

**DESIGN, FABRICATION AND TEST OF INSULATED GATE
BIPOLAR TRANSISTOR (IGBT) INVERTER FOR THREE PHASE
MOTOR DRIVE**

by

MUHAMMAD FAHMIE BIN MOHD NOR

A project dissertation submitted in partial fulfillment of
the Requirements for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

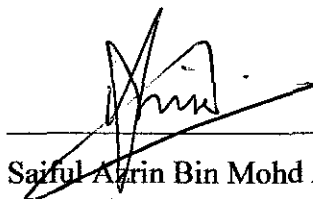
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May 2011

CERTIFICATION OF ORIGINALITY

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



Muhammad Fahmie Bin Mohd Nor

ABSTRACT

A hybrid cars are driven by both gasoline engine and electric 3 phase brushed motor. By using power supply from battery, a suitable motor driver (inverter) is needed to drive that motor. This motor driver should be able to convert from battery DC voltage to 3 phase AC voltage. Plus, the ability for this hardware to accumulate regenerative power from kinetic energy (regenerative braking) is also been considered. Total of six insulated gate bridge transistors (IGBT) are needed with precise gate energization from gate driver. The driver receives input signal from microcontroller in term of pulse width modulation for speed control purposes. This project aims to design, construct, and fabricate the interface of IGBT input output and test the hardware on medium power three phases brushed motor and brushless DC motor. The project covers numerous of researches, tests and analysis to come with full complete working prototype. The rational of this project is to have better understanding in working principle of three phase inverter in addition with six step commutation technique for motor drive purposes. By having a working prototype, the author can experience great challenges and grasp more detail understanding about the subject. In this report, there are several sections; introduction, literature review, methodology, result, discussion and conclusion. In conclusion, the author hopes that this project could actually be implemented in real industry application.

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TABLE OF CONTENT

ABSTRACT	i
ACKNOWLEDGEMENT	ii
LIST OF FIGURES	v
LIST OF TABLE	vii
LIST OF ABBREVIATIONS	viii

CHAPTER 1: INTRODUCTION

1.1	Problem statement.	1
1.2	Objectives.	2
1.3	Scope of study.	2
1.4	The relevancy of the project.	3
1.5	Feasibility of project within time frame.	3

CHAPTER 2: LITERATURE REVIEW

2.1	Insulated Gate Bipolar Transistor (IGBT)	4
2.2	Printed Circuit Board Design..	6
2.3	Gate Driver.	9
2.4	Programmable Integrated Circuit (PIC)	11
2.5	Pulse Width Modulation.	15
2.6	Brushless DC Motor Operation	16

CHAPTER 3: METHODOLOGY

3.1	Procedure Identification.	18
3.2	Tools and Equipments.	20
3.2.1	<i>Software List.</i>	20
3.2.2	<i>Hardware List.</i>	21

3.3	Semikron IGBT SKiiP 39AC12T4V1	21
3.4	Semikron SKHI 23/12 (R) Medium Power Double IGBT Driver	23
3.5	Brushless Motor Drive Test	23
3.6	H-Bridge Test..	25
CHAPTER 4: RESULT AND DISCUSSION		
4.1	Result.	26
4.2	Assembled Full Hardware	27
4.3	Mainboard Design.	29
4.4	Controller Board Design.	32
4.5	User Interface Board Design.	35
4.6	C-Program for Brushless Motor Drive.	37
4.7	C-Program for H-Bridge Test (Brushed DC Motor) ..	39
4.8	Analysis.	40
CHAPTER 5: CONCLUSION AND RECOMMENDATION		
5.1	Conclusion.	42
REFERENCES.		43
APPENDICES.		44
APPENDIX A – C Program for Brushed Motor Drive.		44
APPENDIX B – Gantt Chart For FYP I		48
APPENDIX C – Gantt Chart For FYP II		49

LIST OF FIGURES

Figure 1: Basic Internal Connection of IGBTs.	5
Figure 2: a) Simplified equivalent circuit	
b) More complete equivalent circuit.	6
Figure 3: Voltage- Spacing Requirements for PC Board Conductors (Uninsulated).	7
Figure 4: External Conductor Cross Section versus Current.	8
Figure 5: Simplified IGBT equivalent circuit.	9
Figure 6: IGBT output characteristic.	10
Figure 7: Internal capacitances of IGBT.	10
Figure 8: PIC 40pin DIP type	12
Figure 9: PIC18F4431.	13
Figure 10: PWM Duty Cycle.	15
Figure 11: Inverter Configuration	16
Figure 12: Hall Sensor Input versus Phase Current	17
Figure 13: Project Flow.	18
Figure 14: Semikron IGBT SKiiP 39AC12T4V1	21
Figure 15: Semikron SKHI 23/12 (R).	22
Figure 16: Block Diagram of Hard Disk Motor Testing.	23
Figure 17: Test Bench for Brushed Motor Testing.	24
Figure 18: Test Bench for Brushless Motor Testing.. . . .	25
Figure 19: Motor Driver.	27
Figure 20: Motor Driver (Front Side)	28
Figure 21: Mainboard Schematic.	29
Figure 22: Mainboard PCB (Double Sided)	30
Figure 23: a) Mainboard (Component Side)	
b) Mainboard (Soldering Side)	31

Figure 24: Controller Board Schematic.	32
Figure 25: Controller Board PCB (Double Sided)	33
Figure 26: Controller Board (Component Side)	34
Figure 27: User Interface Schematic..	35
Figure 28: User Interface Board PCB (Double Sided)	36
Figure 29: User Interface Board (Component Side)	36
Figure 30: Pulse Width Modulation (PWM) Generated for Motor Drive.	38

LIST OF TABLE

Table 1: Peripheral Functions Available in 18FXX31.	.	.	.	13
Table 2: Software List.	.	.	.	20
Table 3: Hardware List.	.	.	.	21

LIST OF ABBREVIATIONS

IGBT	Insulated Gate Bipolar Transistor
BJT	Bipolar Junction Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
CMOS	Complementary Metal Oxide Semiconductor
PIC	Programmable Integrated Circuit
PCB	Printed Circuit Board
DC	Direct Current
AC	Alternating Current
PWM	Pulse Width Modulation
EEPROM	Electrically Erasable Programmable Read Only Memory
DIP	Dual In-line Package
QFN	Quad Flat No-lead
TQFP	Thin Quad Flat Pack
PLCC	Plastic Leaded Chip Carrier
ADC	Analogue to Digital Converter
LCD	Liquid Crystal Display

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

In hybrid technology, a car is driven by two power sources; an electric motor and a combustion engine. The electric motor is powered by a pack of high capacity DC battery while for the combustion engine uses fuel.

A motor driver is required to operate a 3 - phase brushless DC in-wheel motor (IWM). 6 Insulated Gate Bipolar Transistors (IGBT) are needed and constructed as a voltage source inverter. The inverter converts DC to three phase 6-step commutations, with precise gate control ability. The interfacing hardware between IGBTs and its input output will be designed and fabricated onto printed circuit boards (PCB).

Programmable Integrated Circuit (PIC) will be used to energize appropriate IGBT to achieve 6 step commutations, thus driving the motor. The inverter will then be tested onto a medium power in-wheel motor (IWM). This study is very important to motor applications especially in electric or hybrid car industry sectors. This study also benefits a student of Power Electronics course.

1.2 Objectives

1. To study general characteristics of 3 - phase inverter using Insulated Gate Bipolar Transistor (IGBT).
2. To design, assemble of the interconnection between IGBT, gate drivers, input and output power and microcontroller assembly according to Generic Standard on Printed Circuit Board Design (IPC 2221).
3. To design appropriate control strategy for 6-step commutation using Programmable Integrated Circuit (PIC).
4. To implement Pulse Width Modulation (PWM) technique for output voltage control purposes.
5. To test complete prototype on three phase motor through controller interface.

1.3 Scope of Study

The study for this project covers in studying basic concepts of voltage source inverter with controllable gate input, the use of IGBT as a high frequency switching device, knowledge on how to use Cadsoft Eagle Layout Editor to construct Printed Circuit Board (PCB) and application of the three phase inverter as a brushless DC motor drive.

This study also establishes basic requirements and guidelines for the design of Printed Circuit Board (PCB). This refers to Generic Standard on Printed Circuit Board Design (IPC2221) and Performance Parameters for Power Conversion Devices (IPC9592).

In addition, the scope of this project includes using PCW software to program a microcontroller PIC18F4431, and using LCD display to show important related variables. Lastly, a graph of speed versus PWM applied is obtained.

1.4 The Relevancy of the Project

This project can be used as assistance in medium power motor controller for electric hybrid car industry sectors, in Proton for example.

1.5 Feasibility of Project within Time Frame

In Final Year Part 1, this project will cover basic study and understanding of inverter application and the hardware that will use. Next would be designing the interface between IGBTs and its input output by fabricating it on Printed Circuit Board (PCB). After that would be the design of compiled inputs from microcontroller and outputs into Semikron gate driver.

In Final Year Part 2, this project will cover basic tests of the driver prototype, output power analysis and possible gate driver controller input using Programmable Integrated Circuit (PIC). In addition, Pulse Width Modulation technique will be implemented to control the output voltage level.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Insulated Gate Bipolar Transistor (IGBT)

With combination of fast switching MOS gate and low conduction loss, IGBTs nowadays are a quick choice for industrial purposes rather than power bipolar transistors in choice of high current and high voltage applications: electric motor driven cars, or solid state Tesla coils.[1]

IGBTs are semiconductors that combine a high-voltage high-current bipolar junction transistor (BJT) with a low-power fast switching metal oxide semiconductor field effect transistor (MOSFET). This combination provides even more faster switching and better output power characteristics than ordinary power transistors and higher current capability that equivalent power MOSFETs.[2]

In selecting appropriate IGBT, several points should be taken into consideration for any project or particular application. Some of them are:

- a) What is the operating voltage? It should block no more than 80% of VCE ratings.
- b) What is the current that will flow into the device? The higher the current, result in higher cost and possible bigger in size.
- c) What is the desired switching speed?

- d) Is short circuit withstanding capability required? In high voltage high current environment, a short circuit protection is very essential.

An N-channel IGBT is basically a power MOSFET of N-channel constructed in P-type substrate. The operation of IGBT is almost the same to a power MOSFET as a positive voltage applied between emitter and gate terminal that at or above threshold voltage, causes electrons to be attracted to gate terminal, forming a conductive N-channel across body region, thus allowing current flow from collector to emitter.[3]

This would be then enable the connection of PNP type BJT transistor thus allowing current flow between collector and emitter of the IGBT. The basic internal connection and simplified equivalent circuits for IGBT are shown below in Figure 1 and Figure 2.

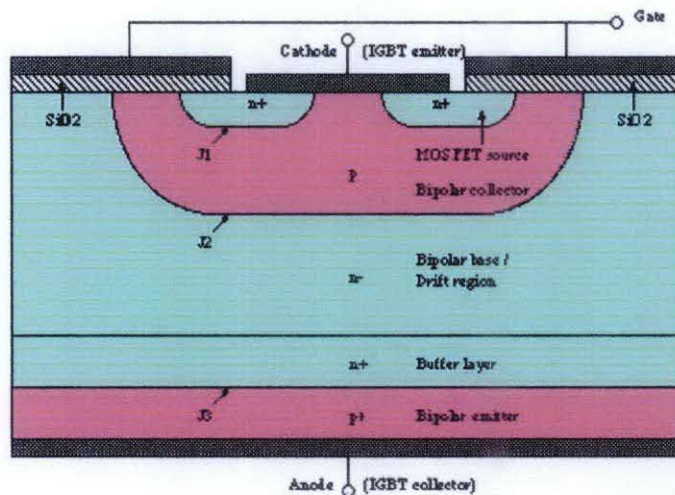


Figure 1: Basic Internal Connection of IGBTs

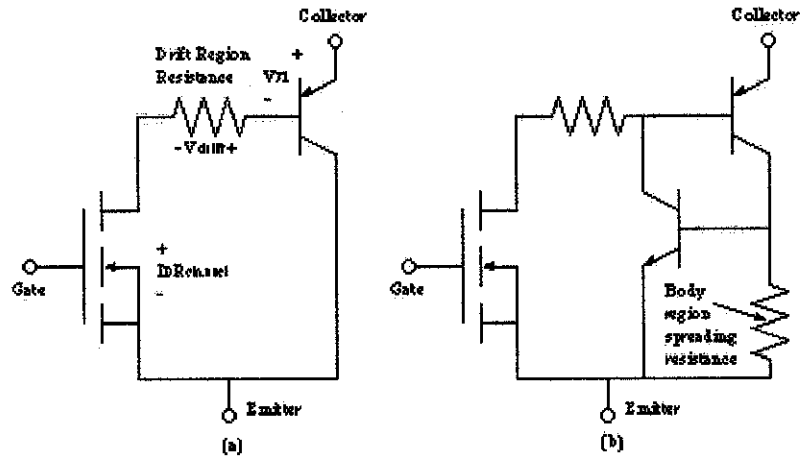


Figure 2: a) Simplified equivalent circuit
 b) More complete equivalent circuit

This structure is very similar to a diode. So, IGBT can only conduct flow of current in one way and block reverse current flow. IGBT manufacturers usually mount in a separate diode in reverse direction for current free-wheeling purposes.

