CHAPTER 3

METHODOLOGY

This project, can be divided into three part, which is the sensor part (transducer and signal conditioning circuits); secondly the data acquisition and data conversion (data interface between analog and digital parts) and the last is the output display. Methodologies that were used in this project will be explained in details in the next subtopic.

As mentioned in the previous chapter, this project consists of three parts to make sure the application for the sensor works. Hence, all the details will be explained in next subtopic. Figure 3.0 shows the flow of the design methodology for this project in general. For all intents and purposes, this project started from design an application by using Barium Tantalum Strontium Titanate (BTST) thin film sensor as Heat indicator.

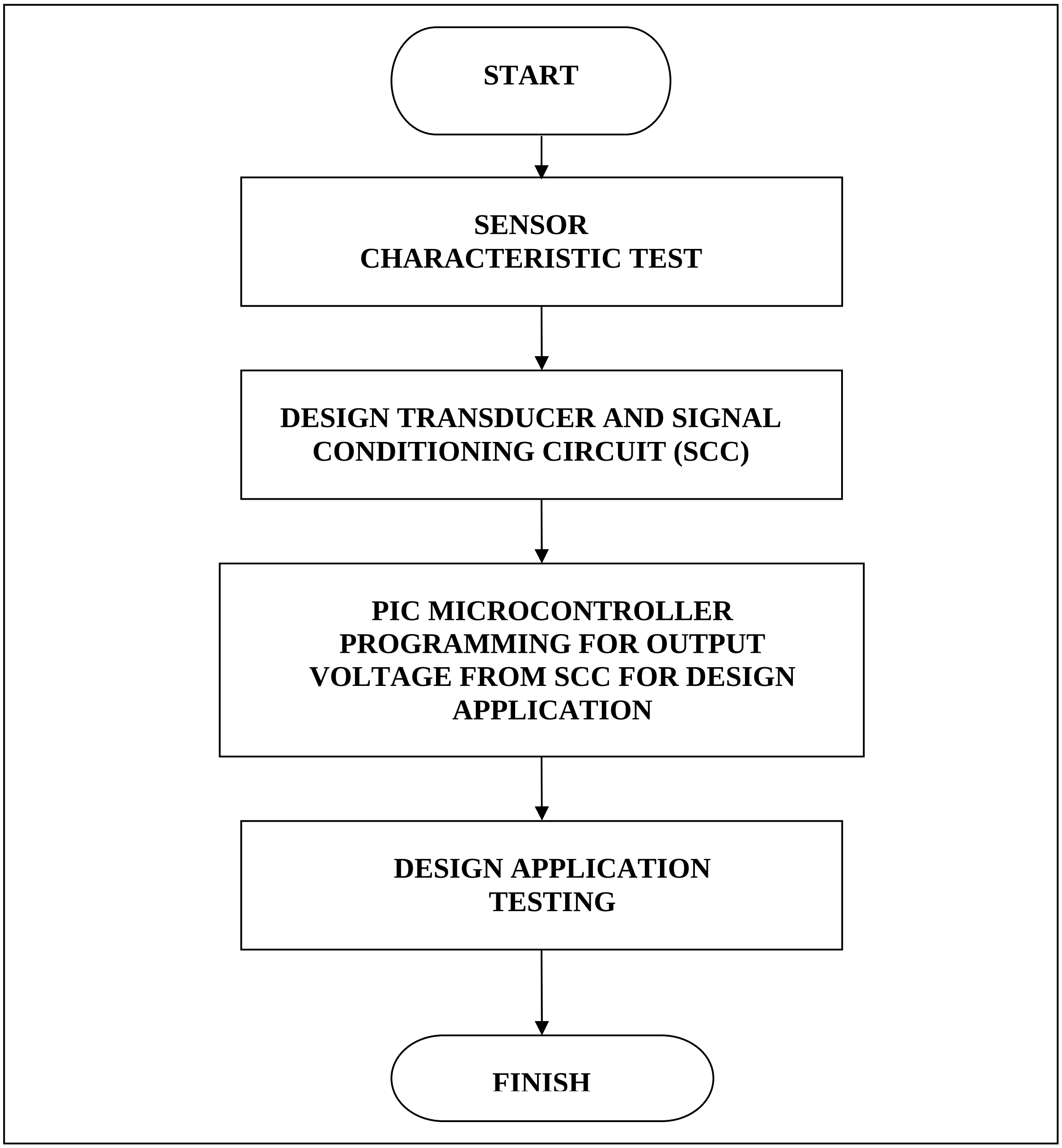

Figure 3.0: Flow of the design methodology

3.1 Sensor Part

The development of the Barium Tantalum Strontium Titanate (BTST) materials shows that the pyroelectricty character sensing capability of the material elements is demonstrated in the form of heat which will be related to the change of temperature. The presence of heat source will indicate the room is hot by a LED indicator. Barium Tantalum Strontium Titanate (BTST) thin film is actually Barium Strontium Titanate (BST) material doped with Tantalum oxide. All fabrication process was being explained in the previous chapter. There are seven steps in fabrication process including preparing solution, fabrication process, annealing/sintering, characterization, metallization, packaging and the electrical properties and the details were explained in the previous chapter. At this stage, sensor characteristic can be found by performing some experiment and analyzed the data. All procedures for sensor characteristic sensing will be explained in subtopic (3.1.1). Meanwhile the circuit design will be explained in subtopic (3.1.2).

3.1.1 Sensor characteristic test

The purpose of sensor characteristic test is to find the characteristic of BTST sensor. This is needed for the design of the application circuit based on the sensor characteristic. From this test, the expected result will be obtained when the temperature increasing, the resistance of sensor will be decreased. The method for this testing is to measure the resistances value with respect to temperature surrounding the sensor. Thus, by referring to Figure 3.1, it shows the method of testing. All the testing must be done in dark condition to overcome the sensor's sensitivity to other modes. The result and analysis of this testing can be referred to Chapter 4: Results and Discussion.

