DESIGN A MICROCONTROLLER BASED MOTOR CONTROLLER WITH HEAT SENSOR

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DESIGN A MICRONCONTROLLER BASED MOTOR CONTROLLER WITH HEAT SENSOR"** was prepared by **PHANG CHEE HOE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

Approved by,

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Date :	_____________	Date :	_____________

Specially dedicated to

my beloved grandfather, family, lecturers, friends

and my loved one

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ABSTRACT

Induction motors are the most widely used motors for in most powered home appliances. Simple and rugged design, low cost, low maintenance and direct connection to an AC power source are the main advantages of an AC induction motor. When power is supplied to an induction motor at recommended specifications, it runs at its rated speed. However, many applications need variable speed operation. One of them is a fan. This report presents a design of a Microcontroller Based Motor Controller with Heat Sensor which is used to vary the speed of a motor. The Microcontroller Based Motor Controller with Heat Sensor project aims to design a controller that varies the speed of the motor with respect to the ambient temperature. This controller will be embedded as an addition to a stand fan. The speed of the fan is expected run in low speed at low ambient temperature and vice versa. A phase control method is chosen to be used for this design. The power delivery to the motor is controlled by the firing angle of a Triac where it will control the AC power supply. When the ambient temperature is sensed, temperature sensor produces an output voltage to the microcontroller. The microcontroller acts as a digital signal processing (DSP) body where it will convert the analogue voltage into digital form and compare with the pre-set values. After that, it generates a signal and sends it to trigger the relay. The relay is used to control the equivalent resistance in the phase control circuit and hence, the firing time of the Triac can be controlled. With the controlled of firing time of the Triac, the input power to the motor can be controlled as well. Besides that, a hand-clap circuit is also included in this project. The hand-clap circuit acts as a switch to activate or deactivate the motor.

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CHAPTER 1

INTRODUCTION

1.1 History

The idea of a rotating magnetic field was developed by François Arago in 1824, (Babbage, C. and Herschel, J.W.F. ,1825) and first implemented by Walter Baily. (Silvanus Phillips Thompson, 1895) Based on this, practical induction motors were independently invented by Nikola Tesla in 1883 and Galileo Ferraris in 1885. (The Electrical Engineer, 1888) Tesla conceived the rotating magnetic field in 1882 and used it to invent the first induction motor in 1883; Ferraris developed the idea in 1885. (Galileo Ferraris 1885) In 1888, Ferraris published his research to the Royal Academy of Sciences in Turin, where he detailed the foundations of motor operation; Tesla, in the same year, was granted U.S. Patent 381,968for his motor. The induction motor with a cage was invented by Mikhail Dolivo-Dobrovolsky a year later.

1.2 Aims and Objectives

For this Final Year Project (FYP), my aim is to design a microcontroller based motor controller with heat sensor. This design is mainly applied to a table fan which will function automatically in adjusting the speed according to the ambient temperature.

Besides that, it is also said to be more energy saving as the speed of the motor depends on the ambient temperature and hence no extra power is needed to drive the motor at higher speed which is not necessary at low ambient temperature. For convenient a hand clap switch will be embedded into the project to turn on and off the motor. As the application is very vast, the design is expected to be simple yet can be functional. In order to accomplish this aim, there are several objectives to be achieved. Here are the objectives:

- To understand the basic concept of the speed control of the motor
- To find a simplest and low cost method of the motor speed control
- To build a suitable circuitry
- To master assembly code programming in order to program the PIC microcontroller
- To understand the basic function of a hand clap circuit and includes it in the project
- To test each of the part of the project
- If the final product is not working as expected, possible solutions will be provided for the future progress

1.3 Description of the Report

There are a few sections in this report, namely, history, aim and objectives, literature review, methodology, results and discussions and also the conclusion and the future recommendations. In the introduction, the history of the induction motor will be explained. Aim and objectives of this project also will be defined in this section. In the literature review section, several methods of speed control of induction motor will be described. Next, methodologies of conducting this project also will be shown. Furthermore, the results from the experiment are illustrated. Lastly, conclusion is made and future recommendation will be suggested for improvement purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 Permanent Split Capacitor ACIM

A permanent split capacitor (PSC) motor as shown in Figure 2.0 has a run type capacitor permanently connected in series with the start winding. This makes the start winding an auxiliary winding once the motor reaches the running speed.

Since the run capacitor must be designed for continuous usage, it cannot provide the starting boost of a starting capacitor. The typical starting torque of the PSC motor is from 30% to 150% of the rated torque. PSC motors have a low starting current, usually lesser than 200% of the rated current, making it excellent for applications with high on/off cycle rates.

The PSC motors have several advantages. The motor design can easily be altered for operating with speed controllers. It can also be designed for optimum efficiency and High-Power Factor (PF) at the rated load. They're considered to be the most reliable among the other single-phase motors, mainly because no centrifugal starting switch is required.

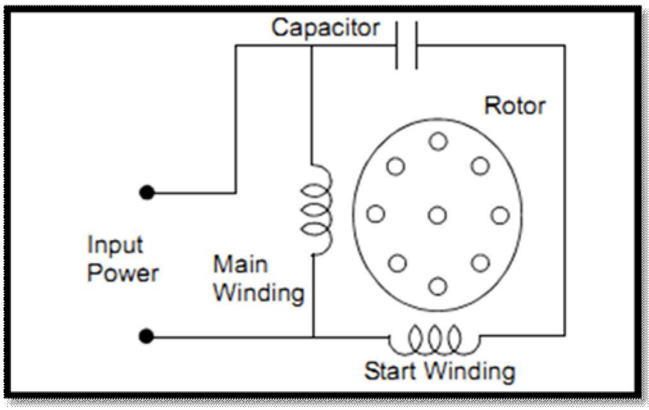


Figure 2.0 PSC (Rakesh Parekh, 2003)

Permanent split-capacitor motors have a wide variety of applications depending on the design. The design variation can be applied to become a fan, blowers with low starting torque and intermittent cycling uses, such as adjusting mechanisms, gate operators and garage door openers.

2.2 Theory and Methods of Speed Control for an Single Phase Induction Motor (SPIM)

The two primary ways to control the speed of a single-phase AC motor is to either change the frequency of the line voltage of the motor sees or by changing the voltage seen by the motor, thereby changing the rotational speed of the motor. An Inverter will convert the AC waveform into a DC Voltage and they create a PWM signal output that will filter into a waveform with a predetermined voltage (controlling torque) and frequency (controlling speed).

2.2.1 V/F Control Theory

Volts/Hertz control is a kind of control method of taking a speed reference commands from an external source and varies the voltage and frequency applied to the motor. As shown in the Figure 2.1, the induction motor draws the rated current and delivers the rated torque at base speed. When the load is increased (over-rated load) while running at base speed, the speed drops and the slip increases. The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply. By varying the frequency, the speed of the motor can be varied. Therefore, by varying the voltage and frequency by the same ratio, flux and hence, the torque can be kept constant throughout the speed range. (Padmaraja Yedamale, 2002)

$$Stator\ Voltage(V) \propto [Stator\ Flux(\phi)] \times [Angular\ Velocity(w)]$$

$$V \propto \phi \times 2\pi f\ where\ w = 2\pi f$$

$$hence, \phi \propto \frac{V}{f}$$

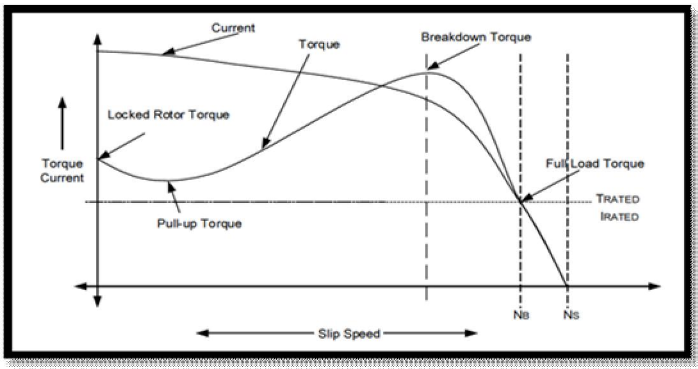


Figure 2.1: Speed-torque characteristics of induction motor (Padmaraja Yedamale, 2002)

The relation between the voltage and torque versus frequency is shown in Figure 2.2. As the voltage and frequency increases up to the base speed, the voltage and frequency will attain the rated values as listed in the nameplate. The motor can be driven beyond base speed by increasing the frequency further. However, the voltage applied cannot be increased beyond the rated voltage. Therefore, only the frequency can be increased, which will result in the field weakening and the torque available being reduced. For slip speed that is above the base speed, the factors governing the torque becomes complex. As the friction and windage losses increases significantly at higher speeds, the torque curve becomes nonlinear with respect to speed or frequency. (Padmaraja Yedamale, 2002)

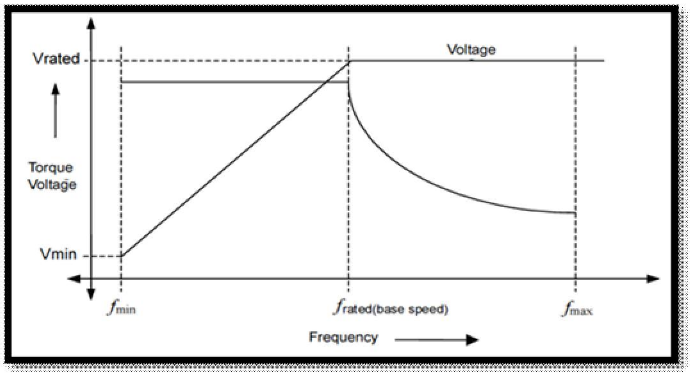


Figure 2.2: Speed-torque characteristics with v/f control (Padmaraja Yedamale, 2002)

It can be further understood by the block diagram shown in Figure 2.3. Typically, a current limit block monitors motor current and alters the frequency command when the motor current exceeds a predetermined value. The volts/hertz block converts the current command to a volts/hertz ratio. It supplies a voltage magnitude command to the voltage control block. This angle advices the voltage where it should be with respect to current. This determines the flux current to the motor. If this angle is incorrect, the motor will operate unstable. Since the angle is not controlled in a volts/hertz drive, low speeds and unsteady states may operate unsatisfactorily.

In order to control the speed motor more precisely, a "slip compensation" block should be installed. It alters the frequency reference when the load changes to keep the actual motor speed close to the desired speed. (AC Drives Using PWM Techniques, 2000)

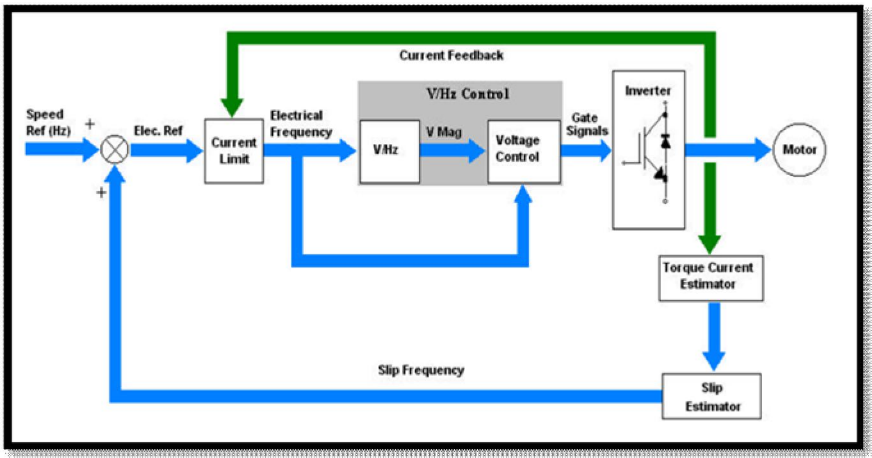


Figure 2.3: V/f Block diagram (AC Drives Using PWM Techniques, 2000)

While this type of control is very good for many applications, it is not very well suited for applications that requires higher dynamic performance, applications where the motor runs at very low speeds, or applications that requires direct control of motor torque rather than motor frequency. The steady state torque performance of a volts/hertz drive is shown in Figure 2.4. (AC Drives Using PWM Techniques, 2000)

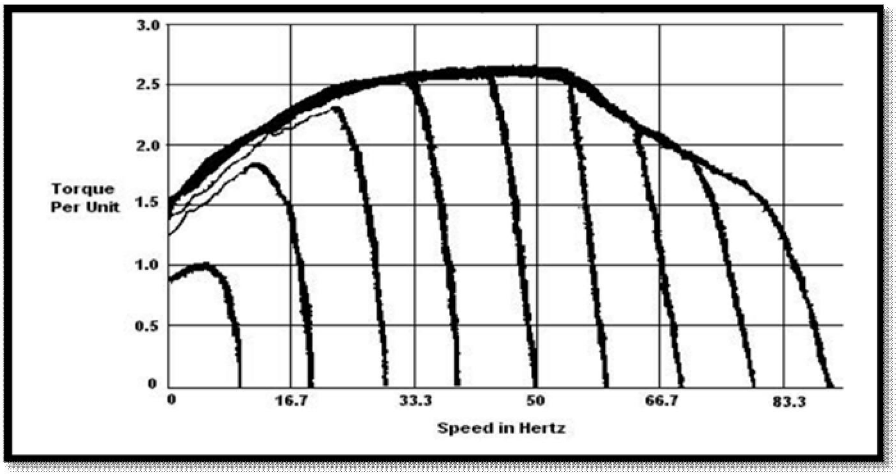


Figure 2.4: Graph v/f speed vs. torque (AC Drives Using PWM Techniques, 2000)

2.2.2 V/F Control of Permanent Split Capacitor (PCS) Single Phase Induction Motor

A PSC motor is usually a 2-phase asymmetrically wound motor. The main winding is used to take the load current. When the current flowing through the start winding is lesser than the main winding, the Magnetomotive Force (MMF) will be generated and causes the rotor to be rotated. The motor is then energized with a single-phase AC power supply with a capacitor connected in series with the start winding as shown in Figure 2.0. The value of the capacitor is controlled so that the total impedance on the winding produces sufficient phase shift in current to generate a rotating magnetic filed in the air gap.

2.2.2.1 H-Bridge Inverter Approach

On the input side, a voltage doubler is used and on the output side a H-bridge or 2-phase inverter is used as shown in Figure 2.5, one end of the main and start windings are connected to each half bridge and the other ends are connected together to the neutral point of the AC power supply, which also serves as the centre point for the voltage doubler.

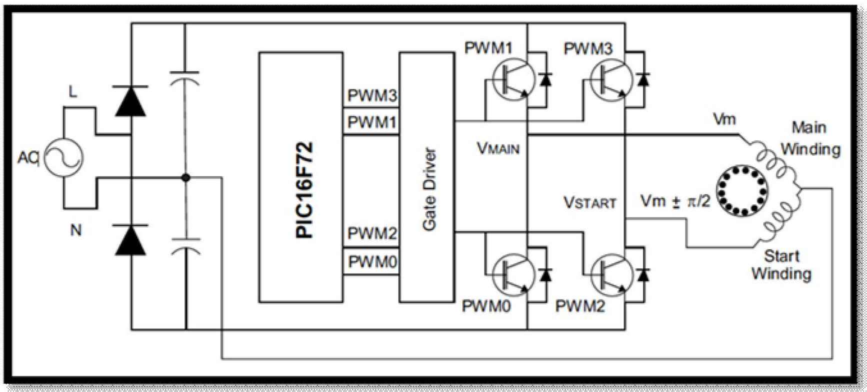


Figure 2.5 A PSC Drive with H-Bridge (Padmaraja Yedamale, 2005)

The control circuit requires four PWMs with two complementary pair with sufficient dead band between the complementary outputs. PWM0-PWM1 and PWM2-PWM3 are the PWM pairs with dead band. By using PWMs, two sine voltages will be synthesized at 90 degrees out of phase with varying amplitude and varying frequency according to the VF profile. The phase voltage vs phase angle is shown in Figure 2.6 (Padmaraja Yedamale, 2005)

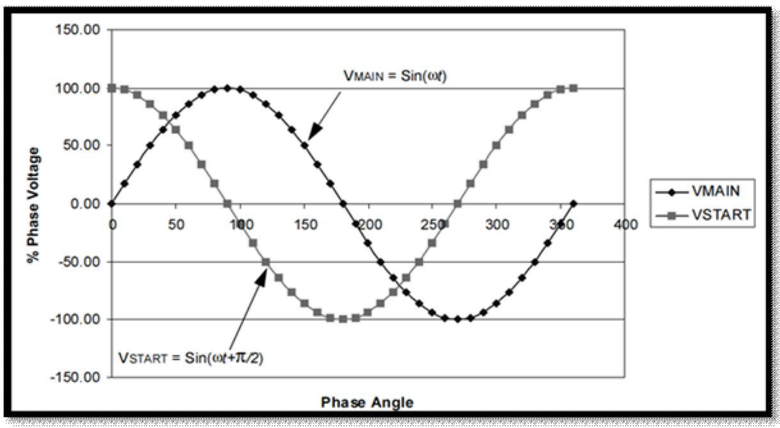


Figure 2.6 Phase Voltage vs Phase Angle (Padmaraja Yedamale, 2005)

2.2.2.2 Three Phase Inverter Bridge

The three phase inverter bridge is similar to the H-Bridge that was discussed earlier, but the input section is now replaced with a standard diode bridge rectifier. The output section has a 3-phase inverter bridge. The main difference from the H-Bridge is that the way the motor windings are connected to the inverter. One end of the main winding and start windings are connected to one half bridge each. The other ends are tied together and connected to the third half bridge which is shown in Figure 2.7. (Padmaraja Yedamale, 2005)

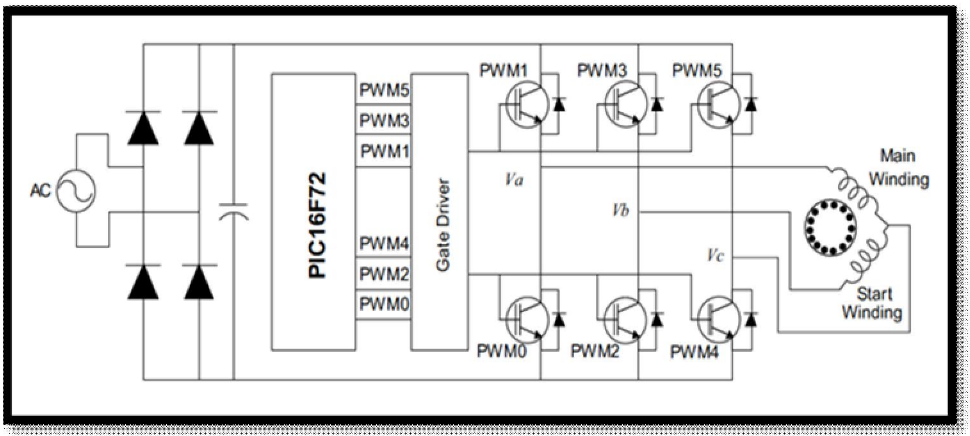


Figure 2.7 Controlling a PSC Motor with a 3-Phase Inverter Bridge (Padmaraja Yedamale, 2005)

2.2.3 Phase Control for Single Phase AC Motor

Basically Phase Control method is simplest way to controlling a SPIM. The Triac, Phase-Control design is simpler. There is a single switch that is in line with the AC line. It chops the AC waveform causing the power to shut off during a portion of the AC Cycle. Figure 2.8 shows the general schematic for a Triac controlled drive. The motor shown is a permanent split capacitor motor having 2 windings and a capacitor for phase shift.

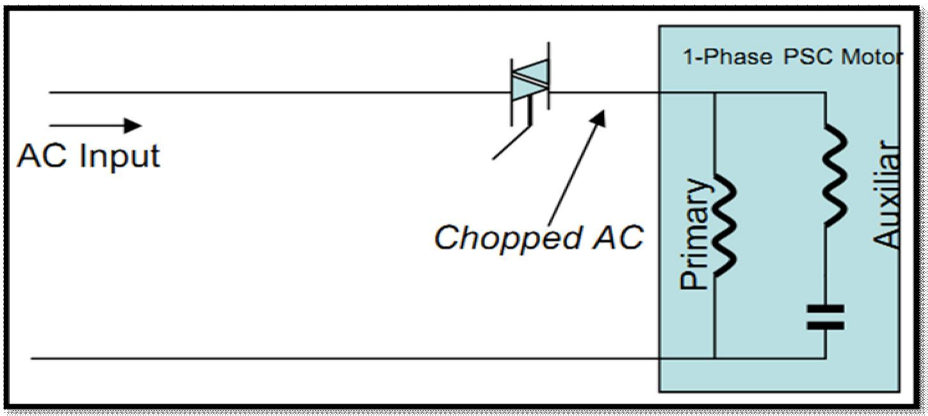


Figure 2.8 AC Chopper / Triac control of 1-Phase AC motor (Howard Abramowitz, 2003)

The AC motor acts as a low pass filter causing the resulting current waveform to be sinusoidal at the same operating frequency with a slight lag. The lower RMS voltage that being created by the chopper increases the slip to the motor, thereby motor speed is reduced. Essentially starving the motor of its power, the motor slows down and eventually stops because there is not enough energy to maintain rotational speed. Hence it meant to say that the speed of the motor willing be controlled by the conducting period of the Triac where the conducting period depends on the firing angle that is controlled by the circuit at the gate of the Triac.

