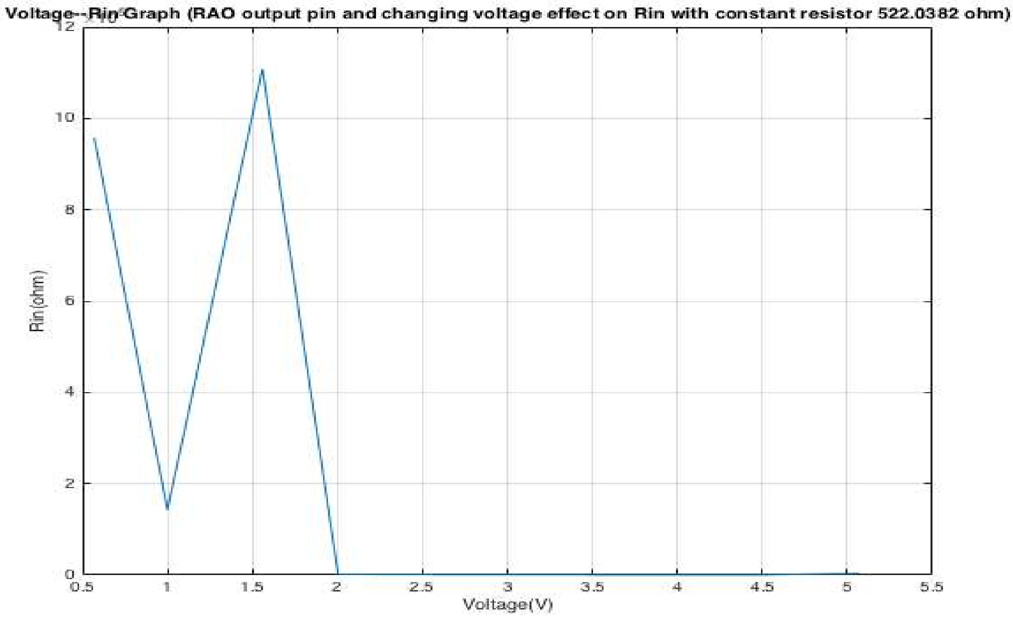


Figure 6.3 Voltage - Rin graph (Rin is Output, constant resistance)

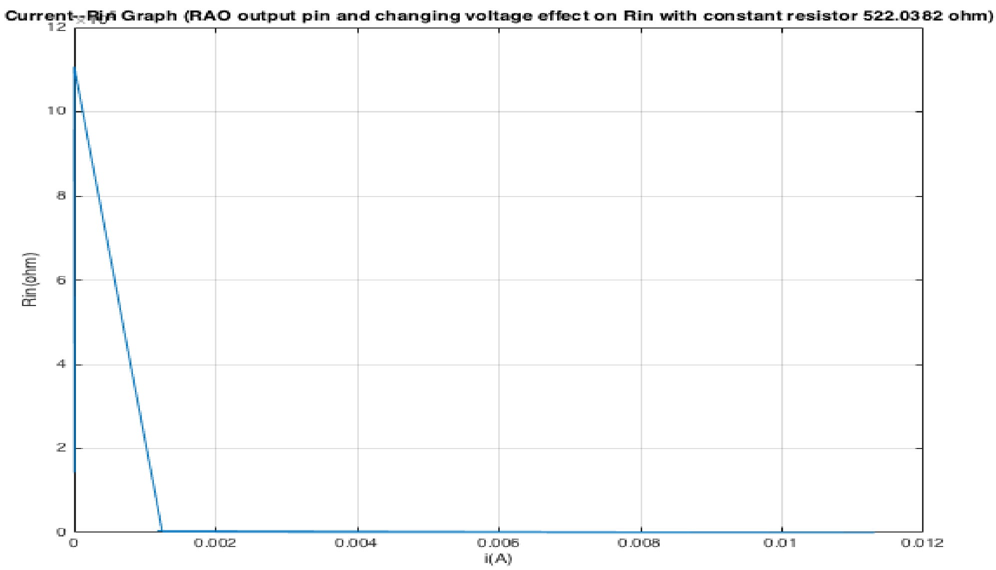


Figure 6.4 Current - Rin graph (Rin is Output, constant resistance)

6. 3 MCR Effect Graphs (Rin as Input Pin)

In this part, Changing resistance effect is analyzed. Rin resistance is calculated by changing Rpot resistance gradually. Supplied voltage is constant approximately 5v. RA0 pin is adjusted as input pin in the code. The pot has maximum 1 Mohm. Rpot Resistance-Rin graph, Current-Rin graph and VRin-Rin graph are created by using measurement values.