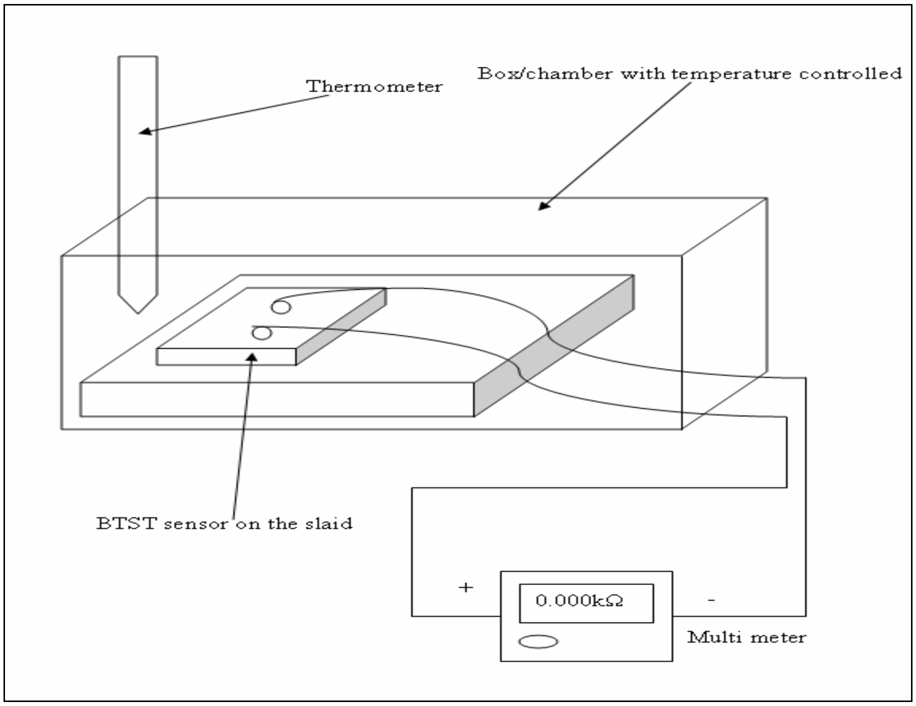

Figure 3.1: Sensor Characteristic Testing Method Diagram

3.1.2 Designing Circuit for Sensor Part by Using Differential Instrumentation Amplifier and Sensor Bridge.

From the circuit shown in Figure 3.2, it shows the simplified circuit of a differential instrumentation using the transducer bridge. As mentioned before, the sensor that has been used is BTST where is a resistive transducer. In designing sensor part circuit, Wheatstone bridge circuit is used to measure unknown sensor's resistance. Hence, in this circuit design, the sensor is connected to an arm of the bridge .

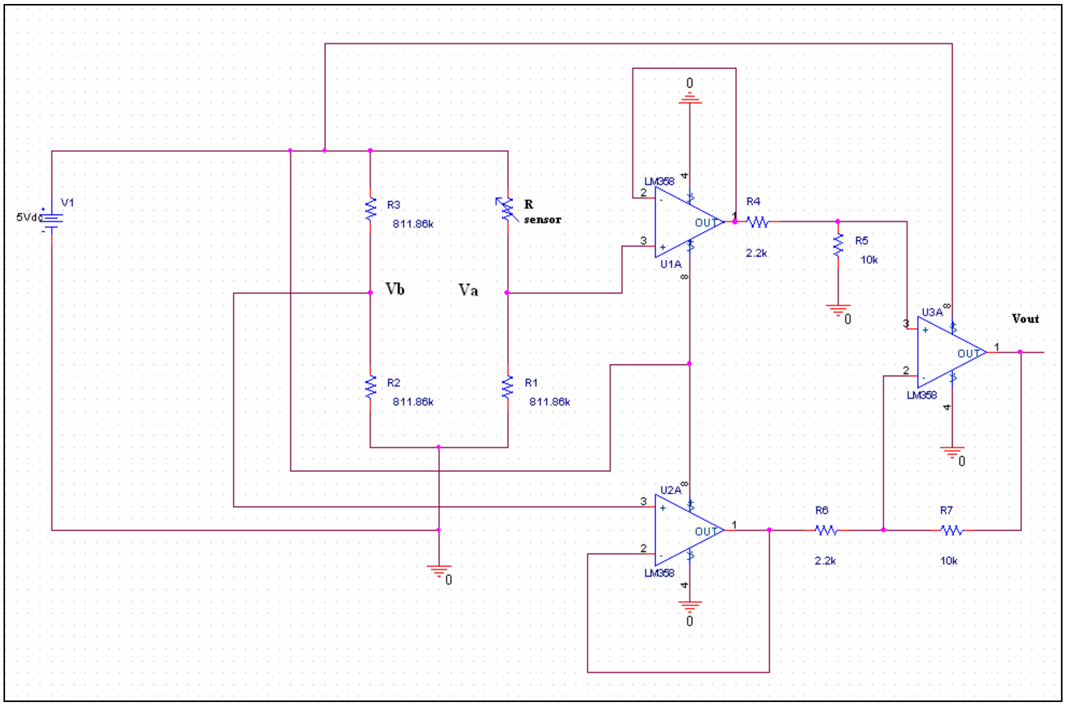

Figure 3.2: Circuit for sensor part

Table 3.0: The equivalent resistor in circuit and equation

Items in circuit	Items in equation
R_1=R_2=R_3	R_A=R_B=R_C
R_4=R_8	R_2=R_1
R_5=R_7	R_3=R_F

