COOLING/HEATING A CONFINED SPACE USING PELTIER EFFECT DEVICE

By

SITI BAHGIA ARIFFIN

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

____

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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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.

SITI BAHGIA ARIFFIN

ABSTRACT

The objective of this project is to design a confined space which can heat or cool the items as required. The mechanism used for cooling and heating is the Peltier Effect Device whereby a normal refrigerant (e.g. gases or water) as the thermal media is not used in the design. Peltier effect device are made of an N and P type semiconductors that are joined together by metal contact to form a junction that can perform cooling on one side while heating on the other side. The literature review aids better understanding of the project title. Analysis stage helps in problem solving thus decision making process. Tools identification is essential to determine the equipments and software needed in this project. The project is developed using a set of defined procedures and is illustrated more vivid in a logic flowchart. H-Bridge circuit analysis has been carried out with the calculated values of resistors in order to obtain the final working circuit. The temperature controller will consists of temperature sensor which is LM35 and microcontroller PIC 16F877. The coding of the PIC program has been finalize and programmed. Heat transfer calculation has also been calculated. The container that will be used for the prototype is 400ml thermos with double wall for temperature retention. The Peltier is attached at the lid of the container where a hole has been made. The temperature sensor is placed near the Peltier. Between the Peltier and the heat sink, thermal paste is applied evenly to help removing the heat faster. Then, a 12V fan is glued on top of the heat sink. This prototype can cool down to 10°C for cooling and go up to 60°C for heating.

ACKNOWLEDGEMENTS

All praises be to Allah S.W.T, The Most Gracious, The Most Merciful for His Guidance and Blessing. Without His blessing, I may not get to where I stand today.

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LIST OF ABBREVIATIONS

CFC	Chlorofluorocarbon
TEC	Thermoelectric cooler
LED	Light Emitting Diode
ROM	Read Only Memory
FYP	Final Year Project
PWM	Pulse Width Modulation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Not so long ago there appeared new cooling devices-semiconductor coolers which utilize the Peltier effect. The given effect was called after a French watchmaker, Jean Charles Athanase Peltier (1785-1845.), who discovered it in 1834. Peltier discovered that the passage of a current through a junction formed by two dissimilar conductors caused a temperature change. This device has a dual purpose: electric generation on one side and cooling/heating on the other. Cooling or heating is achieved by applying electric current. Thermoelectric materials have very attractive features such as small size, simplicity, efficiency, convenient and reliability [1]. Furthermore a thermoelectric micro cooler is a potential candidate for decreasing the operating temperature locally as well as absorbing the heat. The aim of this project is to design and construct a prototype of a confined space which can heat or cool item as required based on bulk semiconductor materials made from bismuth-telluride that is doped appropriately to make P or N type semiconductor-Peltier Effect Device. Such a device contains no moving parts or harmful refrigerants such as CFCs [1]. Without moving parts, thermoelectric coolers are inherently more reliable and require little to no maintenance. The lack of refrigerants carries obvious environmental and safety benefits. This also allows for the manufacture of tiny thermoelectric coolers making them most suitable choice for today's microelectronics. For this project, the Peltier Effect Device is used. The Peltier effect is the driving force behind the thermoelectric cooler or TEC for short. The Peltier Effect is caused by the fact that an electric current is accompanied by a heat current in a homogenous conductor even at constant temperature. Therefore, when an electric current passes through the junction of two dissimilar metals, a cooling or heating effect occurs. The desired direction of heat flow can be controlled by altering the direction of the current flows [4].

1.2 PROBLEM STATEMENT

This project undertakes to design a cooling/heating system of a small area of confined space whereby a normal refrigerant (e.g. gases or water) as the thermal media is not used. Instead, Peltier Effect Device is introduced for this cooling/heating of a confined space system. Peltier Effect Device uses thermoelectric concept in application.

The aim of this project is to design a confined space which is applicable in daily life, and to narrow down the scope, specifically in Malaysia. The suggested design is to make a prototype of a portable food container/confined space which can heat or cool items as required.

1.3 OBJECTIVE AND SCOPE OF STUDY

- To have a theoretical review on Peltier Effect Device, its function, advantages, disadvantages and application.
- To design and simulate the proper circuit for the thermoelectric circuit.
- To design and construct a prototype of a portable food container/confined space which can heat or cool items as required.

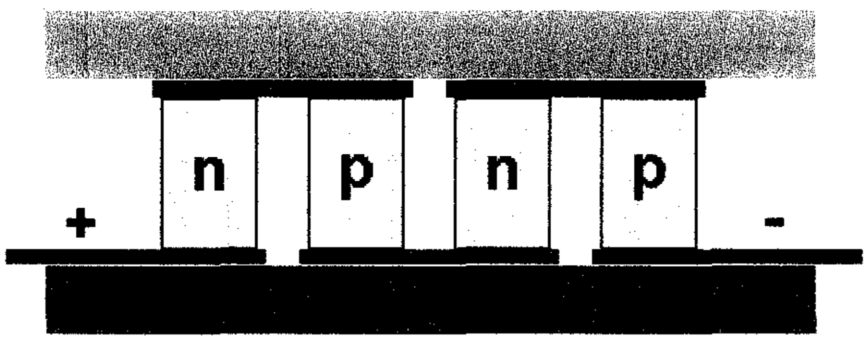
CHAPTER 2

LITERATURE REVIEW/THEORY

2.1 Peltier Devices

Peltier effect device are made of an N and P type semiconductors that are joined together by metal contact to form a junction that can perform cooling on one side while heating on the other side. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. *Figure 2.1* explains how this device works. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type) [1].

COLD



HEAT

Figure 2.1: Usage of semiconductors of p- and n-type in thermoelectric coolers.

Combination of many pairs of p- and n-semiconductors allows creating cooling units - Peltier modules of relatively high power as shown in *Figure 2.2*

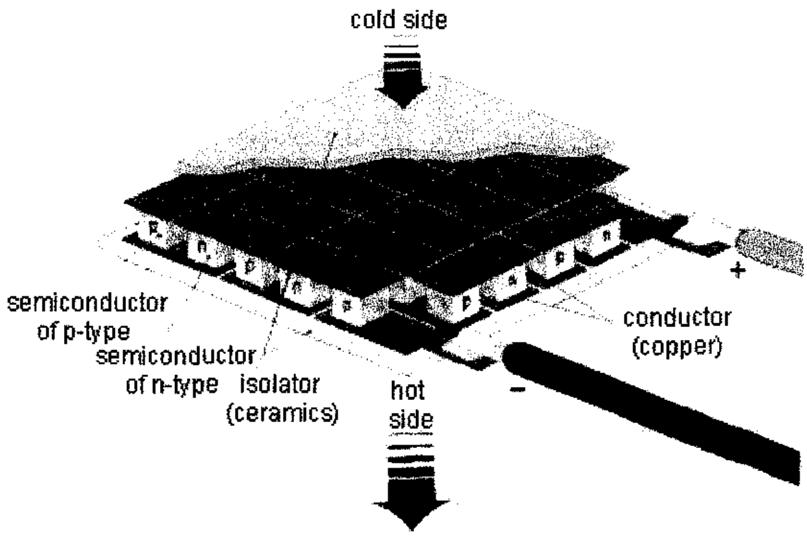


Figure 2.2: Structure of a Peltier module

When switching on the current of the definite polarity, there forms a temperature difference between the radiators one of them warms up and works as a heat sink, the other works as a refrigerator. In case of usage of semiconductors of p- and n- types the effect becomes more vivid.

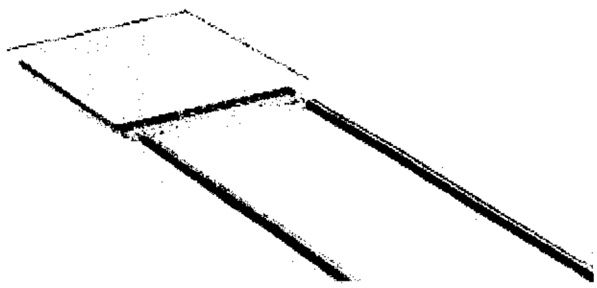


Figure 2.3: Peltier modules

A typical module as shown in *Figure 2.3* provides a temperature difference of several tens degrees Celsius. With forced cooling of the hot radiator, the second one can reach the temperatures below 0 Celsius. For more temperature difference the cascade connection is used as in *Figure 2.4*

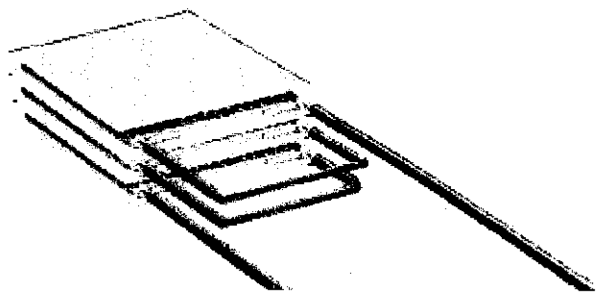


Figure 2.4: An example of cascade connection of Peltier modules

The cooling devices based on Peltier modules are often called active Peltier refrigerators or Peltier coolers.

Peltier modules are very reliable; they have not got any moving parts, unlike refrigerators constructed according to the traditional technology [2]. This technology is compact, totally integrated, and self-contained, and it offers exemplary performance. It solves problems with prior devices by creating a microscopic system that is robust and suitable for use in a variety of applications.

- **Versatile**: This device has fewer toxicity and flammability concerns, which allows use of alternate refrigerants that cannot used in existing systems. It can heat as well as cool.
- **Small and lightweight**: The unit is extremely compact and lightweight
- **Efficient**: The unit requires very low power.
- **Interconnectable**: Devices can be stacked to create a high-temperature lift system, to cool large-scale systems, and/or to function in applications requiring robust and/or redundant operation.
- **Lower cost**: The higher efficiency and lower power requirements of this device result in lower operating costs.

But despite all the mentioned advantages, Peltier modules have some specific features, which must be taken into account when using as a part of a cooling unit. The most important characteristics are:

- The modules, dissipating much heat, require the relative fans and heat sinks which would manage to carry off the heat effectively. We should notice that the thermoelectric modules have a quite low performance factor and they are themselves a powerful source of heat. The usage of these modules might cause overheating of the other components inside the system block. That is why it is necessary to install additional cooling systems inside the block. In case of the module's failure the cooler becomes isolated from the cooled element. It might lead to fast overheating of the latter.
- Low temperatures might cause moisture condensation. This might lead to short circuits between the elements. That is why you should use the modules of the optimal power. Moisture condensation depends on the temperature inside the system block, the temperature of the cooled device and air moisture. The warmer air is and the more moisture is, the condensation is more probable.

2.2 H-Bridge circuit

TEC control requires a reversible power source capable of providing positive and negative voltages. To accomplish this from a single supply, an H-bridge circuit can be used. H-bridge circuit can perform functions such as turn on, off and switching direction for purpose of cooling and heating of Peltier modules.

Based on clockwise and counterclockwise circuitry, H-bridge circuit uses Darlington power transistor to amplify the circuit provided to the connection connected to the thermoelectric and also to reduce cost and simplify the circuit. Forward losses are typically 1 to 2 volts, and since the current must pass through two transistors, expect losses to total up to 4 volts at a maximum current. The 4 Darlington transistors need to be heat sunk based on the expected current and duty cycle.

2.2.1 Voltage Regulator

A voltage regulator LM7805 is used in this circuit to step down the supply voltage from 12V to 5V. Voltage regulator is the best alternative to step down the supply input voltage compared to voltage divider method since it can reduce the number of components used and produce more precise output. A voltage regulator has only three legs and appears to be a comparatively simple device but it is actually a very complex integrated circuit. Voltage regulators are very robust. They can withstand over-current draw due to short circuit and also to over heating. In both cases, the regulators will shut down before damage occurs. The only way to destroy a regulator is to apply reverse voltage to its input.

2.2.2 Transistor

In order to make the Peltier to act as a cooler or heater, the circuit must be constructed in forward and reverse connection. The H-bridge connection is the most appropriate circuit for this type of condition. It is because the transistor acts as a switch in clockwise and counter clockwise connection. Figure 2.5 shows the bipolar junction transistor.