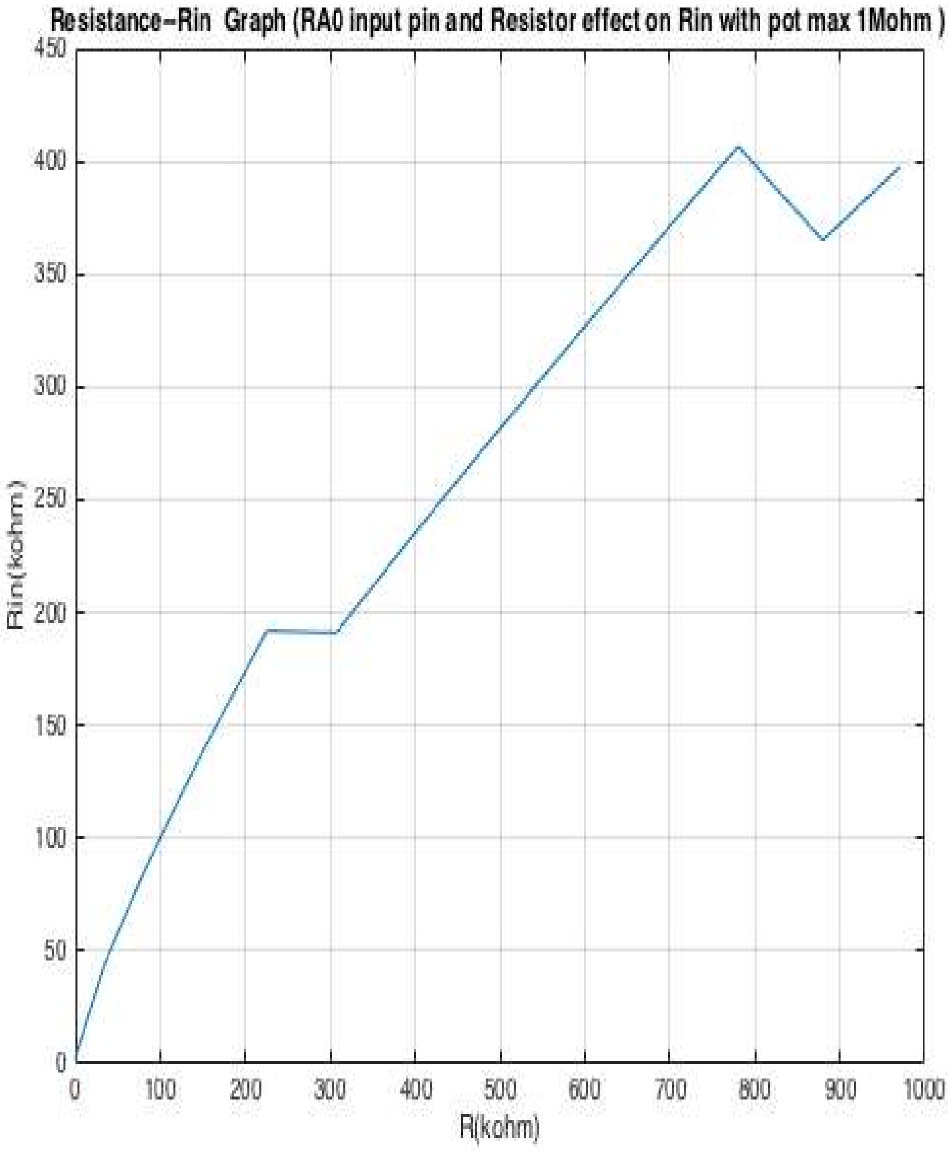


Figure 6.5 Rpot - Rin graph (Rin is input , constant voltage)

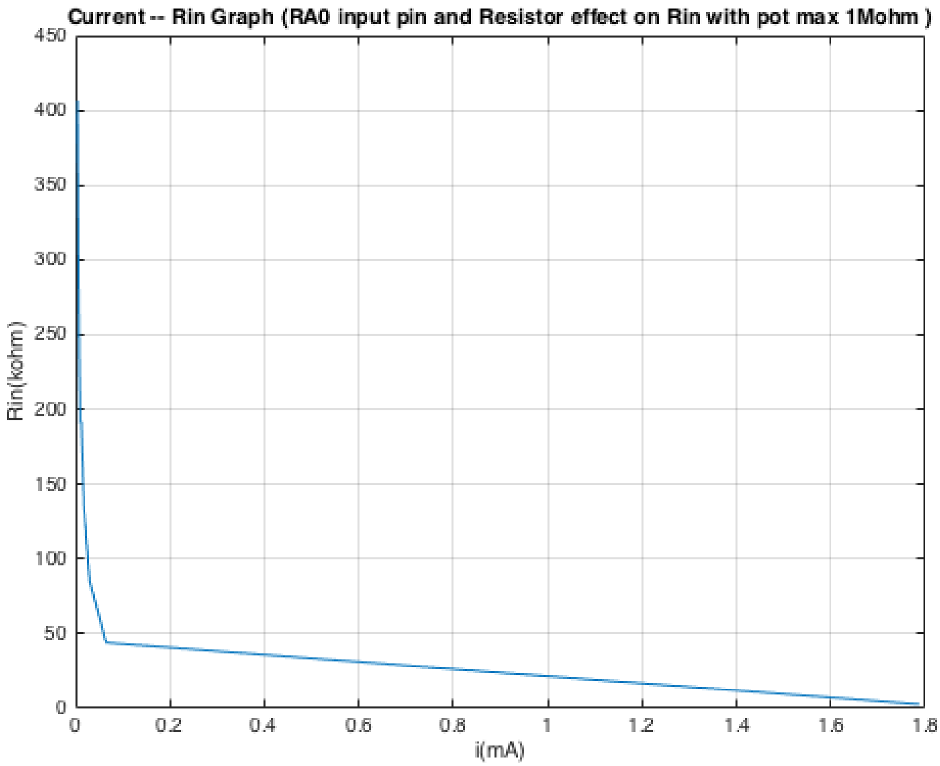


Figure 6.6 Current - Rin graph (Rin is input , constant voltage)

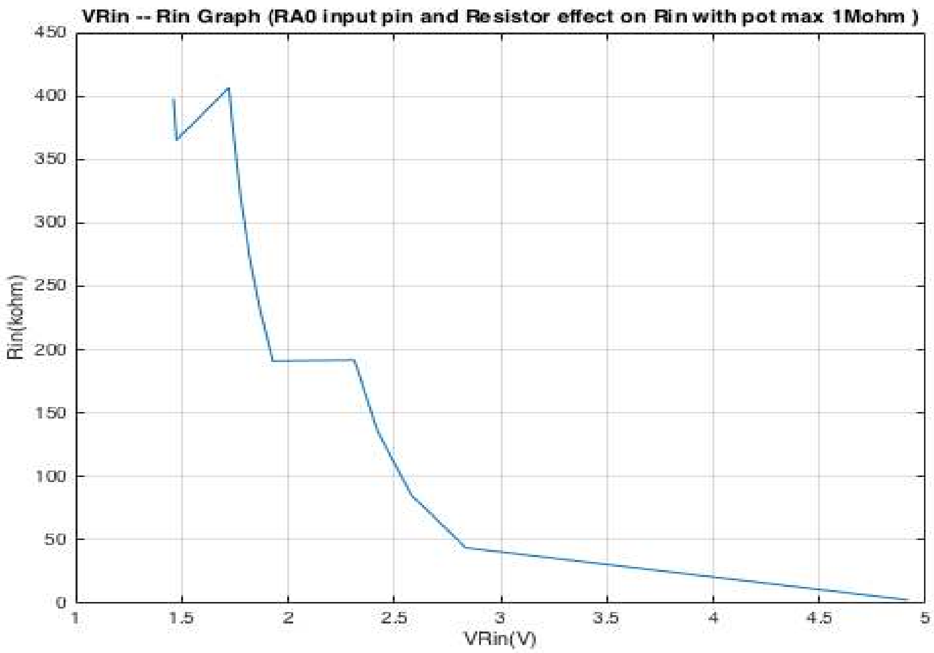


Figure 6.7 Current - Rin graph (Rin is input , constant voltage)

6. 4 MCV Effect Graph (Rin as Input Pin)

Analyzed to changing supplied voltage effect on Rin (RA0) pin by using Rpot which has maximum 1 Mohm. The pot resistance is constant 523.891 Kohm and RA0 is as input pin. Voltage-Rin graph, Current-Rin graph, VRin-Rin graph and Supplied voltage-VRin graph are created by using measurement Values.

