PC BASED DC MOTOR SPEED CONTROL

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PC BASED DC MOTOR SPEED CONTROL

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Power Systems)"

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Date : ……………………….

PC BASED DC MOTOR SPEED CONTROL

MOHAMAD AZIZI BIN OMAR

A thesis submitted in fulfillment of the
Requirements for the award of the degree of
Bachelor of Electrical Engineering
(Power Systems)

Faculty of Electrical & Electronic Engineering
University Malaysia Pahang

NOVEMBER 2008

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To my beloved parent

Omar Abd Razak & Atikah bte Salleh,

my brothers & sisters

for giving a constant source of support and encouragement.

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ABSTRACT

The purpose of this study is in electronic scope to design a DC speed controller circuit controlled by computer as a GUI (Graphical User Interface) from minimum to maximum speed. This project is focus on the DC motor speed control by varying the duty cycle of Pulse With Modulation (PWM) signal via Computer (PC). Nowadays, the computers are widely used in daily applications as a graphical user interface (GUI) because it is easy to monitoring, save cost and time. In this project, PC used to generate PWM signals assisted by Microsoft Visual Basics software thus reduced hardware implementation in a system. PWM speed control is desirable due to its high power efficiency compare with another method of speed control like frequency control, current and voltage control. The motor averages the input duty cycle into a constant speed which is directly proportional to the percent duty cycle. The Software send PWM signal to the driver circuit through the RS232 serial port. The driver circuit will boosted the PWM signal to drive the MOSFET and thus control the motor. The speed of DC motor is depending on the spectrum of PWM that refer to their duty cycle. This project was able to control the motor speed via PC from zero to maximum speed which is most important feature in industrials control applications.

ABSTRAK

Tujuan projek ini adalah untuk merekabentuk pengawal kelajuan motor DC yang mana dikawal oleh komputer sebagai grafik kepada pengguna daripada kelajuan minimum kepada kelajuan maksimum. Projek ini diberi fokus mengenai kawalan motor DC dengan megubah isyarat duty cycle Pulse Width Modulation (PWM) dengan menggunakan komputer. Pada hari ini, komputer banyak digunakan dalam aplikasi kehidupan sebagai grafik pengguna kerana ianya mudah untuk diurus, jimat masa dan tenaga. Komputer digunakan untuk menghasilkan PWM melalui perisian Microsoft visual Basic 2005 Express Edition yang mana mengurangkan perkakasan dalam sesuatu system. Teknik kawalan melalui PWM sangat baik kerana ianya effisien berbanding cara lain seperti kontrol melalui frekuensi, arus, atau voltan. Kelajuan motor adalah berkadar langsung dengan duty cycle. Perisian tersebut menghantar isyarat PWM kepada litar pemacu melalui RS232 port serial. Litar pemacu tersebut akan menaikkan nilai voltan untuk memacu MOSFET seterusnya mengawal motor. Kelajuan motor bergantung kepada spektrum PWM bergantung kepada duty cycle. Projek ini dapat mengawal kelajuan motor DC dari minimum ke maksimum dengan menggunakan komputer yang mana merupakan penting dalam aplikasi dalam industri.

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LIST OF ABBREVIATIONS

AC	Alternating Current
AD/DA	Analog-digital Converter
DC/dc	Direct Current
EMF	Electromagnetic Force
GUI	Graphical User Interface
GND	Ground
IEEE	Institute of Electrical and Electronic Engineer
LED	Light Emitting Diode
MOSFET	metal–oxide–semiconductor field-effect transistor
PIC	Programmable Integrated Circuit
PWM	Pulse Width Modulation
PC	Personal Computer
VB	Visual Basic

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CHAPTER 1

INTRODUCTION

This part described introduction and overview of the research work. It will explain about background of project, problems identification, proposed solutions, and objectives of the project and scope of work that must be done.

1.1 BACKGROUND OF STUDY

Adjustable speed drive or variable-speed drive describes the system of equipment used to control the speed of machinery. There are many industrial processes such as production lines must operate at different speeds for different products. By varying the speed of the drive, energy may save compared with other techniques for control systems. Where speeds may be selected from several different pre-set ranges, usually the drive is said to be "adjustable" speed. If the output speed can be changed without steps over a range, the drive is usually referred to as "variable speed". These types of speed drives may be purely mechanical, electromechanical, hydraulic, or electronic system.

Process control and energy conservation are the two primary reasons for using an adjustable speed drive. Historically, adjustable speed drives were developed for process control, but energy conservation has emerged as an equally important objective. The following are process control benefits that might be provided by an adjustable speed drive:

i. Smoother operation
ii. Acceleration control
iii. Different operating speed for each process recipe
iv. Compensate for changing process variables
v. Allow slow operation for setup purposes
vi. Adjust the rate of production
vii. Allow accurate positioning
viii. Control torque or tension

Actually, there are three general categories of electric drives, DC motor drives, eddy current drives and AC motor drives and can be further divided into numerous variations. Electric drives generally include both an electric motor and a speed control unit or system. The term drive is often applied to the controller. In the early days of electric drive technology, electromechanical control systems were used. For the next, electronic components became available thus new controller designed with latest electronic technology.

Nowadays, the machinery like DC motor is one of the most important devices and very useful especially in industrial sector for the light load applications. For examples are conveyer motor, crane motor, fans, hand drill and others. DC motor is useful in many applications because it provide high torque due to flux and torque are perpendicular causes they have less inertia characteristic.

As points stated before, the advantage of DC speed motor is we can control their speed smoothly down to zero, immediately followed by acceleration in the opposite direction. DC motor respond quickly to changes in control signals due to the DC motor's high ratio of torque of inertia as mentioned before. From research, I have found several ways to control the motor speed using electronic devices. There are included voltage speed control, field speed control (I_{field}), resistance speed control and PWM technique. These control method have their benefit and disadvantages respectively which is more focus to efficiency element.

In this technology era, real world applications often call for controlling small to medium sized DC motors from digital circuits. For smaller motors it is usually economically infeasible to buy a commercial speed controller as the cost of the controller will far outstrip the cost of the motor itself. The PIC's high speed, low cost, and low power requirements lend it to being an inexpensive "smart chip" controller for DC motors. The concept of PIC operation is generating PWM to drive switching devices. It is very easy to control the speed of DC motor from zero to maximum speed. PWM generator can be applied as switching signal thus reduces the losses energy. There is no effect on power quality and no change in speed regulation.

To easy understanding the concept of speed controller, for example imagine a light bulb with a switch. When push the switch button, the bulb goes on and is at full brightness (10 W). When the switch is off, the bulb also goes off (0 W). Now, push switch button for a fraction of a second, and then switch of again for the same amount of time, the filament won't have time to cool down and heat up, and will just get an average glow of 5 W. This is concept of lamp dimmers work, and the same principle is used by speed controllers to drive a motor. When the switch is closed, the motor sees 12 Volts, and when it is open it sees 0 Volts. If the switch is open for the same amount of time as it is closed, the motor will see an average of 6 Volts, and will run more slowly accordingly.

In 21th century, we can see that computers system are applied various application because it easy to monitoring. The computer system can perform the instruction given by software make it advantages. To access a system, the user only interface with the graphic without need explore about hardware or manually control in computer system. Actually, combination of high technology component like processor built in this computer make their system is functioning perfect. The computer system also designed to communicate with another device like printers through communication port, wireless technology, Modem, USB port, Bluetooth, infrared, internet and others. The computer assisted by develop software is able to interfacing with hardware system make the computer system is reliable.

1.2 PROBLEMS IDENTIFICATION

The most issues discusses in speed controller is regarding their efficiency and reliability. The efficiency element is important in order to save cost. The efficiency of speed controller is depending on method of control system. The speed controller usually controlled in analog system.

An analog signal has a continuously varying value, with infinite resolution in both time and magnitude. For example, a 5V is an analog and its output voltage is not precisely 5V, changes over time, and can take any real-numbered value. Similarly, the amount of current drawn from a battery is not limited to a finite set of possible values. Analog signals are distinguishable from digital signals because the latter always take values only from a finite set of predetermined possibilities.

Analog voltages and currents can be used to control things directly, like the volume of a radio or light dim. In a simple analog radio, a knob is connected to a variable resistor. As you turn the knob, the resistance goes up or down. As that happens, the current flowing through the resistor increases or decreases. This changes the amount of current driving the speakers, thus increasing or decreasing the volume. An analog circuit is one, like the radio, whose output is linearly proportional to its input.

As intuitive and simple as analog control may seem, it is not always economically attractive or otherwise practical. For one thing, analog circuits tend to drift over time and can, therefore, be very difficult to tune. Precision analog circuits, which solve that problem, can be very large, heavy, and expensive. There are weaknesses in analog system.

Same as concept of volume tune for radio, the DC motor speed usually controlled in analog system which is the resistance is varying from maximum to minimum. There are many disadvantages of using this method thus effect less efficiency mean high power loss in the system.

In a PWM circuit, common small potentiometers may be used to control a wide variety of loads in PWM generating circuit whereas large and expensive high power variable resistors are needed for resistive controllers. The simplest of PWM circuit is using 555 timers in mono stable operation and it not reliable for high voltage application. There are also may causes high loss, higher damage and others. This application is also not practical and not precise result. [11]

This kind of controller circuits can also get very hot due to power dissipated is proportional to the voltage across the active elements multiplied by the current through them. Analog circuitry can also be sensitive to noise. Because of its infinite resolution, any perturbation or noise on an analog signal necessarily changes the current value.

Manual controller is also not practical in the technology era because it can waste time and cost. Operation cost regarding controller is got attention from industrial field. In order to reduce cost and time, we suggest making a controller based on computer because it is portable. The user can monitor their system at certain place without need to going the plant (machine) especially in industrial implementation. From that, the man power can be reduced and reserve with computer which is more precise and reliable.

The other product regarding this project where control motor via computer may be commercialized but their cost is very expensive. The hardware of this product may be complicated and maintenance cost is higher. The low cost electronic devices can be designed to make a speed controller system.

1.3 PROPOSED SOLUTION

Digital control is the better solution to overcome these problems. By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. Many microcontrollers already include on-chip PWM controllers, making implementation easy.

In order to reduce power loss in the system, PWM switching technique is a best method to control the speed of DC motor compare to another method. The duty cycle can be varied to get the variable output voltage. The concept of this system is same like DC-DC converter which is the output voltage depends on their duty cycle.

One of the advantages of PWM is that the signal remains digital all the way from the processor to the controlled system which no digital-to-analog conversion is necessary. By keeping the signal digital, noise effects are minimized. Noise can only affect a digital signal if it is strong enough to change a logic-1 to a logic-0, or vice versa. Increased noise immunity is yet another benefit of choosing PWM over analog control, and is the principal reason PWM is sometimes used for communication. Switching from an analog signal to PWM can increase the length of a communications channel dramatically.

The most switching device is MOSFET because is a majority carrier device which does not have minority-carrier storage delays make it faster switching thus gain efficiency in a system.

To replace manual control, GUI can be implementing to make the system more reliable. For example, computer system assisted by software can be designed to create a graphical thus user can control based on the graphic.

1.4 OBJECTIVES

Basically, these projects are listing two main objectives. The objectives are a guideline and goal in order to complete this project. This project is conducted to achieve the following objectives:

i. To design a drive circuit to control speed of DC motor driven by PWM
ii. To built a programming coding in order to generate PWM to drive the circuit using Microsoft Visual Basic

1.5 SCOPE

To complete this project, I have decided the scope that should be done step by step. Basically, this project can be divided into two element which hardware and software.

1.5.1 Hardware

The hardware in my project consists of driver circuit to drive the MOSFET. In additional, Power supply circuit was designed to supplying voltage to driver circuit and 24V DC motor.

i. Driver circuit
ii. Power supply circuit

1.5.2 Software

I have using visual basic language express edition which is free to generate PWM. This software also provided GUI thus the user can monitor the speed of the motor easily.

i. Built a program to generate PWM using Microsoft Visual Basic 2005 Express Edition.
ii. Data transmit through the DB9 serial port.
iii. Interface with USB- RS232 converter which allowing the program control via laptop which not provided by serial port communication.

1.6 RESEARCH METHODOLOGY

In order to get the information and knowledge about this project, I need to study further, collect data and do some revision. There are methodologies that I have referred in order to get knowledge.

1.6.1 Literature review.

I have to learn topic about DC motor control. The references of this I get from reference book, internet, journal, and technical paper from IEEE. These references are much assists me to understanding concept and look for some technology.

1.6.2 Understanding the concept and theory.

Some topics regarding this project are complicated to understand like Vb language. To solve this problem, I need to search more information regarding these topic in others source. The theory and concept is important and need to understand completely because it is main point to doing a project.

1.6.3 Refer and discuss with supervisor and lecturer.

If some information is hard to understand, I have referred this topic with the supervisor by weekly and other lecturers.

1.6.4 Simulation.

Simulation technique is common method to test electronic circuit before implement it in circuit board. In this project, I have design circuit using OrCAD simulation. Troubleshooting need to be done before run this project to ensure all the connection is correct. Some misconnection wiring or short circuit can make some electronic device damage.

1.7 ORGANIZATION OF THESIS

This thesis is organized into 5 chapters. The first chapter of this thesis covers on introduction and overview about this project includes backgrounds, objectives, scope, and research methodology.

Chapter two is explanations about literature review as study material and references. The topic that I have studied is about the other method of speed control to compare and analysis their advantages and weakness. From the literature review, knowledge can be gained thus implement in this project.

The methodology that I have done are discusses on chapter 3. This is explanation about the method used to complete hardware and software. Chapter 4 are discusses of the result and analysis of this project and last chapter describes conclusion and future recommendation to make this project greatly.

This thesis included with references and appendices. We can refer the further information about this project in references which states the source and their author. Datasheet of the component, photo and others information also placed on the appendices part.

CHAPTER 2

LITERATURE REVIEW

This part describes the theory of the speed control and how we want control it. From the references, I have found a lot of technique of speed control that can be implementing in this project. I have done study about the pulse width modulation (PWM) switching technique, visual basic language, serial communication port, USB - RS232, DC motor and their application.

2.1 PWM

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. The speed controller works by varying the average voltage sent to the motor. It could do this by simply adjusting the voltage sent to the motor, but this is quite inefficient to do. A better way is to switch the motor's supply on and off very quickly. If the switching is fast enough, the motor doesn't notice it, it only notices the average effect. The PWM signals can be generated in a number of ways [1].

PWM is a common technique for speed control. A good analogy is bicycle riding. You peddle (exert energy) and then coast (relax) using your momentum to carry you forward. As you slow down (due to wind resistance, friction, and road shape) you peddle to speed up and then coast again. The duty cycle is the ratio of peddling time to the total time (peddle coast time). A 100% duty cycle means you are peddling all the time, and 50% only half the time. Switching speeds and the associated power losses are very important in power electronic circuit. The BJT as a minority-carrier device, whereas the MOSFET is a majority carrier device which does not have minority-carrier storage delays, giving the MOSFET an advantage in switching speeds.BJT switching times may be a magnitude longer than for the MOSFET. Therefore, the MOSFET generally has lower switching losses [2].

