A High Power H-Bridge

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Contents

Chapter 1

Overview

This document is intended to give an introduction to H-Bridges and to briefly explain the design principles behind the schematic diagram of the High Power H-Bridge designed. The reader is encouraged to look over the reference list at the end of the document for further information on H-Bridges and Power electronics.

1.1 Brief Specifications of High Power H-Bridge

- 70 Amps - Continuous Current
- 150 Amps - Maximum Current (Short Durations)
- 48 Volts - Maximum Voltage
- 200 mA - Standby By current
- Direction and PWM as inputs
- Solid State - Fast Directional Changing

Chapter 2

H-Bridge Principles

An H-Bridge is an electronic power circuit that allows motor speed and direction to be controlled. Often motors are controlled from some kind of "brain" or micro controller to accomplish a mechanical goal. The micro controller provides the instructions to the motors, but it cannot provide the power required to drive the motors. An H-bridge circuit inputs the micro controller instructions and *amplifies* them to drive a mechanical motor. This process is similar to how the human body generates mechanical movement; the brain can provide electrical impulses that are instructions, but it requires the muscles to perform mechanical force. The muscle represents both the H-bridge and the motor combined. The H-bridge takes in the small electrical signal and translates it into high power output for the mechanical motor. This document will cover the electronic principles in creating the H-Bridge portion of the "muscle". If the reader requires further information consult the references included at the end of the document.

2.1 Direction Control - H-Bridge Topology

Most DC Motors can rotate in two directions depending on how the battery is connected to the motor. Both the DC motor and the battery are two terminal devices that have positive and negative terminals. In order run the motor in the forward direction, connect the positive motor wire to the positive battery wire and negative to negative. However, to run the motor in reverse just switch the connections; connect the positive battery wire to the negative motor wire, and the negative battery wire to the positive motor wire. An H-Bridge circuit allows a large DC motor to be run in both direction with a low level logic input signal.

The H-Bridge electronic structure is explicit in the name of the circuit - **H -**

Bridge. The power electronics actually form a letter H configuration, as shown in Figure 2.1. The switches are symbolic of the electronic Power MOSFETs which are used for switching.

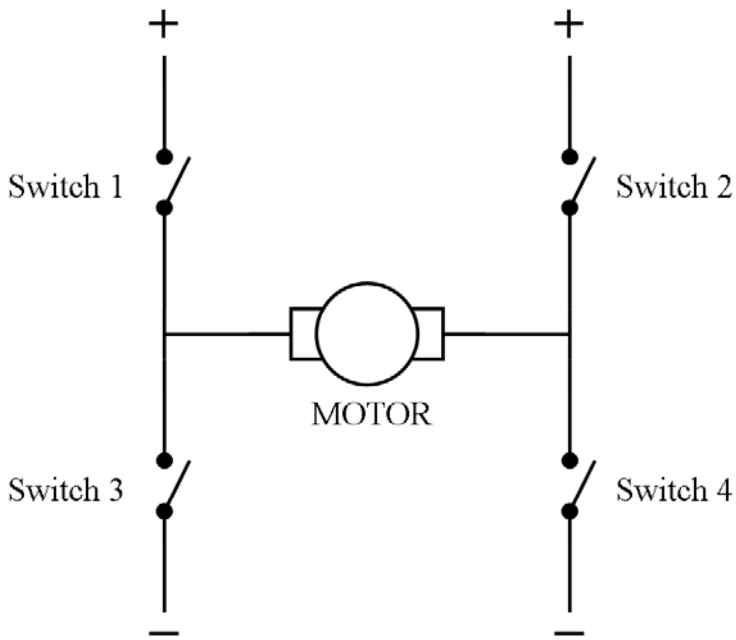


Figure 2.1: H-Bridge Topology

If it is desired to turn the motor on in the ***forward*** direction, switches 1 and 4 must be closed to power the motor. Figure 2.2 below is the H-Bridge driving the motor in the forward direction.

If it is desired to turn the motor on in the ***reverse*** direction, switches 2 and 3 must be closed to power the motor. Figure 2.3 below is the H-Bridge driving the motor in the reverse direction.