2.2.4 ABB ACS800 Speed Drive with Usage of PIC

This section describes the usage of an ABB ACS800 speed drive. ABB ACS800 speed drive is an AC drive technology developed by Asea Brown Boveri (ABB), in Switzerland. ACS800 consists of direct torque control (DTC), a revolutionary motor control method that allows direct torque control to motor magnetizing flux and motor torque. There is no modulator and no requirement for tachometer or position encoder to feed back the speed or position of the motor shaft, down to zero speed. The ACS800 features built-in pre-programmed application macros for configuration of parameter such as inputs, outputs and signal processing. There are five standard macros and two user macros that are available for user to choose. For convenience, the start-up assistant will guide the user through the start-up procedure to help the user to feed the requested data (parameter values) to the drive. (Nader Barsoum, 2009)

ABB ACS800 setting is simple. The motor only takes the signal given by the output PORTD of PIC and instructs the ABB motor to follow the logic input signal. It means that only the sequential control is needed and necessary at this time. However this ABB ACS800 has a speed limitation. It only can be sustained the speed up to maximum of 1350rpm. (Nader Barsoum, 2009)

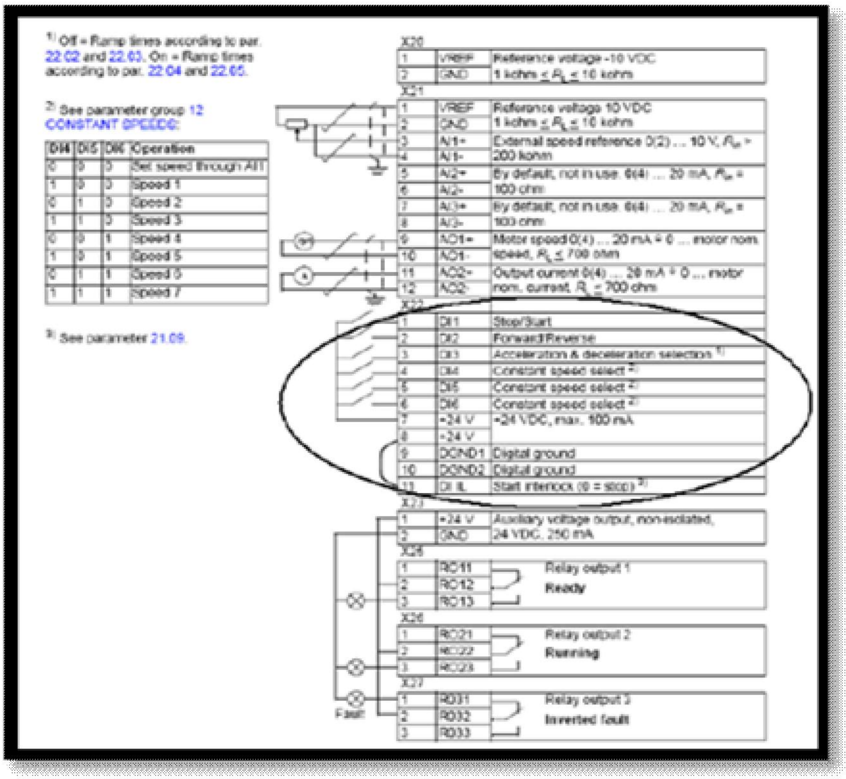


Figure 2.9: The sequential control of ABB ACS800 (Nader Barsoum, 2009)

As shown in Figure 2.9, these are the sequential control in ABB ACS800 speed drive. It only controls start/stop of the motor, the motor direction, and the seven constant speeds. To explain the sequential control on ABB speed drive, this part here is the logic inputs which take signal (zeros and ones) from any logic control device such as PIC16F917. It only reads zeros (0) and ones (1) signal. In addition, every single terminal port of this ABB ACS800 speed drive panel only accepts 24volts as on (1) otherwise below than that is consider to be off (0). The speed of the motor can be controlled by controller the D14, D15, and D16. (Nader Barsoum, 2009)

2.3 Volumetric Flow Rate

Volumetric Flow Rate is the measurement of airflow or flow of a fluid. Hence volumetric flow rate is a very important criterion for a fan. The unit used is cubic feet per minute (CFM). CFM is a standard measurement of airflow that indicates how many cubic feet of air passes by a stationary point in one minute. The higher the number, the more air is being forced through the system. One cubic feet per minute for the volumetric flow rate of a liquid or gas equals to approximately 2 litres per second.

2.4 Hand Clap Switch

A switch is to permit the current flow across two or more terminal to allow interaction between electrical components. Not only that, a switch also is used to terminate the flow when necessary. Hand clap switch is normally used to provide means for connecting two or more terminals in order to permit the flow of current across them to allow the interaction between electrical components and to easily isolate circuits which is useful if to terminate termination of this communication flow is required. The proposal of having such a switch is to alleviate the problem faced by the aged and physically challenged persons in trying to control some household appliances. (Seyi Stephen, 2008)

<u>Summary</u>

	Advantages	Disadvantages
V/F Control of Permanent Split Capacitor (PCS) Single Phase AC Motor	Wide Speed range, low-speed / High efficiency	Higher Cost, Hi-Voltage Pulses, Full Speed losses, Motor Reliability
Phase Control for Single Phase AC Motor	Low Cost, Ease of Control, Robust & Reliable, Multi-loads	Small motor Speed range, Lower Efficiency, lower Power Factor

Table 2: The Summary of Comparison between V/F Control with Inverter and Phase Control for Single Phase AC Motor

CHAPTER 3

METHODOLOGY

This chapter is the root that determines the success of this project. Research design and methodology are plans and the procedures of a research that span the decisions from broad assumptions to detailed methods of data collection (Creswell, 2009). Basically, this chapter discusses in detail the overall design, research and the methodologies adopted in order to achieve the aim and the objectives of this project.

As the budget for this the whole project is limited, the project aim needs to be clear to avoid wastage on purchasing unnecessary components. Therefore it is important to first develop a flowchart that sets out the framework of the overall research process in order to determine the most suitable methods. Therefore, a framework of the overall research process is developed and discussed in this chapter.

3.1 Project Overview

This project involves both hardware and software parts. Before starting on the whole project, a studies on the literature review of the speed controlling method of AC single phase motor is done. Then a test on the volumetric flow rate of the fan for various speed of the current stand fan has also been carried out. For the hardware part, circuits have to be studied and evaluated. The present method of controlling motor speed will be evaluated. A suitable circuitry will be chosen for the project. Software part is also as important as hardware part; this is because a PIC microcontroller will be used to fulfil the requirement for this project. Hence a programming language will also need to be studied.

When both parts are successfully done, it will be combined. Several tests will be done on both the software and hardware parts. As nothing is perfect, this project has its own problems. Problem identification and troubleshooting have to be carried out. Reasons for the failure will be identified and discussed. Few attempts to solve the problems will be done. If the problem still exists, causes of failure will be stated.

Finally, a final report that contains the whole process of the project will be written. Conclusion and future improvement will be included as well.

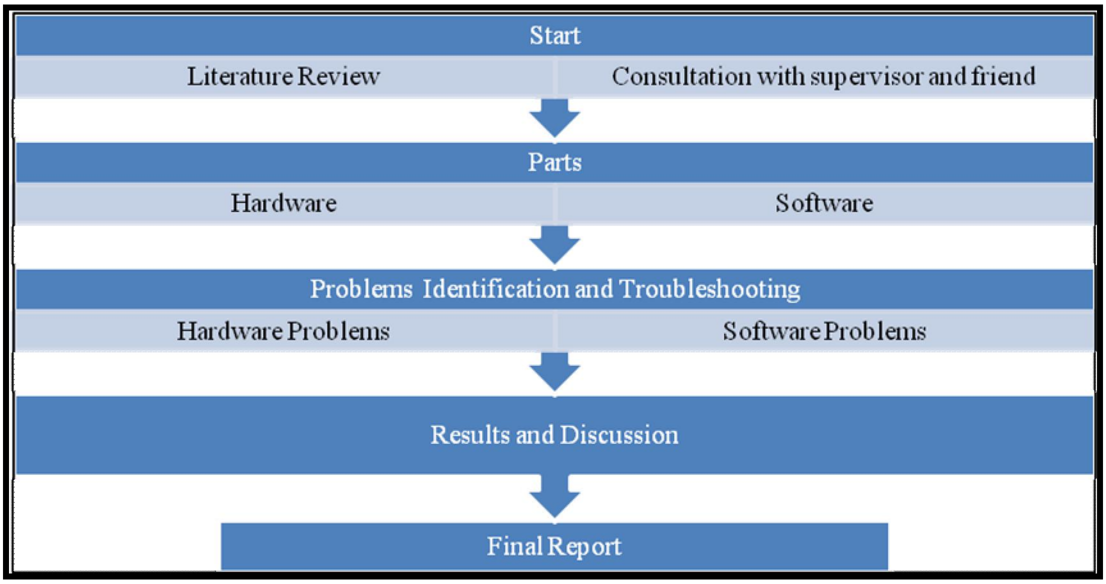


Figure 3.0: Flow Chart of Project Overview

3.2 Present Stand Fan Speed Control

Nowadays the most common method used in controlling the speed of a stand fan is by using the mechanical switches. Each of these mechanical switches is corresponding to one speed. This is mainly done by using the potentiometer concept where different values of the voltage will be sent to the motor as the switches are being operated.

This controlling method, it is fully manual control. When a switch is pressed, the motor will rotate at a fix speed regardless of the ambient temperature. This means that when the maximum speed switch is being pressed; the motor will rotate at the rated maximum speed even if the ambient temperature is very low (cold situation).

3.2.1 Drawback of Current Controlling Method

As discussed in the earlier section, the speed of a stand fan is independent of the ambient temperature; hence there will be wastage of power. Besides that, each motor has its own lifespan. The lifespan of a stand fan motor is the total number of revolution made. As the motor speed does not change with the ambient temperature, there might be extra revolution (high speed in low ambient temperature) and hence the lifetime of a motor will be shortened.

3.3 Volumetric Flow Rate

First of all, a test on the volumetric flow rate for the various speeds on the present stand fan is carried out. The purpose of this experiment is to formulate an approximate relationship between the volumetric flow rates and the speed (revolution per minute) of the fan.

This experiment is done by placing a small DC motor that operate as generator in different positions in front of the stand fan as shown in the Figure 3.1. As the blades of the stand fan are rotating, an air flow will be produced. This air flow forces the blades of the DC motor to rotate and generates a small emf that is proportional to the speed of the stand fan.

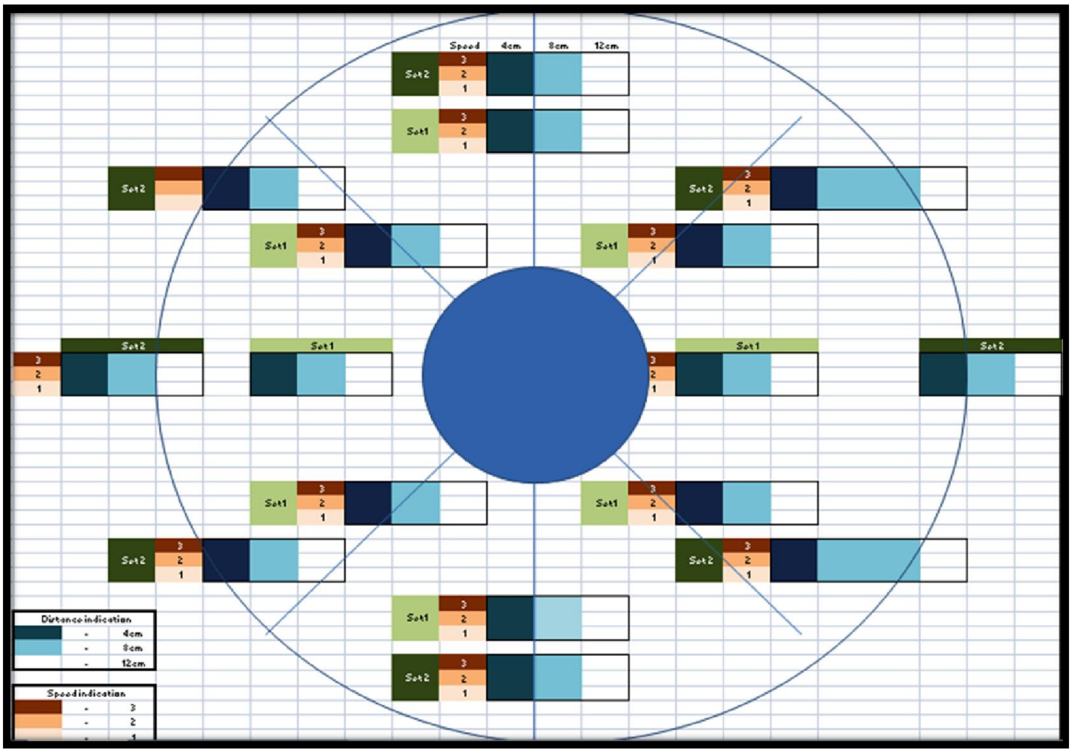


Figure 3.1: Positions of Placing a DC Motor fan in front of the Stand Fan

Besides that, a thermal flow simulation is also carried out to show the importance of volumetric flow rate of a fan in controlling the ambient temperature. This thermal flow simulation is done by using the SolidWork Flow Simulation software.

3.4 The Idea of the Project

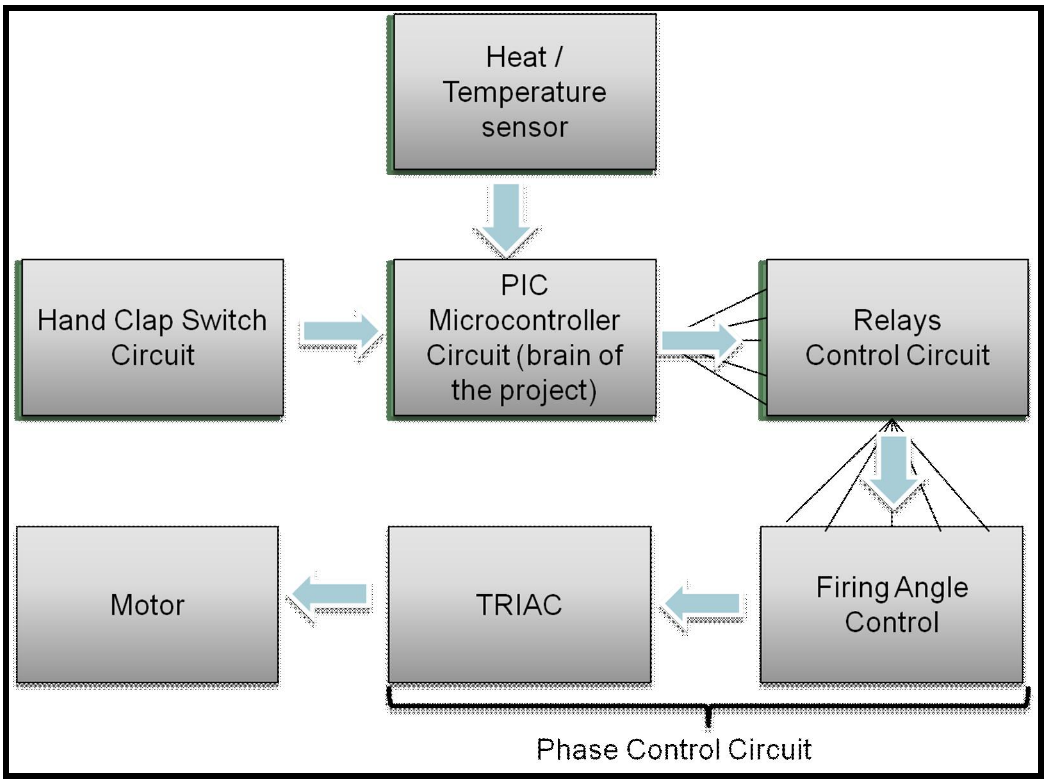


Figure 3.2: The flow of the Idea of the Project

This project consists of several steps. First is to set the desired highest and also the lowest temperature and some of the preset values into the microcontroller. Then a hand clap circuit is used to trigger the on and off of the system. Next as the system is on, the ambient temperature will then be sensed by the temperature sensor. The output of the sensor will then feed to PIC Microcontroller. The PIC Microcontroller will generate the desired output signals which are correspondent to the difference ambient temperatures by comparing the output voltage from the temperature sensor with the preset values. These output signals will then be sent to the firing angle control circuit to trigger certain relay to control the firing angle of the Triac. Therefore, the average power supply to the motor will be varied; hence, speed of the motor can be controlled.

3.5 Hand Clap Circuit

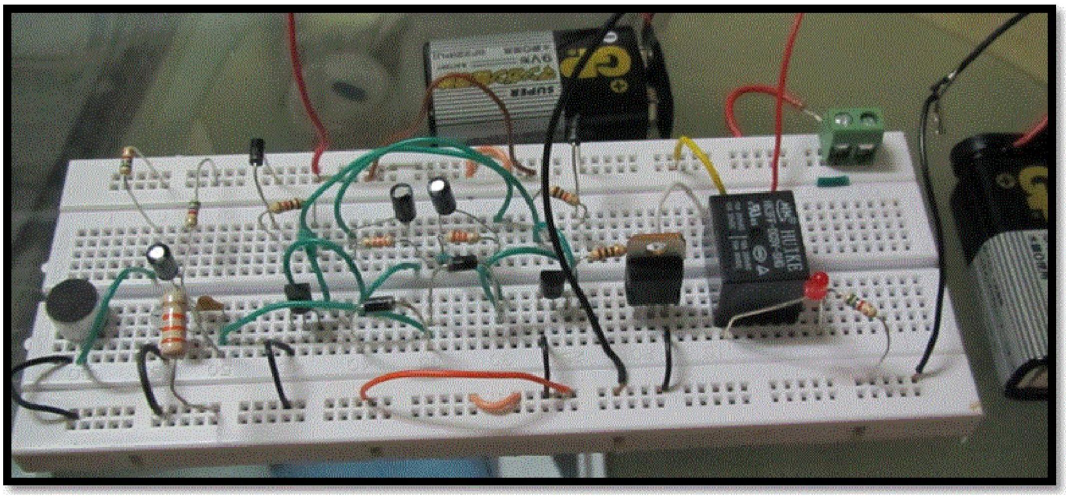


Figure 3.3: Hand Clap Circuit

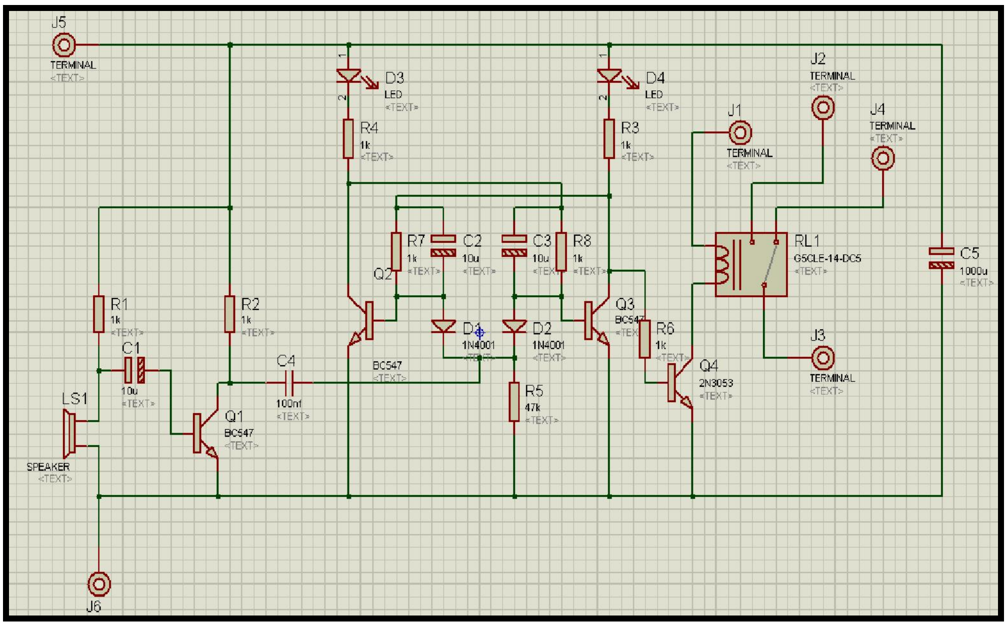


Figure 3.4: Simulation Diagram of Hand Clap Switch Circuit (Proteus)

<u>Input Transducer</u>

The clap sound is first picked up using an electret microphone. Inside the electret microphone there is an electrets film which is stretched so that it will be vibrated in symmetry with any sound falling on it. These vibrations cause the electrical charge on a perforated plate nearby to change, and a field effect transistor converts these into corresponding changes in current.

This microphone has built in amplifier. The power for this built in amplifier is supplied by connecting a resistor to a positive source of voltage, and the changes in current get reflected as changes in voltage across this resistor according to the equation V = I*R. A larger resistor will result in a larger voltage, but the current flows into the device will be reduced and hence, it will lower down the gain.

Amplifier

In transistor stage, the signal which is received from the microphone will be amplified by the biased near cut-off. The output of the microphone is coupled to the base of the transistor by using an electrolytic capacitor. On the first time the microphone detect clap sound; the microphone output will go to positive. This causes the current that flows through the transistor to be increased. When the current increases up to the threshold current, it will trigger the transistor to be activated and thus causing the voltage at the collector to fall nearly zero.

Memory

A bistable multivibrator is formed by connecting two cross transistors. This bistable multivibrator has the function of storing memory. It will store the state of either on or off until the end of time. When one of the transistors conducts, its collector is near ground and a resistor from this collector feeds the base of the other. Since this resistor sees ground at the collector end the base at the other transistor will receive no current and the transistor will be at off state. When it is at off state, the collector is almost the same as the supply potential and resistor connects from this to the base of the other transistor. With the resistor that sees voltage, the base of the first transistor will have voltage supplied to its base. Hence this state is stable and it is also true when it happens vice versa.

Changing state

Once the clap on, the state of the bistable changed. The output of the amplifier is converted to a sharp pulse by passing it through a low valued capacitor, 0.1µF. With the help of IN4001 diodes which helps it to be connected together steers the pulse to the base of the transistor. When the first transistors stop conducting, the other transistor which is already at the off state will remain off.

Then, those two capacitors across the base resistors will pop into action. The capacitor that connected to the base of the transistor which was ON has voltage across it. While on the other hand, the transistor that was off has no voltage across the capacitor that is connected to it.

As the sound of the clap dies away, both bases rise towards the supply voltage. However due to the difference in the charges of the two capacitors, the base of the transistor which was previously not conducting reaches the threshold voltage first, and it gets on until it is activated again via a clap.

There are two Red Light Emitting Diodes (LED) placed in the two collector circuits to direct the voltage/current from the supply flow in one direction. These two LEDs however can be replaced by a normal diode, 1N4001.

Output Stage

In the output stage, there are a relay and a transistor. The relay is used as a switch to trigger another circuitry. One of the coil terminals of the relay is joined to the collector of the transistor, and remain coil terminal will be joint to a relay triggering source. The base of the transistor is joined to the collector of one of the transistors in the bistable multivibrator. As the transistor is in off state, the current from the source that nearby the collector will be flowed to the base and hence the transistor is in on state and the relay triggering source can be flowed to the relay and hence, the relay will be on and able to triggering the third party circuit.

3.5.1 Electret Microphone

Electret microphones are the most commonly used microphones today. An electret microphone is a type of condenser microphone which eliminates the need for a polarizing power supply by using a permanently charged material. They can have an extremely wide frequency response (from 10Hz to 30 kHz). They are also very small and quite sensitive. Despite these good characteristics, they can also have a few drawbacks, such as a high noise floor, high distortion, and uneven frequency response.