Thus, by referring to the Figure 3.2, let R_{BTST} be the resistance of the transducer and meanwhile the ΔR is the change in the resistance of the resistive BTST sensor. Consequently, the total resistance of the BTST sensor is (R_{BTST} + ΔR). When the bridge is in balance, $V_a = V_b$ or when,

$$\frac{R_B(E)}{R_B+R_C}=\frac{R_A(E)}{R_A+R_{BTST}} \quad \textbf{.............(3.0)}$$

By simplified the equation **(3.0),** equation **(3.1)** will be obtained,

$$R_B\left(R_A + R_{BTST}\right) = R_A\left(R_B + R_C\right)$$
$$\left(R_A R_B + R_{BTST} R_B\right) = \left(R_B R_A + R_A R_C\right)$$
$$R_{BTST} R_B = R_A R_C$$
$$\frac{R_C}{R_B} = \frac{R_{BTST}}{R_A} \qquad \textbf{……………….…………..(3.1)}$$

From the equation **(3.0)** and equation **(3.1)**, the bridge is balanced at a desired reference condition, which depends on the specific value of physical quantity to be measured. Under this condition, resistor R_A, R_B and R_C are selected that there are equal in value to the BTST resistance at 25 ^oC. (Value of physical quantity normally depends on the sensor characteristic and obtains from Figure 4.1)

As expected, the bridge is balanced at desired reference condition. If the sensor resistance changes due to the physical quantity measured, it will cause an unbalanced condition. Hence, $V_a \neq V_b$, the output voltage of the bridge will change in resistance of the sensor. The output voltage is a function of the change in the resistance of the BTST sensor. The expression for the output voltage, V_o, in terms of the change in resistance of BTST sensor can be calculated as follows. Let assume, the change in resistance in the BTST sensor is ΔR and since R_A and R_B is a fixed resistors, so the voltage at V_b is constant. As mention before, ΔR can be designed as

$$\boxed{\Delta R = \text{temperature coefficient of resistance x [final temperature-reference temperature]}}$$

Or can be define in follow equation **(3.2)**

$$\Delta R = \text{slope}(\Omega/^oC) \times [\text{final temperature-reference temperature}] \textbf{…….(3.2)}$$

Voltage, V_a changes as a function of transducer resistance. For this reason, by applying the voltage divider rule for V_a and V_b , equation **(3.3)** and **(3.4)** will be obtained.

$$V_a = \frac{R_A(E)}{R_A + (R_{BTST} + \Delta R)} \text{ ....}\mathbf{(3.3)}$$

$$V_b = \frac{R_B(E)}{R_B + R_C} \text{ ....}\mathbf{(3.4)}$$

Hence, the output voltage across the bridge terminal, V_{ab} is given by subtracting the equation **(3.3)** to equation **(3.4)**. So,

$$V_{ab} = \frac{R_A(E)}{R_A + (R_{BTST} + \Delta R)} - \frac{R_B(E)}{R_B + R_C} \text{ ....…...........}\mathbf{(3.5)}$$

On the other hand, if $R_A = R_B = R_C = R_{BTST} = R$, subsequently simplified the equation **(3.5)**

$$V_{ab} = \frac{R(E)}{2R + \Delta R} - \frac{R(E)}{2R}$$

$$V_{ab} = E\left(\frac{R}{2R + \Delta R} - \frac{R}{2R}\right) = E\left(\frac{R}{2R + \Delta R} - \frac{1}{2}\right)$$

$$V_{ab} = E\left(\frac{2R - 2R - \Delta R}{2(2R + \Delta R)}\right) = \frac{-\Delta R(E)}{2(2R + \Delta R)} \text{ ....}\mathbf{(3.6)}$$