2.2 Printed Circuit Board Design

Usually abbreviated as PCB, a printed circuit board is a thin plate which supports electronic components through conductive pathways. It is a component made of one or more layers of insulating material with electric conductors. During manufacturing, specific portion of conductors are etched off using chemical etching, usually ferric chloride, leaving the needed electrical wiring on the board. [4]

According to IPC2221, a board layout design should meet a few requirements as stated below:

- a) Ensure that components have all testable points accessible from the secondary side of the board to facilitate probing with single sided test fixtures.

- b) Have feed-throughs and component holes placed away from board edges to allow adequate test fixture clearance.
- c) Where practical, group test points and jumper points in the same physical location o the board.

For designing purposes, main specifications that should be taken into consideration are:

- a) Spacing between conductor traces with pads, via and same signal traces.
- b) Circuit conductor's width,

The spacing between electrical conductor traces is mainly determined by the peak working voltage, external coating and board applications. According to IPC9592, there are some bases of the design rules on voltage spacing design requirements. Figure 3 below shows the relation of peak voltage with conductors' width generally for power conversion purposes. [5]

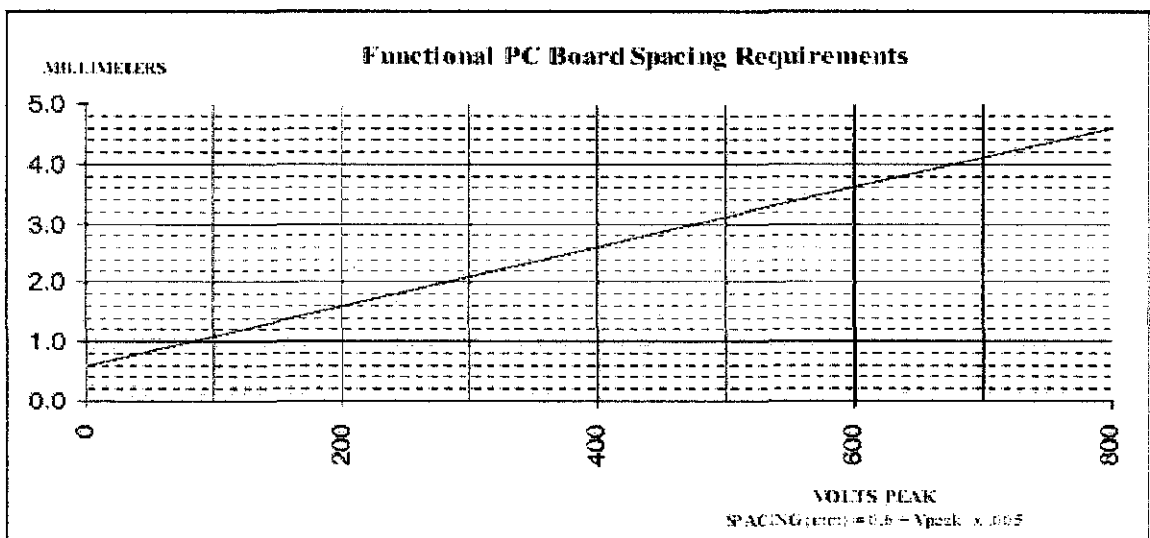


Figure 3: Voltage- Spacing Requirements for PC Board Conductors (Uninsulated)

For any board that does not follow or meet above requirements, the conductors must be insulated, using for example RTV, conformal coating, sleeving or their combinations. [6]

The width and thickness of the conductors should be designed according to current carrying capability, maximum allowable temperature rise and acceptable impedance.[7] Figure 4 below shows the relation of conductors' cross section with current carrying capability. The minimum conductor width should not less than 0.1mm as according to Underwriters Laboratories (UL).[8] It is better to have the width maximized while maintaining the minimum spacing requirements and over the minimum conductor width requirements.

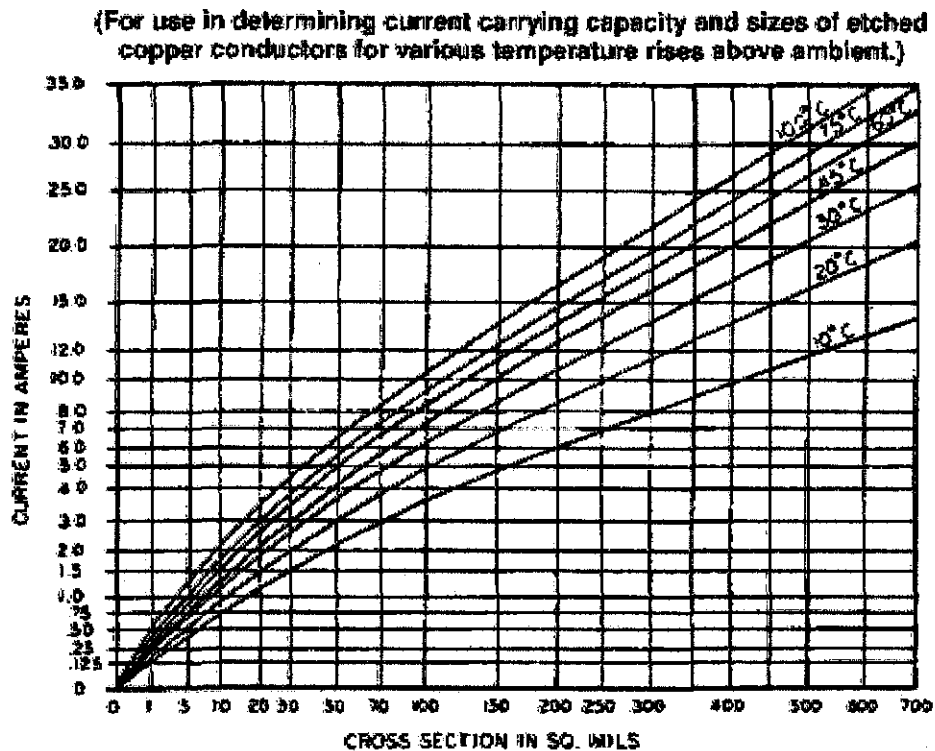


Figure 4: External Conductor Cross Section versus Current

2.3 Gate Driver

A gate driver is a device that controls the specific amount of voltage and current that is needed to open or close the MOSFET gate in IGBT. It also has some additional basic features for example short circuit protection, driver interlock and high-voltage isolation.

An IGBT usually has the ability to support high powered application, involving high current consumption, but usually is limited to its input output contact, depending on the manufacturer. For example, an IGBT can support up to 200A but the contact is limited to only up to 160A. This is where user needs a gate driver. The gate driver chosen must be able to supply sufficient gate voltage above IGBT's threshold, but limited to amount the contact can support, which is at 160A.

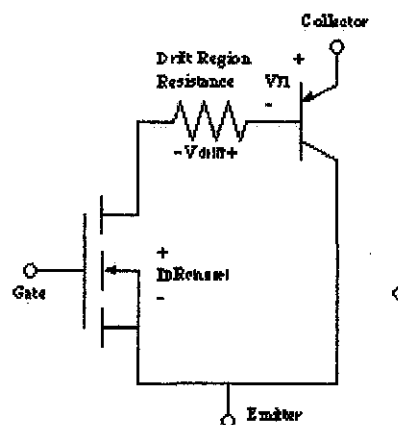


Figure 5: Simplified IGBT equivalent circuit

As recalled back in simplified circuit diagram of IGBT in figure 5 above, in detail, the amount of current that can pass through collector to emitter depends on the amount of current flow at base. That current from emitter that pass through the channel under MOSFET gate is limited based on voltage biased into the gate. In simpler form, the gate is controlling the amount of base current, thus controlling the amount of current at collector.

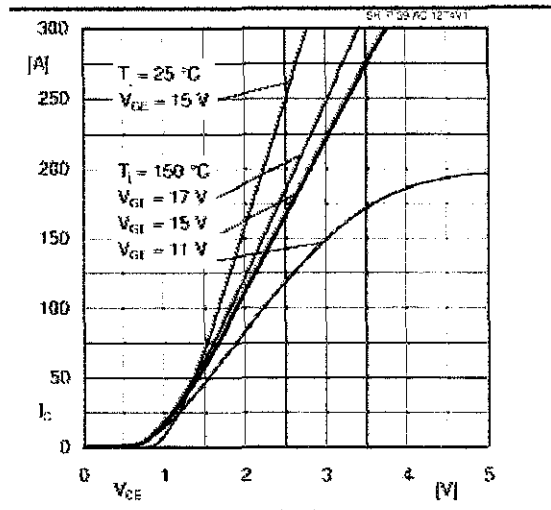


Figure 6: IGBT output characteristic

The second main criterion in choosing the right gate driver is the ability to supply enough current into IGBT gate. An IGBT consist of bipolar junction transistor, BJT and metal oxide semiconductor field effect transistor, MOSFET. Because of MOSFET involvement, there are internal capacitances that cannot be neglected.

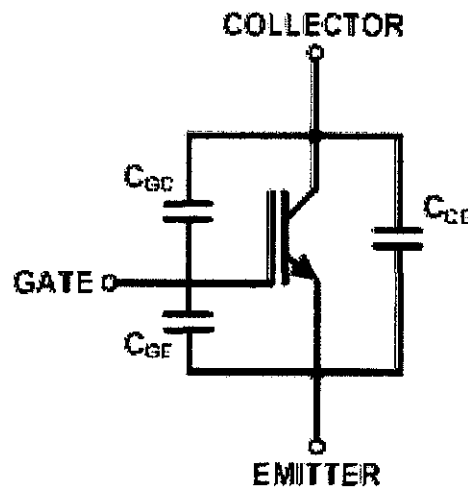


Figure 7: Internal capacitances of IGBT

2.4 Programmable Integrated Circuit (PIC)

A Programmable Integrated Circuit or known as PIC, developed by Microchip Technology Inc., is a type of microcontroller consists of miniaturized electronic circuit, with the ability of reprogramming. Because of its low cost and ease of use, PIC has been the popular choice among students in doing small do-it-yourself project. It also can be able to be used for complicated project, for example driving brushless motor using 6-steps commutations.

A microprocessor usually contains two primary components – random access memory (RAM) and instruction set. RAM is the internal logic in microprocessor that temporarily stores information. The instruction set lists all commands and controls of corresponding functions.

Two types of PIC are available in market; C-type and F-type. PIC of C family can only be programmed once, but for F-family, multiple reprogramming is allowed, up to 100 000 times of erase/write in Enhanced Flash program memory and up to 1000 000 times of erase/write in cycle data EEPROM memory typical. Programmable Integrated Circuit (PIC) can be programmed using common programming language – assembly and C-programming. The basic programming codes are shown as below:

a) Assembly language

```
FUNC1      MOVLW      B'00001111'  
           MOVWF      PORTB  
           CALL       DELAY  
           MOVLW      B'11110000'  
           MOVWF      PORTB  
           CALL       DELAY  
           RETURN
```

b) C Language

```

void main()
{
    setup_adc_ports (an0);
    setup_adc (adc_clock_internal);
    lcd_init ();
    lcd_gotoxy(1,1);
    lcd_putc ("adc value is:");
    delay_ms (10);
    output_high (pin_b7);
}

```

The Programmable Integrated Circuit (PIC) comes in different choices, depending on desired special functions and input-output port number. It also comes with different pin size – DIP, QFN, PLCC, TQFP. Standard type being used is 40-dip pin type, as shown in figure 8 below:

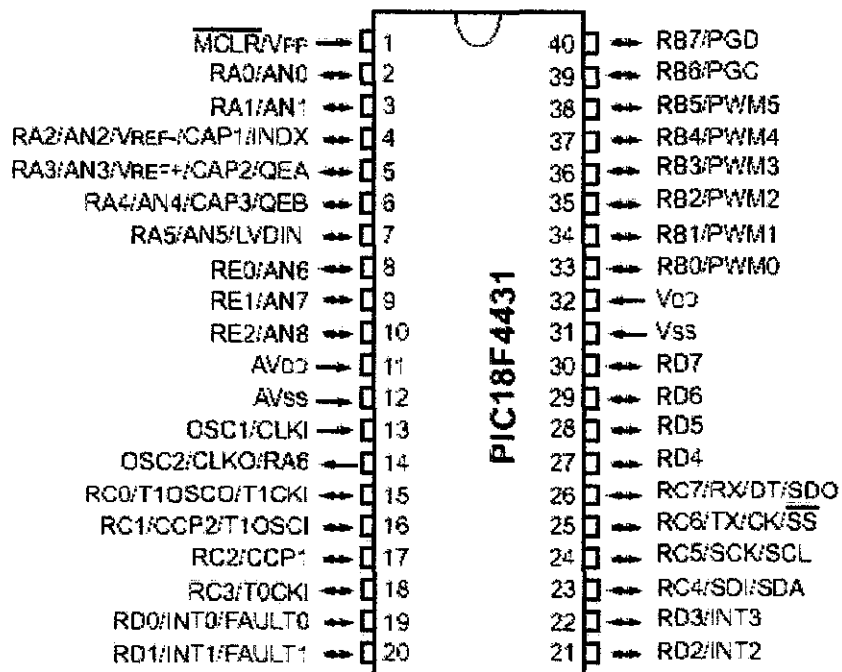


Figure 8: PIC 40pin DIP type

Using standard Complementary Metal Oxide Semiconductor (CMOS) technology, this microcontroller is capable of executing instructions in high speed, and low-power consumption. Typical PICs can accept up to 40 MHz, (depending on the type), with wide operating voltage range (2 – 5.5V).