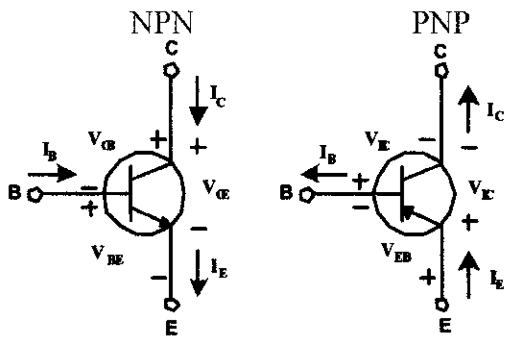


Figure 2.5: BJT Transistor

The work of the transistor as a switch will be used to control the thermoelectric device in two-direction circuit. The transistor is a three-layer semiconductor device consisting two N- and one P- or two p- and n-type layer of material. The former is called an NPN transistor, while the latter is called the PNP transistor. For the biasing, the terminals have been indicated as emitter, collector and base. To show the calculation, by applying Kirchoff's law we obtain

$$I_E = I_C + I_B \tag{2.1}$$

The important basic relationship for a transistor

$$\left.\begin{aligned} V_{BE} &= 0.7V \\ I_C &= (\beta+1)I_B \cong I_C \\ I_C &= I_B \end{aligned}\right\} \tag{2.2}$$

Figure 2.6 shows fixed bias circuit on the transistor. When a current is provided to the collector, and to the base, it will act as a switch.

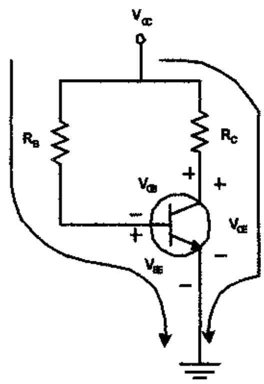


Figure 2.6: Fixed bias circuit

Forward bias of base emitter

$$\left.\begin{aligned} V_{CC} - I_B R_B - V_{BE} &= 0 \\ V_{CE} &= V_{CC} - I_C R_C \\ I_B &= \frac{(V_{CC} - V_{BE})}{R_B} \\ V_{CE} &= V_C - V_E \end{aligned}\right\} \tag{2.3}$$

Collector emitter loop for the use of the transistor

$$\left.\begin{aligned} &V_{CE} = V_C \\ &I_c = \beta I_B \\ &V_{BE} = V_B - V_E \\ &V_{CE} + I_C R_C - V_{CC} = 0 \\ &V_{BE} = V_B \end{aligned}\right\} \quad (2.4)$$

For the transistor to act as a switch, the transistor will be open and close like a switch. The transistor is in the cutoff region when the base-emitter junction is not forward bias. Neglecting leakage current, all the current are zero and V_{CE} is equal to V_{CC}. The saturation will make the current flow to the transistor and act as a close switch. When the base emitter junction is forward bias and there is enough base current, the transistor is saturated. The formula for collector saturation current is

$$I_{C\,sat} = \frac{V_{CC} - V_{CE\,sat}}{R_C} \quad (2.5)$$

Since V_{CEsat} is very small compared to V_{CC}, it can usually be neglected. The minimum value of base current needed to produce the saturation is

$$I_{B\min} = \frac{I_{Csat}}{\beta DC} \quad (2.6)$$

I_B should be significantly greater than $I_B$min to keep the transistor well in saturation. Figure 2.7 shows the connection on Darlington transistor. Darlington transistors amplify the current by amplifying the gain.

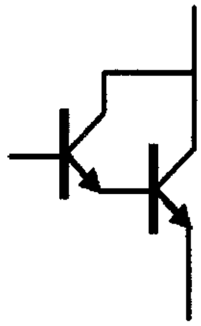


Figure 2.7: Darlington transistor

A single transistor permits the small current from a logic gate (such as an output of a microprocessor) to control a much higher current. A "Darlington pair" (two transistors connected as shown) can deliver an even higher output current. The Darlington have gain twice the normal transistor

$$\beta_{total} = \beta_1 \times \beta_2 \tag{2.7}$$

Table 2.1: Truth table of H-Bridge circuit

Input		Output	
A	B	A	B
0	0	Float	
1	0	1	0
0	1	0	1
1	1	1	1

Table 2.1 shows the logic use in the thermoelectric circuit. When switch A input is given, the output A will be out. When the switch B input is given, the switch A will be closed and the output B will be produced. The connection of the H-Bridge circuit is shown in Figure 2.7:

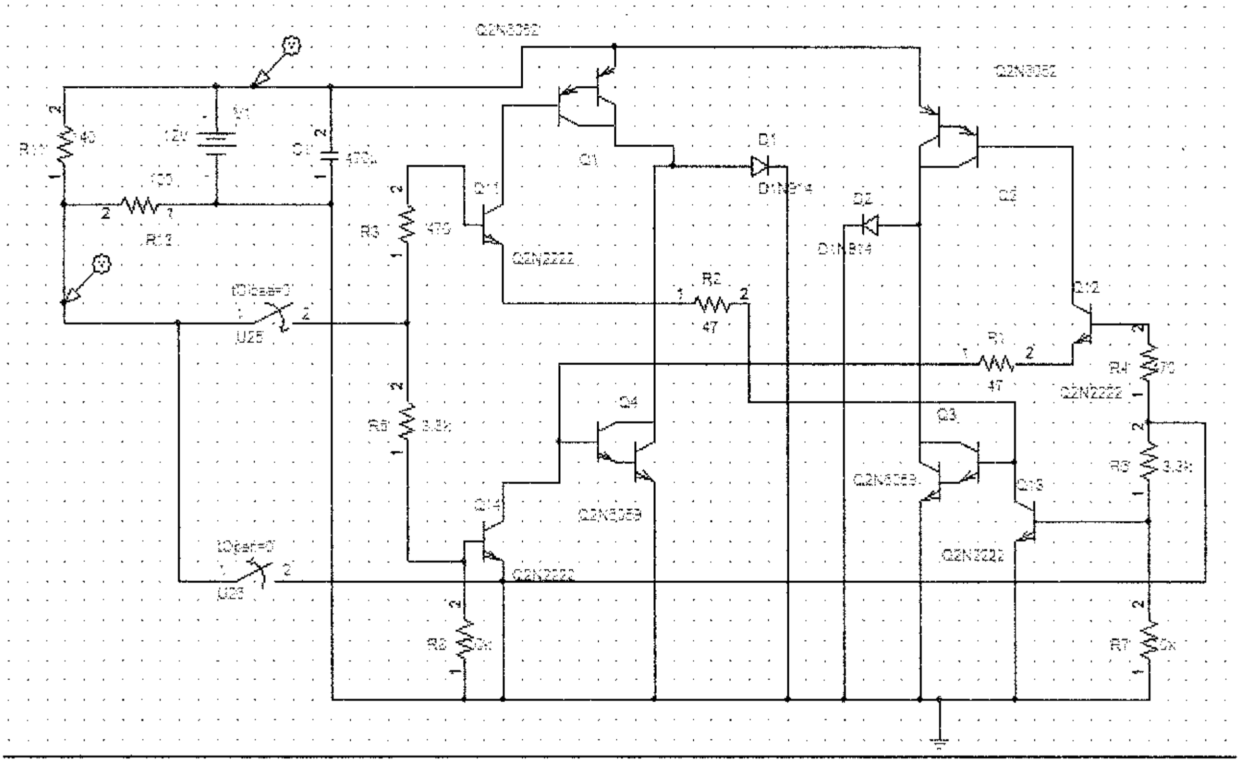


Figure 2.7: H-Bridge circuit

From Figure 2.7, operation with logic signals greater than the peltier supply voltage is allowed and absorbed by R7 and R8. The circuit is really intended to be operated with CMOS logic levels, logic high being about 4 volts.

Transistor Q1,2,3 and 4 must be heatsunk. Insulators shoud be used, or two separate heatsinks isolated from each other and the rest of the world. Note that Q1 and Q3 are grouped together and share common collectors and can share a heatsink. The same is trus for Q2 and Q4.

2.3 Temperature controller

The temperature controller will consist of temperature sensor and microcontroller. In order to control the peltier to the desired temperature, microcontroller is used in this project. The temperature sensor LM35DZ will sense the heat and send it as voltage signal to the microcontroller. When the temperature is still at given range that is between 10°C to 60°C, the PIC will send an appropriate voltage the H-Bridge circuit to drive the peltier in clockwise direction or counterclockwise. Every 1°C, 10mV will be produced inside the temperature sensor. The temperature will increase the voltage output from room temperature 27°C until 60°C in hot mode and from 27°C until 10°C in cold mode.

2.3.1 Temperature Sensor

The LM35 series are precision integrated circuit temperature sensors, whose output voltage is linearly proportional to the Celcius (Centrigade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as user is not required to substract a large constant voltage from its output to obtain convenient Centrigade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ± 1/4°C at room temperature and ± 3/4°C over a full -55°C to +150°C temperature range.

2.3.2 Microcontroller

Microcontrollers can be programmed either in C language or assembly language. In this project C language is used. The major advantage of this language is that it is less complex and easy to maintain compared to assembly language.

Microcontroller is programmed using the CCS compiler. This compiler generates native machine code which can directly be loaded into the memory of the target microcontroller. The CCS compiler is used to compile the program using C language.

2.3.3 Clock Generator-Oscillator

Oscillator is used for providing a microcontroller with a clock. Clock is needed so that microcontroller could execute a program or program instructions. PIC16F877 can work with four configurations of an oscillator. In this project the XT oscillator is used to control the frequency of the microcontroller. This is important because we need to mention the type of oscillator when buying a microcontroller.

2.4 Heat Transfer Calculation

The flow of heat by conduction 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

$$q = hA(T_w - T_\infty) \qquad (2.8)$$

Where h = heat transfer coefficient, A = unit area, T_w = surface temperature, T_∞ = 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 amount 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 has to be removed from the system is obtained from the following equation;

$$Q_{cooling} = mC\Delta T \qquad (2.9)$$

Where m = mass, C = specific heat of the item to be cooled, ΔT = temperature difference. Using the value of heat to be removed, the cooling rate is

$$Q_{cooling} = \frac{Q_{cooling}}{\Delta T} \qquad (2.10)$$

Where Δt 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 the system takes to change the temperature of an object. The duration can be known from the equation;

$$t = \frac{m \times C_p \times \Delta T}{q} \tag{2.11}$$

Where m = mass, C_p = specific heat of material (J / kg . K), ΔT = temperature difference (K), q = heat removed (W).

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project Planning

The project will be developed using a set of defined procedures indicated in *Figure 3.1*. The project consists of 5 major stages. On the first stage, brainstorming is conducted in planning stage. Literature reviews and suitable devices are chosen on the analysis stage. The design stage is to verify a suitable prototype for this project. If the performance of circuit is not acceptable in the simulation stage, the circuit will be analyze and modified until the final approach can be conducted. The implementation of the prototype is the final stage in this project.

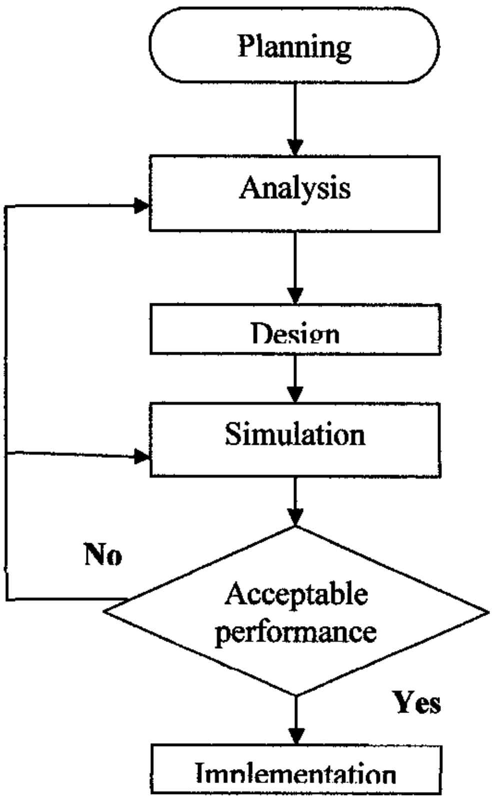


Figure 3.1: Methodology flow diagram

3.2 Planning

A lot of information gained in this process helps a lot in the progress of the design. The advancement of this project is done by weekly basis as can be seen in the attached Gantt chart.