In this design, the output voltage V_{ab} of the bridge is applied to the differential amplifier through the voltage followers. This differential instrumentation amplifier is been used because of it has important feature namely the selectable gain with high “gain accuracy” and “gain linearity”, differential input capability with the high common mode rejection, even with source having unbalanced high output impedance, high stability of gain with low temperature coefficient, low direct current (DC) offset and drift errors referred to input and also low output impedance. The voltage follower configuration gain equals to 1(A_{VF} = 1) and it means that there is no gain; and its functioning as to eliminate the loading effect of the bridge circuit or better known as a buffer. Meanwhile, the differential amplifier works to produce an output voltage proportional to the difference of two input voltage. As in theory, the gain of basic amplifier is expressed by equation **(3.7)**

$$A = \frac{R_F}{R_1} \quad \textbf{……………..(3.7)}$$

Therefore, the output voltage,V_o from the circuit will be given by equation **(3.8)**,

$$V_O = V_{ab}(A) = V_{ab}\left(\frac{R_F}{R_1}\right) = \left(\frac{-\Delta R(E)}{2(2R+\Delta R)}\right) \times \left(\frac{R_F}{R_1}\right) \quad \textbf{………..(3.8)}$$

Table 3.1 and Table 3.2 are shows all calculation for expected output voltage, V_o by using equation **(3.8)**. The results in Table 3.1 and Table 3.2 will be compared to Table 4.1 in Chapter 4.

Table 3.1: Calculation based on theory values

Items	Value of the item
$R_A=R_B=R_C$	800kΩ
R_{BTST}	800kΩ
V=E	5V

No	Temp.(^{o}C)	ΔR (kΩ)	Expected Output Voltage
1	0	166750	-1.07495
2	2	153410	-0.99649
3	4	140070	-0.91683
4	6	126730	-0.83594
5	8	113390	-0.75378
6	10	100050	-0.67033
7	12	86710	-0.58556
8	14	73370	-0.49943
9	16	60030	-0.41192
10	18	46690	-0.32298
11	20	33350	-0.23259
12	22	20010	-0.14071
13	24	6670	-0.04729
14	26	-6670	0.04769
15	28	-20010	0.14428
16	30	-33350	0.242519
17	32	-46690	0.34245
18	34	-60030	0.444117
19	36	-73370	0.547566
20	38	-86710	0.652843
21	40	-100050	0.759997
22	42	-113390	0.86908
23	44	-126730	0.980144
24	46	-140070	1.093243
25	48	-153410	1.208434
26	50	-166750	1.325775
27	52	-180090	1.445327
28	54	-193430	1.567153
29	56	-206770	1.691319
30	58	-220110	1.817892
31	60	-233450	1.946944

Table 3.2: Calculation based on the exact values

Items	Value of the item
$R_A=R_B=R_C$	811.86kΩ
R_{BTST}	800kΩ
V=E	5V

No	Temp.(^{o}C)	ΔR (kΩ)	Expected Output Voltage
1	0	166750	-0.73823
2	2	153410	-0.68272
3	4	140070	-0.62663
4	6	126730	-0.56994
5	8	113390	-0.51266
6	10	100050	-0.45476
7	12	86710	-0.39624
8	14	73370	-0.33709
9	16	60030	-0.27729
10	18	46690	-0.21685
11	20	33350	-0.15574
12	22	20010	-0.09396
13	24	6670	-0.03149
14	26	-6670	0.031669
15	28	-20010	0.09554
16	30	-33350	0.16013
17	32	-46690	0.225453
18	34	-60030	0.291521
19	36	-73370	0.358347
20	38	-86710	0.425943
21	40	-100050	0.494323
22	42	-113390	0.563501
23	44	-126730	0.633491
24	46	-140070	0.704307
25	48	-153410	0.775965
26	50	-166750	0.848478
27	52	-180090	0.921863
28	54	-193430	0.996135
29	56	-206770	1.071311
30	58	-220110	1.147407
31	60	-233450	1.224439

3.2 Data Acquisition, conversion and user interface part

3.2.1 Programming the PIC 16F876A microcontroller

For this part, the PIC 16F876A microcontroller was been used for data acquisition and conversion output. For the application, PIC 16876A will be used to control the output from sensor part and interpret the result for application used. [10] Figure 3.3 is shown the flow of program that used for this application needs. For the source code of the PIC16F876A programming can be referred in Appendix A.

