DESIGN OF SOLID STATE-BASED THERMOELECTRIC DEVICE FOR COOLING AND HEATING DRINKS IN A CAR

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
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(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

Dr. John Ojur Dennis
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmad Majdi Bin Abd Ghani

ABSTRACT

The purpose of this project is to design a solid state based thermoelectric device for cooling and heating drinks in a car. The system will basically be able to cool down or heat up to a certain temperature by connecting the circuit to cigarette lighter as a power supply in a car. The scopes of study of this project are basically focused on three fields which are the Peltier device, the thermoelectric applications and the control circuit. A control circuit has been design for the purpose of cooling and heating as well as maintaining at certain desired temperature. The circuit consists of H-bridge circuit, PIC 16F877 microcontroller and temperature sensor. A prototype which is called cooler/heater made of Peltier module, heat sink and cooling fan has been constructed. A container which is made of material that has low thermal conductivity and properly sealed is chosen and modified to keep the temperature inside cold or hot. The project is able to cool down to 7^0C and heat up to 65^0C and maintain at that temperature for use in a car. The Peltier module surface took about 5.56 seconds to heat up to the expected temperature at 65^0C and took 20.53 seconds to cool down to expected cooling temperature at 7^0C. The air temperature inside the 360 ml container took about 60 minutes to heat up to the expected temperature at 65^0C and 220 minutes to cool down to expected cooling temperature at 7^0C.

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LIST OF ABBREVIATIONS

TEC	–	Thermoelectric cooler
UTP	–	Universiti Teknologi Petronas
PCB	–	Printed circuit board.

CHAPTER 1
INTRODUCTION

1.1 Background

French watchmaker, Jean Charles Athanase Peltier, discovered thermoelectric cooling effect, also known as Peltier cooling effect, in 1834. Peltier discovered that the passage of a current through a junction formed by two dissimilar conductors caused a temperature change. However, Peltier failed to understand this physics phenomenon, and his explanation was that the weak current doesn't obey Ohm's law. Peltier effect was made clear in 1838 by Emil Lenz, a member of the St. Petersburg Academy. Lenz demonstrated that water could be frozen when placed on a bismuth-antimony junction by passage of an electric current through the junction. He also observed that if the current was reversed the ice could be melted. In 1909 and 1911 another scientist Altenkirch derived the basic theory of the thermoelectric effect. His work pointed out that thermoelectric cooling material needed to have high See back coefficients, good electrical conductivity to minimize Joule heating, and low thermal conductivity to reduce heat transfer from junctions to junctions. Shortly after the development of practical semiconductors in 1950's, bismuth telluride began to be the primary material used in the thermoelectric cooling [1].

Beginning around 1990, a combination of factors notably environmental concerns regarding refrigerant fluids and interest in cooling electronics led to renewed activity in the science and technology of alternative refrigeration. Thermoelectric cooling is the most well established of these technologies. Since thermoelectric cooling systems are most often compared to conventional systems, perhaps the best way to show the differences in the two refrigeration methods is to describe the systems themselves

Thermoelectric cooling, a thermoelectric (TE) cooler, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a TEC module, heat will be moved through the module from one side to the other. Thermoelectric coolers employ the Peltier effect, acting as small, solid-state heat pumps. The device is ideally suited to a wide variety of applications where space limitations and reliability are paramount.

1.2 Problem Statement

Peltier effect device are made of an N and P type semiconductors that are joined together by metal contact to form a junction that can perform cooling on one side while heating on the other side. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

The aim of the project is to build a thermoelectric device that has small size (portable), simplicity and reliable and can be used for cooling and heating drinks or food in car. This device is expected to cool down or heat up drinks up to certain temperature with the help of control circuit for temperature control.

For controlling the temperature, a control circuit is used to control the temperature to certain needed temperature.

This system can be used by public by just plugging in to cigarette lighter of an automobile to heat up or cool down their drinks with lower cost possible. The significant of the system is it is expected to be simple, small size and reliable in terms of performance and cost. To heat a cup of coffee, just place the hot/cold switch in the hot position. To cool down a soda, place this switch in the cold position

1.3 Objectives and Scope of Study

The specific objectives of the project are as follows:

- To get and test Thermoelectric modules
- To build a circuit capable of performing cooling and heating function
- To program a PIC microcontroller to set and maintain to the temperature needed for cooling and heating
- To build/choose and design/modified a container that is made of low thermal conductivity materials.
- To design the complete prototype of the thermoelectric cooler or heater for use in a car

The scopes of study of this project will be focused on:

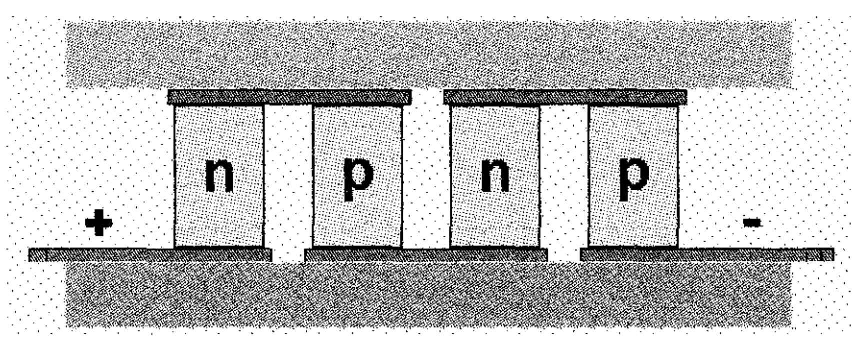
- Peltier device
- Thermoelectric applications
- Control circuit.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Peltier Effect

Peltier effect was called after a French watchmaker (1785-1845.), who discovered it in 1834. Peltier effect is the phenomenon used in the thermoelectric refrigeration, with the rate of reversible heat absorption. When current passes through the junction of the two different types of conductors, it results in a temperature change. Thermoelectric device are made of N and P type semiconductors that are joined by metal contact to form a junction as shown in Figure 2.1. It has dual purpose to cool on one side and heat on the other side [4].

COLD



HEAT

Figure 2.1: N and P type semiconductor joined by metal contact

Referring at the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

When switching on the current of the definite polarity, there forms a temperature difference between the radiators one of them warms up and works as a heat sink, the other works as a refrigerator [2].

Figure 2.2 (a) shows the thermoelectric cooling module while Figure 2.2 (b) shows the movement of electronic carrier in the semiconductor and Figure 2.2 (c) shows the Peltier module construction

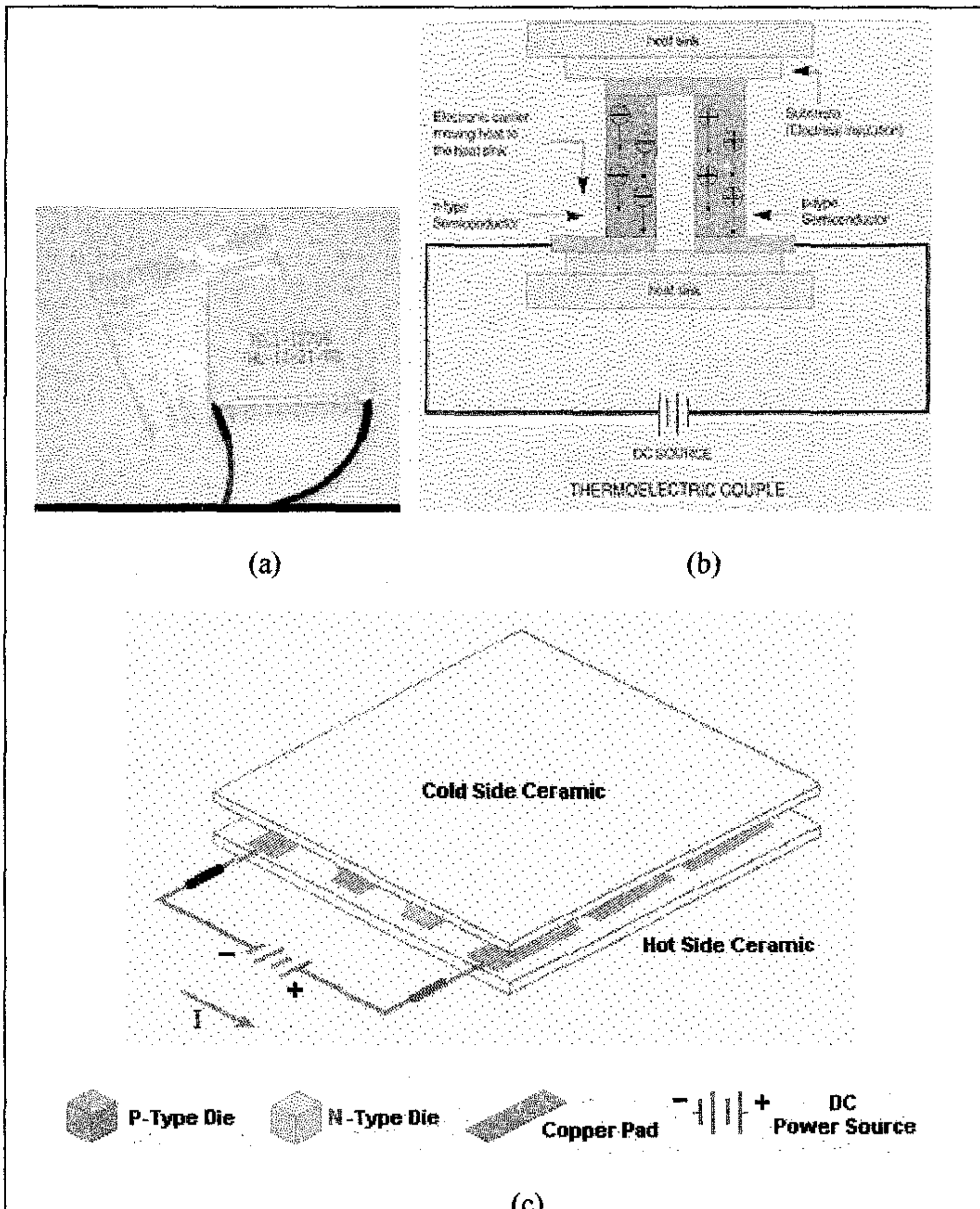


Figure 2.2: (a) Peltier device circuit, (b) Thermoelectric cooling module and (c) Peltier module construction

2.2 Peltier Cooler

Thermoelectric cooler (TEC), or Peltier Cooler is a solid-state heat pump that uses the Peltier effect to move heat. The modern commercial TEC consists of a number of p- and n- type semiconductor couples connected electrically in series and thermally in parallel. These couples are sandwiched between two thermally conductive and electrically insulated substrates. The heat pumping direction can be altered by altering the polarity of the charging DC current. The typical materials used for constructing TEC are:

1. Substrate: aluminum oxide (Al2O3), aluminum nitride (AlN), or barium oxide (BaO)
2. Conductor: Copper
3. Thermoelectric semiconductor
    i. n-type: bismuth-telluride-selenium (BiTeSe) compound
    ii. p-type: bismuth-telluride-antimony (BiTeSb) compound
4. Assembled and joined by solder.

The TEC can be made in different shapes and sizes, but most common shape is a square or a rectangular substrate device. The practical size of a single stage TEC ranges from 3 mm x 3 mm up to 60 mm x 60 mm. The size limitation of 60 mm x 60 mm is due to the thermal stress. This stress comes from thermal expansion deformations between the cold and the hot junctions of the TEC. To obtain a larger temperature difference, a multistage TEC can be build. The multistage TEC is usually in cascade shape and 6 stages are the maximum practical limit.

TEC can be used in different applications where cooling or temperature control of an object is required. In general, TEC is most often used when an object:

1. Needs to be cooled below the ambient temperature, or

2. Requires to be maintained at a consist temperature under a fluctuating ambient temperature.

TEC is perfect for cooling a small, low heat load object. Due to the low COP (Coefficient of Performance) compared with compressor cooling, TEC looses its advantage if the cooling load is higher than 200 watts. But, because TECs have no moving parts, they are lightweight and reliable; they create no electrical noise, and can be operated at any orientation or environment, in some instances TECs are used to cool kilowatts of heat.

TEC is exceptionally suitable for a precision temperature control of an object such as a laser diode, CCD or other small objects. Paired with a DC power supply and an electronics proportional/integral (PI) controller packaged in a single chip device, TEC is able to control an object to +/- 0.1°C accuracy. Today, no other cooling method yet can provide such precise, simple and convenient temperature control [1].

2.3 Control circuit

The control circuit for the thermoelectric cooler and heater can be any types of circuit that can perform heating and cooling operation. The control circuit consists of H-bridge circuit connected with PIC microcontroller 16F877 and temperature sensor and toggle switch.

2.3.1 H-bridge circuit

H-bridge circuit is used basically to perform two basic function cooling and heating as shown in Figure 2.3. This circuit is connected to microcontroller to program the temperature needed for cooling or heating [14]. The H-bridge circuit allows controlling the output of Peltier module. This circuit need some extra circuitry for temperature monitoring and will use PIC for programming of required functions for Peltier modules. PIC that usually used for the purpose is 16F877 or 16F84. If PIC 16F84 is used, an ADC is needed as it does not contain the ADC function as in PIC 16F877 [4].

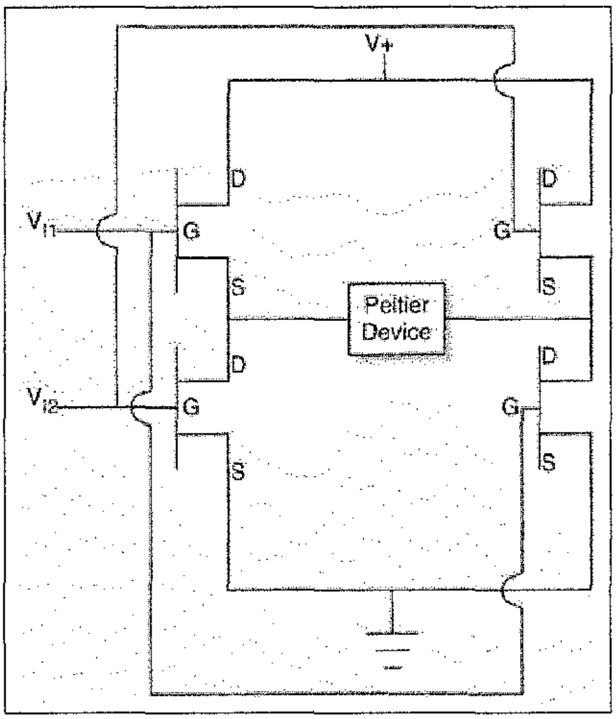


Figure 2.3: Example of simple H-bridge circuit

- Transistor

A transistor consists of three layers of silicon or germanium semiconductor material. Impurities are added to each layer to create a specific electrical positive or negative charged behaviour. "P" is for a positive charged layer and "N" is for a negative charged layer. The leads are labeled base (B), collector (C) and emitter (E) or Gate (G) Drain (D) and Source (S). A transistor may be used as a switch (either fully on with maximum current, or fully off with no current) and as an amplifier (always partly on) [14].