3.3 Analysis

Problem analysis and data gathering is a continuation stage of preliminary research. The identified problem is analyzed at this stage. Data gathering offers better understanding and help in problem solving as well as decision making process. At this stage, the author is able to determine the tools required for the development process and also chooses the suitable devices for the project. The example of templates from the existing design is studied to come out with the conceptual design of the prototype.

3.4 Design

The design of H-bridge circuit is done using the p-spice. The temperature controller is using the programmed PIC 16F877. Figure 3.2 shows the working procedure of the thermoelectric circuit based on the temperature process of the project.

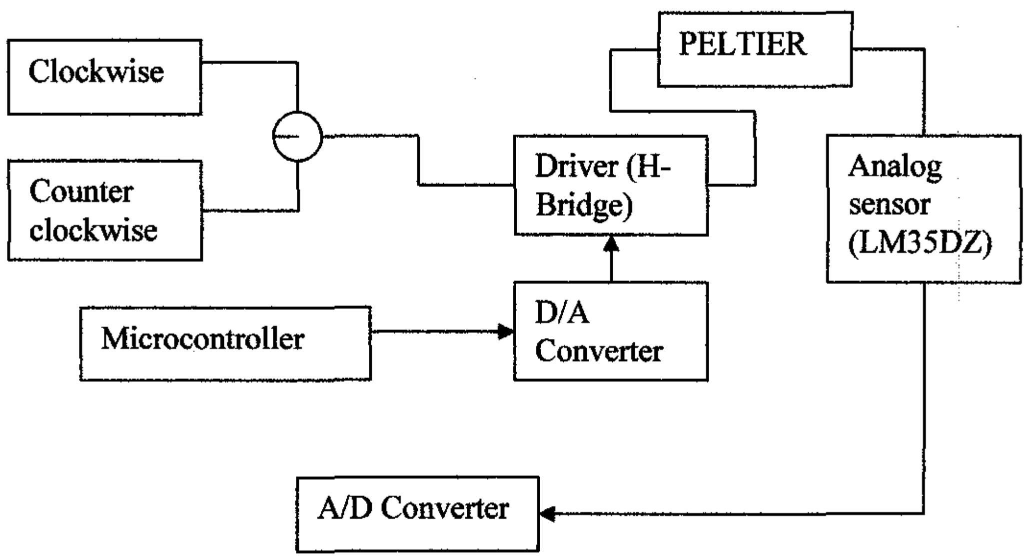


Figure 3.2: The temperature process

The driver of the circuit is the H-Bridge circuit which will be controlled by the user whether clockwise or counterclockwise position. The driver will make the peltier device work. The temperature sensor will sense the temperature using LM35 that will send the heat as voltage signal to the microcontroller. The microcontroller will interpret the analog signal and convert it to the digital signal to control it. The microcontroller will change it back to analog and make sure the driver interrupted by sending signal to be stop automatically when the heater reach appropriate heat.

The design stage will be implemented when all the simulation have worked properly. Table 3.1 shows the list of hardware used for the implementation of thermoelectric cooler or heater.

Table 3.1: List of Hardware and Software requirement.

	Hardware requirement	**Software requirement**
1.	Printed Circuit Board(PCB)	Electronic Workbench(EWB)
2.	Microcontroller(PIC16F877)	P-spice
3.	Crystal Oscillator	Multism
4.	Peltier	CCS Compiler- Microchip PIC C programming software
5.	LM35DZ temperature sensor	WARP-13/Bumble-bee – Microchip PIC Programmer
6.	Resistors, capacitors, fan, heat sink, thermal paste, transistors	

3.5 Simulation

3.5.1 H-Bridge Circuit

The H-Bridge circuit is designed and simulate in the P-Spice software. The concept of it is the circuit is designed so that it can receive two types of power supply assigned by the user.

For positive voltage, the peltier will act as the cooler as the heat will be sink. The semiconductor will absorb heat and leave the plate cool. For simulation, instead of using the Peltier, the author has changed it into LED for easier simulation. The first LED will be on and the second LED will be off.

For negative voltage, instead of sinking the heat, the peltier will produce heat. As it produces heat, it will make the plate hot instead of cold. For simulation, the second LED will be on and the first LED will be off.

3.5.2 Temperature Control Circuit.

The temperature control circuit will be using PIC16f877. The PIC has the built in analog to digital converter. PIC program can be loaded up on the computer and the program can be written on it. When writing is finished, it is ready to be assembled. This converts what have been written into a series of numbers, which the computer understands and will be able to use finally 'blow' the PIC. This new program consisting solely of numbers is called the hex code or hex file. The complicated PIC language is all a raw program consists of numbers. So, the assembler, a piece of software which comes with WINASM translates the words into numbers.

If it fails to recognize one of the 'words' then it will register an error which are definitely wrong. It may register a warning, which is something that is probably wrong. The other thing it may give is a message something which isn't wrong, but shows it has had to think a little bit more than usual when 'translating' that particular line.

Once the program has been assembled into a series of numbers, they get fused into ROM (Read Only Memory) of the PIC when we blow the PIC16f877 and they stay there until we erase it from the PIC.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Peltier Effect Device Analysis

Experiments have been conducted through the first semester of FYP to observe the characteristics of the Peltier Effect Device.

Figure 4.1 shows the result of the hot side test of the Peltier modules.

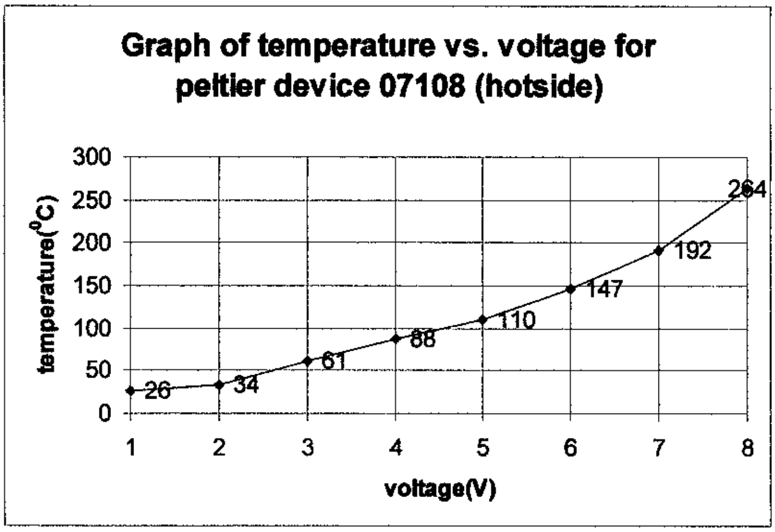


Figure 4.1: Graph Showing the Result of the Hot Side Surface

From the graph we could see that the temperature of the Peltier's surface increases as the voltage applied increases. Figure 4.2 shows the graph of cooling surface of the Peltier.

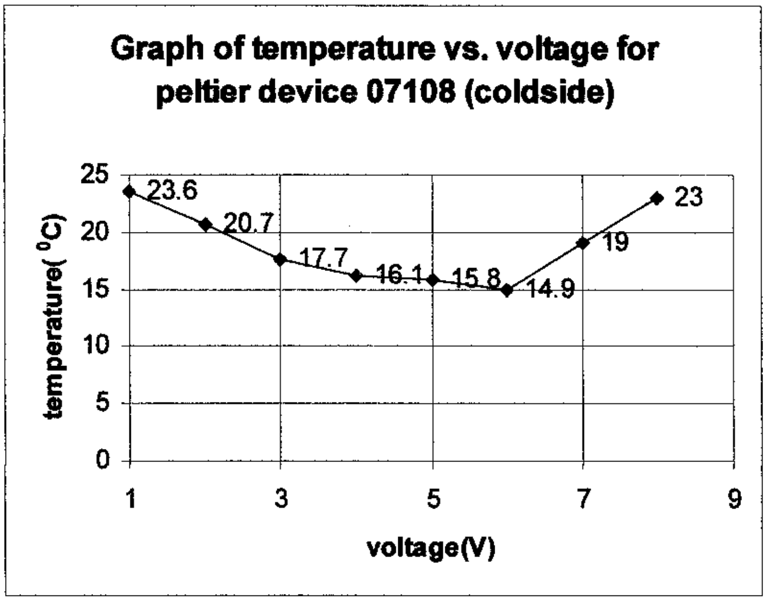


Figure 4.2: Graph Showing the Result of the Cold Side Surface

For measuring the cold side surface, the supply power should be in reverse polarity. However, while doing the experiment, a linear graph like the hot side is not obtained. As the voltage increases, the temperature also cooling down but at certain point (at approximately 4V), the temperature started to rise again. The possibility of this incident happens is maybe due to the fact that this experiment is not conducted in a confined space since we already knew that one Peltier could only cool a small area of confined space. Another possibility is might be because heat sink is not used in this experiment.

Thus, the author realized that cooling fan and heat sinks should be used in the design of the prototype. Although heat sink and cooling fan is used, if the heat sink is not glued to the Peltier with heat compound or heat paste, the is also no much different in the result. This is because the transfer of heat is not effective enough. A bigger cooling fan with more power cooling and also bigger heat sink and heat paste are needed for the Peltier cooler. The separation of the hot and cold side is vital for Peltier cooler. Figure 4.3 and 4.4 below shows the effect of using small and big heat sinks.

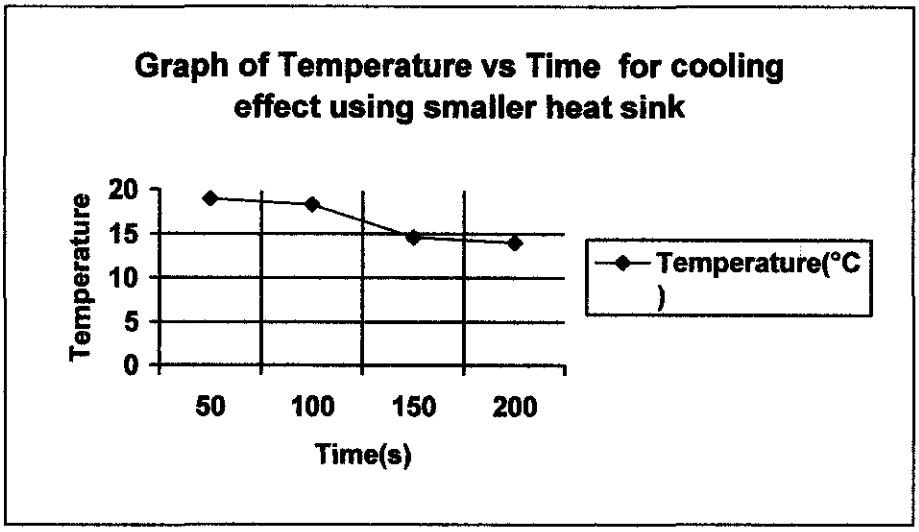


Figure 4.3: Graph showing the cooling effect using smaller heat sink

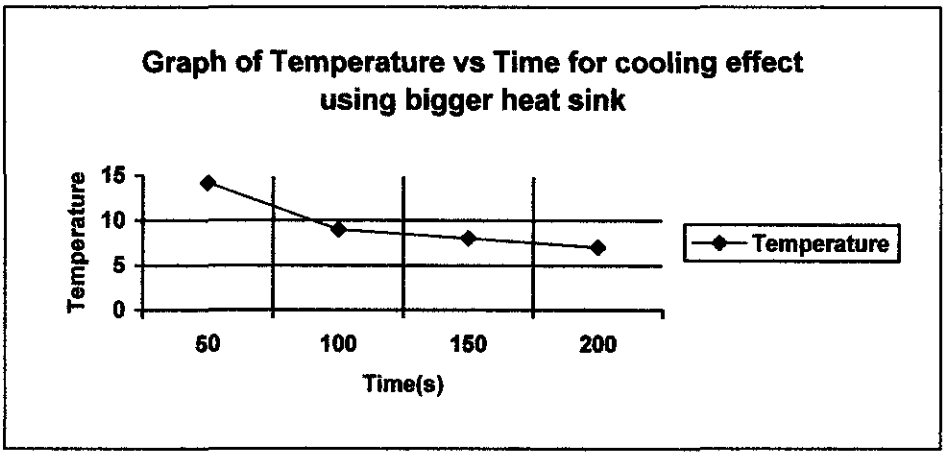


Figure 4.4: Graph showing the cooling effect using bigger heat sink

Based on the result, we could see that by using bigger heat sink with the same fan used, we could increase the effectiveness of cooling effect.