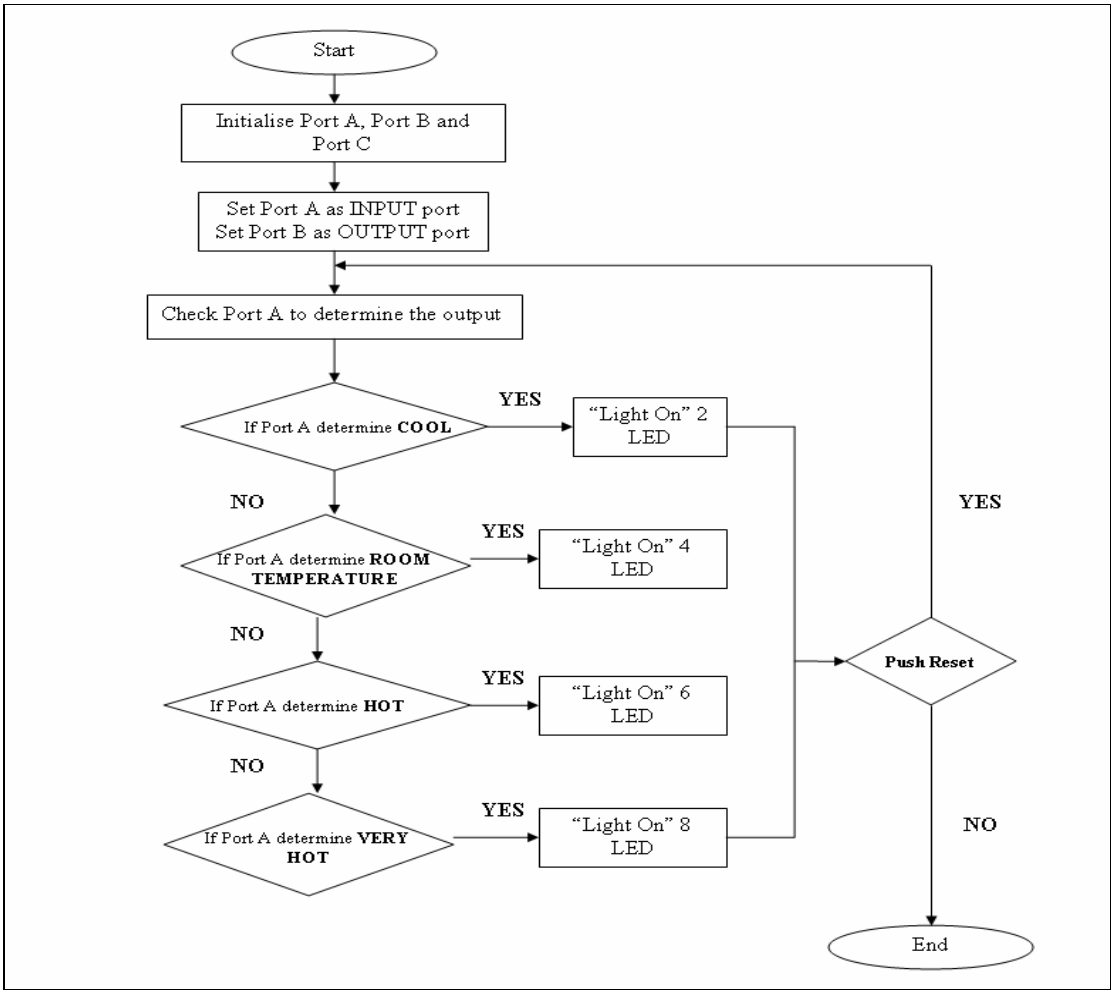

Figure 3.3: Flow of the PIC16F876A program

3.2.2 Data display

Meanwhile, for data display, in this project, LED were been used as indicator to display the data. The LED indicator will light up by referring the microcontroller data acquisition and conversion to indicate whether the room is hot or cool. In the Figure 3.4, show the basic circuit for data display output.