- Darlington transistor

Darlington transistors show in Figure 2.4 such as TIP 122 and TIP 127 are used in the circuit. These transistors are used as they are very convenient for linear power and have good switching characteristic. This is important for the Peltier module to function as cooler or heater.

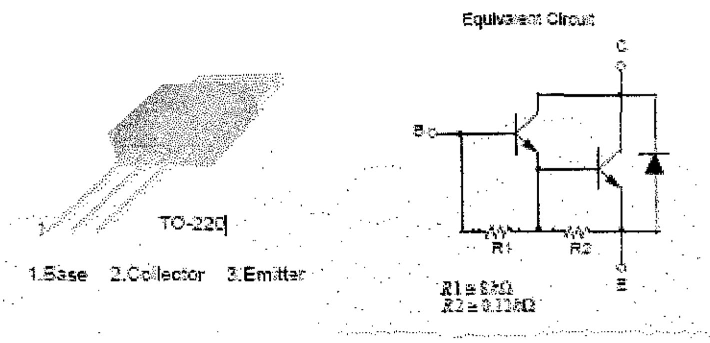


Figure 2.4: Darlington transistor and equivalent circuit

2.3.2 PIC microcontroller 16F877

The PIC16F877 show in Figure 2.5 is the microcontroller used in the control circuit. The PIC (programmable integrated circuit) is programmed to control the h-bridge circuit with the input from the temperature sensor. PIC16F877 features 256 bytes of EEPROM data memory, self programming, an ICD, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I^2C™) bus and a Universal Asynchronous Receiver Transmitter (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications [16].

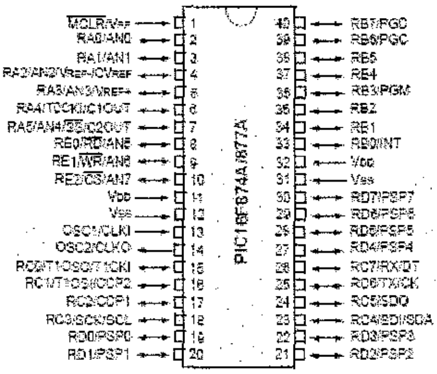


Figure 2.5: 40-pins PIC 16F877

2.3.3 Temperature sensor

In the full circuit, the temperature sensor used is a LM35DZ as shown in Figure 2.6. It is located between the insulator and the container. The LM 35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM 35, which has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling. An output voltage proportional to the centigrade temperature can easily be obtained using LM 35DZ, which has a linear +10.0 mV/°C scale factor and a temperature range from 0°C to +100°C [12]. For temperature measurement, the LM 35 temperature sensor was connected to PIN RA1 of the PIC 16F877.

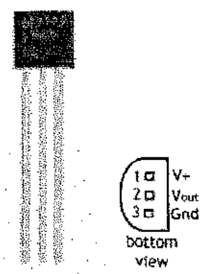


Figure 2.6: Temperature sensor

CHAPTER 3

METHODOLOGY/PROJECT WORK

Some of the specific objectives have been achieved and some are to be realized. In order to realize the objectives, the methodology section indicates the steps that will be followed.

3.1 Ordering the Peltier Device

Some research have been conducted on the supplier for the Peltier effect devices and about 3 to 4 suppliers were found to be available in this region. Among these are RS and a supplier that located in Bangkok, Thailand. An email was sent to them and received the reply for the price and details about the shipment cost and time. For the RS supplier, the catalogue is from their compact disc that has been distributed during RS talk that had been conducted in UTP. The price is quite expensive if compared to another supplier. It might be easier to deal with them. TEC modules TEC1-07108 and TEC1-12708 have been decided to be used. This decision is made due to the maximum current and voltage rating.

Table 3.1: Specifications of the Peltier devices obtained

Item		Max Delta	Max	Max	Max			
Part Number	Description	T	Voltage	Current	Wattage	Length	Width	Thickness
TEC1-07108	Single Stage TEC	68	8.6	8.5	42	30.0	30.0	3.6
TEC1-12708	Single Stage TEC	68	15.4	8.5	76	40.0	40.0	3.6

This is referring to car battery that will be used to power the thermoelectric cooler for drinks; 12V car battery is usually used in car. Referring to a car battery manufacturer, Yokohama Battery is one of the most widely used car battery which supplies car battery for HONDA, PROTON, PERODUA, HYUNDAI, INOKOM and some other famous car company, the battery voltage specification is 12V. It is agreed to order two of each module as backup if any damage happened to the modules and together with another two students to minimize the shipping costs. Figure 3.1 shows the process of getting the information on Peltier device until ordering the Peltier device [3].

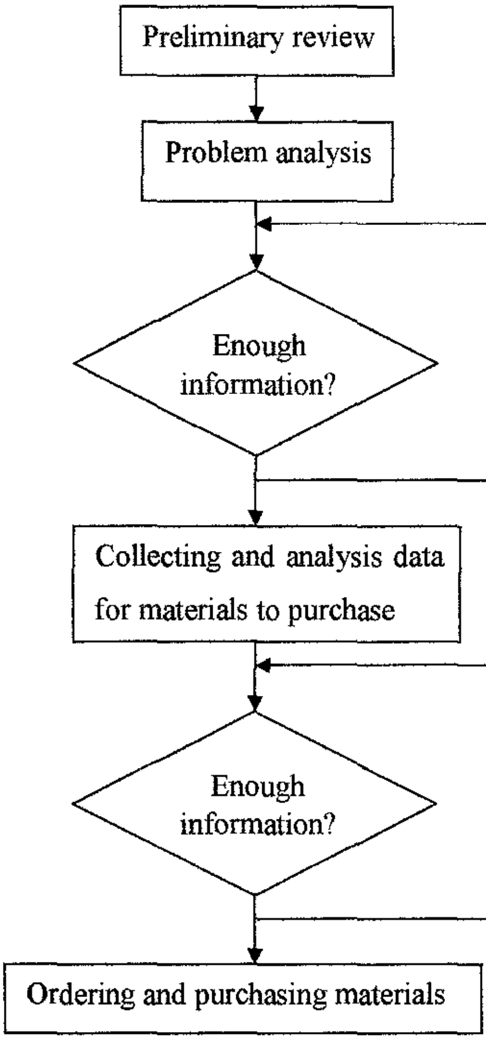
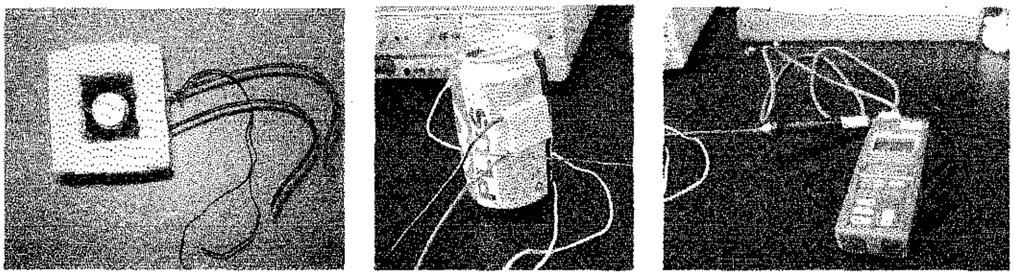


Figure 3.1: Problem analysis and collecting information on materials to purchase

3.2 Testing the Peltier Device

Testing of the Peltier device is done on both sides which consist of analysis of temperature on the hot side of Peltier module and on the cold side of Peltier module. Figure 3.2 shows the experimental setup for testing of the Peltier module.



(a) (b) (c)

Figure 3.2: Experimental setup for test (a) cooling fan and heat sink (b) using water as the heat sink (c) digital thermometer used

3.3 Constructing the Control Circuit

The control circuit may be a simple circuit as shown in Figure 3.3 that consists of only toggle switch, thermal switch to disconnect at certain temperature for heating and fuses for protection of the circuit. The main parts of the circuit are the switches. Toggle switch might be suitable to perform the function of switching. While thermal switch is used to disconnect the circuit as the Peltier reaches certain temperature for example 65^0C or 80^0C

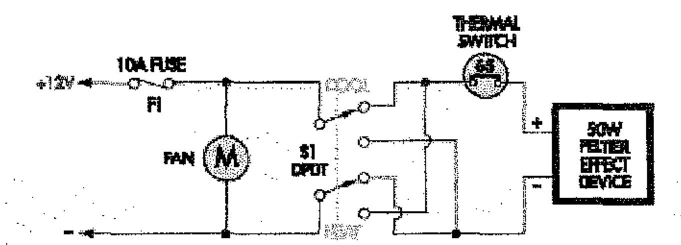


Figure 3.3: Simple circuit

The control circuit may also be a complex circuit that consists of H-bridge circuit to perform heating and cooling operation and PIC microcontroller that can control the temperature. To build or design the circuits, there are some steps to be taken:

- Research on H-bridge circuit for temperature control
- Understanding and analysis of H-bridge circuit for temperature control on the internet and on the circuit from previous semester student.
- Simulation of simple H-bridge circuit to see the characteristic

3.3.1 Full control circuit

The full control circuit connection will be as in Figure 4.12. The control circuit consists of the H-bridge circuit as in Figure 3.4, Peltier module and PIC microcontroller. The H-bridge circuit contains of transistors such as BJT transistors, Darlington transistors, resistors, switches and LEDs to indicate the operation of the Peltier module. The connection of PIC microcontroller to the controller circuit is connected through a Darlington transistor.

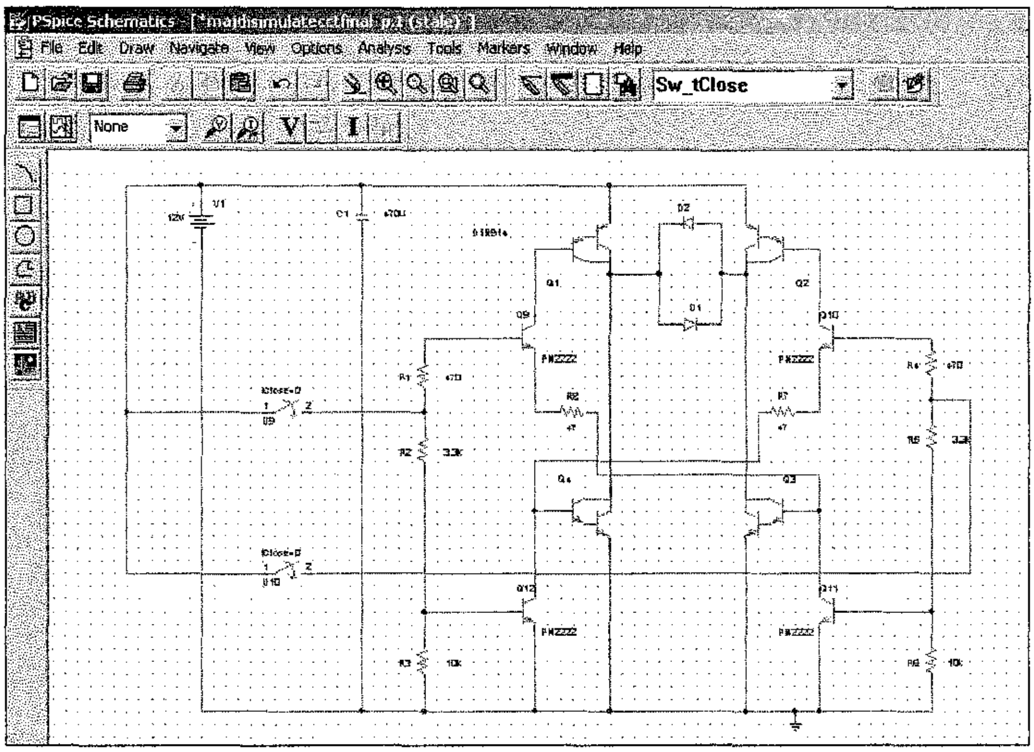


Figure 3.4: H-bridge part of control circuit

3.3.2 Circuit Development

The development of the circuit for the project will go through some stages. The implementation of the circuit will be done as shown in Figure 3.5.

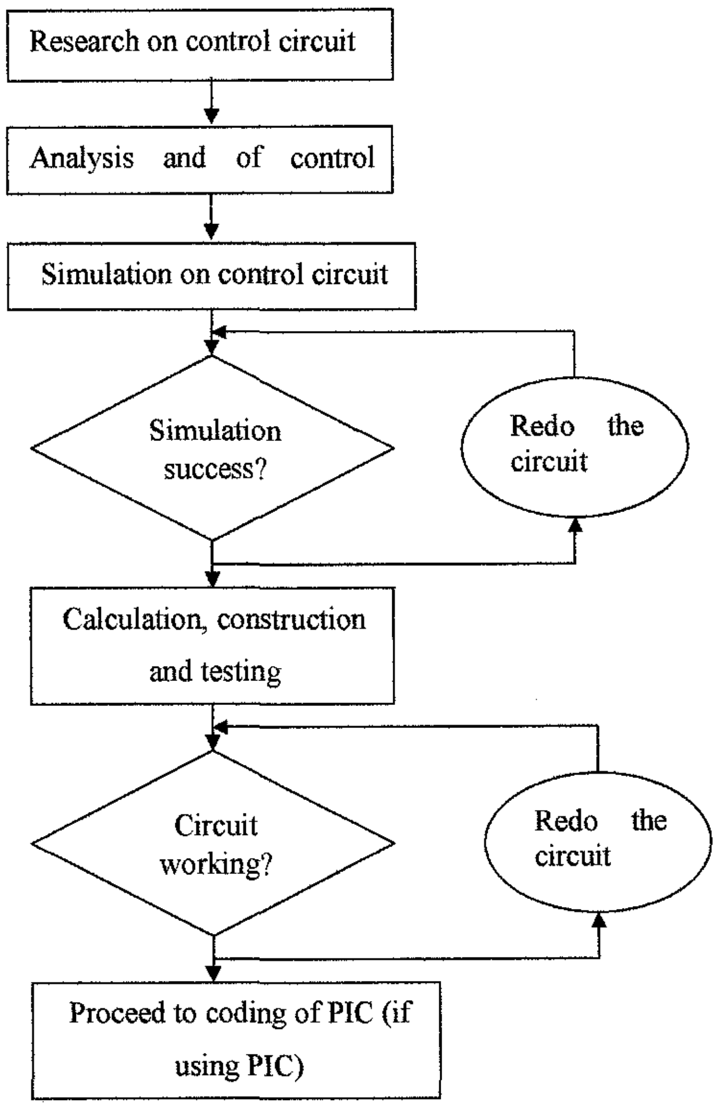


Figure 3.5: Circuit development

3.3.3 Coding and Programming of PIC microcontroller

The examples of program for the temperature control are programmed and tests carried out on PIC microcontroller. The programs of PIC are in the assembly language and C code. Software such as Bumblebee, MPLAB, MPASM, and CCS Compiler are used to write and program the PIC microcontroller. If the program is in C code, it would be easier for writing and programming of PIC microcontroller. The PIC microcontroller that might be used is 16F877 and 16F84. Figure 3.6 shows the setup for programming of PIC microcontroller.