4.2 H-bridge Circuit Analysis

The Peltier has 2 functions which are to operate as cooler and as heater. The H-Bridge circuit is used to control the output of the Peltier module. This circuit is supplied with the 12V. The H-Bridge is set up so that the output voltage can be turned on and off and also to switch the directions with the control of two logic bits.

The circuit uses Darlington power transistors to reduce cost. The function can be seen on Table 4.3. When input A is given, the output from the circuit will be shown in output A by indicating the LED red as in hot mode. If the input A is closed and the input B switch on, the output B will be produced as in cold mode by indicating the green LED.

Table 4.1: H-Bridge circuit logic

Input A(switch 1)	Input B(switch 2)	Output A(D1)	Output B(D2)
0	0	0	0
0	1	0	1(cold)
1	0	1(hot)	0
1	1	nil	nil

In order to reach the resistor value that could satisfy the H-Bridge circuit, the transistor condition in saturation are calculated. From the load line analysis graph, at Q-point it shows that the I_B min is about 64.13μA. From the Q-point the maximum resistor that can be hold in the circuit is lower than 67K. Therefore the resistor chosen is 10K, 3.3K and 47ohm. The resistor chosen satisfied the voltage and current need to control the Peltier device.

In order to use different voltage in one power supply, a voltage regulator is used. The supply voltage 12V will be stepped down to 5V for the microcontroller input. Figure 4.2 shows the constructed H-Bridge schematics.