PWM for motor speed control works in a very similar way. Instead of peddling, your motor is given a fixed voltage value (say +5 V) and starts spinning. The voltage is then removed and the motor "coasts". By continuing this voltage on-off duty cycle, motor speed is controlled. [3]

The concept of PWM inherently requires timing. Two 555 timer ICs and some potentiometers can be used to generate a PWM signal, and since PWM provides a digital, on/off signal, it is also easy to use a PC or micro-controller to create the signal; however this is beyond the scope of this article. [4]

A PWM converter includes voltage mode converters and current mode converters. A synchronous buck converter typically has a controller, driver, a pair of switches, and an LC filter coupled to the pair of switches. The controller provides a control signal to the driver which then drives the pair of switches. The driver alternately turns each switch ON and OFF thereby controlling inductor current and the output voltage of the DC to DC converter. [5]

Motor vehicles use variable speed DC motors for various applications, for example a blower motor for heat and ventilation systems. The motor speed control can be performed in a variety of different ways. Common methods include: voltage dropping resistors, high current rheostats, linear voltage amplifiers and pulse width modulation (PWM). Voltage dropping resistors, high current rheostats and linear voltage amplifiers are becoming less desirable due to their power efficiency and concerns with the conservation of electrical power. [6]

Thus PWM speed control is desirable due to its high power efficiency. PWM speed control switches the applied motor voltage at a fixed frequency while varying the applied duty cycle. The motor averages the input duty cycle into a constant speed which is directly proportional to the percent duty cycle. For example, 50% duty cycle correlates to 50% motor speed. Generally the PWM control frequency must be greater than 20 kHz to eliminate audible resonance that may be produced by the motor. PWM speed control power efficiency is directly proportional to the frequency and rise and fall time of the applied control waveform. To minimize the thermal management requirements and maximize power efficiency the PWM waveform is generally designed with an output switching rise and fall time of less than 0.5 microseconds. However, such rapid current and voltage changes, when applied over leads to the motor, produce radiated electromagnetic emissions which greatly exceed the specifications of automotive manufacturers. The effects of radiated emissions correlate to the output PWM frequency and switching rise and fall times. To decrease radiated emissions it is desirable to decrease the applied frequency and increase the rise and fall times. Since a frequency below 20 kHz is not acceptable, the rise and fall times are negotiable. A rise time between 0.5 and 0.25 microseconds will cause radiated emission problems to occur between 636 kHz and 1.27 MHz, decreasing at 20 dB per decade. This frequency range lies in the middle of the AM frequency band and is deemed unacceptable. Increasing the switching rise time to something greater than 10 microseconds will eliminate AM band radiated emissions but would severely impact speed control power efficiency. [6]

2.2 COM PORT

COM port is more often used than LPT because COM port is more resistive to bigger loads and there is less chances of failing. So if you know Visual Basic a little bit then this shouldn’t be very hard to use MSComm Control component which is located in *Project->Components*. You should check check box *MSComm Control*. Main difficulty with this is that you have to follow RS232 protocol. This is why it is better to use microcontrollers that have built in USART interface. Of course

MSComm component allows reading and controlling single COM pins and this way to control any external devices without using RS232 protocol. One good example is popular programming software PonyProg (which is programmed in other language than VB, but principals are same). You can see various supported circuits that PonyProg supports and you can see that Rx(2) and Tx(3) signals aren't used at all. All data transfer is done via CTS(8), DSR(6), DTR(4), RTS(7) (in some places Tx(3) is used). In order to read pin state of port it is enough to send unipolar positive signals without converting TTL-RS232. Of course this doesn't comply with RS232 standard but this way works perfectly. But this is only recommended to hobby circuits. Professional hardware should have conversion. [8]. so we can read three pins of COM port: CD, CTS, and DSR. Command reading CTS (8) would look as follows:

```
If MSComm1.CTSHolding = False Then
```

Or

```
If MSComm1.CTSHolding = True Then
```

With this command we can read weather logical 0 or 1 is on pin CTS.

COM port pins DTR and RTS are capable to output (+12V) and (-12V) and this way to light a LED or turn on Relay or other device. For instance output for pin RTS command:

MSComm1.RTSEnable = False (+12v on 7 pin)

MSComm1.RTSEnable = True (-12v on 7 pin)

Using these commands it is possible to program simple data transfer or complicated protocols for instance I2C, SPI, MicroWire and so on. One of good examples is *DS1621 pc thermometer*, developed by Alberto Ricci. He programmed I2C protocol for data transfer between DS1621 thermometers. [8]

2.3 RS232

The RS232 standard describes a communication method where information is sent bit by bit on a physical channel. On PC's a length between 5 and 8 bits can be selected. This length is the netto information length of each word. For proper transfer additional bits are added for synchronization and error checking purposes. It is important, that the transmitter and receiver use the same number of bits. Otherwise, the data word may be misinterpreted, or not recognized at all. With *synchronous communication*, a clock or trigger signal must be present which indicates the beginning of each transfer. The absence of a clock signal makes an asynchronous communication channel cheaper to operate. A disadvantage is that the receiver can start at the wrong moment receiving the information. Resynchronization is then needed which costs time. All data received in the resynchronization period is lost. Another disadvantage is that extra bits are needed in the data stream to indicate the start and end of useful information. These extra bits take up bandwidth. Data bits are sent with a predefined frequency, the *baud rate*. With RS232, the line voltage level can have two states. The on state is also known as *mark*, the off state as *space*. No other line states are possible. When the line is idle, it is kept in the mark state. [9] RS232 sending of a data word can start on each moment. If starting at each moment is possible, this can pose some problems for the receiver to know which the first bit to receive is. To overcome this problem, each data word is started with an attention bit. This attention bit, also known as the *start bit*, is always identified by the space line level. Because the line is in mark state when idle, the start bit is easily recognized by the receiver. [9] Directly following the start bit, the *data bits* are sent. A bit value 1 causes the line to go in mark state; the bit value 0 is represented by a space. The least significant bit is always the first bit sent. [9]. the figure 2.1 shows the DB9 pin out.

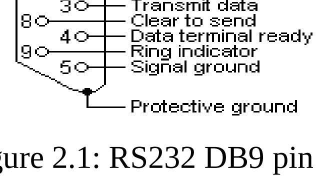


Figure 2.1: RS232 DB9 pin out

2.4 PWM FREQUENCY

The frequency of the resulting PWM signal is dependant on the frequency of the ramp waveform. What frequency do we want? This is not a simple question. Some pros and cons are:

i. Frequencies between 20Hz and 18 kHz may produce audible screaming from the speed controller and motors.
ii. RF interference emitted by the circuit will be worse the higher the switching frequency is.
iii. Each switching on and off of the speed controller MOSFETs results in a little power loss. Therefore the greater the time spent switching compared with the static on and off times, the greater will be the resulting 'switching loss' in the MOSFETs.
iv. The higher the switching frequency, the more stable is the current waveform in the motors. This waveform will be a spiky switching waveform at low frequencies, but at high frequencies the inductance of the motor will smooth this out to an average DC current level proportional to the PWM demand. This spikiness will cause greater power loss in the resistances of the wires, MOSFETs, and motor windings than a steady DC current waveform.

2.5 APPLICATIONS

One potential application of automatic motor speed is regulating room temperature. Your PC can sense the current temperature (using an analog-to-digital converter) and then automatically increase/decrease the fan's speed accordingly. By using your PC you are no longer burdened to manually adjust the fan's speed as the room heats or cools. [7]

CHAPTER 3

METHODOLOGY

This chapter describes methods and step I have been applied to complete the hardware and software.

3.1 DESIGN CONCEPT

PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the periods during which that supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM. [11]

Figure 3.1 shows three different PWM signals. Figure 3.1a shows a PWM output at a 10% duty cycle. That is, the signal is on for 10% of the period and off the other 90%. Figures 3.1b show PWM output at 50% duty cycles while figure 3.1c show 90% duty cycles. These three PWM outputs encode three different analog signal values, at 10%, 50%, and 90% of the full strength. For example, the supply is 9V and the duty cycle is 10%, a 0.9V analog signal results. [11]

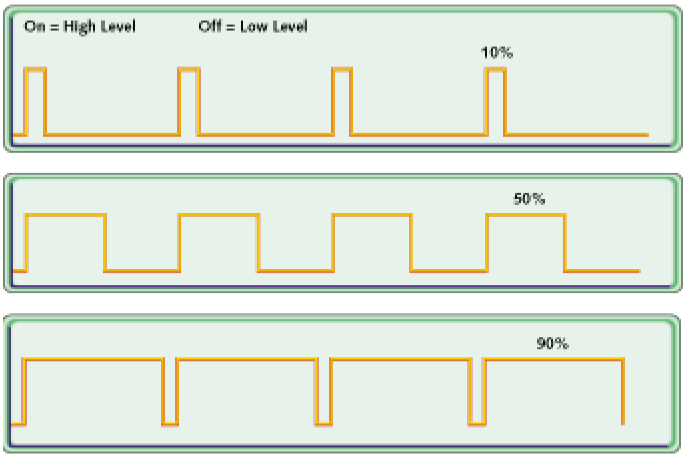


Figure 3.1: PWM signals with different duty cycles

Figure 3.2 shows a simple circuit that could be driven using PWM. In the figure, a 9 V battery powers an incandescent light bulb. If we closed the switch connecting the battery and lamp for 50 ms, the bulb would receive 9 V during that interval. If we then opened the switch for the next 50 ms, the bulb would receive 0 V. If we repeat this cycle 10 times a second, the bulb will be lit as though it were connected to a 4.5 V battery (50% of 9 V). We say that the duty cycle is 50% and the modulating frequency is 10 Hz. [11]

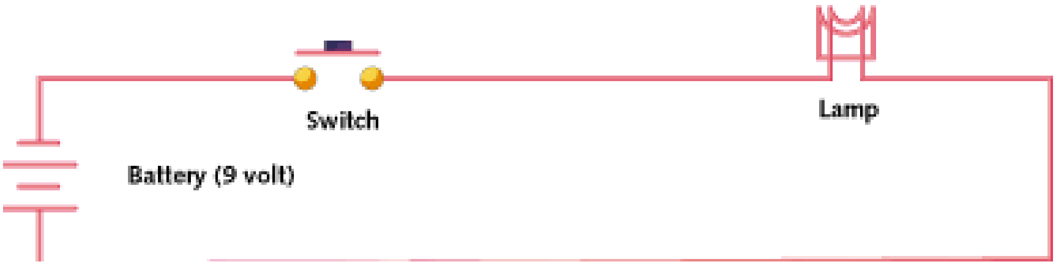


Figure 3.2: A simple PWM circuit

Most loads, inductive and capacitive alike, require a much higher modulating frequency than 10 Hz. Imagine that our lamp was switched on for five seconds, then off for five seconds, then on again. The duty cycle would still be 50%, but the bulb would appear brightly lit for the first five seconds and off for the next. In order for the bulb to see a voltage of 4.5 volts, the cycle period must be short relative to the load's response time to a change in the switch state. To achieve the desired effect of a dimmer (but always lit) lamp, it is necessary to increase the modulating frequency.

The same is true in other applications of PWM. Common modulating frequencies range from 1 kHz to 200 kHz.

The objective of a motor speed controller is to take a signal representing in the demanded speed that controlled by user, and to drive a motor at that speed. The controller may or may not actually measure the speed of the motor and the other word is errors between input and output signal. If it does, it is called a Feedback Speed Controller or Closed Loop Speed Controller, if not it is called an Open Loop Speed Controller. Feedback speed control is better, but more complicated, and may not be required for a simple design and system that has using efficiency equipment. In this project, I need to design Open Loop Speed Controller which is no feedback circuit.

There are many steps to generate the pulse signal from the PWM switching like using 555 timers, microprocessor, MAX038 IC, TL494 IC, SG1525 IC, function generator and others. Computer system assisted by software can use to generate PWM like the C++, Visual Basic, and MATLAB.

In order to achieve the objectives of this project, we decided to design the switching circuit using MOSFET, and the circuit interface to PC with serial port. The flow of this project is constructed in the block diagram for easy to understand in figure3.3 below.

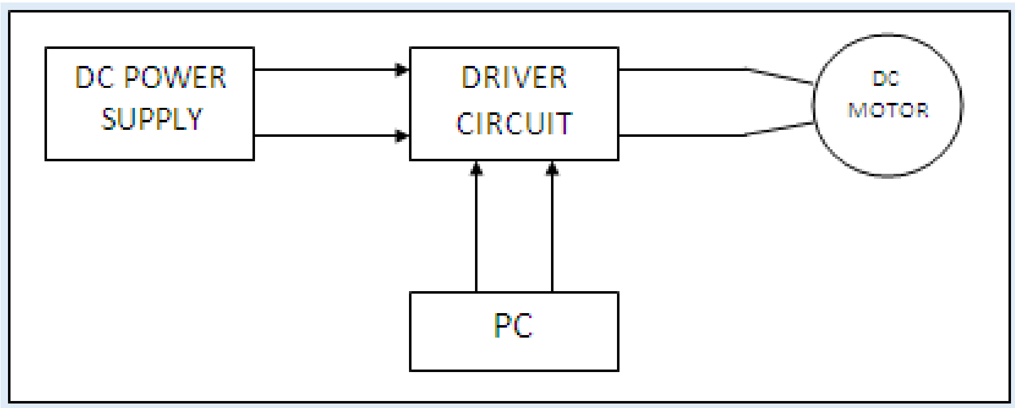


Figure 3.3: Circuit block diagram

The proposed project is shown in figure 3.3. This project is focus on the DC speed motor controller which controlled via PC. For this prototype, I decide to drive 24V DC motor, but in real application we can change the maximum load drive of the prototype depends on the MOSFET used. The output available is 0 to 24 V means that the motor can rotate from minimum speed to maximum.

The PC as a GUI will send the PWM signal driver circuit. When the gate of MOSFET drives by PWM, this is allowing current flow from drain to source. The MOSFET controls the voltage value hence speed of DC motor controlled. Actually, the speed of DC motor is depending on the spectrum of PWM. The snubber circuit may not need to implement because MOSFET characteristic is already snubberless. The PWM signals can be generated in a number of ways.

The speed of a DC motor is directly proportional to the supply voltage, so if we reduce the supply voltage from 24 V to 12 V, the motor will run at half the speed. The speed controller works by varying the average voltage sent to the motor. It could do this by simply adjusting the voltage sent to the motor, but this is quite inefficient to do. A better way is to switch the motor's supply on and off very quickly. If the switching is fast enough, the motor doesn't notice the value of voltage, it only notices the average effect.

As the amount of time that the voltage is on increases compared with the amount of time that it is off, the average speed of the motor increases. This on-off switching is performed by power MOSFET. MOSFET is a device that can turn very large currents on and off under the control of a low signal level voltage. The time that it takes a motor to speed up and slow down under switching conditions is dependant on the inertia of the rotor and how much friction and load torque there is. The figurev3.4 below shows the speed of a motor that is being turned on and off fairly slowly:

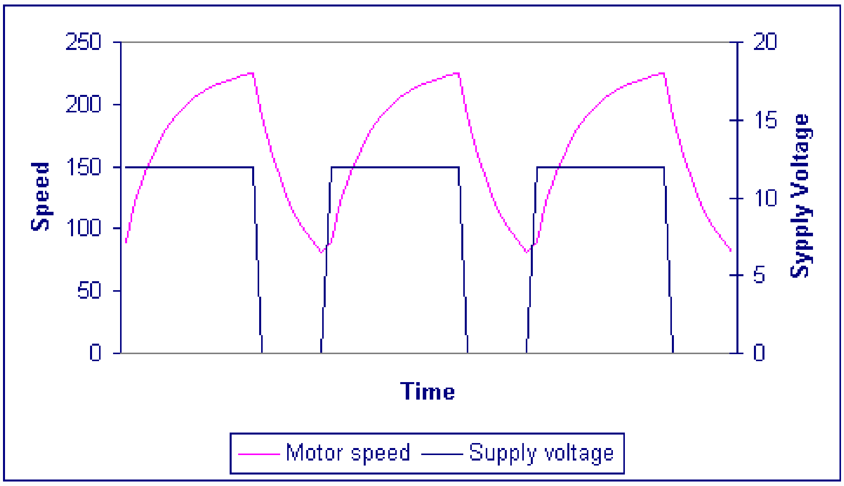


Figure 3.4: Speed of motor and supply voltage versus time

We can see that the average speed is around 150, although it varies quite a bit. If the supply voltage is switched fast enough, it won't have time to change speed much, and the speed will be quite steady. This is the principle of switch mode speed control. Thus the speed is set by PWM.