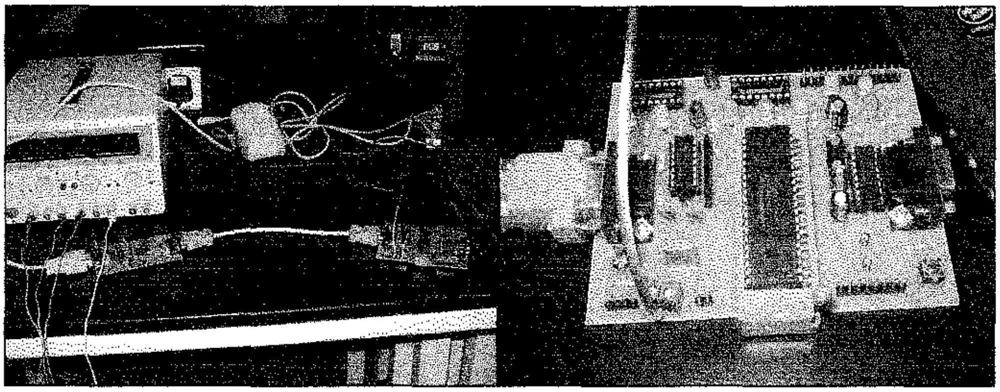


Figure 3.6: Programming board for programming of PIC microcontroller

The codes obtained are run on the software such as CCS compiler first before being programmed into the PIC microcontroller. For the codes in assembly language, there are some errors observed. The errors need to be corrected before programmed into the PIC microcontroller. The programming of PIC microcontroller is basically on the process of running the code and correcting errors found. Figure 3.7 shows the steps for coding and programming of PIC microcontroller

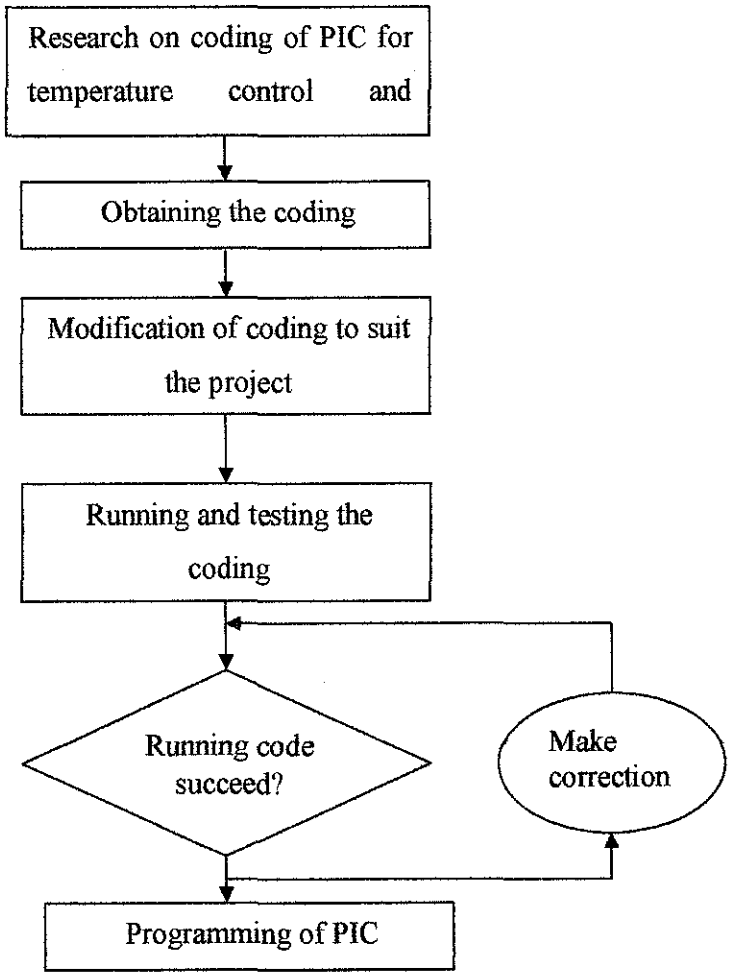


Figure 3.7: Coding and programming of PIC

3.3.4 Interfacing PIC16F877 and temperature sensor

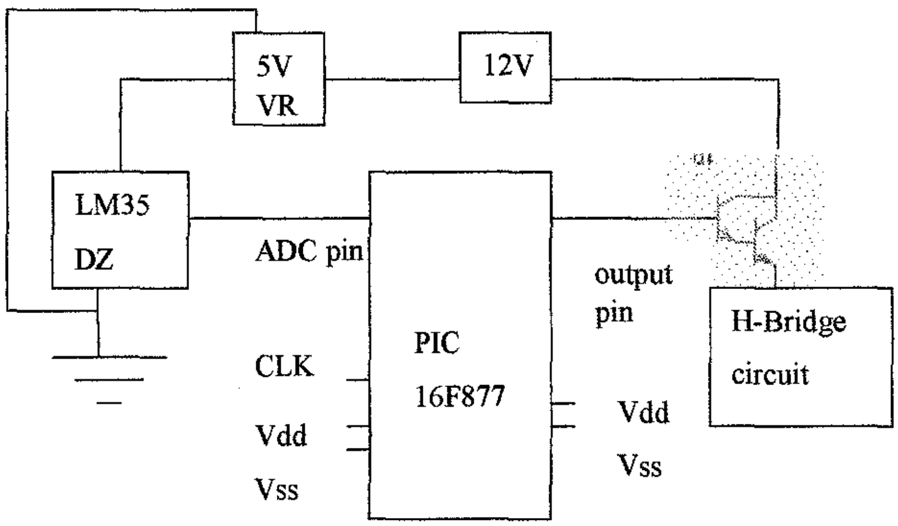


Figure 3.8: Interfacing between PIC 16F877 and temperature sensor

Figure 3.8 shows the connection of microcontroller and temperature sensor. The temperature sensed will be sent to the A/D converter in the PIC 16F877. The digital input from the microcontroller is sent to the h-bridge circuit for switching of the circuit. As the voltage and current from the microcontroller is low, Darlington transistor is used to amplify the circuit.

3.4 Cooler Construction

Cooler construction (with Peltier module, heat sinking equipment such as heat sink, cooling fan, heat transfer materials such as aluminums cube, heat compound or heat paste or heat grease or heat pad, and material to separate between hot and cold side such as polyurethane foam or gasket [7]. Insulation material to protect the couples from contact with water or gases, eliminating corrosion and thermal and electrical shorts that can damage the thermoelectric module

The cooler will be put on top of the container with the heat sink equipments on the outside while thermal conductivity material such as aluminums cube and plate on the inside of the container.

3.4.1 Calculation of heat transfer

- **Heat transfer of Peltier module**

Let say estimated heat load of 22 watts, a forced convection type heat sink with a thermal resistance of 0.15°C/watt, an ambient temperature of 25°C, and an object that needs to be cooled to 7°C.

The TEC-12708 specifications are 40x40x3.5mm in size, weight of 23g, with maximum current 8.5A, maximum voltage 15.4V,Qmax(ΔT=0) is 71W, ΔT max. is 68°C, resistance is 1.50 ohm and 127 couples.

To determine if this thermoelectric is appropriate for this application, it must be shown that the parameters ΔT and Q_c are within the boundaries of the performance curves.

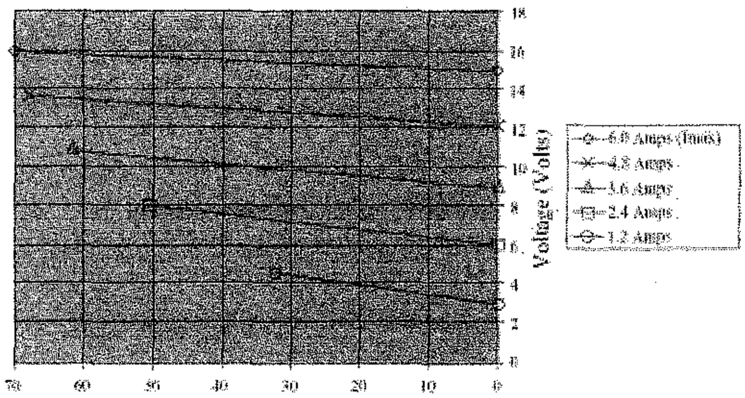
The parameter ΔT follows directly from T_h and T_c. Since the cold side of the thermoelectric is in direct contact with the object being cooled, T_c is estimated to be 7°C. Assuming a 10°C rise above ambient for the forced convection type heat sink,

T_h is estimated to be 35°C. Without knowing the power into the thermoelectric, an exact value of T_h cannot be found. Equation 1 gives the temperature difference across the thermoelectric:

$$\Delta T = T_h - T_c \qquad (1)$$

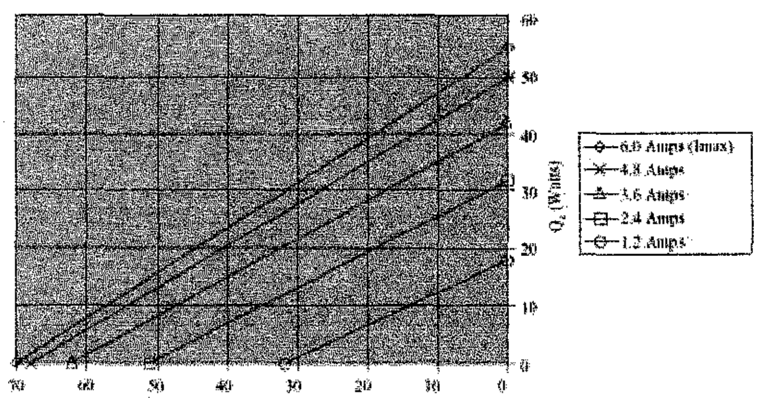
Thus, temperature difference is 28.

Referring to Figure 3.10, the intersection of Q_c and ΔT show that this thermoelectric can pump 22 watts of heat at a ΔT of 30°C with an input current of 3.6 amps.



ΔT(°C)

Figure 3.9: Performance Curve (ΔT vs. Voltage)



ΔT(°C)

Figure 3.10: Performance Curve (ΔT vs. Qc)

These values are based on the estimate $T_h = 35°C$. Once the power into the thermoelectric is determined, solve for T_h and determine whether the original estimate of T_h was appropriate.

The input power to the thermoelectric, Pin, is the product of the current and the voltage. Using the 3.6 amp line in Figure 3.10 for the current, the input voltage corresponding to $\Delta T = 28°C$ is approximately 10 volts [17].

T_h can now be calculated.

$$T_h = T_{amb} + (\theta)(Qh) \tag{2}$$

Where T_{amb} is 25°C Θ is 0.15°C/watt.

$$Q_h = Q_c + P_{in} \tag{3}$$

Giving the value Q_h is 58 W from equation 3 and therefore, T_h is 33.7°C from equation 2.

- **Heat transfer of heat sink and cooling fan**

Heat transfer (natural convection – heat sink)

The material used for the assembly components deserves careful thought. The heat sink and cold side mounting surface should be made out of materials that have a high thermal conductivity (i.e., copper or aluminum) to promote heat transfer [18]. The calculation of heat transfer by heat sink used is as follows:

Rate of natural convection heat transfer,

$$Q = hA_s(T_s - T_\infty) = h(2nLH)(T_s - T_\infty) \tag{4}$$

Where h is the convection coefficient, n is no. of fins, L is length of heat sink, H is height of heat sink, T_∞ is air temperature and T_s is base temperature (let say at 65°C).

Therefore, the heat dissipated by natural convection at rate of 3.169 W from equation 4.

Heat transfer (forced convection – cooling fan)

Rate of forced convection heat transfer,

$$Q = hA_s (T_s - T_\infty) = hLH(T_s - T_\infty) \tag{5}$$

Thus, rate of forced convection heat transfer is 8.91 W

Where h is convection coefficient, L is length of heat sink, W is wide of heat sink, T_∞ is air temperature and T_s is base temperature (let say at 65°C).

Therefore, the heat dissipated by forced convection at rate of 8.91 W.

- **Calculation of thermal load**

For the calculation of thermal load, the length of container, l is 0.115m and the diameter of container, D is 0.065m.

$$Volume, V = \pi \times \left(\frac{D}{2}\right)^2 \times l \tag{6}$$

Giving the volume is 0.000382m3 from equation 6.
Given density of water, r is1000kg/m3 and Cp the specific heat is 4.23 kjoules/kg^{0}C
Therefore,

$$Mass, m = W = r \times Volume \tag{7}$$

$$Q = C_p \times m \times \Delta T \tag{8}$$

Thus, rate of forced convection heat transfer 4757 Joules

According to the Figure 3.10, if the voltage remains 10V, 3.6 A throughout the experiment Q° is 22 watts.

22watts is equal to 22 joules/sec

$$Dt = \frac{Q}{Q_0} \tag{9}$$

Thus, from equation 9, time taken to remove heat is 36 minutes.

3.5 Construction of container and components installation

Research on the low and high thermal conductivity material has been conducted. The amount of heat a material will transmit per unit of temperature is based on the material's cross-sectional area and thickness. Conventional cooling systems such as those used in refrigerators utilize a compressor and a working fluid to transfer heat. Thermal energy is absorbed and released as the working fluid undergoes expansion and compression and changes phase from liquid to vapour and back, respectively.