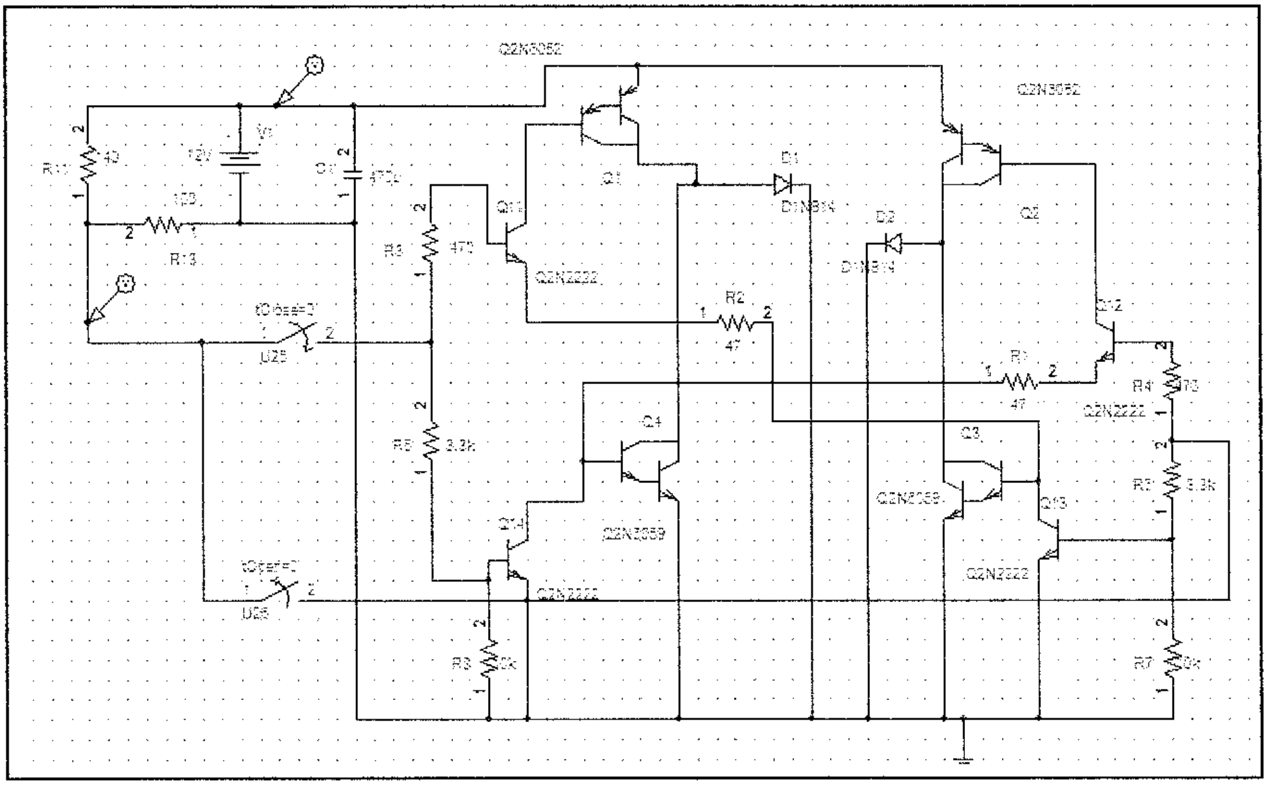


Figure 4.5: H-Bridge schematic

4.2.1 H-Bridge Simulation

<u>HEATING</u>

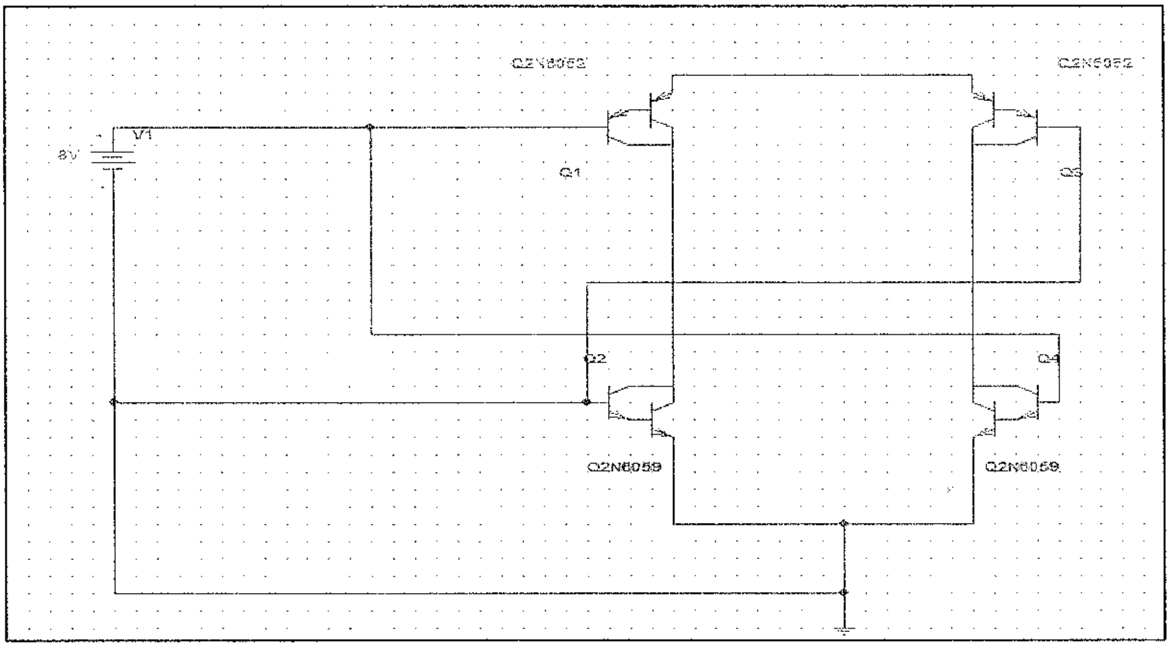


Figure 4.6: Forward polarity for Q1 and Q4, reverse polarity for Q2 and Q3

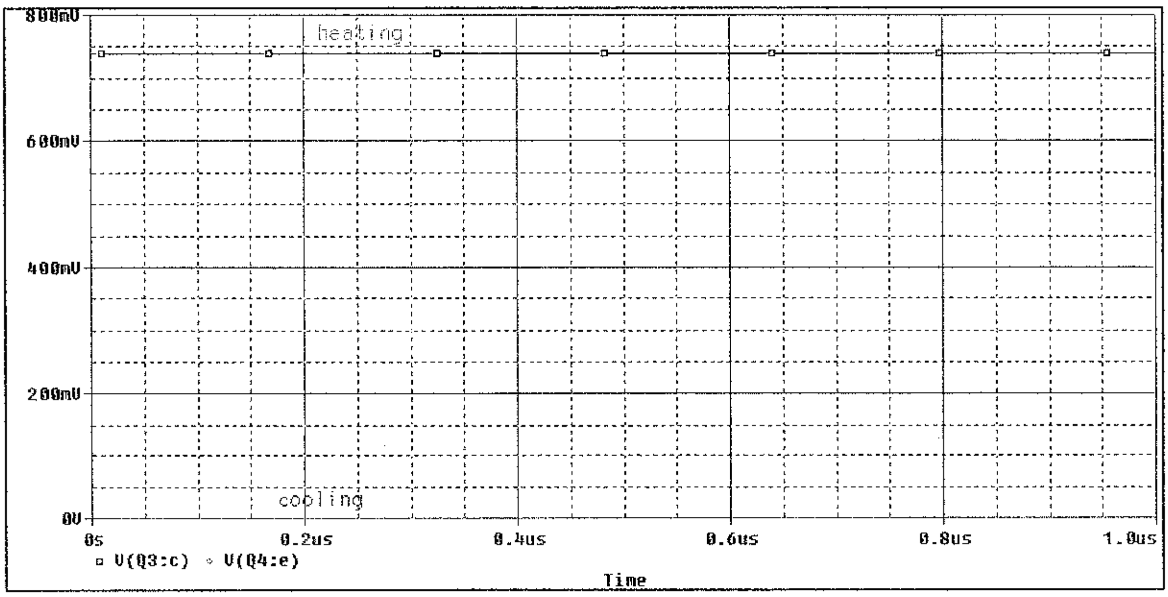


Figure 4.7: Graph of voltage versus time for both above circuits

COOLING

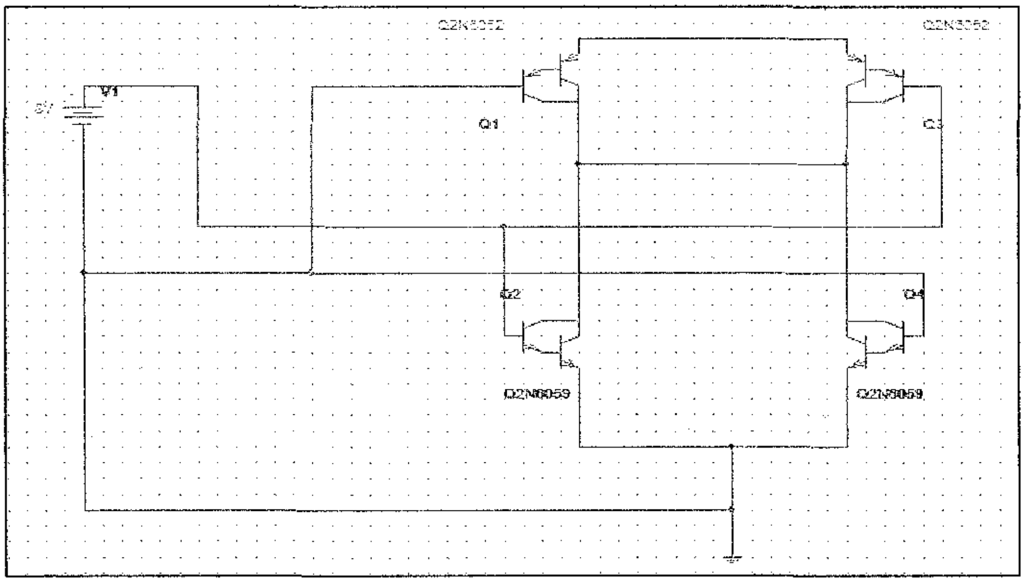


Figure 4.8: Forward polarity for Q2 and Q3, reverse polarity for Q1 and Q4

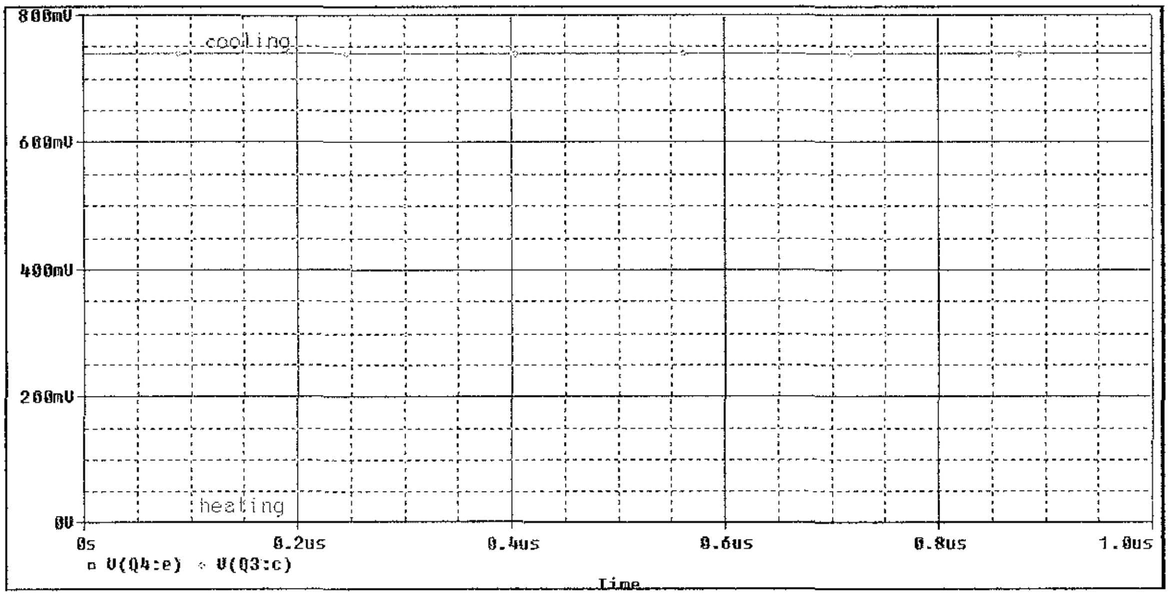


Figure 4.9: Graph of voltage versus time for both above circuits

4.3 Microcontroller

The working inside the PIC will be shown in flow diagram of *Figure 4.12*

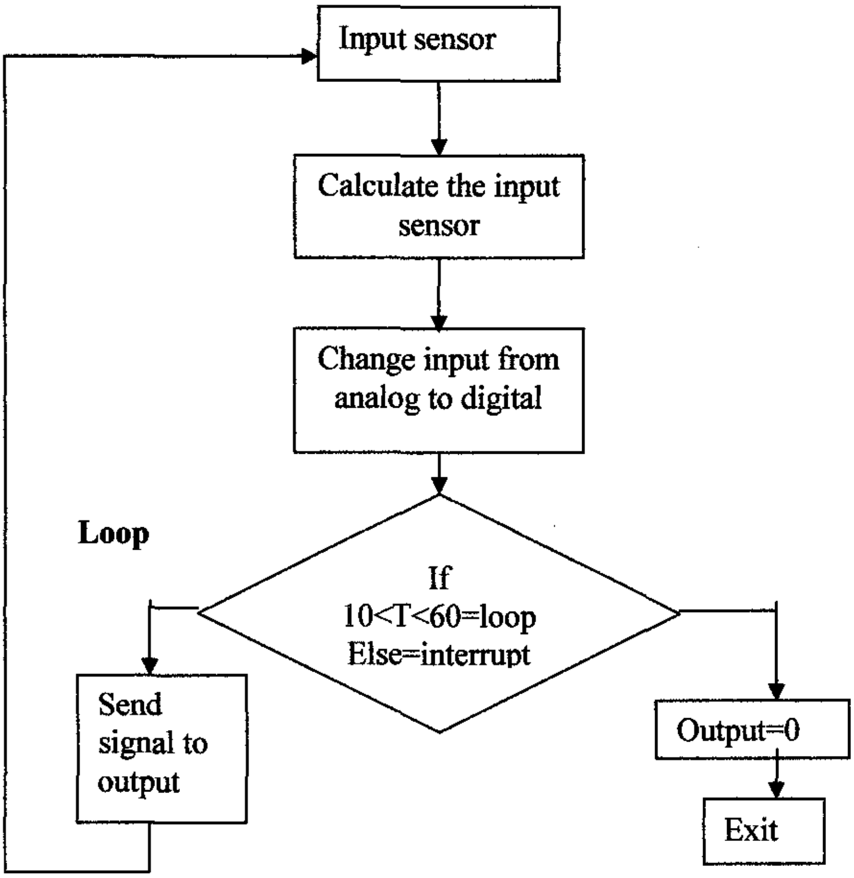


Figure 4.10: Microcontroller flow diagram

PIC 16F877 provides two PWM outputs, known as CCP1 (pin 17) and CCP2 (pin 16). The PWM output CCP1 and CCP2 (pin 16). The PWM output CCP1 is controlled using timer 2 and register PR2, setup time by division 2, CCP_1_low, setup ADC ports. The period of the PWM outputs CCP1 is set by loading value into register PR2 and then selecting a clock multiplier value of either 1,4 or 16 PWM period is set by PWM period= (PR2 + 1) x 4 x Tosc (clock multiplier) where Tosc is the microcontroller clock period (0.25μs with a 4 MHz crystal oscillator). In this project, the clock multiplier chosen is 4. PWM period= (294+1) x 4 x 0.25 x 4. The PWM mode is enabled and the clock multiplier is set to 4. The PIC will detect the interrupt time as in the voltage from the temperature sensor.

The working of the program starts when the circuit is on. The temperature sensor will sense the heat from the thermoelectric and send the signal to PIC16F877. The PIC will translate the analog to digital signal to control the circuit. When the temperature has been detected, exceeded or lower, the PIC will be interrupted and will be off to restart. *Figure 4.9* shows the 8-bit binary input from the sensor. The analog input will be divided to 256 to convert to digital input in 8 binary. Every bit will consists of 2.34 mV signal send in. If the signal is more than 100mV and less than 600mV, the H-Bridge circuit will be on.

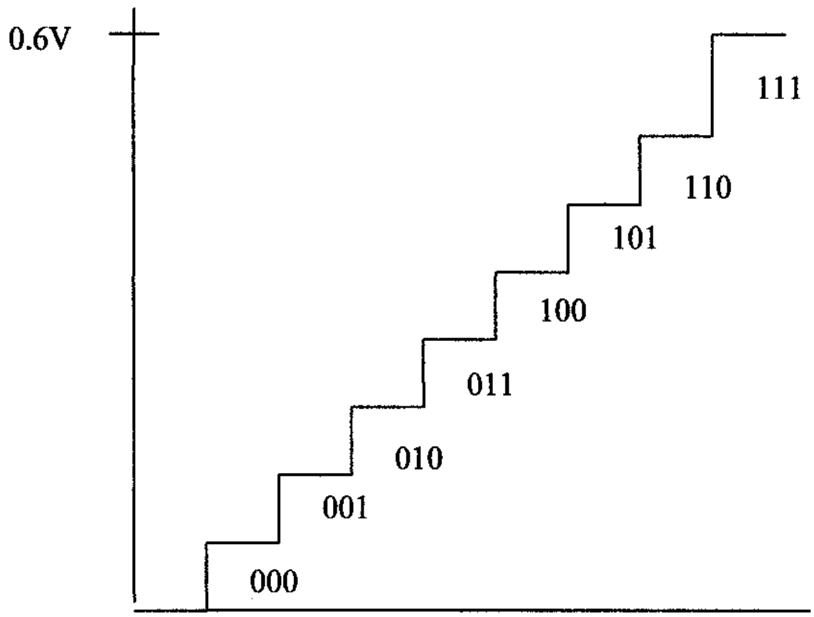


Figure 4.11: 8 bit binary input from the sensor.

The digital input from the microcontroller will be send to H-Bridge circuit to switch on the circuit. As the voltage and current from the microcontroller is low, in order to amplify the output power from the microcontroller, a darlington transistor is used by applying 5V from the circuit. The final program of the microcontroller is shown in *Appendix A*.

4.4 Final Circuit

The final circuit of this project contains of 2 parts which are the H-Bridge circuit and the controller circuit. The circuits are as shown in Figure 4.10 and Figure 4.11 below;