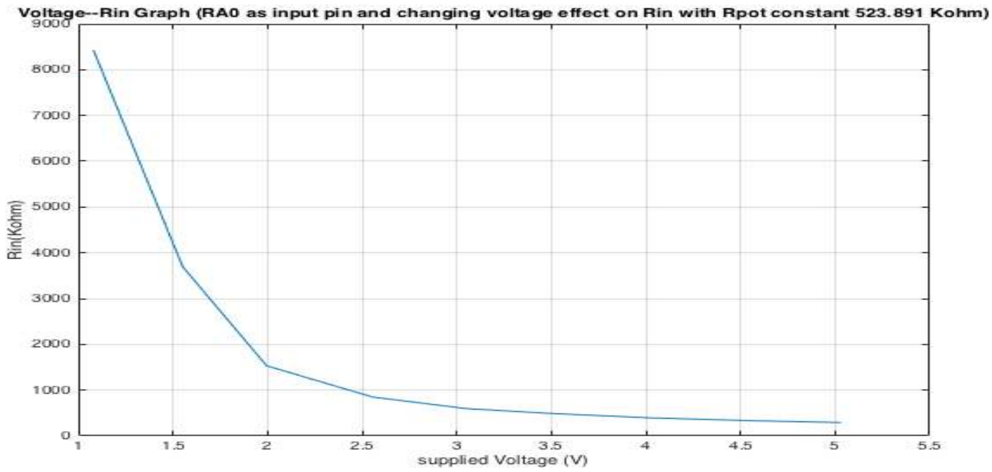


Figure 6.8 Voltage - Rin graph (Rin is input , constant resistance)

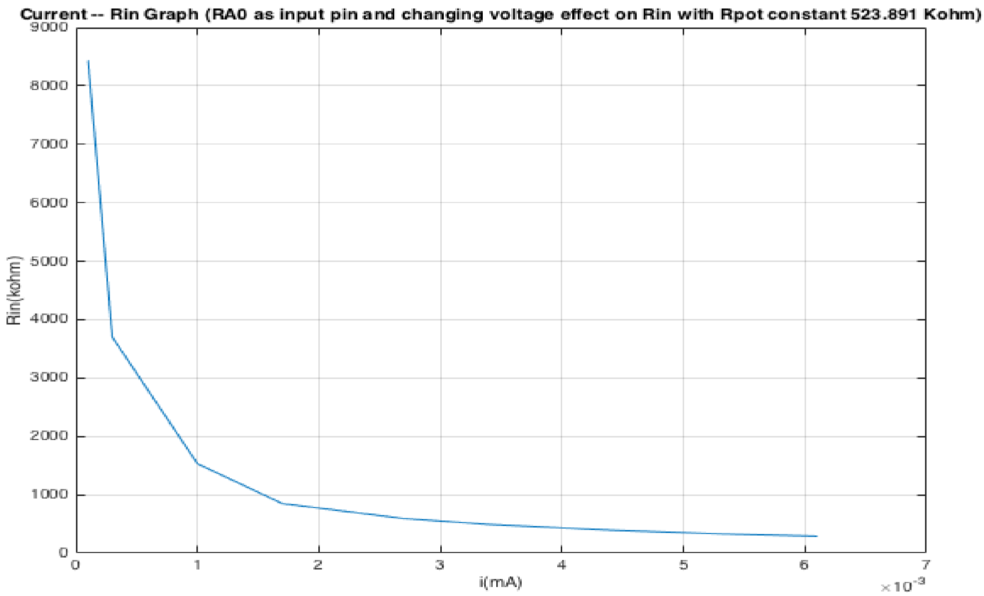


Figure 6.9 Current - Rin graph (Rin is input , constant resistance)

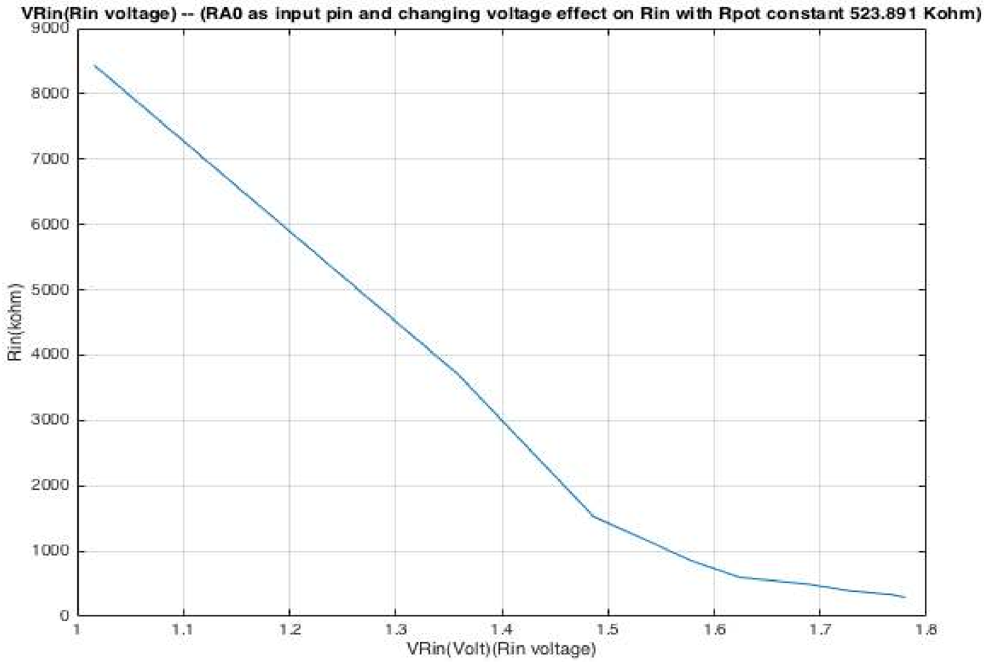


Figure 6.10 VRin - Rin graph (Rin is input , constant resistance)

