# PORTABLE COOLING COMPARTMENT FOR STORAGE OF MEDICATION

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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# CERTIFICATION OF APPROVAL

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Approved:

Dr John Ojur Dennis

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.

Nor Zakiah binti Abdul Lateh

# ABSTRACT

This is a project on development of temperature balancing circuit. The objective of this project is to monitor the temperature of a confined space and keep it at a preset value 10°C. The scope of study covers the microcontroller circuit used to monitor the input by the temperature sensor and give output signal to current amplifier circuit to the peltier device. It also covers the current amplifier circuit and container design to maintain the temperature. Other important components of the system also include heat transfer concept, DC Fan, heatsink and insulation material. Experiments on the peltier device have been performed and its characteristics have been studied. High power with good insulation and heat removal system are most important on the matter of increasing the performance of the peltier. Prototype of the project has been constructed and tested and worked according to specification of cooling the container up to 10°C.

# ACKNOWLEDGEMENTS

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# TABLE OF CONTENTS

LIST OF FIGURES ..... ix
LIST OF ABBREVIATIONS ..... xi
CHAPTER 1 INTRODUCTION ..... 1
1.1 Background of study ..... 1
1.2 Problem Statement ..... 2
1.3 Objectives ..... 2
CHAPTER 2 LITERATURE REVIEW ..... 3
2.1 The Peltier Device ..... 3
2.1.1 The Peltier Effect ..... 4
2.1.2 Performance ..... 5
2.1.3 Heat Removal ..... 5
2.1.4 Cooling using Peltier ..... 6
2.1.5 Application ..... 6
2.2 Peltier's Heat Removal ..... 7
2.2.1 DC Fan ..... 7
2.2.2 Heatsink ..... 8
2.2.3 Thermal Paste ..... 9
2.3 Microcontroller ..... 9
2.3.1 PIC6F877 ..... 10
2.3.2 C Compiler- CCS C PCM ..... 10
2.3.3 Development Cycle ..... 10
2.3.4 Digital I/O Ports ..... 10
2.3.5 Master Clear Pin ..... 11
2.3.6 Pulse Width Modulation ..... 11
2.4 Temperature Sensor, LM 35 ..... 11
2.5 Container - Thermos ..... 12
2.5.1 Vacuum Insulation ..... 12
2.5.2 Silvered insulation. ..... 13
2.6 Insulation Material ..... 13
2.6.1 R-Values ..... 13
2.7 Conduction ..... 14

2.7.1 Heat Transfer Calculation .......... 15
CHAPTER 3 METHODOLOGY .......... 17
3.1 Project Methodology .......... 17
3.2 Container Design .......... 19
3.3 The System Functionality .......... 19
CHAPTER 4 RESULTS AND DISCUSSION .......... 21
4.1 Circuit Simulation .......... 21
4.1.1 Power Dissipation in Q1 .......... 23
4.1.2 Power Dissipation in Q2 .......... 23
4.1.3 Transistor TIP120 AND TIP 127 .......... 24
4.1.4 Peltier Voltage and Current .......... 25
4.2 Microcontroller and Temperature Sensor LM35 .......... 27
4.3 Peltier Characteristic .......... 28
4.3.1 Temperature of Peltier Device when attached to the whole system .......... 29
4.4 Heat Transfer Calculation .......... 30
4.4.1 Calculation of Cooling Rate of The Peltier .......... 30
4.4.2 Calculation of Heat Transfer of the Peltier Device .......... 30
4.5 Design .......... 31
4.5.1 Container Design .......... 31
4.5.2 Container's Body .......... 32
4.5.3 Top Cover .......... 32
4.6 Prototype .......... 34
CHAPTER 5 CONCLUSION .......... 35
5.1 Conclusion .......... 35
REFERENCES .......... 36
APPENDICES .......... 37
Appendix A Peltier datasheet .......... 38
Appendix B chemical properties of peltier (bismuth Telluride) .......... 39
Appendix C Microcontroller Programming Code .......... 40
Appendix D PIC16F877 Datasheet .......... 41
Appendix E LM35 Datasheet .......... 50
Appendix F TIP120 Datasheet .......... 57
Appendix G TIP127 Datasheet .......... 60

Appendix H PN2222 Datasheet ........................................................... 63
Appendix I 7805 Datasheet ................................................................. 65
Appendix J DC Fan Datasheet ............................................................. 69

# LIST OF FIGURES

Figure 1 A diagram of a phase change heat pump: 1) condenser 2) expansion valve, 3) evaporator, 4) compressor. .......... 1
Figure 2 Peltier module .......... 3
Figure 3 Diagram of Peltier effect showing the hot and cold side caused by dissimilar semiconductors .......... 4
Figure 4 Power transferred graph versus temperature across peltier .......... 5
Figure 5 Peltier- powered drink cooler .......... 6
Figure 6 CPU Fan .......... 7
Figure 7 Example of a heatsink .......... 8
Figure 8 Thermal Paste .......... 9
Figure 9 PWM Signal Representation .......... 11
Figure 10 Vaccum and silvered insulation by Thermos .......... 12
Figure 11 Heat transfer by conduction .......... 14
Figure 12 Measurement of thermal conductivity .......... 14
Figure 13 Flow Diagram for Methodology .......... 18
Figure 14 Flow diagram of temperature balancing .......... 20
Figure 15 Overall Circuit .......... 21
Figure 16 Circuit Simulation for current amplifier circuit .......... 22
Figure 17 Power Dissipation graph Q1, 2N2222 .......... 23
Figure 18 Power Dissipation graph Q2, 2N2222 .......... 23
Figure 19 Active load on current amplifier circuit .......... 24
Figure 20 Waveform for TIP120 and TIP127 .......... 25
Figure 21 Input voltage to peltier device .......... 25
Figure 22 Input current to peltier device .......... 26
Figure 23 Actual input voltage to peltier .......... 26
Figure 24 Input voltage to microcontroller .......... 27
Figure 25 Output voltage to microcontroller .......... 27
Figure 26 Actual power transferred versus temperature across peltier graph .......... 28
Figure 27 Theoretical Power transferred versus temperature across peltier graph .......... 28
Figure 28 Peltier's surface temperature versus time graph for the cold side .......... 29
Figure 29 Peltier's surface temperature versus time graph for the hot side .......... 29
Figure 30 Container Design .......... 31

Figure 31 Design of Container's body ........................................................................ 32
Figure 32 Top Cover Design........................................................................................ 33
Figure 33 Top cover seen from the bottom ................................................................ 33
Figure 34 Prototype..................................................................................................... 34
Figure 35 Final Product............................................................................................... 34

# LIST OF ABBREVIATIONS

| | |
|---|---|
| PWM | Pulse Width Modulation |
| TE | Thermoelectrics |
| CCS | Custom Computer Services |
| MCLR | Master clear pin |
| LED | Light Emitting Diode |
| LCD | Liquid Crystal Display |
| CAD | Computer Aided Design |
| I/O | Input / output |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background of study

A conventional cooling system[1,2,3] contains three fundamental parts - the evaporator, compressor and condenser. The diagram of the system is shown in Figure 1[3]. The evaporator (3) or cold section is the part where the pressurized refrigerant is allowed to expand, boil and evaporate. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor (4) acts as the refrigerant pump and recompresses the gas to a liquid. The condenser(1) expels the heat absorbed at the evaporator plus the heat produced during compression, into the environment or ambient.

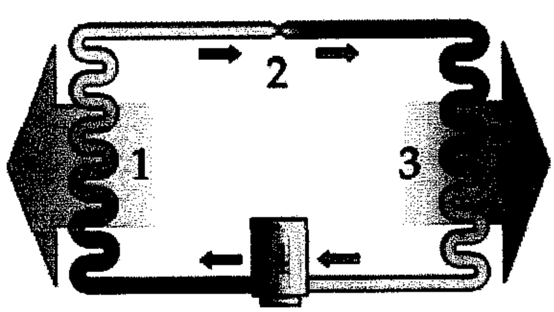


Figure 1 A diagram of a phase change heat pump: 1) condenser 2) expansion valve, 3) evaporator, 4) compressor.

On the other hand, thermoelectric coolers or specifically peltier, are heat pumps, solid state devices without moving parts, fluids or gasses. The basic laws of thermodynamics apply to these devices just as they do to conventional heat pumps, absorption refrigerators and other devices involving the transfer of heat energy.

The usage of thermoelectric cooling instead of other forms of cooling usually comes when there is a special requirement or characteristic that must be fulfilled. A system may require size, space, weight, reliability and environmental conditions that thermoelectrics can provide; such as operating in a vacuum. Other forms of cooling are more desirable if there is no special requirement needed.

Currently, the temperature of a room or confined space are controlled by presetting the temperature of the cooling device. This project requires balancing the temperature and keeping it at a specified value based on the temperature within the confined space.

## 1.2 Problem Statement

It is a common practice that medication are usually stored in a refrigerator. In Malaysia where the temperature is normally high around 30°C during the day, medicine get spoiled very quickly if not stored at the correct temperature. However, when traveling, many people tend to neglect to store their medicine in the proper container. The suggested temperature may vary depending on types of medicine; they may vary from 5 - 10 degree Celsius to 20 – 25 degrees Celsius.

Thus, a storage container that keep medication at a preset value is very useful not only for the usage of traveling doctors and ambulances, but also by traveling people who need to bring delicate and expensive medication.

## 1.3 Objectives

The objectives to be achieved in this project are:

- To study the cooling or heating effects of peltier device
- To design and simulate the control circuit using Pspice and also build and test circuit on breadboard
- To use appropriate material to build a confined space using insulation material
- To design a working prototype of a cooling device

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 The Peltier Device

Peltier devices is also known as thermoelectric (TE) modules[3,4,5]. It is a small solid-state devices that function as heat pumps. Its is a rectangular block with several millimeters thickness and a few centimeters square in length can be seen in Figure 2. It is usually made of Bismuth Telluride which is heavily doped to create two different elements of semiconductor, with either an excess (n-type) or deficiency (p-type) of electrons. The heat that is being absorbed at the cold junction is pumped to the hot junction at a rate that is proportional to the current which is passing through the circuit and the peltier itself.

Figure 2 Peltier module

Peltier modules are available in a great variety of sizes, shapes, operating currents, operating voltages and ranges of heat pumping capacity. The peltier can be obtained to fit in the requirements for the system without wasting excess power by choosing the right quantity, size or capacity of the peltier. The current interest is to operate at lower currents for more peltiers that are being used in the system.

### 2.1.1 *The Peltier Effect*

The Peltier effect is the reverse of the Seebeck effect; where the heat difference is created from an electric voltage[3,5]. The Peltier effect shown in Figure 3[6] occurs when a current is passed through two dissimilar metals or semiconductors (n-type and p-type) that are connected to each other at two junctions (Peltier junctions). The transfer of heat moves from one junction to the other driven by the current causing one junction to cool off while the other heats up. As a result, the effect is often used for thermoelectric cooling. This result was found by Jean Peltier in 1834 by, 13 years after Seebeck's initial discovery.

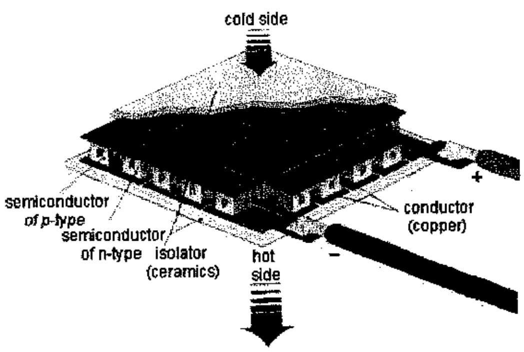


Figure 3 Diagram of Peltier effect showing the hot and cold side caused by dissimilar semiconductors

When a current $I$ is made to flow through the circuit, heat is evolved at the upper junction (at $T_2$), and absorbed at the lower junction (at $T_1$). P-type silicon typically has a positive Peltier coefficient (although not above 550 K), and n-type silicon is typically negative. The conductors are attempting to return to the electron equilibrium that existed before the current was applied by absorbing energy at one connector and releasing it at the other. The individual couples can be connected in series to enhance the effect.

The direction of heat transfer is controlled by the polarity of the current, reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed/evolved.

### 2.1.2 *Performance*

The temperature across peltier rises with the increase of volt can be seen in Figure 4[7]. For cooling purpose, the temperature decrease when the power transferred increase. This statement has been later on studied by doing experiments on the peltier module itself and observed its characteristic.

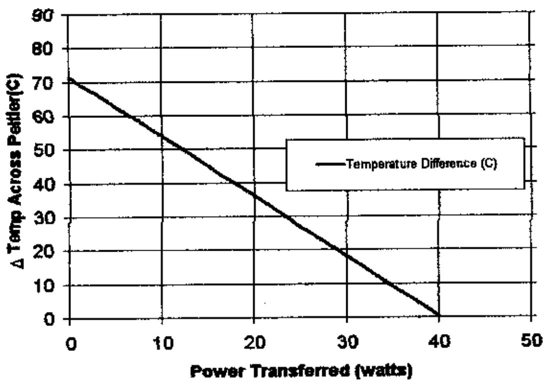


*Figure 4 Power transferred graph versus temperature across peltier*

However, peltier devices have low efficiency and a current and power drainage device[8]. Despite its advantage of having no moving parts, no Freon refrigerant, no noise, no vibration, very small size, long life, capability of precision and temperature control, this quality is a big turn off as low power consumption is one of the highest criteria in designing.

### 2.1.3 *Heat Removal*

The most difficult parameter to accurately quantify is the amount of heat to be removed or absorbed by the cold surface of the peltier[5,8,9]. All thermal loads to the peltier must be considered. These thermal loads include, but are not limited to, the active or heat load from electronic devices and conduction through any object in contact with both the cold surface and any warmer temperature (i.e. electrical leads, insulation, air or gas surrounding objects, mechanical fasteners, etc.). In some cases radiant heat effects must also be considered.

Single stage thermoelectric devices are capable of producing a "no load" temperature differential of approximately 68°C [refer Appendix A].

Temperature differentials greater than this can be achieved by stacking one thermoelectric on top of another called cascading.

### *2.1.4 Cooling using Peltier*

To reduce the temperature of an object, heat must be removed from it, faster than heat enters it[5,8,9]. If the object to be cooled is in direct intimate contact with the cold surface of the peltier, the desired temperature of the object can be considered the temperature of the cold surface of the peltier. There are situations where the object to be cooled is not in intimate contact with the cold surface of the peltier, such as volume cooling where a heat exchanger is required on the cold surface of the peltier. When this type of system is employed the cold surface of the peltier may need to be several degrees colder than the ultimate desired object temperature.

### *2.1.5 Application*

The characteristics of peltier devices makes it more suitable to smaller-cooling applications such as drinks coolers as shown in Figure 5[10], although they are also used in applications as large as portable picnic-type coolers. They can be stacked to achieve lower temperatures, although reaching cryogenic temperatures would require great care.

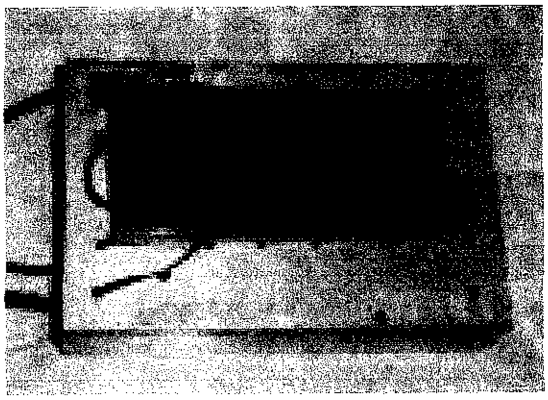

Figure 5 Peltier- powered drink cooler

## 2.2 Peltier's Heat Removal

The peltier device produces heat on one side and cools on the other side thus creating a temperature difference. Based on the law of energy balance, the produced on the hot side will eventually be transferred to the cold side causing the temperature to also rise. To maintain the low temperature on the cool side[5,8,9], the heat produced must be removed faster than the heat that enters it. To increase the heat removal process on the hot side, a combination DC fan, heatsink and thermal paste are used. A CPU fan as shown in Figure 6 is a good choice because it combines all three components in one package.

### *2.2.1 DC Fan*

DC Fan is a type of active cooling that moves air faster than just the surrounding condition which is also a type of forced convection. Performance of fans are usually measured by air volume per time in cubic feet per minute, CFM or by air speed[2,11]. CFM values are more accurate because of the size of the fan which is also taken into consideration. For example, a 120x120mm fan will provide better cooling than a 50x50mm fan, if both produce the same air speed.

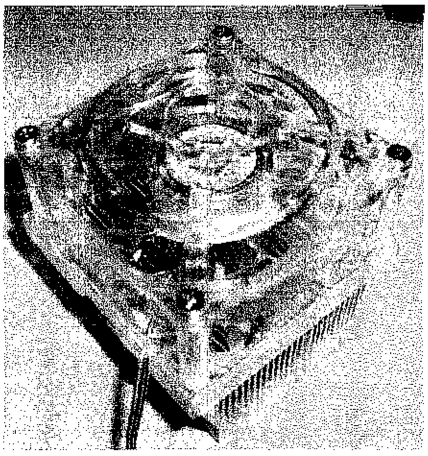

Figure 6 CPU Fan

CFM specifications are only valid when the pressure on both sides of the fan is equal or when the fan is operating in free space. The specified CFM rating of the fan may not be reached when the fan is installed in a device due to external effects.

Installation process and overall design of the cooling system are also very important role to bring the fan to reach its maximum specification.

### *2.2.2 Heatsink*

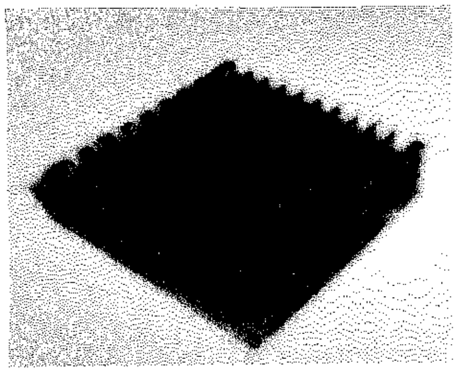

Figure 7 Example of a heatsink

A heatsink [2,11]is an environment or object that is used to absorb heat from another object that has thermal contact with its surface as shown in Figure 7. The part of the heatsink that touches the heat source is where the thermal transfer takes place thus it must be perfectly flat and considerably large surface. The large surface can be achieved by using a large amount of fine fins, or by increasing the size of the heatsink itself.

Heatsinks must have good aerodynamics designed in a way that air can easily and quickly float through the cooler, and reach all cooling fins. Fins are used to increase the surface contact with the air, and thus also increase the rate of heat dissipation. A heatsink that have a large amount of fine fins with small distances between the fins do not have good air flow. Therefore, a powerful DC fan is often used to force air through a heatsink. The DC fan helps to increase the rate of airflow over the heat sink and also maintains a larger temperature gradient by replacing warmed air faster than would be by convection, which is known as a forced air system.

The material of the heatsink must have good thermal conductivity to allow faster heat removal such as aluminum, copper and a combination of aluminum and copper bonded together.

### *2.2.3 Thermal Paste*

Thermal paste is also called thermal compound and thermal grease[9,11]. The substance is used to help to increase the conduction of heat between two touching metal surfaces. When it is applied on a heatsink, the heatsink's flat contact area allows the usage of a thin layer of the substance to help to reduce the thermal resistance between heatsink and heat source.

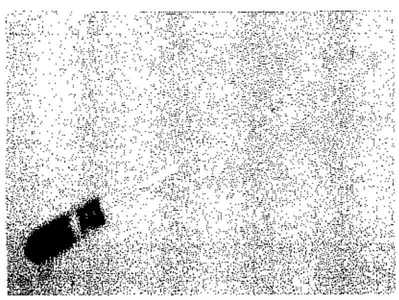

Figure 8 Thermal Paste

There are several types of thermal grease such as silicone-based as shown in Figure 8, ceramic-based and metal-based. Ceramic based thermal paste conducts heat better than most silicone greases, but it is a poorer heat conductor compared to metal based paste. Metal based paste usually contains metal particles including silver thus making it more expensive than silicone based paste.