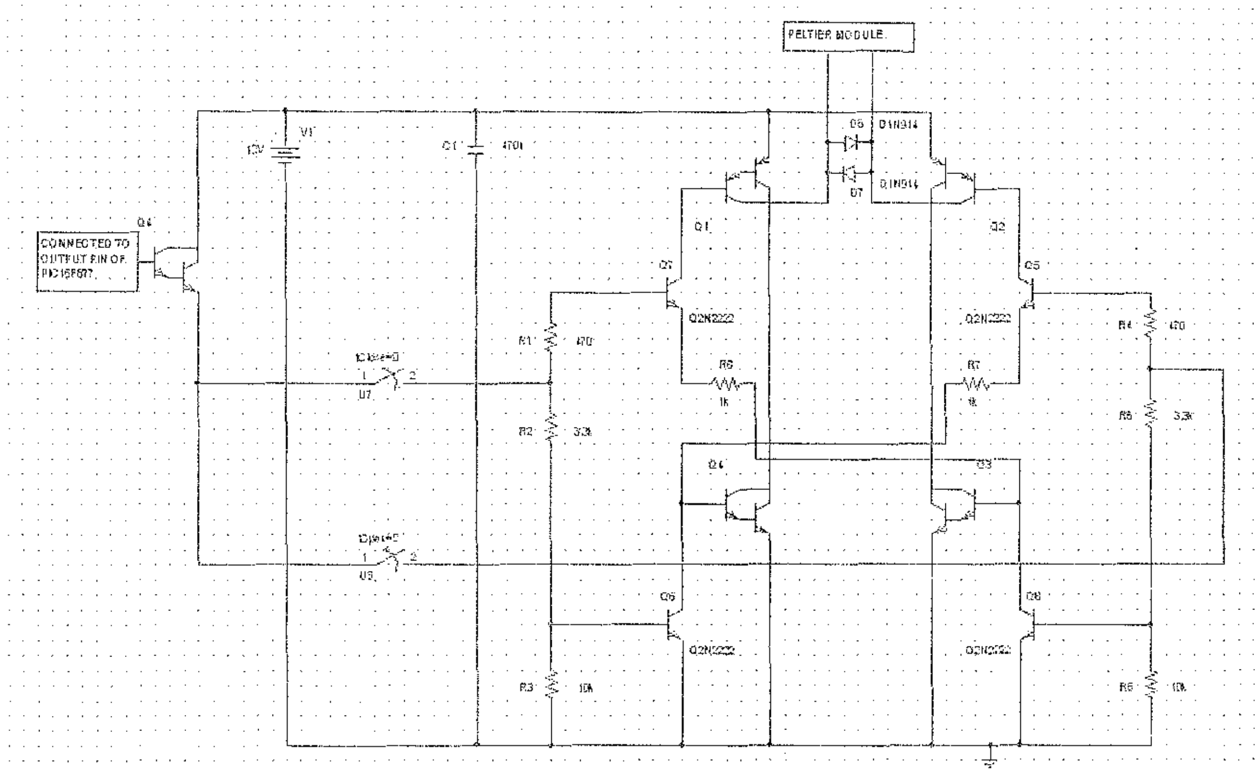


Figure 4.12: Final circuit of H-Bridge circuit

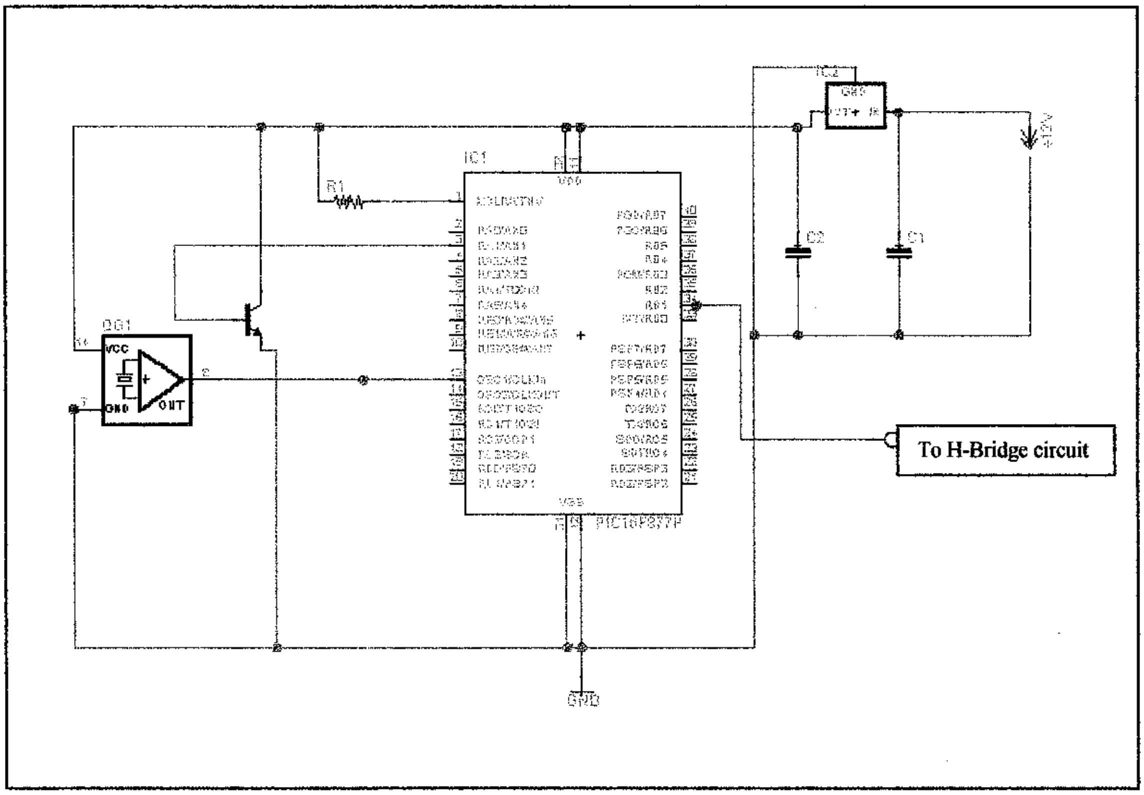


Figure 4.13: Final circuit of controller circuit

4.5 Heat Transfer Calculation

4.5.1 *Calculation of Cooling Rate of the Peltier*

Assumption: The heat through the walls is negligible during operation

Properties of the system: Peltier's surface temperature, $T_W = 10°C$, Ambient temperature, $T_s = 30°C$

Properties of items to be cooled off (assume air at constant temperature)

Volume, v = 0.4*l* = 0.399947 x 10^{-3} m^3, Density, p = 1.2kg / m^3, Specific heat, Cp = 1.005 kJ / kg. °C, Mass, m = pv = 4.799364 x 10^{-4} kg

The cooling rate of the system is equal to the rate of decrease of energy in the air. Heat to be removed from the system is;

$$Q_{cooling} = mC\Delta T = 0.0096467kJ$$

$$Q_{cooling} = \frac{Q_{cooling}}{\Delta t} = 0.107186Js^{-1}$$

Where Δt is the time taken to change temperature of the space from 30°C to 10°C (90s from one experiment).

4.5.2 *Calculation of Heat Transfer of the Peltier*

Properties of the Peltier Device:Heat transfer coefficient of the Peltier, $h_{peltier}$ = 28 W / m^2 . °C, Surface area of the Peltier, A= 0.9 x 10^{-3} m^2

Temperature:Peltier surface's temperature, T_w = 10°C, Ambient temperature, T_∞ = T_s= 30°C

Therefore, heat produced by the system is

$$q = hA(T_w - T_\infty) = 0.504W$$

4.6 Hardware of the prototype

The container that will be used for the prototype is 400ml thermos with double wall for temperature retention. A suitable glue that can withstand heat until 60°C is used to attach the Peltier to avoid the glue from melting during the heating operation. The Peltier is attached at the lid of the container where a hole has been made. The temperature sensor is placed near the Peltier. Between the Peltier and the heat sink, thermal paste is put evenly to help removing the heat faster. Then, a 12V fan is glued on top of the heat sink. Figure 4.16 shows the construction of the prototype.

Figure 4.14: The construction of the prototype

CHAPTER 5

CONCLUSIONS & RECOMMENDATION

5.1 Conclusions

This project is a design of a cooling or heating of a confined space using Peltier Effect Device. It is conducted basically to make Peltier Device applicable in daily life. It can be used for various purposes, such as Clothing cooling systems (e.g., chemical warfare suits), packaging (e.g., food, blood, organ transport; medical specimens), medical wraps (e.g., injury or burn treatment), electronic circuitry (e.g., cooling of microelectronic components), military (e.g., disguise of heat signatures for equipment or personnel to reduce detectability), automobiles, manufacturing, instrumentation, space systems and fire fighting. The prototype can cool down up to 10°C for cooling and go up to 60°C for heating. This project requires lots of knowledge in Peltier Effect Device and simulating software. This project has been accomplished according to the time fame. The Gantt Chant for this project has also been set (*refer to Appendix B*).

5.2 Recommendation

- Devices could be stacked (cascaded) to create a high-temperature lift system, to cool large scale systems, and/or to function in applications requiring robust and/or redundant operation.
- Cooling system should be improved to reduce heat faster for large-scale system and improve efficiency.

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[15]NanoThermal Partnership, Europe

APPENDICES

APPENDIX A

PIC PROGRAM

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

float adcValue, voltage;

void main()
{


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

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

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

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


          if(adcValue >= 25 || adcValue <= 5) //adcValue : 25 = 65 degree celcius and 5 = 10
degree celcius
          output_low(pin_B1);
          else
          output_high(pin_B1);