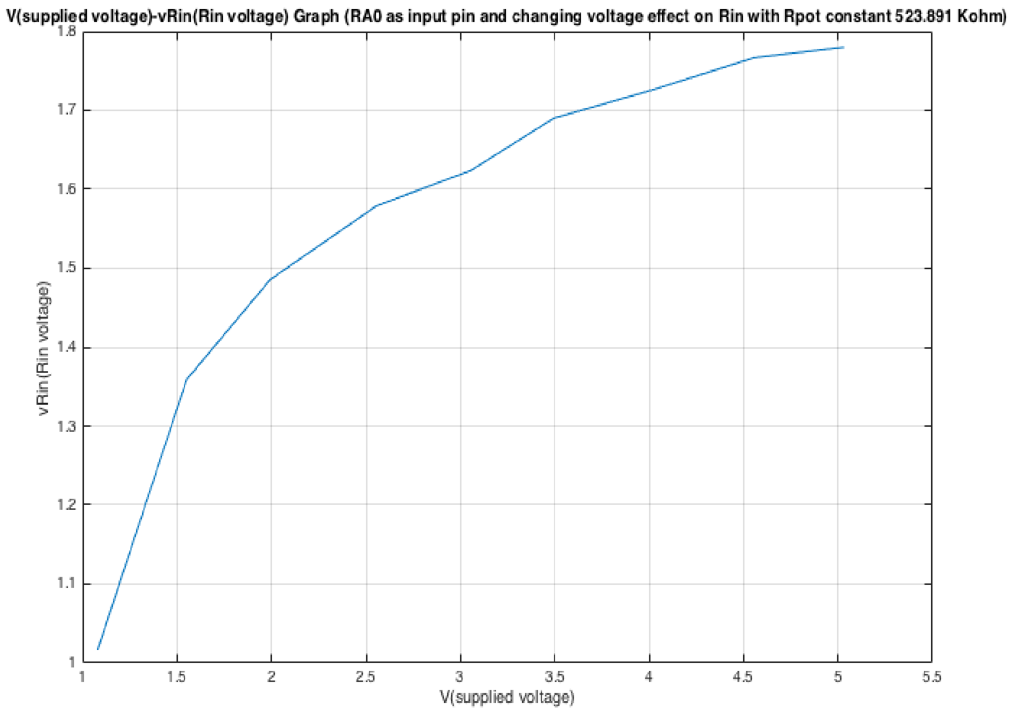


Figure 6.11 Supplied voltage - VRin graph (Rin is input , constant resistance)

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS

In the studies which are carried out in the thesis, the value of unknown resistor and error rates are found with measurements by using one calibration method with PIC16F84A , PIC16F877 and PIC16F887 on breadboard, with different Crystal types and different calibration resistors. This error rate will not be wanted when precise measurement is required. In the thesis, the internal resistance of the microprocessor pins which is measured by changing supplied voltage, current, potentiometer resistance are represented in the table (chart). The measurement results indicate that the internal resistance of the pins of the microprocessors is not negligible in input phase where precision operation is required. It is theoretically demonstrated that a new technique which is called 'proposed method' in this thesis eliminates error which comes from the internal resistance values of the microprocessor pins. All measurement with the proposed (new) method will be more accurate. In the next step, the proposed (new) method should be tested with different code software and different microprocessors to analyze the internal resistance value of pin. After see the internal resistance value of the pins of the microprocessors is destroyed completely and then error which comes from internal resistance value of the charge / discharge capacitor can be eliminated by combining two existing methods called one calibration resistor, two calibration resistor [2-4] and the proposed (new) methods.

In this sense, it is possible to work on a new equation in which the capacitor and pin internal resistance are eliminated from the measurement by combining the existing two methods [2-4] and the new method theoretically. So, All measurement with microcontroller will be more accurate than ever.

REFERENCES

[1] Lin, H., (2012). A Kind of Multipurpose Digital Measurement Instrument Based on Microcontroller, *2012 International Conference on Control Engineering and Communication Technology*. 473-476.

[2] Reverter, F., Jordana, J., Gasulla, M., Pallàs-Areny, R. (2005). Accuracy and resolution of direct resistive sensor-to-microcontroller interfaces, *Sensors and Actuators A: Physical*. **121(1)**, 78-87.

[3] Kokolanski, Z., Gavrovski, C., Dimcev, V. (2014). Modified single point calibration with improved accuracy in direct sensor-to-microcontroller interface, *Measurement*. **53**, 22-9.

[4] Custodio, A., Pallàs-Areny, R., Bragós, R. (2001). Error analysis and reduction for a simple sensor-microcontroller interface, *IEEE Transactions on Instrumentation and Measurement*. **50**, 1644-7.

[5] Kokolanski Z., Gavrovski C., Dimcev V., (2010). Dynamic element matching in direct sensor—Microcontroller interface, *Proceedings of 14th International Power Electronics and Motion Control Conference EPE-PEMC IEEE*. T7-35-T7-38.

[6] Reverter, F., Gasulla, M., Pallàs-Areny, R. (2007). Analysis of power-supply interference effects on direct sensor-to-microcontroller interfaces, *IEEE Transactions on Instrumentation and Measurement*. **56**, 171-7.

[7] Jordana, J., Reverter, F., Pallàs-Areny, R. (2003). Uncertainty in resistance measurements based on microcontrollers with embedded time counters, *Proceedings of the 20th IEEE Instrumentation Technology Conference*. **2**, 1078-1082.

[8] Sifuentes, E., Gasulla, M., Casas, Ò., Reverter, F. (2009). Improving the performance of direct interface circuits using the Vernier technique, *IEEE Instrumentation and Measurement Technology Conference*. 1300-1303.

[9] José, RM., Rodolfo, PR., Javier, VP., José, DG. (2018). Smart module for measurements based on direct interfaces and FPGA-SoC, *IEEE International Instrumentation and Measurement Technology Conference*. 1-6.

[10] Webjörn, Å. (2004). AN477: Simple A/D for MCUs Without Built-in A/D Converters, *Freescale AB.*

[11] Sherman D. (1993). Measure resistance and capacitance without an A/D. *Philips Semiconductors Application Note AN449, Philips Semiconductors, Sunnyvale, CA*. 2540-53.

[12] Philip, VN. (2017). Digital readout circuit with direct microcontroller interface for bridge-connected resistive sensors, *2017 IEEE International Conference on Circuits and Systems (ICCS).* 1-6

[13] Philip, VN. (2017). Direct microcontroller interface based digital readout circuit for single-element resistive sensors, *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI).* 2480-2483.

[14] Sifuentes, E., Casas, O., Reverter, F., Pallas-Areny, R. (2007). Improved direct interface circuit for resistive full-and half-bridge sensors, *2007 4th International Conference on Electrical and Electronics Engineering.* 197-200.