A graphical user interface (GUI) is a type of user interface which allows people to interact with electronic devices like computers. A GUI offers graphical icons, and visual indicators as opposed to text-based interfaces, typed command labels or text navigation to fully represent the information and actions available to a user. The actions are usually performed through direct manipulation of the graphical elements.

3.2 HARDWARE

Hardware is a main part of this project. For the hardware, I need to design the driver circuit to drive the MOSFET. The maximum voltage supplied by computer is not enough to drive the MOSFET. Thus, I need to boost up suitable for the Vgs depend on type of MOSFET used. The next subtopic explained about the circuit diagram and their operations.

3.2.1 Circuit Diagram

Circuit diagram are designed simulate before implement it into circuit board. Figure 3.5 show the circuit diagram of hardware system.

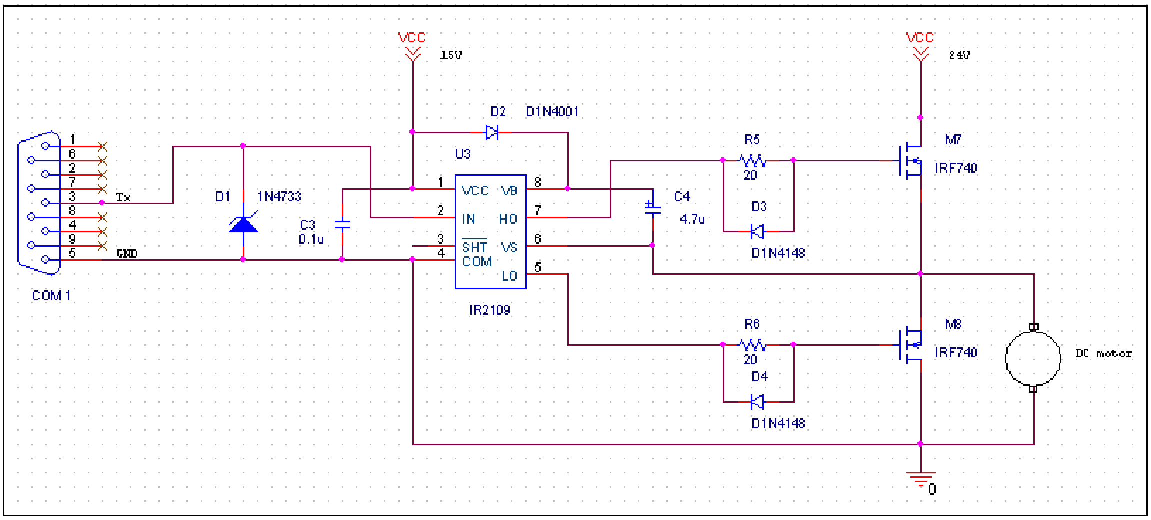


Figure 3.5: Circuit Diagram of Hardware

The PWM signal from PC is transfer to the driver circuit through leg 3 transmit data (Tx) RS232 serial port communication about 9V peak voltage. The ground signals connect in leg 5 in DB9 serial port. For small load application below 12V, we can connect the serial port direct to drive MOSFET. For high load application, the high voltage side and low voltage side must be separately because it is danger to PC. Voltage spike from high voltage side may return to PC and damage the motherboard. The 9V peak voltage may not sufficient to drive the IRF740. The driver circuit design using half bridge driver IC IR2109 boost the peak output voltage depend on the input voltage (Vcc). This IC consists of low voltage side and high voltage side output. I have been applying both to drive the IRF740 making half bridge switching. The resistor placed at the IR2109 driver output to reduce the current. The PWM produce by IC are switch the MOSFET at high speed thus allow the voltage drop through IRF740 depend on their duty cycle of PWM. The maximum duty cycle make motor run at fully speed. The zener diode is purpose to protect the back EMF to return to PC.

3.2.2 Driver Circuit

Minimizing power loses in electronic switches is in important when designing power electronic circuits. On state power losses occur because the voltage across the conducting switch is not zero. Switching losses occur because a device does not make a transition form one state to other instantaneously. Switch losses can be minimized by drive circuit designed to provide fast switching transitions. Snubber circuit is designed to alter the switching waveforms to reduce power losses and to protect the switch. For the MOSFET switching device, they do need snubber circuit because the characteristic of MOSET is snubberless.

A MOSFET drive circuit must be capable of rapidly sourcing and sinking current for high speed switching if the input signal is from low voltage digital logic devices, the logic output may not be sufficient to turn on the MOSFET. A better drive circuit is double emitter follower or 'totem pole' consists of matched NPN and PNP bipolar transistor pair. When the drive input voltage is high NPN transistor is turn on and PNP is off, turning the MOSFET on and vice versa.

Some integrated circuits have outputs with built in current sourcing and sinking arrangement which are capable of driving transistor directly in limited power application. MOSFET gate drivers are available as integrated circuit (IC) packages, the international rectifier IR2109 for example, is designed to drive both high side and low side switch. To easily manage and reduce hardware in a system I have chose IR2109 as a driver circuit. All of component needed by driver circuit is built in this IC.

Electrical isolation between the MOSFET and the control circuit is often desirable because of elevated voltage levels of the MOSFET as in the upper transistor in a full bridge circuit or a buck converter. Magnetically coupled and optically coupled circuits are commonly for electrical isolation.

3.2.3 Components

In order to complete hardware, electronic component are implement based on their functionality and characteristics. We can refer their characteristics in the datasheet which can be downloaded from internet. This characteristic is very important to make the circuit designed function.

3.2.3.1 MOSFET

The MOSFET is a voltage control device differs from Bipolar Junction Transistor (BJT) which current control device. It is relatively simple to turn on and off, which gives it an advantages over a BJT. The on state is achieved when gate to source voltage sufficiently exceed threshold voltage, forcing the MOSFET into the ohmic region of operation. Typically, The MOSFET gate to source for the on state in switching circuit is between 10V and 12V. The off state is achieved by a lower than threshold voltage. On and off state gate current is essentially zero. In this project, I have using IRF740 MOSFET which capable drive load up to 400V with 10A.

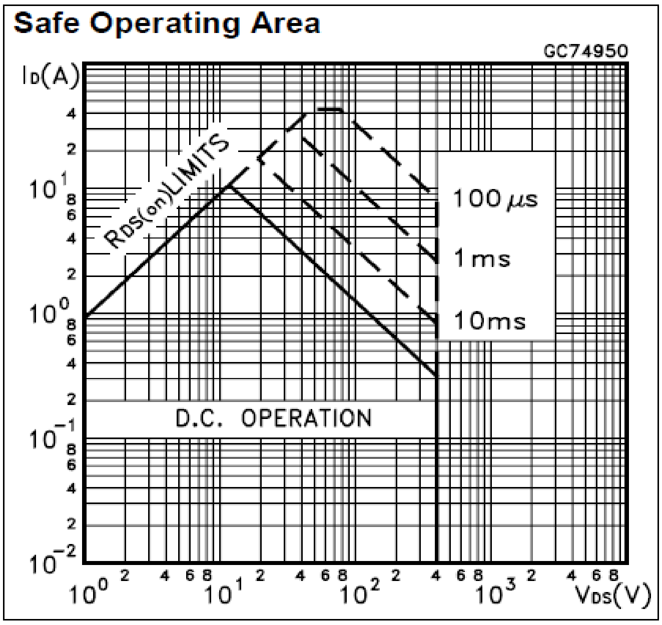


Figure 3.6: Safe Operating Area of IRF740

The load driven by the IRF740 MOSFET is depending on their safe operating area that provided with the datasheet. The characteristic of load must be capable to operate with IRF740. The current and voltage drawn by load must be in DC operation region. The characteristic of safe operating area of IRF740 is shown in figure 3.6. The MOSFET may damage if the load connected has characteristic over safe operating area.

Based on figure 3.6, IRF740 can drive maximum 10A and 400V load. The figure 3.7 shows the IRF740 MOSFET.

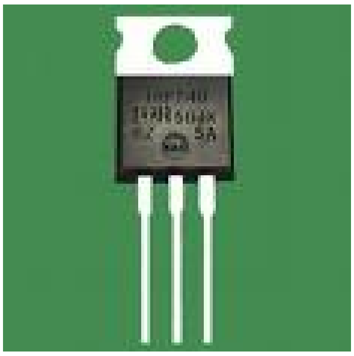


Figure 3.7: IRF740 MOSFET

3.2.3.2 Capacitor

In this project, I have been used electrolytic and ceramic capacitor. A capacitor is a small device that can be charged up with electrical energy, store it and then release it. The capacitor functions as store electrical energy in voltage form. Capacitors are commonly used in electronic devices to maintain power supply while batteries are being changed. An electrolytic capacitor is a type of capacitor that uses an ionic conducting liquid as one of its plates. This is especially the case in power-supply filters, where they store charge needed to moderate output voltage and current fluctuations, in rectifier output. The combination of capacitor in power supply circuit is to reduce the ripple of output voltage that was regulated by regulator IC. Unlike electrolytic capacitor, ceramic capacitor does not have polarity. Figure 3.8 shows electrolytic capacitors while figures 3.8 show ceramic capacitor.

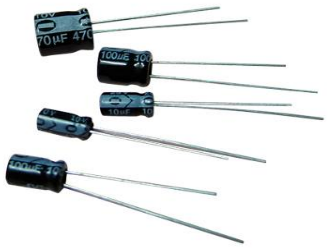


Figure 3.8: Electrolytic Capacitor

Figure 3.9: Ceramic capacitor

3.2.3.3 Resistor

Resistor is common component used in electronic circuit. Usually, the resistance functions to reduce voltage and current limiting or reduce the flow of electric current, in drive circuit, I have been uses the low resistance as current limiting to the MOSFET and LED. Figure 3.10 shows the resistor used in this project.

Figure 3.10: Resistor

3.2.3.4 DC Motor

The DC motor act as load, in this project, I have using 24V DC motor as a load. Figure 3.11 show the 24Vdc Motor.

Figure 3.11: DC motor

3.2.3.5 Diode

As we know, diode acts to allow one direction of current only to prevent it from backward. Diode is widely uses in rectifier and converter circuit. In this project, I have use diode types IN4007 and IN4148. Figure 3.12 show the diodes.

Figure 3.12: Diode

3.2.3.6 Zener Diode

A Zener diode is a type of diode that permits current in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage. The main function of zener diode is for protection device in electronic circuit suitable for their characteristics. Figure 3.13 shows the characteristic of zener diode which function when the voltage is larger than breakdown voltage. The Figure 3.14 shows zener diode.

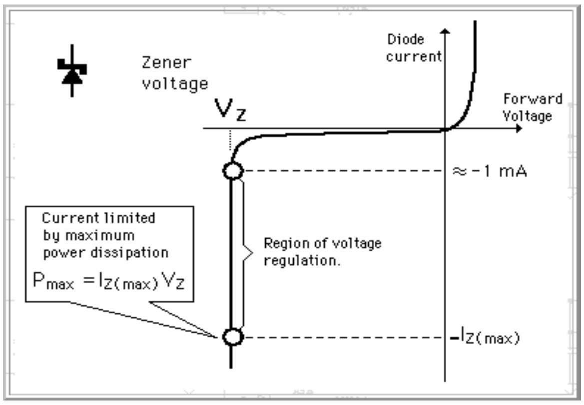


Figure 3.13: Zener diode characteristic

Figure 3.14: Zener diode

3.2.3.7 IR2109

The IR2109 are high voltage, high speed power MOSFET drivers with dependent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET in the high side configuration which operates up to 600 volts. In this project, the low and high side of output are connect to gate MOSFET make it function like half bridge switching. Figure 3.15 show the IR2109 half bridge driver.

Figure 1.15: IR2109 half bridge driver

3.2.3.8 Voltage Regulator

A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level. In power supply circuit, I have use three 1A voltage regulator which are LM7812 to drive cooling fan, LM7815 to supply IR2109 and LM7824 for motor supply. Figure 3.16 show voltage regulator.

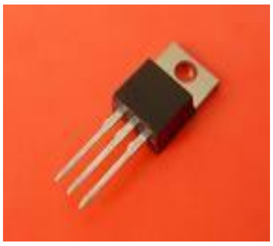


Figure 3.16: voltage regulator

3.2.3.9 LED

Typically LED is used as indicator in an electronic circuit. The characteristic of this component that produce light make it widely used in electronic application like sign indicator, watch, and display devices. In my project, LED is used as switch indicator and dimmer indicator which depend on PWM generated by computer. When duty cycle is high, the LED flame in brightness or in other word the brightness of LED is proportional to duty cycle. Figure 3.17 show LED.

Figure 3.17: LED

3.2.4 Power Supply Circuit

In this project, I have done to designed own power supply to supply the driver circuit and motor. The figure 3.18 show circuit diagram of power supply.

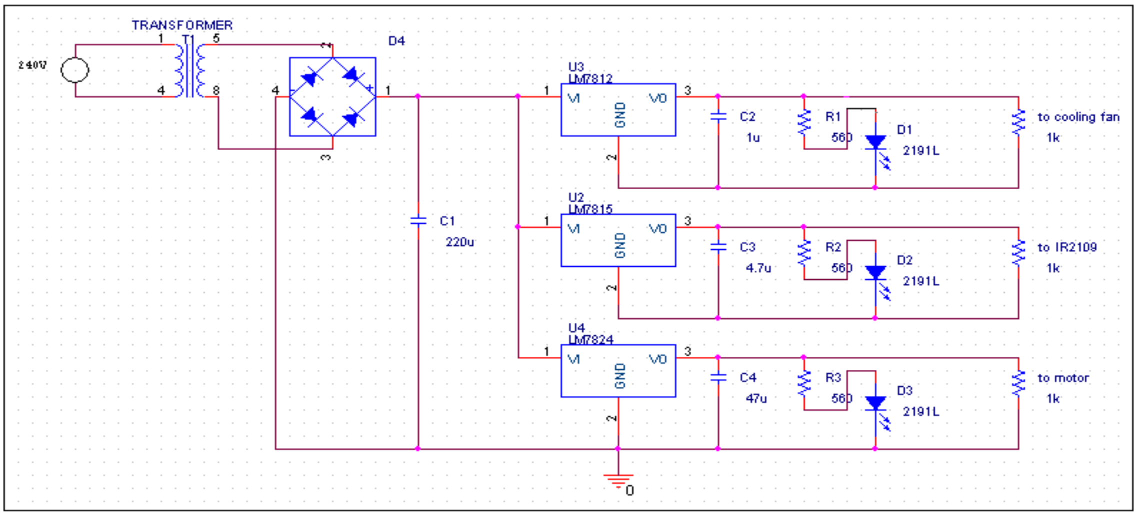


Figure 3.18: Power supply circuit

The 240V AC input voltage is step down to 24V AC transformer through a 1A fuse. The 24V AC is rectified by diode to produce DC voltage. The dc output voltage produced by diode is about 33.9V.

$$Vdc = Vac\,\sqrt{2}$$

$$Vdc = 24\,\sqrt{2}$$

$$\text{Vdc} = 33.9\ \text{V}$$

The dc output voltage is not smooth and still have ripple. To reduce ripple voltage, the 220uF capacitor added parallel with voltage regulator. Three voltage regulators used to regulate different voltage suitable for application. Then the voltage regulator was regulating the voltage based on their types. The small capacitor added parallel with load in order to smooth the output voltage because it still has small ripple. The LED used as indicator of the output voltage which flaming when is the switch is on.