    }
}
```

APPENDIX B (i)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		■	■											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report			●											
4	Project Work				■	■	■	■							
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report								●						
6	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft												●		
8	Oral Presentation													●	
9	Submission of Interim Report														●

● Suggested milestone

■ Process

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

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	-Practical/Laboratory Work														
2	Submission of Progress Report 1			●											
3	Project Work Continue				■	■	■	■							
	-Practical/Laboratory Work														
4	Submission of Progress Report 2								●						
5	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
6	Submission of Dissertation Final Draft												●		
7	Oral Presentation													●	
8	Submission of Project Dissertation														●

● Suggested milestone

■ Process

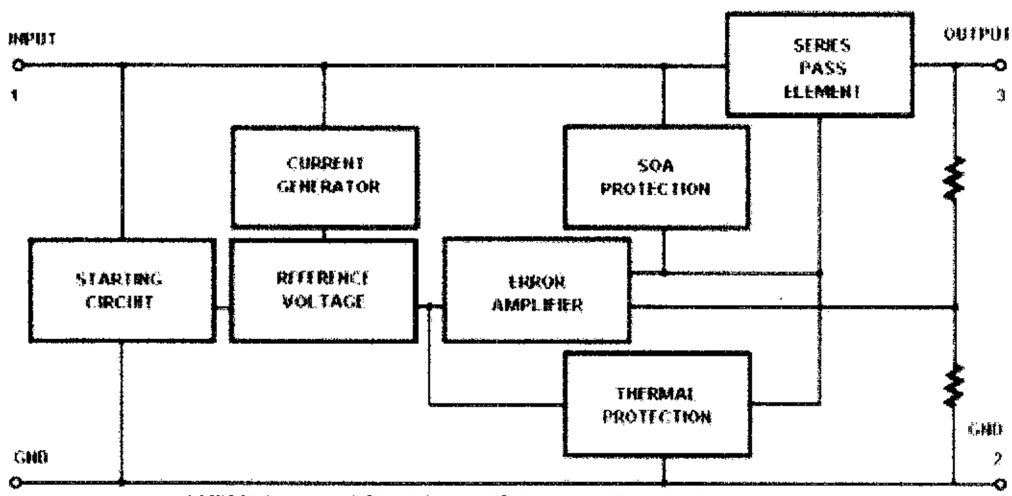
APPENDIX B (ii)

APPENDIX C

VOLTAGE REGULATORS

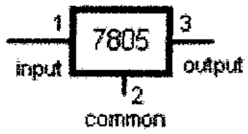
A Voltage Regulator (also called a "regulator") has only three legs and appears to be a comparatively simple device but it is actually a very complex integrated circuit. A regulator converts varying input voltage and produces a constant "regulated" output voltage. Voltage regulators are available in a variety of outputs, typically 5 volts, 9 volts and 12 volts. The last two digits in the name indicate the output voltage.

Name	Voltage
LM7805	+ 5 volts
LM7809	+ 9 volts
LM7812	+ 12 volts
LM7905	- 5 volts
LM7909	- 9 volts
LM7912	- 12 volts



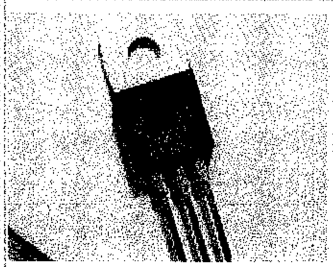
LM7805 Integrated Circuit Internal Schematic - Fairchild Semiconductors

The "LM78XX" series of voltage regulators are designed for positive input. For applications requiring negative input the "LM79XX" series is used.

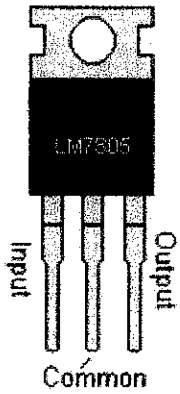


Symbol for a Voltage Regulator.

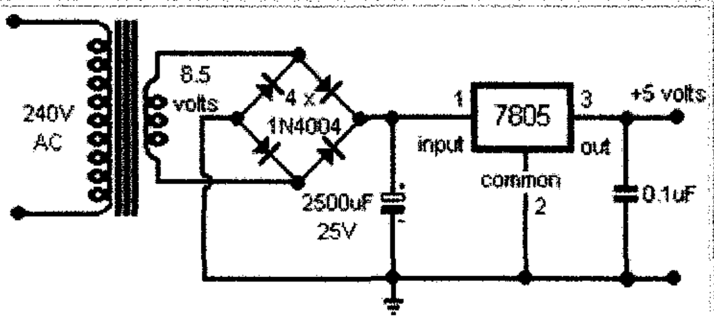
This device looks like a Transistor, but it is actually a complex Integrated Circuit.



A LM7805 Regulator



The circuit diagram below represents a typical use of a voltage regulator.



The LM7805 can reliably deliver 1 amp at a constant voltage.

How it Works:

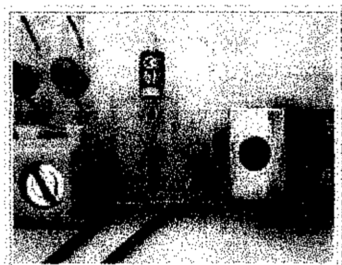
The transformer drops the 240 volt 'mains' voltage to 8.5 volts. The diode 'bridge' rectifies the 8.5 volts AC from the output side of the power transformer into DC. The 2500uF capacitor helps to maintain a constant input into the regulator.

As a general guide this capacitor should be rated at a minimum of 1000uF for each amp of current drawn and at least TWICE the input voltage. The 0.1uF capacitor eliminates any high frequency pulses that could otherwise interfere with the operation of the regulator.

Voltage regulators are very robust. They can withstand over-current draw due to short circuits and also over-heating. In both cases the regulator will shut down before damage occurs. The only way to destroy a regulator is to apply reverse voltage to its input.

Reverse polarity destroys the regulator almost instantly. To avoid this possibility you should always use diode protection of the power supply. This is especially important when using nine volt battery supplies as it is common for people to 'test' the battery by connecting it one way and then the other. Even this short 'test' could destroy the regulator if a protection diode is not used.

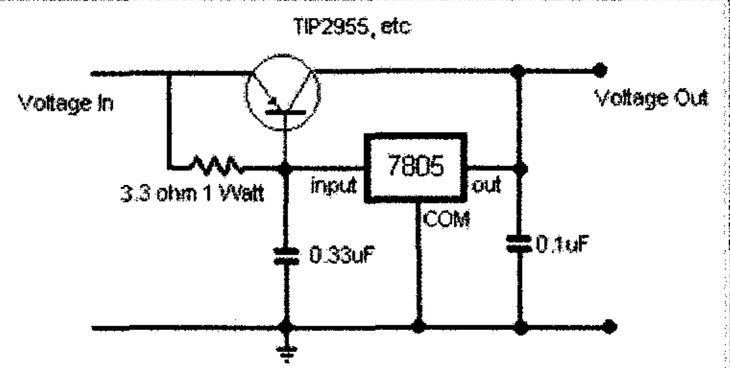
All of the interfaces described on this site have protection diodes connected into the power supply circuit to prevent damage due to incorrect polarity. Generally a 1N4004, 1 amp power diode is connected in series with the power supply. If the supply is connected the wrong way around, the regulator will be protected from damage.



A Protection Diode on the power supply input line.

Input Voltage:
As a general rule the input voltage should be limited to 2 to 3 volts above the output voltage. The LM78XX series can handle up to 30 volts input, but the power difference between the input voltage/current ratio and output voltage/current ratio appears as heat. If the input voltage is unnecessarily high the regulator will get very hot. Unless sufficient heat-sinking is provided the regulator will shut down.

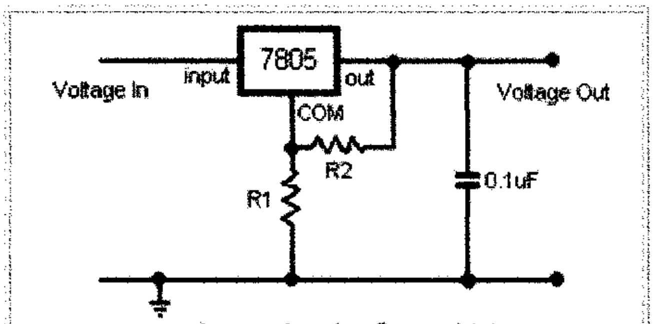
The output current of a power supply based on a Voltage Regulator can be increased using a power transistor such as the 2955 series. These transistors can pass several amps quite safely.



Increasing the Output Current

It is possible to increase the output voltage of a Regulator circuit using a pair of 'voltage-divider' resistors (R1 and R2 in the diagram below), or a zener diode. It is not possible to obtain a voltage lower than the stated rating. You could not use a 12 volt regulator to make a 5 volt power supply, but you could use a 5 volt regulator to make a 12 volt supply.

If R1 is replaced with a suitable variable resistor ("potentiometer") it is possible to make a simple 'variable' power supply.



Increasing the Output Voltage

Some regulators are designed to produce a regulated voltage as low as 1.7 volts, for example the LM317. This type of regulator is ideal to use in 'variable' power supplies able to provide 1 amp regulated DC at voltages ranging from 1.7 to around 40 volts.

The interfaces described on this site are based on either 5 volt, or 12 volt integrated circuits. They use either LM7805, or LM7812 regulators.

Typical Characteristics

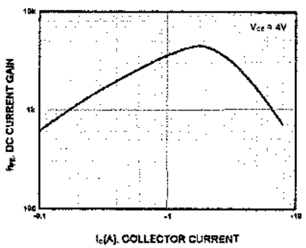


Figure 1. DC current Gain

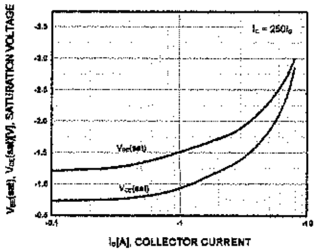


Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

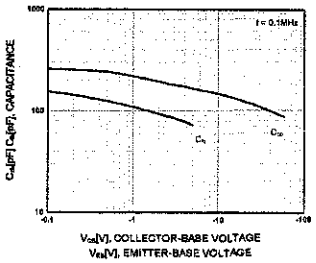


Figure 3. Output and Input Capacitance vs. Reverse Voltage

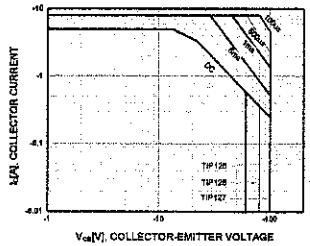


Figure 4. Safe Operating Area

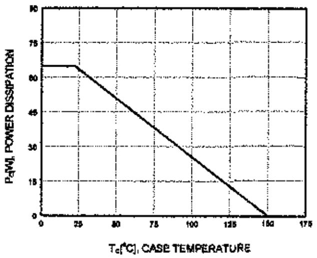


Figure 5. Power Derating

TIP125/126/127

FAIRCHILD SEMICONDUCTOR®

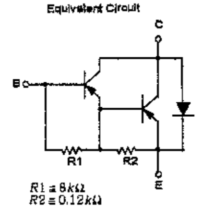
TIP125/126/127

Medium Power Linear Switching Applications

- Complementary to TIP120/121/122

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

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%

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EcoSPARK™	ISOPLANAR™	QS™	TruTranslation™
E^2CMOS™	LittleFET™	QT Optoelectronics™	TinyLogic™
EnSigna™	MicroFET™	Quiet Series™	UHC™
FACT™	MICROWIRE™	SLIENT SWITCHER®	UltraFET®
FACT Quiet Series™	OPTOLOGIC™	SMART START™	VCX™

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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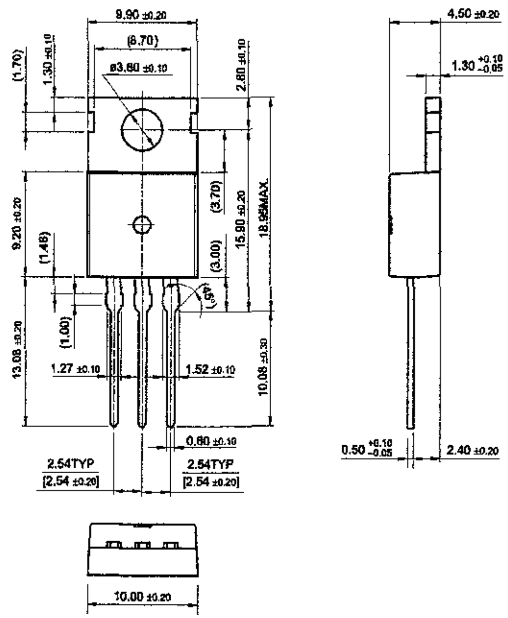
Package Demensions

TO-220



Dimensions in Millimeters

Typical characteristics

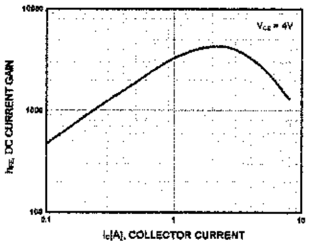


Figure 1. DC current Gain

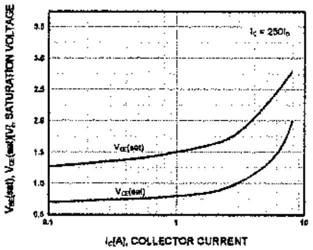


Figure 2. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

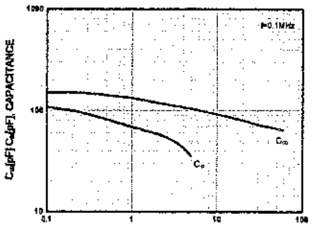


Figure 3. Output and Input Capacitance vs. Reverse Voltage

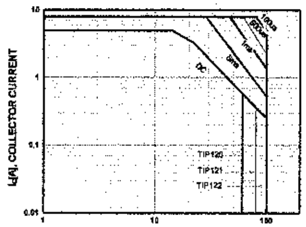


Figure 4. Safe Operating Area

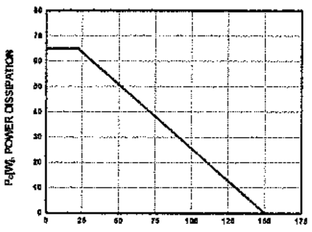


Figure 5. Power Derating

FAIRCHILD SEMICONDUCTOR®

TIP120/121/122

Medium Power Linear Switching Applications

- Complementary to TIP125/126/127

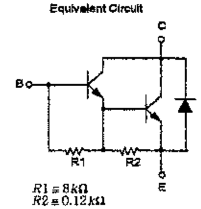
1.Base 2.Collector 3.Emitter

NPN Epitaxial Darlington Transistor

Absolute Maximum Ratings T_C=25°C unless otherwise noted

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

Equivalent Circuit



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%

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DenseTrench™	GTO™	PowerTrench®	SuperSOT™-8
DOME™	HiSeC™	QFET™	SyncFET™
EcoSPARK™	ISOPLANAR™	QS™	TruTranslation™
E^2CMOS™	LittleFET™	QT Optoelectronics™	TinyLogic™
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FACT Quiet Series™	OPTOLOGIC™	SMART START™	VCX™

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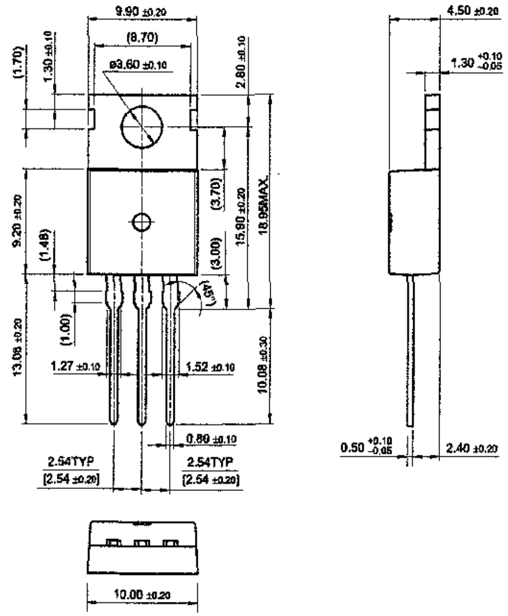
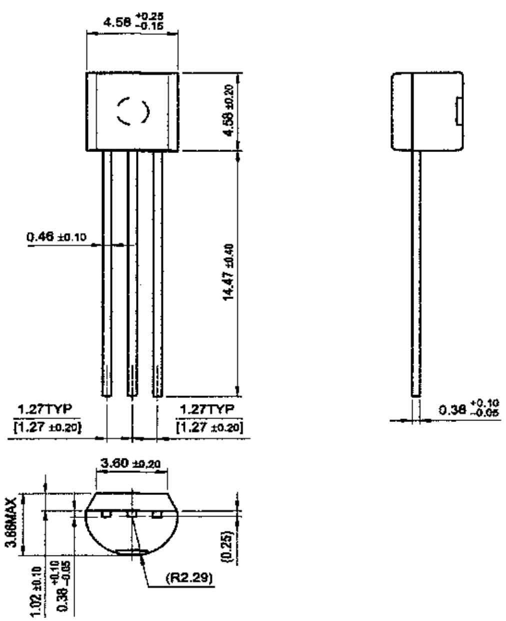
TO-220



Dimensions in Millimeters

Package Dimensions

TO-92



Dimensions In Millimeters

FAIRCHILD SEMICONDUCTOR®

PN2222

General Purpose Transistor

1. TO-92
1. Emitter 2. Base 3. Collector

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

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

Electrical Characteristics T_a=25°C unless otherwise noted

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

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

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CoolFET™	FRFET™	MicroFET™	PowerTrench®	SuperSOT™-6
CROSSVOLT™	GlobalOptoisolator™	MicroPak™	QFET®	SuperSOT™-8
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FACT™	ImpliedDisconnect™	OCXPro™	RapidConnect™	UHC™
FACT Quiet Series™		OPTOLOGIC®	µSerDes™	UltraFET®
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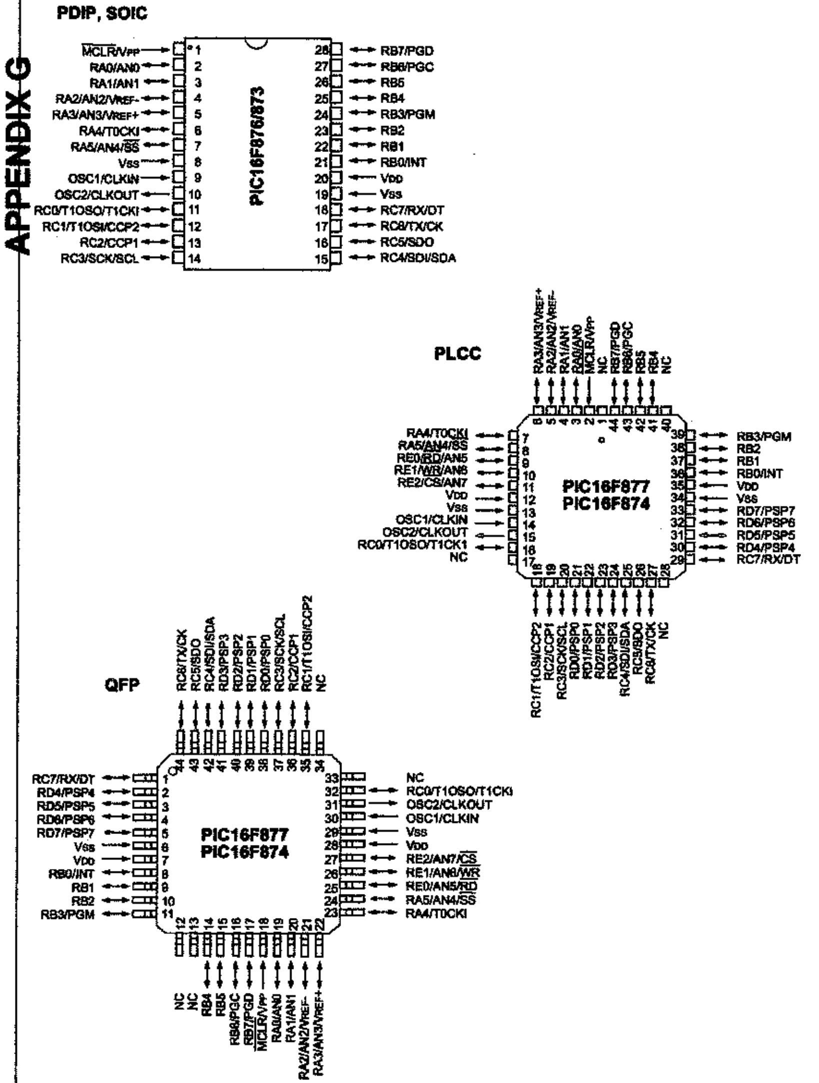