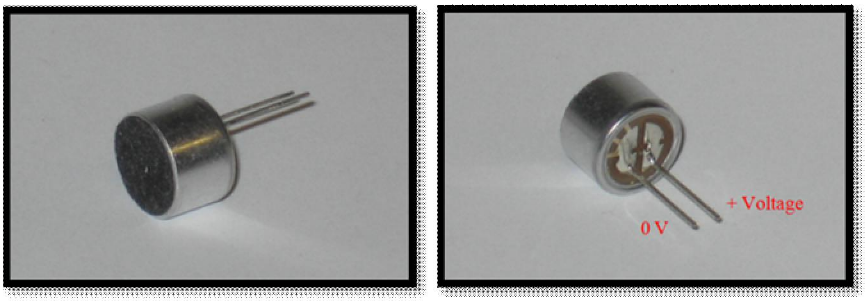


Figure 3.5: Front View and Back View of Electret Microphone

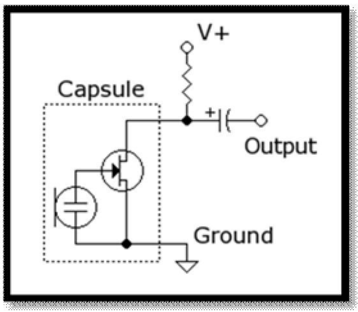


Figure 3.6: Schematic Diagram of the Electret Microphone

As mentioned before the electret microphone is a stable dielectric material which has a permanently-embedded static electric charge. It usually contains polar molecules which then allow it to re-solidify in a powerful electrostatic field. The polar molecules of dielectric align themselves via the direction of the electrostatic field creating a permanent electrostatic bias.

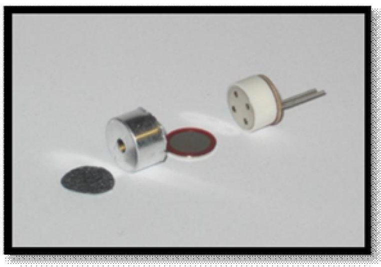
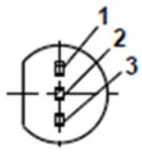


Figure 3.7: Electret Materials

The electret material is the shiny silver circle shown in the Figure 3.7. It is made of a metalized Mylar film which is adhered to a metal washer. There is also a small red plastic spacer to keep the film at a fix distance from the amplifier module. Both the spacer and electret are extremely thin (.001inch or less).

3.5.2 Transistor

Based on the Philips datasheet of BC547, those are the pins and how it is located. A transistor can act as an amplifier or even a switch when it comes to electronic signals and is made of semiconductor. The norm of a transistor is that it will usually have three terminals: emitter, base and collector for connection purposes in an external circuit. Nowadays, it is commonly used in modern electronic devices due to its functionality.



PIN	DESCRIPTION
1	emitter
2	base
3	collector

Figure 3.8: Pins and Locations of a Transistor

Operation of BC547 NPN Transistor

1. The base-emitter junction behaves like a diode.
2. A base current I_B flows only when the voltage V_{BE} across the base-emitter junction is 0.7V or more.
3. The small base current I_B controls the large collector current Ic; where Ic = $h_{FE} \times I_B$ (unless the transistor is full on and saturated)
4. h_{FE} is the current gain (strictly the DC current gain), a typical value for h_{FE} is 100.
5. The collector-emitter resistance R_{CE} is controlled by the base current I_B :
   a) As $I_B = 0$, R_{CE} = infinity, hence the transistor will be in off state.

b) As I_B is small, R_{CE} will be reduced, hence transistor will be partly on

c) As I_B increased, $R_{CE} = 0$, and the transistor will be fully on or it so called saturated condition

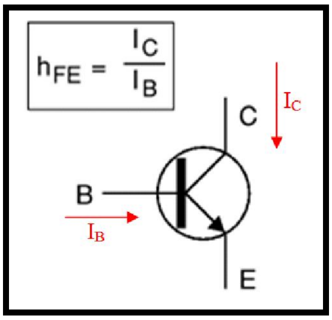


Figure 3.9: General BJT transistor

3.5.3 Capacitor

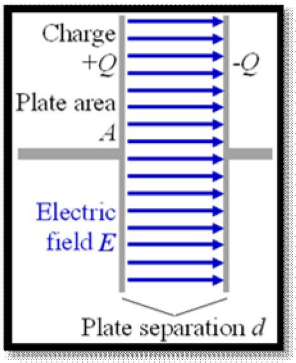
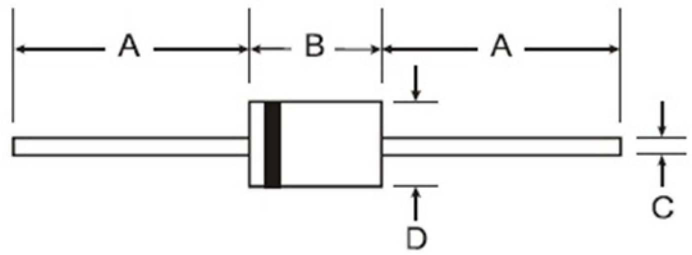


Figure 3.10: Operation of Capacitor

Usually, there are a few types of capacitors which polarities should be considered. The 100 n F capacitors do not have polarities and comes in many form of material, for example, ceramic or even plastic film. For the 10 μ F, which is an electrolytic capacitors, usually has marking on them which states the capacitance value, voltage rating and the indicator for negative polarity.

This component is used for storing electrical charge purposes. It is a passive component whereby it has a pair of conductors that is separated by a dielectric. Existence of a potential difference across the conductors will create a positive charge to collect on one plate and negative charge on the other plate. This energy is then stored in the electrostatic field. Additionally, it is used to block DC current while allowing AC current to pass through and is most suitably used as filtering networks (smoothing output signal) and many others. A capacitance is greatest when there is a narrow separation between large areas of conductors. Practically, leakage of current exists between the plates and also with an electric field strength limit which will result in voltage breakdown.

3.5.4 Diode



Dim	DO-41 Plastic	
	Min	Max
A	25.40	—
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All Dimensions in mm		

Figure 3.11: Dimension of Diode

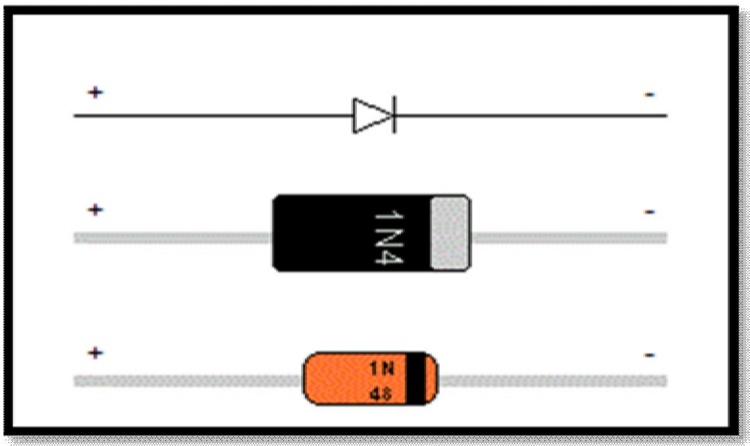


Figure 3.12: Polarity of Diode

For common cases, a diode usually consists of two-terminal electronic component which only conducts current in one direction. It is common to find the semiconductor material in crystalline piece. The diode's function is to allow electrical current to pass through in one direction while it blocks the opposite current. This can also be called rectification and commonly used to convert AC current to DC current via bridge connection and also for extraction process in modulation for radio signals. Zener diodes, however can work as a voltage regulator, for radio tuning, TV receivers and so on. The characteristics of 1N4001 diode is as below

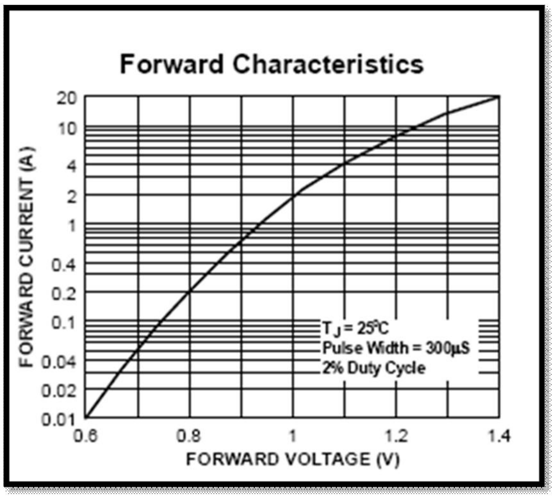


Figure 3.13: Characteristics of Diode

3.5.5 Relay

Figure 3.14: 5Volt PCB type Relay

A relay is an electrically operated switch. Current flowing through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts.

The coil current can be on or off, so relays have two switch positions and most have double throw (changeover) switch contacts as shown in the Figure 3.15.

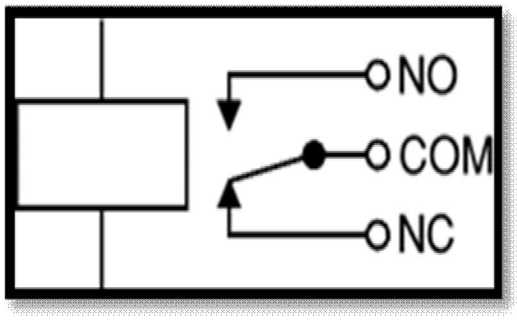


Figure 3.15: Schematic of Operation Relay

Relays allow one circuit to switch a second circuit which can be completely separate from the first. For example a low voltage battery circuit can use a relay to switch a 230V AC main circuit. There is no electrical connection inside the relay between the two circuits; the link is magnetic and mechanical.

Relays are usually SPDT or DPDT but they can have many more sets of switch contacts, for example, relays with 4 sets of changeover contacts are readily available. The relay's switch connections are usually labelled COM, NC and NO where COM, NC AND NO are meant to be:

COM = Common, the moving part of the switch.

NC = Normally Closed, COM is connected to this when the relay coil is off.

NO = Normally Open, COM is connected to this when the relay coil is on.

For the HK3FF-DC5V-SHG model relay, its specifications are:

Max. Switching Current: 3A

Max .Switching Voltage: 300VAC/60VDC

Max Switching Power: 750VA /90W

Coil Voltage: 3V, 5V, 6V, 9V, 12V, 24V

Coil Power: 0.5W, 0.2W, 0.36

3.6 PIC Microcontroller Circuit

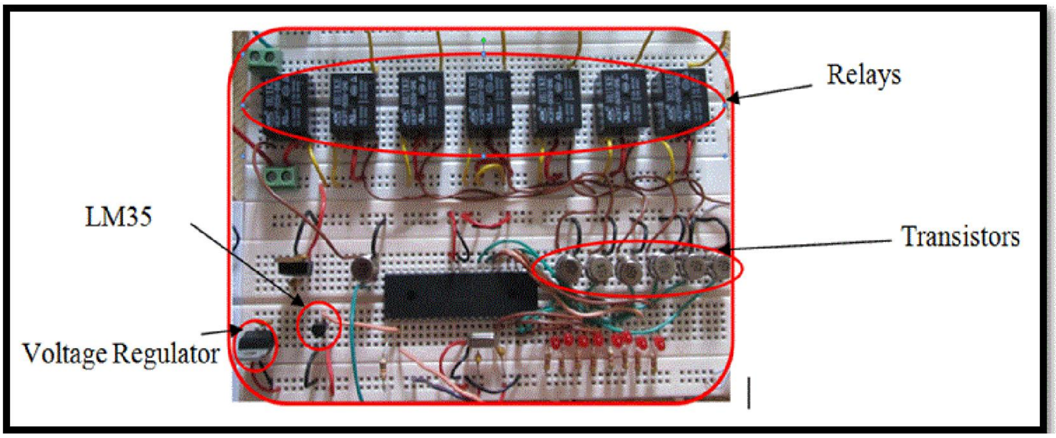


Figure 3.16: PIC Microcontroller Circuit

The voltage regulator is used to supply the required voltage for the whole circuit where in this case, a 5volt supply is needed. When the temperature sensor, LM35 sensed the surrounding ambient temperature, it will produce a very small output voltage. This output voltage will then be fed to the PIC microcontroller. PIC microcontroller in this case will perform as a digital signal process medium where it takes the output voltage and converts it into digital form for further processing.

Before the system work, it requires the two different values to be set at the highest and the lowest temperatures. These values are the crucial values in this project. The highest reference temperature will be set to a limit boundary temperature where there should be no temperature higher than it. If the output voltage from temperature sensor is found to be higher than the highest preset reference temperature value, it indicates that there might be fire breakout occurring or there are some faulty errors occurred in the circuit, for example, a short circuit could causes the circuit's temperature to go higher and cause the ambient temperature sensed by the sensor to reach an abnormal level.

The lowest reference temperature is used to set the maximum requirement temperature in order for the speed of the motor to be stopped. It means that when the ambient temperature is found to be lower than the lowest reference temperature, the motor will be stopped.

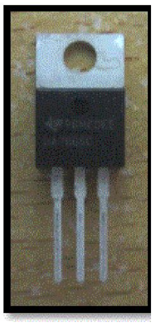
Besides that, some of the preset values for difference temperatures are also being set in the microcontroller. After the output voltage from the LM35 is compared with several preset values in the microcontroller, a result output from the microcontroller will then be used to trigger the BJT transistor where the BJT transistors are link to the relays in the phase control circuit.

Ambient Temperature (^oC)	**Temperature Sensor Output (input to PIC) (mV)**	**The Suggestion Speed**
20	200	Stop
26	260	0
27	270	1
28	280	2
29	290	3
30	300	5
38	380	Stop

Table 3.0: The Suggestion Speed for Difference Ambient Temperatures

3.6.1 Voltage Regulator

Voltage Regulator (regulator) usually has three legs and used to generates a fixed output voltage of a preset magnitude. The output will remain constant regardless of any changes to its input voltage or load conditions.



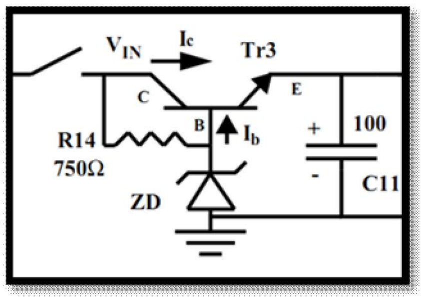


Figure 3.17: 5Volt Regulator

The most common part numbers start with the numbers 78 or 79 and finish with two digits indicating the output voltage. The number 78 represents positive voltage and 79 negative one. The 78XX series of voltage regulators are designed for positive input. And the 79XX series is designed for negative input.

For the LM7805, it has the ability to drive current up to 1A. As mentioned above, the component has three legs: Input leg which can hold up to 36VDC, common leg (GND) and an output leg with the regulator's voltage. For maximum voltage regulation, adding a capacitor in parallel between the common leg and the output is usually recommended. Typically a 0.1uF and 0.33uF capacitors are used. This is to eliminate any high frequency AC voltage that could otherwise combine with the output voltage.

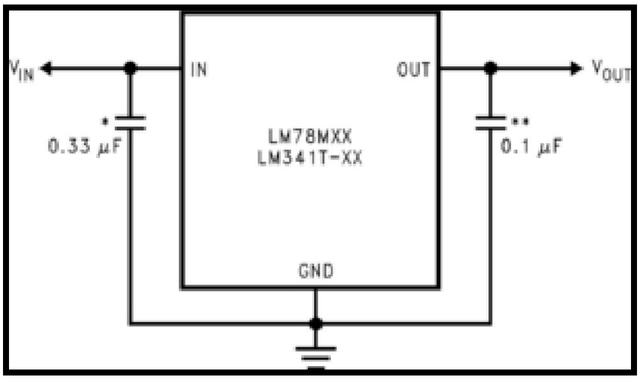


Figure 3.18: Typical Connection of Voltage Regulator

As a general rule, the input voltage should be limited to 2 to 3 volts above the output voltage. The LM7805 can handle up to 36 volts input. It is advised that the power difference between the input and output will appear as heat. If the input voltage is unnecessarily high, the regulator will overheat. Unless sufficient heat dissipation is provided through heat sinking, the regulator will shut down.

3.6.2 Temperature Sensor

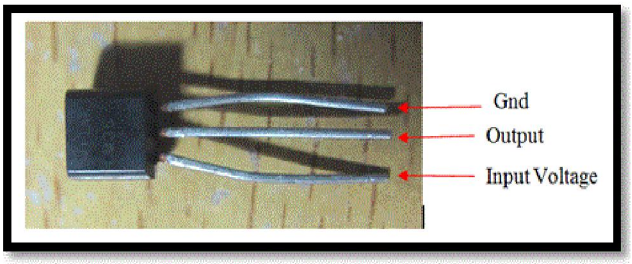


Figure 3.19: LM35

In this project, the temperature sensor used is LM35. The LM35 temperature sensor is the easiest of all the temperature sensors to use because it is an integrated circuit that emits a voltage proportional to the temperature in degrees Celsius. The sensor itself takes care of the non-linear effects that occur with some other sensors so the sensor input circuitry is simplified. Another benefit is that the output voltage is higher than other sensors (such as thermocouples) and therefore an amplifier circuit is not necessary. The scale factor for a typical LM35 is 0.01V/'C. It has a typical accuracy of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range.

3.6.3 PIC Microcontroller

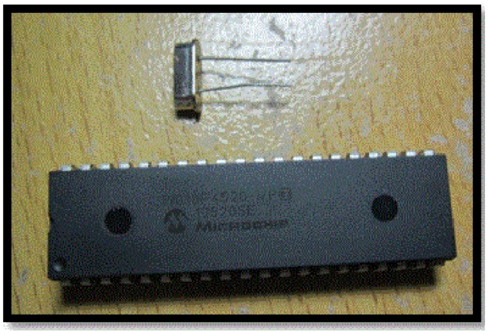


Figure 3.20: PIC Microcontroller P18f4520

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology which originally developed by General Instrument's Microelectronics

Division. The name PIC initially referred to "Peripheral Interface Controller". PIC microcontrollers (Programmable Interface Controllers) are electronic circuits that can be programmed to carry out a vast range of tasks. In this project the PIC Microcontroller used is PIC18F4520. The reason it is being used is because PIC18F is considered as a modern/common PIC model in the market. Hence there will be no harm when there is a need of replacing the PIC. Besides that, PIC18F4520 consists of 40pins which means that more input and output ports can be programmed and used.

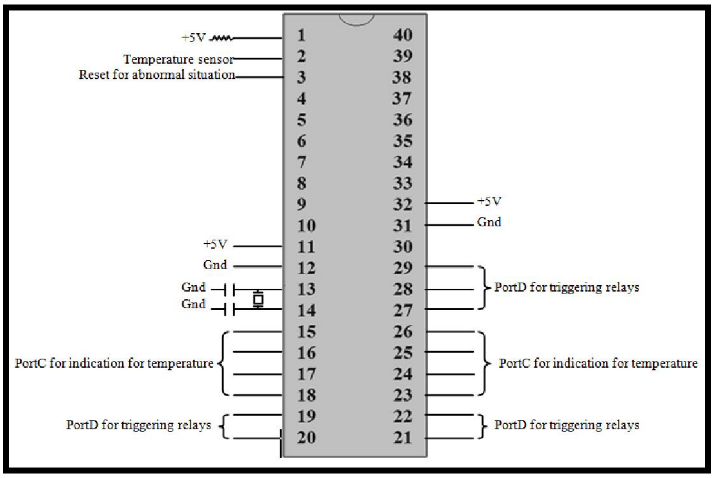


Figure 3.21: PIC I/O Pins Diagram

The PIC microcontroller in this system works as a digital processing component. The temperature sensor is connected to RA0, hence the output voltage from the sensor will be sent to RA0. After that the PIC will do the Analogue to digital (ADC) operation to digitalize the analogue signals. Next, it will compare the ambient temperature to each of the reference temperatures. The comparison results will then be used to generate different signals at the PortD (RD0-RD6) to the relay to control the firing angle of the Triac. With the firing angle controlled, the motor speed can also be controlled. In addition, the temperature will also be indicated in PortC. Note that the values shown in PortC need to be divided by 2 in order to get the actual temperature reading of the ambient temperature sensed.