Standard peripheral features, integrated in a typical PIC are 8-bit timer (or counter), with prescaler and postscaler, capture, compare and PWM modules with 10-bit resolution, 10-bit Analogue to Digital Converter (ADC), Synchronous Serial Port (SSP), Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) and Parallel Slave Port (PSP).

For this project, the author has chosen microcontroller model PIC18F4431. This type of PIC can support main functions of this project – to generate PWM Voltage control for 6-step commutation, for pulse generation to drive a three-phase brushless motor drive. The standard available function from 18F family is shown in Table 1 below:

Table 1: Peripheral Functions Available in 18FXX31

Device	Program Memory		Data Memory		I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8-bit/ 16-bit	12-bit PWM (ch)
	Bytes	# Single Word Instructions	SRAM (bytes)	EEPROM (bytes)				SPI	Master I ² C			
PIC18F2331	8K	4096	512	128	22	5	2	Y	Y	Y	1/3	6
PIC18F2431	16K	8192	768	256	22	5	2	Y	Y	Y	1/3	6
PIC18F4331	8K	4096	512	128	34	9	2	Y	Y	Y	1/3	6
PIC18F4431	16K	8192	768	256	34	9	2	Y	Y	Y	1/3	6



Figure 9: PIC18F4431

In summary, a microprocessor usually contains the following elements, in order of importance:

- Instruction set
- Random access memory (RAM)
- EEPROM
- I/O ports
- Clock
- Watchdog
- Serial port
- Interrupts
- Timers
- Analog digital converter (ADC)
- Digital analog converter

2.5 Pulse Width Modulation

Pulse Width Modulation is a technique to precisely control voltage level in analogue circuitry. Using PWM, user can achieve desired analog voltage using digital input, or in other word, encoding analogue signal level. Many famous microcontrollers and digital signal processors have this function embedded in their hardware, making it easy for implementation.

PWM is executed by controlling the on-off duty cycle. The term duty cycle, is defined as the portion of on-time over the total period of the signal. Duty cycle is usually expressed in percentage (%). Thus for duty cycle of 50%, the ON time and OFF time is equal, decreasing the output voltage level to half of the input level. The ON and OFF time is seen at the output as average voltage, thus controlling voltage level is achievable. Figure 10 shows the basic PWM implementation.

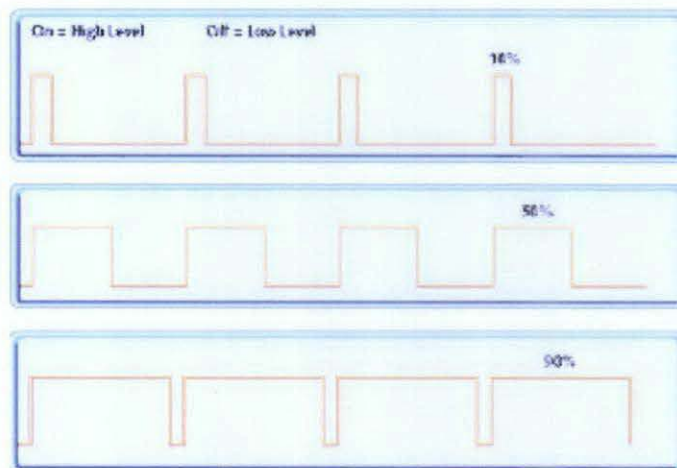


Figure 10: PWM Duty Cycle

The PWM output from the controller could be connected to a switch between supply and load. When PWM is implemented, the load gets average voltage level from supply in percentage. The duty cycle is determined by user, usually from variable resistor.

2.6 Brushless DC Motor Operation

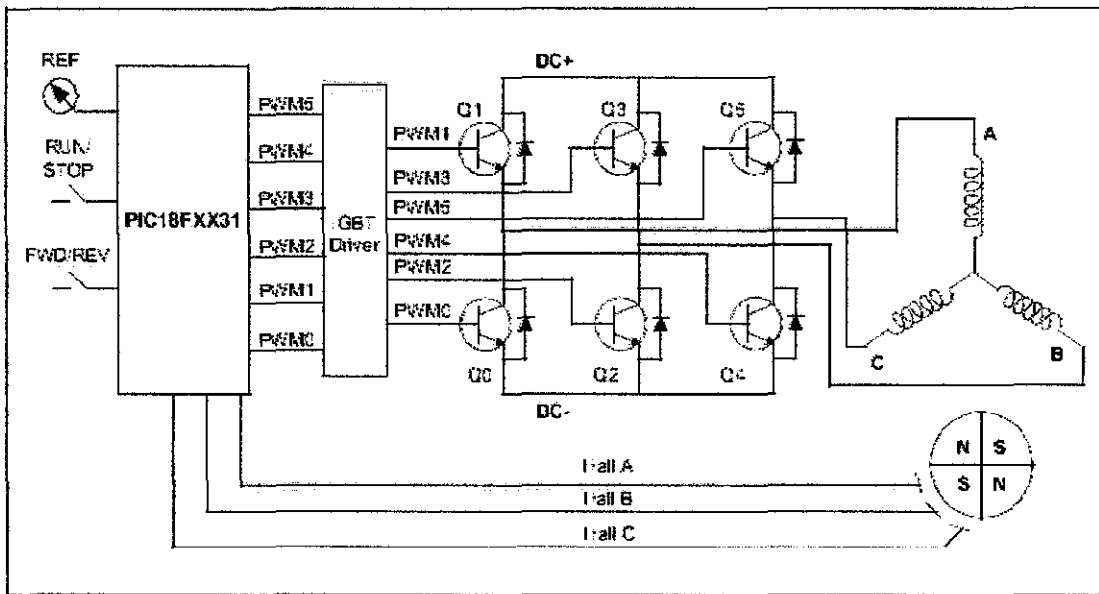


Figure 11: Inverter Configuration

The motor driver operates using inverter configuration, as shown in figure above. The inverter converts DC input voltage into switched DC output voltage, using 6-step commutation technique, using hall sensors as position input reference.

The IGBT gates are energized corresponding to hall input position sensor, to provide maximum torque to the load. Figure below shows the relationship between motor phase current, and the hall sensor inputs, and the corresponding PWM signals that have to be activated, to follow the switching sequence. The sequence will then runs the motor, either clockwise or anticlockwise, based on predetermined sequences.

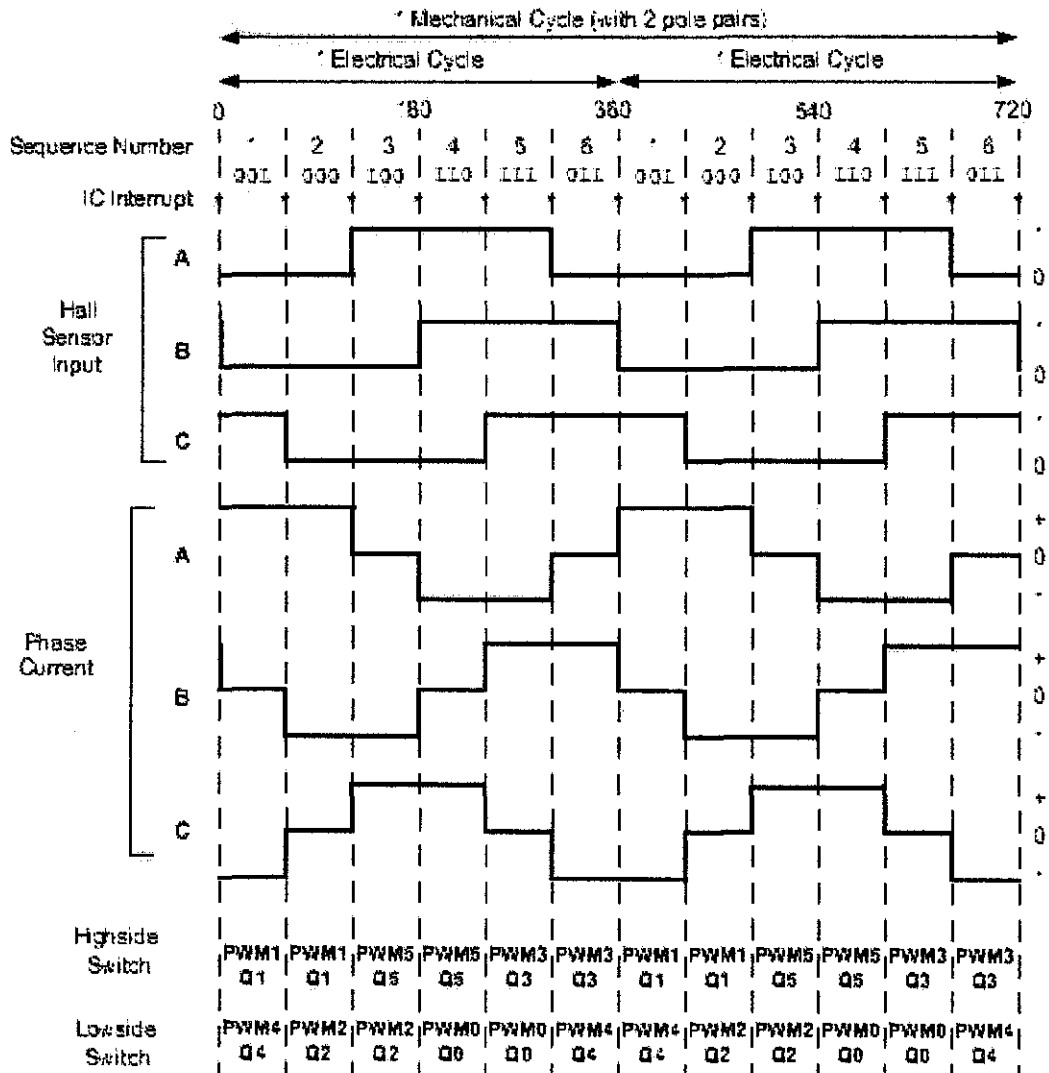


Figure 12: Hall Sensor Input versus Phase Current

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

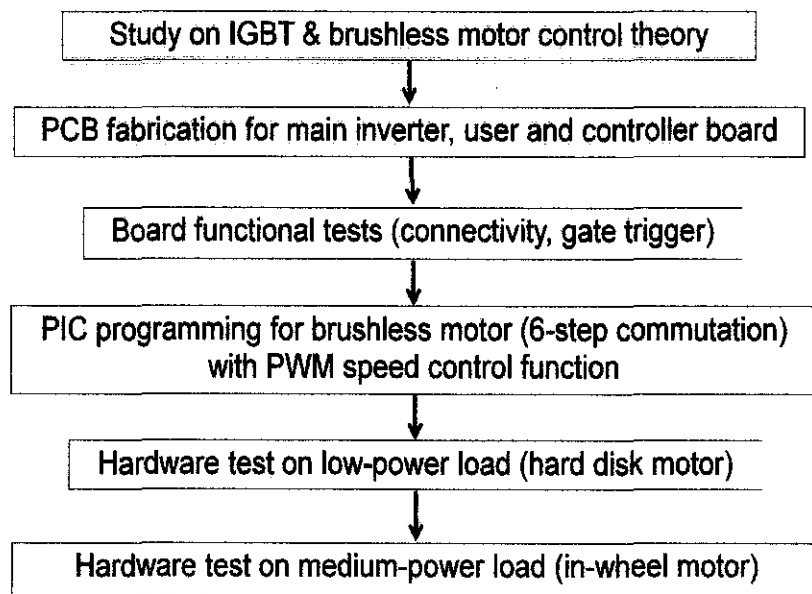


Figure 13: Project flow

The process flow of the project will be done based on the flow above, on which, each of them is applied thoroughly in the project. Final project output will be the data from three phase brushless in wheel motor (IWM).

The basic research paradigm is:

- 1) Basic concept of IGBT inverters
- 2) Basic connection of IGBT inverter, its input output
- 3) Technical information on IGBT gate driver
- 4) Learning printed circuit board (PCB) construction using Cadsoft Eagle
- 5) Basic testing of IGBT inverter
- 6) Dry test using both Brushed and Brushless motor.

The definition of an inverter is a device that is capable of converting direct current (DC) into alternating current (AC) with a predetermined frequency. For the application of DC motor drive, the output of the motor drive is not 3 phase AC, but switched DC, to allow brushless commutation of a brushless DC motor. A three phase inverter using IGBTs will be constructed in this project and by the end, the inverter should be capable of handling any medium power three phase motor.

The project was done by first constructing the circuit in scratch. The author had referred several power electronic books and other company inverter design to have overall view on the project. There were other completed IGBT inverters from company such POWEREX, Bel and other SEMIKRON devices to be referred to.

In designing the circuit, the author has to refer to articles and basic guidelines mainly from The Institute of Interconnecting and Packaging Electronic Circuits, IPC on Generic Standard on Printed Board Design (IPC2221) and Performance Parameters for Power Conversion Devices (IPC9592).

Several tests will be done to ensure the functionality of the interface printed circuit board of IGBT. The test will only involve low voltage supply with miniature motor. The test consists of brushed and brushless motor drive.