[15] Cox, D. (1997). Implementing ohmmeter/temperature sensor, *Microchip Technology, Chandler, AZ, Appl Note AN512*.

[16] Merritt, B. (1999). MSP430 based digital thermometer. *Application report, Texas Instruments 1-5*.

[17] Amri, I., Yuliza, E., Atmajati, ED., Salam, RA., Yuliza, E., Munir, MM. (2016). Potentiometer a simple light dependent resistor-based digital, *2016 International Seminar on Sensors, Instrumentation, Measurement and Metrology (ISSIMM)*. 24-27.

[18] Kokolanski, Z., Gavrovski, C. (2013). Comparative Analyzis of Callibration Performances in a Simpe Interface for Passive Sensors, *INFOTEH-Jahorina*. 450-4.

[19] Microchip (2015), PIC16F84X CMOS Flash Microcontroller, https://www.microchip.com/doclisting/TechDoc.aspx?type=datasheet

[20] Microchip (2015), PIC16F87X CMOS Flash Microcontroller, https://www.microchip.com/doclisting/TechDoc.aspx?type=datasheet

[21] Tektronix, DMM 4040 Precision Digital Multimeter https://www.tek.com/datasheet/dmm4050-4040-digital-multimeter

APPENDICES

APPENDIX A

The Codes by Using Mikroc Language

Code1: Calculate Discharging Time of Capacitor

```
// LCD module connections
sbit LCD_RS at Rd4_bit;
sbit LCD_EN at Rd5_bit;
sbit LCD_D4 at Rd0_bit;
sbit LCD_D5 at Rd1_bit;
sbit LCD_D6 at Rd2_bit;
sbit LCD_D7 at Rd3_bit;
sbit LCD_RS_Direction at TRISd4_bit;
sbit LCD_EN_Direction at TRISd5_bit;
sbit LCD_D4_Direction at TRISd0_bit;
sbit LCD_D5_Direction at TRISd1_bit;
sbit LCD_D6_Direction at TRISd2_bit;
sbit LCD_D7_Direction at TRISd3_bit;

// End LCD module connections
float COUNT=0;
float COUNT2=0;

float COUNT3=0;

int vdd=5;
```

```
int vtl=1;
int cap;
char TEXT[15];


char TEXT2[15];
 int TIME=0;
 int VALUE=0;
void interrupt(){

if(INTCON.T0IF==1){                              //TMR0 exceed flag
COUNT=COUNT+1;                          // each 8 bits end, count++
INTCON.T0IF=0;
TMR0=0;
}
      if(INTCON.INTF==1)  {
       COUNT2=TMR0;
       // TIME=COUNT*256+COUNT2;
       //VALUE=TIME/(c*ln(vdd/vtl));
       COUNT3=COUNT*256.0+COUNT2;
       floattostr(COUNT3,TEXT);                             // LCD just show string
         Lcd_Init();                                        // Initialize LCD
         Lcd_Cmd(_LCD_CLEAR);                               // Clear display
         Lcd_Cmd(_LCD_CURSOR_OFF);
```

```
Lcd_out(1,1,TEXT)
While(1){}
INTCON.INTF=0;
          }

}

void main(){

ANSEL  = 0;                          // Configure AN pins as digital I/O
ANSELH = 0;
C1ON_bit = 0;                        // Disable comparators
C2ON_bit = 0;

     TRISC=0xff;                      // All portC are input pins
     TRISB=0x00;                      // All portB are as output pins
     PORTB = 0x01;                    // portB0 output (5v)
     delay_ms(100);
     TRISB=0Xff;                     // All portB are as input pins
     TRISC=0X00;                     // All portC are as output pins

OPTION_REG=0X80;
INTCON = 0xB0;                       // activate Intcon.T0IF and T0IE

   TMR0 = 0;                         // İnitialize Timer with 0
   COUNT = 0;
   COUNT2=0;



}
```

Code2: One-Point Calibration Code

```
// LCD module connections
sbit LCD_RS at RD4_bit;
sbit LCD_EN at RD5_bit;
sbit LCD_D4 at RD0_bit;
sbit LCD_D5 at RD1_bit;
sbit LCD_D6 at RD2_bit;
sbit LCD_D7 at RD3_bit;

sbit LCD_RS_Direction at TRISD4_bit;
sbit LCD_EN_Direction at TRISD5_bit;
sbit LCD_D4_Direction at TRISD0_bit;
sbit LCD_D5_Direction at TRISD1_bit;
sbit LCD_D6_Direction at TRISD2_bit;
sbit LCD_D7_Direction at TRISD3_bit;
// End LCD module connections configuration


char txt1[] = "COUNT2";      // to show discharging time of unkown resistor

char txt2[] = "COUNT4";      // to show discharging time of the calibration resistor

char txt3[15];               // to show value of the unknown resistor on LCD


 float COUNT1=0;

 float COUNT2=0;                    //discharging time on unknown resistor(10 kohm)

 float COUNT3=0;

 float COUNT4=0;                      //discharging time on  100kohm

 float Rx=0;                         // it is unknown resistor

float RC=100;                        // the calibration resistor 100kohm
```

```
void interrupt(){


if(INTCON.T0IF==1){

     COUNT1=COUNT1+1;

     INTCON.T0IF=0;

     TMR0=0;

     }

 if(INTCON.INTF==1)  {

        COUNT3=COUNT3+1;

if(COUNT3==1){ COUNT2=TMR0+COUNT1*256; TMR0=0; COUNT1=0;}


  if(COUNT3==3){

              COUNT4=TMR0+COUNT1*256;

               Rx=(COUNT2/COUNT4)*RC;

              // floattostr(COUNT2,txt1);                         //to see COUNT2

              //   floattostr(COUNT4,txt2);                       //to see COUNT4

 floattostr(Rx,txt3);                                    //convert float value to string

 Lcd_Init();                                                    // Initialize LCD

 Lcd_Cmd(_LCD_CLEAR);                                           // Clear display

 Lcd_Cmd(_LCD_CURSOR_OFF);

 //lcd_out(1,1,txt3);                                           // to show Rx on LCD
```

```
// LCD display character (if there is a error to show on LCD) Use this method below
lcd_Chr_Cp(txt3[0]);
lcd_Chr_Cp(txt3[1]);
lcd_Chr_Cp(txt3[2]);
lcd_Chr_Cp(txt3[3]);
lcd_Chr_Cp(txt3[4]);
lcd_Chr_Cp(txt3[5]);
          while(1){}                          // stop the code
}
         TMR0=0;                              // TMR0 interrupt is zero
         COUNT1=0;
        INTCON.INTF=0;                        //reset the interrupt bit
      }}
void main(){
 ANSEL  = 0;                        // Configure AN pins as digital I/O
 ANSELH = 0;
 C1ON_bit = 0;                                // Disable comparators
 C2ON_bit = 0;
 TRISA=0XFF;                                  //portA input
 TRISB=0X00;                                  // portB output
 TRISE=0XFF;                                  //portE input
 PORTB=0XFF;                                  // All portB=5v
 DELAY_MS(1000);                              // Charge to the capacitor
```

```
OPTION_REG=0X80;                    //TMR0 interrupt available
INTCON = 0xB0;                      // portB changing interrupt is available
TMR0 = 0;                                        // initialize timer with 0
COUNT1 = 0;                                      // count to each 256
TRISA=0X00;                                      // portA is output
TRISB=0XFF;                                      // portB is input
TRISC=0XFF;                                      // portC is input
PORTA=0X00;                         // All  portA pins are zero volt.
while(1){
        if(COUNT3==1){
        COUNT3=COUNT3+1;
        INTCON.GIE=0;               // global interrupt is closed
        TRISA=0XFF;                          // all portA pins are input
        TRISB=0X00;                          // all portB pins are output
      TRISC=0XFF;                            // all portC pins are input
        PORTB=0XFF;                 // all portB pins are high ( 5v)
        DELAY_MS(1000);                          // wait 1000  ms
        OPTION_REG=0X80;                         // set TMR0 interrupt
  INTCON = 0xB0;                // set global and portB interrupt available
        TRISA=0XFF;                              // all portA pins are  input
        TRISB=0XFF;                              // all portB pins are input
        TRISC=0X00;                              // all portC pins are output
  PORTC=0X00;                              // all portC pins are low (0v)
}}}
```