The substance's primary purpose is as a substitute for the constructional imperfections of a heatsink's surface. It fills in the tiny pits and grooves of an imperfect surface when applied in appropriate quantities, thereby increasing the amount of surface-to-surface contact. Excessive amount of thermal paste applied will create air gap between the heatsink and the source thus reducing conductivity.

## 2.3 Microcontroller

A microcontroller [12] can be called a computer on a chip. It contains CPU, RAM, ROM, I/O, Timer, Pulse Width Modulation and A/D and D/A conversion. The most basic circuit of a microcontroller system consists of the microcontroller, power supply, ground, oscillator, master clear pin (MCLR) and additional features such as Light Emitting Diode (LED), Liquid Crystal Display (LCD) and in this project peltier device, temperature sensor and DC Fan.

### *2.3.1 PIC6F877*

PIC6F877 is a mid-range microcontroller that supports 8kB of flash memory program, interrupts, in-circuit programming, hardware timers, capture/compare/PWM modules,10-bit A/D conversion, built-in USART serial communication and digital I/O.

### *2.3.2 C Compiler- CCS C PCM*

To program the microcontroller, CCS Compiler from Custom Computer Services Inc. was used. PCM C Compiler is a subset of ANSI C. CCS can support C I/O, built in math functions, and special functions for dealing with the microcontroller such as timer.

### *2.3.3 Development Cycle*

The development of microcontroller consists of designing hardware architecture, defining state machine or abstraction that represent the operation to be accomplished and lastly use do iterative design. For iterative design, we use CCS's PCM C Compiler for the programming language. After the program has been compiled, it will be programmed into the microcontroller. The program is run and tested using PIC6F877 general purpose target board and the iterative process can be repeated until the program is successfully running.

### *2.3.4 Digital I/O Ports*

There are 5 digital I/O ports in a PIC6F877 that can be accessed through 8 bit registers; LSB and MSB. Mnemonic for registers are listed include files or #use pre-compiler directives can be used. The port's data direction register must set up. Some I/O pins have additional functionality and may be overridden by some other register bits.

### 2.3.5 *Master Clear Pin*

This is an active low pin that provides a reset feature. Grounding this pin causes the PIC to reset and restart the program stored in the FLASH ROM. At any other time (e.g) the MCLR should be made logic 1 by connecting it to a power supply +5V through a pull up resistor.

### 2.3.6 *Pulse Width Modulation*

The Pulse Width Modulation (PWM) is the CCP1 (pin 17) and CCP2 (pin 16) of PIC6F877. It can be used to vary the speed of motor or the brightness of a bulb. To activate PWM control, the CCP pin should be assigned as an output. PWM can be used to increase or decrease the temperature of the peltier device in this project. Figure 2 is an example of a PWM signal representation.

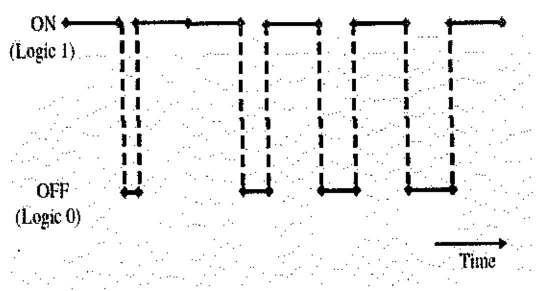


Figure 9 PWM Signal Representation

## 2.4 Temperature Sensor, LM 35

Temperature sensor are very important to sense the change of temperature in the environment accurately. LM35 is a precision integrated-circuit temperature sensor that has an output voltage proportional to the temperature in °Celsius. Its sensing limits is from -55°C to 150°C with accuracy of ± 0.5°C typically at room temperature (25°C). The sensor has low output impedance and linear output characteristic at 10.0mV/°C which make the interfacing and control circuitry easy. It is also not as susceptible to large errors in its output from low leakage currents. The output of this sensor is in analog, thus an ADC is needed if the function is going to be used in a microcontroller [refer Appendix E].

## 2.5 Container - Thermos

Thermos is one of the leading brand that produce good thermal insulation for drinks and food container. There are many types of container available in the market in different shapes, sizes and heat conductivity. For example, there are lunch boxes, sports bottles for hikers, and coolers. From a variety of selection, Thermos Travel Mug is the most suitable to be used as container in this project. This is due to its light weight and the thin layer of the top cover. It is essential that the top cover is not so thick because of placement of the peltier. however, it is noticeable that the thinness might cause temperature leak and disturb the performance of the system.

Despite the thin cover, the body of the container is already well insulated. This could make up to more that three quarter of the whole system. The thermos technology uses vacuum as one of its method of insulation.

### *2.5.1 Vacuum Insulation*

In a vacuum condition, there is a lack of atoms or zero atoms in a perfect vacuum condition[2]. Conduction and convection can only occur when there are atoms that can be energized or de-energized. Lack of atom is a perfect condition where conduction or convention could be totally eliminated. A perfect vacuum condition is almost impossible to create but with the right technology, it can be achieved.

Thermoshas vacuum insulation[13] which is called TherMax™ which can virtually eliminates temperature change by creating an airless vacuum space between two stainless steel walls. This type of insulation layer, shown in Figure 10 gives very good performance and are dependable to keep beverages hotter, cooler, fresher longer.

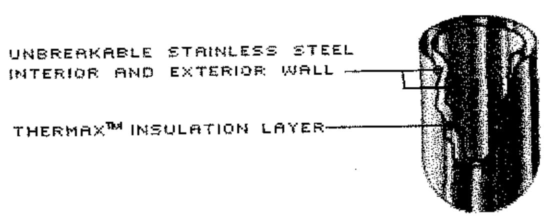


Figure 10 Vaccum and silvered insulation by Thermos

### *2.5.2 Silvered insulation.*

The internal insulation of the thermos has been lined with silver. This silvered surface helps to reduce infrared radiation. Therefore, by combining both vacuum and silver lining, heat transfer can be greatly reduced either by convection, conduction or radiation.

## 2.6 Insulation Material

Despite the container that has built in insulation, external insulation is another way to increase the performance of the system. In the market, there are many thermal container manufacturer that produce products that not only have built-in thermal quality but also external insulation to keep the temperature constant for a longer time.

There are many types of insulation material available commercially in form of sheets, blanket, board and pipe. The easiest to work with for this project is sheets or blankets. This type of material can be bent and shaped to make the external insulation of the container in this project.

However, the cheapest and available type of insulator is polystyrene thus it will be used as insulator in this project.

### *2.6.1 R-Values*

The R-value [2,3] is the reciprocal of the amount of heat energy per area of material per degree difference between the outside and inside. The following equation is used to measure R-values

$$R = \frac{\Delta T}{\left( q/A \right)} \tag{2}$$

Where $\Delta T$ is the temperature difference, q is the heat flow and A is the unit area.

### 2.7 Conduction

The flow of heat by conduction[2,3] occurs via collisions between atoms and molecules in the substance and the subsequent transfer of kinetic energy. Let us consider two substances at different temperatures separated by a barrier which is subsequently removed, as in the following Figure 11.

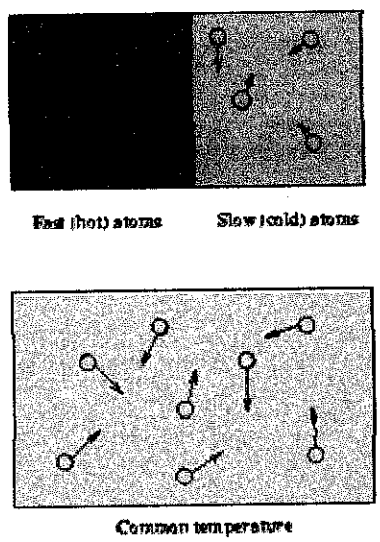


Figure 11 Heat transfer by conduction

Collision between hot atoms with high kinetic energy with cold atoms with low kinetic energy occurs once the barrier between the two is removed. This collision causes the hot atoms to lose energy and the cold atoms to increase their energy thus their speed by means of kinetic transfer called conduction as shown in Figure 12.

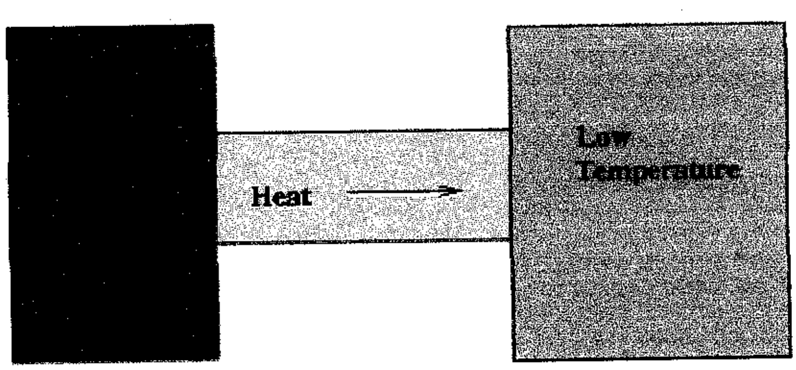


Figure 12 Measurement of thermal conductivity

### 2.7.1 *Heat Transfer Calculation*

The flow of heat by conduction [1,2] occurs via collisions between atoms and molecules in the substance and the subsequent transfer of kinetic energy. The flow of heat through the material over time could be measure by knowing the material's cross-sectional area and length. Thus, the heat flow can be calculated as

$$q = hA(T_w - T_\infty) \tag{1}$$

where h is the heat transfer coefficient, A is the unit area, $T_w$ is the surface temperature and $T_\infty$ is the ambient temperature.

Thus, for a given temperature difference between the reservoirs, materials with a large thermal conductivity will transfer large amounts of heat over time - such materials, like copper, are good thermal conductors. Conversely, materials with low thermal conductivities will transfer small amounts of heat over time - these materials, like concrete, are poor thermal conductors. Fiberglass insulation, feathers and fur have air pockets and so the air pockets aid in cutting back on the heat loss through the material.

Another important parameter that must be obtained is how much heat that must be removed in order for the peltier to cool off. To calculate the cooling rate of the system, first the heat that has to be removed from the system is obtained from the following equation

$$Q_{cooling} = mC\Delta T \tag{2}$$

where m is the mass, C is the specific heat of the item to be cooled and $\Delta T$ is the temperature difference. Using the value of heat removed, the cooling rate is

$$\dot{Q}_{cooling} = \frac{Q_{cooling}}{\Delta t} \tag{3}$$

where $\Delta t$ is the time taken for the system to reach the desired temperature.

A system must not only function, but also efficient. Therefore, it is important to know how long does the system takes to change the temperature of an object. The duration can be known from the equation

$$t = \frac{m \times C_p \times \Delta T}{q} \tag{4}$$

where m is the mass, $C_p$ is the specific heat of material (J/kg.K), $\Delta T$ is the temperature difference in Kelvin and q is the amount of heat removed in Watt.

# CHAPTER 3
# METHODOLOGY

## 3.1 Project Methodology

First and foremost, extensive research to obtain materials for literature review has been done. Next, vital components such as peltier device has to be obtained. The characteristic of the components must be further studied for maximum performance. Then, the control circuit have been designed and simulated using Pspice. To develop the temperature sensing circuit, a study on current temperature control circuitry was developed. The characteristic of the components that build the circuit are under study for further improvement of the circuit.

The microcontroller circuit are also being developed. Microcontroller is actually an important component in this project due to the fact that it helps to reduce the number of components in a circuit with its built in functions.

Next, the design circuit using Pspice must be done. After the circuit is run and working when assembled on breadboard, the design on printed circuit boards (PCB) are going to be fabricated. Then, process of soldering are going to be done alongside with troubleshooting.

Data from the would be gathered based on performance of the circuit. The data obtained have to be analyzed for discussion and room for improvement. Figure 13 shows the flow of activities that has been done in this project.

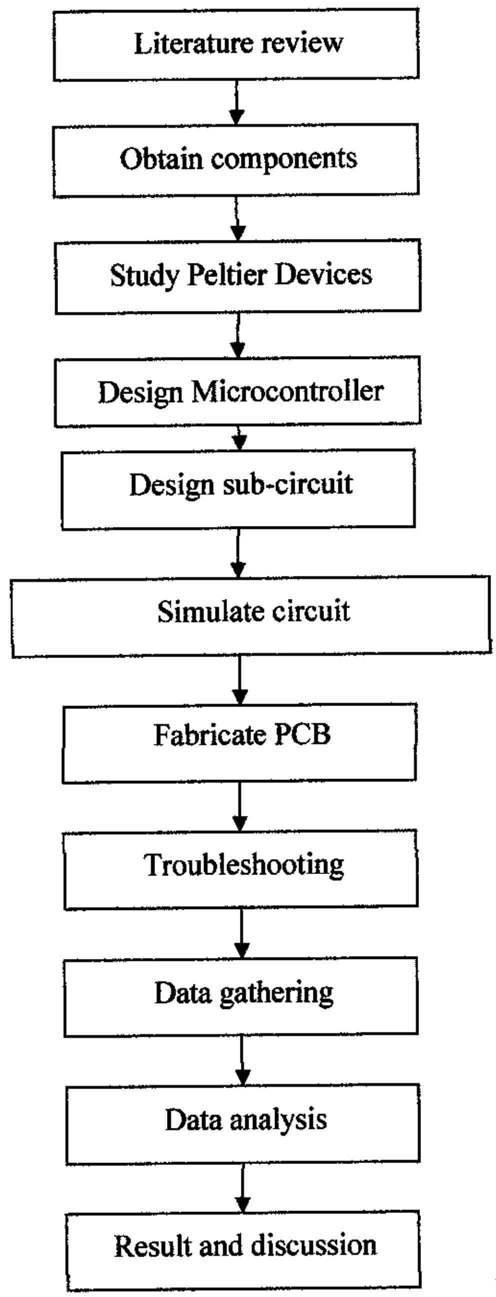


Figure 13 Flow Diagram for Methodology

## 3.2 Container Design

Initially, the container was to be build from scratch using good insulation material. However, it proves that using an existing container that later modified to suit the need of this project is much easier, cheaper and efficient. The container will be wrapped by external insulation material to maximize the insulation capacity of the system. Thus, a design is needed for this purpose; container design as well as external insulation design. One of the main constraint is leakage that causes heat to enter into the container.

The size of the container and the peltier was measured. The container was studied to find which side could be cut to mount the peltier. The top cover is the most suitable as it is made of plastic and thin compared to the body. Then the top was cut according to the dimensions of the peltier. The peltier was mounted onto the top cover using sealant; a type of glue that is strong enough to bond plastic and ceramic.

To increase the insulation of the thin top cover, 3 layers of aluminum foil was mounted underneath. To minimize heat loss from the container, an external insulation will be made from suitable insulation material. This method is popular with existing commercialized cooling container.

## 3.3 The System Functionality

This project consists of a few combination of different components, thus it has an overall functions that are going to be developed for temperature balancing. Firstly, the temperature are preset within microcontroller at a predetermined value. Then the sensor will detect the surrounding temperature as input. The input temperature are then compared with the preset value. If the input value is lower than the preset value, the sensor will go back to detecting the temperature. If the temperature is higher, then the more power will be supplied to the peltier and cool off the peltier. The functionality of the system can be seen from the flow diagram in Figure 14.

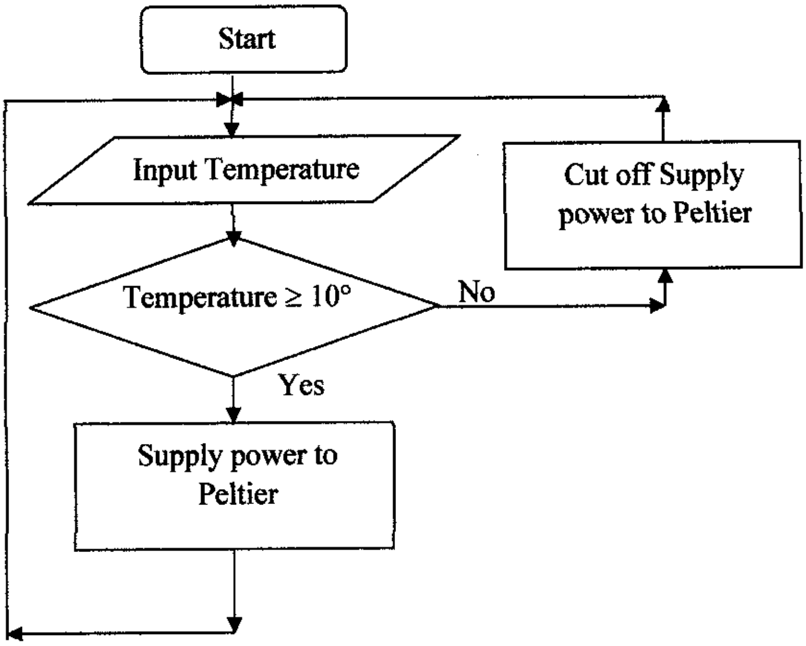


Figure 14 Flow diagram of temperature balancing

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Circuit Simulation

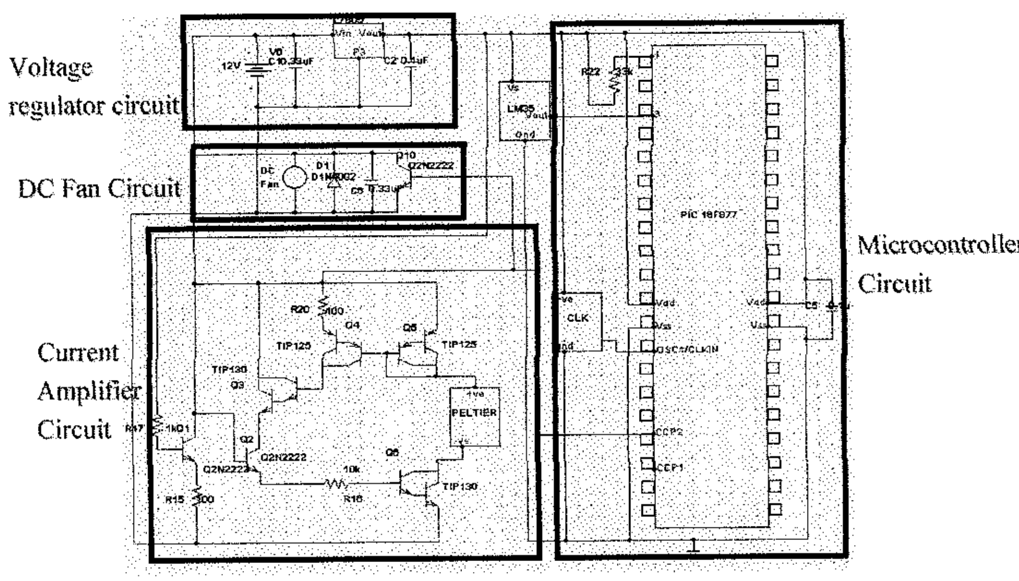


Figure 15 Overall Circuit

The project comprises of microcontroller 16F877, temperature sensor LM35 and controller circuit. The overall circuit is shown in Figure 15. Voltage Regulator LM7805 is used to give a regulated +5VDC supply to the microcontroller. The temperature sensor gives input the microcontroller that compares it with 10°C and give or cut off the supply to the current amplifier circuit. The current amplifier circuit functions to give a high current, thus high power to the peltier.