3.2 Tools and Equipments

Throughout the project, several tools had been utilized. The tools are divided into two categories; hardware and software.

3.2.1 Software List

Table 2: Software List

Software name	Function
Eagle Layout Editor	Software to design PCB
GC Power Station	Software to design PCB
Orcad PSPice	Circuit simulation
PICC PCW	PIC C program editor, compiler
Microchip PICKit2	PIC HEX programmer

The circuit board were manufactured by En. Isnani and En. Hasrul, technicians from academic building block 22, an expert in this field. Two cam processing files were generated from EAGLE, namely GERBER RS274X for component side and EXCELLON for generating drill data.

3.2.2 Hardware list

Table 3: Hardware List

Hardware name	Function
SKiiP 39AC12T4V1	6 packs of IGBT
SKHI 23/12®.	IGBT driver
24V adapter	Regulated 24V power supply
Voltage regulator (7815)	15V output for driver power supply
LED	General purpose indicator
Resistor	General purpose
Heat sink	Temperature dispersion
Multimeter	General purpose

3.3 Semikron IGBT SKiiP 39AC12T4V1

Semikron IGBT SKiiP 39AC12T4V1 is a trench 4 IGBT that arranged in three phase bridge inverter configuration, built up in a single hardware. Consists of 6 IGBTs with ability to support up to 1200V and 160A continuous current.

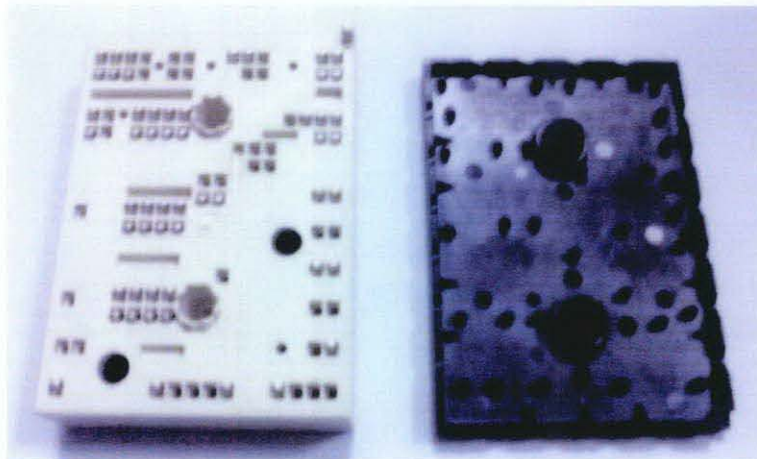


Figure 14: Semikron IGBT SKiiP 39AC12T4V1

Because of spring contact, a Printed Circuit Board has to be constructed to provide connection from this IGBT for output and input. Plus, there are built in diode for feedback current purposes. This IGBT pack also has built in temperature sensor that capable of detecting range of 25 to 100 Celsius.

3.4 Semikron SKHI 23/12 (R) Medium Power Double IGBT Driver

SKHI 23/12 is a gate driver for Semikron IGBT family. It is used to precisely apply the amount of gate voltage needed into the 6 pack IGBTs. Each board is capable of driving two IGBT gates. For this project, 3 boards are needed.

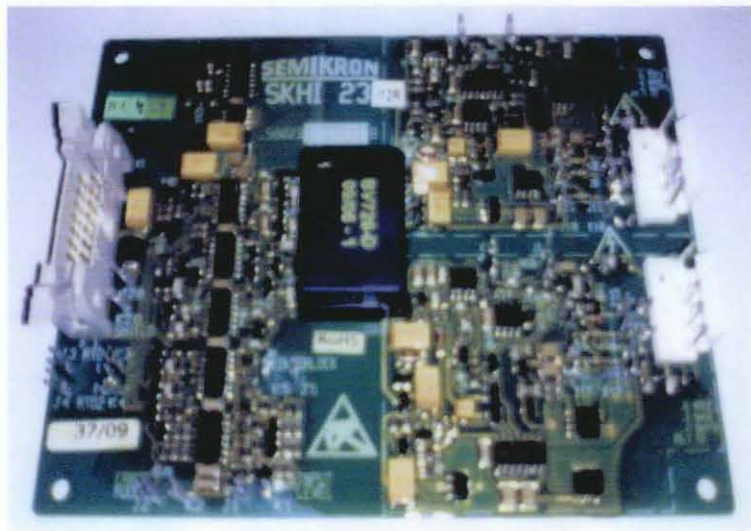


Figure 15: Semikron SKHI 23/12 (R)

Several internal features are built in this module. Interlock circuit to prevent two IGBTs firing at the same time. Error detection is to detect any V_s malfunction, thus blocking any input signal to the drive. When error occurs, output signal can be detected at certain pin, for controller purposes. V_s monitoring is to detect voltage level for board power supply below 13V. Ferrite transformer is to ensure the isolation between low and high voltage application.

15V of power supply is needed to power up the module. Input signal voltage is selectable either using 15V or 5V.

3.5 Brushless Motor Drive Test

In order to test the functionality of all boards, simple motor test were conducted using a computer hard-disk motor. It behaves almost similar to actual 3-phase brushless motor, but it has no hall sensor. It uses back EMF signal extracted from the motor itself, as input to microcontroller to determine the rotor position.

In this simple test, the motor runs without using any position sensor, but just using a small time delay between any steps. The motor is capable of running, but PWM function cannot be implemented. The motor runs at the same speed, even when there are changes in voltage level in the supply. Motor speed varies according to amount of time delay applied between each step.

The motor rotation test was conducted, based on illustrated block diagram in figure 16 below:

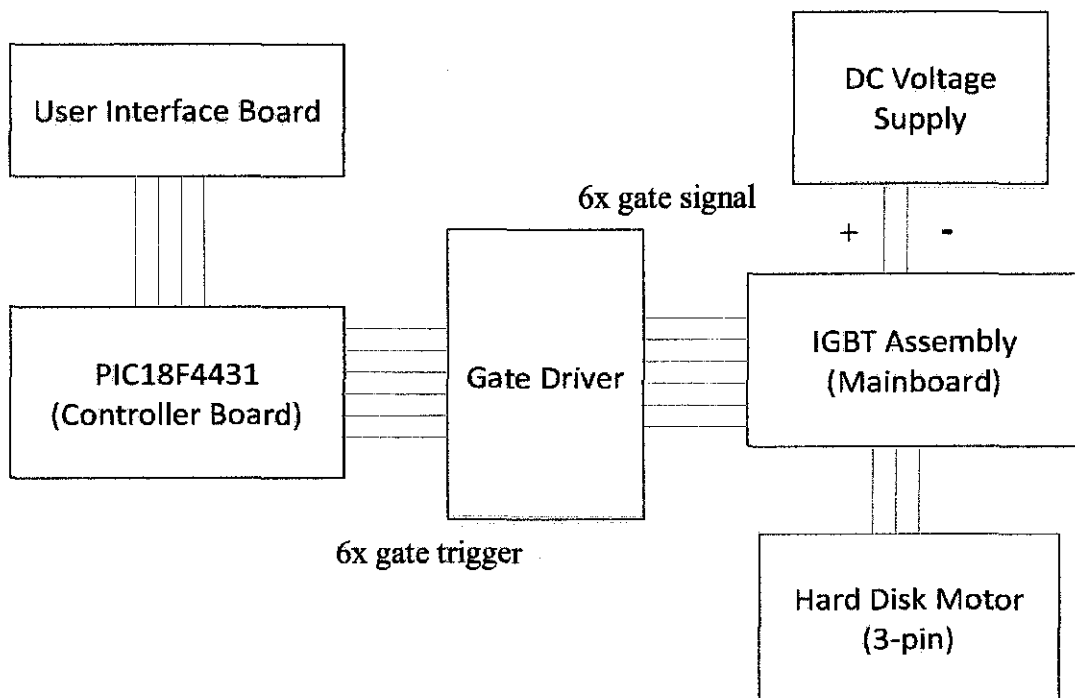


Figure 16: Block Diagram of Hard Disk Motor Testing

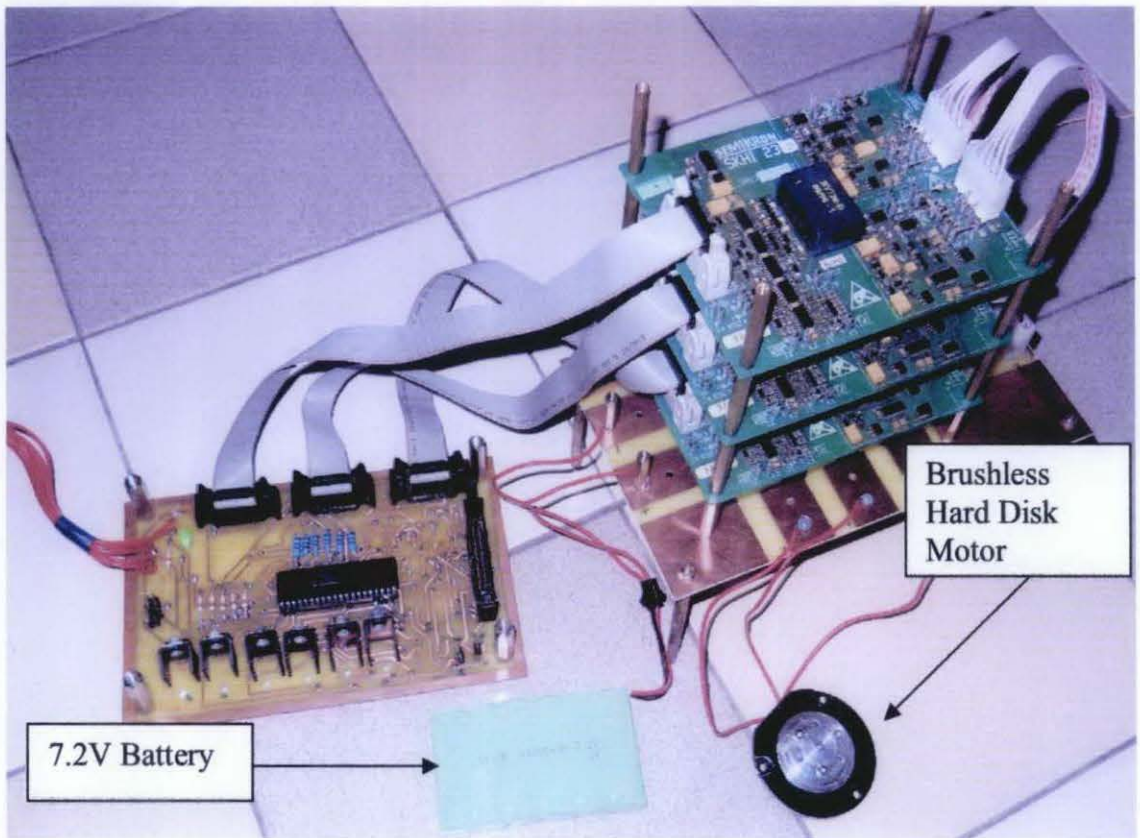


Figure 17: Test Bench for Brushless Motor Testing

3.6 H-Bridge Test

This hardware is also capable of operating a DC brushed motor, with ability to control speed and direction of the motor. The same PWM function was used, but only two output pins were connected to the motor.

The motor speed is proportional to the voltage level applied to the motor. The voltage level control can be done using PWM function by generating predetermined desired average output voltage, set by user. Motor direction can be controlled by changing the output voltage sign. The test bench for brushed motor drive test is shown in figure 18 below:

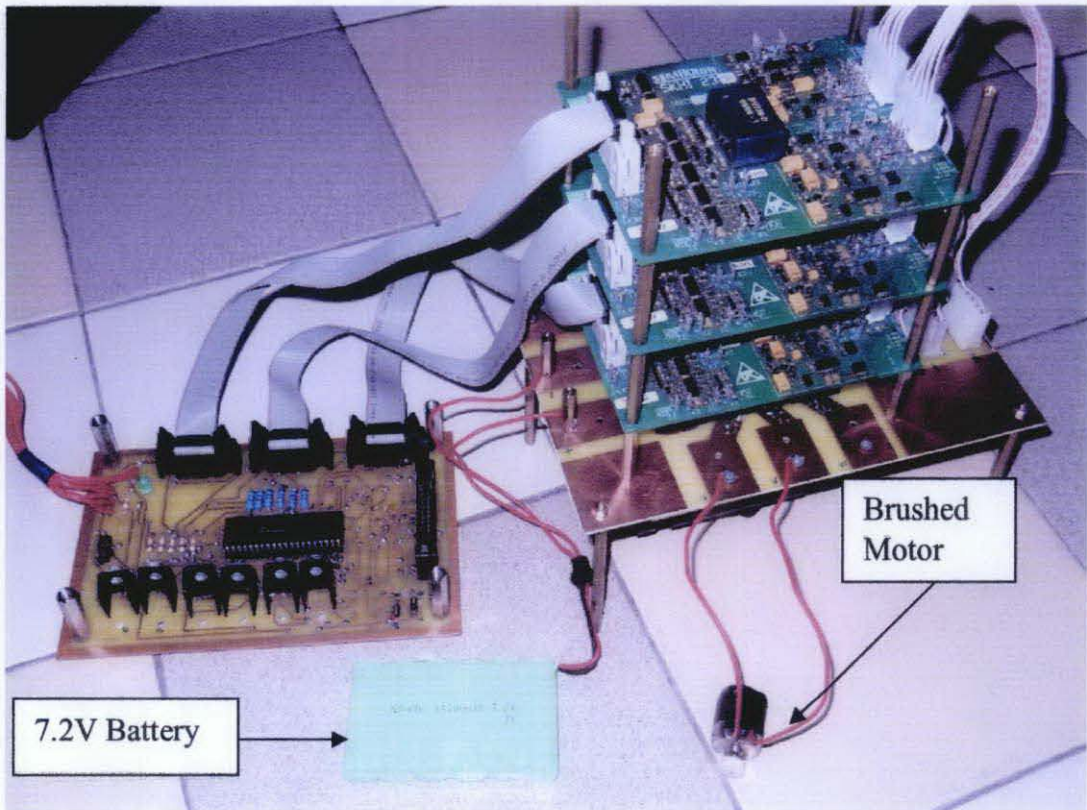


Figure 18: Test Bench for Brushed Motor Testing

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

The author has completed the design of main board, controller and user interface board. Main board consists of three pins output, two pins input and 6 sets of connection from the board to gate drivers. Controller board consists of PIC18F4431, 4 output pins. Output pins are connected to user interface board and gate drivers. User interface board consists of LCD, input switches and knob. The knob gives input to microcontroller for PWM and speed control purposes.