Code3: Two-Point Calibration Codes

```
// RB0 always charge the capacitor and External cutout flag (portB interrupt)
// LCD module connections
sbit LCD_RS at RD4_bit;
sbit LCD_EN at RD5_bit;
sbit LCD_D4 at RD0_bit;
sbit LCD_D5 at RD1_bit;
sbit LCD_D6 at RD2_bit;
sbit LCD_D7 at RD3_bit;

sbit LCD_RS_Direction at TRISD4_bit;
sbit LCD_EN_Direction at TRISD5_bit;
sbit LCD_D4_Direction at TRISD0_bit;
sbit LCD_D5_Direction at TRISD1_bit;
sbit LCD_D6_Direction at TRISD2_bit;
sbit LCD_D7_Direction at TRISD3_bit;
// End LCD module connections

char text13[15];
float COUNT1=0;
 float COUNTA=0;                              //discharging time on RA 10kohm
 float COUNT3=0;
```

```
float COUNTE=0;                    // discharging time on RE 100 kohm

float COUNTC=0;                    // discharging time on RC 50 kohm

float RC1=50;                      // first calibration resistor (50 kohm)

float RC2=100;                     // second calibration resistor (100 kohm)


float result;

float result11;

float result12;

float result2;

long int result3;


void interrupt(){
if(INTCON.T0IF==1){
 COUNT1=COUNT1+1;

 INTCON.T0IF=0;

 TMR0=0;

     }

 if(INTCON.INTF==1)  {


            COUNT3=COUNT3+1;


            if(COUNT3==1){ COUNTA=TMR0+COUNT1*256; }
```

```
if(COUNT3==3){
COUNTE=TMR0+COUNT1*256;
COUNT1=0;
TMR0=0;
INTCON.INTF=0;}
if(COUNT3==5){
 COUNTC=TMR0+COUNT1*256;

result11=(COUNTA-COUNTC);          // COUNTA= Nx, COUNTC=Nc1
result12=(COUNTE-COUNTC);          // COUNTE = Nc2 times
result=result11/result12;
result2=result*(RC2-RC1);
result3=result2+RC1;               // result3 is unknown resistor (10kohm)

inttostr(result3,text13);          // convert integer to string for  LCD

Lcd_Init();                        // Initialize LCD
Lcd_Cmd(_LCD_CLEAR);               // Clear display
Lcd_Cmd(_LCD_CURSOR_OFF);
lcd_out(1,1,text13);               // show the value on the LCD
// if Lcd_out command doesn't work, use the codes below to show value on LCD
 // lcd_Chr_Cp(text13[0]);
 //lcd_Chr_Cp(text13[1]);
```

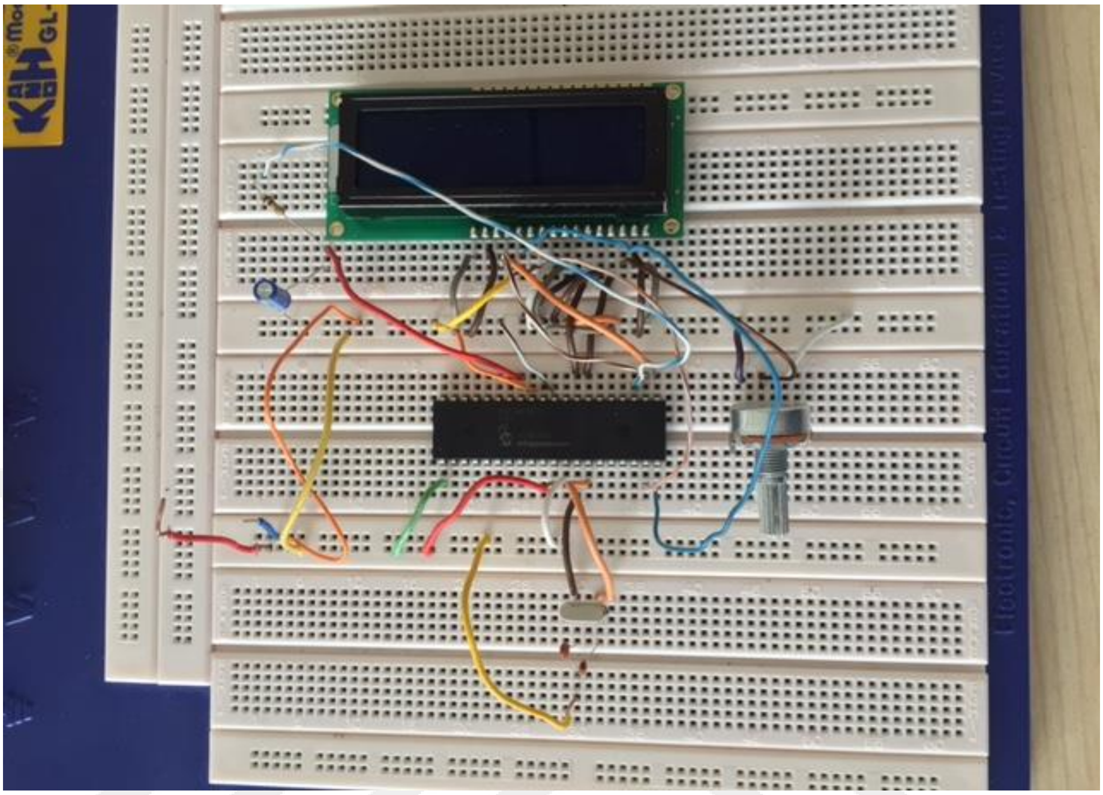
```
//lcd_Chr_Cp(text13[2]);
//lcd_Chr_Cp(text13[3]);
//lcd_Chr_Cp(text13[4]);
//lcd_Chr_Cp(text13[5]);
//lcd_Chr_Cp(text13[6]);
//lcd_Chr_Cp(text13[7]);
//lcd_Chr_Cp(text13[8]);
//lcd_Chr_Cp(text13[9]);
//lcd_Chr_Cp(text13[10]);

while(1){}                                  //All code returns empty here
}
        TMR0=0;                             // reset timer
        COUNT1=0;
        INTCON.INTF=0;                      // reset PortB interrupt
}
}

void main(){
  ANSEL  = 0;                          // Configure AN pins as digital I/O
  ANSELH = 0;
  C1ON_bit = 0;                             // Disable comparators
  C2ON_bit = 0;
```