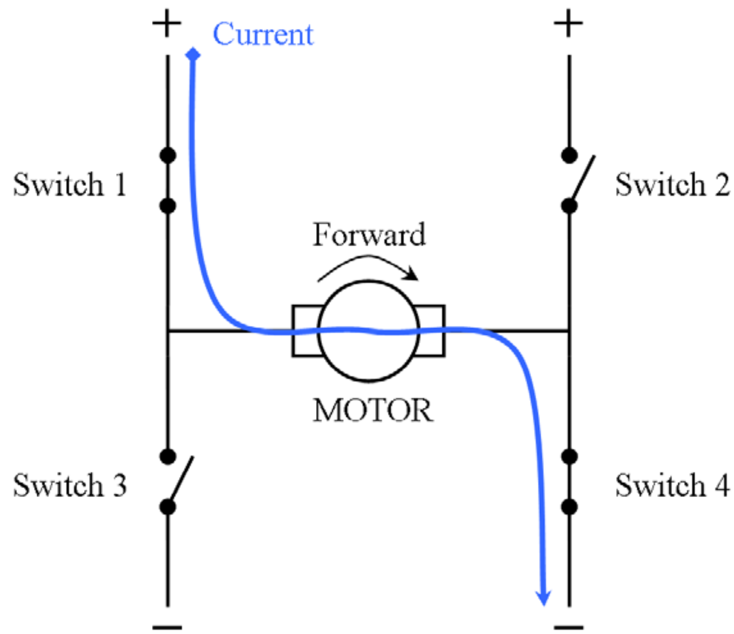


Figure 2.2: H-Bridge Topology - Forward Direction

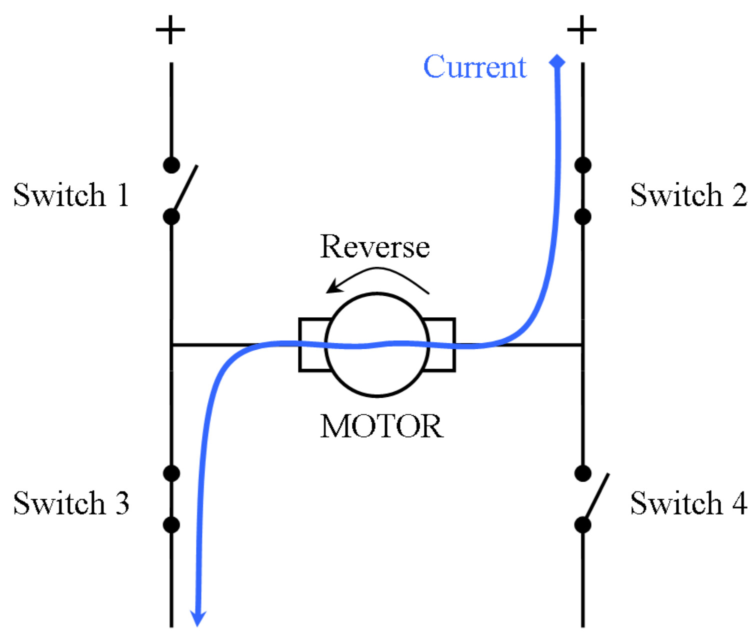


Figure 2.3: H-Bridge Topology - Reverse Direction

2.2 Speed Control - PWM Technique

The motor is controlled by the 4 switches above. For the speed control explanation that follows only switches 1 and 4 will be considered because speed control is identical in the forward and reverse direction. Say the switches 1 and 4 are turned on, the motor will eventually run at full speed. Similarly if only switch 4 is turned on while switch 1 is off the motor stops. Using this system, how could the motor be run at 1/2 of the full speed? The answer is actually quite simple; turn switch 1 on for half the time and turn it off for the other half. In order to implement this system in reality, one must consider two main factors, namely frequency and duty cycle.

Frequency: Using the switch example, the frequency would be how fast the switch was turned on and off. If the frequency is too low (switch is changed slowly), then the motor will run at full speed when the switch is on, and completely stop when the switch is off. But if the frequency is too high, the switch may mechanically fail. In reality there is no switch, but rather an electronic board named an H-Bridge that switches the motor on and off. So in electrical terms; if the frequency is too low, the time constant of the motor has enough time to fully switch between on and off. Similarly the upper limit on the frequency is the limit that the H-Bridge board will support, analogous to the mechanical switch. The maximum frequency of this H-Bridge Board is 500 kHz, but the recommended frequency of the PWM for this board is 31.25 kHz.