APPENDIX G

Pin Diagrams



PIC16F87X

28/40-Pin 8-Bit CMOS FLASH Microcontrollers

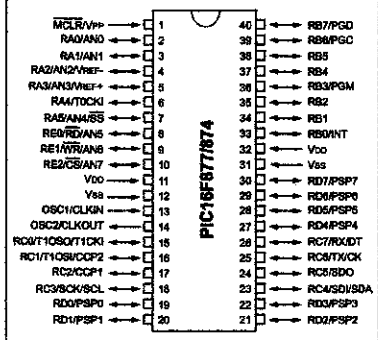
Devices Included in this Data Sheet:

- 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



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

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30	I	ST/CMOS(4)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/V_{PP}	1	2	18	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/V_{REF-}	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/V_{REF+}	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	37	41	14	I/O	TTL	Interrupt-on-change pin.
RB5	38	42	15	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	39	43	16	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.

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.

TABLE 1-1: PIC16F873 AND PIC16F876 PINOUT DESCRIPTION

Pin Name	DIP Pin#	SOIC Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	9	9	I	ST/CMOS(3)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	10	10	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, the OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/V_{PP}	1	1	I/P	ST	Master Clear (Reset) input or programming voltage input. This pin is an active low RESET to the device.
					PORTA is a bi-directional I/O port.
RA0/AN0	2	2	I/O	TTL	RA0 can also be analog input0.
RA1/AN1	3	3	I/O	TTL	RA1 can also be analog input1.
RA2/AN2/V_{REF-}	4	4	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage.
RA3/AN3/V_{REF+}	5	5	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage.
RA4/T0CKI	6	6	I/O	ST	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	7	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
					PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	21	21	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	22	22	I/O	TTL	
RB2	23	23	I/O	TTL	
RB3/PGM	24	24	I/O	TTL	RB3 can also be the low voltage programming input.
RB4	25	25	I/O	TTL	Interrupt-on-change pin.
RB5	26	26	I/O	TTL	Interrupt-on-change pin.
RB6/PGC	27	27	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	28	28	I/O	TTL/ST(2)	Interrupt-on-change pin or In-Circuit Debugger pin. Serial programming data.
					PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	11	11	I/O	ST	RC0 can also be the Timer1 oscillator output or Timer1 clock input.
RC1/T1OSI/CCP2	12	12	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	13	13	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	14	14	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	16	16	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	17	17	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	18	18	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.
V_{SS}	8, 19	8, 19	P	—	Ground reference for logic and I/O pins.
V_{DD}	20	20	P	—	Positive supply for logic and I/O pins.

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 the 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 in RC oscillator mode and a CMOS input otherwise.

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.

APPENDIX H

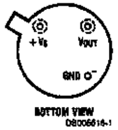
Peltier Effect Device Data Sheet

		Ambient = 30C						
Item Number	Description	Max Delta T	Max Voltage	Max Current	Max Wattage	Length	Width	Thickness
1-01704	Single Stage TEC	68	2.1	4.5	5	15.0	15.0	4.8
1-03104	Single Stage TEC	68	3.8	4.5	10	20.0	20.0	4.8
1-07104	Single Stage TEC	68	8.6	4.5	22	30.0	30.0	4.8
1-12704	Single Stage TEC	68	15.4	4.5	40	40.0	40.0	4.8
1-01705	Single Stage TEC	68	2.1	5.5	7	15.0	15.0	4.0
1-03105	Single Stage TEC	68	3.8	5.5	12	20.0	20.0	4.0
1-07105	Single Stage TEC	68	8.6	5.5	27	30.0	30.0	4.0
1-12705	Single Stage TEC	68	15.4	5.5	49	40.0	40.0	4.0
1-01706	Single Stage TEC	68	2.1	6.5	8	15.0	15.0	3.9
1-03106	Single Stage TEC	68	3.8	6.5	14	20.0	20.0	3.9
1-07106	Single Stage TEC	68	8.6	6.5	32	30.0	30.0	3.9
1-12706	Single Stage TEC	68	15.4	6.5	58	40.0	40.0	3.9
1-01707	Single Stage TEC	68	2.1	7.5	9	15.0	15.0	3.9
1-03107	Single Stage TEC	68	3.8	7.5	16	20.0	20.0	3.9
1-07107	Single Stage TEC	68	8.6	7.5	37	30.0	30.0	3.9
1-12707	Single Stage TEC	68	15.4	7.5	67	40.0	40.0	3.9
1-01708	Single Stage TEC	68	2.1	8.5	10	15.0	15.0	3.6
1-03108	Single Stage TEC	68	3.8	8.5	18	20.0	20.0	3.6
1-07108	**Single Stage TEC**	**68**	**8.6**	**8.5**	**42**	**30.0**	**30.0**	**3.6**
1-12708	**Single Stage TEC**	**68**	**15.4**	**8.5**	**76**	**40.0**	**40.0**	**3.6**
1-12702	Single Stage TEC	68	15.4	2.0	18	30.0	30.0	4.6
1-12703	Single Stage TEC	68	15.4	3.0	27	30.0	30.0	3.8
1-12704	Single Stage TEC	68	15.4	4.0	40	30.0	30.0	3.4

APPENDIX I

Connection Diagrams

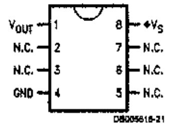
TO-46
Metal Can Package*



*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



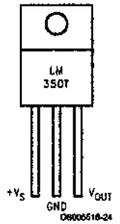
N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-92
Plastic Package

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

TO-220
Plastic Package*



*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

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

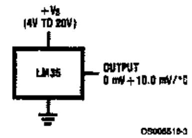
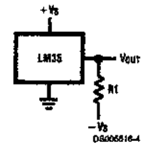


FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)



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

LM35 Precision Centigrade Temperature Sensors

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35 Typical	LM35 Tested Limit (Note 4)	LM35 Design Limit (Note 5)	LM35C, LM35D Typical	LM35C, LM35D Tested Limit (Note 4)	LM35C, LM35D Design Limit (Note 5)	Units (Max.)
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)	$T_{MIN}\le T_A\le T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	°C
Sensor Gain (Average Slope)	$T_{MIN}\le T_A\le T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/°C
Load Regulation (Note 3) $0\le I_L\le 1$ mA	T_A=+25°C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN}\le T_A\le T_{MAX}$	**±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
	$4V\le V_S\le 30V$	**±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)	$4V\le V_S\le 30V$, +25°C	0.2	2.0		0.2	2.0		μA
	$4V\le V_S\le 30V$	**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: $-55°C\le T_J\le +150°C$ for the LM35 and LM35A; $-40°C\le T_J\le +110°C$ for the LM35C and LM35CA; and $0°C\le T_J\le +100°C$ 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.

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp.;	
TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-220 Package,	−65°C to +150°C
Lead Temp.:	
TO-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

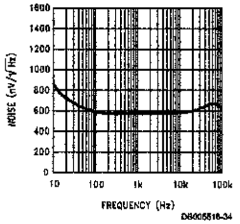
Electrical Characteristics

(Notes 1, 6)

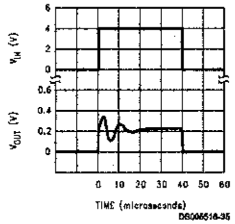
Parameter	Conditions	LM35A Typical	LM35A Tested Limit (Note 4)	LM35A Design Limit (Note 5)	LM35CA Typical	LM35CA Tested Limit (Note 4)	LM35CA Design Limit (Note 5)	Units (Max.)
Accuracy (Note 7)	T_A=+25°C	±0.2	±0.5		±0.2	±0.5		°C
	T_A=−10°C	±0.3			±0.3		±1.0	°C
	$T_A=T_{MAX}$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A=T_{MIN}$	±0.4	±1.0		±0.4		±1.5	°C
Nonlinearity (Note 8)	$T_{MIN}\le T_A\le T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	$T_{MIN}\le T_A\le T_{MAX}$	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) $0\le I_L\le 1$ mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN}\le T_A\le T_{MAX}$	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	T_A=+25°C	±0.01	±0.05		±0.01	±0.05		mV/V
	$4V\le V_S\le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25°C	56	67		56	67		μA
	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
Change of Quiescent Current (Note 3)	$4V\le V_S\le 30V$, +25°C	0.2	1.0		0.2	1.0		μA
	$4V\le V_S\le 30V$	**0.5**		**2.0**	**0.5**		**2.0**	μA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	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

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, θ_{JA})

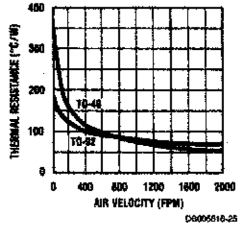
	TO-46, no heat sink	TO-46*, small heat fin	TO-92, no heat sink	TO-92**, small heat fin	SO-8 no heat sink	SO-8** small heat fin	TO-220 no heat sink
Still air	400°C/W	100°C/W	180°C/W	140°C/W	220°C/W	110°C/W	90°C/W
Moving air	100°C/W	40°C/W	90°C/W	70°C/W	105°C/W	90°C/W	26°C/W
Still oil	100°C/W	40°C/W	90°C/W	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.

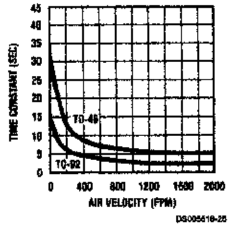
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Performance Characteristics

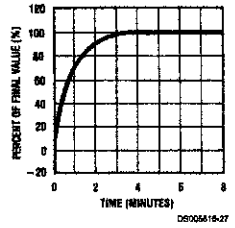
Thermal Resistance Junction to Air



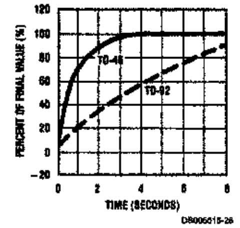
Thermal Time Constant



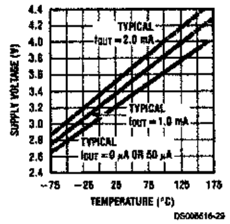
Thermal Response in Still Air



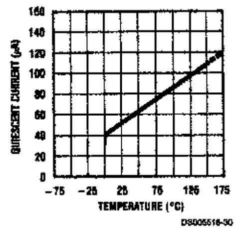
Thermal Response in Stirred Oil Bath



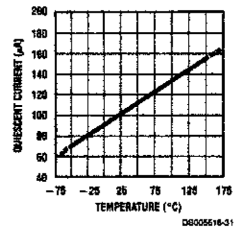
Minimum Supply Voltage vs. Temperature



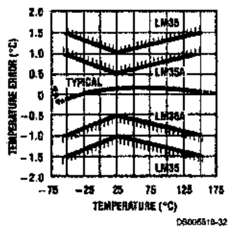
Quiescent Current vs. Temperature (In Circuit of *Figure 1.*)



Quiescent Current vs. Temperature (In Circuit of *Figure 2.*)



Accuracy vs. Temperature (Guaranteed)



Accuracy vs. Temperature (Guaranteed)