3.3 SOFTWARE

3.3.1 Graphical User Interface (GUI)

A graphical user interface (GUI) is a type of user interface which allows people to interact with electronic devices like computers, hand-held devices, household appliances and office equipment. A GUI offers graphical icons, and visual indicators as opposed to text-based interfaces, typed command labels or text navigation to fully represent the information and actions available to a user. The actions are usually performed through direct manipulation of the graphical elements.

Designing the visual composition and temporal behavior of GUI is an important part of software application programming. Its goal is to enhance the efficiency and ease of use for the underlying logical design of a stored program, a design discipline known as usability. Techniques of user-centered design are used to ensure that the visual language introduced in the design is well tailored to the tasks it must perform.

In software part, I have use Microsoft Visual Basic language to create GUI so thus user can control motor speed through instruction provided. I have create a login form in order to protect this system from incent people to access this application. After login, main menu form will appear on the window. The system provided by calendar, time and some graphic. Main menu form provided link to access the abstract form, student profile form and supervisor form. From that, user can get further information about this program. When the users choose to control speed motor, the control form will appear by click the ok button. Then, they can control the speed which consists of 8 steps. The figure 3.19 shown login form, figure 3.20 main menu form and figure 3.21 show control form.

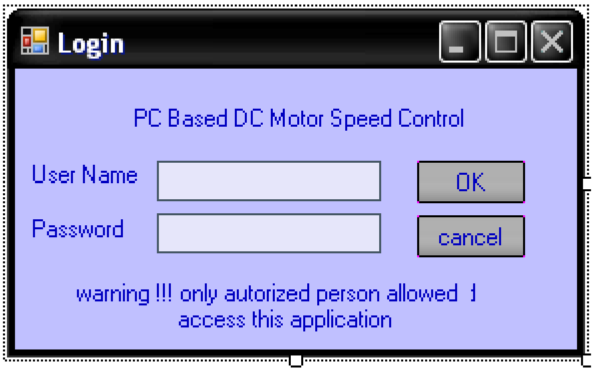


Figure 3.19: Login form

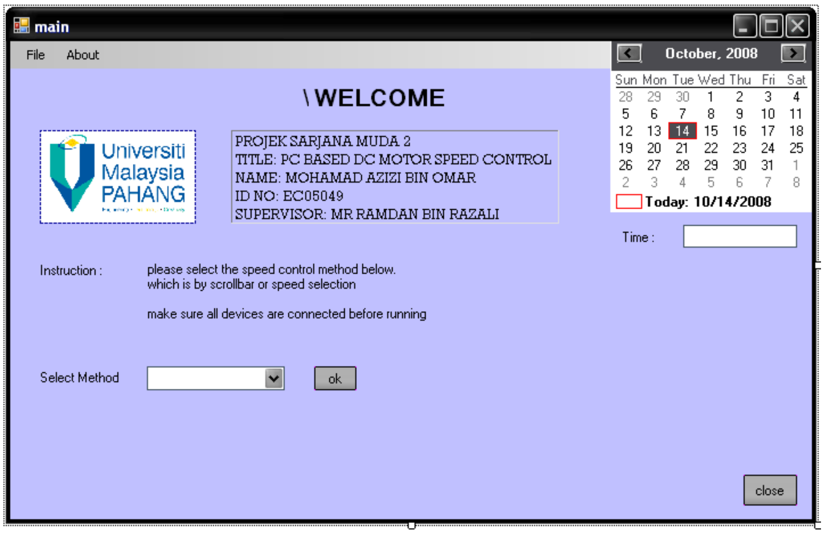


Figure 3.20: Main menu form

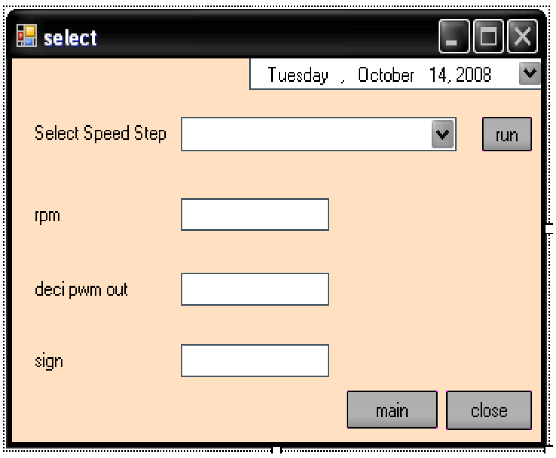


Figure 3.21: Control form

3.3.2 Visual Basic

Visual Basic .NET (VB.NET) is an object-oriented computer language that can be viewed as an evolution of Microsoft's Visual Basic (VB) implemented on the Microsoft .NET framework. Its introduction has been controversial, as significant changes were made that broke backward compatibility with older versions and caused a rift within the developer community.

In this project, I have been using Microsoft Visual Basic 2005 express edition which can be download free. This software is able to support the system and make instruction to generate PWM. Actually, we are also can use another software as GUI like C, C++, java language, but I decide to using VB because it more easier than other and can interface with hardware simply.

3.3.3 Coding

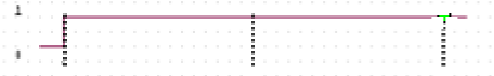
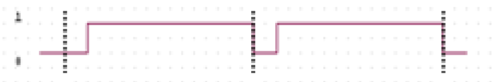
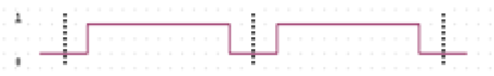
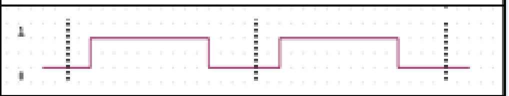
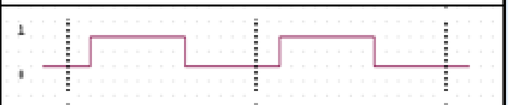
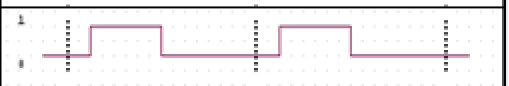
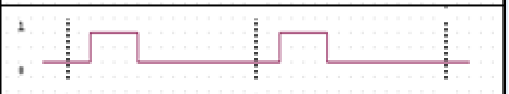
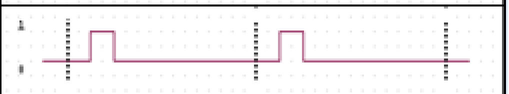
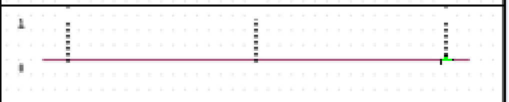
. In this project, I have applied ComboBox tool which user can select speed step from zero to 8 steps. Val is refer to the step that chosen by user. If value of step is zero, MotorON define false means motor is in off condition. If the value of ComboBox between one to eight steps, the MotorON define true means motor is in ON condition and serial port is open to transfer PWM.

```
    Dim pwm As UShort
    Dim val As UShort

    val = ComboBox1.Text

    If val = 0 Then
        MotorON = False

    Else
        pwm = (255 << (val - 1)) And 127
        curChr = pwm
        MotorON = True
```

Figure 3.22: PWM coding

Figure 3.22 above show coding for PWM generating. Actually, the data transfer is in binary code in 8 bits. In logic 1 state, the voltage sent is 0V while logic 0 sent 12V. The PWM define 255 in decimal at zero speed means that the data sent 8 bits logic 1. For the step 1, there is sending 7 bits logic 1 and 1 logic 0. For the next step, the bits sent are decrease by 1 based in the step chosen by user. For easy understanding, we can refer table 3.1 below.

Table 3.1: Topologies for logic input

step	decimal	Duty cycle %	logic 1 = OFF state logic 0 = ON state
0	255	0	
1	127	12.5	
2	126	25	
3	124	37.5	
4	120	50	
5	112	62.5	
6	96	75	
7	64	87.5	
8	0	99	

3.4 INTERFACING

It is difficult to interface the hardware and software in a system because it is isolated with two side which is high voltage and low voltage side. Low voltage side refers to computer system that operates in small voltage about 5V and low current. Back EMF from the motor supply may be killing the PC when fault occur. The wire connection of this circuit must be troubleshooting before run the system because error connection of wire may damage PC effect of back EMF.

In this project, the PWM signal data is transferred from PC through serial port (RS232). The parallel port is the easiest port to access for general purpose IO. The RS232 standard is one of the oldest physical communication standards in computer world. The standard defines low-cost serial communication in a robust way where bits are sent sequentially on a copper line. It was originally defined for connecting devices such as computers, terminals and printers to modems. This equipment is connected through their serial port. Nowadays, the computer to computer link with a so-called null modem cable is commonly used.

Communication as defined in the **RS232** standard is an asynchronous serial communication method. The word *serial* means, that the information is sent one bit at a time. *Asynchronous* tells us that the information is not sent in predefined time slots. Data transfer can start at any given time and it is the task of the receiver to detect when a message starts and ends. Asynchronous communication has some advantages and disadvantages which are both discussed in the next paragraph.

The original serial port definition limited the maximum transfer speed to 20 kbps, but practice has shown that higher bandwidth is possible. To overcome these limitations, the RS232-E standard allows much higher communication speeds than its predecessor. These pages provide not only information on the standard itself, but also on how to use serial communication in practice, several connection possibilities to the serial port etc. This includes handshaking and how to choose the right null modem cable for computer to computer communication.

3.4.1 RS232 communication port

The **RS232** standard describes a communication method where information is sent bit by bit on a physical channel. The information must be broken up in data words. The length of a data word is variable. On **PC**'s a length between 5 and 8 bits can be selected. This length is the net to information length of each word. For proper transfer additional bits are added for synchronization and error checking purposes. It is important, that the transmitter and receiver use the same number of bits. Otherwise, the data word may be misinterpreted, or not recognized at all. [9]. Data bits are sent with a predefined frequency, the *baud rate*. Both the transmitter and receiver must be programmed to use the same bit frequency. After the first bit is received, the receiver calculates at which moments the other data bits will be received. It will check the line voltage levels at those moments. [9]

3.4.2 Start bit

RS232 defines an asynchronous type of communication. This means, that sending of a data word can start on each moment. If starting at each moment is possible, this can pose some problems for the receiver to know which the first bit to receive is. To overcome this problem, each data word is started with an attention bit. This attention bit, also known as the *start bit*, is always identified by the space line level. Because the line is in mark state when idle, the start bit is easily recognized by the receiver. [9]

3.4.3 Data bits

Directly following the start bit, the *data bits* are sent. A bit value 1 causes the line to go in mark state; the bit value 0 is represented by a space. The least significant bit is always the first bit sent. [9]

3.4.4 Stop bits

Suppose that the receiver has missed the start bit because of noise on the transmission line. It started on the first following data bit with a space value. This causes garbled date to reach the receiver. A mechanism must be present to resynchronize the communication. To do this, framing is introduced. Framing means, that all the data bits and parity bit are contained in a frame of start and *stop bits*. The period of time lying between the start and stop bits are a constant defined by the baud rate and number of data and parity bits. The start bit has always space value, the stop bit always mark value. If the receiver detects a value other than mark when the stop bit should be present on the line, it knows that there is a synchronization failure. This causes a framing error condition in the receiving **UART**. The device then tries to resynchronize on new incoming bits. [9]

For desynchronizing, the receiver scans the incoming data for valid start and stop bit pairs. This works, as long as there is enough variation in the bit patterns of the data words. If data value zero is sent repeatedly, resynchronization is not possible for example. The stop bit identifying the end of a data frame can have different lengths. Actually, it is not a real bit but a minimum period of time the line must be idle (mark state) at the end of each word. On **PC**'s this period can have three lengths: the time equal to 1, 1.5 or 2 bits. 1.5 bits is only used with data words of 5 bits length and 2 only for longer words. A stop bit length of 1 bit is possible for all data word sizes. [9]

3.4.5 Voltage

The signal level of the **RS232** pins can have two states. A high bit, or mark state is identified by a *negative* voltage and a low bit or space state uses a *positive* value. This might be a bit confusing, because in normal circumstances, high logical values are defined by high voltages also. The voltage limits are shown in table 3.2 below. [9]

Table 3.2: RS232 Voltage values

RS232 voltage values

Level	Transmitter capable (V)	Receiver capable (V)
Space state (0)	+5 ... +15	+3 ... +25
Mark state (1)	-5 ... -15	-3 ... -25
Undefined	-	-3 ... +3

The maximum voltage swing the computer can generate on its port can have influence on the maximum cable length and communication speed that is allowed. Also, if the voltage difference is small, data distortion will occur sooner. For example, my Toshiba laptop mark's voltage is -9.3 V, compared to -11.5 V on desktop computer. The laptop has difficulties to communicate with Mitsubishi PLC's in industrial environments with high noise levels where the desktop computer has no data errors at all using the same cable. [9]

Despite the high voltages present, it is not possible to destroy the serial port by short circuiting. Only applying external voltages with high currents may eventually burn out the driver chips. Still then, the **UART** won't be damaged in most cases.

3.4.6 Maximum cable lengths

The cable length mentioned in the standard allows maximum communication speed to occur. If speed is reduced by a factor 2 or 4, the maximum length increases dramatically. Texas Instruments has done some practical experiments years ago at different baud rates to test the maximum allowed cable lengths. Keep in mind, that the RS232 standard was originally developed for 20 kbps. By halving the maximum communication speed, the allowed cable length increases a factor ten. [10] The table 3.2 and 3.3 shows the length of cable and RS232 characteristic respectively.

Table 3.3: Length of Cable

RS232 cable length according to Texas Instruments

Baud rate	Maximum cable length (ft)
19200	50
9600	500
4800	1000
2400	3000

Table 3.4: RS232 Characteristics

	RS232
Differential	no
Max number of drivers Max number of receivers	1 1
Modes of operation	half duplex full duplex
Network topology	point-to-point
Max distance (acc. standard)	15 m
Max speed at 12 m Max speed at 1200 m	20 kbs (1 kbs)
Max slew rate	30 V/μs
Receiver input resistance	3..7 kΩ
Driver load impedance	3..7 kΩ
Receiver input sensitivity	±3 V
Receiver input range	±15 V
Max driver output voltage	±25 V
Min driver output voltage (with load)	±5 V

The figure 3.23 shows the DB9 communication port, figure 3.24 shows USB-RS232 converter and figure 3.25 shows the DB9 terminal which implement in this project hardware.

Figure 3.23: DB9 Comm. port

Figure 3.24: USB-RS232 converter

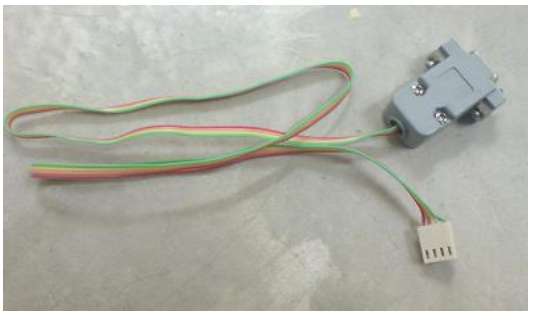


Figure 3.25: DB9 terminal

3.5 SUMMARY

This chapter has discussed about methodology or step that I apply in order to perform this project included software and hardware. The reasons for the selection of methods are state briefly in this chapter.