Duty Cycle: The duty cycle is analogous to how long the upper switch (switch 1) remains on as a percentage of the total switching time. In essence it is an average of how much power is being delivered to the motor. Duty cycle gives the proportional speed control of the motor. Figure 2.4 is an example of 1/4, 1/2, and 3/4 duty cycles. Effectively, these duty cycles would run the motor at 1/4, 1/2, and 3/4 of full speed respectively.

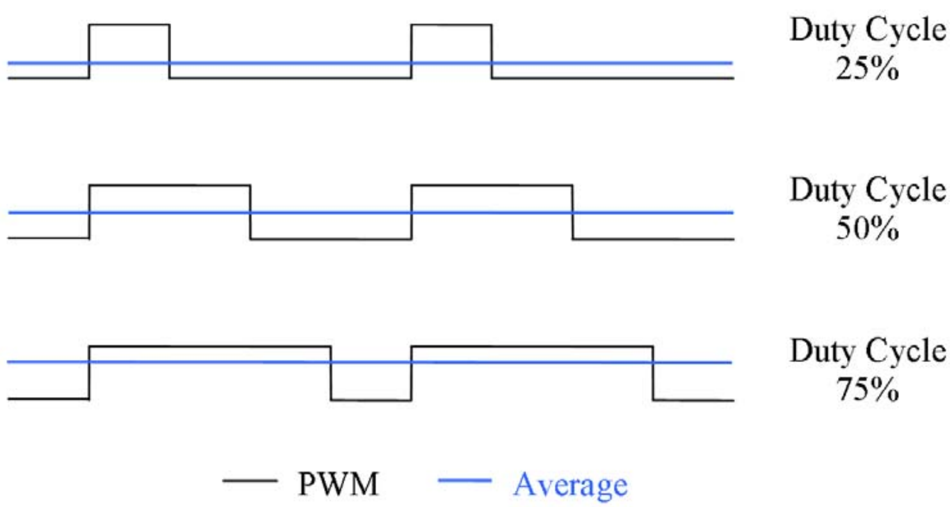


Figure 2.4: Pulse Width Modulation Used For Motor Control

Chapter 3

Design Description

3.1 Turning On The Upper MOSFETS

This section will explain what the "switches" above actually are in terms of electronic components. The switches are power MOSFETs (transistors) that have certain properties that allow them to switch high currents based on an input signal. The MOSFETs are used in two regions of operation; Cut-off mode and Saturation mode which correspond to switched off and switched on respectively. In the H-Bridge case, to put a MOSFET into the Cut-off mode, the input signal (Gate Voltage) to the MOSFET must be grounded. However, to turn on the MOSFETs and put them into saturation mode requires a more complicated process.

MOSFETS are three terminal devices with the terminals being the Gate, Drain, and Source. In order to turn on the MOSFET into saturation mode the voltage at the gate terminal must be approximately 12 volts higher than the voltage at source terminal. Figure 3.1 illustrates the slightly more complicated process of turning on the top MOSFETS.

The more complicated part; how can 36 volts be used at the Gate when the battery voltage is only 24V? The MOSFET Driver chip solves this problem by using a Charge Pump and a Bootstrap circuit.

3.1.1 MOSFET Driver Chip - HIP4081A

A MOSFET driver chip performs all of the following functions.

- Generate the VGS to turn on (saturate) the top N-Channel MOSFETS. This is accomplished by two methods, a charge pump and a bootstrap circuit. Information on both these methods can be found in data sheet for the HIP4081A, or in the references at the end of this document.