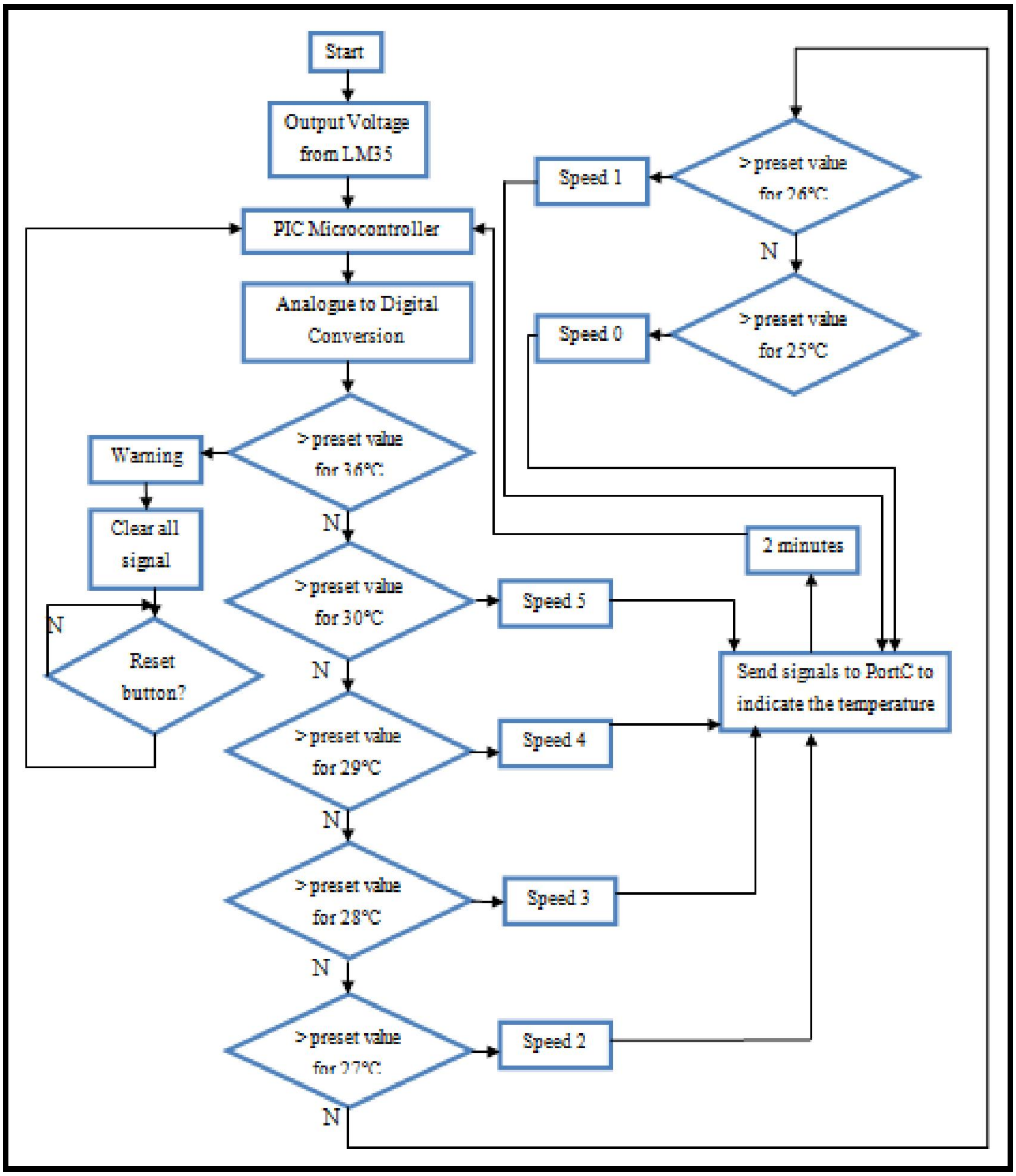


Figure 3.22: PIC Microcontroller Processing Flow Chart

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3.7 Phase Control Circuit

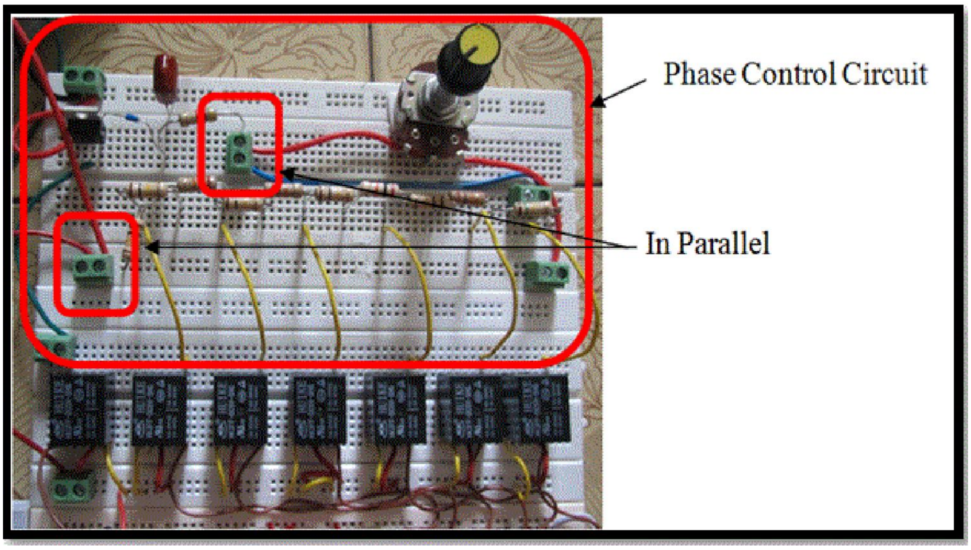


Figure 3.23: Phase Control Circuit

The phase control circuit is the combination of Triac with the firing angle control circuit. The basic full-wave Triac phase control circuit shown in the Figure 3.23. It requires only five components which consist of a Triac, Diac, potentiometer, capacitor and also resistors. The resistance component and the capacitor are a single-element phase-shift network. When the voltage across capacitor reaches breakover voltage (V_{BO}) of the Diac, capacitor is partially discharged by the Diac into the Triac gate. The Triac is then triggered into the conduction mode for the remainder of that half-cycle

As shown in the Figure 3.23, there is a potentiometer connected parallelly with the resistors. This potentiometer is used to set the minimum speed for the motor. To do this, all the relay will be turn off (no output signal from PIC microcontroller) initially so that the resistance for the bottom side will be maxima, then adjusts the potentiometer (with the yellow knob) to obtain the minimum speed desired. Before the Triac gets triggered, it will be in the off state. When there is no voltage passing to the motor, no energy being transfer to the motor hence the speed of the motor will decrease. In this circuit, triggering is in Quadrants I and III. The unique simplicity of this circuit makes it suitable for applications with small control range. The firing time is given by the formula, τ=RC.

3.7.1 Triac

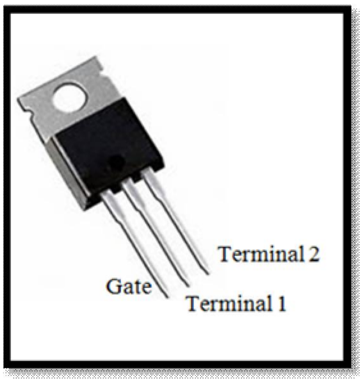


Figure 3.24: Triac BT136-600D

The Triac is a three-terminal device similar in construction and operation to the SCR. The Triac controls and conducts current flow during both alternations of an AC cycle instead of only one. The schematic symbols for the SCR and the Triac are compared in the Figure 3.25. Both the SCR and the Triac have a gate lead. However, in the Triac, the lead on the same side as the gate is "main terminal 1," and the lead opposite the gate is "main terminal 2." This method of lead labelling is necessary because the Triac is essentially two SCRs back to back, with a common gate and common terminals. Each terminal is, in effect, the anode of one SCR and the cathode of another and either terminal can receive an input. In fact, the functions of a Triac can be duplicated by connecting two actual SCRs as shown in the Figure 3.26. The result is a three-terminal device identical to the Triac. The common anode-cathode connections form main terminals 1 and 2, and the common gate forms terminal 3.

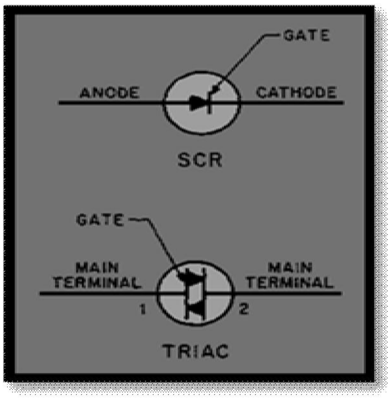


Figure 3.25: Triac vs. SCR

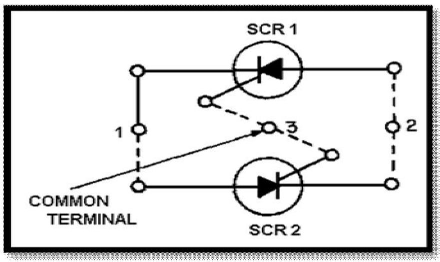


Figure 3.26: Schematic Diagram of Triac

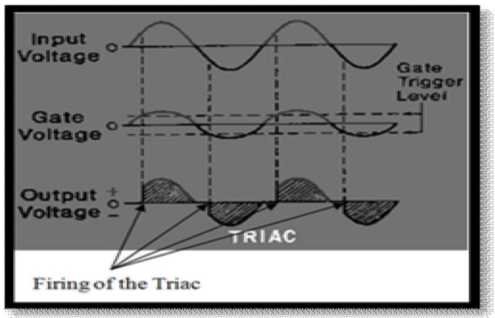


Figure 3.27 Triac Response graph

The Triac used in this project is BT136-600D. This Triac is mainly designed for motor speed control as stated in its datasheet. It can sustain a repetitive peak off state voltage up to 600V. Besides that, it has a low triggering power whereby the gate trigger current is typically only up to 2-5mA.

3.7.2 Diac

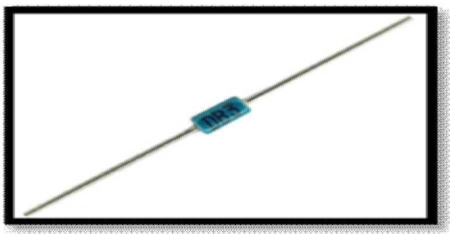


Figure 3.28: Diac DB3

A Diac operated with a DC voltage across it behaves exactly the same as a Shockley diode. With AC, however, the behavior is different from what one might expect. Because alternating current repeatedly reverses direction, Diac will not stay latched longer than one-half cycle. If a Diac becomes latched, it will continue to conduct current only as long as voltage is available to push enough current in that direction. When the AC polarity reverses, the Diac will drop out due to insufficient current, necessitating another breakover before it conducts again. The waveform result is the current waveform in the Figure 3.29.

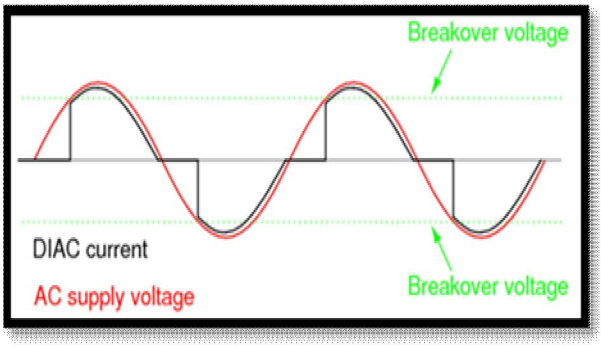


Figure 3.29: Current Waveform for Diac

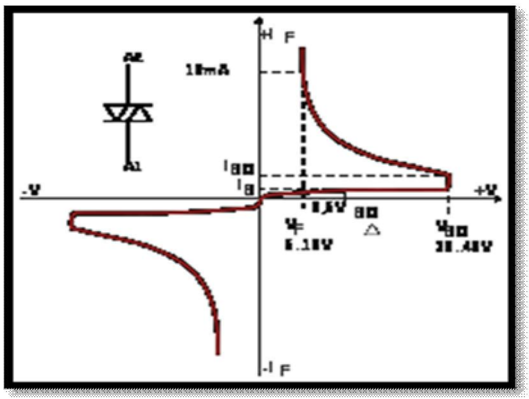


Figure 3.30: Typical Diac Voltage and Current Relationship

For the Diac used in this project, DB3, it has a low breakdown current up to 50uA. It can sustain the breakdown voltage from 28V to 36V (maximum limit). For any breakdown voltage higher than 36V, the Diac will get burn and spoilt.

3.7.3 Potentiometer

A potentiometer is a manually adjustable electrical resistor that uses three terminals. In many electrical devices, potentiometers are what establish the levels of output.

Potentiometers, sometimes called pots, are relatively simple devices. One terminal of the potentiometer is connected to a power source, and another is hooked up to a ground, a point with no voltage or resistance which serves as a neutral reference point. The third terminal slides across a strip of resistive material. This resistive strip generally has a low resistance at one end, and its resistance gradually increases to a maximum resistance at the other end. The third terminal serves as the connection between the power source and ground, and it is usually operated by the user through the use of a knob or lever.

The user can adjust the position of the third terminal along the resistive strip to manually increase or decrease resistance. The amount of resistance determines how many current flows through a circuit. When used to regulate current, the potentiometer is limited by the maximum resistivity of the strip.

As this project involves a large AC voltage, the value rated of the potentiometers chosen is 0.5watt where more power can be sustained compare to the 0.25 watt. Besides that, a knob will also be placed on the potentiometer for safety purpose when adjusting its resistance. For the large power potentiometer, the size will be bigger than the lower one. The Figure 3.31 shows the size of 0.5watt compare to 0.25 watt potentiometer.

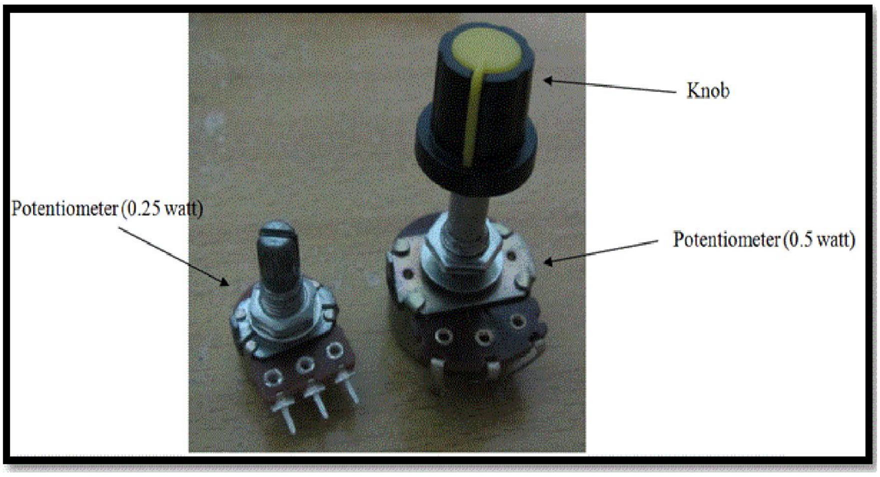


Figure 3.31: Potentiometers for 0.25watt and 0.5watt with the Knob

3.8 Printed Circuit Board (PCB) Design

To make the product of this project marketable, there is a need to make the circuit in PCB type. This is because in PCB, this circuit will be looked tidier and also can be stacked over one another. Hence, the space required can be reduced for the whole circuit board. The following are the schematic diagrams and the corresponding PCB design layouts for the circuits that involved in this project. Note that the ratio for the PCB layout is not 1 to 1.