The material used for the assembly components of Peltier cooler deserves careful thought. The heat sink and cold side mounting surface should be made out of materials that have a high thermal conductivity (copper or aluminium) to promote heat transfer. However, insulation and assembly hardware should be made of materials that have low thermal conductivity (i.e., polyurethane foam and stainless steel) to reduce heat loss [12].

In order to maximize thermal performance and minimize condensation, all cooled objects should be properly insulated. Insulation type and thickness often is governed by the application and it may not be possible to achieve the optimum insulation arrangement in all cases. Every effort should be made, however, to prevent ambient air from blowing directly on the cooled object and/or thermoelectric device. Environmental concerns such as humidity and condensation on the cold side can be alleviated by using proper sealing methods. A perimeter seal protects the couples from contact with water or gases, eliminating corrosion and thermal and electrical shorts that can damage the thermoelectric module.

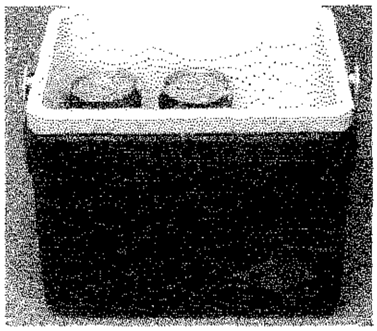


Figure 3.11: Portable beverage container

The container of the Peltier cooler must be made of low thermal conductivity material to prevent thermal lost. Portable food or beverage cooler container as shown in Figure 3.11 can be used. This container is usually made of ABS and polyurethane inside that have low thermal conductivity characteristic. Figure 3.12 shows the steps to implement it.

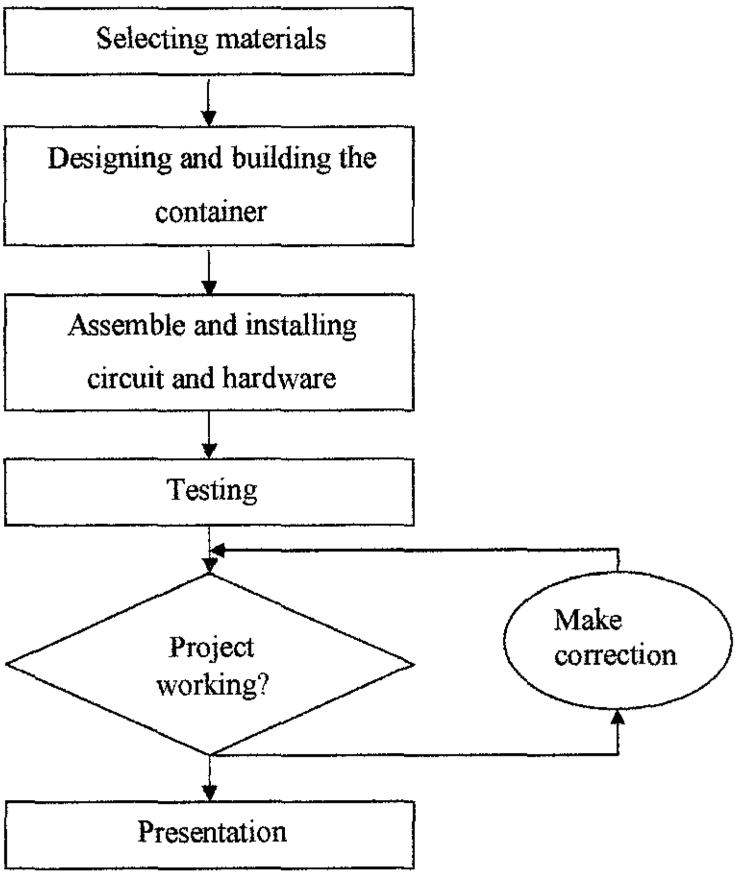


Figure 3.12: Construction of container and installing the components

3.6 Research Tools

The tools and equipments that will be used are Peltier modules, regulated dc power supply, heat sinks, heat source (material with high thermal conductivity), fan for forced convection air cooled heat sink, thermocouples, insulation and assembly hardware (made up of low thermal conductivity materials such as polyurethane foam and stainless steel to reduce heat loss), perimeter sealed to prevent environmental concern such as humidity and condensation on cold side. Software such as PSPICE, PIC simulator, MULTISIM, and PCB design software might be used to build up microcontroller circuit to control the temperature. Testing devices such as multimeter is really important to conduct test to ensure reliability and measuring the performance of the devices use in this project.

Lists of hardware equipment

- Peltier modules
- DC power supply(car battery)
- DC connector to connect the project to the supply in car
- Heat sink and cooling fan if needed
- Low thermal conductivity materials such as polyurethane foam and stainless steel to reduce heat loss (to confine the cooling or heating space – the container)
- Low thermal conductivity materials such as aluminums to ensure better thermal flow.
- Heat compound for better heat transfer
- Perimeter sealed

Lists of testing equipments

- Multimeter
- DC power supply
- Digital thermometer

Lists of software

- PSPICE
- MULTISIM
- PCB design / EAGLE
- PIC simulator and programmer (MPLAB,MPASM,BUMBLEBEE,CCS compiler)
- ULTIBOARD

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Measurement on Peltier module

A test on the Peltier module has been carried out to see whether the Peltier module surface can achieve desired temperature. The setup of the test is by using digital thermometer. The test was conducted using 360 ml container. The cooler/heater was placed on the top of the container. The digital thermometer and temperature sensor were placed on the surface of the Peltier module.

The test was conducted in a closed container to reduce the affect of ambient temperature to the temperature inside the closed container. The container was properly sealed and has better insulation to prevent exchange of heat between in side and outside of container. The placement of the temperature sensor is assuming such as there is direct contact between cooler/heater with the subject to be cool down or heat up. Figure 4.1 shows the setup of the experiment.

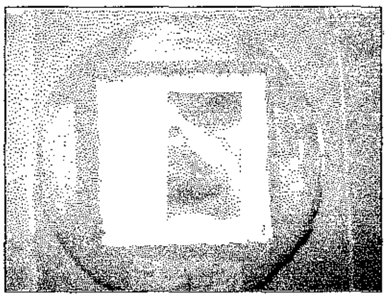


Figure 4.1: Placement of digital thermometer on the Peltier module surface

4.1.1 Heating operation

The result for heating can be seen in the Table 4.1 and Figure 4.2.

Table 4.1: Table of temperature versus time test for heating operation (Peltier surface temperature)

Temperature (^{0}C)	**Time (s)**	**Current (A)**	**Voltage across Peltier Module (V)**	**Power (W)**
28	0	2.18	8.64	18.84
35	0.82	2.18	8.64	18.84
40	1.90	2.18	8.64	18.84
45	2.04	2.18	8.64	18.84
50	2.75	2.18	8.64	18.84
55	3.82	2.18	8.64	18.84
60	4.86	2.18	8.64	18.84
65	5.56	2.18	8.64	18.84

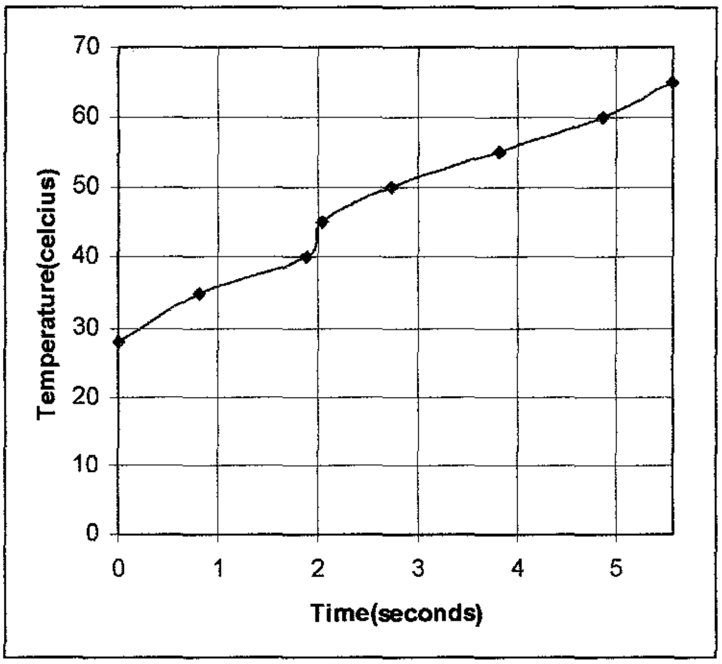


Figure 4.2: Graph of of temperature versus time test for heating operation (Peltier surface temperature)

4.1.2 Cooling operation

The result for cooling can be seen in the Table 4.2 and Figure 4.3.

Table 4.2: Table of temperature versus time test for cooling operation (Peltier surface temperature)

Temperature (^{0}C)	**Time (s)**	**Current (A)**	**Voltage across Peltier Module (V)**	**Power (W)**
28	0	3.01	7.82	23.54
25	1.21	3.01	7.82	23.54
20	3.06	3.01	7.82	23.54
15	6.21	3.01	7.82	23.54
10	12.53	3.01	7.82	23.54
7	20.53	3.01	7.82	23.54

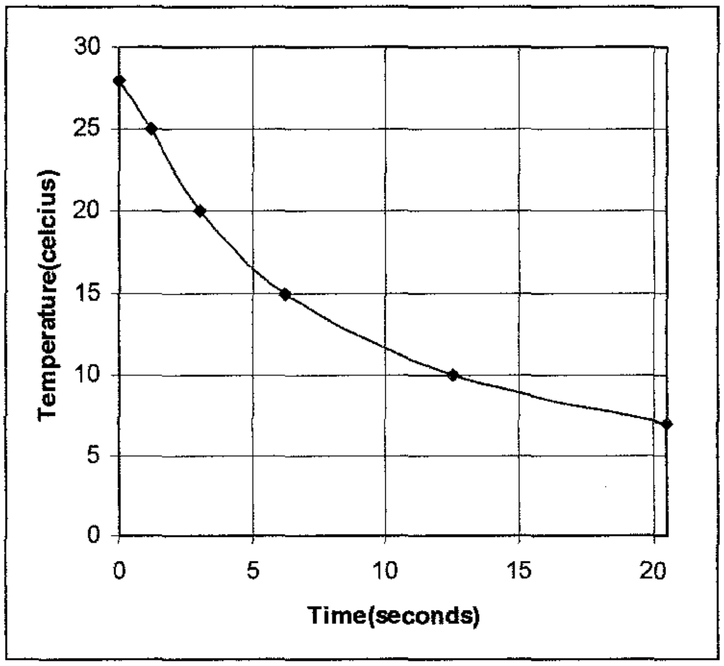


Figure 4.3: Graph of temperature versus time test for cooling operation (Peltier surface temperature)

4.1.3 Discussions on results

From the result obtained, we can see that the Peltier module surface took about 5.56 seconds to heat up to the expected temperature at 65^0C and took 20.53 seconds to cool down to expected cooling temperature at 7^0C. This is a really good result as the Peltier module can cool down and heat up very fast in fact the result can go down to below 0^0C for cooling operation. However, it will take some time for the Peltier module to cool down and heat up the temperature inside container

4.2 Simulation on part of control circuit (H-Bridge)

Analysis of the H-bridge circuit was done using PSIPCE. This simulation is done to see the characteristic and function of the circuit. Table 4.3 shows the result of the logic heating and cooling operation on H-bridge circuit.

Table 4.3: Result of the logic heating and cooling operation on H-bridge circuit

Heating (Q1 and Q3) logic	Cooling (Q2 and Q4) logic	Peltier operation
0	0	No heating or cooling
1	0	Heating
0	1	Cooling

4.2.1 Heating operation

Figure 4.4 shows the setup of the circuit for heating operation simulation and Figure 4.5 and Figure 4.6 show the output window of heating operation.

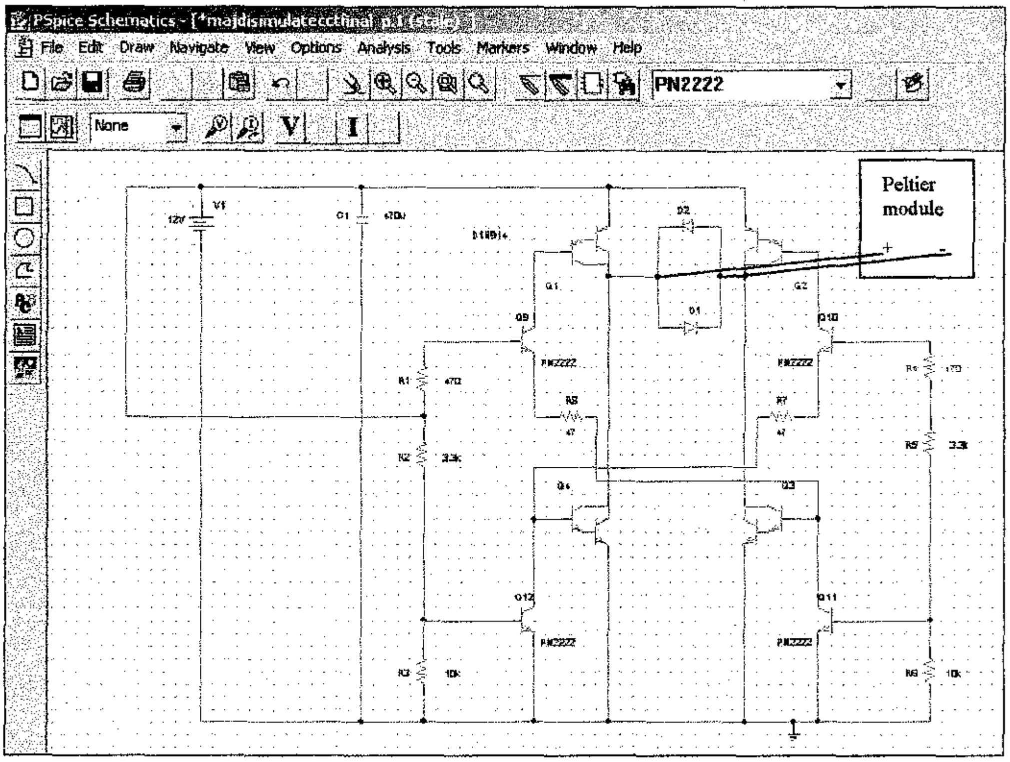


Figure 4.4: H-bridge schematic (heating operation)