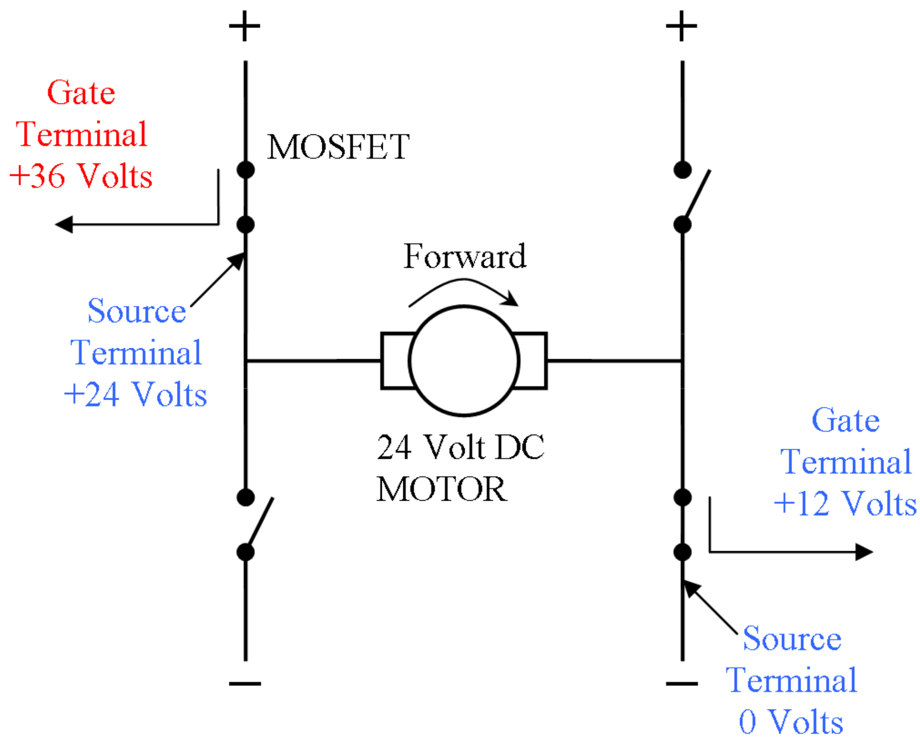


Figure 3.1: Gate Voltage Problem With Top N-Channel MOSFETS

1. Charge Pump - Uses a set of internal diodes and capacitors to provide a small amount of current to ensure that the top MOSFETS stay saturated.
2. Bootstrap Method - Uses a set of external diodes and capacitors to provide a significant amount of current to turn on (saturate) the top MOSFETS rapidly.

- Switches MOSFETS at high speeds. Since the MOSFETS must be switched on and off very fast, 31.25 kHz, a significant amount of current must be used to overcome the gate capacitance. The MOSFET Driver Chip can source the current required to switch the MOSFETS rapidly.
- Acts as a Buffer to the logic input signals.
- Introduce a Dead Time to prevent Shoot-Through Current. This is topic is discussed later in this document in section MOSFET Driver Dead Time.

3.2 Feedback EMF Reduction - Large Main Capacitor

The large main capacitors primary purpose is to suppresses transient spikes caused by the motor. Often when the motor accelerates, decelerates, or stops suddenly, an EMF "feedback" voltage will spike on the main battery voltage. These spikes cause micro controllers to reset and are harmful to most low level electronics. By placing a filter capacitor in parallel with the battery, these feedback spikes can be reduced in magnitude.

The reasoning behind this filter capacitor has its roots in basic electronics. One of the laws from basic electronics states that voltage can not change instantaneously across a capacitor; therefore, since the capacitor is parallel to the battery, the battery voltage cannot change instantly. This results in a reduction of the feedback voltage spikes generated by the motor.

3.3 Regenerative Current Circulation

Another law from basic electronics states that current cannot change instantaneously through an inductor. Since the main motor coil is a large inductor, the current running through the motor can only change gradually. Abrupt changes cause the feedback voltage spikes mentioned earlier. As an additional feature to the main capacitor, an RCC (regenerative current circulation) technique was implemented to reduce EMF voltage spikes. Additionally, the RCC technique implemented redirects unused current back into the battery, maximizing battery life.

Recall that when using the PWM technique, the upper switch is rapidly turned on and off to create variable speed control, and the lower switch is left on. When the motor is running at 1/2 speed, the top switch (switch 1) is switched on 1/2 the time and it is switched off 1/2 the time. During the OFF part of the PWM cycle (switch 1 - off and switch 4 - on), where does the current circulate? Remember this is a large inductor and current cannot jump from a definite value to zero instantly!, see Figure 3.2.