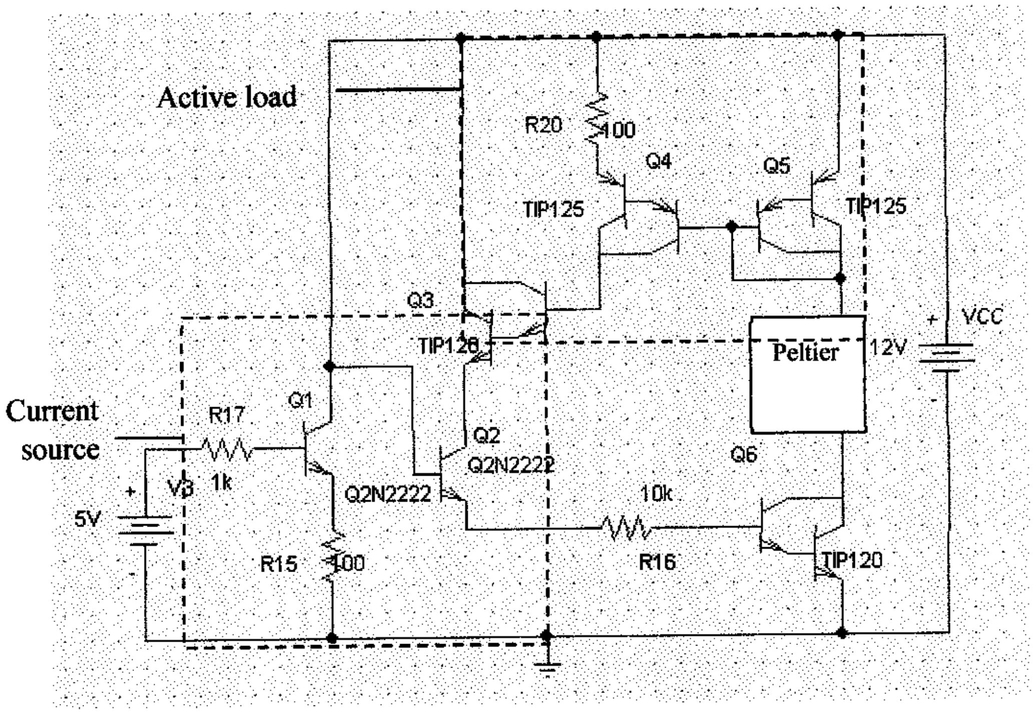


Figure 16 Circuit Simulation for current amplifier circuit

The simulation of the circuit is shown in Figure 16. This circuit has two main stage; current source and active load [14]. Current source is two cascaded transistor that amplified the current to provide sufficient input for the system. When small current flow from the +5V supply, transistor Q1 amplified this small circuit to transistor Q2 and turn it ON. Transistor Q2 further amplified this current and turns ON transistor Q6.

The output of this current source stage is then used by the active load or current mirror amplifier to generate more current. When transistor Q6 turned ON, it will provide current to the active load. Active load is a current source whose output resistance is used in place of collector resistance. All of the current exists in the source and not the output resistance, thus there is no need for high voltage to produce high current. In the circuit, PNP darlington transistors, Q4 and Q5 are used because PNP transistors provide the appropriate direction of collector current. However, PNP current mirrors is inferior to NPN sources thus another NPN darlington transistor, Q3 was added.

### 4.1.1 *Power Dissipation in Q1*

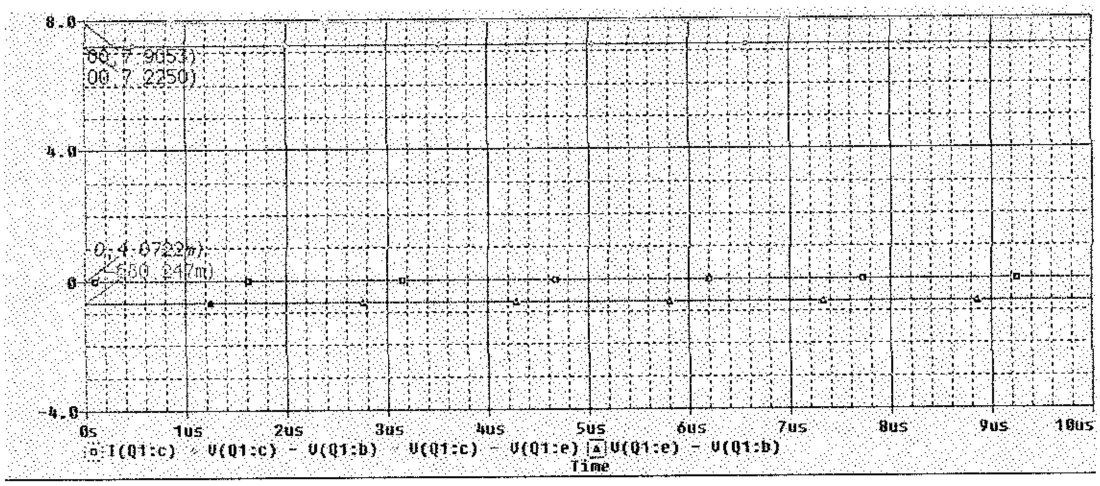


Figure 17 Power Dissipation graph Q1, 2N2222

The waveform in Figure 17 shows the power dissipation graph for transistor Q1 using 2N2222. The transistor is used to amplify the current and supply 1.0722mA to Q2 creating a cascaded amplifier as a current sourcefor the circuit. The base-collector voltage is 7.2250V, collector-emitter voltage is 7.9053 and the emitter base voltage is -680.247mV.

### 4.1.2 *Power Dissipation in Q2*

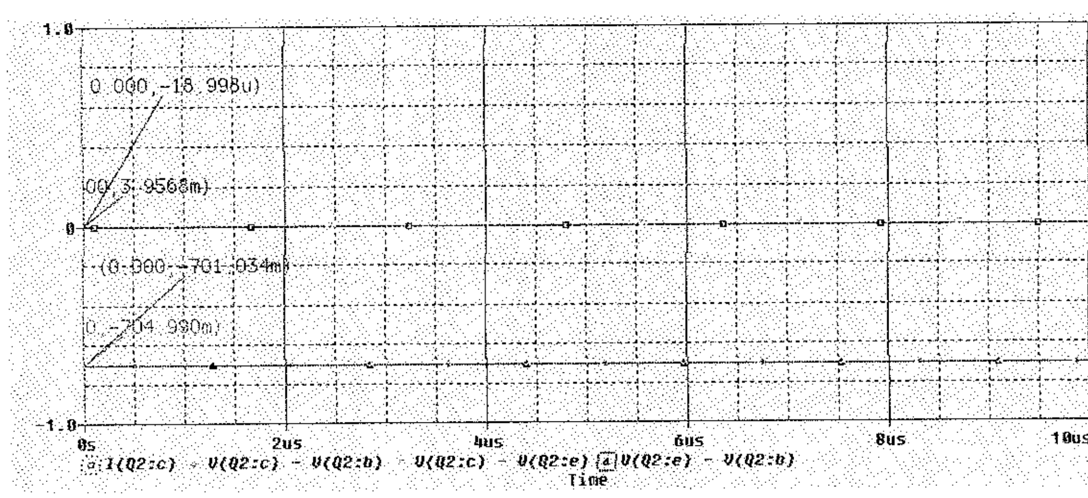


Figure 18 Power Dissipation graph Q2, 2N2222

The waveform in Figure 18 shows the power dissipation graph for transistor Q2 using 2N2222. The transistor is used to amplify the current and supply 3.968mA to active load stage. The base-collector voltage is -794.990mV, collector-emitter voltage is -18.998mV and the emitter base voltage is -701.034mV.

### *4.1.3 Transistor TIP120 AND TIP 127*

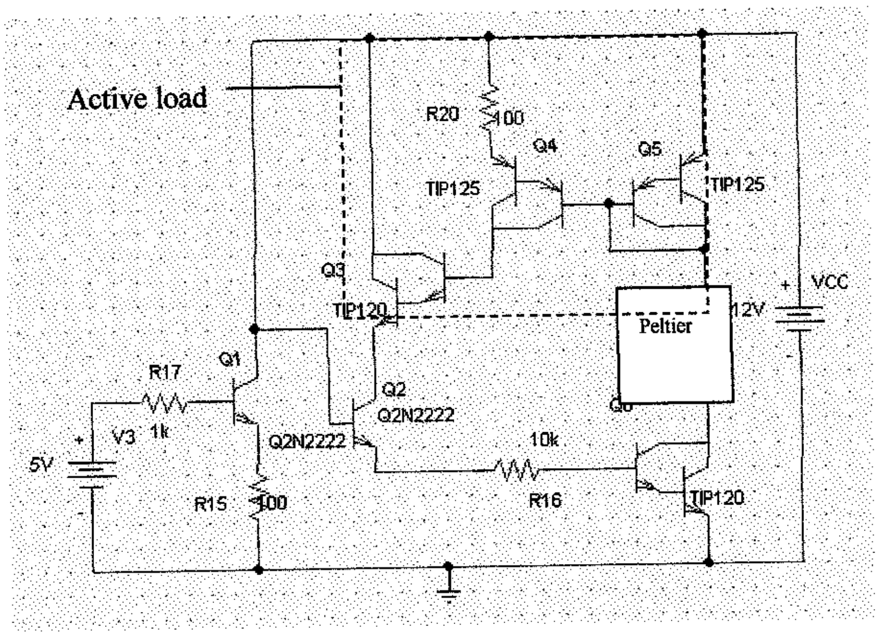


Figure 19 Active load on current amplifier circuit

The connection of the darlington transistor is shown in Figure 19. TIP120 is an NPN transistor and TIP is a PNP transistor that could drive high current value up to 5A. TIP127 is used to drive current to the circuit and TIP120 is used to supply the current to the peltier. these type of transistors are suitable for power linear application in addition to its good switching characteristic. The switching is applied to this circuit as the circuit will be turned ON and OFF to suit the temperature.

From the circuit simulation, the power from the circuit is measured. This measurement is done to show that these transistors are suitable to be used in the circuit. From the graph in Figure 20, the power measured is 41.5Watt. The thermal resistor for TIP120 and TIP127 in the ambient temperature is 62.5°C/W which is the heatsink rating for the transistor.

The thermal power to be dissipated, $P = I_c \times V_{CE}$ = 41.5Watt. the maximum operating temperature($T_{max}$) for the transistor referred to the datasheet is 150°C. The maximum ambient temperature for surrounding air is $T_{AIR}$ which is equals to 25°. If the heatsink is going to be inside a case, the maximum thermal resistance, $R_{TH}$ must be calculated because $T_{AIR}$ might rise due to operation.

$$R_{TH} = (T_{MAX} - T_{AIR}) \tag{7}$$

Using equation (7), the maximum thermal resistance is 3.012 °C/W. A heatsink with a lower thermal resistance is chosen to allow a safety margin. A 1°C/W heatsink dissipating 41.5Watt will have a temperature difference of 1 x 41.5 = 41.5 °C, thus the transistor will rise to 25 + 41.5 = 66.5 °C. This value is lower than the maximum operating temperature of the transistor.

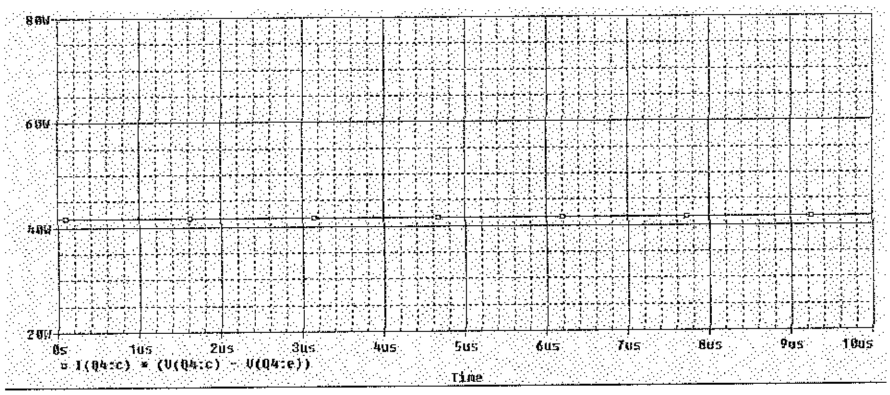


Figure 20 Waveform for TIP120 and TIP127

### *4.1.4 Peltier Voltage and Current*

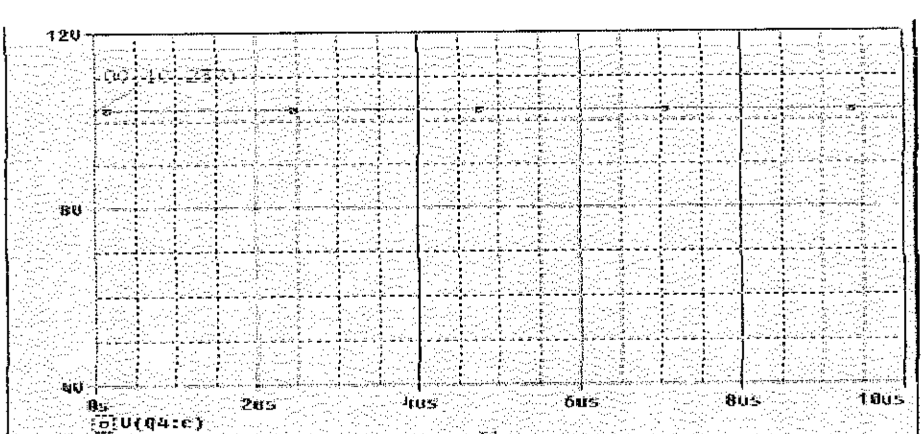


Figure 21 Input voltage to peltier device

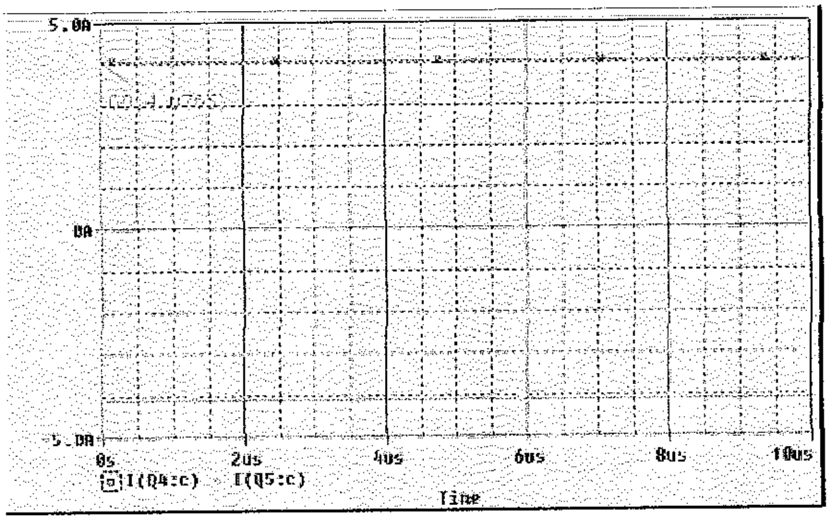


Figure 22 Input current to peltier device

Figure shows the simulated voltage supplied to the peltier at 10.237V and Figure 21 shows the current supply at. The peltier is a current drainage device thus require high power to drive it. However, the output of peltier can only be varied by means of varying current thus high current is needed. Therefore the high current of 4.0765A supplied to it is suitable for this purpose as shown in Figure 22. When compare to the actual voltage supplied to peltier shown in Figure 23, the measurement of voltage is 10V showed that there waspower dissipation due to heat.

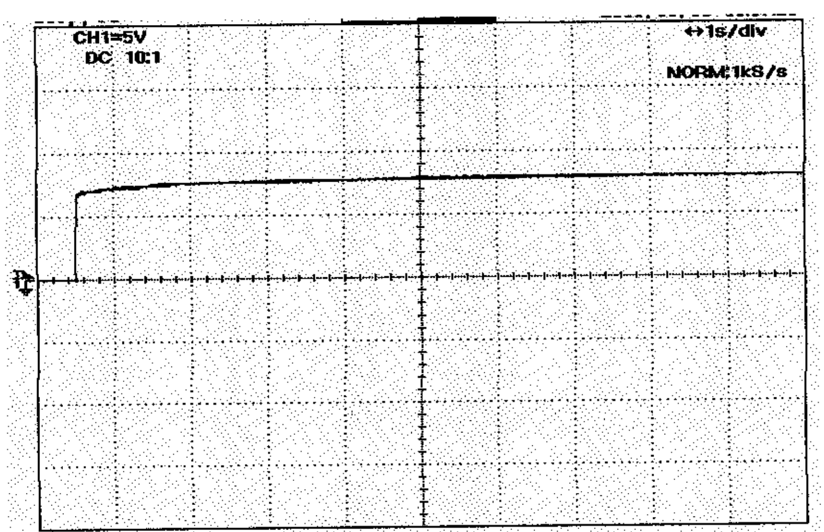


Figure 23 Actual input voltage to peltier

## 4.2 Microcontroller and Temperature Sensor LM35

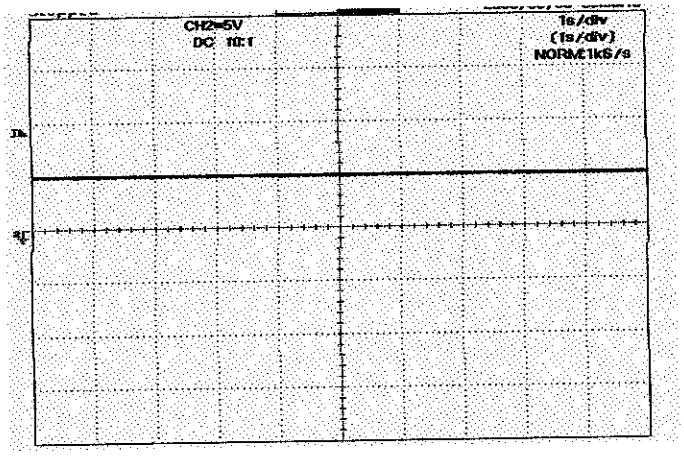


Figure 24 Input voltage to microcontroller

Microcontroller PIC16F877 operates when given output 5VDC and the input graph to the microcontroller is shown in Figure 24. Microcontroller will only be stable if given the input +5VDC will very small tolerance. From the microcontroller program code, the output is measured at PIN RB1 and the output graph is shown in Figure 25. From the graph, the output measured is 4.5V.

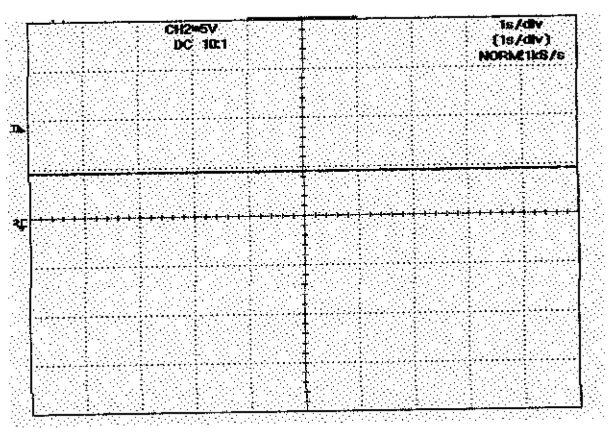


Figure 25 Output voltage to microcontroller

Temperature sensor LM35 gave output in form of voltage whereby 10 mV equals to 1°Celsius. For example when the temperature is 23°Celsius, the sensor will give output 230mV or 0.23V. In the system, the output of the sensor became the input for the microcontroller. The microcontroller turn on the current amplifier circuit when the input is more than 0.1V or 10°Celsius. When the input is higher, microcontroller will turn off the circuit.

## 4.3 Peltier Characteristic

The comparison between actual peltier's characteristic can be seen from Figure 26 and Figure 27[4]. The graphs shows that the peltier is capable to cool better when given higher power. The temperature also decreased inverse proportionally to the power transferred. These values are obtained from experiment done by varying the voltage and current of a DC power supply. The values are limited due to the limitation of the DC supply for peltier is a current drainage device. The power is obtained by mostly varying the current supplied to the peltier.