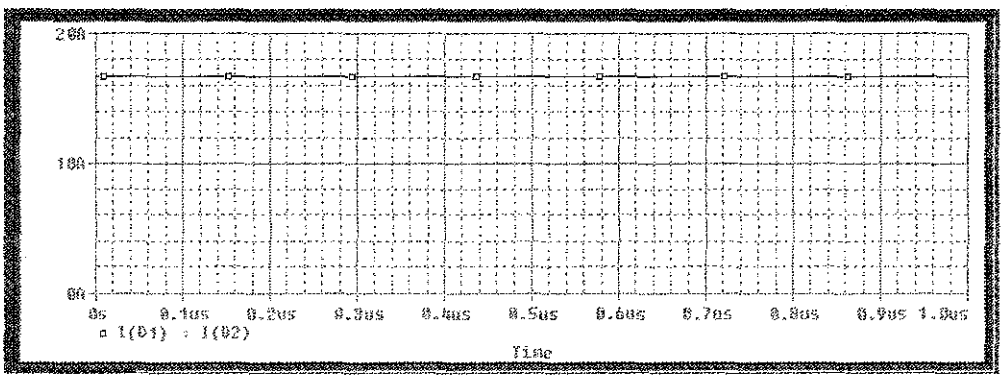


Figure 4.5: Output window for diode current (heating operation)

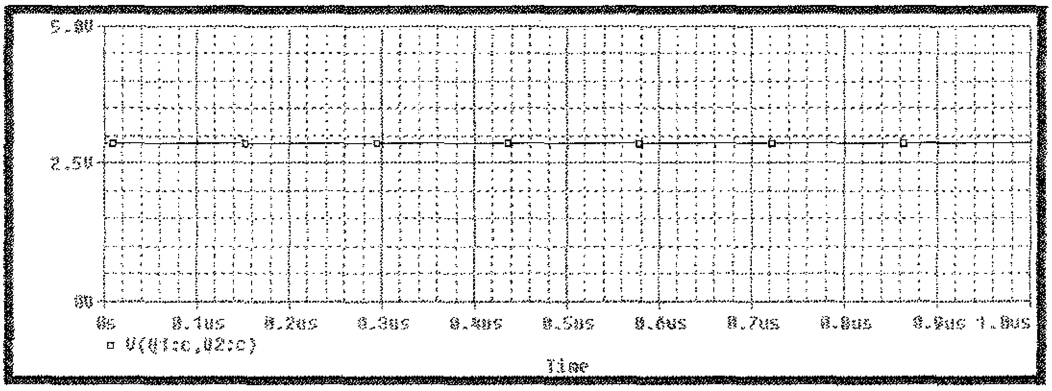


Figure 4.6: Output window for voltage between Q1 and Q2 (heating operation)

4.2.2 Cooling operation

Figure 4.7 shows the setup of the circuit for cooling operation simulation and Figure 4.8 and Figure 4.9 show the output window of cooling operation.

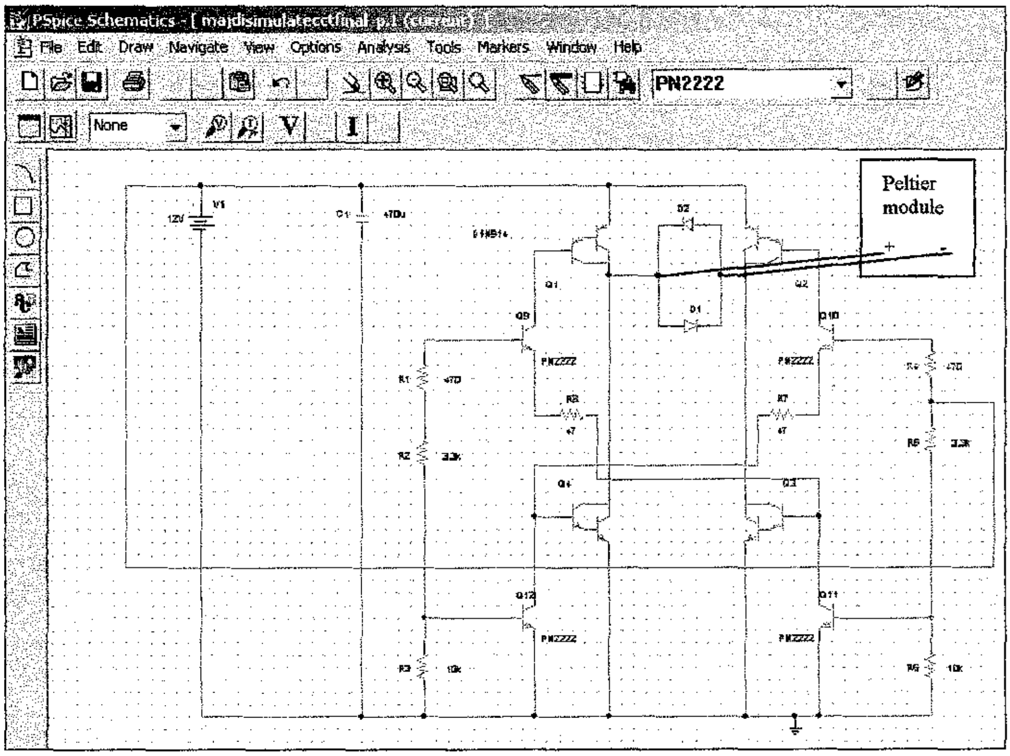


Figure 4.7: H-bridge schematic (cooling operation)

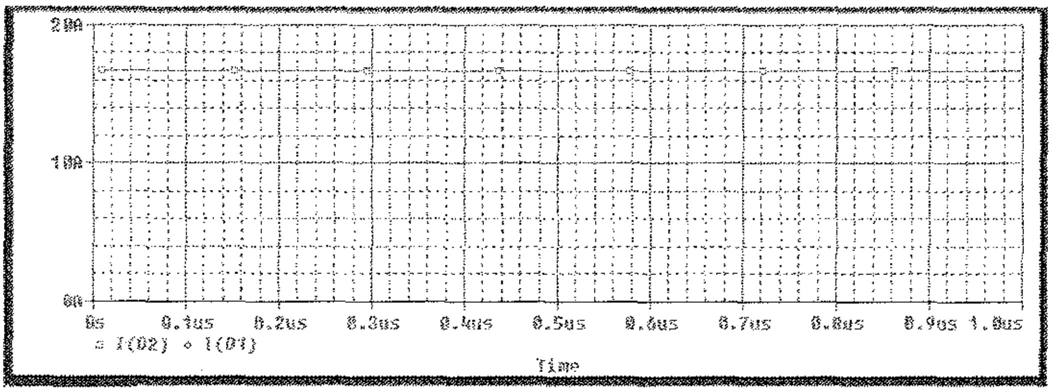


Figure 4.8: Output window for diode current (cooling operation)

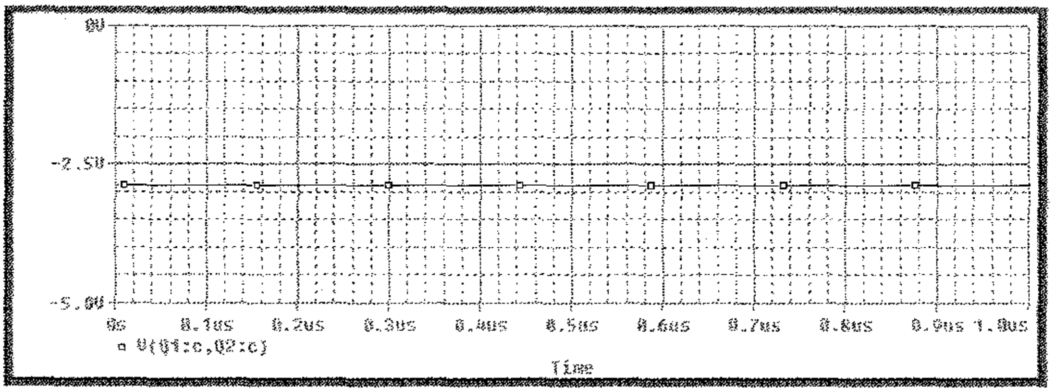


Figure 4.9: Output window for voltage between Q1 and Q2 (cooling operation)

4.2.3 Discussions on results

TEC control requires a reversible power source capable of providing positive and negative voltages as shown in Figure 4.5 and Figure 4.8. To accomplish this from a single supply, an H-bridge circuit can be used. While linear supplies offer low noise, their poor efficiency requires large components and added thermal insulation to prevent the regulator waste heat from loading the cooler. H-bridge circuit can perform functions such as turn on, off and switching direction for purpose of cooling and heating of Peltier modules. From the simulation done, we can see that the H-bridge circuit can forward and reverse the current in the output windows as needed for the Peltier module to perform heating and cooling operation. For the heating operation, the current flow from Q1 into D1 and D2 but the characteristic of diode that only allows one way of current flow cause D1 will allow current to flow and D2 will open circuit. That will lead to the result as in Figure 4.4. For cooling operation current flow from Q2 into D1 and D2, D2 will allow current to flow and D1 open circuit as can be seen in Figure 4.6. Thus, H-bridge circuit is a suitable circuit for performing reversible power. The full circuit will consists of h-bridge circuit with PIC microcontroller to control the temperature and some other components such as temperature sensor.

4.3 Construction of control circuit

Figure 4.10 shows the constructed circuit that consists of H-bridge circuit and PIC microcontroller, temperature sensor and also voltage regulator for the supply to the PIC that can only takes maximum of 5V voltage.

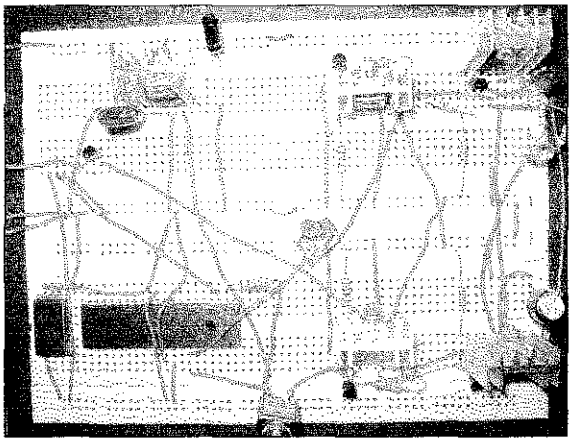


Figure 4.10: Control circuit

The circuit work very well which can be seen from the light of the LED which GREEN LED indicates cooling mode and RED LED indicates heating operation. The Peltier module also seems to work as it is connected to the H-bridge circuit.

4.4 Temperature sensor test

A test on the temperature sensor has been conducted to see the output voltage and temperature of LM35DZ characteristic. The temperature is measured using digital thermometer starting from 0^0C up to 90^0C as the range of the temperature sensor is between 0^0C to 100^0C. Table 4.4 shows the output voltage and temperature value recorded.

Table 4.4: Temperature and output voltage of LM35DZ

Temperature (^{0}C)	Output Voltage (V)
0	0
10	0.10
20	0.21
30	0.32
40	0.41
50	0.52
60	0.59
70	0.69
80	0.80
90	0.91

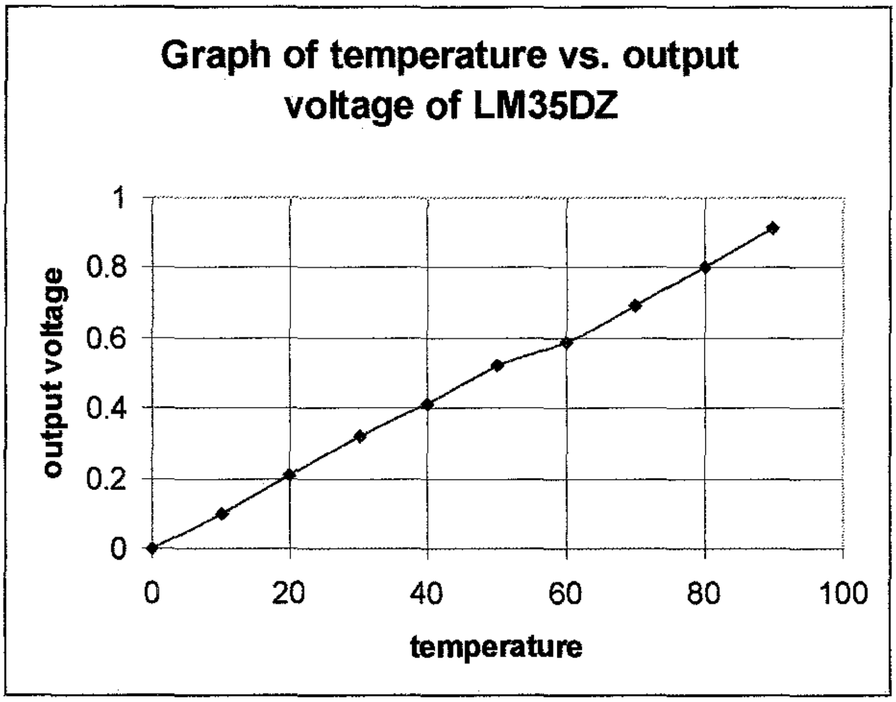


Figure 4.11: Graph of temperature versus output voltage of LM35DZ

From Figure 4.11, we can see that the output voltage of LM35DZ is linear with the temperature changes. This proved that the linear 10mV/^{0}C scale factor as stated in the datasheet is correct. This result will lead to the calculation of the ADC value for PIC microcontroller program.

4.5 PIC microcontroller program

The program seems to work as initially it will turn on the circuit. The circuit is connected to the PIC microcontroller to pin B1. As the temperature sensor send analogue input to pin AN1, the initially output high pin B1 will give output low pin B1, thus will turn off the circuit as Peltier cooler/heater reach temperature more than or equal 65^{0}C(heating operation) and less than or equal to 7^{0}C (cooling operation). The program is also written for the circuit to maintain the temperature at 65^{0}C (heating operation) and 7^{0}C (cooling operation) which means the circuit will turn on back if the temperature is more than 7^0C (cooling operation) and less than 65^0C (heating operation).The program for temperature control of the project can be seen in Appendix A.

4.5.1 Calculation of ADC value in PIC microcontroller program

.PIC microcontroller 16F877 is set to 8-bit ADC value range between 0 – 255. The control circuit is set to operate between 7^0C to 65^0C. Calculation of the ADC value for the program is done based on the result from the temperature sensor test and the datasheet of the LM35DZ.