To solve this problem, the PWM technique will be refined to incorporate RCC. The RCC technique involves turning on both bottom switches when the PWM is in the off

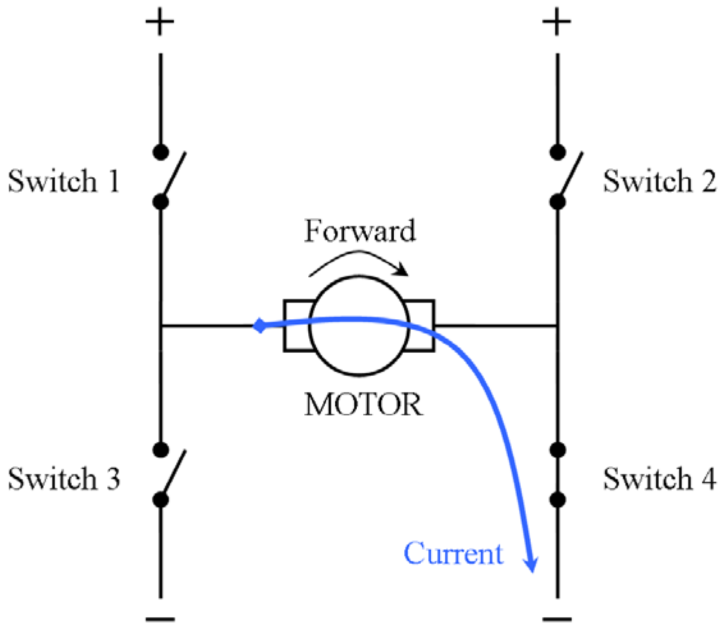


Figure 3.2: No RCC - During Off Portion Of PWM Cycle

portion of the cycle. This involves inverting the PWM signal that controls switch 1 and feeding it to switch 3. Essentially, when the top switch 1 is on, the bottom switch 3 is off, and when the top switch 1 is off, the bottom switch 3 is on. The inversion technique is the same for the other side of the H-Bridge. The effect of RCC is shown in Figure 3.3.

The following are logic equations for each switch based on input PWM (Speed) and input DIR (Direction):

$$Switch\ 1 = PWM \bullet DIR \tag{3.1}$$

$$Switch\ 2 = PWM \bullet \overline{DIR} \tag{3.2}$$

$$Switch\ 3 = \overline{Switch\ 1} = \overline{PWM} + \overline{DIR} \tag{3.3}$$

$$Switch\ 4 = \overline{Switch\ 2} = \overline{PWM} + DIR \tag{3.4}$$

When implementing the RCC, there is an inherent danger; what if the top switch 1 and bottom switch 3 are on at the same time, even for a small amount of time? The battery will be shorted out and the H-Bridge will literally blow up. This is called **Shoot Through** and it is shown in Figure 3.4.