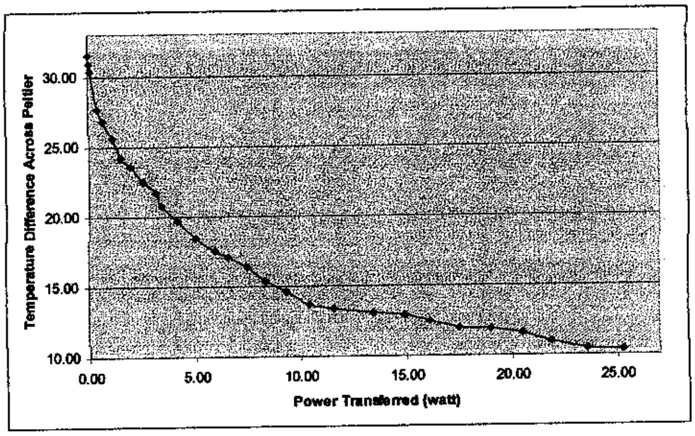


Figure 26 Actual power transferred versus temperature across peltier graph

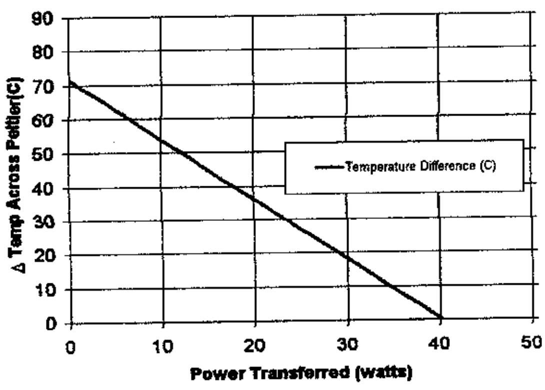


Figure 27 Theoretical Power transferred versus temperature across peltier graph

### *4.3.1 Temperature of Peltier Device when attached to the whole system*

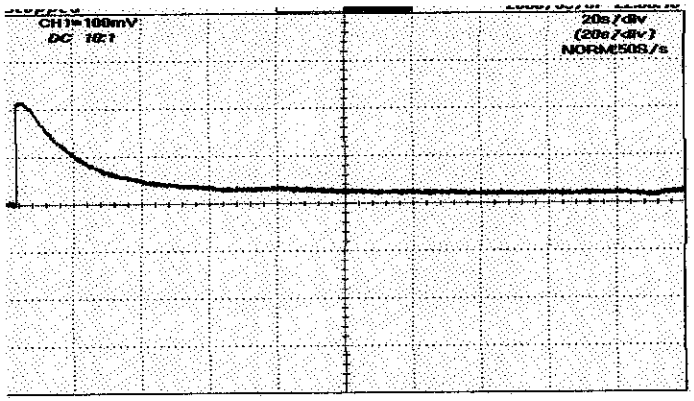


Figure 28 Peltier's surface temperature versus time graph for the cold side

The circuit built has been connected to the peltier device and tested. With the amount of current applied to the circuitry, the peltier has been capable to cool to as low as 2°Celsius. The input is taken from the output of temperature sensor LM35 that gives output 10mV for 1°Celsius. From the graph in Figure 28, 100mV is equal to 10°Celsius, thus the initial temperature was 22°Celsius and the surface of the temperature dropped to 2°Celsius within 60 seconds. The temperature remained at 2°Celsius for as long as the power supplied was maintained.

On the other hand, the temperature on the hot side was measured. The hot side increased rapidly from initial temperature 36°Celsius to 68°Celsius in 48 seconds as shown in Figure 21. This proves that the hot side will get hotter alongside with the cold side that cools off and also an indication of the amount of heat that must be removed in order to cool the cold side.

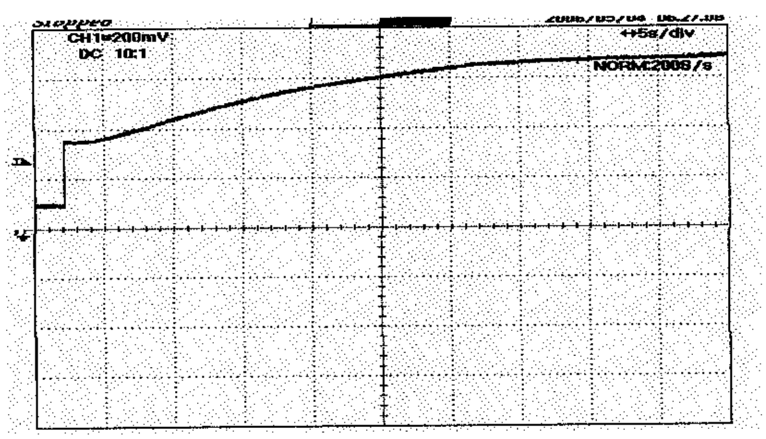


Figure 29 Peltier's surface temperature versus time graph for the hot side

## 4.4 Heat Transfer Calculation

### *4.4.1 Calculation of Cooling Rate of The Peltier*

In this calculation, the heat through the walls is assumed negligible during operation. Taking the peltier's surface temperature, $T_w$ is 10°C and the ambient temperature, $T_s$ is 30°C.

The item to be cool is assumed to be air in the container. The volume of the container, v is 0.4 *l* or 0.399947 x 10 $^{-3}$ m$^3$ with density, $\rho$ equals to1.2 kg / m$^3$. the specific heat for air, Cp $_{AIR}$ is 1.005 k J / kg . $^0$ C. From the value of density and volume, the mass of the air inside the container given by m = $\rho$ v is 4.799364 x 10$^{-4}$ kg.

The cooling rate of the system is equal to the rate of decrease of energy of the air. Using equation 2, heat to be removed from the system is 0.012058 kJ.

### *4.4.2 Calculation of Heat Transfer of the Peltier Device*

To calculate the heat transfer of the peltier, the properties of peltier device (refer to Appendix B) and the temperature must be known. Taking the surface area of the peltier, A is equals to 0.9 x 10$^{-3}$ m$^2$, the peltier's surface temperature, $T_w$ equals to 10 $^0$ C and ambient temperature, $T_\infty$ is 30 $^0$ C, the heat produced is 0.63 W.

A system must not only function, but also efficient. Therefore, it is important to know how long the system takes to change the temperature of an object. The duration can be known from the equation (4), 0.8 hour or 48 minutes providing that the system is a closed loop system.

## 4.5 Design

Previously, the container was to be build from scratch using good insulation material. However, it proves that using an existing container that later will be modified to suit the need of this project is much easier, cheaper and efficient. The container will be wrapped by external insulation material to maximize the insulation capacity of the system. Thus, a design is needed for this purpose; container design as well as external insulation design.

### *4.5.1 Container Design*

The container is actually separated into two pieces; top cover and body. There will be no modification done on the body; it will be used as it is. The top cover has been cut through to enable peltier to be placed in the middle of it. Figure 30 is the overall design of the container.

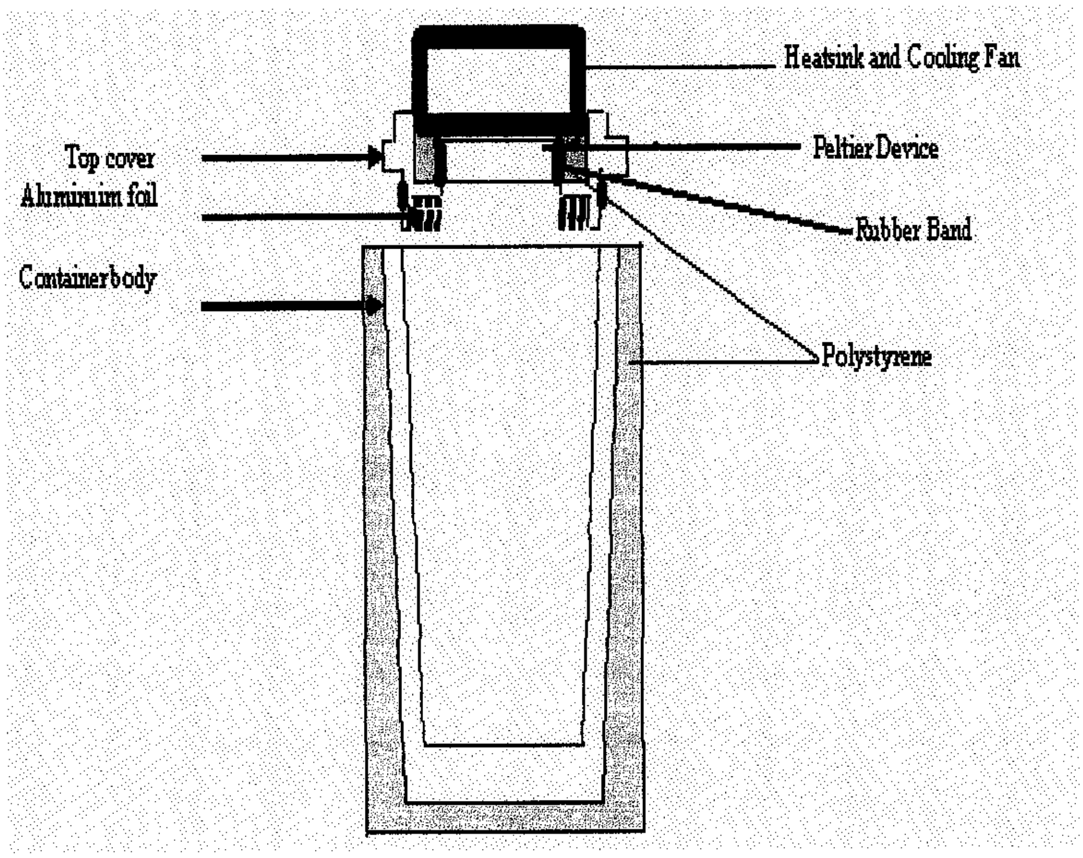


Figure 30 Container Design

### *4.5.2 Container's Body*

The container body is able to leak heat into the container from the visible silvered side. Therefore, polystyrene has been used as insulator and placed around the body as shown in Figure .

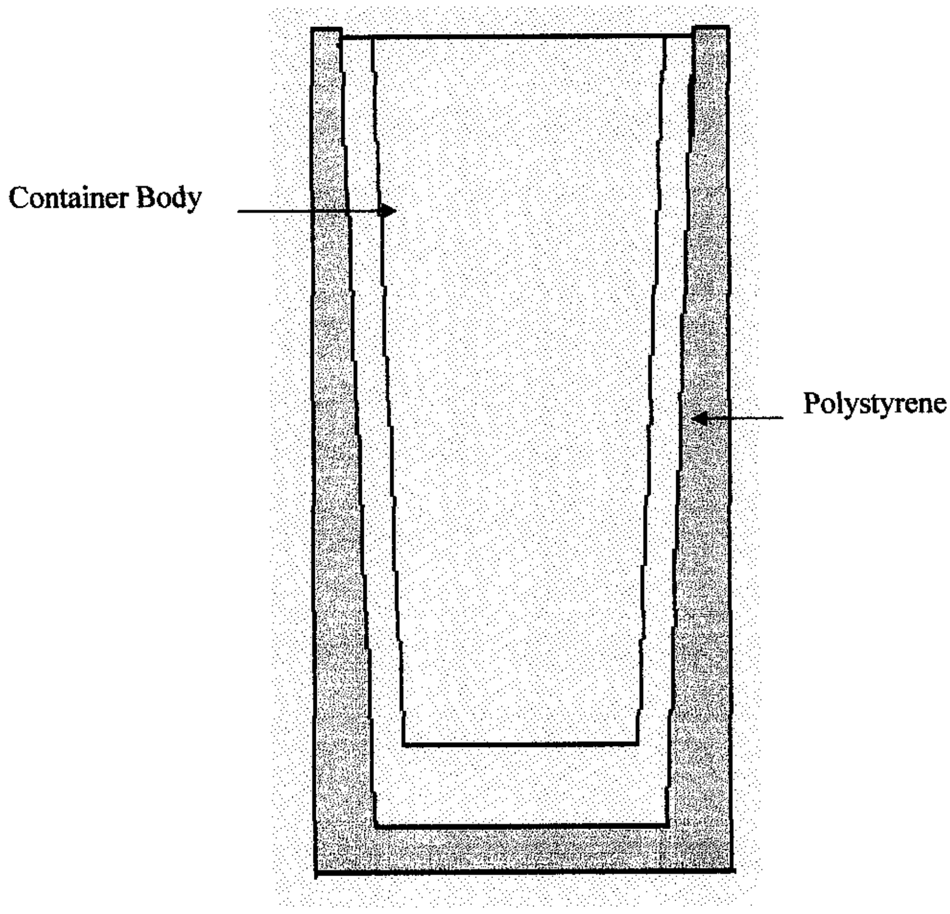


Figure 31 Design of Container's body

### *4.5.3 Top Cover*

The cover itself is very thin thus does not provide much insulation. Thus, polystyrene is placed as insulator. In addition, three layers of aluminum foil will be placed underneath. Air is another form of insulation, thus there are some gap between the layers of aluminum. Rubber is also placed in between peltier and the polystyrene to fill the small gap that could leak external heat into the container. Figure 32 shows the top cover design.

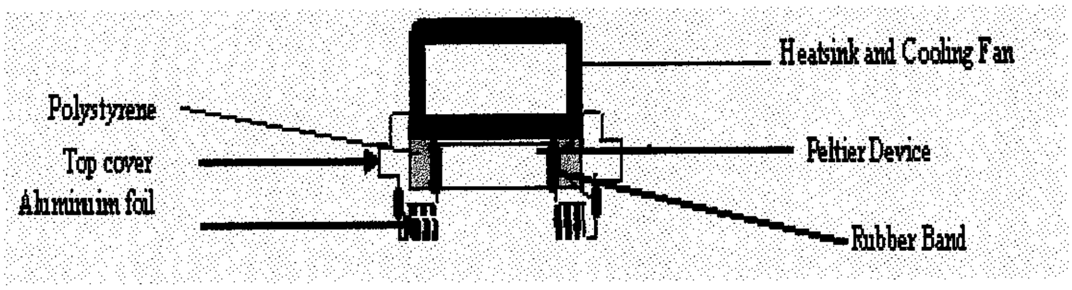


Figure 32 Top Cover Design

The process of installing the aluminum foil is quite a delicate work for the foil tend to break easily. This caused the process of creating an air gap between layers to be very challenging. Another thicker type of aluminum maybe more suitable to be placed as it has shape that can stand by itself.

Mounting the foil onto the top cover is a difficult task due to surface difference; plastic and aluminum. Both require different type of glue and while one glue stick to one surface, it refused to stick to the other. Experimentation with different types of glue helps to make the task possible. Finally, the peltier sticks nicely onto the top cover using sealant which could be adjusted easily and also easy to use.

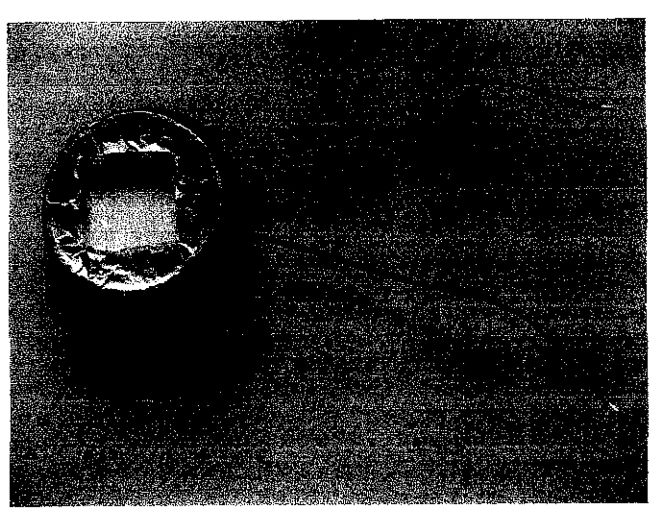

Figure 33 Top cover seen from the bottom

## 4.6 Prototype

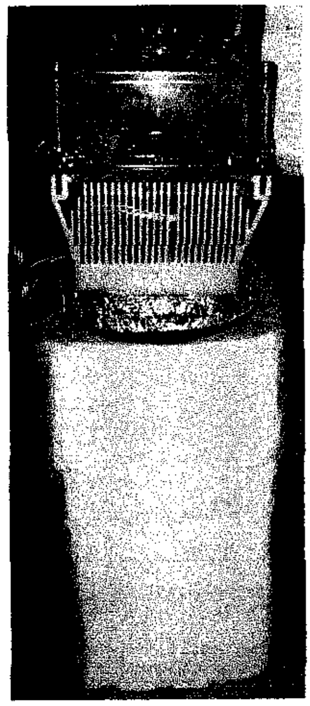

Figure 34 Prototype

The final prototype is shown in Figure 34. The final product is 29cm high and 10cm wide. The system turned OFF when the temperature sensed by the temperature sensor reached lower than 10°C and turned ON when the temperature raised above 10°C. Currently the container is only capable of cooling to 18°C due to external heat that leaks into it. Figure 35 is the output graph of minimum temperature that can be achieved by the prototype that is 180mV output by the temperature sensor equals to 18°C. This probably due to the polystyrene which is not a very good insulator with only 5 R-Value. Due to its price and most importantly availability, it has been used as insulator.

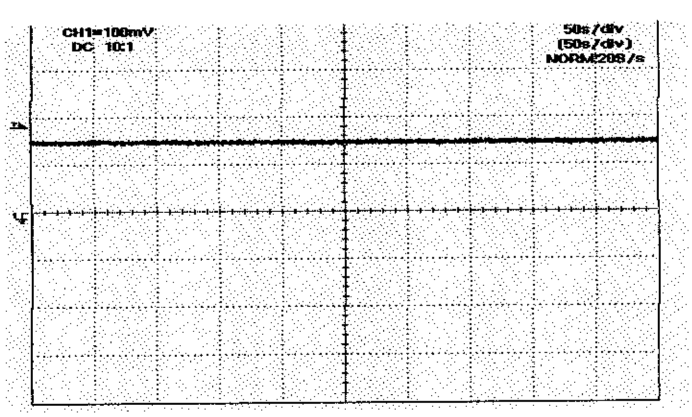


Figure 35 Final Product

# CHAPTER 5
# CONCLUSION

## 5.1 Conclusion

The peltier is a good cooling device that can cool to very low temperatures when supplied enough power. To use peltier device for cooling purposes, the cooling system must be able to remove heat faster than the heat produced. The heatsink and DC Fan used are powerful cooling system that the peltier managed to cool as low as 2°C. However, due to heat leakage, the temperature within the container does not drop as low as the desired value. It only managed to cool up to 18°C when the ambient temperature is 23°C .Thus, the system required good insulation to help the system achieve and maintain temperature at preset value.

The container is built using existing commercial container, a thermos flask that are being modified into desired container. It has been insulated with polystyrene as an added insulation. Overall, the system functions accordingly, but did not achieve the desired cooling temperature of 10°C.