Two main tests were conducted, using this hardware; brushed motor and brushless motor drive tests. Both motor were capable of running, but some feature, such as speed control cannot be implemented, and discussed in analysis section below. Using oscilloscope, PWM output can be observed, as shown in figure 30 below.

4.2 Assembled Full Hardware

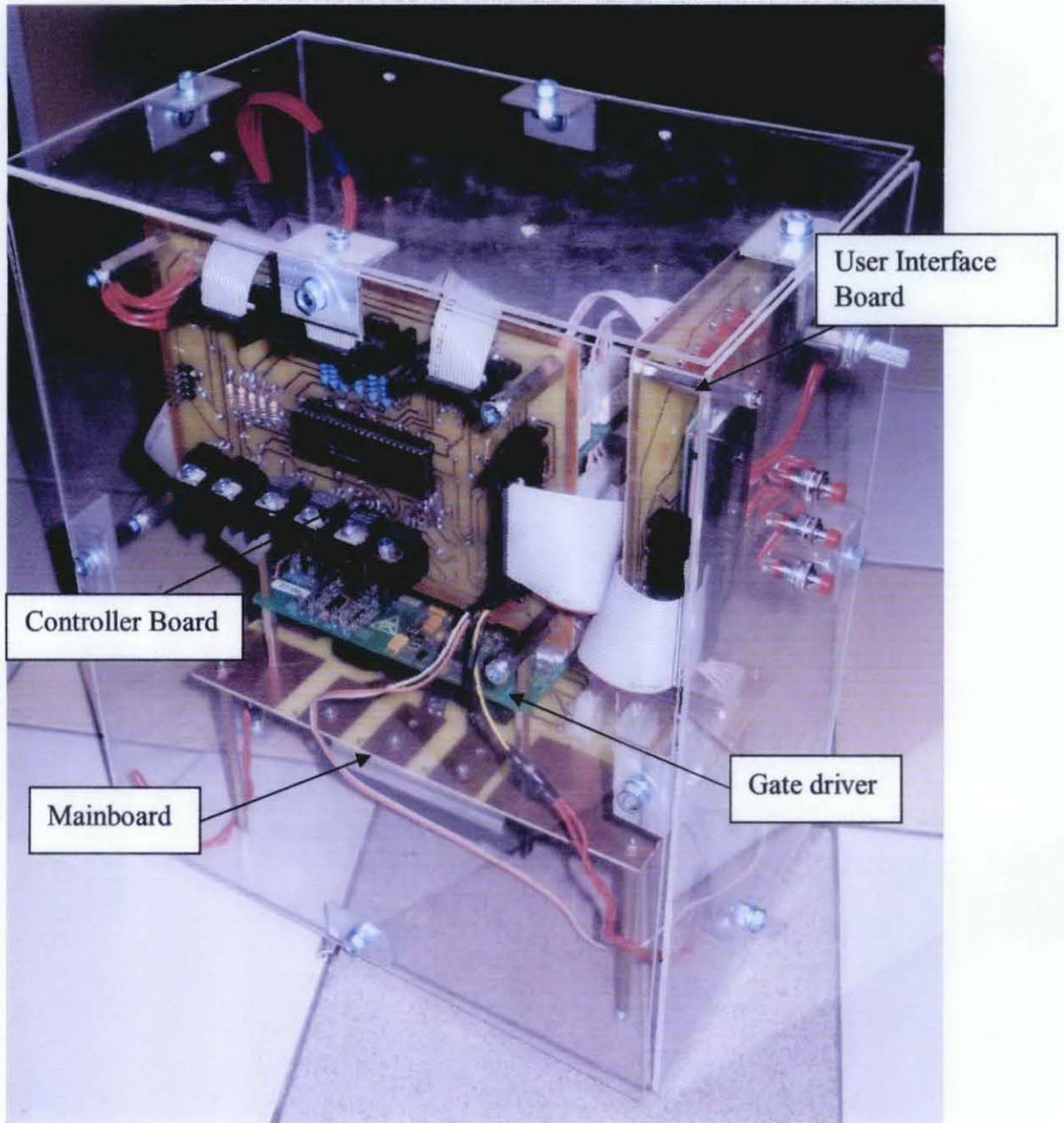


Figure 19: Motor Driver

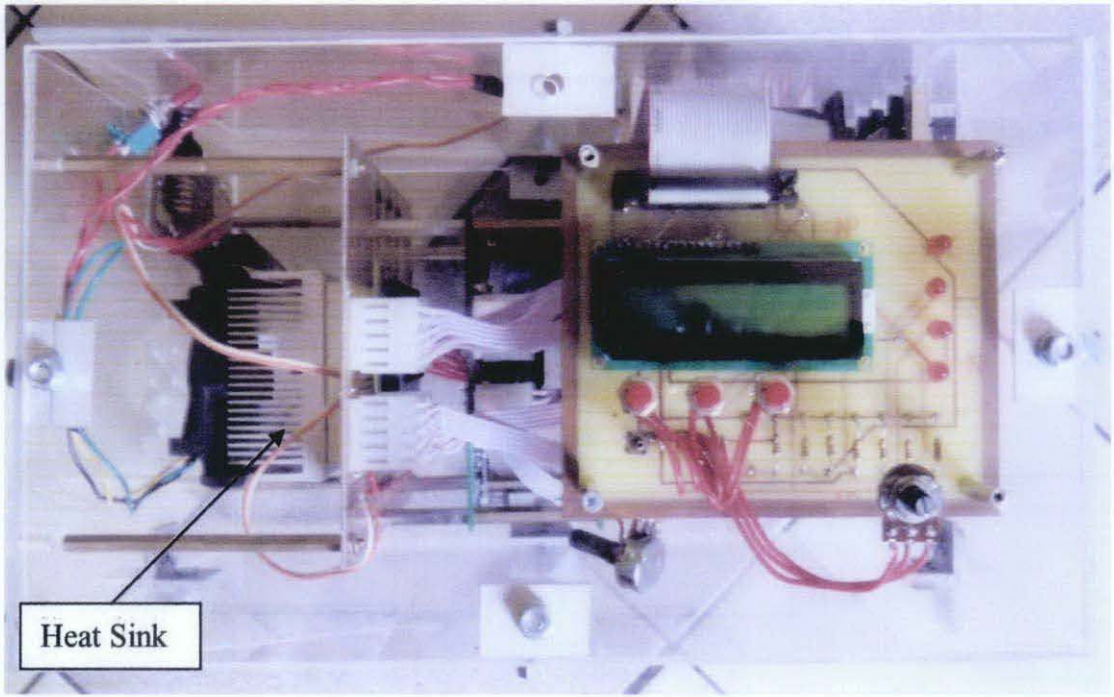


Figure 20: Motor Driver (Front Side)