CHAPTER 4

RESULT AND DISCUSSION

This chapter explains the result obtained from the oscilloscope that showing the PWM wave, their frequency, voltage and others. It is followed by discussion and problem that I face in this project.

4.1 RESULT

The result of this project can be seen by rotation of motor fan. The motor speed is proportional to the mean voltage. We can differ their speed based on step selected by user when motor running. The PWM output is catch from oscilloscope to see their duty cycle at different step.

4.1.1 PWM output at serial port

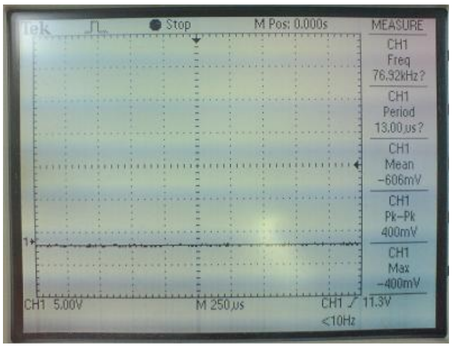


Figure 2.1: PWM at 0% duty cycle

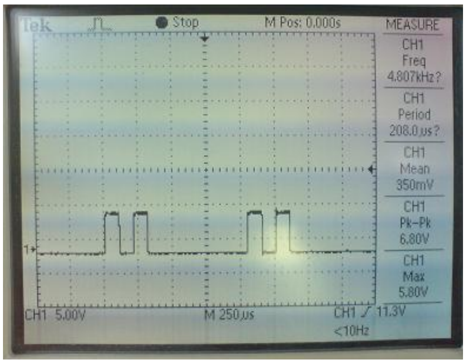


Figure 4.2: PWM at 12.5% duty cycle

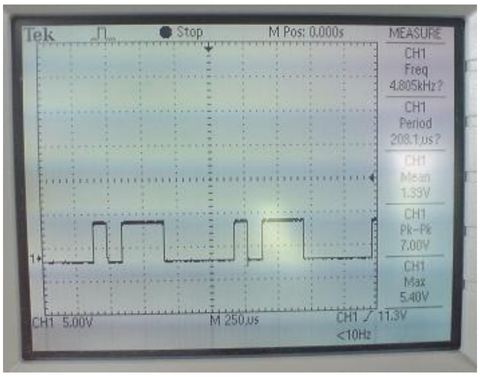


Figure 4.3: PWM at 25% duty cycle

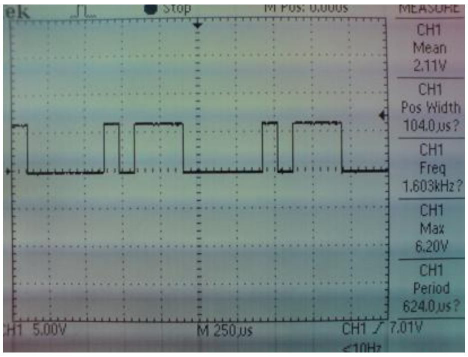


Figure 4.4: PWM at 37.5% duty cycle

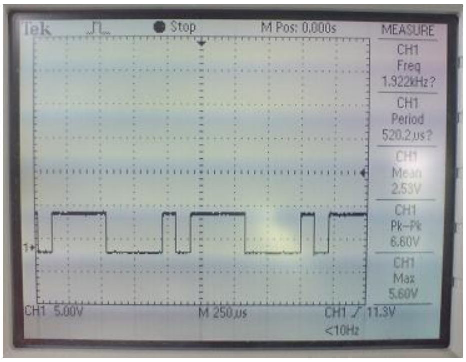


Figure 4.5: PWM at 50% duty cycle

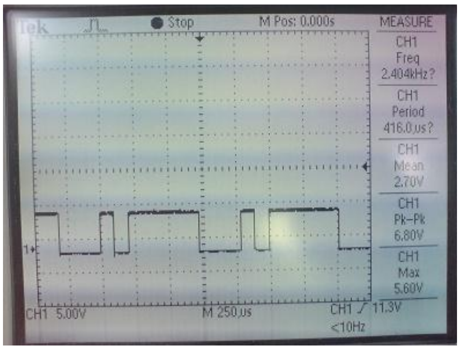


Figure 4.6: PWM at 62.5% duty cycle

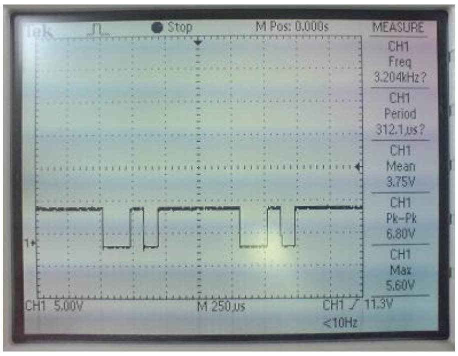


Figure 4.7: PWM at 75% duty cycle

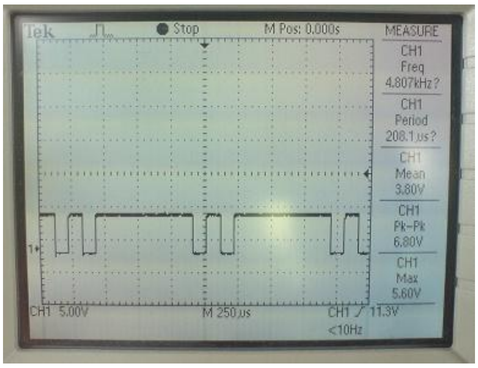


Figure 4.8: PWM at 87.5% duty cycle

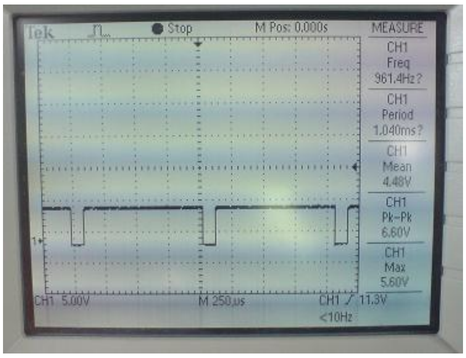


Figure 4.9: PWM at 100% duty cycle

4.1.2 PWM output at motor

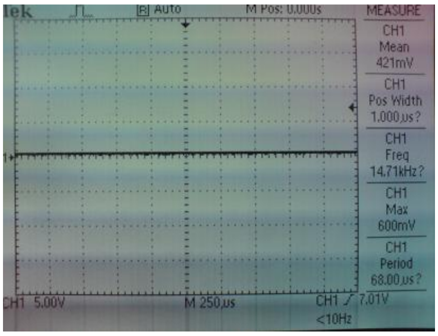


Figure 4.10: 0% duty cycle

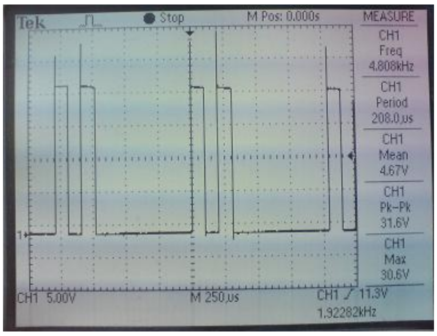


Figure 4.11: PWM at 12.5% duty cycle

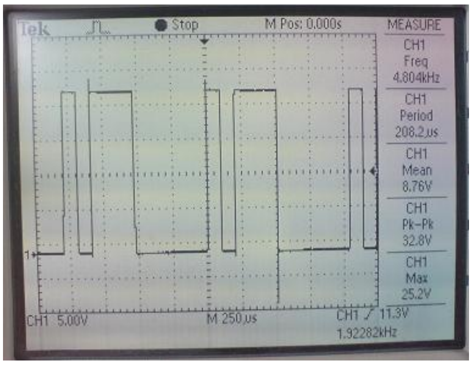


Figure 4.12: PWM at 25% duty cycle

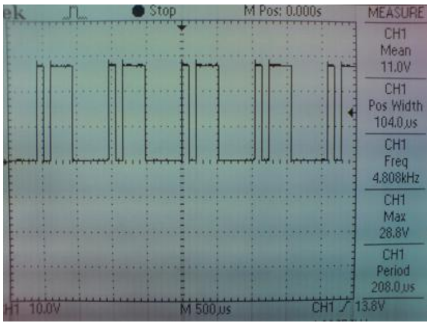


Figure 4.13: PWM at 37.5% duty cycle

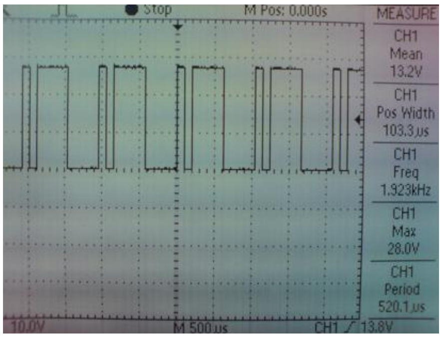


Figure 4.14: PWM at 50% duty cycle

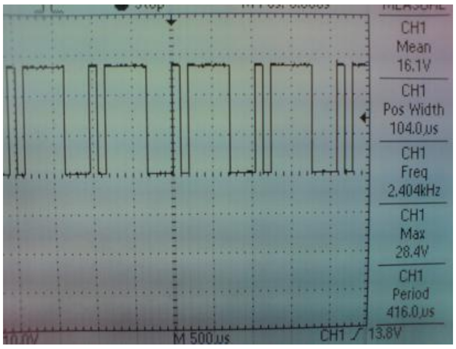


Figure 4.15: PWM at 62.5% duty cycle

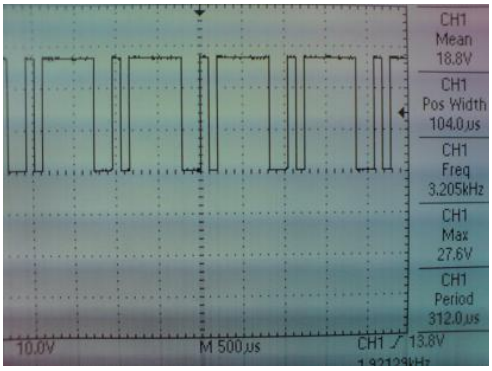


Figure 4.16: PWM at 75% duty cycle

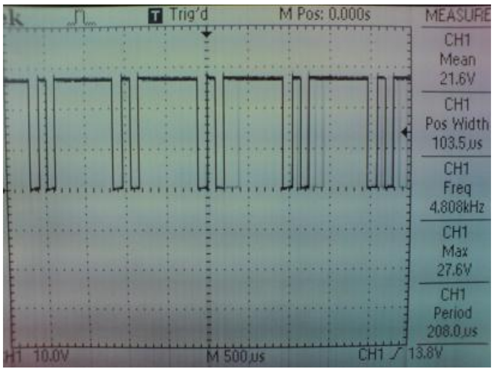


Figure 4.17: PWM at 87.5% duty cycle

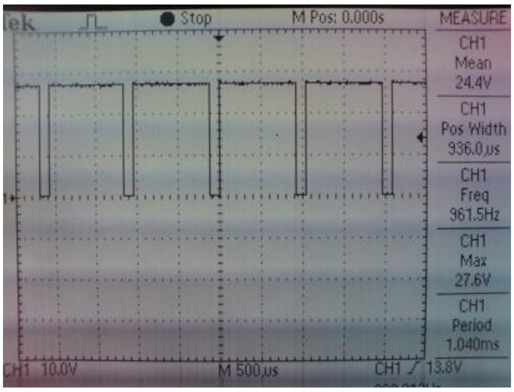


Figure 4.18: PWM at 100% duty cycle

4.2 ANALYSIS

Actually, the speed of motor is directly proportional to the duty cycle. We can see that when motor running at 12.5% duty cycle, their speed is lower and increasing when select next step while when the motor operates at maximum duty cycle, the motor rotate at maximum speed. The frequency of PWM generated by computer is fixing about 4 kHz. From the result, PWM has two rise times in one period because there has start and stop bit which is the protocol of communication of RS232.

Fro GUI form, I create a coding which can read the estimated speed which calculates by manually. From this, the estimated speed display in the form thus user can differ at various speed.

4.3 DISCUSSIONS

During doing this project, there are some error occur. The oscilloscope reading may not correct because of noise. The result is taken in the air conditioner room which can influence the oscilloscope reading cause the PWM waveform and data of frequency, voltage are not accurate.

As I mention before, the motor is operate in high voltage which is danger to PC. The biggest danger would be that could somehow mis wire connection, and get the motor power supply connected wrongly to your serial port. I supposed that will really beefy motors and really beefy motor power supplies. There might be some danger of getting the back EMF spikes onto the motherboard. A separate serial card or USB/serial converter would provide additional isolation

4.4 SUMMARY

From the result and discussion, the PWM waveform shown the result is correct depend on their duty cycle but it has some noise. To prevent noise, the circuit can implement with filter circuit. Basically, the problem that I had face in this project can be solve through the studying the references information whether internet sources or books, or discussion.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter explains about the conclusion of this project overall. The future recommendation are also discusses in order to improve the weakness of the prototype. The cost of this prototype is calculated in order to commercialize it.

5.1 CONCLUSION

At the end of the experiment, this project is done as planning before. Generally, the objective of this project was successfully fulfilled. From this project, I have done to design the driver circuit which suitable to drive the MOSFET. I have also created a coding to generate PWM using visual basic language. From this project, I have got a lot of new knowledge. In the designing this project, the combination of knowledge involved electric, electronic, mechanical, computers & programming knowledge and hand on individual skill are implement to create the circuit and programming language based on reference that I have studied and discussion with supervisor and lecturers.

The computers act as a brain that process and generate PWM based on the instruction given by coding language. The visual basic software from Microsoft is able to make instruction to interfacing with the hardware through serial port. The advantages of this prototype provided with GUI and can be economical compare to another product on the market. This project is not done perfectly and still has weakness. This can be developing for the future to make it functions perfectly. In the technology epoch, there are technologies that can be combined with the system for the future prospect.

5.2 FUTURE RECOMMENDATION

This prototype is able to be commercialized due to their advantage. It can be develop to control the DC motor in industrial application or small appliances which the hardware implementation can be reduced. The user can control their system automatically in their room without need going to plant. The cost of hardware by controlling the speed of DC motor using this method is reduced compare to another method because no additional hardware implement.

For advance, we can use DAQ card because it provided more analog and digital port included input and output. Compare with, DB9 serial port, their port is limited and difficult to define the port. The DAQ is advance technology which can transfer convert data from digital to analog and vice versa simultaneously. The price of DAQ about thousand dollar make project cost higher if I using this device.

To make the system more precise, PID controller can be implementing in this system. PID is very widely used in industrial control systems because it can produce good result. PID acts as controller which correcting errors from feedback thus make the voltage output as set.

In order to create feedback circuit, the best way to do this is to fit an optical encoder. This shines a beam of light from a transmitter across a small space and detects it with a receiver the other end. If a disc is placed in the space, which has slots cut into it, then the signal will only be picked up when a slot is between the transmitter and receiver. An alternative way to measure the speed is using a magnetic sensing device. If motor or gearing has steel teeth, then sensors are available that can detect and count these as they go by.