- **LM35DZ temperature sensor**

Operation range: 4V to 30V

Temperature range: 0^0C to 100^0C (100-0 = 100)

- **ADC value calculation for cut off circuit of the Peltier heater/cooler**

Heating operation

65^0C is equal to 0.65V as referred to Figure 4.13.

$$adcValue = V_{out} \times \left(\frac{5V}{255} \right) \tag{6}$$

Thus, using equation 6, adcValue is 33 equivalents to 65^0C that the circuit will be off.

Cooling operation

7^0C is equal to 0.07V as referred to Figure 4.13.

Thus, using equation 6, adcValue is 4 equivalents to 7^0C that the circuit will be off.

Those value calculated above are used in the PIC microcontroller program. The voltage equivalent value can be used to replace the temperature sensor for testing of the circuit as the temperature sensor. The voltage can be simply injected to pin AN1 of the PIC microcontroller to see whether the circuit is function as planned. From the test conducted using the injected voltage and using LM35DZ itself, the circuit is working as planned.

4.6 Printed Circuit Board (PCB) design

One of the final parts of the project is to do the PCB design that will convert the control circuit into the PCB board. This is done to make the connection and performance of the circuit is more reliable. The software used for the purpose is Eagle 4.16. The PCB design done is in two layers which are top and bottom layer. The board is manufactured in the PCB laboratory. Figure 4.12 and 4.13 shows the designed PCB.

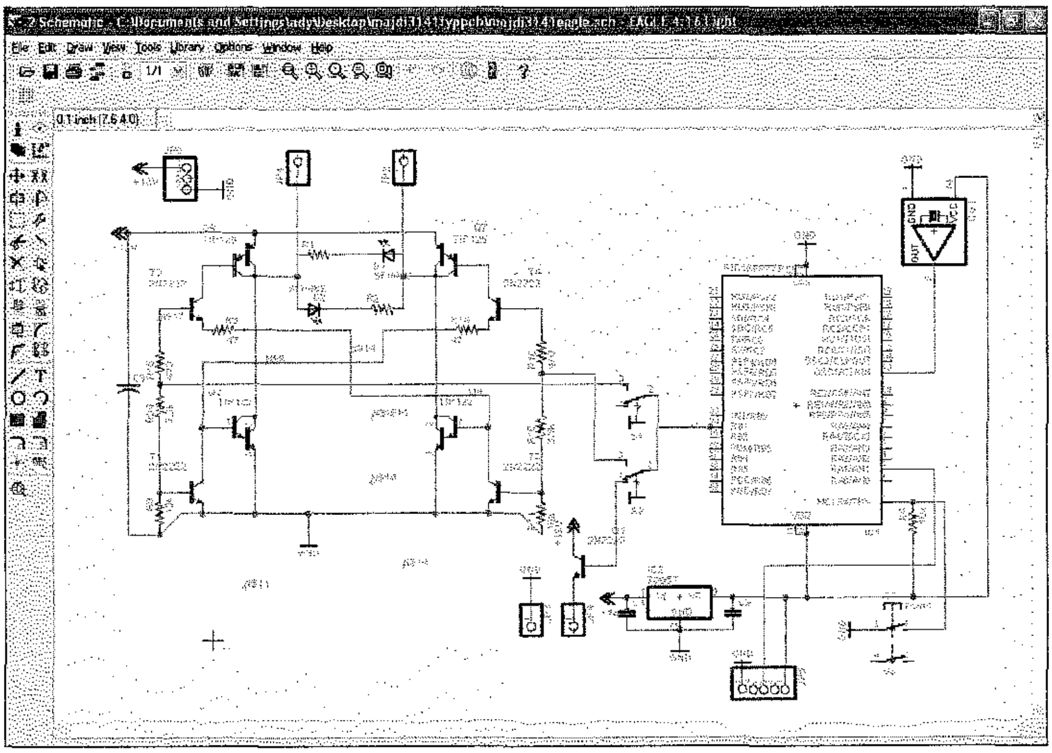


Figure 4.12: Eagle circuit schematic of the project

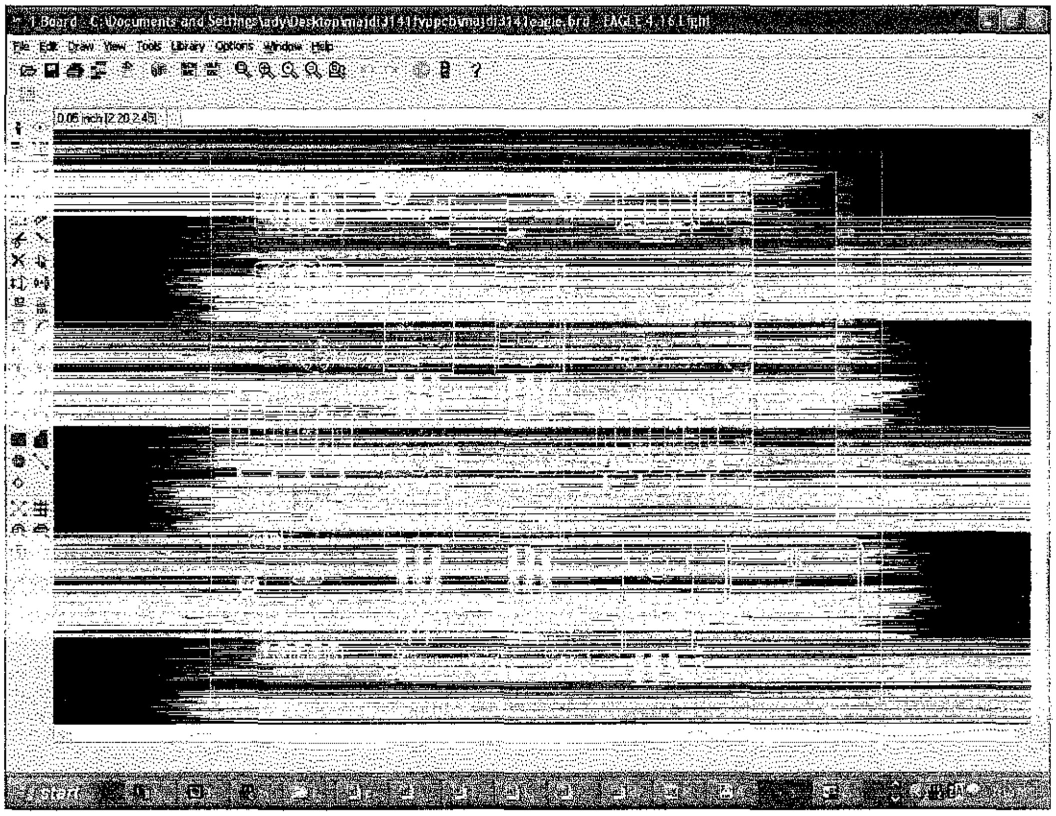


Figure 4.13: Eagle board schematic of the project

As the board is done, it is ready for installation of the components which require soldering of the components to the board. The board should be ready for testing and use if all the components are installed. Figure 4.14 shows the fabricated PCB of the of the control circuit.

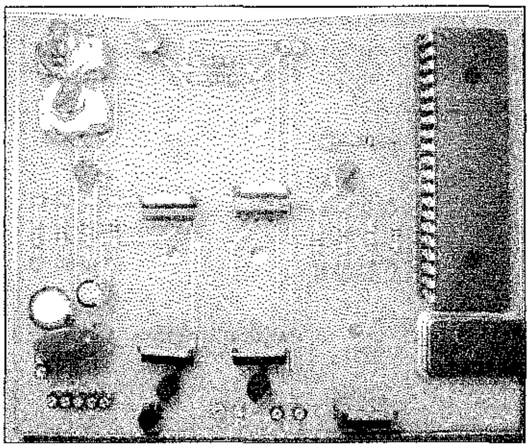


Figure 4.14: PCB fabricated

4.7 Cooler/heater design

Cooler/heater construction consists of Peltier module, heat sinking equipment such as heat sink, cooling fan, heat transfer materials such as heat compound or heat paste or heat grease or heat pad, and material to separate between hot and cold side. Figure 4.15, 4.16, and 4.17 show the drawings for the design of cooler/heater:

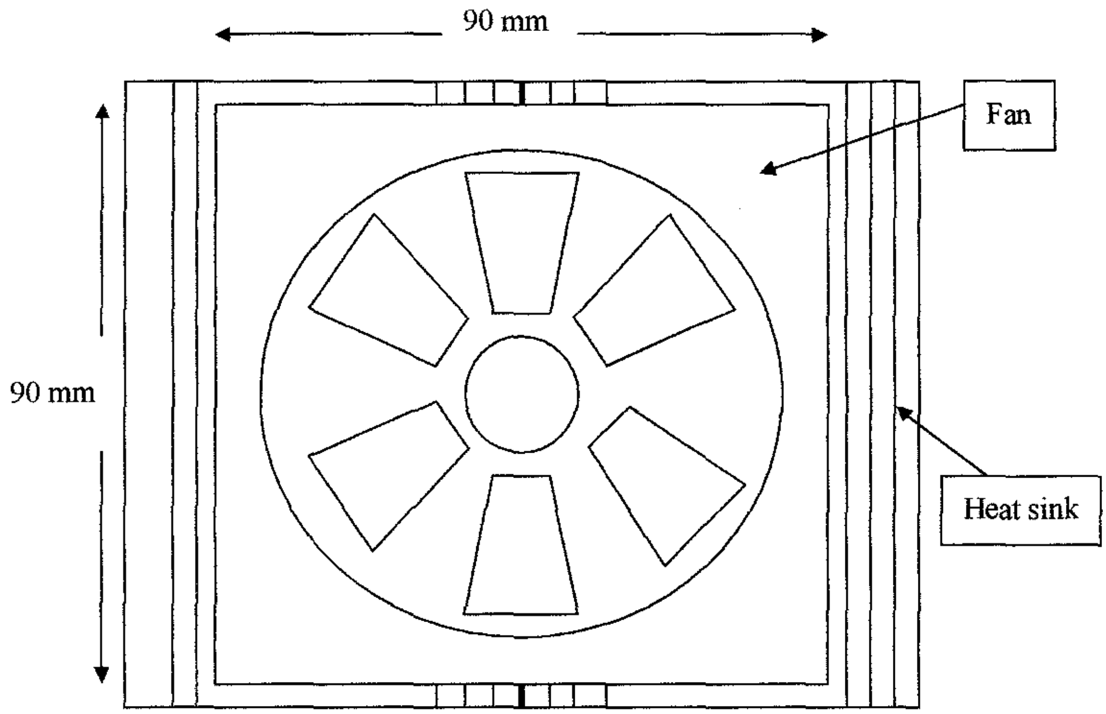


Figure 4.15: Top view of cooler/heater

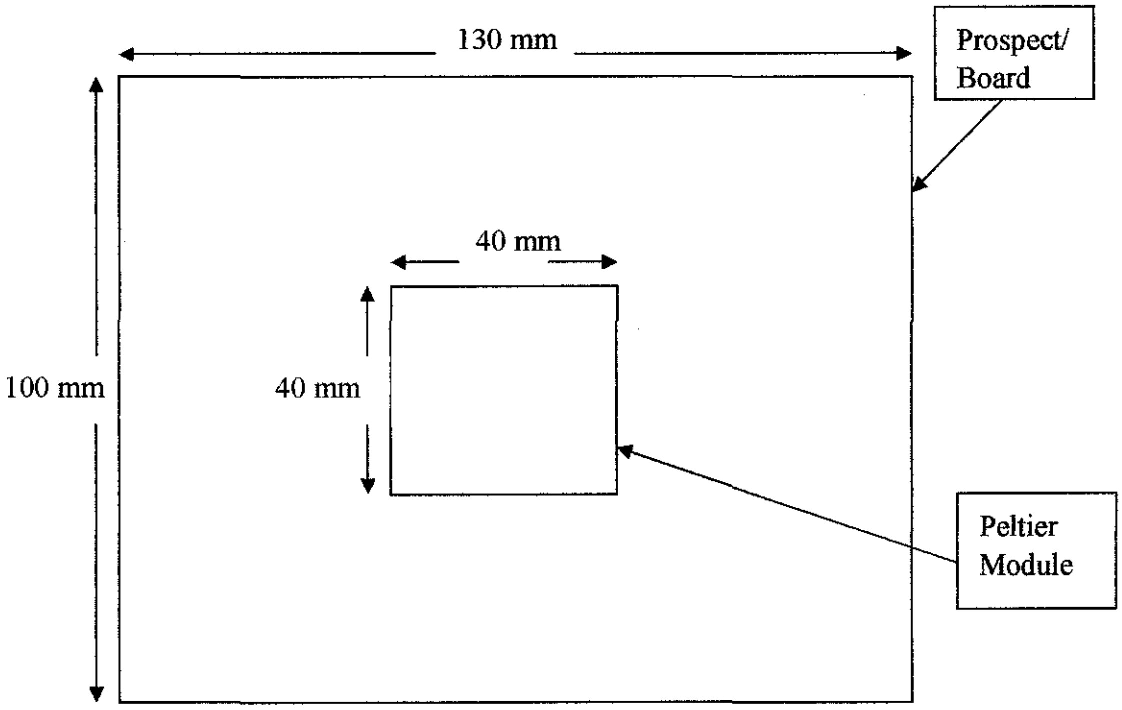


Figure 4.16: Bottom view of cooler/heater

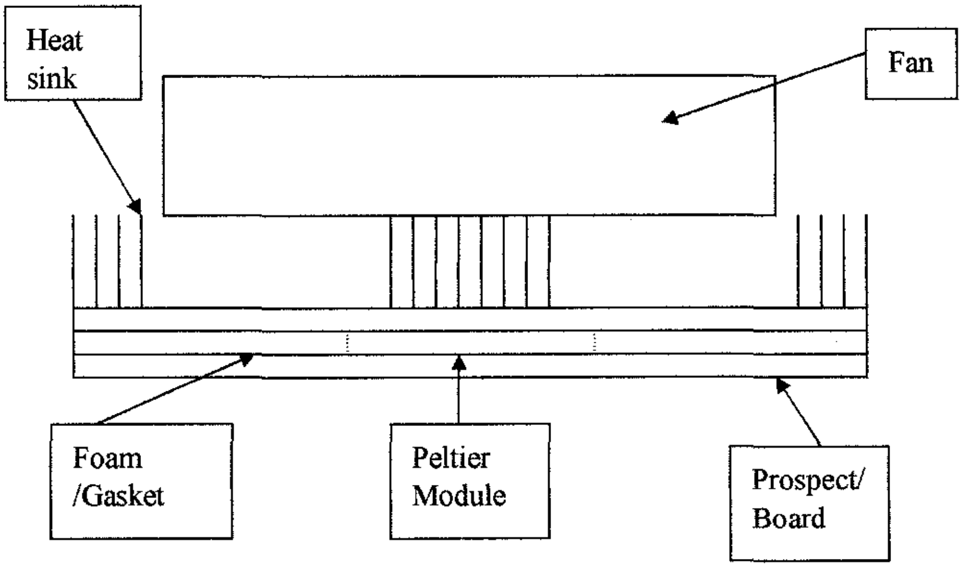


Figure 4.17: Side view of cooler/heater

4.8 Cooler/heater construction

Cooler for the project has been constructed as propose in the methodology section. Cooler construction consists of Peltier module, heat sinking equipment such as heat sink, cooling fan, heat transfer materials such as heat compound or heat paste or heat grease or heat pad, and material to separate between hot and cold side. Figure 4.18 shows the finished constructed cooler.