3.8.1 Hand Clap Circuit

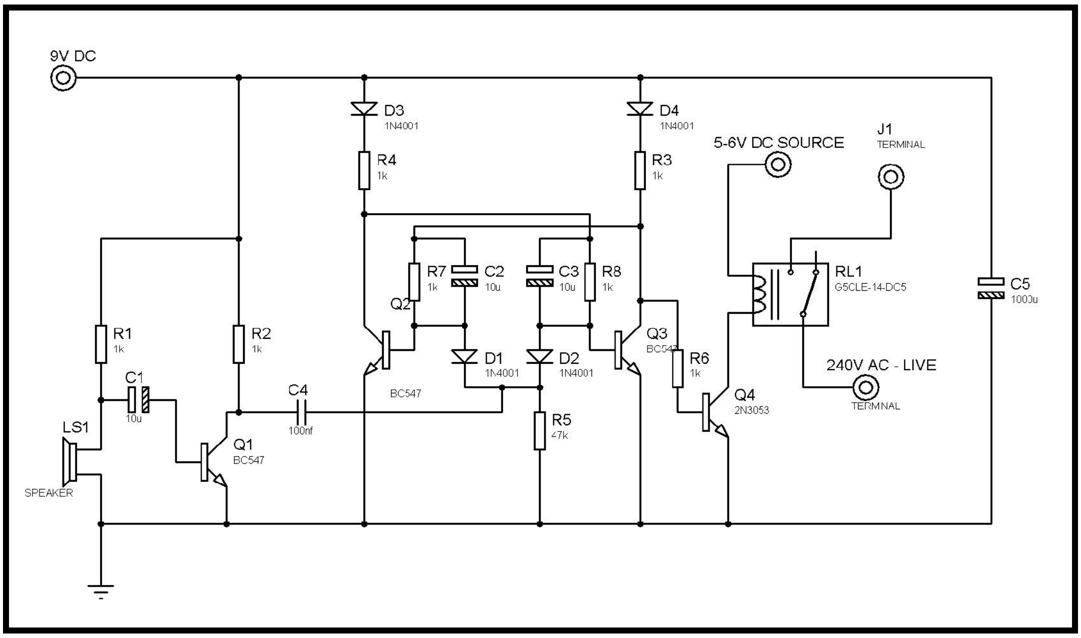


Figure 3.32: Schematic Diagram of Hand Clap Circuit

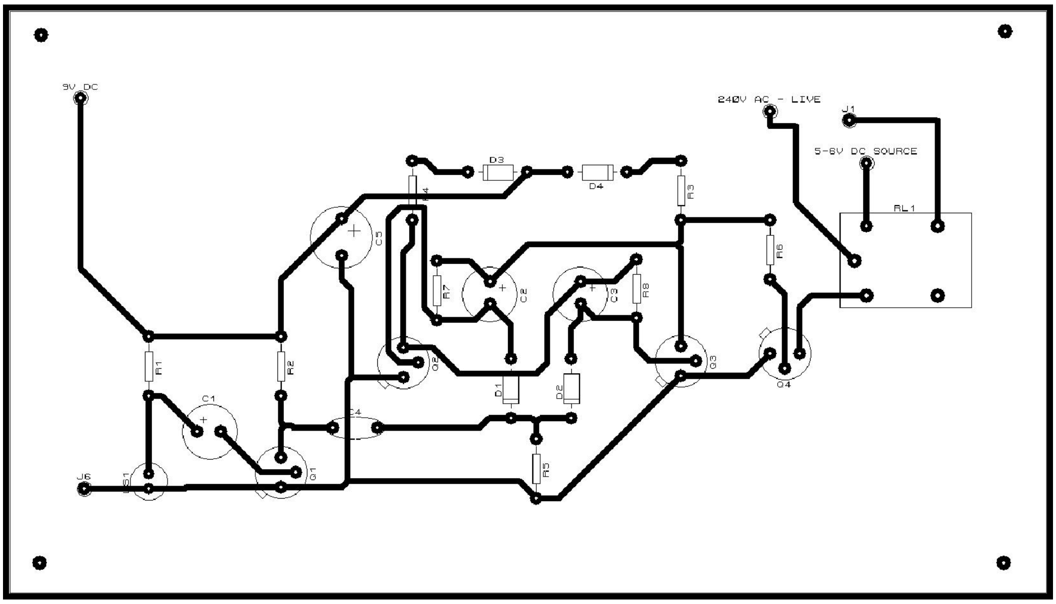


Figure 3.33: PCB Design Layout of Hand Clap Circuit

3.8.2 PIC Microcontroller Circuit

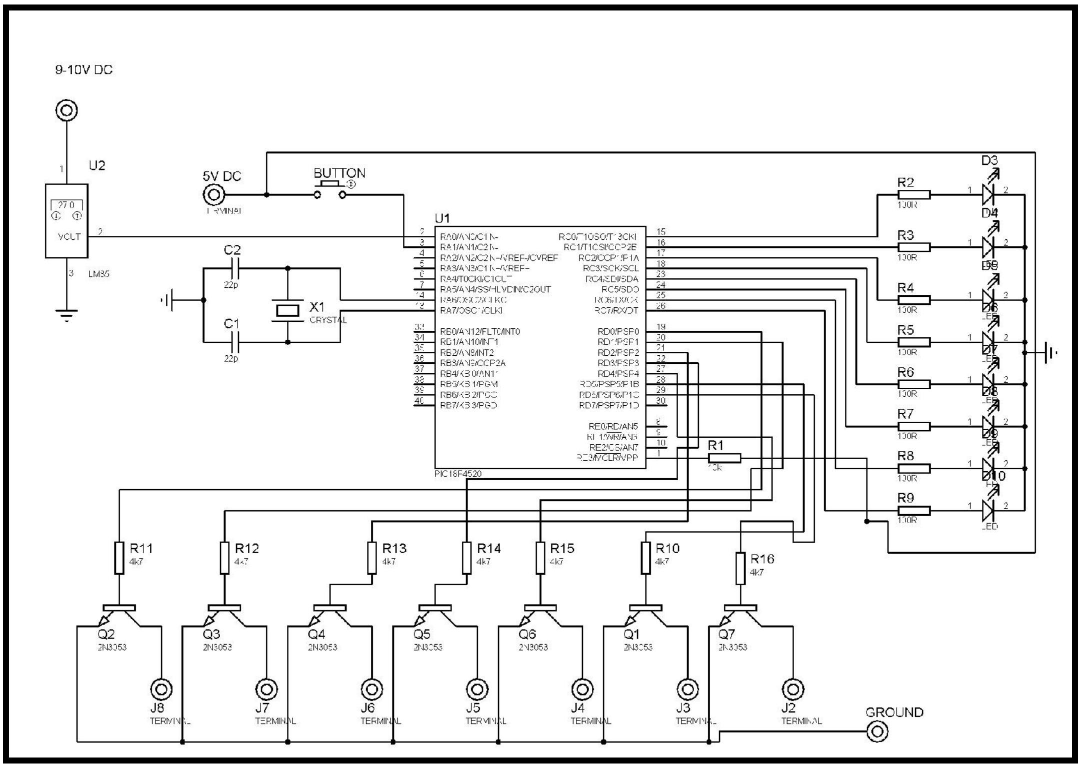


Figure 3.34: Schematic Diagram of PIC Microcontroller Circuit Board

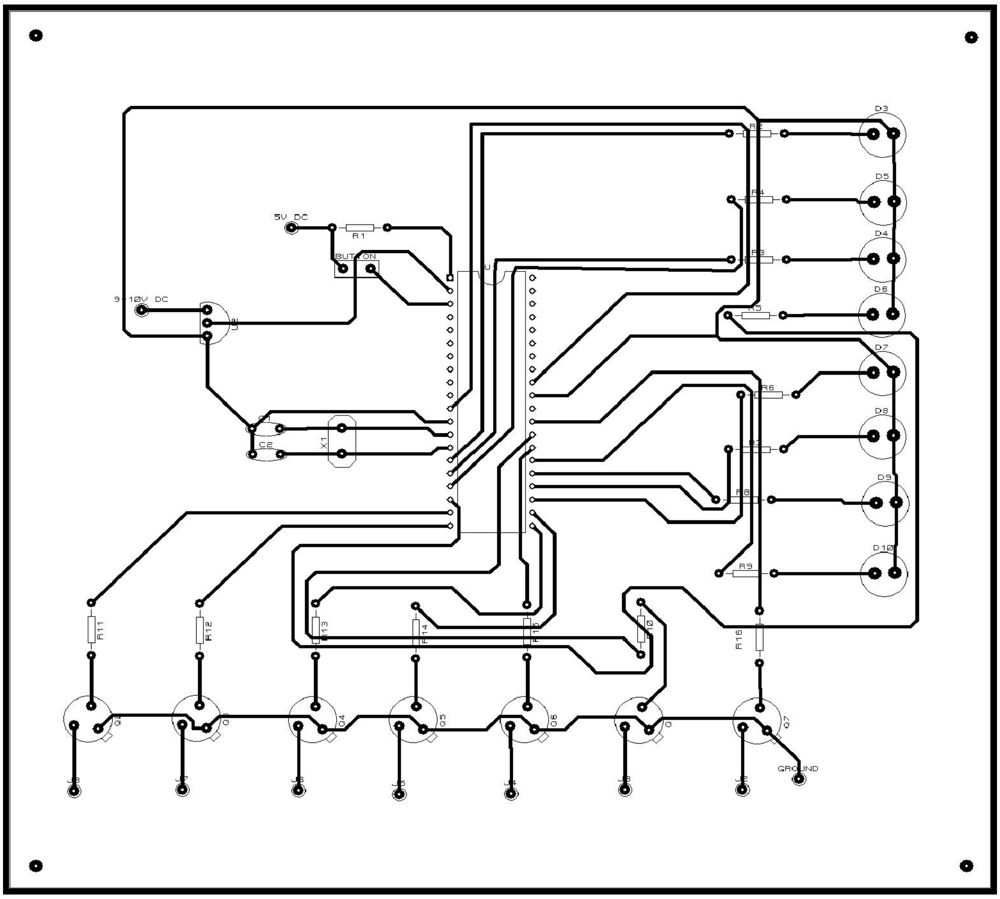


Figure 3.35: PCB Design Layout for PIC Microcontroller Circuit

3.8.3 Relays Control Circuit

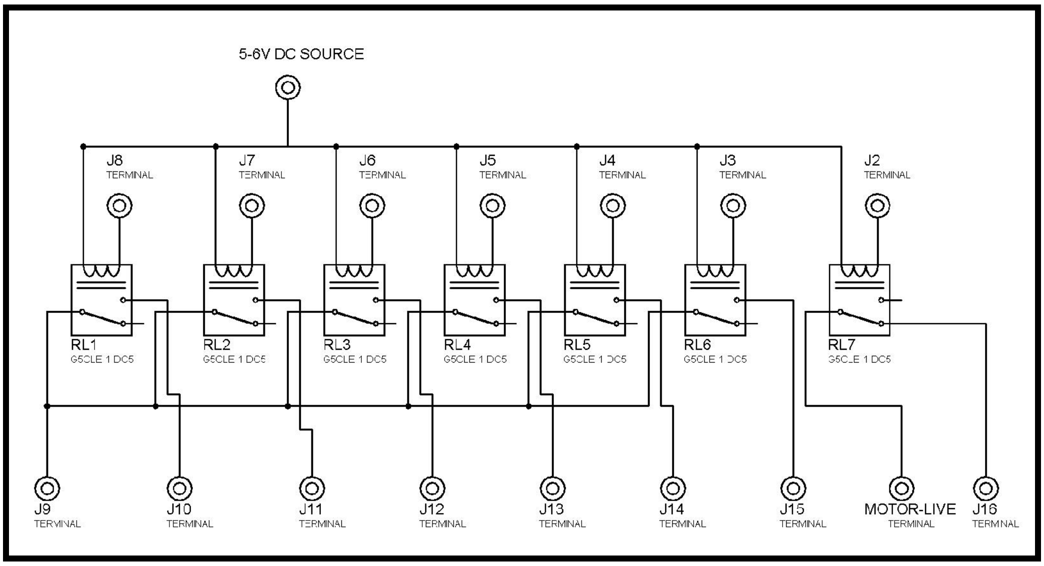


Figure 3.36: Schematic Diagram for Relays Board

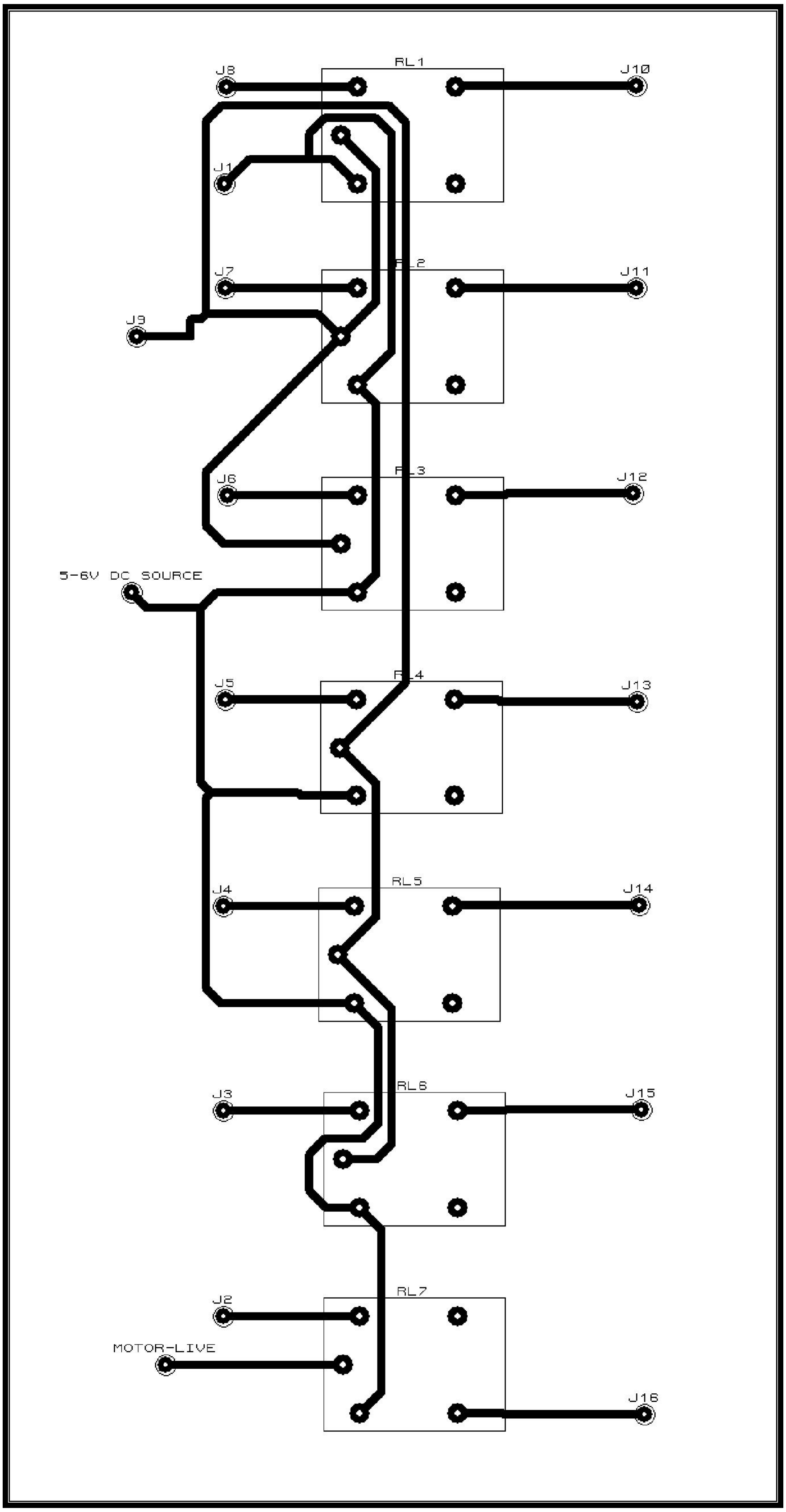


Figure 3.37: PCB Design Layout for Relays Board

3.8.4 Phase Control Circuit

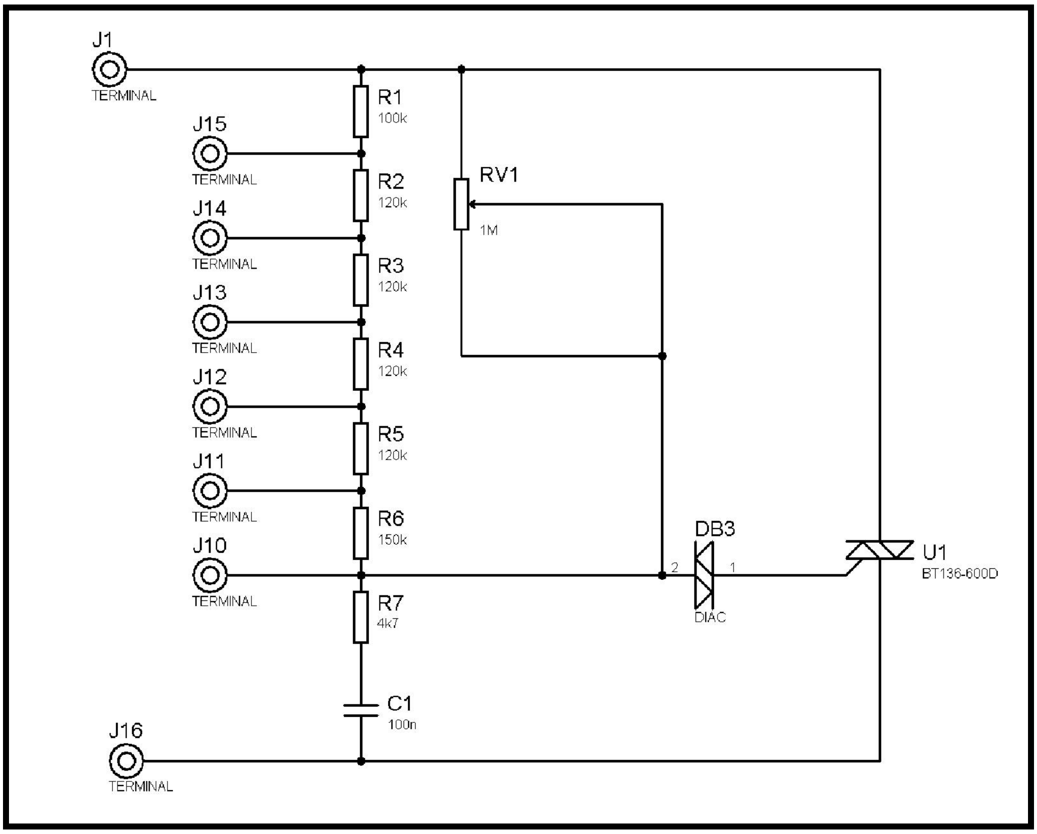


Figure 3.38: Schematic Diagram of Phase Control Circuit

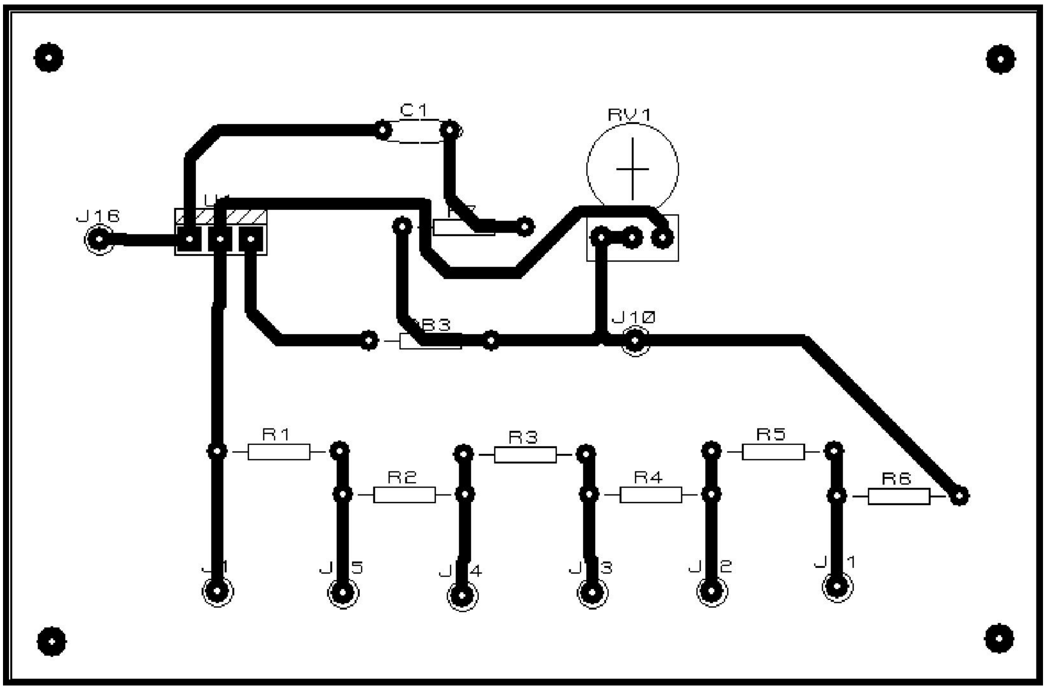


Figure 3.39: PCB Design Layout for Phase Control Circuit

3.9 Cost Estimated

The budget for this FYP is RM500. Hence, the total price for each component must be calculated and planed carefully to avoid over budget. The table below shows the components that are needed to construct and make this project a success.

Item	**Quantity**	**Price**	**Total**
Temperature Sensor LM35DZ	1	RM 4.00	16
Triac	1	RM 2.50	10
Diac	1	RM0.30	0.30
Table Fan	1	RM 70.00	70
Relays	8	RM 2.00	16
Transistor	8	RM2.00	16
Resistors	20	Rm0.20	4
Capacitor	10	Rm0.40	4
Microcontroller 18F4520	1	RM 23.00	23
Components used to conduct experiments	~	~	240
Total			399.30

Table 3.1: Components Price

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Volumetric Flow Rate

In this experiment, the DC motor fan is placed in 16 difference positions in front of the stand fan, hence the results obtain are reliable as plenty of readings are taken. The average value for the results is calculated.

		SET 1			SET 2		
Speed	Direction	Distance from fan			Distance from fan		
		4 cm	8cm	12cm	4 cm	8cm	12cm
3	TOP	0.88	0.82	0.74	0.85	0.79	0.76
2		0.65	0.57	0.53	0.79	0.64	0.6
1		0.5	0.46	0.41	0.76	0.46	0.45
3	RIGHT TOP	0.97	0.86	0.8	0.76	0.74	0.71
2		0.75	0.73	0.67	0.59	0.58	0.57
1		0.58	0.56	0.52	0.45	0.45	0.42
3	RIGHT	0.93	0.87	0.83	0.73	0.67	0.65
2		0.72	0.67	0.65	0.6	0.52	0.49
1		0.54	0.5	0.48	0.42	0.4	0.35
3	RIGHT BTM	0.83	0.79	0.82	0.57	0.5	0.45
2		0.64	0.62	0.59	0.41	0.38	0.33
1		0.49	0.47	0.44	0.27	0.27	0.22
3	BTM	0.88	0.86	0.82	0.7	0.64	0.61
2		0.71	0.67	0.64	0.58	0.5	0.46
1		0.55	0.51	0.47	0.45	0.4	0.34
3	LEFT BTM	0.92	0.82	0.8	0.66	0.56	0.54
2		0.75	0.67	0.63	0.51	0.42	0.42
1		0.6	0.53	0.49	0.39	0.36	0.29
3	LEFT	0.81	0.75	0.73	0.71	0.63	0.59
2		0.64	0.58	0.57	0.57	0.53	0.48
1		0.5	0.46	0.42	0.46	0.41	0.35
3	LEFT TOP	0.82	0.7	0.67	0.7	0.67	0.64
2		0.58	0.54	0.5	0.56	0.53	0.52
1		0.44	0.4	0.37	0.44	0.43	0.38

Table 4.0: Results obtained by Placing the DC motor fan in front of difference positions of the Stand Fan

	Set 1				Set 2		
	4cm	8cm	12cm		4cm	8cm	12cm
Speed 3	0.88	0.80875	0.77625		0.71	0.65	0.61875
Speed 2	0.68	0.63125	0.5975		0.57625	0.5125	0.48375
Speed 1	0.525	0.48625	0.45		0.455	0.3975	0.30625

Table 4.1: Average Value for the Results

By making the assumption formula of

$$output\ voltage = k \times volumetric\ flow\ rate$$

As the output voltage produced by the DC motor is proportional to the speed of the motor, the constant k can be obtained from the assumption formula. With the K value known, evaluation of the relationship between the speeds (RPM) of the fan with the volumetric flow rate is given by the formula,

$$speed = k \times volumetric\ flow\ rate$$

	speed = k . Volumetric flow rate	k	cubic meter/minute
Speed 3	0.88 = k . 40m^3/mins	0.022	40
Speed 2	0.68 = 0.022 *cubic meter/minute	0.022	30.9091
Speed 1	0.525=0.022*cubic meter/minute	0.022	23.8636

Table 4.2: Overall Results for Cubic Meter per Minute for difference Speed of the Motor Fan

The following diagrams show the results for the thermal flow simulation. Figure 4.0 shows the temperature distribution by using the cut plot of a situation when the fan running in a very low volumetric flow rate whereas for Figure 4.1 is the cut plot of a situation when the fan is running at 40 cubic meter per minute.

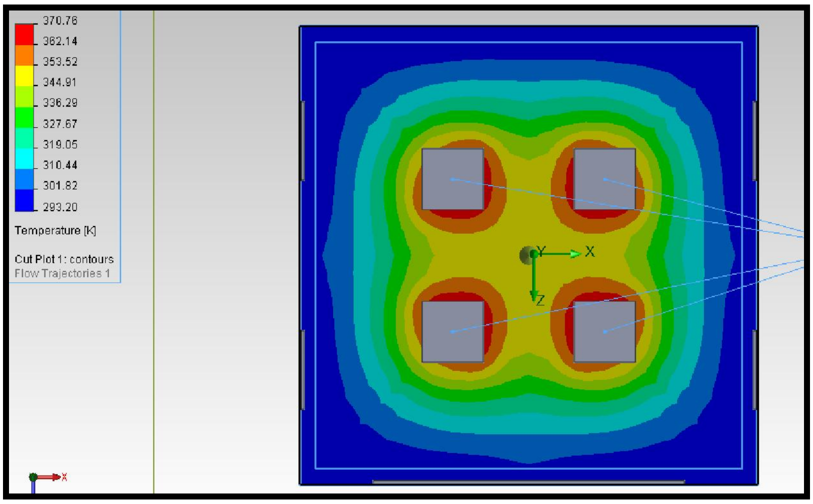


Figure 4.0: Temperature Distribution by using the Cut Plot in the situation of Low Volumetric Flow Rate

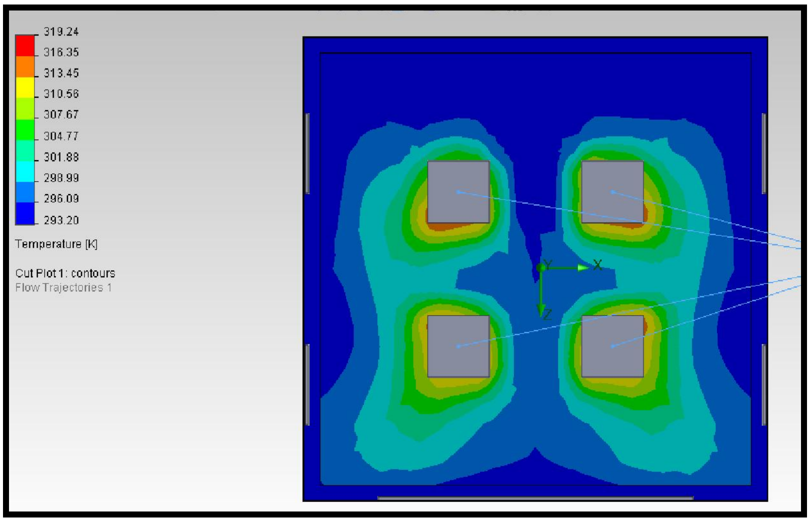


Figure 4.1: Temperature Distribution by using the Cut Plot in the Situation with the Volumetric Flow Rate equal to 40 Cubic Meter per Minute

The 4 boxes in both the figures represented a heat sources. As this project is designed to be used in stand fan, hence, the heat sources are set to be similar with house appliance devices. When there is low volumetric flow rate, the heat produced by the heat sources will be accumulated as shown in Figure 4.0. If this accumulated heat is not circulated out or removed, the temperature will keep increasing, and cause hazard or discomfort if there is a human. Besides that, the devices surrounding the heat sources or the heat source devices will be facing a high temperature. If the high temperature exceeds the maximum rated temperature which can be sustained by the devices, the lifespan of the devices will be reduced by half for every excessive 1 degree Celsius.

4.2 Hand Clap Switch

As mentioned in the section 3, the amplifier of microphone is not the stronger one; hence, the pulse generated by the microphone is not that strong. Therefore, there is a need to study the characteristics of the BJT transistors. This is because, for certain transistor such as 2N3053, the gate triggering current is 0.7A whereas for BC547, the requirement gate trigger current is just 0.5mA – 0.5A. Therefore, BC547 is chosen in this hand clap circuit.

Initially, the first draft prototype of the hand clap circuit is built as shown in the Figure 4.2. Notice that for the first draft, relay was not installed into the circuit.

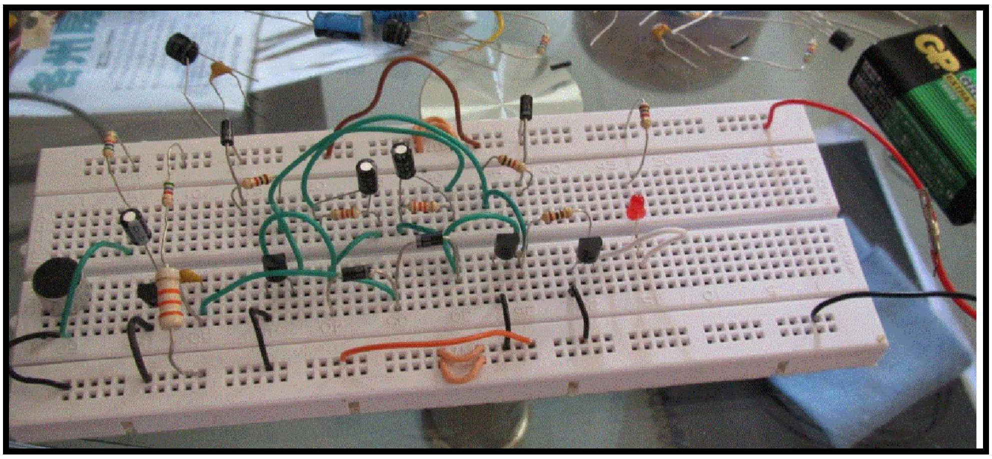


Figure 4.2: First Draft Hand Clap Circuit

After the "hand clap" test is performed to this circuit, the results are shown below.

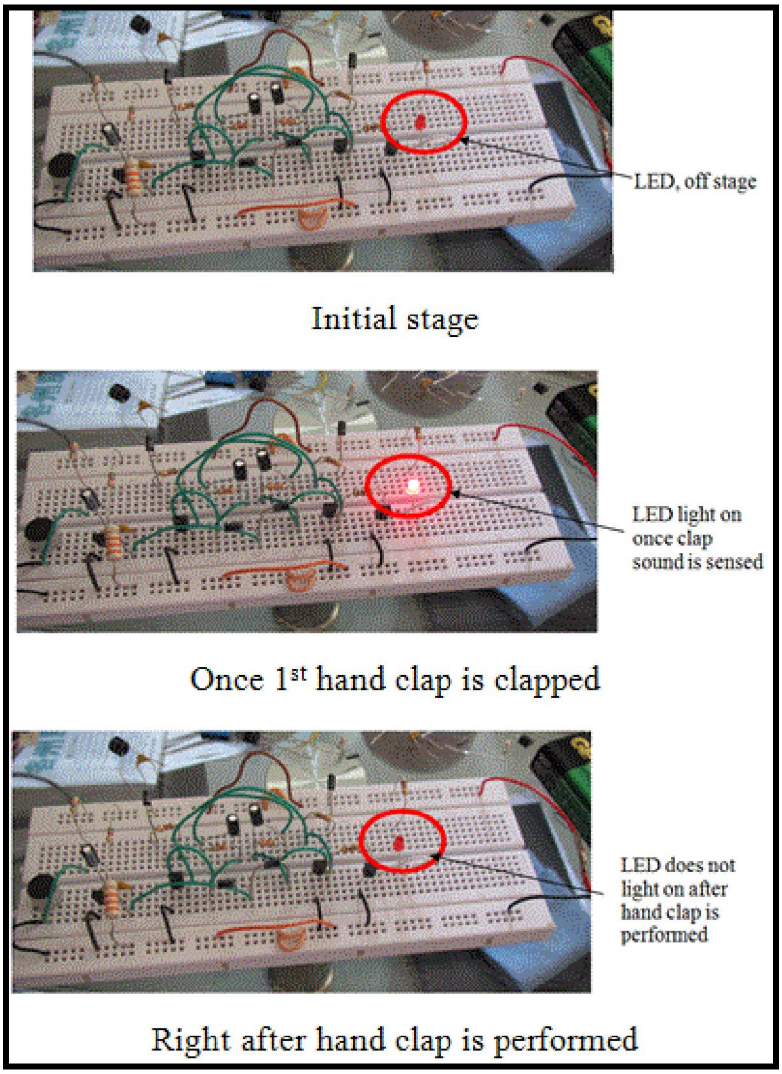


Figure 4.3: Results at Initial Stage, the moment Hand Clap is Clapped and right after the Hand Clap is Performed

Hand clap	Result
0 (initial stage)	The LED light does not light up, the transistor, T4 is react as open switch
1st clap	The LED light on, but it immediately goes off, it does not stay on
2nd Clap	The LED light on, but it immediately goes off, it does not stay on

Table 4.3: Result of first draft Hand Clap Circuit

From the results shown, the signal to the base of the transistors seems unstable. Once it is triggered on, the signal cannot be hold. Hence the output LED light in the test result can be considered in the pulse form.