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# APPENDICES

APPENDIX A Peltier Datasheet

APPENDIX B Chemical Properties of Peltier (Bismuth Telluride)

APPENDIX C Microcontroller Programming Code

APPENDIX D PIC16F877 Datasheet

APPENDIX E LM35 Datasheet

APPENDIX F TIP120 Datasheet

APPENDIX G TIP 127 Datasheet

APPENDIX H 2N2222 Datasheet

APPENDIX I 7805 Datasheet

APPENDIX J DC Fan Datasheet

# APPENDIX A

# PELTIER DATASHEET

| | | Ambient = 30C | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | | Max Delta | Max | Max | Max | | | |
| Part Number | Description | T | Voltage | Current | Wattage | Length | Width | Thickness |
| | | | | | | | | |
| TEC1-01704 | Single Stage TEC | 68 | 2.1 | 4.5 | 5 | 15.0 | 15.0 | 4.8 |
| TEC1-03104 | Single Stage TEC | 68 | 3.8 | 4.5 | 10 | 20.0 | 20.0 | 4.8 |
| TEC1-07104 | Single Stage TEC | 68 | 8.6 | 4.5 | 22 | 30.0 | 30.0 | 4.8 |
| TEC1-12704 | Single Stage TEC | 68 | 15.4 | 4.5 | 40 | 40.0 | 40.0 | 4.8 |
| TEC1-01705 | Single Stage TEC | 68 | 2.1 | 5.5 | 7 | 15.0 | 15.0 | 4.0 |
| TEC1-03105 | Single Stage TEC | 68 | 3.8 | 5.5 | 12 | 20.0 | 20.0 | 4.0 |
| TEC1-07105 | Single Stage TEC | 68 | 8.6 | 5.5 | 27 | 30.0 | 30.0 | 4.0 |
| TEC1-12705 | Single Stage TEC | 68 | 15.4 | 5.5 | 49 | 40.0 | 40.0 | 4.0 |
| TEC1-01706 | Single Stage TEC | 68 | 2.1 | 6.5 | 8 | 15.0 | 15.0 | 3.9 |
| TEC1-03106 | Single Stage TEC | 68 | 3.8 | 6.5 | 14 | 20.0 | 20.0 | 3.9 |
| TEC1-07106 | Single Stage TEC | 68 | 8.6 | 6.5 | 32 | 30.0 | 30.0 | 3.9 |
| TEC1-12706 | Single Stage TEC | 68 | 15.4 | 6.5 | 58 | 40.0 | 40.0 | 3.9 |
| TEC1-01707 | Single Stage TEC | 68 | 2.1 | 7.5 | 9 | 15.0 | 15.0 | 3.9 |
| TEC1-03107 | Single Stage TEC | 68 | 3.8 | 7.5 | 16 | 20.0 | 20.0 | 3.9 |
| TEC1-07107 | Single Stage TEC | 68 | 8.6 | 7.5 | 37 | 30.0 | 30.0 | 3.9 |
| TEC1-12707 | Single Stage TEC | 68 | 15.4 | 7.5 | 67 | 40.0 | 40.0 | 3.9 |
| TEC1-01708 | Single Stage TEC | 68 | 2.1 | 8.5 | 10 | 15.0 | 15.0 | 3.6 |
| TEC1-03108 | Single Stage TEC | 68 | 3.8 | 8.5 | 18 | 20.0 | 20.0 | 3.6 |
| 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 |
| TES1-12702 | Single Stage TEC | 68 | 15.4 | 2.0 | 18 | 30.0 | 30.0 | 4.6 |
| TES1-12703 | Single Stage TEC | 68 | 15.4 | 3.0 | 27 | 30.0 | 30.0 | 3.8 |
| TES1-12704 | Single Stage TEC | 68 | 15.4 | 4.0 | 40 | 30.0 | 30.0 | 3.4 |

# APPENDIX B

# CHEMICAL PROPERTIES OF PELTIER (BISMUTH TELLURIDE)

| | | |
|---|---|---|
| Density, $\rho$ | = | 7.53 gm / cm$^3$ |
| Thermal Conductivity, k | = | 1.5 watt / m $^0$C |
| Specific Heat, $C_p$ | = | 0.13 cal / gm $^0$C |
| Heat Transfer Coefficient, h | = | 28 W / m$^2$ . $^0$C |

# APPENDIX C

# MICROCONTROLLER PROGRAMMING CODE

```
#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 <= 5) //adcValue : 18 = 10 degree celcius
        output_low(pin_B1);
        else
        output_high(pin_B1);

   }
}
```

MICROCHIP

# PIC16F87X

## 28/40-Pin 8-Bit CMOS FLASH Microcontrollers

### Devices Included in this Data Sheet:

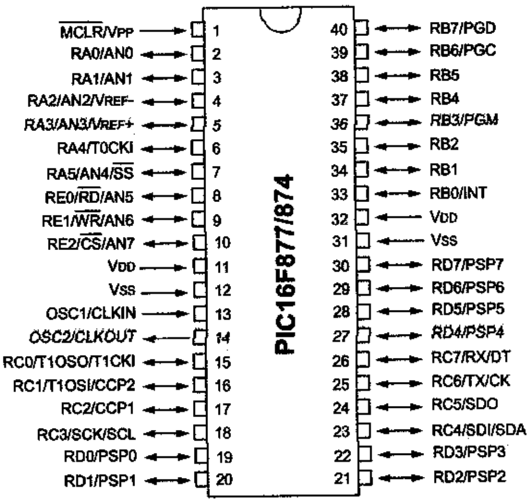
- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

### 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, Industrial and Extended temperature ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

### Pin Diagram

PDIP




### 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 I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

| Key Features PICmicro™ Mid-Range Reference Manual (DS33023) | PIC16F873 | PIC16F874 | PIC16F876 | PIC16F877 |
|---|---|---|---|---|
| Operating Frequency | DC - 20 MHz | DC - 20 MHz | DC - 20 MHz | DC - 20 MHz |
| RESETS (and Delays) | POR, BOR (PWRT, OST) | POR, BOR (PWRT, OST) | POR, BOR (PWRT, OST) | POR, BOR (PWRT, OST) |
| FLASH Program Memory (14-bit words) | 4K | 4K | 8K | 8K |
| Data Memory (bytes) | 192 | 192 | 368 | 368 |
| EEPROM Data Memory | 128 | 128 | 256 | 256 |
| Interrupts | 13 | 14 | 13 | 14 |
| I/O Ports | Ports A,B,C | Ports A,B,C,D,E | Ports A,B,C | Ports A,B,C,D,E |
| Timers | 3 | 3 | 3 | 3 |
| Capture/Compare/PWM Modules | 2 | 2 | 2 | 2 |
| Serial Communications | MSSP, USART | MSSP, USART | MSSP, USART | MSSP, USART |
| Parallel Communications | — | PSP | — | PSP |
| 10-bit Analog-to-Digital Module | 5 input channels | 8 input channels | 5 input channels | 8 input channels |
| Instruction Set | 35 instructions | 35 instructions | 35 instructions | 35 instructions |

**TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION (CONTINUED)**

| Pin Name | DIP Pin# | PLCC Pin# | QFP Pin# | I/O/P Type | Buffer Type | Description |
|---|---|---|---|---|---|---|
| | | | | | | PORTC is a bi-directional I/O port. |
| RC0/T1OSO/T1CKI | 15 | 16 | 32 | I/O | ST | RC0 can also be the Timer1 oscillator output or a Timer1 clock input. |
| RC1/T1OSI/CCP2 | 16 | 18 | 35 | I/O | ST | RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output. |
| RC2/CCP1 | 17 | 19 | 36 | I/O | ST | RC2 can also be the Capture1 input/Compare1 output/PWM1 output. |
| RC3/SCK/SCL | 18 | 20 | 37 | I/O | ST | RC3 can also be the synchronous serial clock input/ output for both SPI and $I^2C$ modes. |
| RC4/SDI/SDA | 23 | 25 | 42 | I/O | ST | RC4 can also be the SPI Data In (SPI mode) or data I/O ($I^2C$ mode). |
| RC5/SDO | 24 | 26 | 43 | I/O | ST | RC5 can also be the SPI Data Out (SPI mode). |
| RC6/TX/CK | 25 | 27 | 44 | I/O | ST | RC6 can also be the USART Asynchronous Transmit or Synchronous Clock. |
| RC7/RX/DT | 26 | 29 | 1 | I/O | ST | RC7 can also be the USART Asynchronous Receive or Synchronous Data. |
| | | | | | | PORTD is a bi-directional I/O port or parallel slave port when interfacing to a microprocessor bus. |
| RD0/PSP0 | 19 | 21 | 38 | I/O | ST/TTL(3) | |
| RD1/PSP1 | 20 | 22 | 39 | I/O | ST/TTL(3) | |
| RD2/PSP2 | 21 | 23 | 40 | I/O | ST/TTL(3) | |
| RD3/PSP3 | 22 | 24 | 41 | I/O | ST/TTL(3) | |
| RD4/PSP4 | 27 | 30 | 2 | I/O | ST/TTL(3) | |
| RD5/PSP5 | 28 | 31 | 3 | I/O | ST/TTL(3) | |
| RD6/PSP6 | 29 | 32 | 4 | I/O | ST/TTL(3) | |
| RD7/PSP7 | 30 | 33 | 5 | I/O | ST/TTL(3) | |
| | | | | | | PORTE is a bi-directional I/O port. |
| RE0/$\overline{RD}$/AN5 | 8 | 9 | 25 | I/O | ST/TTL(3) | RE0 can also be read control for the parallel slave port, or analog input5. |
| RE1/$\overline{WR}$/AN6 | 9 | 10 | 26 | I/O | ST/TTL(3) | RE1 can also be write control for the parallel slave port, or analog input6. |
| RE2/$\overline{CS}$/AN7 | 10 | 11 | 27 | I/O | ST/TTL(3) | RE2 can also be select control for the parallel slave port, or analog input7. |
| VSS | 12,31 | 13,34 | 6,29 | P | — | Ground reference for logic and I/O pins. |
| VDD | 11,32 | 12,35 | 7,28 | P | — | Positive supply for logic and I/O pins. |
| NC | — | 1,17,28, 40 | 12,13, 33,34 | | — | These pins are not internally connected. These pins should be left unconnected. |

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

**Note 1:** This buffer is a Schmitt Trigger input when configured as an external interrupt.
**2:** This buffer is a Schmitt Trigger input when used in Serial Programming mode.
**3:** This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
**4:** This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

## 1.0 DEVICE OVERVIEW

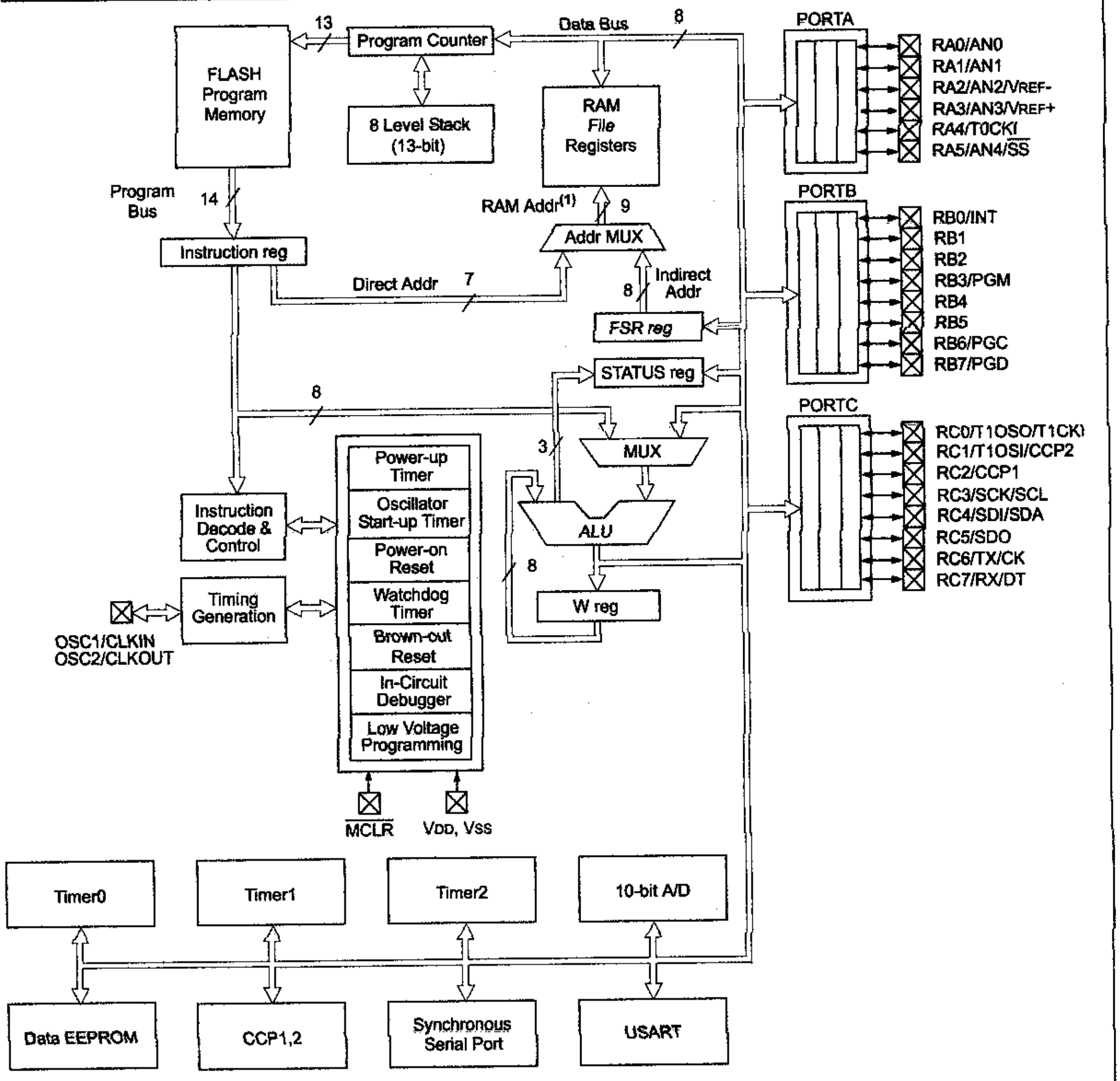
This document contains device specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

There are four devices (PIC16F873, PIC16F874, PIC16F876 and PIC16F877) covered by this data sheet. The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40-pin packages. The Parallel Slave Port is not implemented on the 28-pin devices.

The following device block diagrams are sorted by pin number; 28-pin for Figure 1-1 and 40-pin for Figure 1-2. The 28-pin and 40-pin pinouts are listed in Table 1-1 and Table 1-2, respectively.

**FIGURE 1-1: PIC16F873 AND PIC16F876 BLOCK DIAGRAM**

| Device | Program FLASH | Data Memory | Data EEPROM |
|---|---|---|---|
| PIC16F873 | 4K | 192 Bytes | 128 Bytes |
| PIC16F876 | 8K | 368 Bytes | 256 Bytes |




**Note 1:** Higher order bits are from the STATUS register.

## 5.2 Using Timer0 with an External Clock

When no prescaler is used, the external clock input is the same as the prescaler output. The synchronization of T0CKI with the internal phase clocks is accomplished by sampling the prescaler output on the Q2 and Q4 cycles of the internal phase clocks. Therefore, it is necessary for T0CKI to be high for at least 2Tosc (and a small RC delay of 20 ns) and low for at least 2Tosc (and a small RC delay of 20 ns). Refer to the electrical specification of the desired device.

## 5.3 Prescaler

There is only one prescaler available, which is mutually exclusively shared between the Timer0 module and the Watchdog Timer. A prescaler assignment for the Timer0 module means that there is no prescaler for the Watchdog Timer, and vice-versa. This prescaler is not readable or writable (see Figure 5-1).

The PSA and PS2:PS0 bits (OPTION_REG<3:0>) determine the prescaler assignment and prescale ratio.

When assigned to the Timer0 module, all instructions writing to the TMR0 register (e.g. `CLRF 1, MOVWF 1, BSF 1,x`....etc.) will clear the prescaler. When assigned to WDT, a `CLRWDT` instruction will clear the prescaler along with the Watchdog Timer. The prescaler is not readable or writable.

| Note: | Writing to TMR0, when the prescaler is assigned to Timer0, will clear the prescaler count, but will not change the prescaler assignment. |
|---|---|

**REGISTER 5-1: OPTION_REG REGISTER**

| R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
|---|---|---|---|---|---|---|---|
| $\overline{\text{RBPU}}$ | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 |
| bit 7 | | | | | | | bit 0 |

bit 7 **$\overline{\text{RBPU}}$**

bit 6 **INTEDG**

bit 5 **T0CS**: TMR0 Clock Source Select bit
1 = Transition on T0CKI pin
0 = Internal instruction cycle clock (CLKOUT)

bit 4 **T0SE**: TMR0 Source Edge Select bit
1 = Increment on high-to-low transition on T0CKI pin
0 = Increment on low-to-high transition on T0CKI pin

bit 3 **PSA**: Prescaler Assignment bit
1 = Prescaler is assigned to the WDT
0 = Prescaler is assigned to the Timer0 module

bit 2-0 **PS2:PS0**: Prescaler Rate Select bits

| Bit Value | TMR0 Rate | WDT Rate |
|---|---|---|
| 000 | 1 : 2 | 1 : 1 |
| 001 | 1 : 4 | 1 : 2 |
| 010 | 1 : 8 | 1 : 4 |
| 011 | 1 : 16 | 1 : 8 |
| 100 | 1 : 32 | 1 : 16 |
| 101 | 1 : 64 | 1 : 32 |
| 110 | 1 : 128 | 1 : 64 |
| 111 | 1 : 256 | 1 : 128 |

| Legend: | | |
|---|---|---|
| R = Readable bit | W = Writable bit | U = Unimplemented bit, read as '0' |
| - n = Value at POR | '1' = Bit is set | '0' = Bit is cleared    x = Bit is unknown |

| Note: | To avoid an unintended device RESET, the instruction sequence shown in the PICmicro™ Mid-Range MCU Family Reference Manual (DS33023) must be executed when changing the prescaler assignment from Timer0 to the WDT. This sequence must be followed even if the WDT is disabled. |
|---|---|

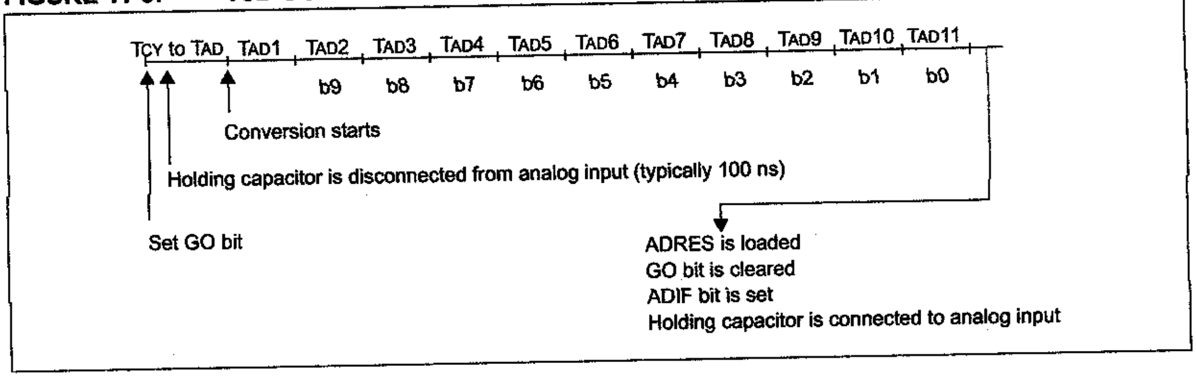
### 11.4 A/D Conversions

Clearing the GO/$\overline{\text{DONE}}$ bit during a conversion will abort the current conversion. The A/D result register pair will NOT be updated with the partially completed A/D conversion sample. That is, the ADRESH:ADRESL registers will continue to contain the value of the last completed conversion (or the last value written to the ADRESH:ADRESL registers). After the A/D conversion is aborted, a 2TAD wait is required before the next acquisition is started. After this 2TAD wait, acquisition on the selected channel is automatically started. The GO/$\overline{\text{DONE}}$ bit can then be set to start the conversion.