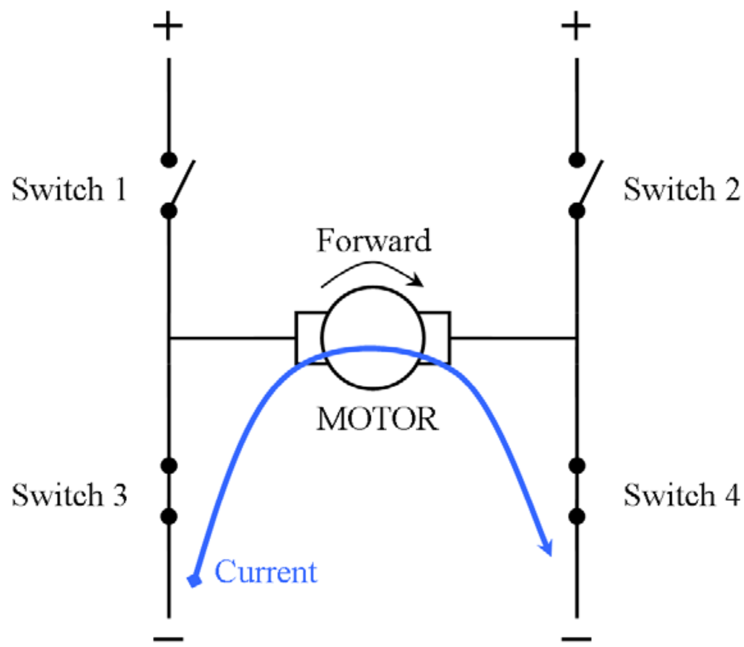


Figure 3.3: RCC Technique - During Off Portion Of PWM Cycle

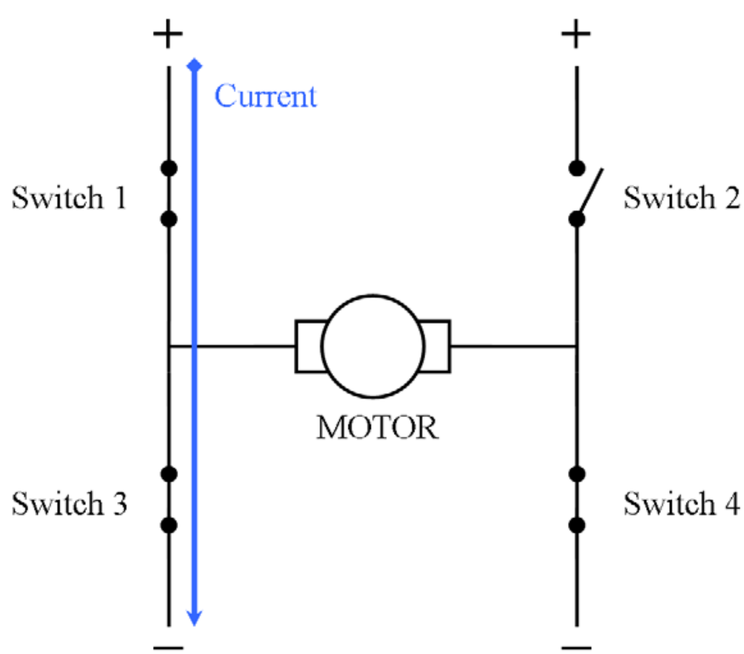


Figure 3.4: Shoot Through Current - Danger Of RCC

3.4 Shoot-Through Protection

To prevent the condition that causes shoot-through, a dead time is introduced as shown in Figure 3.5. Switch 2 is off and Switch 4 is on in Figure 3.5.