4.3 Mainboard Design

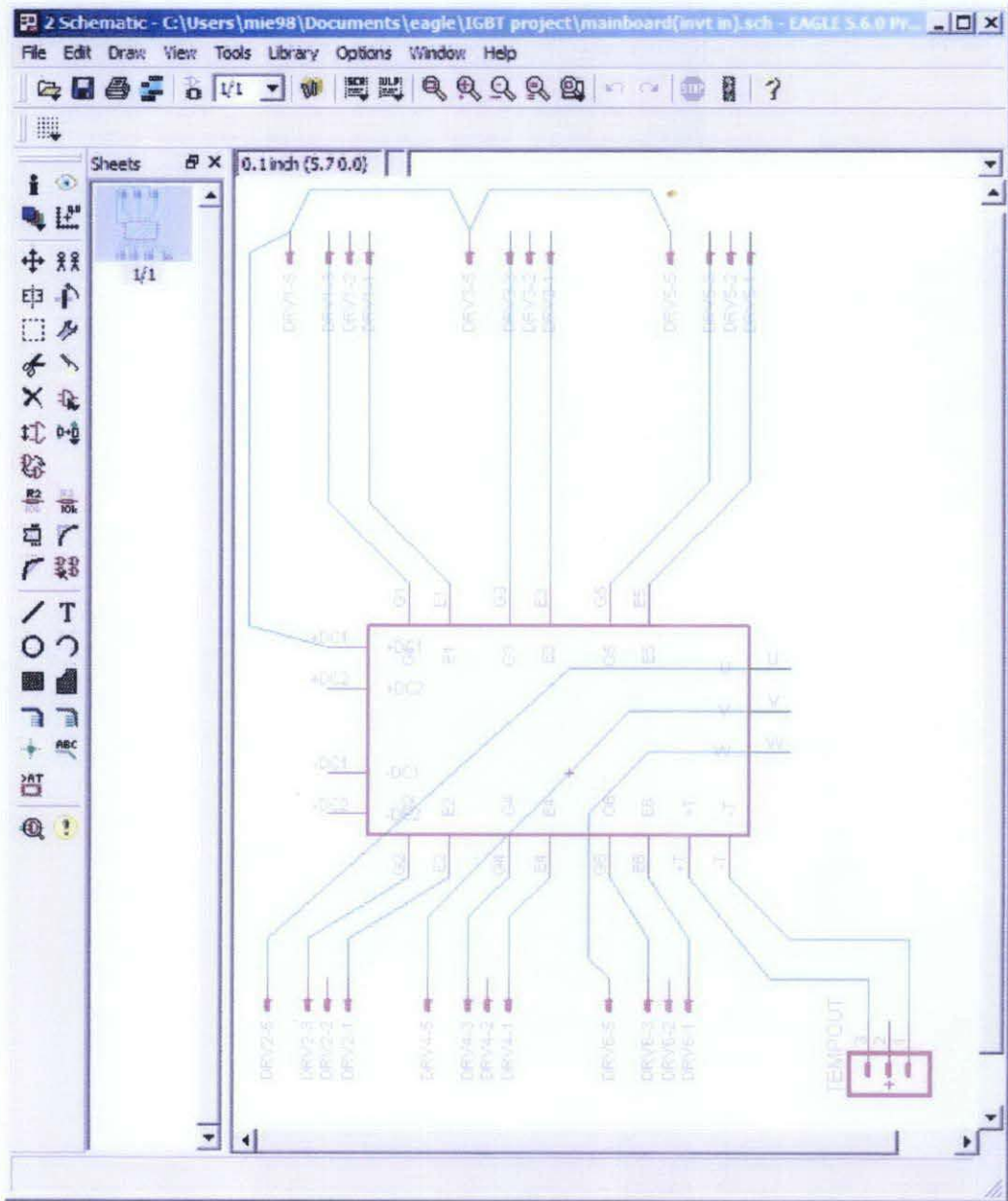


Figure 21: Mainboard Schematic

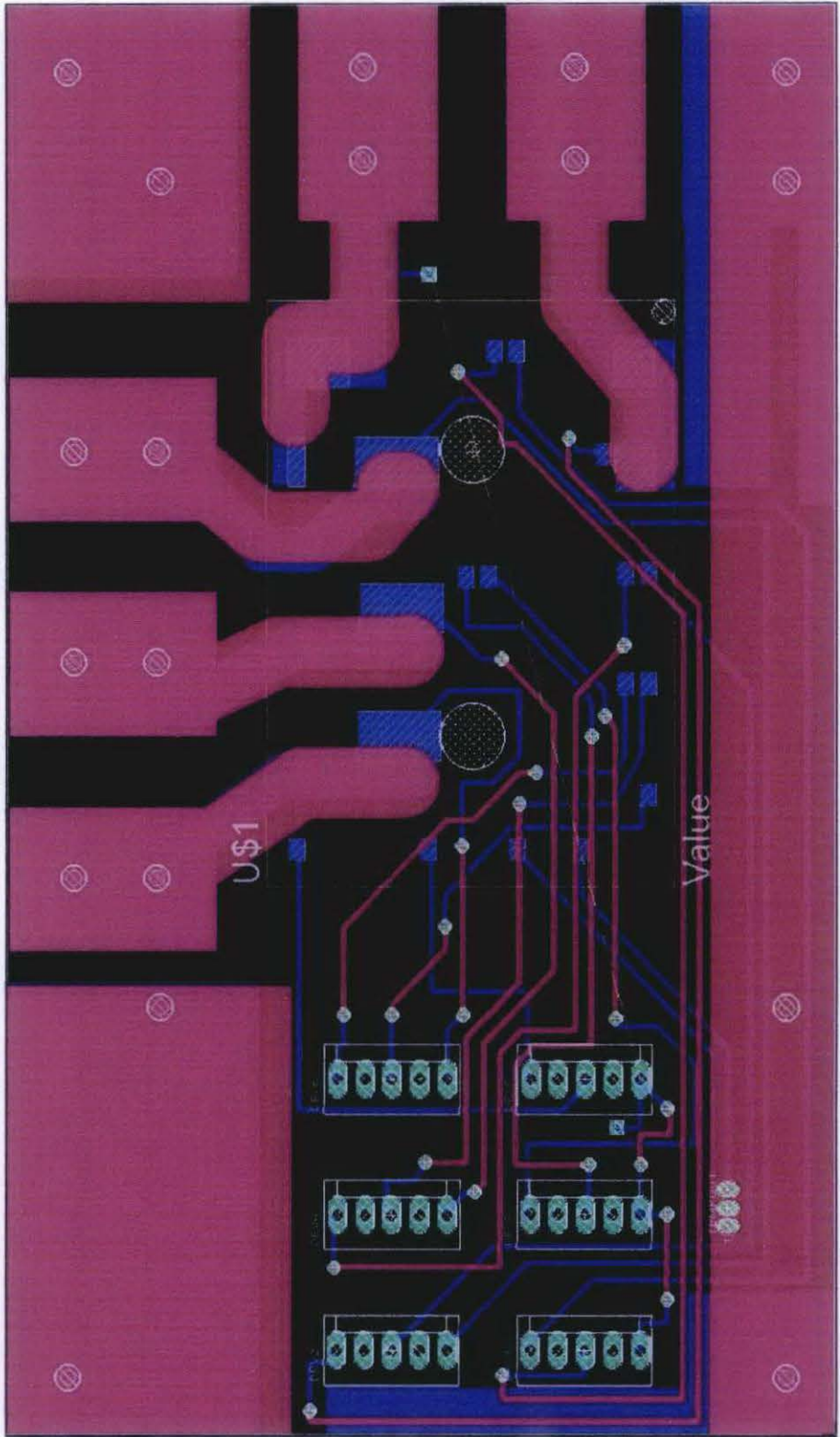


Figure 22: Mainboard PCB (Double Sided)

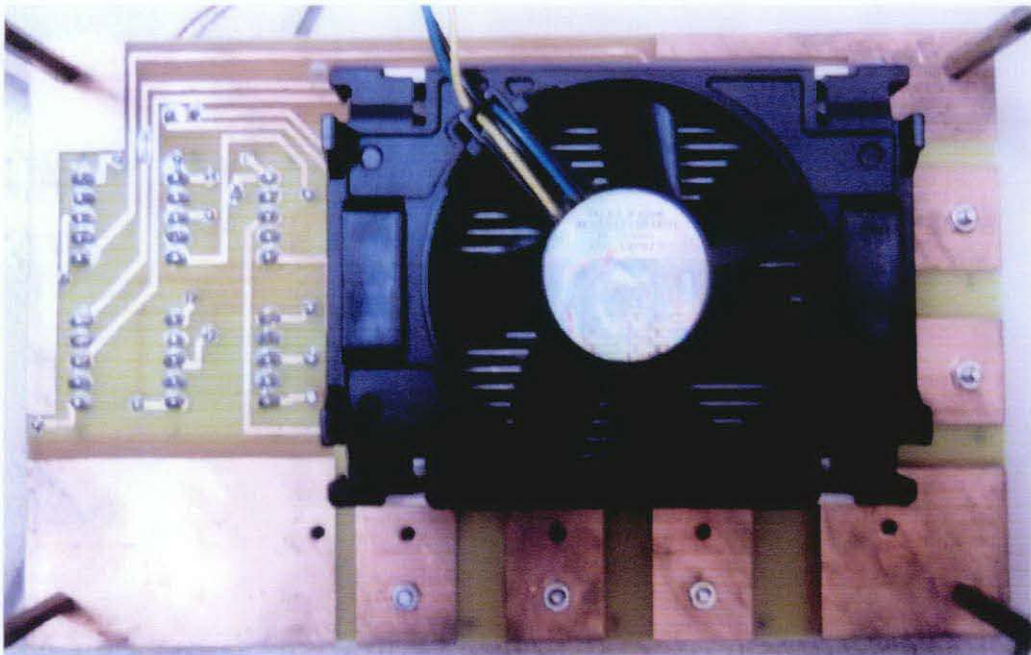
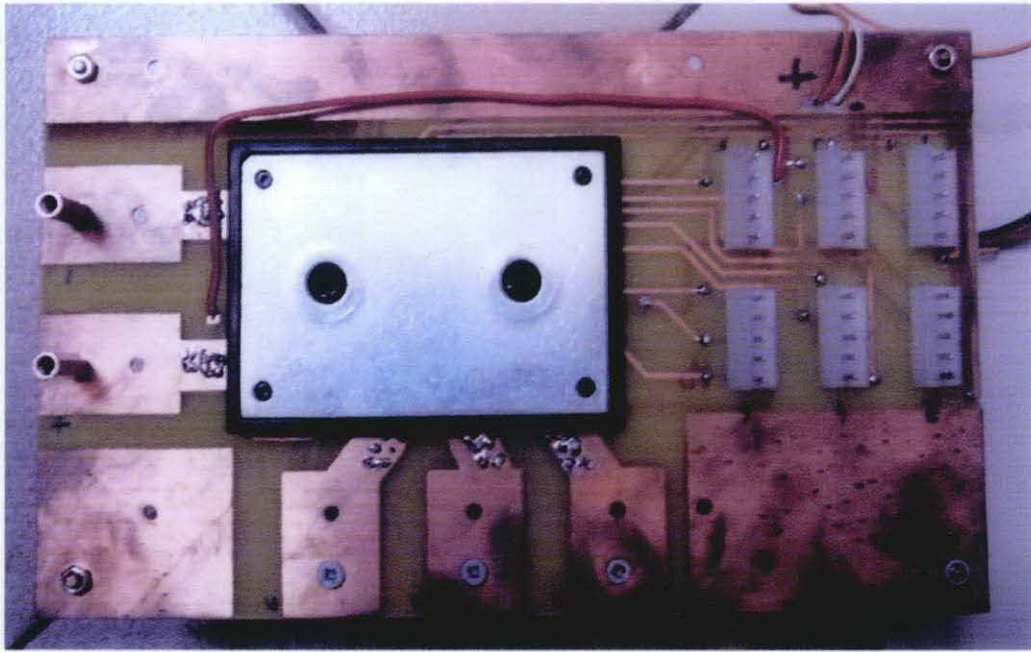


Figure 23: a) Mainboard (Component Side)
b) Mainboard (Soldering Side)

4.4 Controller Board Design

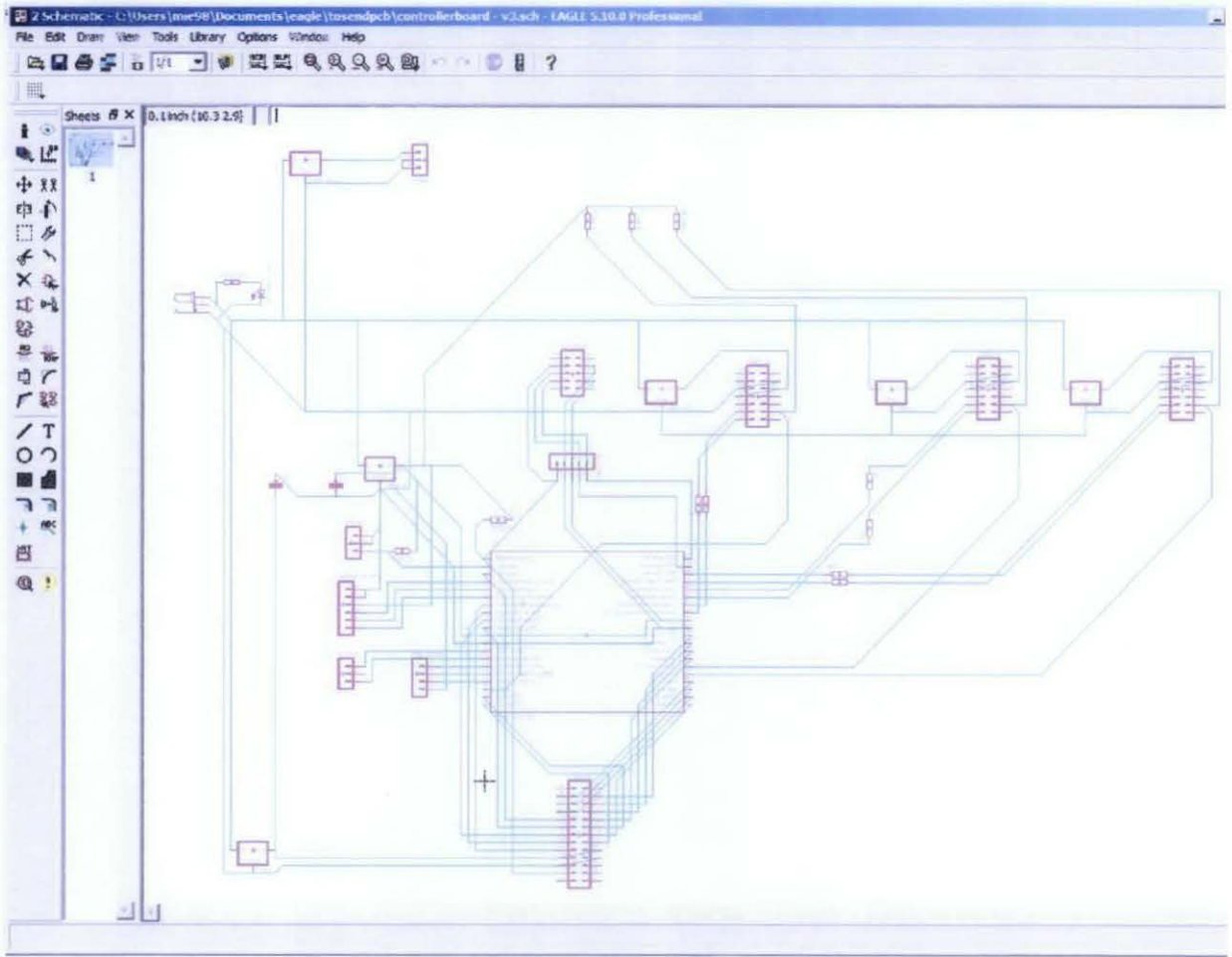


Figure 24: Controller Board Schematic

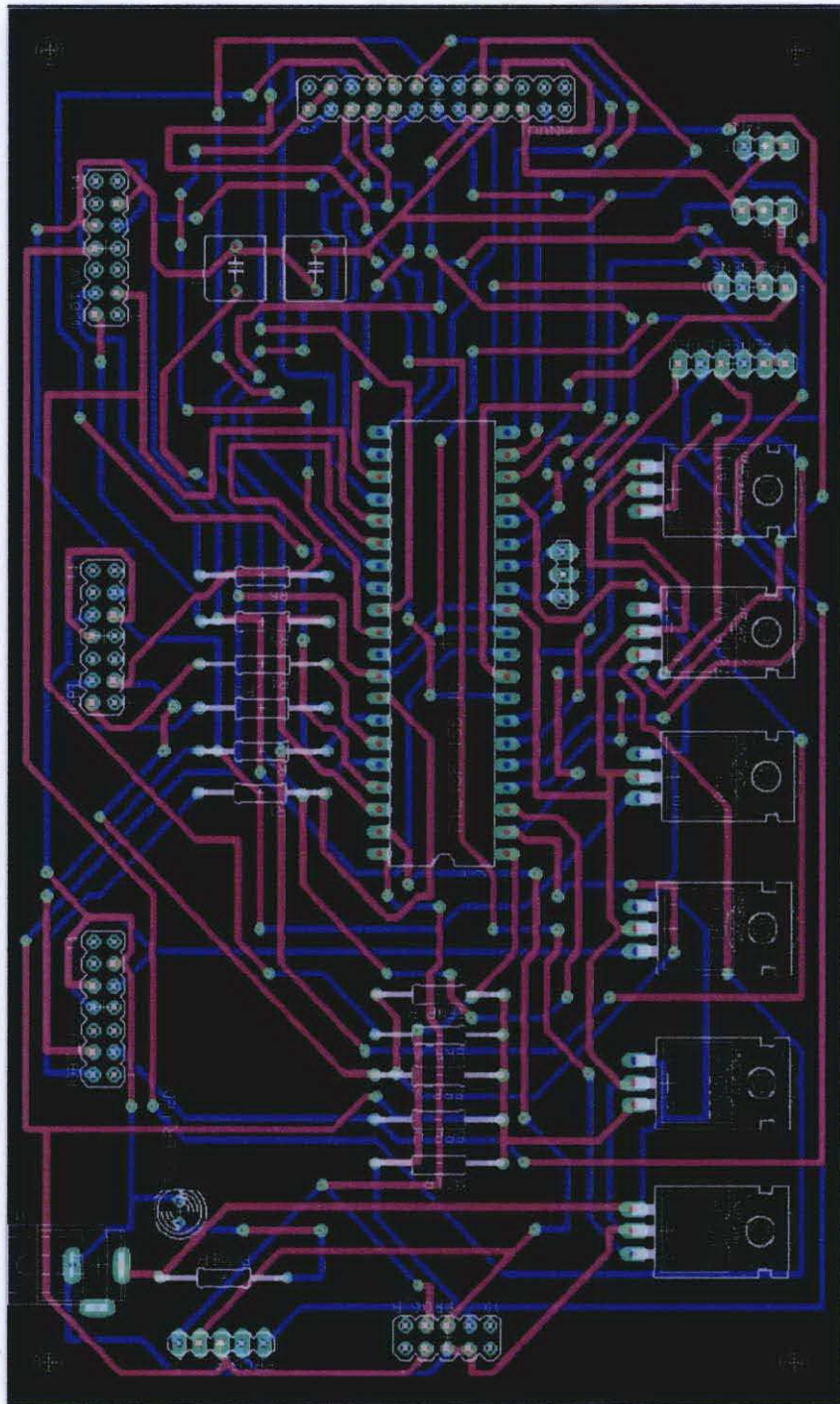


Figure 25: Controller Board PCB (Double Sided)