To overcome this problem, only one change will be made. The last transistor which is closest to the LED has to be replaced by pulse triggering component, IGBT or Mosfet. This is because IGBT and Mosfet is a pulse triggering component where a single pulse to the gate can be used to trigger the component.

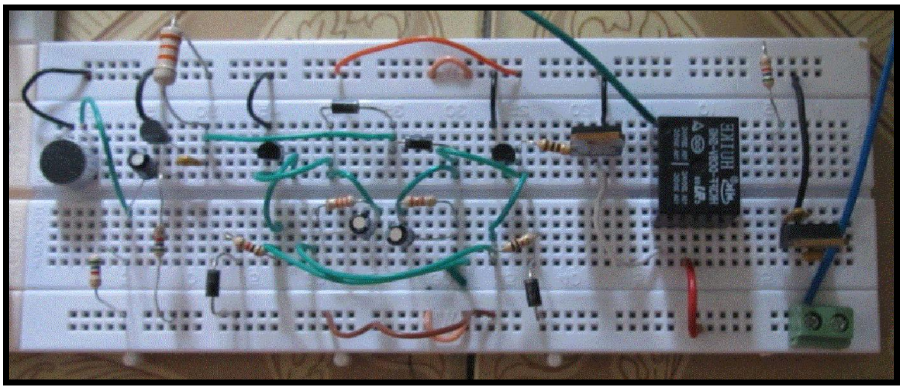


Figure 4.4: Final circuit for Hand Clap Circuit

The following shows the result after replacing by IGBT.

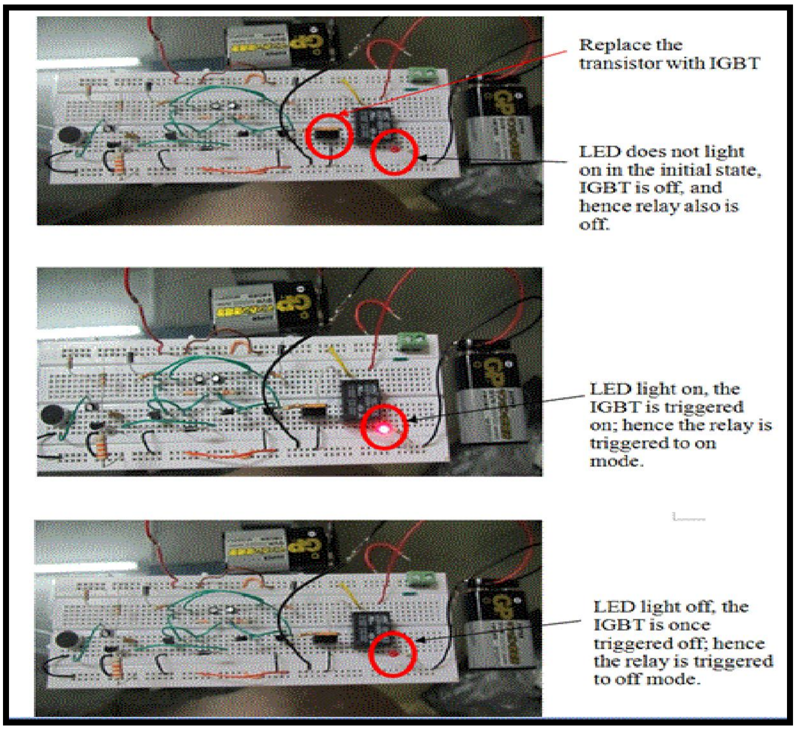


Figure 4.5: Result obtained from the Final circuitry for Hand Clap Circuit

Hand clap	Result
0 (initial stage)	The LED light does not light up, the IGBT is off mode; hence relay is also in off mode. The circuit is opened.
1st clap	The LED light on, the IGBT is triggered on; hence relay is also triggered on. The circuit is closed
2nd Clap	The LED light on, the IGBT is triggered off; hence relay is also triggered off. The circuit is now opened

Table 4.4: Result for the Final Circuit of the Hand Clap Circuit

In this circuit, there must be an adequate supply source to supply the sufficient voltage and current in order for it to work properly. If the supply source does not have enough voltage or current, the gate of the IGBT might not be able to be switched on and switched off like it suppose to.

4.3 PIC Microcontroller Circuit

One of the key factors of this PIC microcontroller circuit is that, the small analogue output voltage generated from the heat sensor, LM35 has to be converted into digital form so that the PIC microcontroller can use it and perform a simple comparison task. In the code programmed into the PIC microcontroller, the ADC conversion is not one to one ratio conversion. This means that for example, if the ambient temperature is 31 degree Celsius, the digital output from the microcontroller will be 00111110. 00111110 is the binary code, where if converted to decimal, should have the value of 62. Hence, each time the result is obtained from the LED indicator; it has to be divided by 2 in order to get the actual ambient temperature reading.

The ADC conversion is not perfect as the resolution of the ADC of the PIC has its limit and hence there will be a quantization error. Let’s say if the output analogue signal from the LM 35 is 0.316V, the output will be 01000000 based on calculation for ADC conversion. However in the practical case, the value obtained is slightly difference from the calculated.

The resolution of the ADC is given by the formula,

$$ADC = \frac{Vin\ (analog\ input)}{step\ size\ (resolution)}$$

$$ADC = \frac{analog\ input}{Vref/2^{bit\ of\ the\ PIC}}$$

In this project, the bit of the PIC microcontroller is 10bit and the $V_{ref} \sim 4.98V$.
For $V_{in} = 0.316V$,

$$ADC = \frac{Vin\ (analog\ input)}{step\ size\ (resolution)}$$

$$ADC = \frac{0.316}{4.98\ \div 2^{10}}$$

$$ADC = \frac{0.316}{249/51200}$$

$$ADC = 64.97$$

In the binary code, the minimum value output is 0 or 1. Hence the 2 decimal values will be roughly close to the integer value. In this case, it will be considered either 64 or 65. Hence the output is ~ 01000000 or 01000001. This problem can be minimized by using high resolution PIC or ADC device. The following shows the output voltage from LM35 with the LED indicator

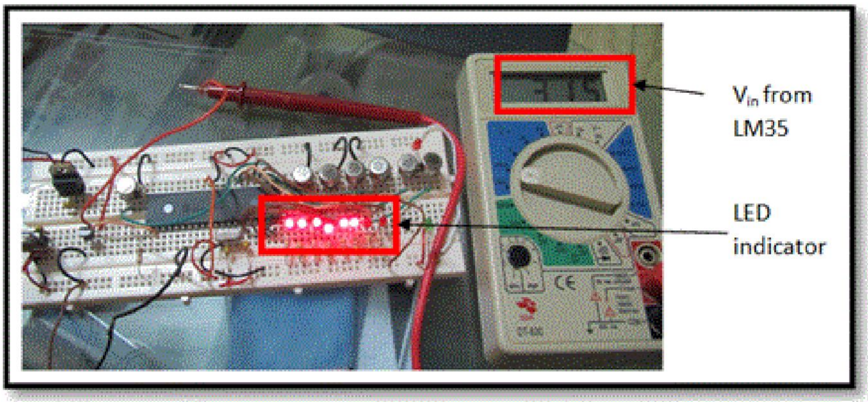


Figure 4.6: Normal ambient temperature, 31.5 degree Celsius (0.315V_{in})

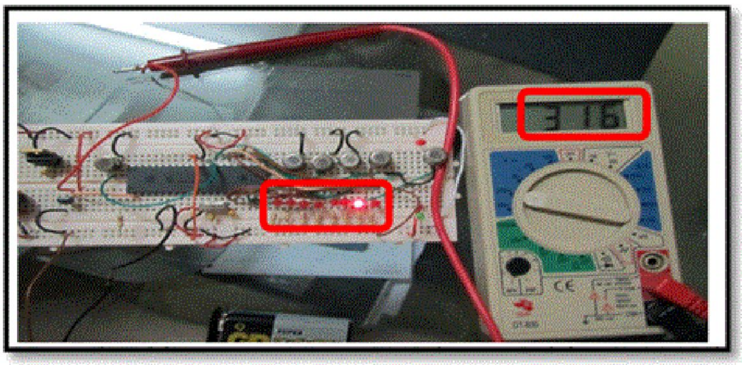


Figure 4.7: Normal ambient temperature, 31.6 degree Celsius (0.316 V_{in})

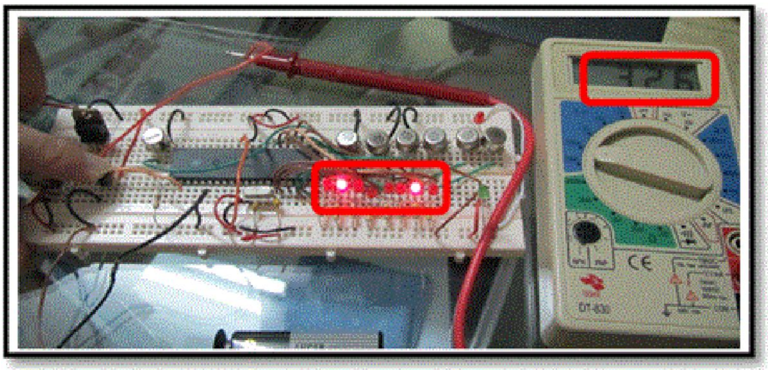


Figure 4.8: Finger temperature 32.6 degree Celsius (0.326 V_{in})

Vin	Step Size (resolution)	Calculated output	Output from LED Indicator (binary form)	Decimal form	Percentage difference, %
0.315	249/512000	64.77	00111111	63	2.73
0.316	249/512000	64.97	01000000	64	1.49
0.326	249/512000	67.03	01000010	66	1.53

Table 4.5: Results for the Output binary from the PIC Microcontroller

From the results obtained, we noticed that there is a percentage difference. The percentage difference is calculated by using the formula,

$$Percentage\ difference = \frac{calculated\ value - measured\ value}{calculated\ value} \times 100\%$$

Although the ADC is not perfect, but from the percentage difference shown, it is less than 5% which can be accepted for our project. As there is a percentage difference, the preset values for different temperatures need to be increased by 2 to compensate the quantization error. The Table 4.6 shows the preset compensated binary values for different temperatures in PIC.

Temperature (°C)	Supposing Binary Value	Compensated Binary Value
20	00101000	00101010
26	00110100	00110110
27	00110110	00111000
28	00111000	00111010
29	00111010	00111100
30	00111100	00111110
38	01001100	01001110

Table4.6: Preset Compensated Binary Values for different Temperatures

Besides ADC control, the process of sending the output signal from the microcontroller to triggering the relay is equally important. The Figure 4.9 shows that when the temperature is higher than 30 degree Celsius, the relay 5 will be triggered as expected and as programmed. For different temperature, different relay will be triggered on the controlled resistance so that the firing angle of Triac changes and hence motor speed will be change as well.

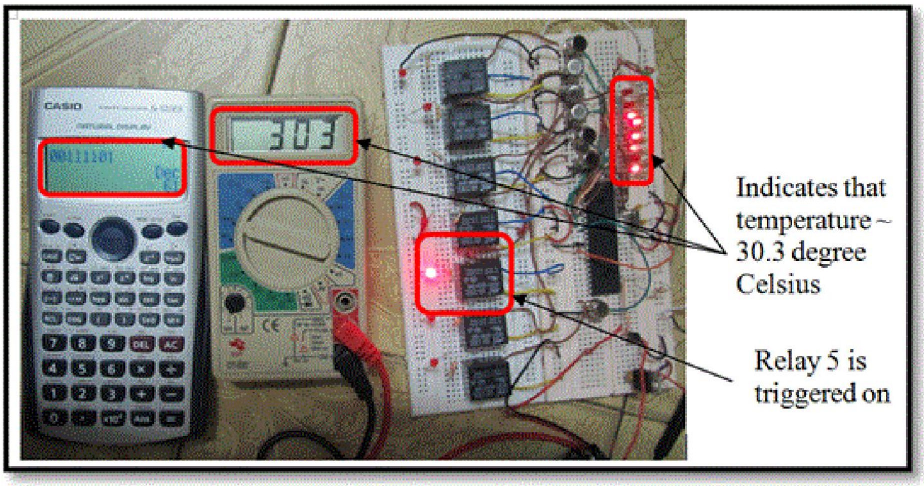


Figure 4.9: Relay 5 at temperature 30.3 degree Celsius

4.4 Phase Control Circuit

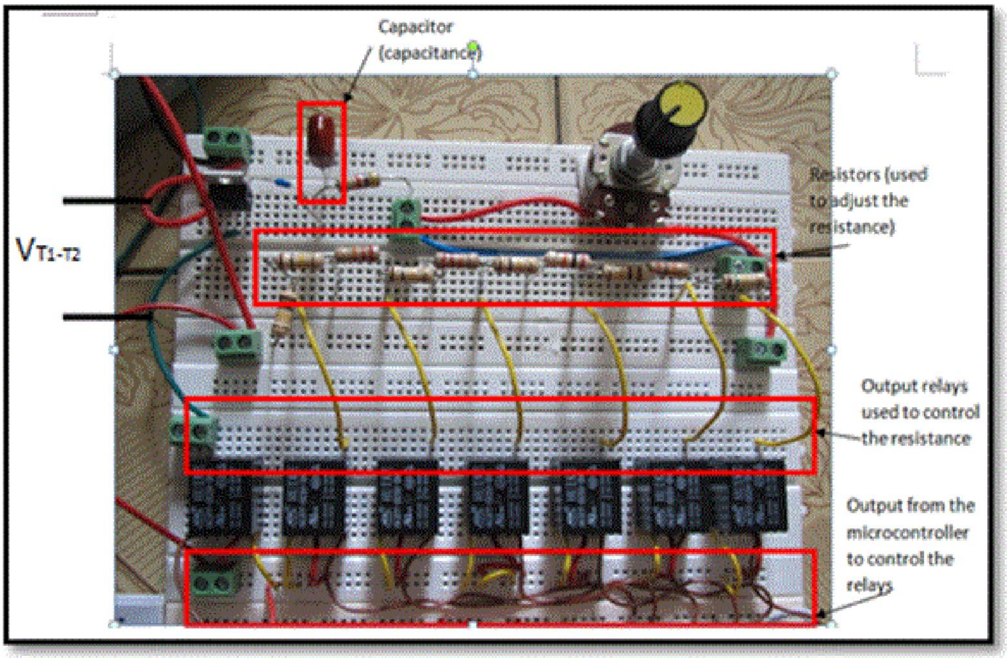


Figure 4.10: Phase Angle Circuit

Phase-controlling circuit is the main circuit for this project. In the phase control circuit, the resistance is adjusted so that the firing time can be varied, $\tau=CR_{eq}$ where C= capacitance and R_{eq}= equivalent resistance.

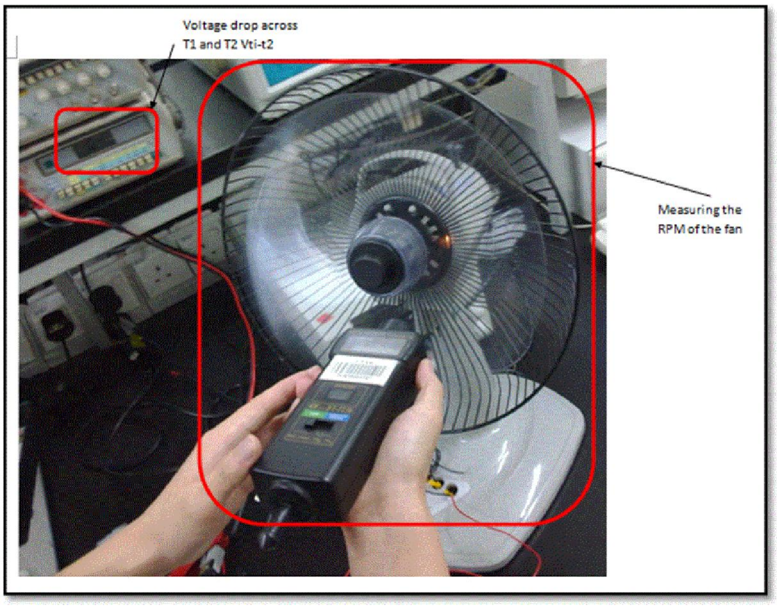


Figure 4.11: Measuring RPM with tachometer

Figure 4.12: Reading shown in tachometer

By using the specification given by the manufacturer, at the highest speed, 1320 rpm, the cubic feet per minute (CFM) is 40 CFM and the conceptual formula, $CFM = k \times speed\ where\ k\ is\ the\ constant\ to\ link\ cfm\ and\ the\ speed.$

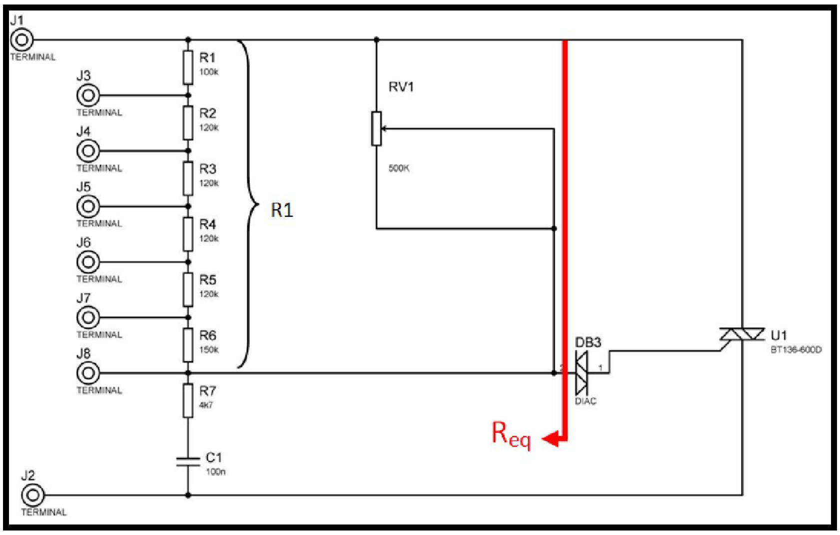
$$k = \frac{40}{1320} = \frac{1}{33}$$

the CFM values for different speed are calculated and recorded in the table shown below.

Ambient Temperature	Speed	Ampere, I (A)	Capacitance (uF)	Resistance (Ω) , R1	Req = (R1 + 100k ‖ 1M) + 4.7k (kΩ)	T=CR (10^{-3}s)	VT1-T2	Voltage to the motor (240 -VT1-T2), Vin (V)	Power to the motor , P = power factor x VinI, Watt	RPM	CFM m^3/minute
≥ 30	5	0.11	0.1	0	95.6091	9.5609	44.2	195.8	21.538	1216	36.85
≥ 29	4	0.09	0.1	150k	204.700	20.47	98.9	141.1	12.699	1100	33.33
≥ 28	3	0.08	0.1	270k	274.772	27.48	134.1	105.9	8.472	988	29.94
≥ 27	2	0.06	0.1	390k	333.559	33.36	163.5	76.5	4.59	823.7	24.96
≥ 26	1	0.05	0.1	510k	383.582	38.36	187.7	52.3	2.65	588.9	17.85
≤ 25	0	0	0.1	632k	427.333	42.73	243	~0	0	0	0

Table 4.7: Results obtained for the Various Speed of the Motor

Calculation



Calculation for equivalent resistance, R_{eq}

$$Req = ((\mathrm{R1} + 100\mathrm{k}) \,||\, 1\mathrm{M}) + 4.7\mathrm{k}$$

For R1 = 270k,

$$Req = ((270\mathrm{k} + 100\mathrm{k}) \,||\, 1\mathrm{M}) + 4.7\mathrm{k}$$

$$Req = (370\mathrm{k}^{-1} + (1 \times 10^{6})^{-1})^{-1} + 4.7\mathrm{k} = 274772\Omega$$

Calculation for the input power to the system, P_{in}

$$Pin = Powerfactor, pf \times Input\ Voltage, Vin \times Input\ Current, Iin$$

For Speed 3,

$$Pin = 1 \times 105.9 \times 0.08 = 8.472W\ where\ the\ power\ factor$$
$$= 1\ (provided\ by\ the\ manufacturing\ specification)$$

From the results obtained, we found that the firing time, Ʈ is larger, so the delay of firing of the angle will be longer, and hence, the voltage supply to the motor will be lesser. This can be measured by using the multimeter across the T1 and T2. At the close loop with no firing time, the voltage is fully supplied to the motor; which means that there should be no voltage drop across T1 and T2. However, if there is a firing time, the time for firing of a voltage will be lagged and hence, there will be voltage difference between the source and the motor.

It is obvious that the power required to run at high speed is more than running in the low speed. Hence, if the motor speed is controlled according to the ambient temperature, more power will be saved. In Malaysia, the frequency of the source is 50Hz ~ 60Hz, where the period will be T = 0.02s ~ 0.016s. For speed 0, the firing time is 42.73ms; it means that for every 42.73ms, the Triac will be fired one time. This long delay causes the input power that is transferred to the motor to become insufficient for the motor to be rotated.