In Figure 11-3, after the GO bit is set, the first time segment has a minimum of TCY and a maximum of TAD.

| Note: | The GO/$\overline{\text{DONE}}$ bit should **NOT** be set in the same instruction that turns on the A/D. |
|---|---|

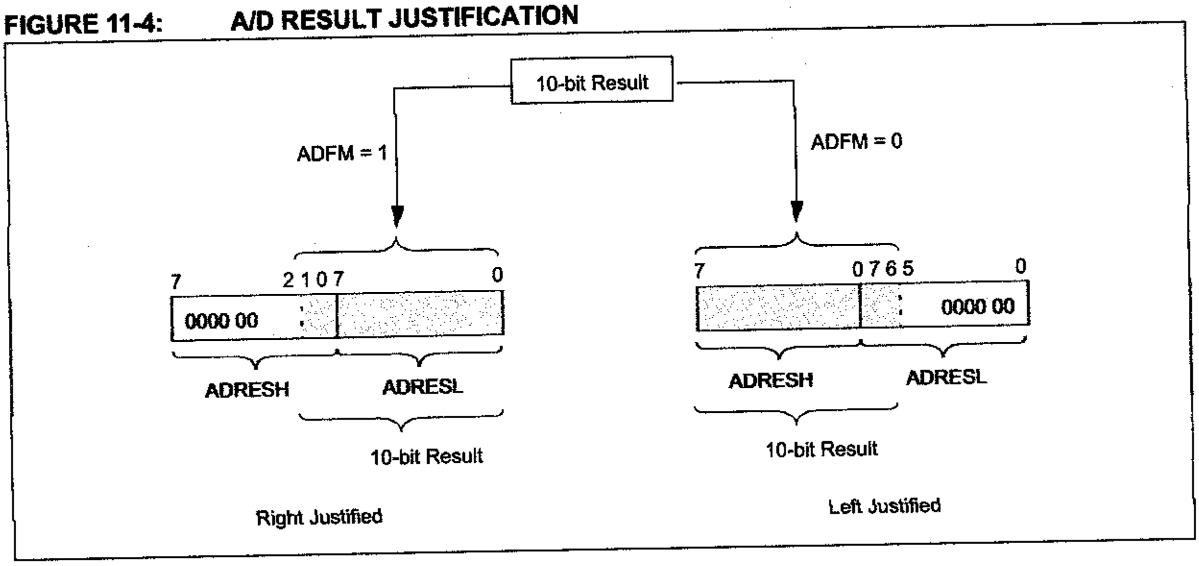
**FIGURE 11-3: A/D CONVERSION TAD CYCLES**




#### 11.4.1 A/D RESULT REGISTERS

The ADRESH:ADRESL register pair is the location where the 10-bit A/D result is loaded at the completion of the A/D conversion. This register pair is 16-bits wide. The A/D module gives the flexibility to left or right justify the 10-bit result in the 16-bit result register. The A/D Format Select bit (ADFM) controls this justification. Figure 11-4 shows the operation of the A/D result justification. The extra bits are loaded with '0's'. When an A/D result will not overwrite these locations (A/D disable), these registers may be used as two general purpose 8-bit registers.

**FIGURE 11-4: A/D RESULT JUSTIFICATION**



## 15.1 DC Characteristics: PIC16F873/874/876/877-04 (Commercial, Industrial) PIC16F873/874/876/877-20 (Commercial, Industrial) PIC16LF873/874/876/877-04 (Commercial, Industrial)

| PIC16LF873/874/876/877-04 (Commercial, Industrial) | | | **Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial; 0°C ≤ TA ≤ +70°C for commercial | | | | |
|---|---|---|---|---|---|---|---|
| **PIC16F873/874/876/877-04 PIC16F873/874/876/877-20** (Commercial, Industrial) | | | **Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial; 0°C ≤ TA ≤ +70°C for commercial | | | | |
| **Param No.** | **Symbol** | **Characteristic/ Device** | **Min** | **Typ†** | **Max** | **Units** | **Conditions** |
| | VDD | **Supply Voltage** | | | | | |
| D001 | | 16LF87X | 2.0 | — | 5.5 | V | LP, XT, RC osc configuration (DC to 4 MHz) |
| D001 | | 16F87X | 4.0 | — | 5.5 | V | LP, XT, RC osc configuration |
| D001A | | | 4.5 | | 5.5 | V | HS osc configuration |
| | | | VBOR | | 5.5 | V | BOR enabled, FMAX = 14 MHz(7) |
| D002 | VDR | **RAM Data Retention Voltage(1)** | — | 1.5 | — | V | |
| D003 | VPOR | **VDD Start Voltage** to ensure internal Power-on Reset signal | — | VSS | — | V | See section on Power-on Reset for details |
| *D004* | SVDD | **VDD Rise Rate** to ensure internal Power-on Reset signal | *0.05* | — | — | *V/ms* | *See section on Power-on Reset for details* |
| D005 | VBOR | **Brown-out Reset Voltage** | 3.7 | 4.0 | 4.35 | V | BODEN bit in configuration word enabled |

Legend: Rows with standard voltage device data only are shaded for improved readability.

† Data in "Typ" column is at 5V, 25°C, unless otherwise stated. These parameters are for design guidance only, and are not tested.

**Note 1:** This is the limit to which VDD can be lowered without losing RAM data.

**2:** The supply current is mainly a function of the operating voltage and frequency. Other factors such as I/O pin loading, switching rate, oscillator type, internal code execution pattern and temperature also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail to rail; all I/O pins tri-stated, pulled to VDD;
$\overline{\text{MCLR}}$ = VDD; WDT enabled/disabled as specified.

**3:** The power-down current in SLEEP mode does not depend on the oscillator type. Power-down current is measured with the part in SLEEP mode, with all I/O pins in hi-impedance state and tied to VDD and VSS.

**4:** For RC osc configuration, current through REXT is not included. The current through the resistor can be estimated by the formula Ir = VDD/2REXT (mA) with REXT in kOhm.

**5:** Timer1 oscillator (when enabled) adds approximately 20 μA to the specification. This value is from characterization and is for design guidance only. This is not tested.

**6:** The Δ current is the additional current consumed when this peripheral is enabled. This current should be added to the base IDD or IPD measurement.

**7:** When BOR is enabled, the device will operate correctly until the VBOR voltage trip point is reached.

## 4.0 DATA EEPROM AND FLASH PROGRAM MEMORY

The Data EEPROM and FLASH Program Memory are readable and writable during normal operation over the entire VDD range. These operations take place on a single byte for Data EEPROM memory and a single word for Program memory. A write operation causes an erase-then-write operation to take place on the specified byte or word. A bulk erase operation may not be issued from user code (which includes removing code protection).

Access to program memory allows for checksum calculation. The values written to program memory do not need to be valid instructions. Therefore, up to 14-bit numbers can be stored in memory for use as calibration parameters, serial numbers, packed 7-bit ASCII, etc. Executing a program memory location containing data that form an invalid instruction, results in the execution of a NOP instruction.

The EEPROM Data memory is rated for high erase/write cycles (specification D120). The FLASH program memory is rated much lower (specification D130), because EEPROM data memory can be used to store frequently updated values. An on-chip timer controls the write time and it will vary with voltage and temperature, as well as from chip to chip. Please refer to the specifications for exact limits (specifications D122 and D133).

A byte or word write automatically erases the location and writes the new value (erase before write). Writing to EEPROM data memory does not impact the operation of the device. Writing to program memory will cease the execution of instructions until the write is complete. The program memory cannot be accessed during the write. During the write operation, the oscillator continues to run, the peripherals continue to function and interrupt events will be detected and essentially "queued" until the write is complete. When the write completes, the next instruction in the pipeline is executed and the branch to the interrupt vector will take place, if the interrupt is enabled and occurred during the write.

Read and write access to both memories take place indirectly through a set of Special Function Registers (SFR). The six SFRs used are:

- EEDATA
- EEDATH
- EEADR
- EEADRH
- EECON1
- EECON2

The EEPROM data memory allows byte read and write operations without interfering with the normal operation of the microcontroller. When interfacing to EEPROM data memory, the EEADR register holds the address to be accessed. Depending on the operation, the EEDATA register holds the data to be written, or the data read, at the address in EEADR. The PIC16F873/874 devices have 128 bytes of EEPROM data memory and therefore, require that the MSb of EEADR remain clear. The EEPROM data memory on these devices do not wrap around to 0, i.e., 0x80 in the EEADR does not map to 0x00. The PIC16F876/877 devices have 256 bytes of EEPROM data memory and therefore, uses all 8-bits of the EEADR.

The FLASH program memory allows non-intrusive read access, but write operations cause the device to stop executing instructions, until the write completes. When interfacing to the program memory, the EEADRH:EEADR registers form a two-byte word, which holds the 13-bit address of the memory location being accessed. The register combination of EEDATH:EEDATA holds the 14-bit data for writes, or reflects the value of program memory after a read operation. Just as in EEPROM data memory accesses, the value of the EEADRH:EEADR registers must be within the valid range of program memory, depending on the device: 0000h to 1FFFh for the PIC16F873/874, or 0000h to 3FFFh for the PIC16F876/877. Addresses outside of this range do not wrap around to 0000h (i.e., 4000h does not map to 0000h on the PIC16F877).

### 4.1 EECON1 and EECON2 Registers

The EECON1 register is the control register for configuring and initiating the access. The EECON2 register is not a physically implemented register, but is used exclusively in the memory write sequence to prevent inadvertent writes.

There are many bits used to control the read and write operations to EEPROM data and FLASH program memory. The EEPGD bit determines if the access will be a program or data memory access. When clear, any subsequent operations will work on the EEPROM data memory. When set, all subsequent operations will operate in the program memory.

Read operations only use one additional bit, RD, which initiates the read operation from the desired memory location. Once this bit is set, the value of the desired memory location will be available in the data registers. This bit cannot be cleared by firmware. It is automatically cleared at the end of the read operation. For EEPROM data memory reads, the data will be available in the EEDATA register in the very next instruction cycle after the RD bit is set. For program memory reads, the data will be loaded into the EEDATH:EEDATA registers, following the second instruction after the RD bit is set.

## 11.1 A/D Acquisition Requirements

For the A/D converter to meet its specified accuracy, the charge holding capacitor (CHOLD) must be allowed to fully charge to the input channel voltage level. The analog input model is shown in Figure 11-2. The source impedance (RS) and the internal sampling switch (RSS) impedance directly affect the time required to charge the capacitor CHOLD. The sampling switch (RSS) impedance varies over the device voltage (VDD), see Figure 11-2. **The maximum recommended impedance for analog sources is 10 kΩ.** As the impedance is decreased, the acquisition time may be decreased.

After the analog input channel is selected (changed), this acquisition must be done before the conversion can be started.

To calculate the minimum acquisition time, Equation 11-1 may be used. This equation assumes that 1/2 LSb error is used (1024 steps for the A/D). The 1/2 LSb error is the maximum error allowed for the A/D to meet its specified resolution.

To calculate the minimum acquisition time, TACQ, see the PICmicro™ Mid-Range Reference Manual (DS33023).

**EQUATION 11-1: ACQUISITION TIME**

$$\begin{aligned}
T_{ACQ} &= \text{Amplifier Settling Time} + \\
&\quad\ \text{Hold Capacitor Charging Time} + \\
&\quad\ \text{Temperature Coefficient} \\
&= T_{AMP} + T_C + T_{COFF} \\
&= 2\mu s + T_C + [(\text{Temperature} - 25°C)(0.05\mu s/°C)] \\
T_C &= C_{HOLD}\,(R_{IC} + R_{SS} + R_S)\ \ln(1/2047) \\
&= -120pF\,(1k\Omega + 7k\Omega + 10k\Omega)\ \ln(0.0004885) \\
&= 16.47\mu s \\
T_{ACQ} &= 2\mu s + 16.47\mu s + [(50°C - 25°C)(0.05\mu s/°C)] \\
&= 19.72\mu s
\end{aligned}$$

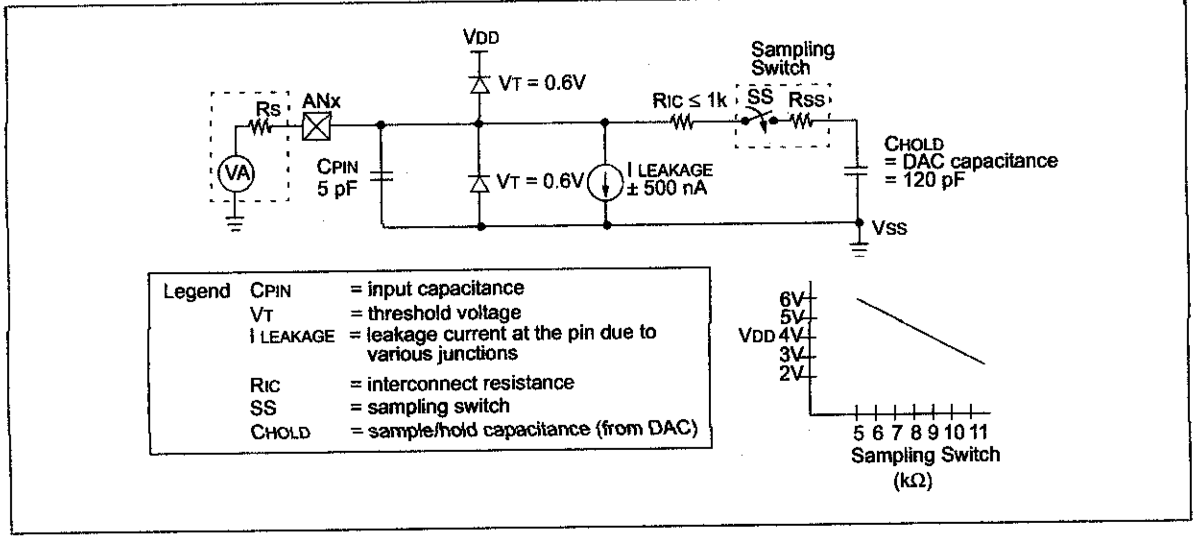
**Note 1:** The reference voltage (VREF) has no effect on the equation, since it cancels itself out.

**2:** The charge holding capacitor (CHOLD) is not discharged after each conversion.

**3:** The maximum recommended impedance for analog sources is 10 kΩ. This is required to meet the pin leakage specification.

**4:** After a conversion has completed, a 2.0TAD delay must complete before acquisition can begin again. During this time, the holding capacitor is not connected to the selected A/D input channel.

**FIGURE 11-2: ANALOG INPUT MODEL**



National Semiconductor

November 2000

# LM35
# Precision Centigrade Temperature Sensors

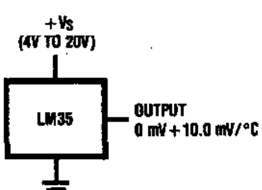
## General Description

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

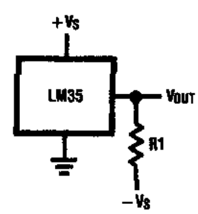
- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- 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 $R_1 = -V_S/50\ \mu A$

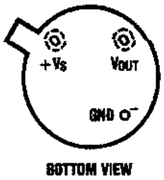
$V_{OUT}$=+1,500 mV at +150°C
= +250 mV at +25°C
= −550 mV at −55°C

**FIGURE 2. Full-Range Centigrade Temperature Sensor**

 DS005516

## Connection Diagrams

**TO-46**
**Metal Can Package***

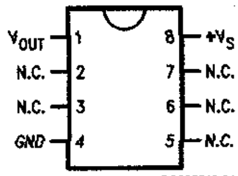



DS005516-1

*Case is connected to negative pin (GND)

**Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH**
**See NS Package Number H03H**

**SO-8**
**Small Outline Molded Package**

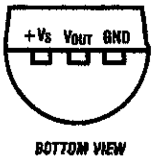



DS005516-21

N.C. = No Connection

**Top View**
**Order Number LM35DM**
**See NS Package Number M08A**

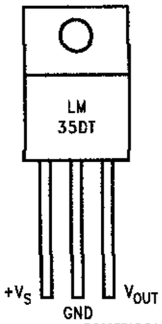
**TO-92**
**Plastic Package**




DS005516-2

**Order Number LM35CZ, LM35CAZ or LM35DZ**
**See NS Package Number Z03A**

**TO-220**
**Plastic Package***




DS005516-24

**Tab is connected to the negative pin (GND).*
**Note:** The LM35DT pinout is different than the discontinued LM35DP.

**Order Number LM35DT**
**See NS Package Number TA03F**

## ›solute Maximum Ratings (Note 10)

**ilitary/Aerospace specified devices are required, ıse contact the National Semiconductor Sales Office/ :ributors for availability and specifications.**

| | |
|---|---|
| ply Voltage | +35V to −0.2V |
| ›ut Voltage | +6V to −1.0V |
| put Current | 10 mA |
| ·age Temp.; | |
| O-46 Package, | −60°C to +180°C |
| ›-92 Package, | −60°C to +150°C |
| O-8 Package, | −65°C to +150°C |
| ›-220 Package, | −65°C to +150°C |
| d Temp.: | |
| O-46 Package, (Soldering, 10 seconds) | 300°C |
| TO-92 and TO-220 Package, (Soldering, 10 seconds) | 260°C |
| SO Package (Note 12) | |
| Vapor Phase (60 seconds) | 215°C |
| Infrared (15 seconds) | 220°C |
| ESD Susceptibility (Note 11) | 2500V |

Specified Operating Temperature Range: $T_{MIN}$ to $T_{MAX}$ (Note 2)

| | |
|---|---|
| LM35, LM35A | −55°C to +150°C |
| LM35C, LM35CA | −40°C to +110°C |
| LM35D | 0°C to +100°C |

## ›ctrical Characteristics

›s 1, 6)

| Parameter | Conditions | LM35A Typical | LM35A Tested Limit (Note 4) | LM35A Design Limit (Note 5) | LM35CA Typical | LM35CA Tested Limit (Note 4) | LM35CA Design Limit (Note 5) | Units (Max.) |
|---|---|---|---|---|---|---|---|---|
| acy | $T_A$=+25°C | ±0.2 | ±0.5 | | ±0.2 | ±0.5 | | °C |
| 7) | $T_A$=−10°C | ±0.3 | | | ±0.3 | | ±1.0 | °C |
| | $T_A$=$T_{MAX}$ | ±0.4 | ±1.0 | | ±0.4 | ±1.0 | | °C |
| | $T_A$=$T_{MIN}$ | ±0.4 | ±1.0 | | ±0.4 | | ±1.5 | °C |
| ıearity 8) | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **±0.18** | | **±0.35** | **±0.15** | | **±0.3** | °C |
| ›r Gain ›ge Slope) | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **+10.0** | **+9.9, +10.1** | | **+10.0** | | **+9.9, +10.1** | mV/°C |
| Regulation | $T_A$=+25°C | ±0.4 | ±1.0 | | ±0.4 | ±1.0 | | mV/mA |
| 3) 0≤$I_L$≤1 mA | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **±0.5** | | **±3.0** | **±0.5** | | **±3.0** | mV/mA |
| Regulation | $T_A$=+25°C | ±0.01 | ±0.05 | | ±0.01 | ±0.05 | | mV/V |
| 3) | 4V≤$V_S$≤30V | **±0.02** | | **±0.1** | **±0.02** | | **±0.1** | mV/V |
| ›cent Current | $V_S$=+5V, +25°C | 56 | 67 | | 56 | 67 | | μA |
| 9) | $V_S$=+5V | **105** | | **131** | **91** | | **114** | μA |
| | $V_S$=+30V, +25°C | 56.2 | 68 | | 56.2 | 68 | | μA |
| | $V_S$=+30V | **105.5** | | **133** | **91.5** | | **116** | μA |
| ge of | 4V≤$V_S$≤30V, +25°C | 0.2 | 1.0 | | 0.2 | 1.0 | | μA |
| ›cent Current 3) | 4V≤$V_S$≤30V | **0.5** | | **2.0** | **0.5** | | **2.0** | μA |
| erature icient of ›cent Current | | **+0.39** | | **+0.5** | **+0.39** | | **+0.5** | μA/°C |
| ıum Temperature ›ted Accuracy | In circuit of *Figure 1*, $I_L$=0 | +1.5 | | +2.0 | +1.5 | | +2.0 | °C |
| Term Stability | $T_J$=$T_{MAX}$, for 1000 hours | ±0.08 | | | ±0.08 | | | °C |