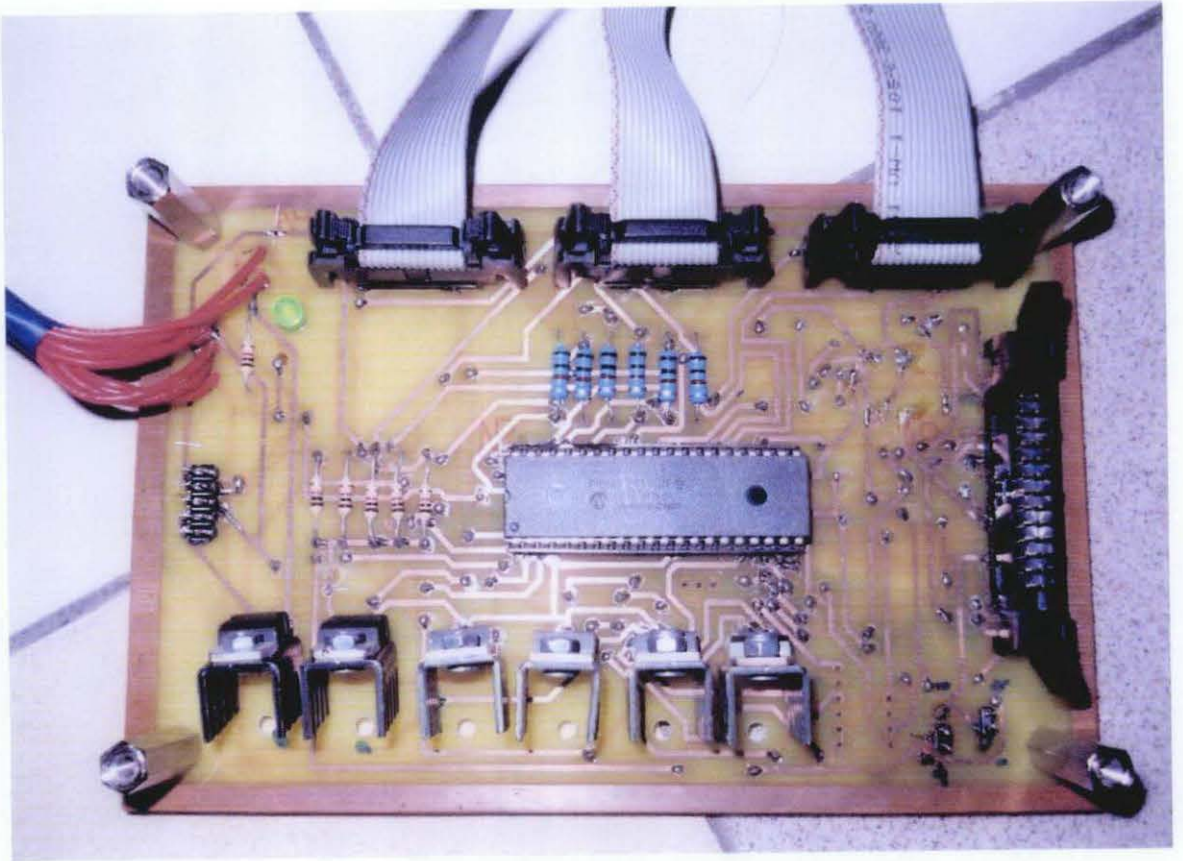


Figure 26: Controller Board (Component Side)

4.5 User Interface Board Design

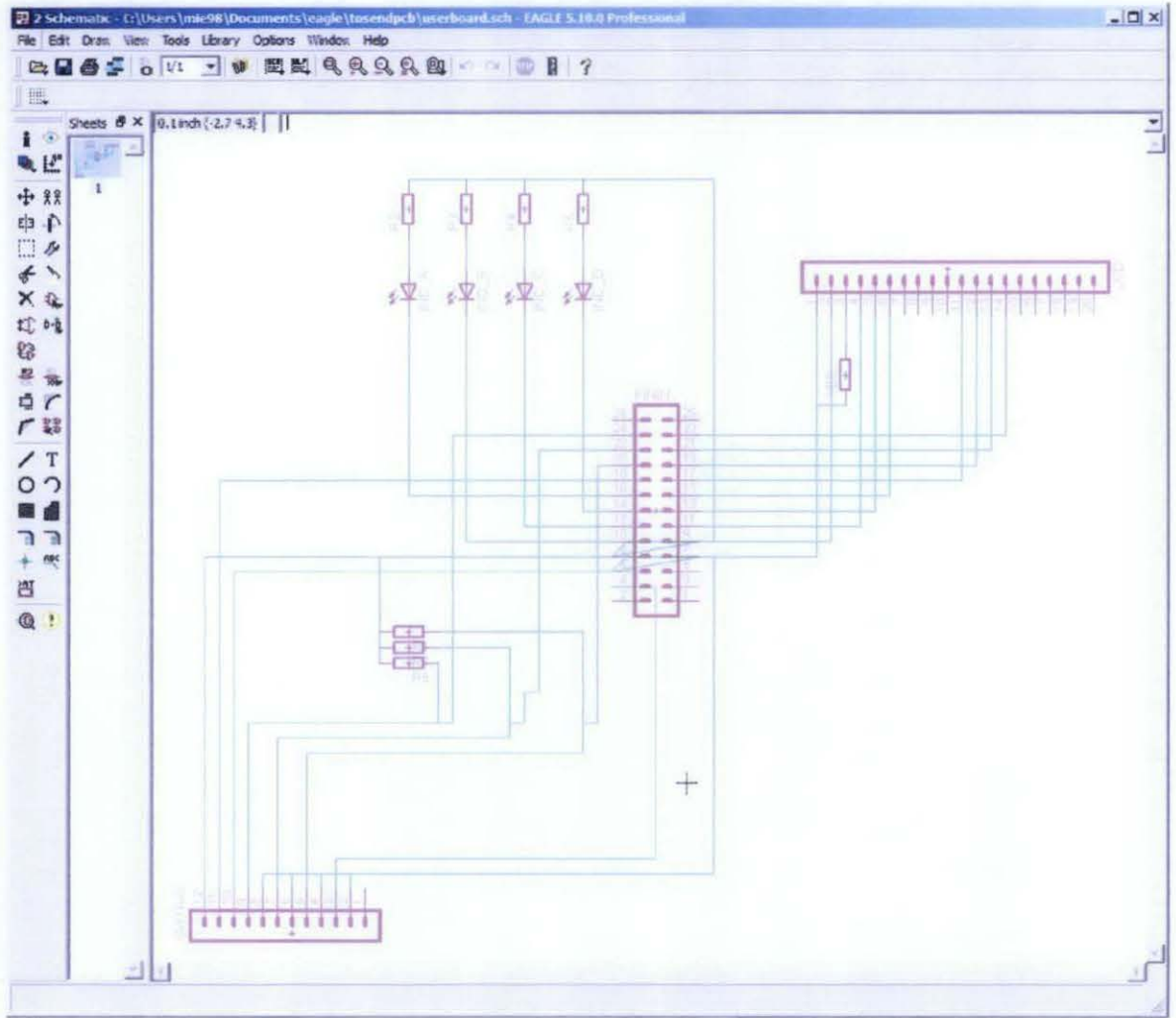


Figure 27: User Interface Schematic

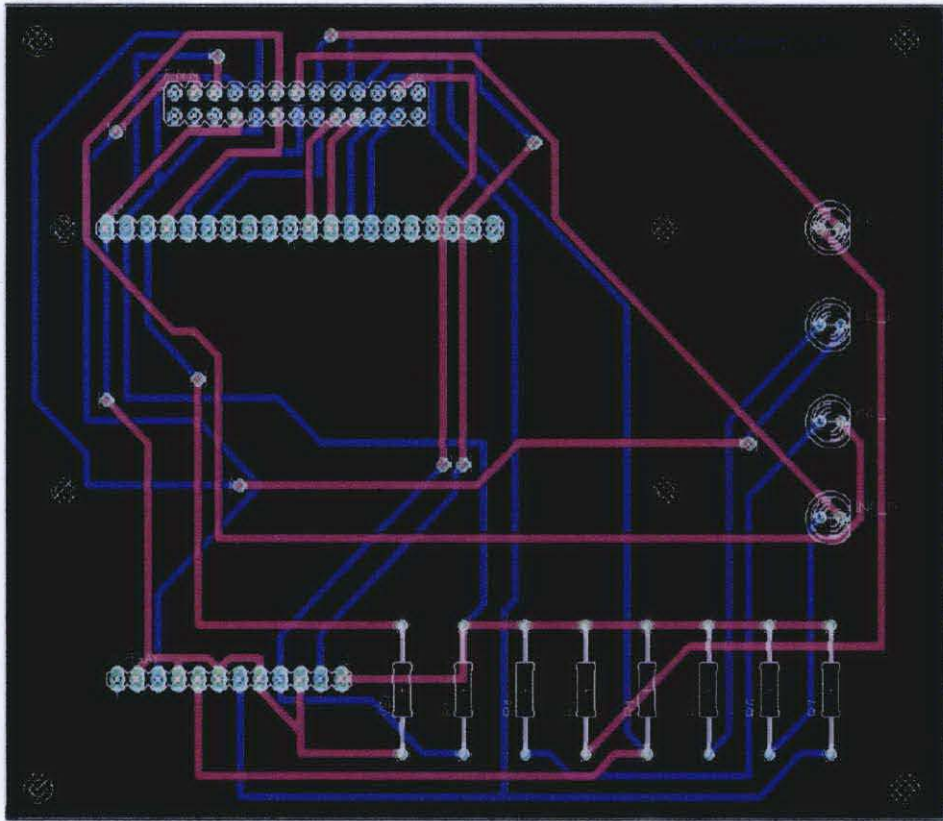


Figure 28: User Interface Board PCB (Double Sided)



Figure 29: User Interface Board (Component Side)

4.6 C-Program for Brushless Motor Drive

Using PICC C-code Compiler, the programming for basic brushless running motor was constructed. The program consists of both forward and reverse direction of the motor. Although PWM function was enabled, voltage level control cannot be implemented because the motor runs without any position sensor. Small time delay was implemented in between each step. So, the motor can only rotate at a constant speed, based on the time delay. Part of the programming code is shown as below:

```
void main()
{
    setup_adc_ports (san0);
    setup_adc (adc_clock_internal);

    // Setup the 4 Power PWM channels as ordinary pwm channels.
    setup_power_pwm_pins(PWM_BOTH_ON, PWM_BOTH_ON, PWM_BOTH_ON,
    PWM_OFF);
    setup_power_pwm(PWM_FREE_RUN, 1, 0, POWER_PWM_PERIOD, 0, 1,0);
    while (1)
    {
        //motor runs at clockwise direction
        step1 ();
        step2 ();
        step3 ();
        step4 ();
        step5 ();
        step6 ();
    }
}

void step1 ()
{
    vartest = read_adc ();
    vartest2 = vartest*34;
    set_power_pwm0_duty(vartest2);
    set_power_pwm2_duty(vartest2);
}
```



```

set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,true,0); //(x,y,z),pwm x y overridden to z state
delay_us(70);
}