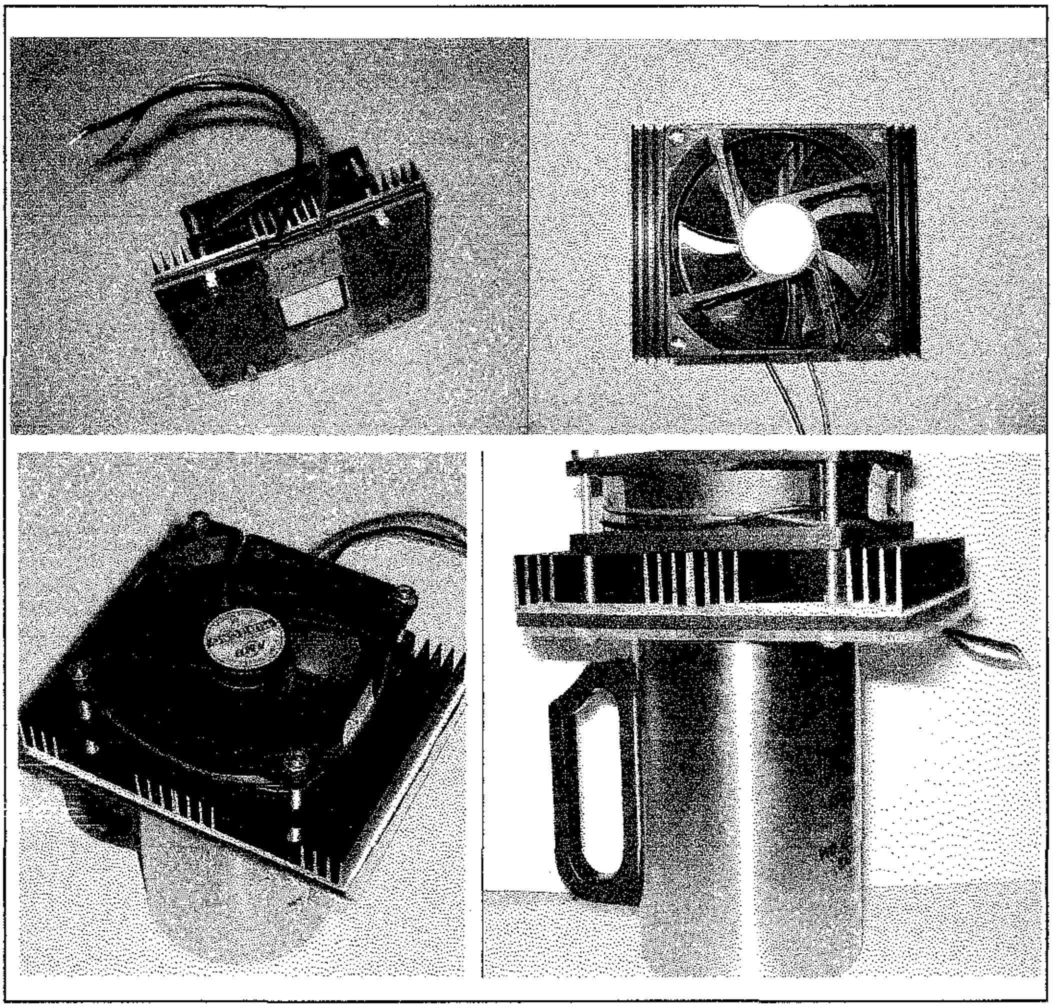


Figure 4.18: Cooler constructed

4.9 Measurement on temperature of the container

Another test was conducted to measure the same figures except the temperature sensor and digital thermometer were placed in the container not on the Peltier surface assuming no direct contact between the temperature sensor and the Peltier module surface. The temperature measured is expected to be the air temperature inside the container. The setup of the test can be seen in Figure 4.19.

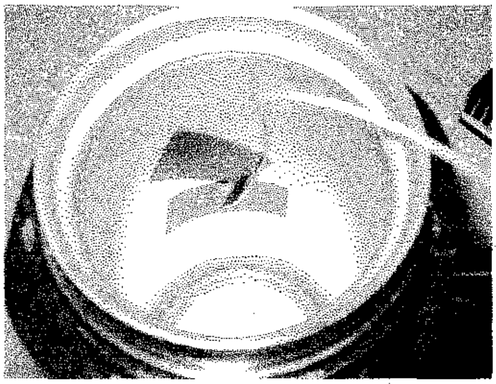


Figure 4.19: Placement of digital thermometer and temperature sensor inside the container

4.9.1 Heating operation

The results of the experiment or test carried out for heating operation are as in Table 4.5 and Figure 4.20.

Table 4.5: Table of temperature versus time test for heating operation (container temperature)

Time (m)	**Temperature (^0C)**	**Current (A)**	**Voltage across Peltier Module (V)**	**Power (W)**
0	30	2.19	8.63	18.89
10	37	2.18	8.63	18.81
20	42	2.17	8.63	18.72
30	47	2.17	8.65	18.77
40	52	2.17	8.64	18.74
50	57	2.17	8.65	18.77
60	65	2.17	8.65	18.77
70	65	2.18	8.66	18.87
80	65	2.17	8.65	18.77
90	65	2.17	8.65	18.77
100	65	2.17	8.66	18.77

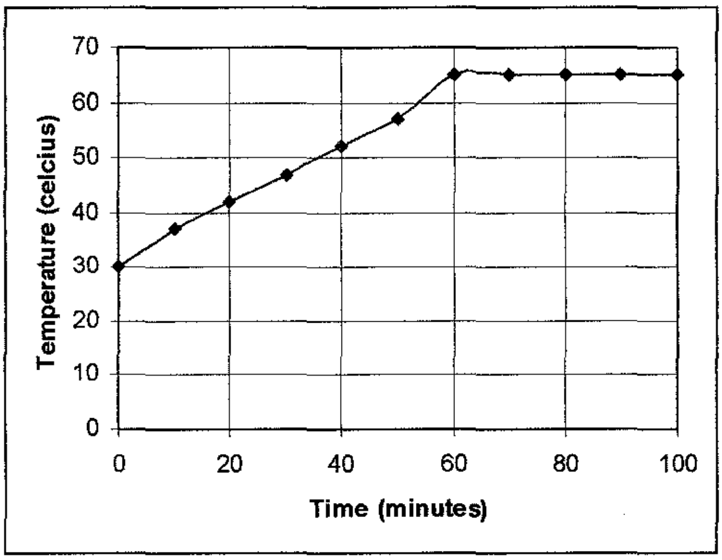


Figure 4.20: Graph of temperature versus time test for heating operation (container temperature)

4.9.2 Cooling operation

The results of the experiment or test carried out for cooling operation are as in Table 4.6 and Figure 4.21.

Table 4.6: Result of temperature versus time test for cooling operation (container temperature)

Time (m)	Temperature (^{0}C)	Current (A)	Voltage across Peltier Module (V)	Power (W)
0	30	3.04	7.84	23.83
10	25	2.99	7.66	22.90
20	23	2.99	7.85	23.47
30	21	3.00	7.70	23.01
40	19	3.01	7.56	22.75
50	18	3.01	7.70	23.17
60	17	3.02	7.81	23.58
70	17	2.97	7.80	23.16
80	16	3.01	7.72	23.23
90	16	3.02	7.80	23.55
100	15	3.02	7.81	23.58
110	15	2.99	7.74	23.14
120	14	2.99	7.66	22.90
130	14	2.98	7.77	23.15
140	13	3.00	7.80	23.40
150	12	3.01	7.81	23.50
160	11	2.99	7.55	22.57
170	10	2.99	7.57	22.63
180	10	2.97	7.60	22.57
190	9	2.98	7.70	22.94
200	9	2.97	7.60	22.57
210	8	2.97	7.56	22.45
220	7	2.97	7.70	22.86
230	7	2.97	7.60	22.57
240	7	2.97	7.65	22.72

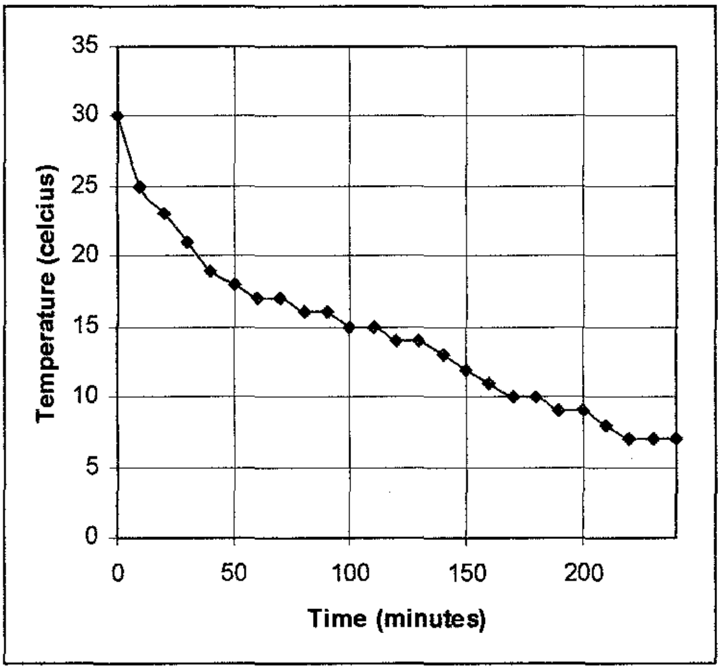


Figure 4.21: Graph of temperature versus time test for cooling operation (container temperature)

4.9.3 Discussions on results

From the results obtained, we can see that from the heating mode, it takes 60 minutes for the air temperature inside the 360 ml container to reach 65^0C. For the cooling mode, the air temperature inside the container reached until 7^0C in 220 minutes. The result for cooling mode did take much time to cool down because of some factors such as the container might not be perfectly sealed. This will lead to the exchange of heat between outside and inside air temperature.

Some modifications and recommendations for the project might be using better insulated and sealed between container and cooler/heater. The heat sink and fan chosen might be one of the factors. The Peltier module to be used itself might be a better performance Peltier module. A number of Peltier modules can be used to increase the efficiency of cooling mode. Besides, if the Peltier module is in direct contact with the subject to be cool down, the time taken to cool it down should be lower. A good heat conductor such as copper and aluminium can be used for connecting or contacting between the Peltier module surface and the subject to be cooled.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Solid state thermoelectric device or Peltier effect device can perform two tasks which are cooling on one side and heating on the other side. Cooling or heating is obtained by applying electric current. This device is simple, small in size and has reliable performances. This device is widely used in space cooling application as well as cooling of electronic circuits also in today conventional air conditioning. The objective of the project is to design that device that can be use in car for cooling or heating food or drinks. It has to fulfill certain requirement such as simplicity, small in size and reliable.

The Peltier module surface can achieve desired temperature as it took about 5.56 seconds to heat up to the expected temperature at 65^0C and took 20.53 seconds to cool down to expected cooling temperature at 7^0C. The H-bridge circuit can perform functions such as turn on, off and switching direction for purpose of cooling and heating of Peltier modules. The full circuit consists of H-bridge circuit, PIC microcontroller, temperature sensor (LM35DZ) and also voltage regulator for the supply to the PIC that can only takes maximum of 5V voltage. The circuit was constructed on bread board as well as on Printed Circuit Board (PCB) and work very well which can be seen from the light of the LED which green LED indicates cooling mode and red LED indicates heating operation. Cooler/heater was designed and constructed consists of Peltier module, heat sinking equipment such as heat sink, cooling fan, heat transfer materials such as heat compound or heat paste or heat grease or heat pad, and material to separate between hot and cold side. The output voltage of LM35DZ is linear with the temperature changes with $10mV/^0C$ scale factor. This scale factor is used in the calculation of the ADC value for PIC microcontroller program. The PIC microcontroller program seems to work as initially it will turn on the circuit. The circuit is connected to the PIC microcontroller to pin B1. As the temperature sensor send analogue input to pin AN1, the initially output high pin B1 will give output low pin B1, thus will turn off the circuit as Peltier cooler/heater reach temperature more than or equal 65^0C(heating operation) and less than or equal to 7^0C (cooling operation). The program is also written for the circuit to maintain the temperature at 65^0C (heating operation) and 7^0C (cooling operation) which means the circuit will turn on back if the temperature is more than 7^0C (cooling operation) and less than 65^0C (heating operation). The air temperature inside the 360 ml container took about 60 minutes to heat up to the expected temperature at 65^0C and 220 minutes to cool down to expected cooling temperature at 7^0C.

All the objectives are managed to be achieved and the final hardware or prototype and circuit has been constructed and working properly.

5.2 Recommendation

For further improvement of the project, a suitable container or compartment that are properly sealed and insulated may be designed or used. A properly sealed beverage container available I the market can be used with some modification to fit the cooler/heater constructed. A better heat sink and cooling fan may also increase the efficiency of the system. Some modification can be done to the container to place the can of drinks close to the cooler/heater source to improve the cooling or heating operation. More discussion and recommendation can be seen in the result and discussion section.

REFERENCES

[1] 'Thermoelectric cooling-The basics revision 12/05/2000', Enerton –Inc.

[2] http://www.electracool.com

[3] http://www.tkyokocom

[4] Robert Fransman, 'Portable solid state cooler/heater', SUNY College of Technology.

[5] http://www.digit-ifecom

[6] http://www.electracool.com

[7] http://www.peltier-info.com

[8] G. S. Nolas, J. Sharp, H. J. Goldsmid, *Thermo-electrics : basic principles and new materials developments,* Springer.