## Electrical Characteristics

(Notes 1, 6)

| Parameter | Conditions | LM35 | | | LM35C, LM35D | | | Units (Max.) |
|---|---|---|---|---|---|---|---|---|
| | | Typical | Tested Limit (Note 4) | Design Limit (Note 5) | Typical | Tested Limit (Note 4) | Design Limit (Note 5) | |
| Accuracy, LM35, LM35C (Note 7) | $T_A$=+25°C | ±0.4 | ±1.0 | | ±0.4 | ±1.0 | | °C |
| | $T_A$=−10°C | ±0.5 | | | ±0.5 | | ±1.5 | °C |
| | $T_A$=$T_{MAX}$ | ±0.8 | ±1.5 | | ±0.8 | | ±1.5 | °C |
| | $T_A$=$T_{MIN}$ | ±0.8 | | ±1.5 | ±0.8 | | ±2.0 | °C |
| Accuracy, LM35D (Note 7) | $T_A$=+25°C | | | | ±0.6 | ±1.5 | | °C |
| | $T_A$=$T_{MAX}$ | | | | ±0.9 | | ±2.0 | °C |
| | $T_A$=$T_{MIN}$ | | | | ±0.9 | | ±2.0 | °C |
| Nonlinearity (Note 8) | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **±0.3** | | **±0.5** | **±0.2** | | **±0.5** | °C |
| Sensor Gain (Average Slope) | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **+10.0** | **+9.8, +10.2** | | **+10.0** | | **+9.8, +10.2** | mV/°C |
| Load Regulation (Note 3) 0≤$I_L$≤1 mA | $T_A$=+25°C | ±0.4 | ±2.0 | | ±0.4 | ±2.0 | | mV/mA |
| | $T_{MIN}$≤$T_A$≤$T_{MAX}$ | **±0.5** | | **±5.0** | **±0.5** | | **±5.0** | mV/mA |
| Line Regulation (Note 3) | $T_A$=+25°C | ±0.01 | ±0.1 | | ±0.01 | ±0.1 | | mV/V |
| | 4V≤$V_S$≤30V | **±0.02** | | **±0.2** | **±0.02** | | **±0.2** | mV/V |
| Quiescent Current (Note 9) | $V_S$=+5V, +25°C | 56 | 80 | | 56 | 80 | | μA |
| | $V_S$=+5V | **105** | | **158** | **91** | | **138** | μA |
| | $V_S$=+30V, +25°C | 56.2 | 82 | | 56.2 | 82 | | μA |
| | $V_S$=+30V | **105.5** | | **161** | **91.5** | | **141** | μA |
| Change of Quiescent Current (Note 3) | 4V≤$V_S$≤30V, +25°C | 0.2 | 2.0 | | 0.2 | 2.0 | | μA |
| | 4V≤$V_S$≤30V | **0.5** | | **3.0** | **0.5** | | **3.0** | μA |
| Temperature Coefficient of Quiescent Current | | **+0.39** | | **+0.7** | **+0.39** | | **+0.7** | μA/°C |
| Minimum Temperature for Rated Accuracy | In circuit of *Figure 1*, $I_L$=0 | +1.5 | | +2.0 | +1.5 | | +2.0 | °C |
| *Long Term Stability* | $T_J$=$T_{MAX}$, for 1000 hours | *±0.08* | | | *±0.08* | | | °C |

**Note 1:** Unless otherwise noted, these specifications apply: −55°C≤$T_J$≤+150°C for the LM35 and LM35A; −40°≤$T_J$≤+110°C for the LM35C and LM35CA; and 0°≤$T_J$≤+100°C for the LM35D. $V_S$=+5Vdc and $I_{LOAD}$=50 μA, in the circuit of *Figure 2*. These specifications also apply from +2°C to $T_{MAX}$ in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

**Note 2:** Thermal resistance of the TO-46 package is 400°C/W, junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-220 package is 90°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

**Note 3:** Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

**Note 4:** Tested Limits are guaranteed and 100% tested in production.

**Note 5:** Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

**Note 6:** Specifications in **boldface** apply over the full rated temperature range.

**Note 7:** Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

***Note 8:*** *Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature* range.

**Note 9:** Quiescent current is defined in the circuit of *Figure 1*.

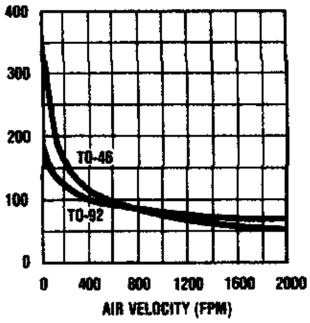
**Note 10:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

**Note 11:** Human body model, 100 pF discharged through a 1.5 kΩ resistor.

**Note 12:** See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

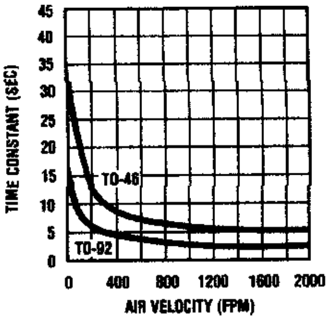
## pical Performance Characteristics

***rmal Resistance***
**ction to Air**



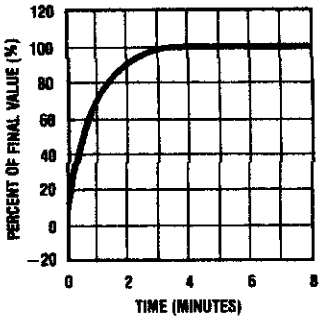

DS005516-25

***Thermal Time Constant***



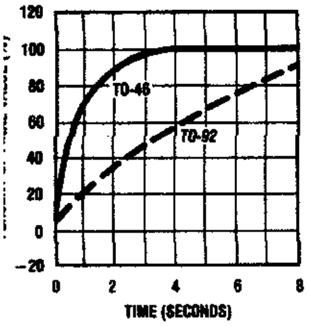

DS005516-26

***Thermal Response***
**in Still Air**



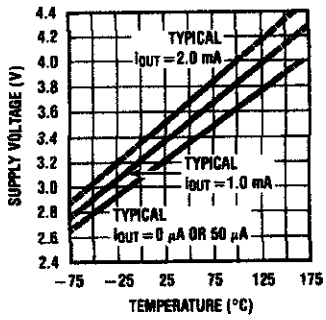

DS005516-27

**rmal Response in**
**red Oil Bath**



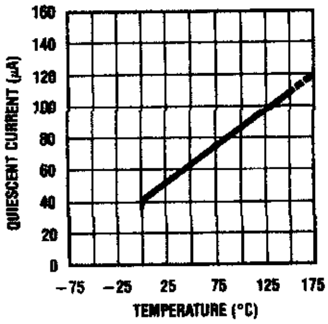

DS005516-28

**Minimum Supply**
**Voltage vs. Temperature**



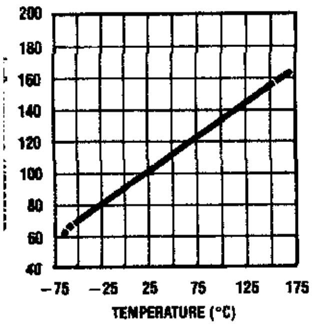

DS005516-29

**Quiescent Current**
**vs. Temperature**
**(In Circuit of *Figure 1.*)**



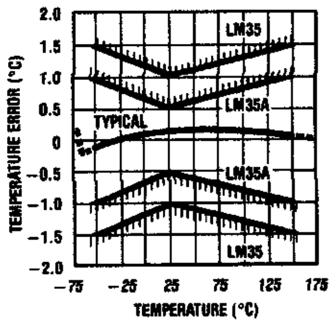

DS005516-30

**escent Current**
**Temperature**
**Circuit of *Figure 2.*)**



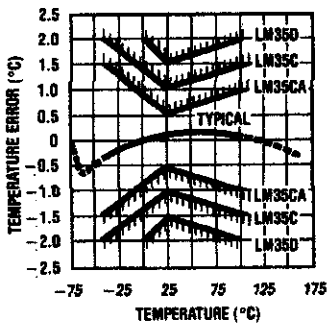

DS005516-31

**Accuracy vs. Temperature**
**(Guaranteed)**




DS005516-32

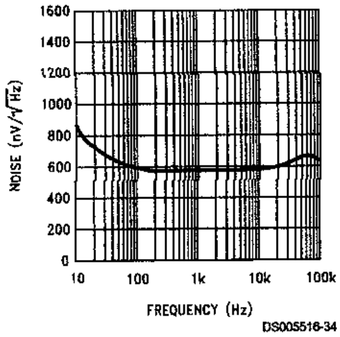
**Accuracy vs. Temperature**
**(Guaranteed)**



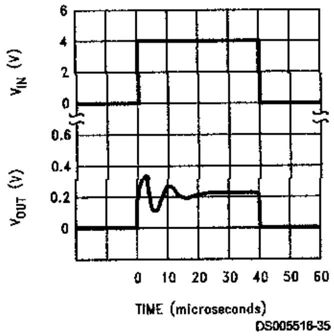

DS005516-33

## Typical Performance Characteristics (Continued)

**Noise Voltage**




**Start-Up Response**




# Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01˚C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

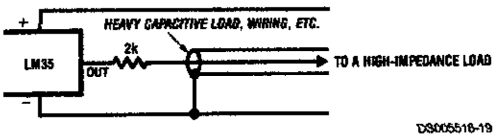
# Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, $\theta_{JA}$)

| | TO-46, no heat sink | TO-46*, small heat fin | TO-92, no heat sink | TO-92**, small heat fin | SO-8 no heat sink | SO-8** small heat fin | TO-220 no heat sink |
|---|---|---|---|---|---|---|---|
| Still air | 400˚C/W | 100˚C/W | 180˚C/W | 140˚C/W | 220˚C/W | 110˚C/W | 90˚C/W |
| Moving air | 100˚C/W | 40˚C/W | 90˚C/W | 70˚C/W | 105˚C/W | 90˚C/W | 26˚C/W |
| Still oil | 100˚C/W | 40˚C/W | 90˚C/W | 70˚C/W | | | |
| Stirred oil | 50˚C/W | 30˚C/W | 45˚C/W | 40˚C/W | | | |
| (Clamped to metal, Infinite heat sink) | (24˚C/W) | | | | (55˚C/W) | | |

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.

**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

## pical Applications




URE 3. LM35 with Decoupling from Capacitive Load

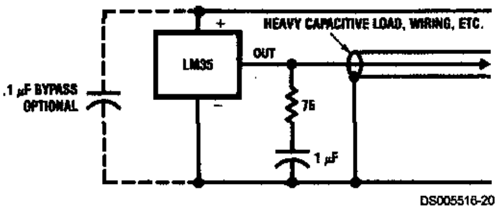



*FIGURE 4. LM35* **with R-C Damper**

### 'ACITIVE LOADS

most micropower circuits, the LM35 has a limited ability rive heavy capacitive loads. The LM35 by itself is able to e 50 pf without special precautions. If heavier loads are cipated, it is easy to isolate or decouple the load with a stor; see *Figure 3*. Or you can improve the tolerance of acitance *with a series R-C damper from output to* und; see *Figure 4*.

in the LM35 is applied with a 200Ω load resistor as wn in *Figure 5*, *Figure 6* or *Figure 8* it is relatively immune iring capacitance because the capacitance forms a bys from ground to input, not on the output. However, as any linear circuit connected to wires in a hostile envinent, its performance can be affected adversely by ine electromagnetic sources such as relays, radio transers, motors with arcing brushes, SCR transients, etc, as wiring can act as a receiving antenna and its internal tions can act as rectifiers. For best results in such cases, ypass capacitor from $V_{IN}$ to ground and a series R-C per such as 75Ω in series with 0.2 or 1 µF from output to und are often useful. These are shown in *Figure 13*, *ıre 14*, and *Figure 16*.

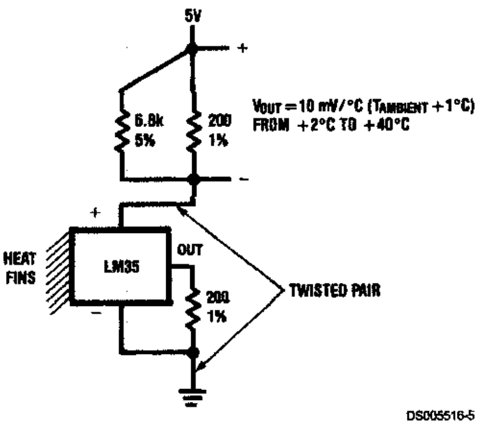



FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

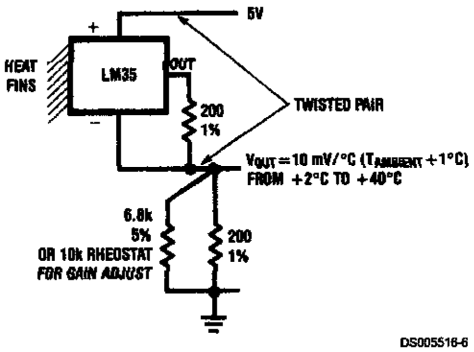



**FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)**

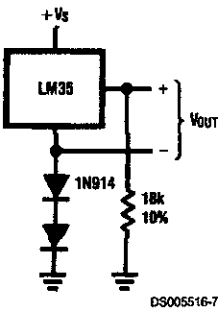



**FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C**

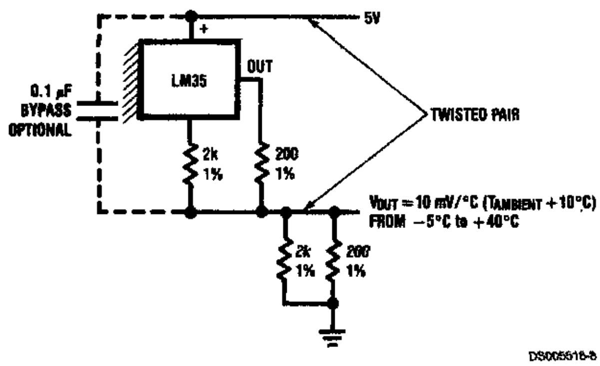



**FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)**

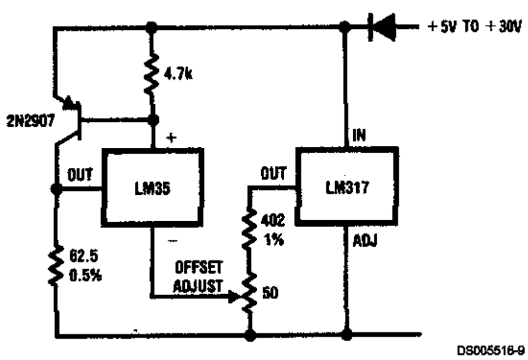



**FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)**

FAIRCHILD SEMICONDUCTOR®

# TIP120 DATASHEET

# TIP120/121/122

TIP120/121/122

## Medium Power Linear Switching Applications

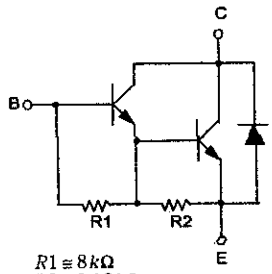
- Complementary to TIP125/126/127

1 TO-220

1.Base 2.Collector 3.Emitter

## NPN Epitaxial Darlington Transistor

Equivalent Circuit




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

### 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 |
| | 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 | | | | |
| | : 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%*



Rev. A1, June 2001

## Typical characteristics

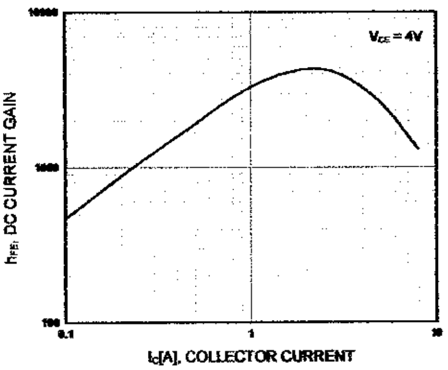



**Figure 1. DC current Gain**

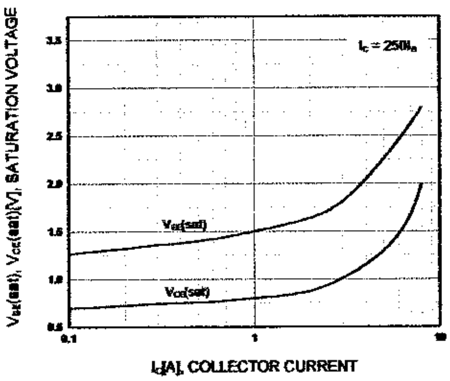



**Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage**

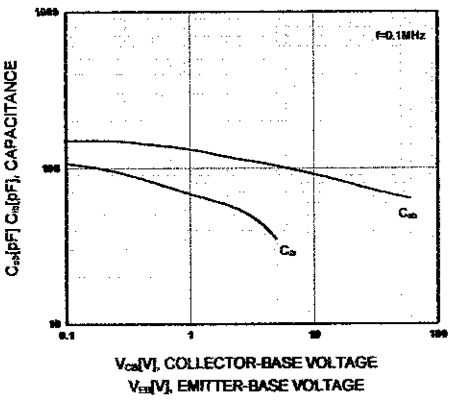



**Figure 3. Output and Input Capacitance vs. Reverse Voltage**

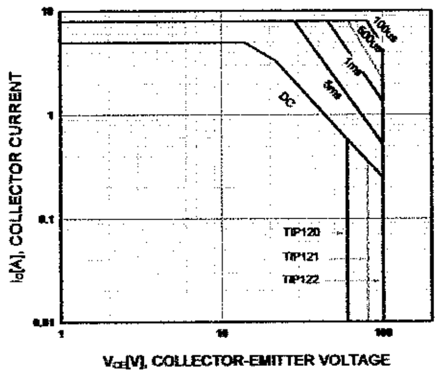



**Figure 4. Safe Operating Area**

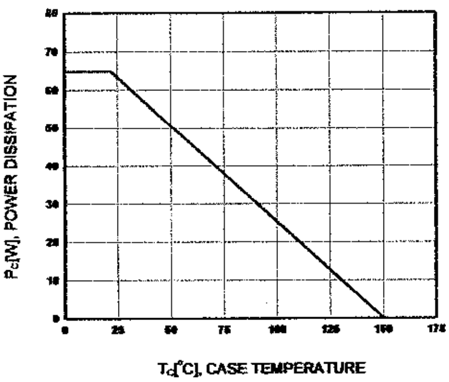
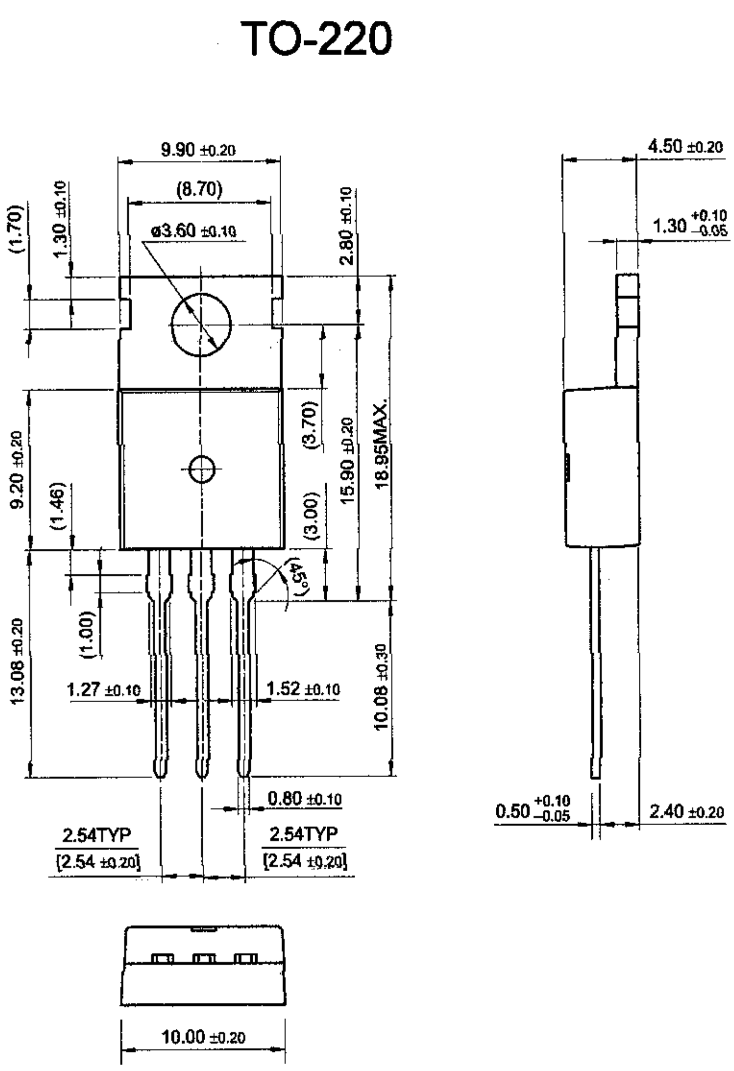