```

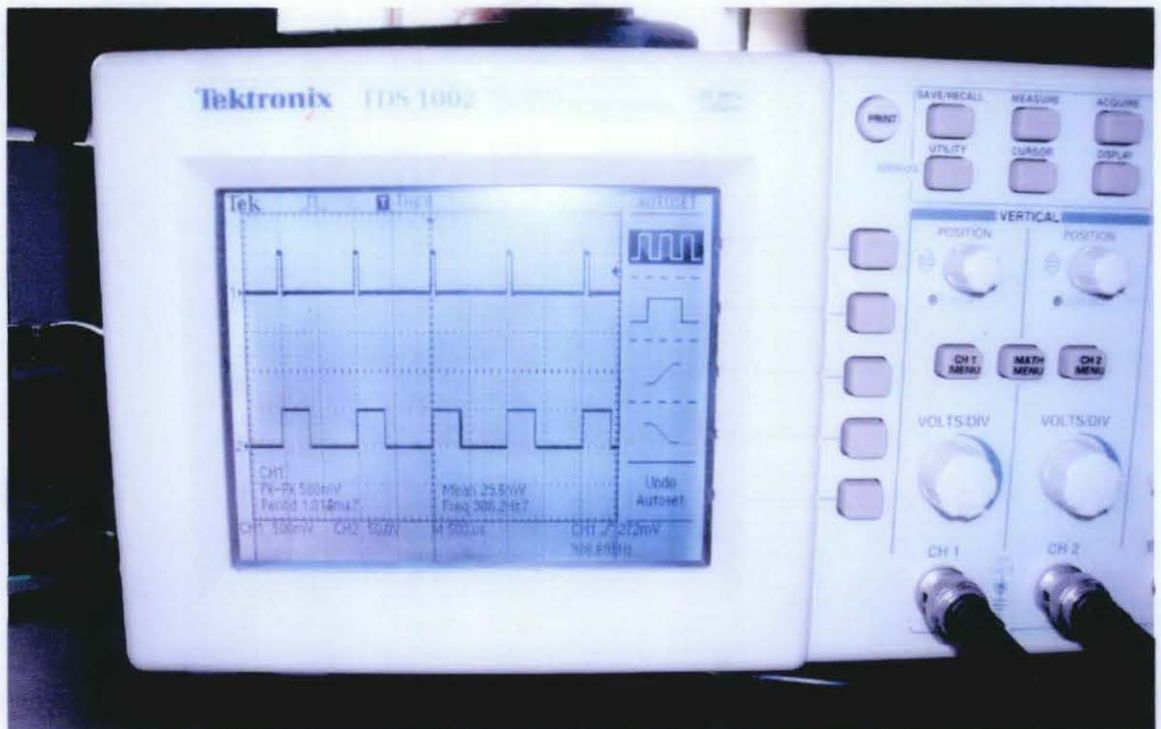


Figure 30: Pulse Width Modulation (PWM) Generated for Motor Drive

Figure 30 above shows two PWM output generated using PIC18F4431. The upper waveform represents 10% duty cycle. The average voltage at output was about 0.5V. The lower waveform represents 40% duty cycle. The average voltage was about 2V. Both signals were generated at frequency of 1 kHz (period of 1ms).

4.7 C-Program for H-Bridge Test (Brushed DC Motor)

By connecting a simple brushed DC motor at the mainboard output, and standard battery at the DC input, the hardware can operate a DC brushed motor, with regulated speed using PWM function. PWM regulated the output voltage level based on user input (variable resistor).

Part of the programming code is shown below:

```
void main()
{
    setup_adc_ports (san0);
    setup_adc (adc_clock_internal);

    // Setup the 4 Power PWM channels as ordinary pwm channels.
    setup_power_pwm_pins(PWM_BOTH_ON, PWM_BOTH_ON, PWM_OFF, PWM_OFF);
    setup_power_pwm(PWM_FREE_RUN, 1, 0, POWER_PWM_PERIOD, 0, 1,0);
    while (1)
        step1 ();          //motor runs at clockwise direction
        step2 ();
    }

void step1 ()
{
    vartest = read_adc ();
    vartest2 = vartest*34;
    set_power_pwm0_duty(vartest2);
    set_power_pwm2_duty(vartest2);
    set_power_pwm_override (0,false,0); //(x,y,z),pwm x y overridden to z state
    set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
    set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
    set_power_pwm_override (3,false,0); //(x,y,z),pwm x y overridden to z state
    delay_us(70);
}
```

4.8 Analysis

The raw PCB boards that were used are 1.6millimeter thick with 16 micrometer thick of copper layer. Mainboard dimension was 20mm x 12.5mm. The interface board dimension was 12.8mm x 10.3mm. Blue and green colors represent the bottom copper layer of components connections and electrical conductors. Red color represents manual jumping wires on the upper side of the board. Manual jumping is required because PCB machine in UTP can only support single sided board not double sided.

Several electrical conductors were purposely enlarged for current carrying capability. Main highlights were at the DC input and three phase switched DC output of main board. The widths of conductors were set at 6.4516mm, as it were meant to support high current. Conductors for grounding purposes were set to 0.6096mm width, also for current capacity. Normal electronic conductors for signal were set to default width, 0.254mm. The calculation shows that the board is capable to support approximate 20A of continuous current.

Main board was design to accept up until 1000V. According to spacing requirement in Figure 3, for that peak voltage, spacing required would be minimum of 6mm. Minimum spacing between wire to wire and wire to pad were also taken into considerations. Ground with positive voltage conductors were kept at reasonable spacing and other conductors were left as default.

All Printed Circuit Board (PCB) designed in this report, are constructed in double sided. The red color represents top side of PCB (component side). The blue color represents bottom side of PCB (soldering side). The green color represents pads and vias. Via is a connection between component side to soldering side. The vias were connected manually using piece of wire, as PCB copper plating machine is out of use.

The H-bridge test shows that the driver and its interfacing can support continuous current supply to a load. The hardware is capable of controlling the speed and direction of a simple DC motor. The speed is proportional to the voltage level applied to the motor. Battery used as input supply is at 7.2V. That was the maximum voltage level that can be supplied to the output when PWM was at 100%. The circuit is called H-bridge or Full Bridge, because it has 4 switching elements at corners of the H. The 4 switches were IGBT 1, 2, 3 and 4. The motor runs clockwise when gate of IGBT 1 and 4 energized. It turns anti clockwise for IGBT 3 and 2. Should any combination of IGBT 1 and 4 or 2 and 3, were energized, the battery will short circuit. For this hardware, this event will not happen because of safety feature in Semikron, that disable all gates output when these signal is generated.

The hardware is also capable of executing basic 6 steps commutation. The commutation is applied by energizing specific motor armature, to provide maximum torque to the load. As the torque generated by this 6 step commutations, this technique is not often used in servo application. Each step represents 60 electrical degrees, and precisely positioned by hall sensor. In this test, the motor runs without sensor. Between each step, small time delay (70us) was applied. The motor will run slower in increasing time delay. Using this time delay technique, only small torque was generated.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion and Recommendation

In hybrid vehicle technology, dual source of power is applied; from combustion engine and from electric motor. The electric motor is driven by a power electronic circuit. For this project, a medium power three phase brushless in-wheel motor (IWM) was used. A prototype that uses 6 IGBTs in inverter configurations was built as the motor driver. 6 steps commutations technique were used to provide switched DC output into the brushless three phase motor. Each step was precisely fired using Programmable Integrated Circuit (PIC) with respect to position input from hall sensor. Using this technique, maximum torque can be applied to the load for electrical step of 60 degree each. Plus, with Pulse Width Modulation (PWM) implementation, output voltage level to the motor can be varied, thus varying the motor rotation speed.

For this project, the author has managed to complete the objectives of this project, at board and motor dry tests. In building a circuit board that supports high power, critical criteria for example conductors' width and spacings have to be taken into consideration to ensure longer lifetime and durability of the board. Failure in meeting the guidelines may result in catastrophic events. As a conclusion, this hardware manages to drive both brushed and brushless miniature motor. Speed and direction control of both motor can be achieved using this hardware. It is much recommended for the management to expand FYP period longer for student.

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APPENDICES

APPENDIX A – C Program for Brushless Motor Drive

```
#include<18F4431.h>
#fuses INTRC_IO, NOWDT, NOPROTECT, NOBROWNOUT, PUT, NOLVP
#use delay(clock=8000000)
#include <string.h>
#include <lcd.c>
#define POWER_PWM_PERIOD 1999 // 1 KHz pwm freq with 8 MHz osc.
#define timedel 70
unsigned int16 vartest,vartest2;
unsigned int16 percent,sw1,sw2;

void step1 ();
void step2 ();
void step3 ();
void step4 ();
void step5 ();
void step6 ();
void forward ();
void reverse ();
void loading ();
void select ();
void swinput ();

void main()
{
    setup_adc_ports (san0);
    setup_adc (adc_clock_internal);

    // Setup the 4 Power PWM channels as ordinary pwm channels.
    setup_power_pwm_pins(PWM_BOTH_ON, PWM_BOTH_ON, PWM_BOTH_ON, PWM_OFF);
    setup_power_pwm(PWM_FREE_RUN, 1, 0, POWER_PWM_PERIOD, 0, 1,0);

    lcd_init ();
    loading ();
    select ();
    while (1)
        swinput ();
}

void swinput ()
{
    sw1 = input(pin_c4);
    sw2 = input(pin_d3);
    if (!sw1)
        forward ();
    if (!sw2)
        reverse (); }

void loading ()
{
```

```

    lcd_gotoxy(1,1);
    lcd_putc ("Loading.");
    delay_ms (500);
    lcd_gotoxy(1,1);
    lcd_putc ("Loading..");
    delay_ms (500);
    lcd_gotoxy(1,1);
    lcd_putc ("Loading...");
    delay_ms (500);
    lcd_gotoxy(1,1);
    lcd_putc ("Loading....");
    delay_ms (500);
}

void reverse ()
{
    lcd_gotoxy(1,1);
    lcd_putc ("c-clkwise:      ");
    delay_ms (10);
    while (1)
    {
        step1 ();
        step2 ();
        step3 ();
        step4 ();
        step5 ();
        step6 ();
    }
}

void forward ()
{
    lcd_gotoxy(1,1);
    lcd_putc ("clkwise:      ");
    delay_ms (10);
    while (1)
    {
        step6 ();
        step5 ();
        step4 ();
        step3 ();
        step2 ();
        step1 ();
    }
}

void step1 ()
{
    vartest = read_adc ();
    percent = vartest*0.4;
    vartest2 = vartest*34;
    lcd_gotoxy(1,2);
    printf (lcd_putc,"%lu pwm percent " ,percent);
    delay_ms (5);
    set_power_pwm0_duty(vartest2);
    set_power_pwm2_duty(vartest2);
    set_power_pwm4_duty(vartest2);
    set_power_pwm_override (0,false,0); //(x,y,z),pwm x y overridden to z state
}

```



```

set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,true,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

```

void step2 ()
{
vartest = read_adc ();
percent = vartest*0.4;
vartest2 = vartest*34;
lcd_gotoxy(1,2);
printf (lcd_putc,"%lu pwm percent" ,percent);
delay_ms (5);
set_power_pwm0_duty(vartest2);
set_power_pwm2_duty(vartest2);
set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,false,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

```

void step3 ()
{
vartest = read_adc ();
percent = vartest*0.4;
vartest2 = vartest*34;
lcd_gotoxy(1,2);
printf (lcd_putc,"%lu pwm percent" ,percent);
delay_ms (5);
set_power_pwm0_duty(vartest2);
set_power_pwm2_duty(vartest2);
set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,false,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

```

void step4 ()
{
vartest = read_adc ();
percent = vartest*0.4;
vartest2 = vartest*34;

```

```

lcd_gotoxy(1,2);
printf (lcd_putc,"%lu pwm percent" ,percent);
delay_ms (5);
set_power_pwm0_duty(vartest2);
set_power_pwm2_duty(vartest2);
set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,true,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

```

void step5 ()
{
vartest = read_adc ();
percent = vartest*0.4;
vartest2 = vartest*34;
lcd_gotoxy(1,2);
printf (lcd_putc,"%lu pwm percent" ,percent);
delay_ms (5);
set_power_pwm0_duty(vartest2);
set_power_pwm2_duty(vartest2);
set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,true,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

```

void step6 ()
{
vartest = read_adc ();
percent = vartest*0.4;
vartest2 = vartest*34;
lcd_gotoxy(1,2);
printf (lcd_putc,"%lu pwm percent" ,percent);
delay_ms (5);
set_power_pwm0_duty(vartest2);
set_power_pwm2_duty(vartest2);
set_power_pwm4_duty(vartest2);
set_power_pwm_override (0,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (1,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (2,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (3,true,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (4,false,0); //(x,y,z),pwm x y overridden to z state
set_power_pwm_override (5,true,0); //(x,y,z),pwm x y overridden to z state
delay_us(timedel);
}

```

**APPENDIX B
GANTT CHART FOR FYP I**

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	x	x												
2	Research work			x	x	x	x	x							
3	Equipment survey				x										
4	Submission of Preliminary Report			x											
5	Submission of Progress Report									x	x	x			
6	PCB manufacturing					x	x	x							
7	Hardware assembly								x	x	x				
8	Hardware testing and configuration									x	x	x	x		
9	Submission of Interim Report												x		
10	Oral Presentation													x	

**APPENDIX C
GANTT CHART FOR FYP II**

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Continue Prototype Work	x	x	x											
2	PIC Programming			x	x	x	x	x							
3	PCB Fabrication				x	x	x	x							
4	Submission of Progress Report 2								x						
5	Continue Project Work									x	x	x			
6	Controller Testing										x	x			
7	Continue project work								x	x	x	x	x	x	
8	Poster Presentation										x				
9	Submission of Dissertation												x		
10	Oral Presentation													x	
11	Submission of Project Dissertation														x