[9] Dogan Ibrahim, *Microcontroller based temperature monitoring and control,* Newnes.

[10] M. F. Thorpe, *Chemistry, Physics and Material Science of Thermoelectric Materials beyond Bismuth Telluride,* Kluwer academic/Plenum publishers.

[11] Edward E. Johnson, *Technical report writing today*, 7th edition, Thermodynamics.

[12] http://www.techneusa.com

[13] http://www.tellurex.com

[14] http://www.omega.com

[15] http://www.campingworld.com

[16] http://www.microchip.com

[17] http://www.melcor.com

[18] Yunus A. Cengel, *Heat Transfer a Practical Approach*, 2^{nd} edition, Mc Graw Hill.

[19] Other websites related to Thermoelectric, H-bridge circuits, and PIC programming

APPENDICES

APPENDIX A: PIC microcontroller program

APPENDIX B: Suggested Milestone for the First Semester of 2 Semester FYP

APPENDIX C: Suggested Milestone for the Second Semester of 2 Semester FYP

APPENDIX D: Datasheet of PIC 16F877

APPENDIX E: Datasheet of TIP 122

APPENDIX F: Datasheet of TIP 127

APPENDIX G: Datasheet of PN2222

APPENDIX H: Datasheet of LM35DZ

APPENDIX I: Datasheet of LM7805CV

APPENDIX A: PIC MICROCONTROLLER PROGRAM

```
#include <16F877.h>
#device ADC=8
#fuses XT,NOWDT,NOPROTECT, NOPUT, NOBROWNOUT, NOLVP
#use delay(clock = 4000000)

float adcValue, voltage;

void main()
{

  setup_adc_ports( ALL_ANALOG );
   setup_adc(ADC_CLOCK_INTERNAL);      // Use internal ADC clock.
   set_adc_channel(1);

   while(1)
   {
        delay_us(50);  // Delay for sampling cap to charge
        adcValue = read_adc(); // Get ADC reading

        delay_us(50);  // Preset delay, repeat every 10ms

        voltage = 5.000 * adcValue / 255.000;  //0-256 = 2^8
                                    //voltage calculation for adcValue read given 5V


        if(adcValue >= 33 || adcValue <= 4) //adcValue : 33 = 65 degree celcius and
4 = 7 degree celcius
        output_low(pin_B1);
        else
        output_high(pin_B1);
   }
}
```

APPENDIX B

Suggested Milestone for the First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic - Topic assigned to students: Design of Solid State Based Thermoelectric Device for Cooling and Heating (cooling drinks in car).														
2	Research Work														
	-preliminary review														
	-research and literature review														
	-research on peltier device to order														
	-research on current and voltage supply for the project														
3	Submission of Preliminary Report			●											
4	Research Work Continue														
	-research on the circuits														
	-research on coding														
	-research on low conductivity material														
5	Project Work														

	-ordering material-peltier device														
	-simulation of circuits														
6	Submission of Progress Report								●						
7	Project work continue														
	-assembling and testing peltier device														
	-assembling and testing circuits														
	-writing coding and testing coding														
8	Submission of Interim Report Final Draft												●		
9	Oral Presentation													●	
10	Submission of Interim Report														●

● Dateline

Process

APPENDIX C

Suggested Milestone for the Second Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue														
	-Cooler construction														
	-H-bridge circuit implementation														
2	Submission of Progress Report 1			●											
3	Project Work Continue														
	-Writing and modifying PIC program														
	-Simulation of circuits														
	-Calculation of heat transfer														
	-Designing of full prototype														

4	Submission of Progress Report 2								●						
5	Project work continue														
	-Testing and troubleshooting circuit														
	-Testing and troubleshooting circuit PIC program														
	-Building full prototype														
6	Submission of Dissertation Final Draft												●		
7	Oral Presentation													●	
8	Submission of Project Dissertation														●

● Suggested milestone

Process

MICROCHIP

PIC16F87X

28/40-pin 8-Bit CMOS FLASH Microcontrollers

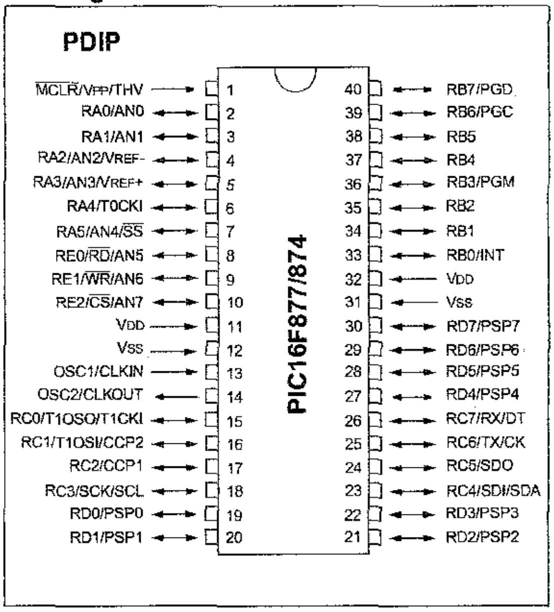
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Pin Diagram



Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master Mode) and I^{2}C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

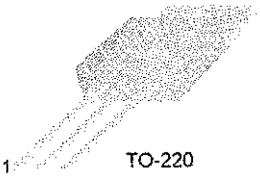
APPENDIX E

FAIRCHILD
SEMICONDUCTOR ™

TIP120/121/122

Medium Power Linear Switching Applications

- Complementary to TIP125/126/127



TO-220

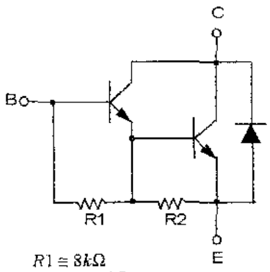
1.Base 2.Collector 3.Emitter

NPN Epitaxial Darlington Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : TIP120	60	V
	: TIP121	80	V
	: TIP122	100	V
V_{CEO}	Collector-Emitter Voltage : TIP120	60	V
	: TIP121	80	V
	: TIP122	100	V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	5	A
I_{CP}	Collector Current (Pulse)	8	A
I_B	Base Current (DC)	120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
P_C	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

Equivalent Circuit



$R1 \cong 8k\Omega$
$R2 \cong 0.12k\Omega$

Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
$V_{CEO}(sus)$	Collector-Emitter Sustaining Voltage				
	: TIP120	I_C = 100mA, I_B = 0	60		V
	: TIP121		80		V
	: TIP122		100		V
I_{CEO}	Collector Cut-off Current				
	: TIP120	V_{CE} = 30V, I_B = 0		0.5	mA
	: TIP121	V_{CE} = 40V, I_B = 0		0.5	mA
	: TIP122	V_{CE} = 50V, I_B = 0		0.5	mA
I_{CBO}	Collector Cut-off Current				
	: TIP120	V_{CB} = 60V, I_E = 0		0.2	mA
	: TIP121	V_{CB} = 80V, I_E = 0		0.2	mA
	: TIP122	V_{CB} = 100V, I_E = 0		0.2	mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = 5V, I_C = 0		2	mA
h_{FE}	* DC Current Gain	V_{CE} = 3V, I_C = 0.5A	1000		
		V_{CE} = 3V, I_C = 3A	1000		
$V_{CE}(sat)$	* Collector-Emitter Saturation Voltage	I_C = 3A, I_B = 12mA		2.0	V
		I_C = 5A, I_B = 20mA		4.0	V
$V_{BE}(on)$	* Base-Emitter ON Voltage	V_{CE} = 3V, I_C = 3A		2.5	V
C_{ob}	Output Capacitance	V_{CB} = 10V, I_E = 0, f = 0.1MHz		200	pF

* Pulse Test : PW≤300μs, Duty cycle ≤2%

APPENDIX F

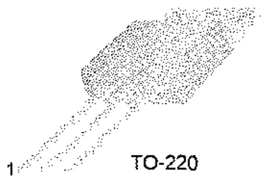
FAIRCHILD
SEMICONDUCTOR®

TIP125/126/127

TIP125/126/127

Medium Power Linear Switching Applications

- Complementary to TIP120/121/122



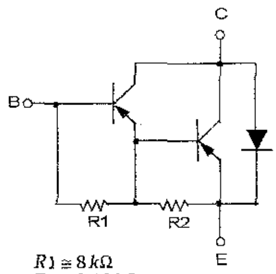
TO-220

1.Base 2.Collector 3.Emitter

PNP Epitaxial Darlington Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Equivalent Circuit



$R1 \cong 8k\Omega$
$R2 \cong 0.12k\Omega$

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : TIP125	- 60	V
	: TIP126	- 80	V
	: TIP127	- 100	V
V_{CEO}	Collector-Emitter Voltage : TIP125	- 60	V
	: TIP126	- 80	V
	: TIP127	- 100	V
V_{EBO}	Emitter-Base Voltage	- 5	V
I_C	Collector Current (DC)	- 5	A
I_{CP}	Collector Current (Pulse)	- 8	A
I_B	Base Current (DC)	- 120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage				
	: TIP125	I_C = -100mA, I_B = 0	-60		V
	: TIP126		-80		V
	: TIP127		-120		V
I_{CEO}	Collector Cut-off Current				
	: TIP125	V_{CE} = -30V, I_B = 0		-2	mA
	: TIP126	V_{CE} = -40V, I_B = 0		-2	mA
	: TIP127	V_{CE} = -50V, I_B = 0		-2	mA
I_{CBO}	Collector Cut-off Current				
	: TIP125	V_{CB} = -60V, I_E = 0		-1	mA
	: TIP126	V_{CB} = -80V, I_E = 0		-1	mA
	: TIP127	V_{CB} = -100V, I_E = 0		-1	mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = -5V, I_C = 0		-2	mA
h_{FE}	* DC Current Gain	V_{CE} = -3V, I_C = 0.5A	1000		
		V_{CE} = -3V, I_C = -3A	1000		
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = -3A, I_B = -12mA		-2	V
		I_C=-5A, I_B=-20mA		-4	V
V_{BE}(on)	* Base-Emitter ON Voltage	V_{CE} = -3V, I_C = -3A		-2.5	V
C_{ob}	Output Capacitance	V_{CB} = -10V, I_E = 0, f = 0.1MHz		300	pF

* Pulse Test : PW≤300μs, Duty cycle ≤2%

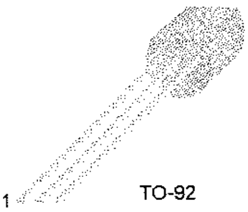
APPENDIX G

PN2222

FAIRCHILD
SEMICONDUCTOR®

PN2222

General Purpose Transistor



1 TO-92

1. Emitter 2. Base 3. Collector

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage	60	V
V_{CEO}	Collector-Emitter Voltage	30	V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current	600	mA
P_C	Collector Power Dissipation	625	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	-55 ~ 150	°C

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
BV_{CBO}	Collector-Base Breakdown Voltage	I_C=10μA, I_E=0	60		V
BV_{CEO}	Collector Emitter Breakdown Voltage	I_C=10mA, I_B=0	30		V
BV_{EBO}	Emitter-Base Breakdown Voltage	I_E=10μA, I_C=0	5		V
I_{CBO}	Collector Cut-off Current	V_{CB}=50V, I_E=0		0.01	μA
I_{EBO}	Emitter Cut-off Current	V_{EB}=3V, I_C=0		10	nA
h_{FE}	DC Current Gain	V_{CE}=10V, I_C=0.1mA V_{CE}=10V, *I_C=150mA	35 100	 300	
V_{CE} (sat)	* Collector-Emitter Saturation Voltage	I_C=500mA, I_B=50mA		1	V
V_{BE} (sat)	* Base-Emitter Saturation Voltage	I_C=500mA, I_B=50mA		2	V
f_T	Current Gain Bandwidth Product	V_{CE}=20V, I_C=20mA, f=100MHz	300		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		8	pF

* Pulse Test: Pulse Width≤300μs, Duty Cycle≤2%

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

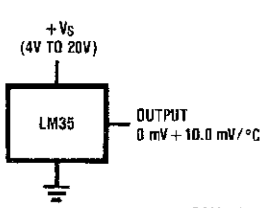
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 μA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

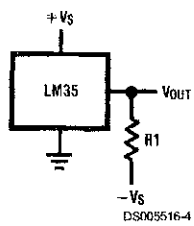
- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 μA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)



DS005516-4

Choose $R_1 = -V_S/50\ \mu A$

V_{OUT}=+1,500 mV at +150°C

= +250 mV at +25°C

= −550 mV at −55°C

FIGURE 2. Full-Range Centigrade Temperature Sensor

 DS005516

APPENDIX I

Absolute Maximum Ratings(Note 1)

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V)	V_I	35	V
(for V_O = 24V)	V_I	40	V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range	T_{OPR}	0 ~ +125	°C
LM78xx		−40 ~ +125	°C
LM78xxA		0 ~ +125	°C
Storage Temperature Range	T_{STG}	−65 ~ +150	°C

Note 1: Absolute maximum ratings are those values beyond which damage to the device may occur. The datasheet specifications should be met, without exception, to ensure that the system design is reliable over its power supply, temperature, and output/input loading variables. Fairchild does not recommend operation outside datasheet specifications.

Electrical Characteristics (LM7805)

(Refer to the test circuits. -40°C < T_J < 125°C, I_O = 500mA, V_I = 10V, C_I = 0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		Min	Typ	Max	Unit
Output Voltage	V_O	T_J = +25°C		4.8	5.0	5.2	V
		5mA ≤ I_O ≤ 1A, P_O ≤ 15W, V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note 2)	Regline	T_J = +25°C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50.0	
Load Regulation	Regload	T_J = +25°C	I_O = 5mA to 1.5mA	-	9.0	100	mV
			I_O = 250mA to 750mA	-	4.0	50.0	
Quiescent Current	I_Q	T_J = +25°C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	0.03	0.5	mA
		V_I = 7V to 25V		-	0.3	1.3	
Output Voltage Drift (Note 3)	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A = 25°C		-	42.0	-	μV/V_O
Ripple Rejection (Note 3)	RR	f = 120Hz, V_O = 8V to 18V		62.0	73.0	-	dB
Dropout Voltage	V_{DROP}	I_O = 1A, T_J = 25°C		-	2.0	-	V
Output Resistance (Note 3)	rO	f = 1KHz		-	15.0	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A = 25°C		-	230	-	mA
Peak Current (Note 3)	I_{PK}	T_J = 25°C		-	2.2	-	A

Note 2: Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Note 3: These parameters, although guaranteed, are not 100% tested in production.