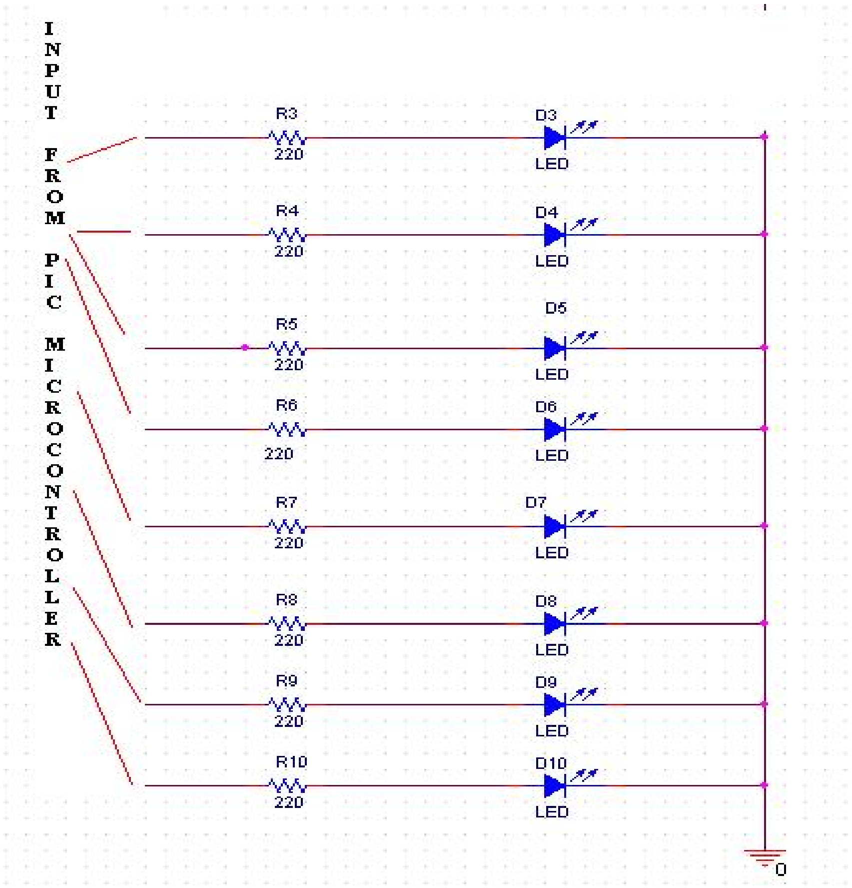

Figure 3.4: LED circuit indicator

From Figure 2.13, and the discussion on the chapter 2, that a series current limiting resistor is required to prevent excessive current from destroying the LED. From a rule of thumb is that the maximum safe current for most LEDs is 20 mA. Figure 2.14, shows a electrical schematic with a series current limiting resistor in circuit with the LED. As long as the applied voltage exceeds the +VF of the LED the voltage across the LED remains fairly constant (see Figure 2.13). By using a good digital multi meter with a diode test function, one can easily find the forward voltage of the LED.

The advantage of an active high drive circuit like that the one in Figure 3.4, above, is that it’s easier for a programmer to follow the logic that lights the LED. When output is ‘1’ or a high voltage from the microcontroller, LED will turn on. In other hand, if the output is ‘0’ or a low voltage, LED will turn off.

3.3 Heat indicator prototype

Figure 3.5 shows the prototype of this project. This prototype includes all parts that were mentioned before in the previous chapter.

Figure 3.5: Heat Indicator