The results obtained are still not perfect yet, hence, it cannot be 100 percent reliable. This is due to insufficient measurement tests done on the product. As the power source for this project is using AC 230 Voltage; there is a regulation in the laboratory /workshop that requires checking from the head officer of laboratory each time the test is run. Due to this regulation, a lot of time has been allocated for the checking. Hence, there is insufficient time to be used to construct a proper testing for this project. Besides that, for the AC 230V, there are very limited human resources that can be consulted. Hence, there were some difficulties on choosing the suitable components used in this project.

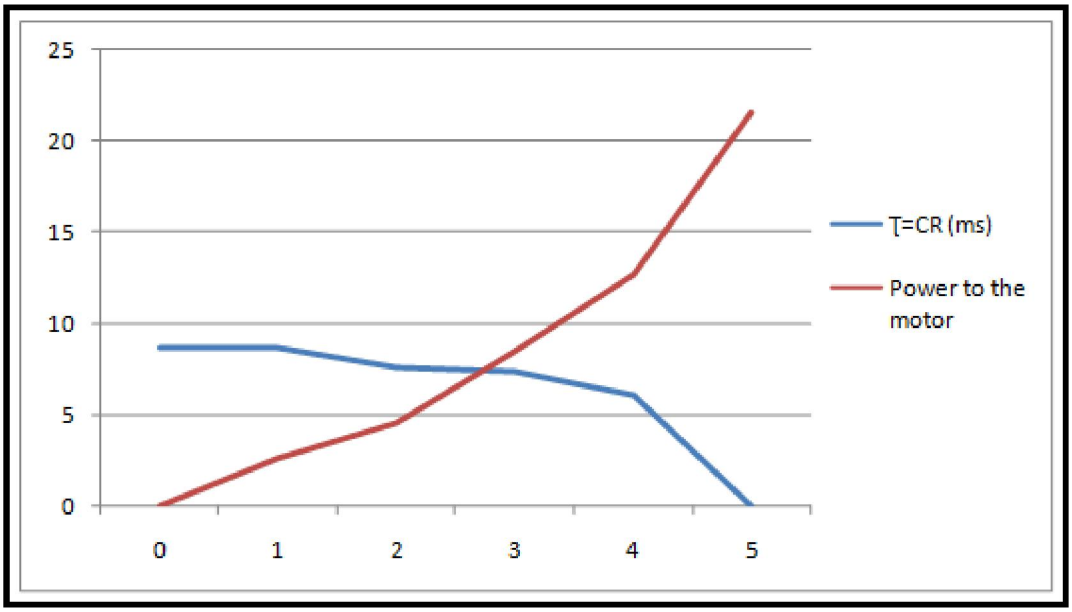


Figure 4.13: Firing Period and Power vs. Speed selection

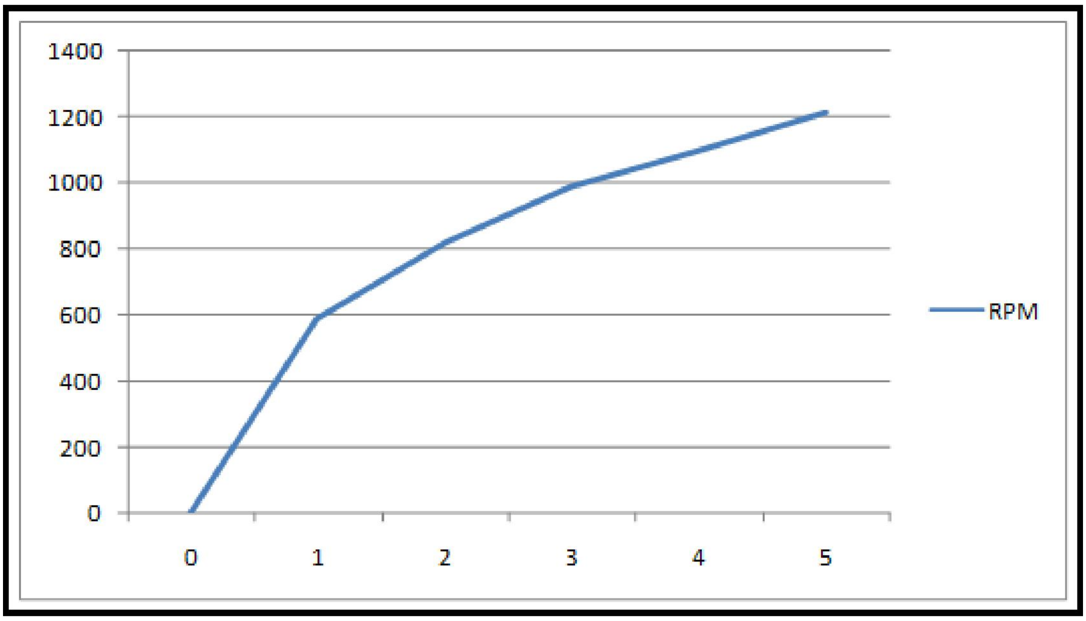


Figure 4.14: RPM vs. Speed selection

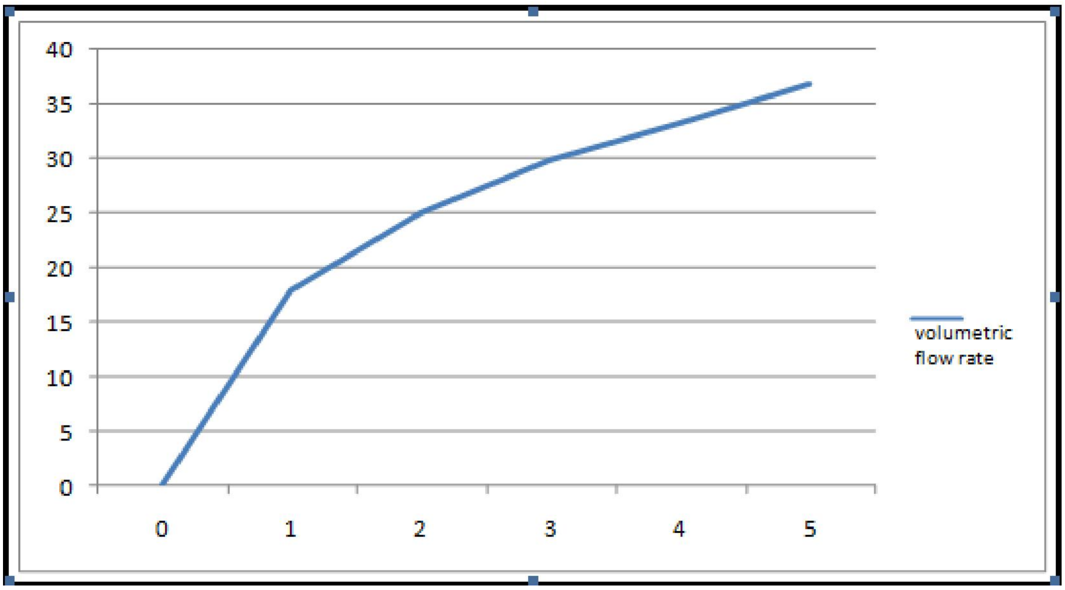


Figure 4.15: Volumetric flow rate (cubic meter per minute) vs. Speed Selection

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

In conclusion, the aim and the objectives of this project have been achieved. By testing each section of the hardware parts, the results shown prove that all the desired objectives are achieved. However due to the limited time and certain rules that prohibit the tests to be run on the product, this product lacks quality check. Therefore, this product is advisable not to be introduced in the market at this moment. In the future, hopefully there will be a proper place and laboratory set up for this kind of control to be tested and will one day become the norm for the motor speed control and more energy can be saved.

5.2 Future Recommendations

As nothing is perfect in this world, there will be always some improvement that can be done; same goes to this project. In the future, there are few recommendations/ changes that could be done on this project:

1. In the hand clap circuit, filter could be installed so that only certain range of frequency can be passed through the microphone and produce an output. It is especially useful to avoid the noises from triggering the circuit. Besides that,

the hand clap circuit could be built up by other components which are less power/current consuming.

2. In the PIC Microcontroller circuit, the LED indicator could be replaced by LCD so that a visualised decimal value can be obtained. Users can read the ambient temperature more easily.
3. A further study on Triac operation could be done. The present circuit could be simplified by using zero crossing method which is used to detect the zero crossing of the sources and control the precise firing time.
4. A Snubber circuit could be installed in parallel with the motor. Snubber circuit is used to prevent the undesired voltage to the load by conducting transient current around the load.
5. The whole circuits could be done in PCB so that is look tidy and neat. Besides that, it is also a crucial factor to make this product to be introduced in the market.
6. As at this moment, it is very hard to implement a motor speed monitoring system that can be used to send feedback to the microcontroller, hence, the speed of the motor cannot be controlled precisely. In the future, this project could be improved by installing more sensors on the fan to track the speed and send a feedback signal to the controller so that the motor fan will be rotating in the desired angular velocity.
7. As a safety evaluation, more tests such as electric surge test could be done on this project to ensure that this product is safe to be used.

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APPENDICES

APPENDIX A: PIC Programme Code

Assembly code for PIC Microcontroller

```
CONFIG OSC=HS
LIST P=18F4520
LIST F=INHX8M

#include P18F4520.INC

R2          SET     0X02
R3          SET     0X03
R4          SET     0X04
R5          SET     0X05
TEMP_L      SET     0X20
TEMP_H      SET     0X21
BIN_TEMP    SET     0X22
REF_L       SET     0X23
REF_H       SET     0X24
BIN_REF1    SET     0X25
REF_L1      SET     0X26
REF_H1      SET     0X27
BIN_REF2    SET     0X28
MAX_TEMP    SET     0X29
MIN_TEMP    SET     0X2A
TEMP_1      SET     0X40
TEMP_2      SET     0X41
TEMP_3      SET     0X42
TEMP_4      SET     0X43
TEMP_5      SET     0X44

        ORG     0X00
        BSF     TRISA,RA0       ; SET RA0 AS INPUT
        BSF     TRISA,RA1
        CLRF    TRISC
```

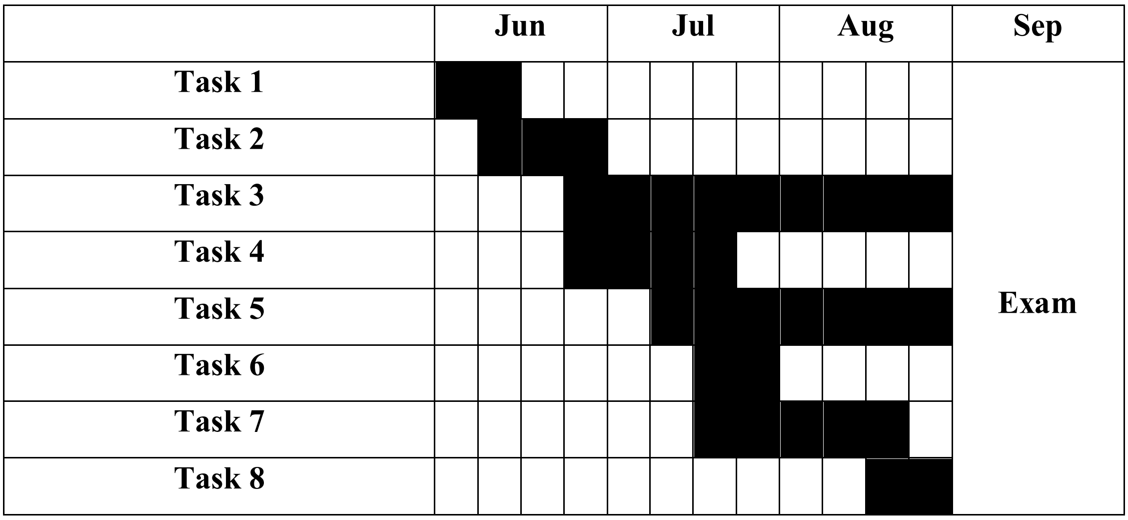
```
        CLRF        TRISD               ; SET PORTD AS OUTPUT
        CLRF        PORTA               ; RESET PORTA
        CLRF        PORTC
        CLRF        PORTD               ; RESET PORTD
        MOVLW       D'78'               ; SET MAXIMUM TEMP = 38 DEGREE CELSIUS
        MOVWF       MAX_TEMP
        MOVLW       D'42'               ; SET MINIMUM TEMP = 20 DEGREE CELSIUS
        MOVWF       MIN_TEMP
        MOVLW       D'54'               ; SET TEMP_1 = 26 DEGREE CELSIUS
        MOVWF       TEMP_1
        MOVLW       D'56'               ; SET TEMP_2 = 27 DEGREE CELSIUS
        MOVWF       TEMP_2
        MOVLW       D'58'               ; SET TEMP_3 = 28 DEGREE CELSIUS
        MOVWF       TEMP_3
        MOVLW       D'60'               ; SET TEMP_4 = 29 DEGREE CELSIUS
        MOVWF       TEMP_4
        MOVLW       D'62'               ; SET TEMP_5 = 30 DEGREE CELSIUS
        MOVWF       TEMP_5
        MOVLW       D'0'                ; CLEAR WREG
        MOVLW       0X81                ; FOSC/64 , CHANNEL 0 , A/D IS ON
        MOVWF       ADCON0
        MOVLW       0XCE                ; RIGHT JUSTIFIED, FOSC/64 , AN0 = ANALOGUE
        MOVWF       ADCON1
OVER    CLRF        PORTD               ; CLEAR PORTD
        CALL        READY
        MOVFF       ADRESL,TEMP_L
        MOVFF       ADRESH,TEMP_H
        CALL        ALGO_10_to_8        ; TO CONVERT 10 BIT TO 8 BIT OUTPUT
        MOVFF       BIN_TEMP,PORTC      ; MOVE BIN_TEMP TO PORTC FOR LED INDICATOR
        MOVF        BIN_TEMP,W          ; MOVE BIN_TEMP TO WREG FOR COMPARISON TASK
        CALL        TEST
        BRA         OVER


READY
        CALL    DELAY_20
        BSF     ADCON0,GO           ; START CONVERSION
BACK_2  BTFSC   ADCON0,DONE         ; CHECK FOR CONVERSION TO BE DONE
        BRA     BACK_2
        RETURN


ALGO_10_to_8
        RLNCF   TEMP_L,F            ; ROTATE ONE TO LEFT, STORE IT IN FILE REGISTER
        RLNCF   TEMP_L,W            ; ROTATE ONE TO LEFT, STORE IT IN WREG
        ANDLW   0X03                ; THE CLEAR THE 6 MOST SIGNIFICANT
        MOVWF   TEMP_L              ; MOVE WREG TO TEMP_L
        RLNCF   TEMP_H,F            ; ROTATE ONE TO LEFT, STORE IT IN FILE REGISTER
        RLNCF   TEMP_H,W            ; ROTATE ONE TO LEFT, STORE IT IN WREG
        ANDLW   0XFC                ; TO CLEAR THE 2 LEAST SIGNIFICANT
```

```
        IORWF   TEMP_L,W                ; ADD TEMP_L TO WREG
        MOVWF   BIN_TEMP                ; MOVE WREG TO BIN_TEMP
        RETURN



TEST
        CPFSLT      MAX_TEMP    ; check again for the maximum temperature
        BRA         T_3_1
        GOTO        WARNING
T_5_1   CPFSLT      TEMP_5      ; IF GREATER THAN TEMP_5, SEND SPEED 5 TO THE MOTOR
        BRA         T_5_2       ; ELSE GO FOR 1ST CHECK
        GOTO        SPEED5
T_5_2   CPFSEQ      TEMP_5      ; IF EQUAL TO TEMP_5, SEND SPEED 5 TO THE MOTOR
        BRA         T_5_3       ; ELSE GO FOR 2ND CHECK
        GOTO        SPEED5
T_5_3   CPFSLT      TEMP_4      ; IF GREATER THAN TEMP_4, SEND SPEED 5 TO THE MOTOR
        BRA         T_4_1       ; ELSE GO FOR 3RD CHECK
        GOTO        SPEED5
T_4_1   CPFSEQ      TEMP_4      ; IF EQUAL TO TEMP_4, SEND SPEED 4 TO THE MOTOR
        BRA         T_4_2       ; ELSE GO FOR 4TH CHECK
        GOTO        SPEED4
T_4_2   CPFSLT      TEMP_3      ; IF GREATER THAN TEMP_3, SEND SPEED 4 TO THE MOTOR
        BRA         T_3_1       ; ELSE GO FOR 5TH CHECK
        GOTO        SPEED4
T_3_1   CPFSEQ      TEMP_3      ; IF EQUAL TO TEMP_3, SEND SPEED 3 TO THE MOTOR
        BRA         T_3_2       ; ELSE GO FOR 6TH CHECK
        GOTO        SPEED3
T_3_2   CPFSLT      TEMP_2      ; IF GREATER THAN TEMP_2, SEND SPEED 3 TO THE MOTOR
        BRA         T_2_1       ; ELSE GO FOR 7TH CHECK
        GOTO        SPEED3
T_2_1   CPFSEQ      TEMP_2      ; IF EQUAL TO TEMP_2, SEND SPEED 2 TO THE MOTOR
        BRA         T_2_2       ; ELSE GO FOR 8TH CHECK
        GOTO        SPEED2
T_2_2   CPFSLT      TEMP_1      ; IF GREATER THAN TEMP_1, SEND SPEED 2 TO THE MOTOR
        BRA         T_1_1       ; ELSE GO FOR 9TH CHECK
        GOTO        SPEED2
T_1_1   CPFSEQ      TEMP_1      ; IF EQUAL TO TEMP_1, SEND SPEED 1 TO THE MOTOR
        BRA         T_1_2       ; ELSE GO FOR 10TH CHECK
        GOTO        SPEED1
T_1_2   CPFSLT      MIN_TEMP    ; IF GREATER THAN MIN_TEMP, SEND SPEED 1TO THE MOTOR
        BRA         T_1_3       ; ELSE GO FOR 10TH CHECK
        GOTO        SPEED1
T_1_3   CPFSEQ      MIN_TEMP    ; IF EQUAL TO MIN_TEMP, SEND SPEED 1 TO THE MOTOR
        GOTO        SPEED0      ;ANY VALUE SMALLER THAN MIN_TEMP, SPEED0 WILL BE SENT
                                  TO THE MOTOR.
        GOTO        SPEED1
        RETURN
```

```
SPEED0                                          ; GO FOR SPEED 0 FOR 2 MINS
        BSF     PORTD,RD0
        CALL    DELAY_2MIN
        GOTO    OVER

SPEED1                                          ; GO FOR SPEED 1 FOR 2 MINS
        BSF     PORTD,RD1
        CALL    DELAY_2MIN
        GOTO    OVER

SPEED2                                          ; GO FOR SPEED 2 FOR 2 MINS
        BSF     PORTD,RD2
        CALL    DELAY_2MIN
        GOTO    OVER

SPEED3                                          ; GO FOR SPEED 3 FOR 2 MINS
        BSF     PORTD,RD3
        CALL    DELAY_2MIN
        GOTO    OVER

SPEED4                                          ; GO FOR SPEED 4 FOR 2 MINS
        BSF     PORTD,RD4
        CALL    DELAY_2MIN
        GOTO    OVER

SPEED5                                          ; GO FOR SPEED 5 FOR 2 MINS
        BSF     PORTD,RD5
        CALL    DELAY_2MIN
        GOTO    OVER

WARNING
        BSF     PORTD,RD6                       ; STOP THE MOTOR
CHK     BTFSS   PORTA,RA1                       ; RESET BUTTON PRESSED?
        BRA     CHK
        GOTO    OVER



DELAY_20                                ; DELAY FOR 0.5S
        MOVLW   D'10'
        MOVWF   R4
BACK_1  MOVLW   D'100'
        MOVWF   R3
AGAIN_1 MOVLW   D'250'
        MOVWF   R2
HERE_1  NOP
        NOP
        DECF    R2,F
        BNZ     HERE_1
        DECF    R3,F
        BNZ     AGAIN_1
```

```
        DECF    R4,F
        BNZ     BACK_1
        RETURN



DELAY_2MIN                      ; DELAY FOR 2 MINS
        MOVLW   D'6'
        MOVWF   R5
FINAL   MOVLW   D'160'
        MOVWF   R4
BACK    MOVLW   D'250'
        MOVWF   R3
AGAIN   MOVLW   D'250'
        MOVWF   R2
HERE    NOP
        NOP
        DECF    R2,F
        BNZ     HERE
        DECF    R3,F
        BNZ     AGAIN
        DECF    R4,F
        BNZ     BACK
        DECF    R5,F
        BNZ     FINAL
        RETURN
        END
```

APPENDIX B: Grant Chart



Task Planning (Part 1)

Task 1: Identification of the Objectives and Main Application. As mention in the earlier section, after the topic is get, it is very important to identify the objectives and also the main application of the project. Based on the title, online searching and critical thinking on the ideas for the project will be done.

Task 2: Understand the Problems of the Project. Understand the possible harsh will be faced in this project for a further planning.

Task 3: Finding the methods. Always think of the suitable methods to solve the problems. Consultation with supervisor and discussion with friend will be one of the methods.

Task 4: Do the literature review. Review what are the techniques used or what other people have been done that related to the project. Online searching the related topics for this project. And also find the suitable components for the project.

Task 5: Do some experiments. Build a draft prototype for the project. Find the constant for calculating the Cfm of the fan. Collects the data.

Task 6: Planning for the report. Plan for chapters and section should be included.

Task 7: Do the first three chapters report and send to supervisor for checking purposes. And correct the report if there is any mistake.

Task 8: Report submission for the first three chapters. Preparation for the presentation. Deliver the oral presentation for the supervisor and also the modulator.

	Oct				**Nov**				**Dec**				**Jan**				**Feb**				**Mar**				**April**				**May**
Task 9	■	■	■	■	■	■	■	■	■	■	■	■																	
Task 10													■	■	■	■													
Task 11																■	■	■											**Exam**
Task 12																		■	■	■	■	■	■	■	■				
Task 13																										■	■	■	

Task Planning (Part 2)

Task 9: Construct the final Prototype. And tests are run.

Task 10: Data collection for the project. And analyze for the collected data.

Task 11: Improvement the project if possible.

Task 12: Writing the final report. The final report will include all the chapters for this project. And final checking for the report will be done. Correction will be made.

Task 13: Report Submission for the final report. Deliver an oral presentation for the supervisor and also moderator.