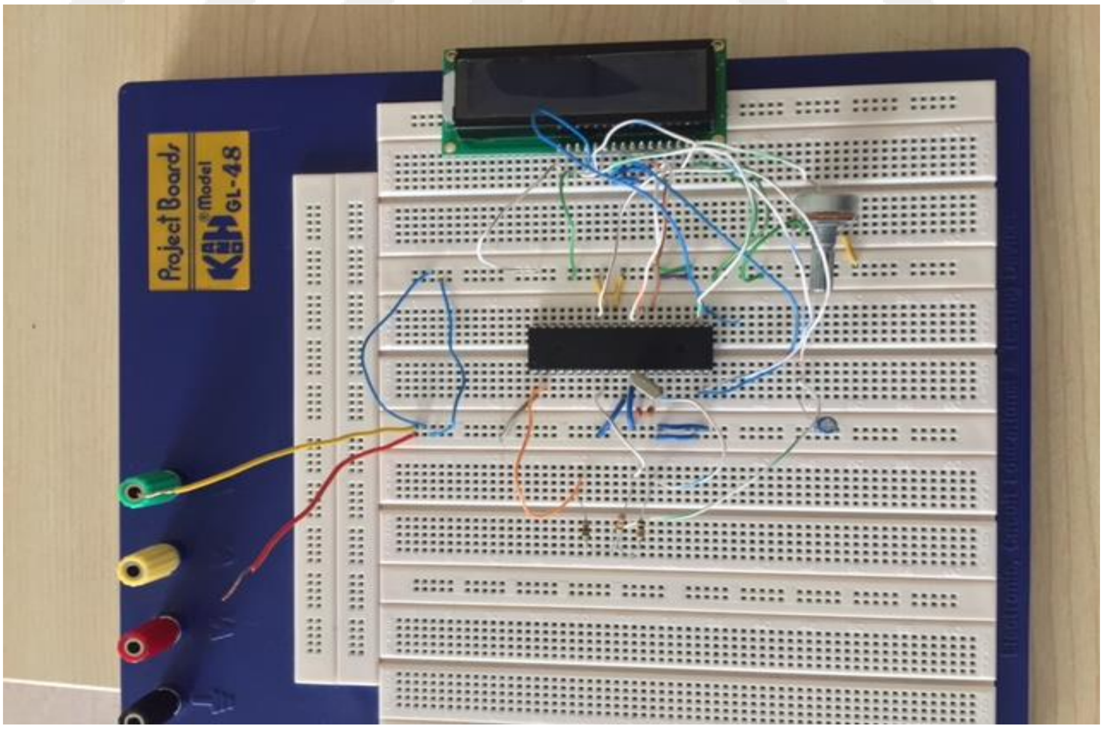
```
TRISA=0XFF;                    // All port A are as input
TRISB=0X00;                    // All port B are as output
TRISC=0xFF;                    // All port C are as input
TRISE=0XFF;                    // All port E are as input
PORTB=0XFF;                    // All port B are high (5v)
OPTION_REG=0X80;               // set TMR0 interrpt
INTCON = 0xA0;                 // set PortB interrupt
delay_ms(200);                 // wait the capacitor is charged fully
TMR0 = 0;
COUNT1 = 0;
COUNT3=0;
//Discharging time on PortA
  TRISA=0X00;                  // All portA are as output
  TRISB=0XFF;                  // All portB are as input
  TRISC=0xFF;                  // All portC are as input
  TRISE=0XFF;                  // All portE are as input
  PORTA=0X00;                  // All portA are low (0 volt)

while(1){
if(COUNT3==1){
 // Discharging time on portE0
COUNT3=COUNT3+1;
INTCON.GIE=0;
```