To detect the speed rotation, an encoder must be implementing. We need a device that will measure the speed of the motor shaft. The best way to do this is to fit an optical encoder. This shines a beam of light from a transmitter across a small space and detects it with a receiver the other end. If a disc is placed in the space, which has slots cut into it, then the signal will only be picked up when a slot is between the transmitter and receiver. The signal will send to computer to process and compare with the source and correct it if errors occur. There is much software that provided PID controller like MATLAB. Besides, we can use microcontroller or PIC as a controller if we can't use PC. The disadvantage of this method is they do not provided GUI. But, we can add LED display as indicator. The propose block diagram are shown in figure 5.1 below.

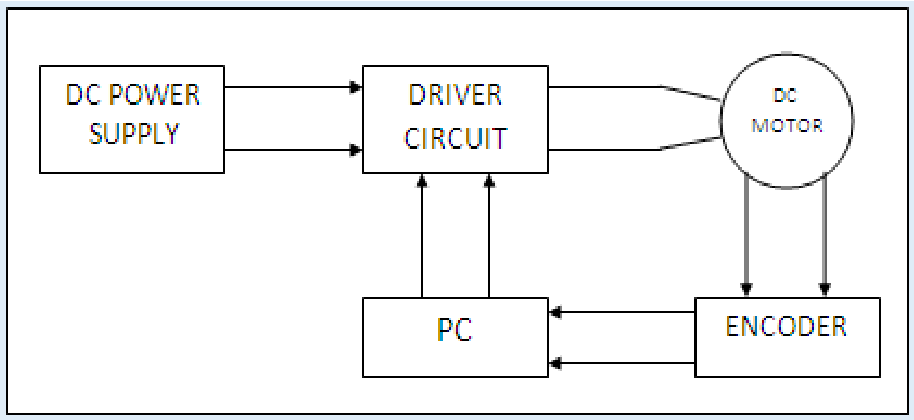


Figure 5.1: Proposed closed loop system

This project can be developing for future application to make it more practical. For example, the web based application is implementing where the user can control several motor through one computer. The small microprocessor system can be designed with a keypad as GUI thus user can monitor their motor easily. The illustration of the system shows in figure 5.2.

Figure 5.2: Illustration of dc motor control via web

This method can be apply in industrial application which is has many plant at the different places. The engineer can't need waste their time to turn on the machines system. This concept also can be implemented by using RF signal, Wi-Fi, Wimax and others method.

5.3 COSTING AND COMMERCIALIZATION

The total costs about the hardware project are calculated in order to see their profit when it marketed. Although the speed controller is exist market, most of them is expensive because the implementation cost is high. In this project, the software development Microsoft Visual Basic 2005 Express Edition is free which can be downloaded from Microsoft web page. The cost of this project is included in hardware only. The cost of hardware is shown in table 5.1 below. If the user want control their speed through computer which has the communication port, the USB/RS232 converter is not needed. The costing of the driver included the USB/RS232 converter can be applied with the laptop which not included with communication port.

Table 5.1: Costing for driver circuit

No.	Component	Price	Quantity	Total
1	IR2109	15.00	1	15.00
2	MOSFET IRF740	3.50	2	3.50
3	Zener diode IN4735	0.30	1	0.30
4	diode	0.10	3	0.30
5	Resistor	0.10	3	0.30
6	LED	0.30	1	0.30
7	Circuit board	2.00	1	2.00
8	Terminal connector	1.50	3	4.50
9	PCB stand	1.00	4	4.00
10	RS232//USB converter	28.00	1	28.00
11	Heat sink	0.50	2	1.00
12	IC stand	0.50	1	0.50
13	wire	1.00	1	1.00
14	DB9	1.50	1	1.50
15	Terminal DB9	0.50	1	0.50
16	Toggle switch	1.50	1	1.50
17	capacitor	0.30	3	0.9
Total (RM)				65.10

For additional, I have design the power supply circuit which is not included the commercialization cost. The user can use their own power supply depend on the load up to 400V dc. The power supply I have designed was supplying voltage to the driver circuit, cooling fan and 24Vdc motor. The cost is shown in table 5.2 below:

Table 5.2: costing for power supply

No.	Component	Price	Quantity	Total
1	Transformer 240/24V	20.00	1	20.00
2	Capacitor	0.30	4	1.20
3	Terminal connector	1.50	3	4.50
4	Circuit board	2.00	1	2.00
5	Power supply casing with fan	10.0		10.00
6	LED	0.30	2	0.60
7	Resistor	0.10	2	0.20
8	Diode	0.10	4	0.40
9	Wire	1.00		1.00
10	Switch	0.80	2	1.60
11	Fuse 2A	0.50	1	0.50
Total (RM)				42.00

The commercialization price for this prototype which includes driver circuit and GUI (software) is about 30% of total cost. Thus the prices for marketing is about RM90.00 include software. Before commercialize, this prototype need some improvement and casing design to make it look as commercial value.

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APPENDIX A

INSTRUCTION CODING

Coding for control form

```
Public Class Form4
    Dim curChr As UShort
    Dim MotorON As Boolean
    Private Sub run_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
run.Click
        Dim pwm As UShort
        Dim val As UShort
        val = ComboBox1.Text
        If val = 0 Then
            MotorON = False
        Else
            pwm = (255 << (val - 1)) And 127
            curChr = pwm
            MotorON = True
            Select Case val
                Case "1"
                    speed.Text = " 300 rpm"
                    deci.Text = +Str(pwm)
                Case "2"
                    speed.Text = " 600 rpm"
                    deci.Text = +Str(pwm)
                Case "3"
                    speed.Text = " 900 rpm"
                    deci.Text = +Str(pwm)
                Case "4"
                    speed.Text = " 1200 rpm"
                    deci.Text = +Str(pwm)
                Case "5"
                    speed.Text = " 1500 rpm"
                    deci.Text = +Str(pwm)
                Case "6"
                    speed.Text = " 1800 rpm"
                    deci.Text = +Str(pwm)
                Case "7"
                    speed.Text = " 2100 rpm"
                    deci.Text = +Str(pwm)
                Case "8"
                    speed.Text = " 2400 rpm"
                    deci.Text = +Str(pwm)
            End Select
        End If
    End Sub
    Private Sub BackgroundWorker1_DoWork(ByVal sender As System.Object, ByVal e As
System.ComponentModel.DoWorkEventArgs) Handles BackgroundWorker1.DoWork
        SerialPort2.Open() '
        While (True)
            If MotorON Then
                If Len(sign.Text) > 15 Then
                    sign.Text = ""
                End If
                sign.Text = sign.Text + Chr(curChr) '  SerialPort2.Write(StrDup(100, Chr(curChr))) '
                        End If
        End While
    End Sub
```

```
  Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button1.Click
      Me.Close()
      Form1.Visible = False
      Form2.Visible = False
      Form3.Visible = False
  End Sub
  Private Sub Form4_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load
      Control.CheckForIllegalCrossThreadCalls = False  '       MotorON = False
      BackgroundWorker1.RunWorkerAsync()
  End Sub
  Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button2.Click
      Me.Close()
      Form3.Visible = True
  End Sub
  Private Sub ComboBox1_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles ComboBox1.SelectedIndexChanged
  End Sub
End Class
```

Coding for login form

```
Public Class Form2
  Inherits System.Windows.Forms.Form
  Dim azizi As String
        Private Sub btnOK_Click(ByVal sender As System.Object, _ByVal e As System.EventArgs)
        Handles btnOK.Click
                If UserName.Text.Length = 0 Then
                        MsgBox("You must enter a user name", _
                        MsgBoxStyle.Exclamation)
                        UserName.Focus()
                ElseIf Password.Text.Length = 0 Then
                        MsgBox("You must enter a password", _
                        MsgBoxStyle.Exclamation)
                        Password.Focus()
                ElseIf PasswordInvalid(UserName.Text, _
                        Password.Text) Then
                        MsgBox("User name/password invalid", _
                        MsgBoxStyle.Exclamation)
                        UserName.Focus()
                Else
                        UserName.Text = azizi
                        Password.Text = azizi
                        Form3.Visible = True
                End If
        End Sub
        Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
        Handles Timer1.Tick
                If Label1.Visible = True Then
                        Label1.Visible = False
                        Label2.Visible = True
                Else : Label2.Visible = True
                        Label2.Visible = False
```

```
                        Label1.Visible = True
                    End If
                End Sub
    Private Function PasswordInvalid(ByVal user_name As String, ByVal password As String) As
Boolean
    Return (user_name <> password)
    End Function

                Private Sub btnCancel_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles
                BtnCancel.Click
                    MessageBox.Show("Are y0u sure to Exit", "Confirmation",
                    MessageBoxButtons.YesNo, MessageBoxIcon.Question)
                Me.Close()
                End Sub
                Private Sub UserName_TextChanged(ByVal sender As System.Object, ByVal e As
                System.EventArgs) Handles UserName.TextChanged
    End Sub
End Class
```

Coding for Main Menu Form

```
Public Class Form3
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button1.Click
        Dim choose As String
        choose = ComboBox2.Text
        Select Case choose
            Case "selection"
                Form4.Visible = True
            Case "scroll"
                Form1.Visible = True
        End Select
    End Sub
    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button2.Click
        MessageBox.Show("Are y0u sure to Exit", "Confirmation", MessageBoxButtons.YesNo,
MessageBoxIcon.Question)
        Form2.Visible = False
        Me.Close()
    End Sub
    Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Timer1.Tick
        TextBox1.Text = (String.Format("{0:hh:mm:ss tt}", Date.Now))
    End Sub
    Private Sub Timer2_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Timer2.Tick
        If Label4.Visible = True Then
            Label4.Visible = False
            Label5.Visible = True
        Else : Label5.Visible = True
            Label5.Visible = False
            Label4.Visible = True
        End If
    End Sub
```

```
   Private Sub AbstractToolStripMenuItem_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles AbstractToolStripMenuItem.Click
      Form5.Visible = True
   End Sub
   Private Sub SupervisorToolStripMenuItem1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles SupervisorToolStripMenuItem1.Click
      Form7.Visible = True
   End Sub
   Private Sub CloseToolStripMenuItem_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles CloseToolStripMenuItem.Click
      Me.Close()
   End Sub
   Private Sub LinkLabel1_LinkClicked(ByVal sender As System.Object, ByVal e As
System.Windows.Forms.LinkLabelLinkClickedEventArgs)
   End Sub
End Class
```

APPENDIX B
DATASHEET

IR2109 DATASHEET

International
IOR Rectifier

Data Sheet No. PD60163-P

IR2109(4) (S)

HALF-BRIDGE DRIVER

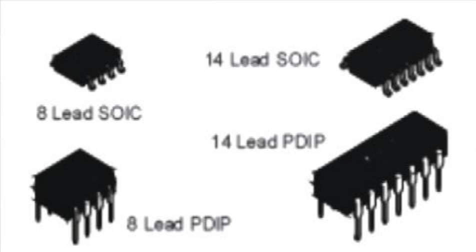
Features

- Floating channel designed for bootstrap operation
  Fully operational to +600V
  Tolerant to negative transient voltage
  dV/dt immune
- Gate drive supply range from 10 to 20V
- Undervoltage lockout for both channels
- 3.3V, 5V and 15V input logic compatible
- Cross-conduction prevention logic
- Matched propagation delay for both channels
- High side output in phase with IN input
- Logic and power ground +/- 5V offset.
- Internal 540ns dead-time, and programmable up to 5us with one external R_{DT} resistor (IR21094)
- Lower di/dt gate driver for better noise immunity
- Shut down input turns off both channels.

Product Summary

V_{OFFSET}	600V max.
I_O+/-	120 mA / 250 mA
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	750 & 200 ns
Dead Time	540 ns
(programmable up to 5uS for IR21094)	

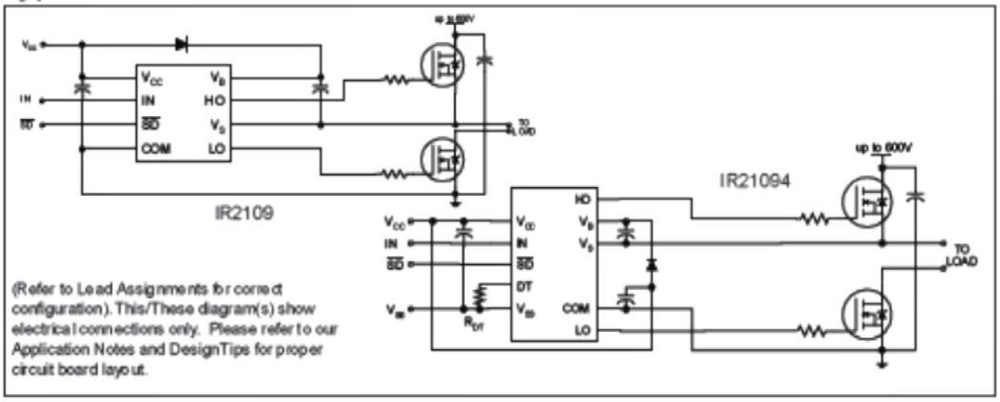
Packages



Description

The IR2109(4)(S) are high voltage, high speed power MOSFET and IGBT drivers with dependent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.

Typical Connection



Absolute Maximum Ratings

Absolute maximum ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition		Min.	Max.	Units
V_B	High side floating absolute voltage		-0.3	625	V
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{CC}	Low side and logic fixed supply voltage		-0.3	25	
V_{LO}	Low side output voltage		-0.3	V_{CC} + 0.3	
DT	Programmable dead-time pin voltage (IR21094 only)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{SS}	Logic ground (IR21094/IR21894 only)		V_{CC} - 25	V_{CC} + 0.3	
dV_S/dt	Allowable offset supply voltage transient		—	50	V/ns
P_D	Package power dissipation @ $T_A \le +25°C$	(8 Lead PDIP)	—	1.0	W
		(8 Lead SOIC)	—	0.625	
		(14 lead PDIP)	—	1.6	
		(14 lead SOIC)	—	1.0	
Rth_{JA}	Thermal resistance, junction to ambient	(8 Lead PDIP)	—	125	°C/W
		(8 Lead SOIC)	—	200	
		(14 lead PDIP)	—	75	
		(14 lead SOIC)	—	120	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-50	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

Recommended Operating Conditions

The input/output logic timing diagram is shown in figure 1. For proper operation the device should be used within the recommended conditions. The V_S and V_{SS} offset rating are tested with all supplies biased at 15V differential.

Symbol	Definition	Min.	Max.	Units
VB	High side floating supply absolute voltage	V_S + 10	V_S + 20	V
V_S	High side floating supply offset voltage	Note 1	600	
V_{HO}	High side floating output voltage	V_S	V_B	
V_{CC}	Low side and logic fixed supply voltage	10	20	
V_{LO}	Low side output voltage	0	V_{CC}	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)	V_{SS}	V_{CC}	
DT	Programmable dead-time pin voltage (IR21094 only)	V_{SS}	V_{CC}	
V_{SS}	Logic ground (IR21094 only)	-5	5	
T_A	Ambient temperature	-40	125	°C

Note 1: Logic operational for V_S of -5 to +600V. Logic state held for V_S of -5V to $-V_{BS}$. (Please refer to the Design Tip DT97-3 for more details).

Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, V_{SS} = COM, C_L = 1000 pF, T_A = 25°C, DT = VSS unless otherwise specified.