**Figure 5. Power Derating**

## Package Demensions




Dimensions in Millimeters

FAIRCHILD
SEMICONDUCTOR®

# TIP127 DATASHEET

# TIP125/126/127

## Medium Power Linear Switching Applications

- Complementary to TIP120/121/122

1 TO-220

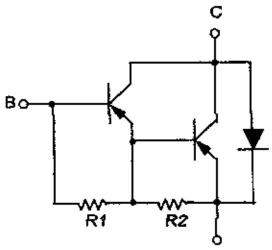
1.Base 2.Collector 3.Emitter

## PNP Epitaxial Darlington Transistor

### Absolute Maximum Ratings $T_C$=25°C unless otherwise noted

| 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 |

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 | | | | |
| | : 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%*



Rev. A1, June 2001

## Typical Characteristics

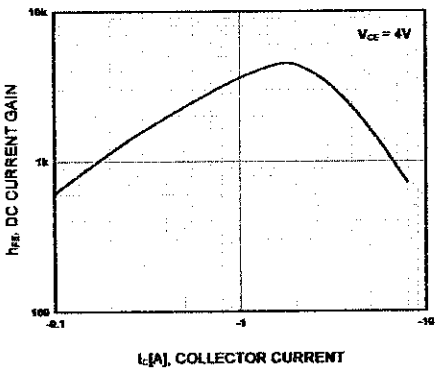



Figure 1. DC current Gain

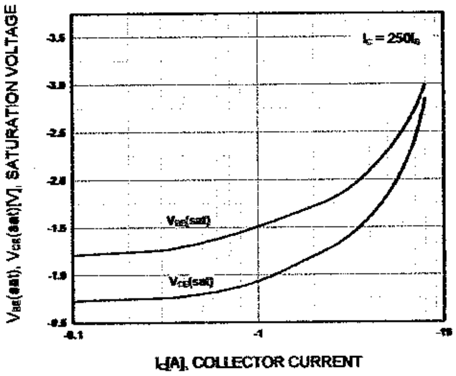



Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

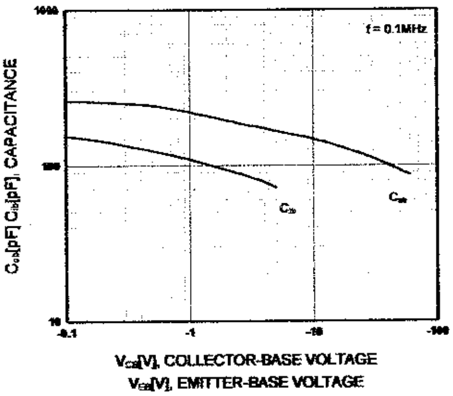



Figure 3. Output and Input Capacitance vs. Reverse Voltage

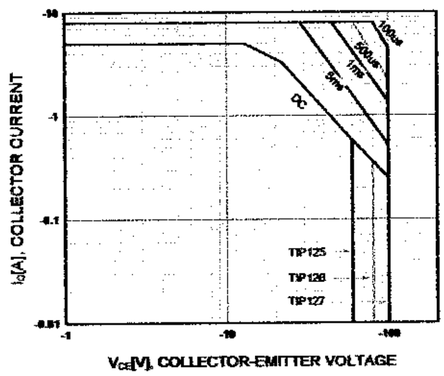



Figure 4. Safe Operating Area

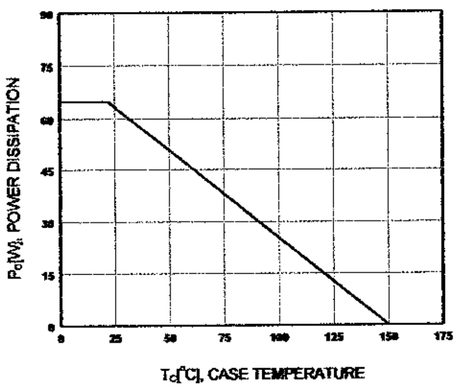
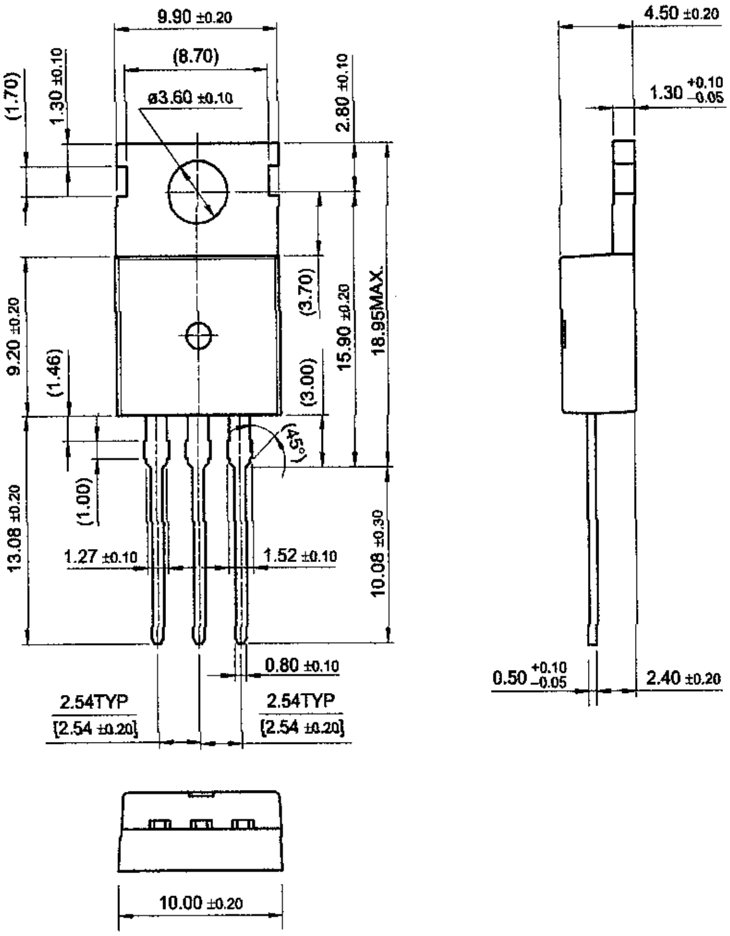



Figure 5. Power Derating

## Package Demensions

TO-220




Dimensions in Millimeters

# 2N2222 DATASHEET

FAIRCHILD SEMICONDUCTOR®

PN2222

# 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 |

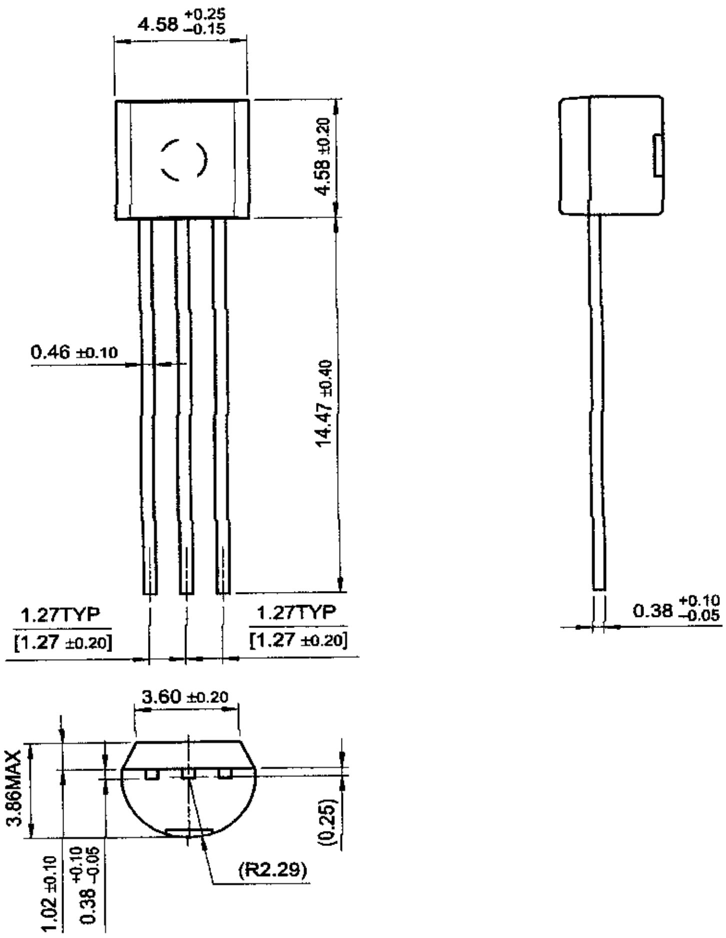
### Electrical Characteristics $T_a$=25°C unless otherwise noted

| 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<br>$V_{CE}$=10V, *$I_C$=150mA | 35<br>100 | <br>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%

## Package Dimensions

TO-92




Dimensions in Millimeters

APPENDIX I

# KA78XX/KA78XXA DATASHEET

## 3-Terminal 1A Positive Voltage Regulator

### Features

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

### Description

The KA78XX/KA78XXA series of three-terminal positive regulator are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

TO-220

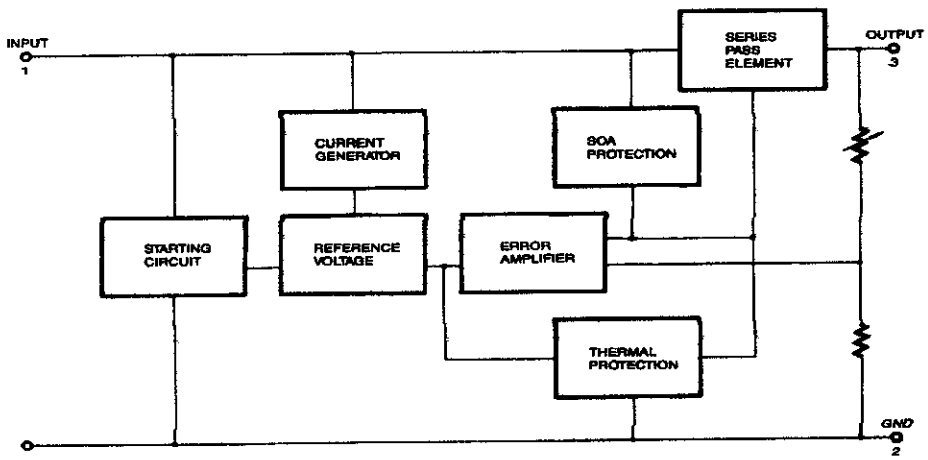
1

D-PAK

1

1. Input 2. GND 3. Output

### Internal Block Digram




Rev. 1.0.0

## Absolute Maximum Ratings

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Input Voltage (for $V_O$ = 5V to 18V)<br>(for $V_O$ = 24V) | $V_I$<br>$V_I$ | 35<br>40 | V<br>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 (KA78XX/A/R)* | $T_{OPR}$ | 0 ~ +125 | °C |
| Storage Temperature Range | $T_{STG}$ | -65 ~ +150 | °C |

## Electrical Characteristics (KA7805/KA7805R)

(Refer to test circuit ,0°C < $T_J$ < 125°C, $I_O$ = 500mA, $V_I$ =10V, $C_I$= 0.33μF, $C_O$=0.1μF, unless otherwise specified)

| Parameter | Symbol | Conditions | | KA7805 Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|---|
| Output Voltage | $V_O$ | $T_J$ =+25 °C | | 4.8 | 5.0 | 5.2 | V |
| | | 5.0mA ≤ Io ≤ 1.0A, $P_O$ ≤ 15W<br>$V_I$ = 7V to 20V | | 4.75 | 5.0 | 5.25 | |
| Line Regulation (Note1) | Regline | $T_J$=+25 °C | $V_O$ = 7V to 25V | - | 4.0 | 100 | mV |
| | | | $V_I$ = 8V to 12V | - | 1.6 | 50 | |
| Load Regulation (Note1) | Regload | $T_J$=+25 °C | $I_O$ = 5.0mA to1.5A | - | 9 | 100 | mV |
| | | | $I_O$ =250mA to 750mA | - | 4 | 50 | |
| Quiescent Current | $I_Q$ | $T_J$ =+25 °C | | - | 5.0 | 8.0 | mA |
| *Quiescent Current Change* | $\Delta I_Q$ | $I_O$ = 5mA to 1.0A | | - | 0.03 | 0.5 | mA |
| | | $V_I$= 7V to 25V | | - | 0.3 | 1.3 | |
| Output Voltage Drift | $\Delta V_O/\Delta T$ | $I_O$= 5mA | | - | -0.8 | - | mV/ °C |
| Output Noise Voltage | $V_N$ | f = 10Hz to 100KHz, $T_A$=+25 °C | | - | 42 | - | μV/$V_O$ |
| Ripple Rejection | RR | f = 120Hz<br>$V_O$ = 8V to 18V | | 62 | 73 | - | dB |
| Dropout Voltage | $V_{Drop}$ | $I_O$ = 1A, $T_J$ =+25 °C | | - | 2 | - | V |
| Output Resistance | $r_O$ | f = 1KHz | | - | 15 | - | mΩ |
| Short Circuit Current | $I_{SC}$ | $V_I$ = 35V, $T_A$ =+25 °C | | - | 230 | - | mA |
| Peak Current | $I_{PK}$ | $T_J$ =+25 °C | | - | 2.2 | - | A |

**Note:**

1. 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.

## Electrical Characteristics (KA7805A)

(Refer to the test circuits. 0°C < $T_J$ < +125 °C, $I_o$ =1A, $V_I$ = 10V, $C_I$=0.33µF, $C_O$=0.1µF, unless otherwise specified)

| Parameter | Symbol | Conditions | | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|---|
| Output Voltage | VO | TJ =+25 °C | | 4.9 | 5 | 5.1 | V |
| | | IO = 5mA to 1A, PO ≤ 15W<br>VI = 7.5V to 20V | | 4.8 | 5 | 5.2 | |
| Line Regulation (Note1) | Regline | VI = 7.5V to 25V<br>IO = 500mA | | - | 5 | 50 | mV |
| | | VI = 8V to 12V | | - | 3 | 50 | |
| | | TJ =+25 °C | VI= 7.3V to 20V | - | 5 | 50 | |
| | | | VI= 8V to 12V | - | 1.5 | 25 | |
| Load Regulation (Note1) | Regload | TJ =+25 °C<br>IO = 5mA to 1.5A | | - | 9 | 100 | mV |
| | | IO = 5mA to 1A | | - | 9 | 100 | |
| | | IO = 250mA to 750mA | | - | 4 | 50 | |
| Quiescent Current | IQ | TJ =+25 °C | | - | 5.0 | 6.0 | mA |
| Quiescent Current Change | ΔIQ | IO = 5mA to 1A | | - | - | 0.5 | mA |
| | | VI = 8 V to 25V, IO = 500mA | | - | - | 0.8 | |
| | | VI = 7.5V to 20V, TJ =+25 °C | | - | - | 0.8 | |
| Output Voltage Drift | ΔV/ΔT | Io = 5mA | | - | -0.8 | - | mV/°C |
| Output Noise Voltage | VN | f = 10Hz to 100KHz<br>TA =+25 °C | | - | 10 | - | µV/Vo |
| Ripple Rejection | RR | f = 120Hz, IO = 500mA<br>VI = 8V to 18V | | - | 68 | - | dB |
| Dropout Voltage | VDrop | IO = 1A, TJ =+25 °C | | - | 2 | - | V |
| Output Resistance | rO | f = 1KHz | | - | 17 | - | mΩ |
| Short Circuit Current | ISC | VI= 35V, TA =+25 °C | | - | 250 | - | mA |
| Peak Current | IPK | TJ= +25 °C | | - | 2.2 | - | A |

**Note:**

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

# Typical Applications

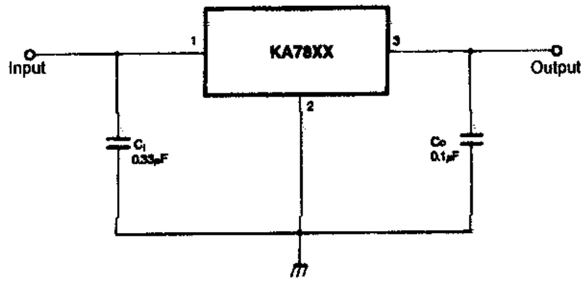



Figure 5. DC Parameters

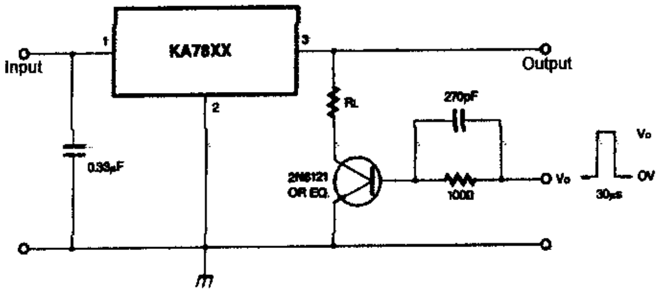



Figure 6. Load Regulation

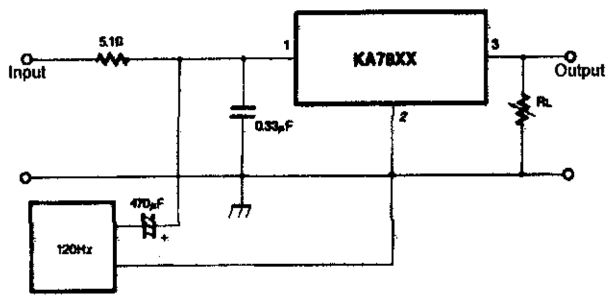



Figure 7. Ripple Rejection

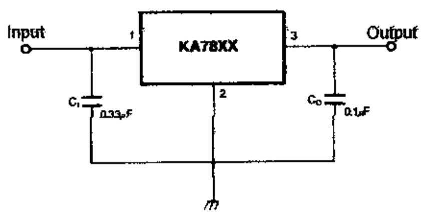



Figure 8. Fixed Output Regulator

# APPENDIX J

## DC FAN DATASHEET

| | |
|---|---|
| Socket Type | Socket 370, 462 |
| Heat Sink Dimension | 80x77x45 mm & Cu. Base |
| Heat Sink Material | Aluminum Extrusion fin with copper base |
| Fan Dimension | 80x80x32 mm |
| Fan Speed | 2,000 rpm |
| Fan Airflow | 32.5 CFM |
| Fan Air Pressure | 1.84 mm. H2O |
| Fan Life Expectance | 40,000 hrs |
| Bearing Type | Riffle Bearing |
| Voltage Rating | 7~13.2V |
| Noise Level | 20 dBA |
| Connector | 3 Pin |
| Weight | 420 g |
| Thermal Resistance | Rja 0.53573 C/W |
| Application | AMD XP Athlon 3400+ and higher |