APPENDIX C: Datasheets

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

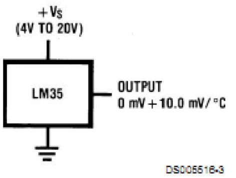
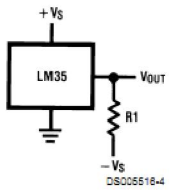


FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



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

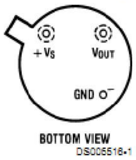
V_{OUT} = +1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

 DS005516

Connection Diagrams

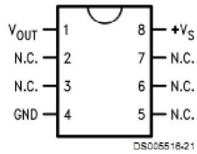
TO-46
Metal Can Package*



*Case is connected to negative pin (GND)

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

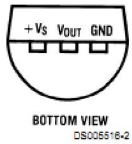
SO-8
Small Outline Molded Package



N.C. = No Connection

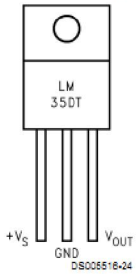
Top View
Order Number LM35DM
See NS Package Number M08A

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

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			LM35CA			Units
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	(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}≤T_A≤T_{MAX}	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	T_{MIN}≤T_A≤T_{MAX}	**+10.0**	**+9.9, +10.1**		**+10.0**		**+9.9, +10.1**	mV/°C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25°C	±0.4	±1.0		±0.4	±1.0		mV/mA
	T_{MIN}≤T_A≤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≤V_S≤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≤V_S≤30V, +25°C	0.2	1.0		0.2	1.0		μA
	4V≤V_S≤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

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≤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*.

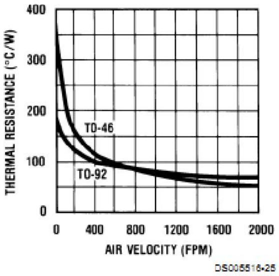
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

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

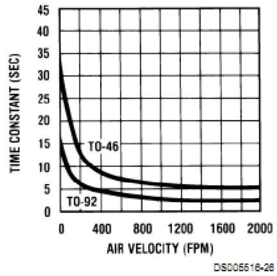
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

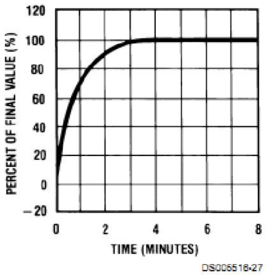
Thermal Resistance Junction to Air



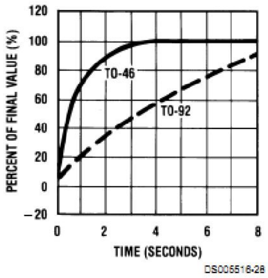
Thermal Time Constant



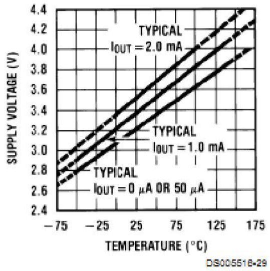
Thermal Response in Still Air



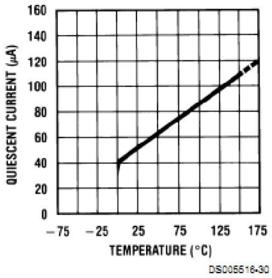
Thermal Response in Stirred Oil Bath



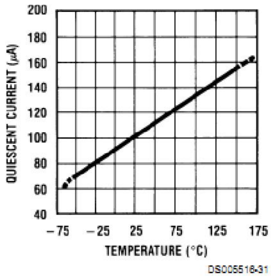
Minimum Supply Voltage vs. Temperature



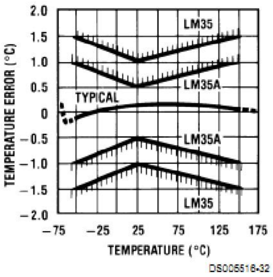
Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)



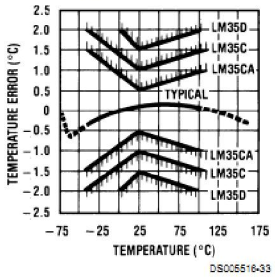
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



Accuracy vs. Temperature (Guaranteed)

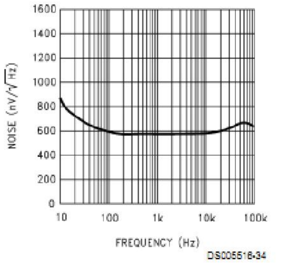


Accuracy vs. Temperature (Guaranteed)

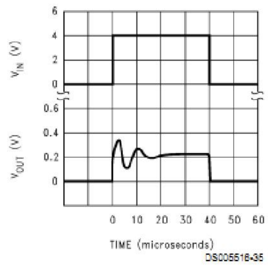


Typical Performance Characteristics (Continued)

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.

DB3 DB4 SMDB3

DIAC

FEATURES

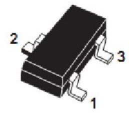
- V_{BO} : 32V and 40V
- LOW BREAKOVER CURRENT

DESCRIPTION

Functioning as a trigger diode with a fixed voltage reference, the DB3/DB4 series can be used in conjunction with triacs for simplified gate control circuits or as a starting element in fluorenscent lamp ballasts.

A new surface mount version is now available in SOT-23 package, providing reduced space and compatibility with automatic pick and place equipment.

DO-35
(DB3 and DB4)



SOT-23
(SMDB3)*
Pin 1 and 3 must be shorted together

ABSOLUTE MAXIMUM RATINGS (limiting values)

Symbol	Parameter		Value	Unit
I_{TRM}	Repetitive peak on-state current tp = 20 µs F= 120 Hz	SMDB3	1.00	A
		DB3 / DB4	2.00	
Tstg Tj	Storage temperature range Operating junction temperature range		- 40 to + 125	°C

Note: * SMDB3 indicated as Preliminary spec as product is still in development stage.

ELECTRICAL CHARACTERISTICS (Tj = 25°C unless otherwise specified)

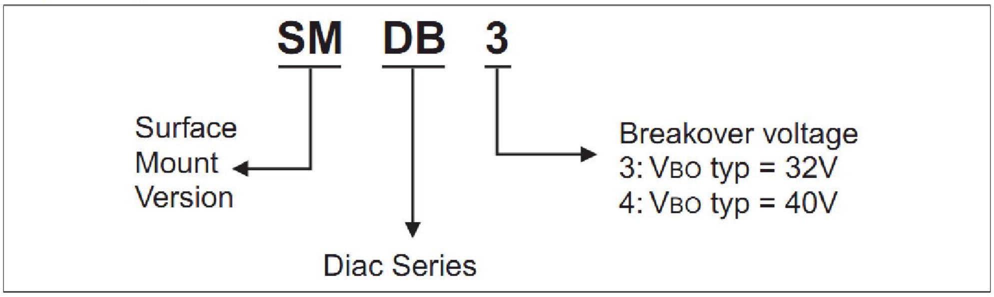
Symbol	Parameter	Test Conditions		SMDB3	DB3	DB4	Unit
V_{BO}	Breakover voltage *	C = 22nF **	MIN.	28	28	35	V
			TYP.	32	32	40	
			MAX.	36	36	45	
$\vert V_{BO1} - V_{BO2} \vert$	Breakover voltage symmetry	C = 22nF **	MAX.		3		V
ΔV	Dynamic breakover voltage *	V_{BO} and V_F at 10mA	MIN.	10	5		V
V_O	Output voltage *	see diagram 2 (R=20Ω)	MIN.	10	5		V
I_{BO}	Breakover current *	C = 22nF **	MAX.	10	50		μA
tr	Rise time *	see diagram 3	MAX.	0.50	2		μs
I_R	Leakage current *	$V_R = 0.5\ V_{BO}$ max	MAX.	1	10		μA
I_P	Peak current *	see diagram 2 (Gate)	MIN.	1	0.30		A

* Applicable to both forward and reverse directions.
** Connected in parallel to the device.

PRODUCT SELECTOR

Part Number	V_{BO}	Package
SMDB3	28 - 36	SOT-23
DB3	28 - 36	DO-35
DB4	35 - 45	DO-35

ORDERING INFORMATION



OTHER INFORMATION

Part Number	Marking	Weight	Base Quantity	Packing Mode
SMDB3	DB3	0.01 g	3000	Tape & Reel
DB3	DB3 (Blue Body Coat)	0.15 g	5000	Tape & Reel
DB4	DB4 (Blue Body Coat)	0.15 g	5000	Tape & Reel

Diagram 1: Voltage - current characteristic curve.

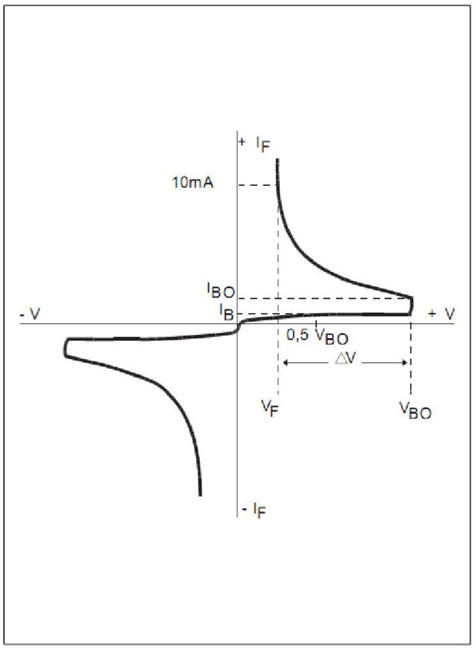


Diagram 2: Test circuit.

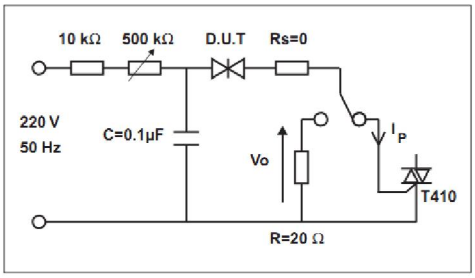
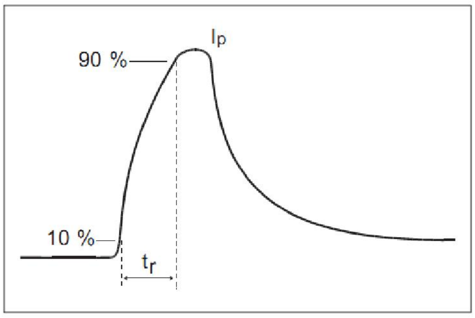


Diagram 3: Rise time measurement.



BT136-600D

4Q Triac

Rev. 03 — 1 April 2011 Product data sheet

1. Product profile

1.1 General description

Planar passivated very sensitive gate four quadrant triac in a SOT78 plastic package intended for use in general purpose bidirectional switching and phase control applications, where high sensitivity is required in all four quadrants. This very sensitive gate "series D" triac is intended to be interfaced directly to microcontrollers, logic integrated circuits and other low power gate trigger circuits.

1.2 Features and benefits

- Direct triggering from low power drivers and logic ICs
- High blocking voltage capability
- Low holding current for low current loads and lowest EMI at commutation
- Planar passivated for voltage ruggedness and reliability
- Triggering in all four quadrants
- Very sensitive gate

1.3 Applications

- General purpose motor control
- General purpose switching

1.4 Quick reference data

Table 1. Quick reference data

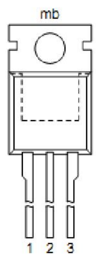
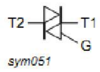
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DRM}	repetitive peak off-state voltage		-	-	600	V
I_{TSM}	non-repetitive peak on-state current	full sine wave; $T_{j(init)}$ = 25 °C; t_p = 20 ms; see Figure 4; see Figure 5	-	-	25	A
$I_{T(RMS)}$	RMS on-state current	full sine wave; T_{mb} ≤ 107 °C; see Figure 1; see Figure 2; see Figure 3	-	-	4	A

Table 1. Quick reference data *...continued*

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Static characteristics						
I_{GT}	gate trigger current	V_D = 12 V; I_T = 0.1 A; T2+ G+; T_j = 25 °C; see Figure 7	-	2	5	mA
		V_D = 12 V; I_T = 0.1 A; T2+ G-; T_j = 25 °C; see Figure 7	-	2.5	5	mA
		V_D = 12 V; I_T = 0.1 A; T2- G-; T_j = 25 °C; see Figure 7	-	2.5	5	mA
		V_D = 12 V; I_T = 0.1 A; T2- G+; T_j = 25 °C; see Figure 7	-	5	10	mA
I_H	holding current	V_D = 12 V; T_j = 25 °C; see Figure 9	-	1.2	10	mA

2. Pinning information

Table 2. Pinning information

Pin	Symbol	Description	Simplified outline	Graphic symbol
1	T1	main terminal 1	 SOT78 (TO-220AB)	
2	T2	main terminal 2		
3	G	gate		
mb	T2	mounting base; main terminal 2		

3. Ordering information

Table 3. Ordering information

Type number	Package		
	Name	Description	Version
BT136-600D	TO-220AB	plastic single-ended package; heatsink mounted; 1 mounting hole; 3-lead TO-220AB	SOT78
BT136-600D/DG	TO-220AB	plastic single-ended package; heatsink mounted; 1 mounting hole; 3-lead TO-220AB	SOT78

4. Limiting values

Table 4. Limiting values
In accordance with the Absolute Maximum Rating System (IEC 60134).

Symbol	Parameter	Conditions	Min	Max	Unit
V_{DRM}	repetitive peak off-state voltage		-	600	V
$I_{T(RMS)}$	RMS on-state current	full sine wave; $T_{mb} \leq 107$ °C; see Figure 1; see Figure 2; see Figure 3	-	4	A
I_{TSM}	non-repetitive peak on-state current	full sine wave; $T_{j(init)} = 25$ °C; $t_p = 20$ ms; see Figure 4; see Figure 5	-	25	A
		full sine wave; $T_{j(init)} = 25$ °C; $t_p = 16.7$ ms	-	27	A
I^2t	I^2t for fusing	$t_p = 10$ ms; sine-wave pulse	-	3.1	A^2s
dI_T/dt	rate of rise of on-state current	$I_T = 6$ A; $I_G = 0.2$ A; $dI_G/dt = 0.2$ A/μs; T2+ G+	-	50	A/μs
		$I_T = 6$ A; $I_G = 0.2$ A; $dI_G/dt = 0.2$ A/μs; T2+ G-	-	50	A/μs
		$I_T = 6$ A; $I_G = 0.2$ A; $dI_G/dt = 0.2$ A/μs; T2- G-	-	50	A/μs
		$I_T = 6$ A; $I_G = 0.2$ A; $dI_G/dt = 0.2$ A/μs; T2- G+	-	10	A/μs
I_{GM}	peak gate current		-	2	A
V_{GM}	peak gate voltage		-	5	V
P_{GM}	peak gate power		-	5	W
$P_{G(AV)}$	average gate power	over any 20 ms period	-	0.5	W
T_{stg}	storage temperature		-40	150	°C
T_j	junction temperature		-	125	°C

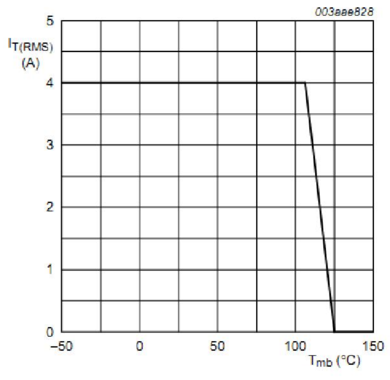
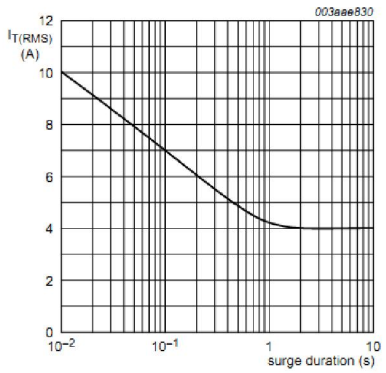


Fig 1. RMS on-state current as a function of mounting base temperature; maximum values



f = 50 Hz
$T_{mb} \leq 107$ °C

Fig 2. RMS on-state current as a function of surge duration; maximum values

MICROCHIP

PIC18F2420/2520/4420/4520

28/40/44-Pin Enhanced Flash Microcontrollers with 10-Bit A/D and nanoWatt Technology

Power Management Features:

- Run: CPU on, Peripherals on
- Idle: CPU off, Peripherals on
- Sleep: CPU off, Peripherals off
- Ultra Low 50nA Input Leakage
- Run mode Currents Down to 11 μA Typical
- Idle mode Currents Down to 2.5 μA Typical
- Sleep mode Current Down to 100 nA Typical
- Timer1 Oscillator: 900 nA, 32 kHz, 2V
- Watchdog Timer: 1.4 μA, 2V Typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, up to 40 MHz
- 4x Phase Lock Loop (PLL) – Available for Crystal and Internal Oscillators
- Two External RC modes, up to 4 MHz
- Two External Clock modes, up to 40 MHz
- Internal Oscillator Block:
  - Fast wake from Sleep and Idle, 1 μs typical
  - 8 use-selectable frequencies, from 31 kHz to 8 MHz
  - Provides a complete range of clock speeds from 31 kHz to 32 MHz when used with PLL
  - User-tunable to compensate for frequency drift
- Secondary Oscillator using Timer1 @ 32 kHz
- Fail-Safe Clock Monitor:
  - Allows for safe shutdown if peripheral clock stops

Peripheral Highlights:

- High-Current Sink/Source 25 mA/25 mA
- Three Programmable External Interrupts
- Four Input Change Interrupts
- Up to 2 Capture/Compare/PWM (CCP) modules, one with Auto-Shutdown (28-pin devices)
- Enhanced Capture/Compare/PWM (ECCP) module (40/44-pin devices only):
  - One, two or four PWM outputs
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart

Peripheral Highlights (Continued):

- Master Synchronous Serial Port (MSSP) module Supporting 3-Wire SPI (all 4 modes) and I²C™ Master and Slave modes
- Enhanced Addressable USART module:
  - Supports RS-485, RS-232 and LIN/J2602
  - RS-232 operation using internal oscillator block (no external crystal required)
  - Auto-wake-up on Start bit
  - Auto-Baud Detect
- 10-Bit, up to 13-Channel Analog-to-Digital (A/D) Converter module:
  - Auto-acquisition capability
  - Conversion available during Sleep
- Dual Analog Comparators with Input Multiplexing
- Programmable 16-Level High/Low-Voltage Detection (HLVD) module:
  - Supports interrupt on High/Low-Voltage Detection

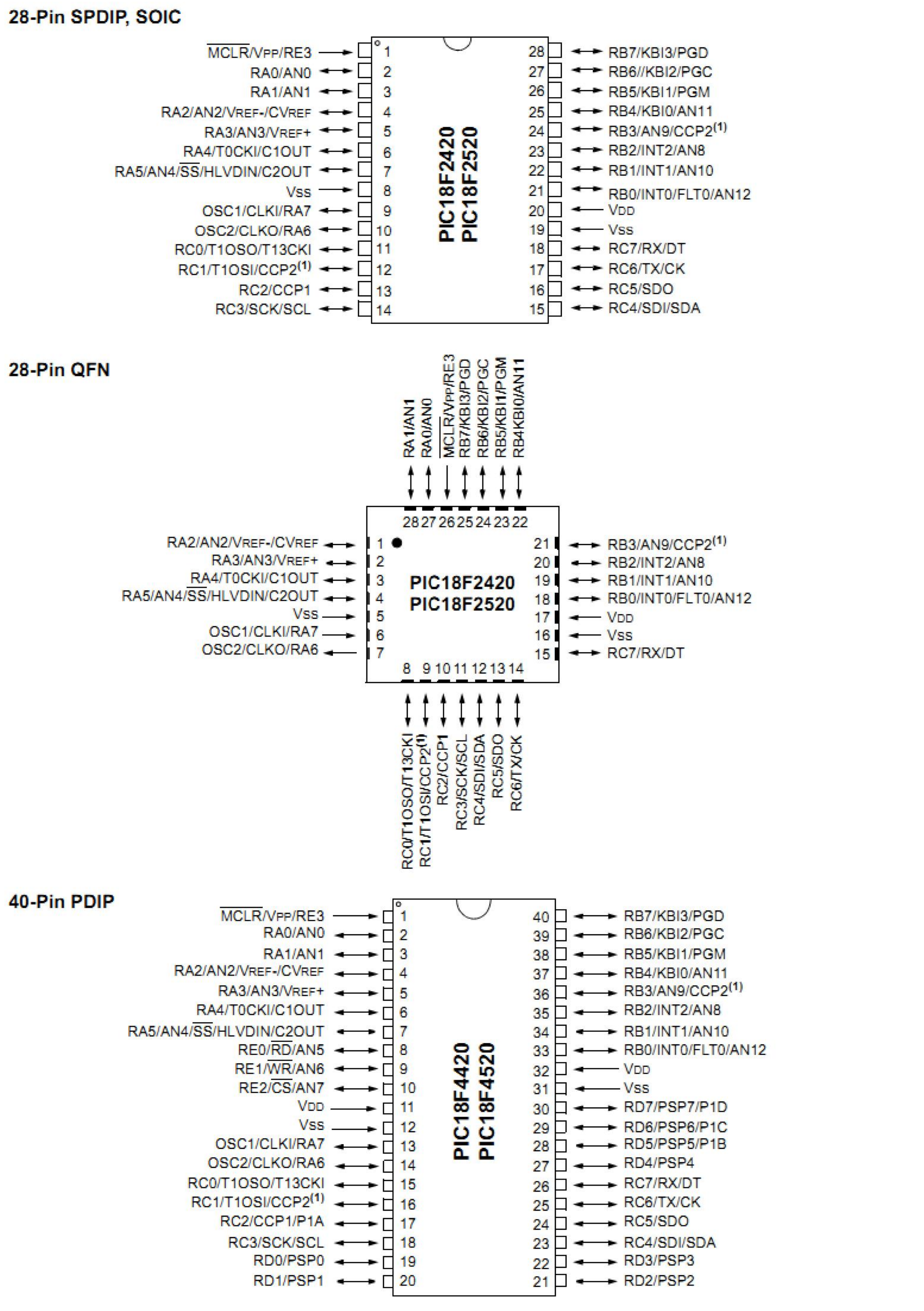
Special Microcontroller Features:

- C Compiler Optimized Architecture:
  - Optional extended instruction set designed to optimize re-entrant code
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory Typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory Typical
- Flash/Data EEPROM Retention: 100 Years Typical
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 4 ms to 131s
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via Two Pins
- In-Circuit Debug (ICD) via Two Pins
- Wide Operating Voltage Range: 2.0V to 5.5V
- Programmable Brown-out Reset (BOR) with Software Enable Option

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ ECCP (PWM)	MSSP		EUSART	Comp.	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)				SPI	Master I²C™			
PIC18F2420	16K	8192	768	256	25	10	2/0	Y	Y	1	2	1/3
PIC18F2520	32K	16384	1536	256	25	10	2/0	Y	Y	1	2	1/3
PIC18F4420	16K	8192	768	256	36	13	1/1	Y	Y	1	2	1/3
PIC18F4520	32K	16384	1536	256	36	13	1/1	Y	Y	1	2	1/3

PIC18F2420/2520/4420/4520

Pin Diagrams



Note 1: RB3 is the alternate pin for CCP2 multiplexing.