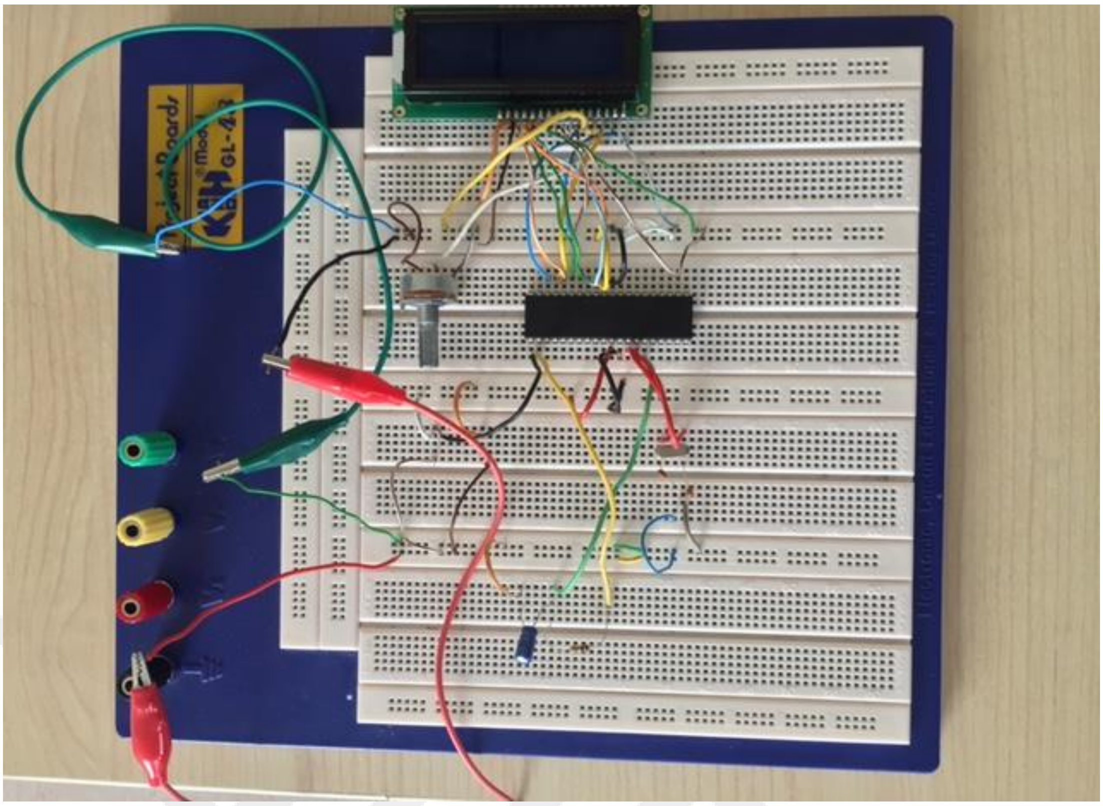
```
TRISA=0xFF;                     // All portA are as input
TRISB=0x00;                     // All portB are as output
TRISC=0xFF;                     // All portC  are as input
TRISE=0xFF;                     // All portE are as input
PORTB=0xFF;                     // All portB are high (5v)
delay_ms(200);                  // wait to charge capacitor fully
OPTION_REG=0x80;                // set Timer interrupt
INTCON = 0xA0;                  // set portB interrupt
TRISA=0xFF;                     // All portA are as input
TRISB=0xFF;                     // All portB are as input
TRISC=0XFF;                     // All portC  are as input
TRISE=0x00;                     // All portE are as output
PORTE=0x00;
 // All portE are low (0 volt) and  discharging the  capacitor on  portE0
 }
if(COUNT3==3){
// Discharging time on portC0
        COUNT3=COUNT3+1;
         INTCON.GIE=0;                  // Cancel portB interrupt
         TRISA=0XFF;                    // All portA are as input
         TRISB=0X00;                    // All portB are as output
         TRISC=0xFF;                    // All portC are as input
TRISE=0XFF;                     // All portE are as input
```

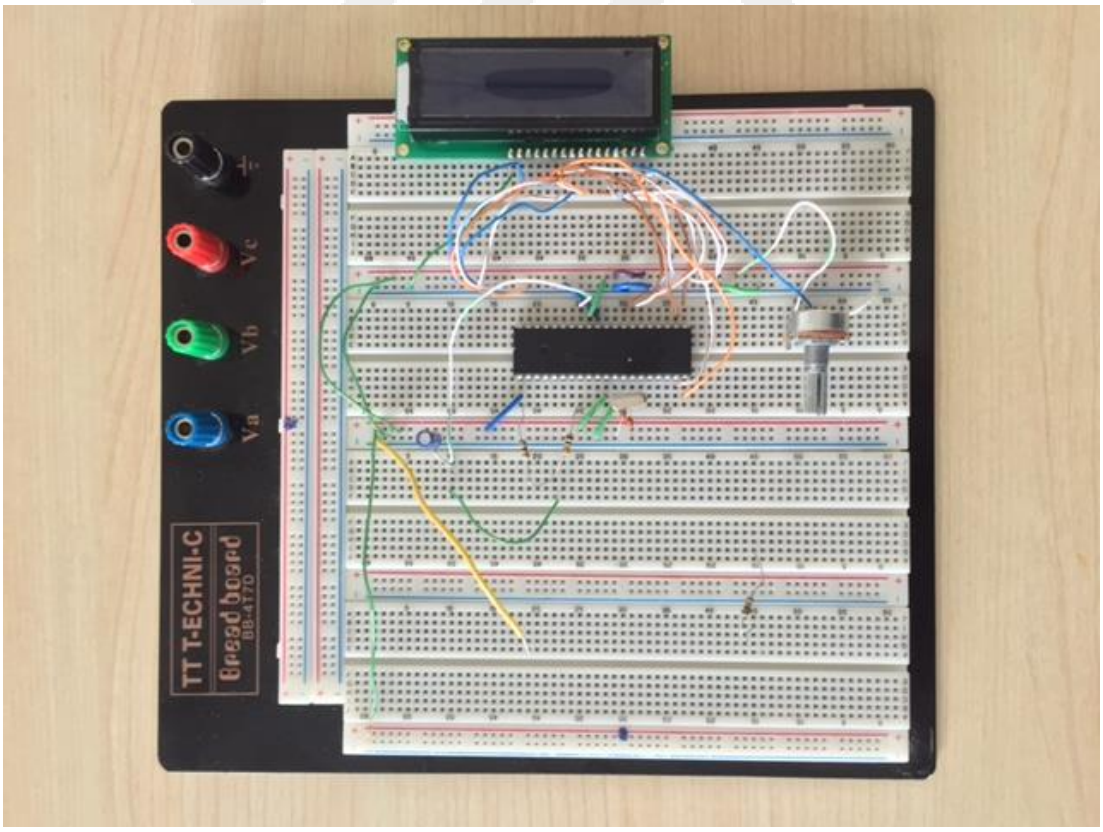
```
PORTB=0XFF;

//All portB are high (5volt) to charge capacitor

delay_ms(200);                      // Wait to charge the capacitor fully

OPTION_REG=0X80;                    // set Timer interrupt

INTCON = 0xA0;                      // set portB interrupt

TRISA=0XFF;                         // All portA are as input

TRISB=0XFF;                         // All portB are as input

TRISC=0x00;                         // All portC are as output to discharge

TRISE=0XFF;                         // All portE are as input

 PORTC=0X00;

// All portC are low (0 volt) to discharging

        }

}

}
```

IMPLEMENTATION PICTURES








Vc
Vb
Va
TT T-ECHNI-C
Bread board