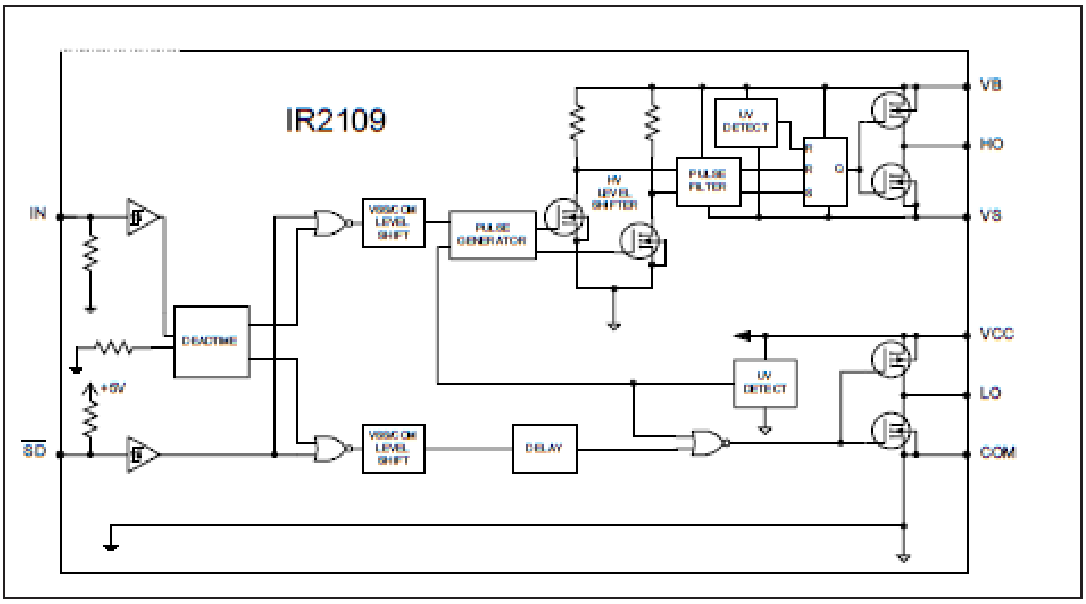
Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-on propagation delay	—	750	950	nsec	V_S = 0V
t_{off}	Turn-off propagation delay	—	200	280		V_S = 0V or 600V
t_{sd}	Shut-down propagation delay	—	200	280		
MT	Delay matching, HS & LS turn-on/off	—	0	70		
t_r	Turn-on rise time	—	150	220		V_S = 0V
t_f	Turn-off fall time	—	50	80		V_S = 0V
DT	Deadtime: LO turn-off to HO turn-on(DT_{LO-HO}) &	400	540	680		RDT=0
	HO turn-off to LO turn-on (DT_{HO-LO})	4	5	6	usec	RDT = 200k (IR21094)
MDT	Deadtime matching = DT_{LO-HO} - DT_{HO-LO}	—	0	60	nsec	RDT=0
		—	0	600		RDT = 200k (IR21094)

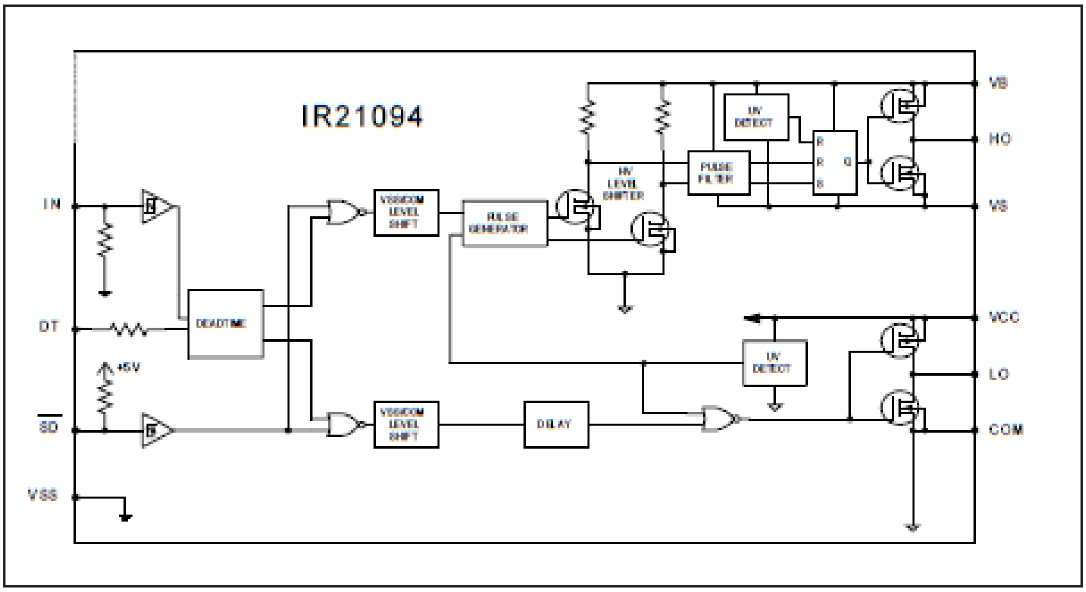
Static Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, V_{SS} = COM, DT= V_{SS} and T_A = 25°C unless otherwise specified. The V_{IL}, V_{IH} and I_{IN} parameters are referenced to V_{SS} /COM and are applicable to the respective input leads: IN and $\overline{SD}$. The V_O, I_O and Ron parameters are referenced to COM and are applicable to the respective output leads: HO and LO.

Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
V_{IH}	Logic "1" input voltage for HO & logic "0" for LO	2.9	—	—	V	V_{CC} = 10V to 20V
V_{IL}	Logic "0" input voltage for HO & logic "1" for LO	—	—	0.8	V	V_{CC} = 10V to 20V
$V_{SD,TH+}$	$\overline{SD}$ input positive going threshold	2.9	—	—	V	V_{CC} = 10V to 20V
$V_{SD,TH-}$	$\overline{SD}$ input negative going threshold	—	—	0.8	V	V_{CC} = 10V to 20V
V_{OH}	High level output voltage, V_{BIAS} - V_O	—	0.8	1.4	V	I_O = 20 mA
V_{OL}	Low level output voltage, V_O	—	0.3	0.6	V	I_O = 20 mA
I_{LK}	Offset supply leakage current	—	—	50	µA	V_B = V_S = 600V
I_{QBS}	Quiescent V_{BS} supply current	20	60	150	µA	V_{IN} = 0V or 5V
I_{QCC}	Quiescent V_{CC} supply current	0.4	1.0	1.6	mA	V_{IN} = 0V or 5V RDT = 0
I_{IN+}	Logic "1" input bias current	—	5	20	µA	IN = 5V, $\overline{SD}$ = 0V
I_{IN-}	Logic "0" input bias current	—	1	2	µA	IN = 0V, SD = 5V
V_{CCUV+} V_{BSUV+}	V_{CC} and V_{BS} supply undervoltage positive going threshold	8.0	8.9	9.8	V	
V_{CCUV-} V_{BSUV-}	V_{CC} and V_{BS} supply undervoltage negative going threshold	7.4	8.2	9.0	V	
V_{CCUVH} V_{BSUVH}	Hysteresis	0.3	0.7	—	V	
I_{O+}	Output high short circuit pulsed vurrent	120	200	—	mA	V_O = 0V, PW ≤ 10 µs
I_{O-}	Output low short circuit pulsed current	250	350	—	mA	V_O = 15V,PW ≤ 10 µs

Functional Block Diagrams

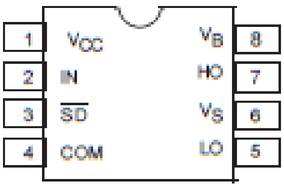




Lead Definitions

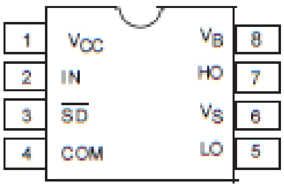
Symbol	Description
IN	Logic input for high and low side gate driver outputs (HO and LO), in phase with HO (referenced to COM for IR2109 and VSS for IR21094)
$\overline{SD}$	Logic input for shutdown (referenced to COM for IR2109 and VSS for IR21094)
DT	Programmable dead-time lead, referenced to VSS. (IR21094 only)
VSS	Logic Ground (21094 only)
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side and logic fixed supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments



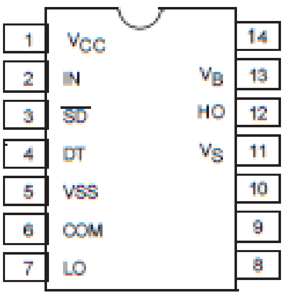
8 Lead PDIP

IR2109



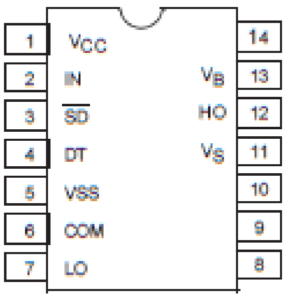
8 Lead SOIC

IR2109S



14 Lead PDIP

IR21094



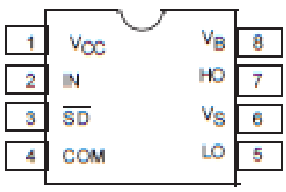
14 Lead SOIC

IR21094S

Lead Definitions

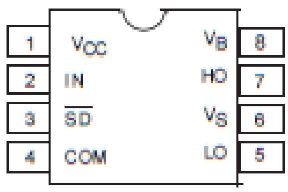
Symbol	Description
IN	Logic input for high and low side gate driver outputs (HO and LO), in phase with HO (referenced to COM for IR2109 and VSS for IR21094)
$\overline{SD}$	Logic input for shutdown (referenced to COM for IR2109 and VSS for IR21094)
DT	Programmable dead-time lead, referenced to VSS. (IR21094 only)
VSS	Logic Ground (21094 only)
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side and logic fixed supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments



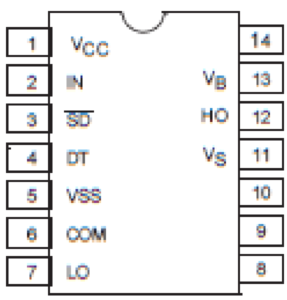
8 Lead PDIP

IR2109



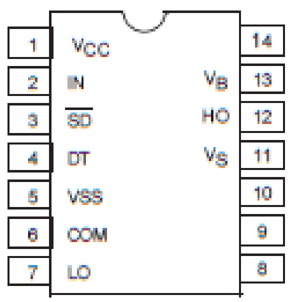
8 Lead SOIC

IR2109S



14 Lead PDIP

IR21094



14 Lead SOIC

IR21094S

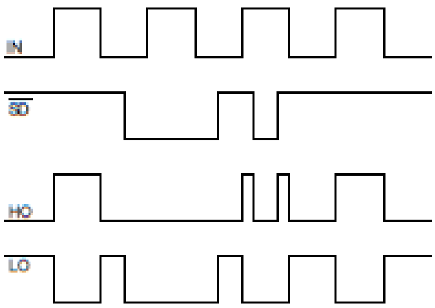


Figure 1. Input/Output Timing Diagram

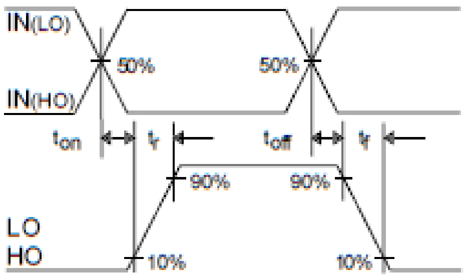


Figure 2. Switching Time Waveform Definitions

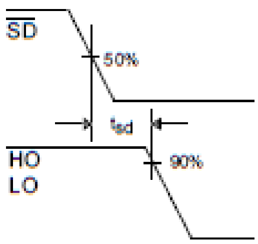


Figure 3. Shutdown Waveform Definitions

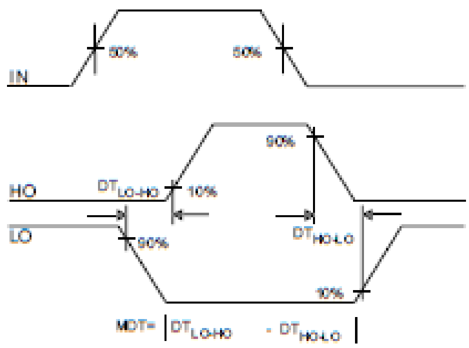


Figure 4. Deadtime Waveform Definitions

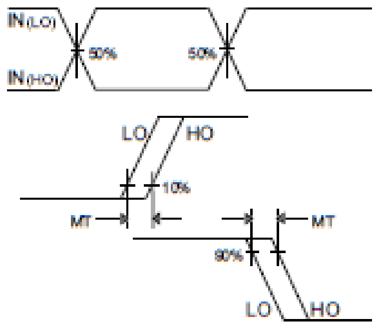


Figure 5. Delay Matching Waveform Definitions

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Data and specifications subject to change without notice. 5/18/2001

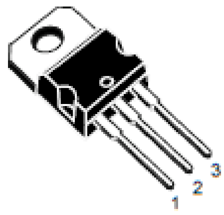
IRF740 DATASHEET

IRF740

N-CHANNEL 400V - 0.46Ω - 10A TO-220 PowerMESH™II MOSFET

TYPE	V_{DSS}	$R_{DS(on)}$	I_D
IRF740	400 V	< 0.55 Ω	10 A

- TYPICAL R_{DS}(on) = 0.46Ω
- EXCEPTIONAL dv/dt CAPABILITY
- 100% AVALANCHE TESTED
- LOW GATE CHARGE
- VERY LOW INTRINSIC CAPACITANCES



TO-220

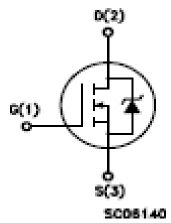
DESCRIPTION

The PowerMESH™II is the evolution of the first generation of MESH OVERLAY™. The layout refinements introduced greatly improve the Ron*area figure of merit while keeping the device at the leading edge for what concerns swithing speed, gate charge and ruggedness.

APPLICATIONS

- HIGH-EFFICIENCY DC-DC CONVERTERS
- UPS AND MOTOR CONTROL

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source Voltage (V_{GS} = 0)	400	V
V_{DGR}	Drain-gate Voltage (R_{GS} = 20 kΩ)	400	V
V_{GS}	Gate- source Voltage	± 20	V
I_D	Drain Current (continuos) at T_C = 25°C	10	A
I_D	Drain Current (continuos) at T_C = 100°C	6.3	A
I_{DM} (•)	Drain Current (pulsed)	40	A
P_{TOT}	Total Dissipation at T_C = 25°C	125	W
	Derating Factor	1.0	W/°C
dv/dt(1)	Peak Diode Recovery voltage slope	4.0	V/ns
T_{stg}	Storage Temperature	– 65 to 150	°C
T_j	Max. Operating Junction Temperature		

(•) Pulse width limited by safe operating area

(1)$I_{SD} \le 10A$, di/dt ≤120A/µs, $V_{DD} \le V_{(BR)DSS}$, $T_j \le T_{JMAX}$

THERMAL DATA

Rthj-case	Thermal Resistance Junction-case Max	1	°C/W
Rthj-amb	Thermal Resistance Junction-ambient Max	62.5	°C/W
T_l	Maximum Lead Temperature For Soldering Purpose	300	°C

AVALANCHE CHARACTERISTICS

Symbol	Parameter	Max Value	Unit
I_{AR}	Avalanche Current, Repetitive or Not-Repetitive (pulse width limited by T_j max)	10	A
E_{AS}	Single Pulse Avalanche Energy (starting T_j = 25 °C, $I_D = I_{AR}$, V_{DD} = 50 V)	520	mJ

ELECTRICAL CHARACTERISTICS (TCASE = 25 °C UNLESS OTHERWISE SPECIFIED)

OFF

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source Breakdown Voltage	I_D = 250 μA, V_{GS} = 0	400			V
I_{DSS}	Zero Gate Voltage Drain Current (V_{GS} = 0)	V_{DS} = Max Rating			1	μA
		V_{DS} = Max Rating, T_C = 125 °C			50	μA
I_{GSS}	Gate-body Leakage Current (V_{DS} = 0)	V_{GS} = ±20V			±100	nA

ON (1)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$V_{GS(th)}$	Gate Threshold Voltage	$V_{DS} = V_{GS}$, I_D = 250μA	2	3	4	V
$R_{DS(on)}$	Static Drain-source On Resistance	V_{GS} = 10V, I_D = 5.3 A		0.46	0.55	Ω

DYNAMIC

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
g_{fs} (1)	Forward Transconductance	$V_{DS} > I_{D(on)} \times R_{DS(on)max}$, I_D = 6 A		7		S
C_{iss}	Input Capacitance	V_{DS} = 25V, f = 1 MHz, V_{GS} = 0		1259		pF
C_{oss}	Output Capacitance			206		pF
C_{rss}	Reverse Transfer Capacitance			25.6		pF

ELECTRICAL CHARACTERISTICS (CONTINUED)

SWITCHING ON

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$ t_r	Turn-on Delay Time Rise Time	V_{DD} = 200V, I_D = 5 A R_G = 4.7 Ω V_{GS} = 10V (see test circuit, Figure 3)		17 10		ns ns
Q_g Q_{gs} Q_{gd}	Total Gate Charge Gate-Source Charge Gate-Drain Charge	V_{DD} = 320V, I_D = 10.7 A, V_{GS} = 10V		35 11 12	43	nC nC nC

SWITCHING OFF

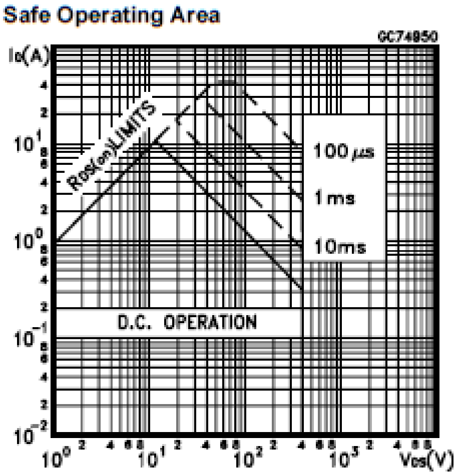
Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$t_{d(off)}$ t_f t_c	Off-voltage Rise Time Fall Time Cross-over Time	Vclamp = 320V, I_D = 10 A R_G = 4.7Ω, V_{GS} = 10V (see test circuit, Figure 5)		10 10 17		ns ns ns

SOURCE DRAIN DIODE

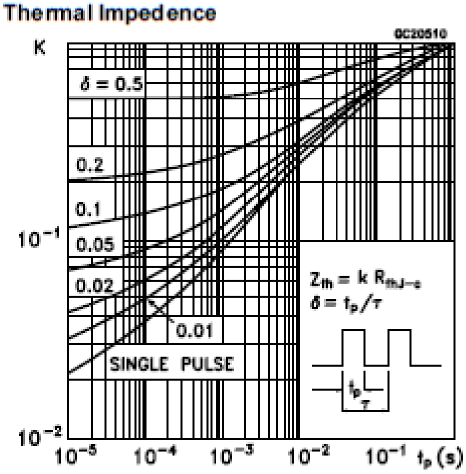
Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{SD} I_{SDM} (2)	Source-drain Current Source-drain Current (pulsed)				10 40	A A
V_{SD} (1)	Forward On Voltage	I_{SD} = 10 A, V_{GS} = 0			1.6	V
t_{rr} Q_{rr} I_{RRM}	Reverse Recovery Time Reverse Recovery Charge Reverse Recovery Current	I_{SD} = 10 A, di/dt = 100A/μs, V_{DD} = 100V, T_j = 150°C (see test circuit, Figure 5)		370 3.2 17		ns μC A

Note: 1. Pulsed: Pulse duration = 300 μs, duty cycle 1.5 %.
2. Pulse width limited by safe operating area.

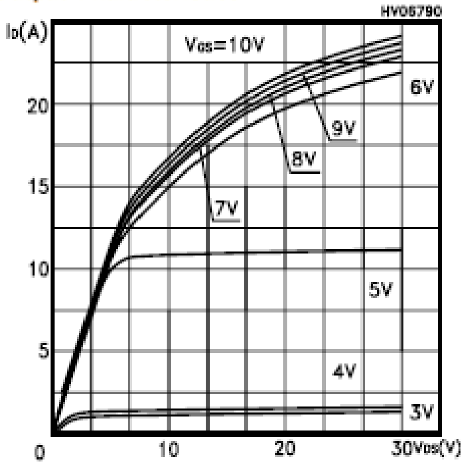
Safe Operating Area



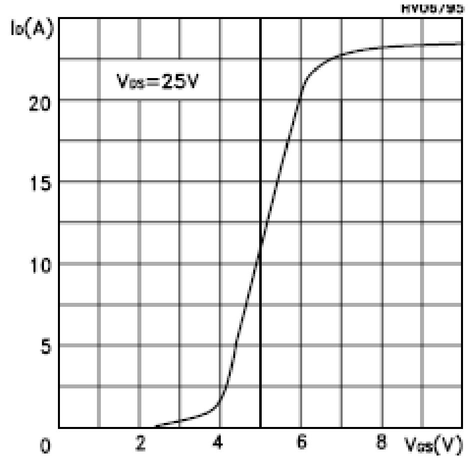
Thermal Impedence



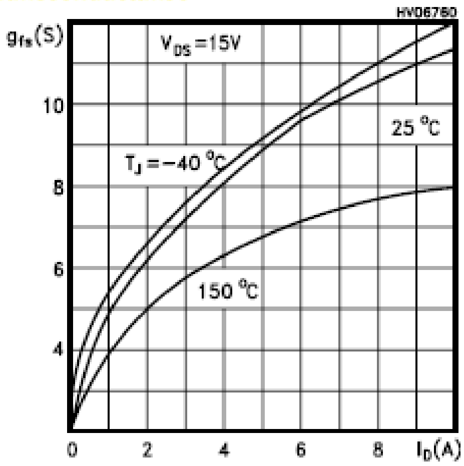
Output Characteristics



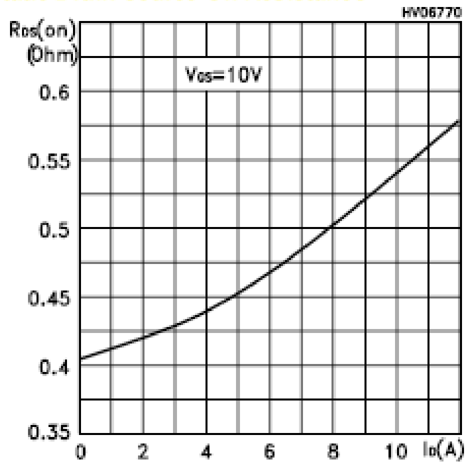
Transfer Characteristics



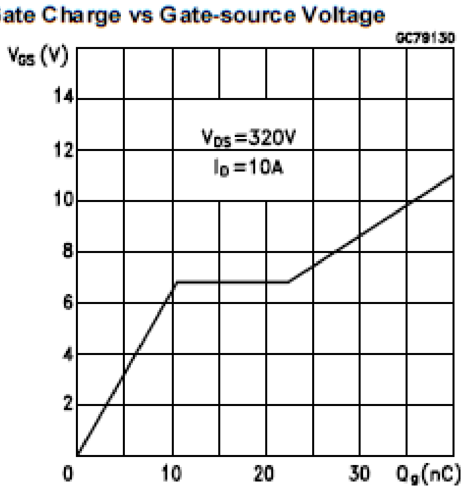
Transconductance



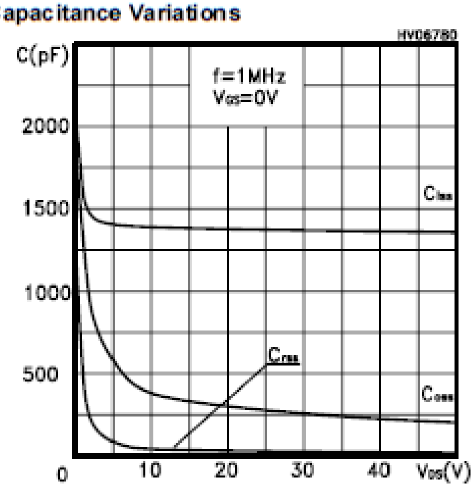
Static Drain-source On Resistance



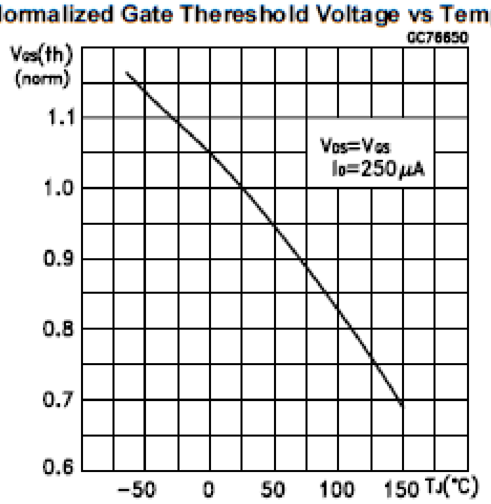
Gate Charge vs Gate-source Voltage



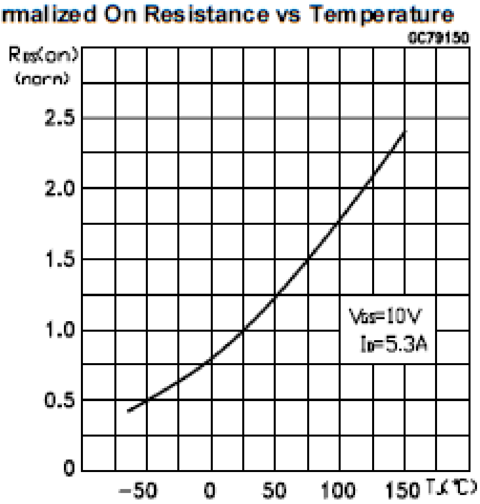
Capacitance Variations



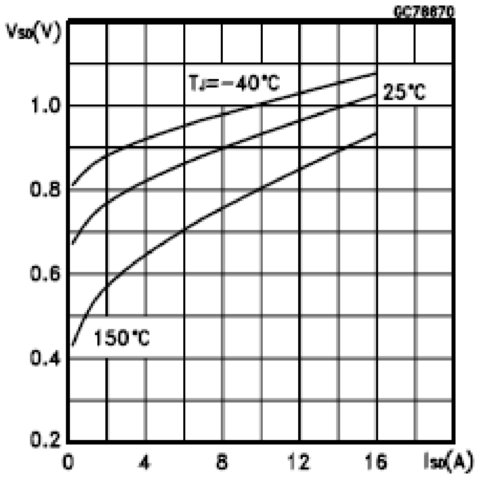
Normalized Gate Thereshold Voltage vs Temp.



Normalized On Resistance vs Temperature



Source-drain Diode Forward Characteristics



APPENDIX C

PHOTOS OF PROJECT

Photo C1: Assembly of System

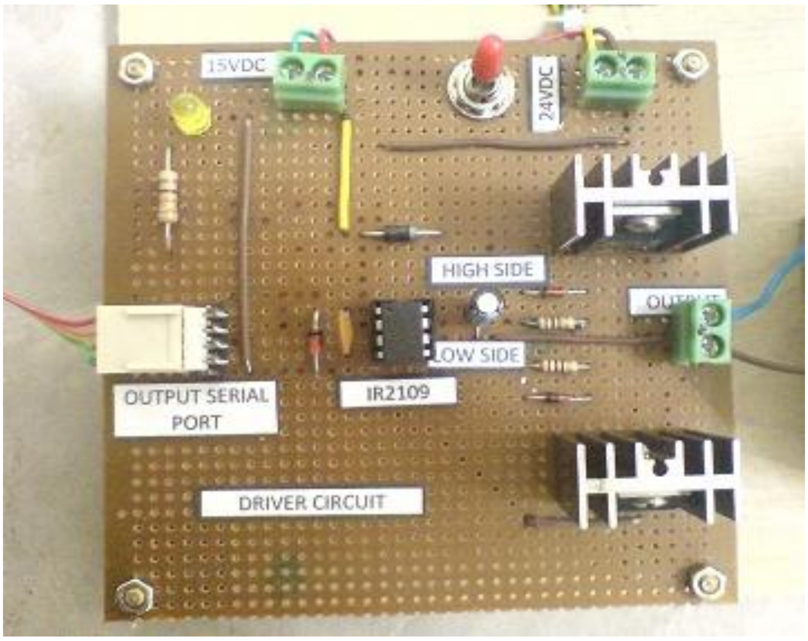


Photo C2: Driver Circuit

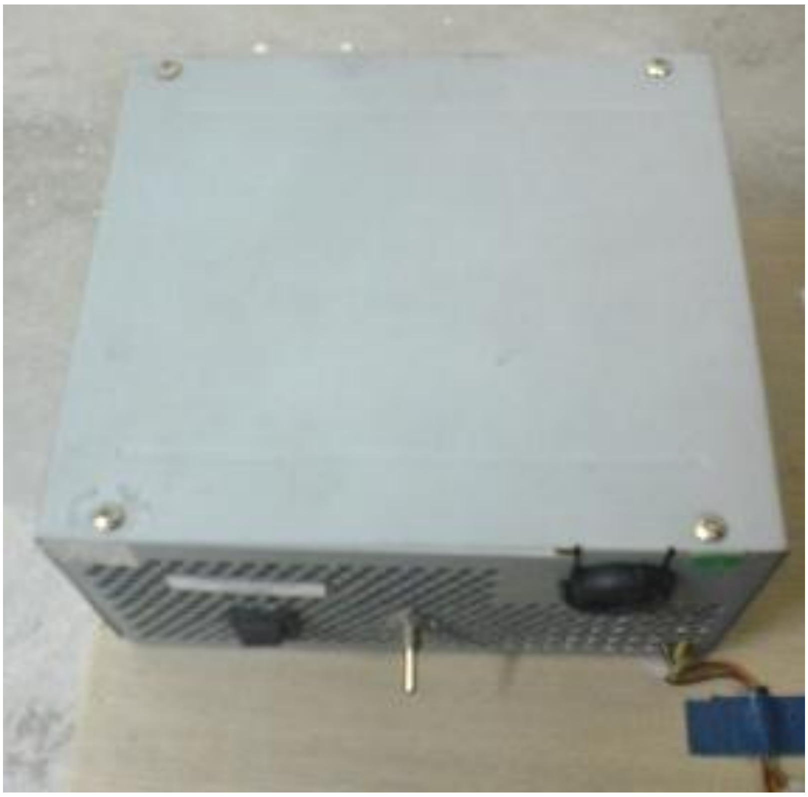


Photo C3: Power Supply

Photo C4: Assembly of Hardware

BIODATA OF AUTHOR

Mohamad Azizi Bin Omar was born on 1st November 1986 in Kg Jalan Baru, Guar Chempedak, Kedah Darul Aman. His permanent address is at Batu 27 Bukit Jenun, Pendang Kedah Darul Aman. He is second last brother from 7 siblings. His secondary school at Sekolah Menengah Kebangsaan Agama Kedah and complete in 2003. Then, he further education at Kedah Matriculation College in the field biology until April 2005. Currently, he was studying in University Malaysia Pahang in Electrical course majoring Power System. His complete their research in Power Electronic & Drives System scope which is related to the industrial field.