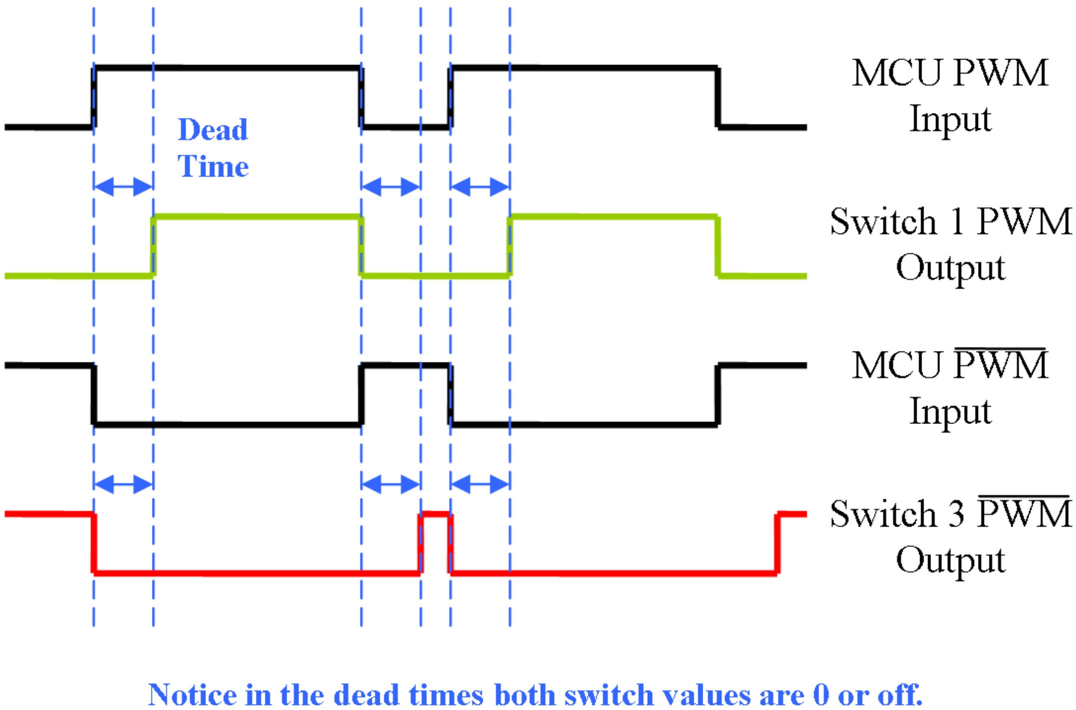


Figure 3.5: Dead Time - Timing Relationships For Switches

The Dead Time is accomplished by delaying only the rising edge of the PWM as shown in Figure 3.5. The falling edge passes through the dead time circuit unaffected.

The MOSFET Driver HIP4081A adds a small amount of dead time. However, to be on the safe side, an additional dead time circuit was designed as shown in Appendix - Schematic. The dead time circuit will add approximately a 1us delay to the rising edges of the PWM, which ensures that the MOSFETS are never turned on at the same time.

Pictures of Final PCB

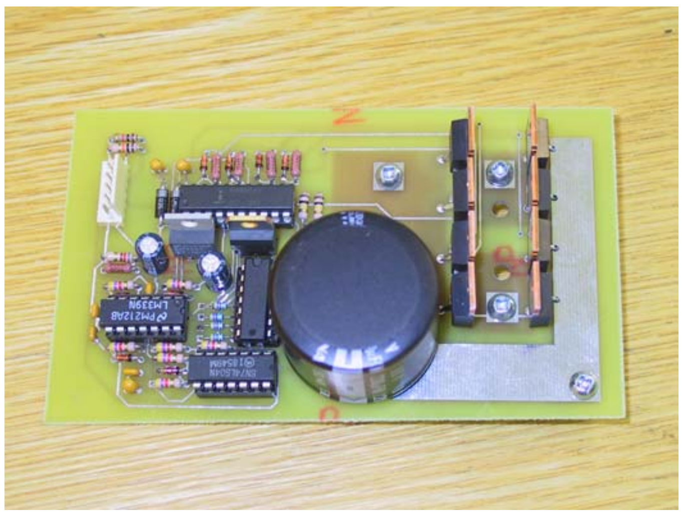


Figure 4.1: Top of PCB

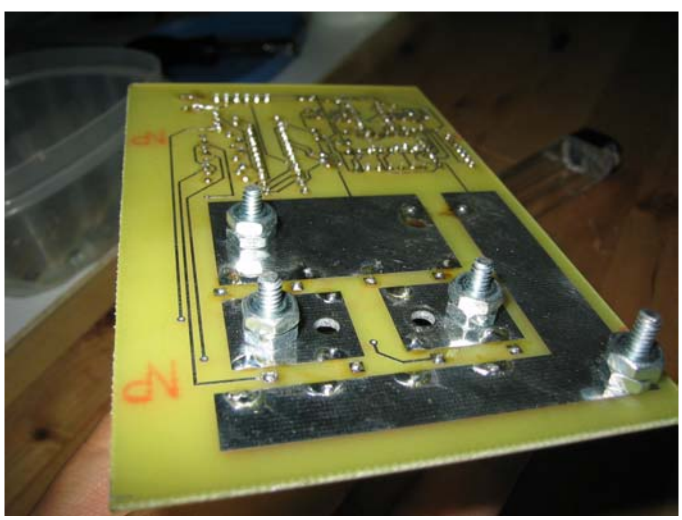


Figure 4.2: Bottom of PCB

Chapter 5

Future Improvements

- Reduce PCB Size. Possibly incorporate two H-bridges on one board with a micro controller.
- Switch the bottom MOSFETS instead of top MOSFETS.
- Possibly eliminate the voltage regulators and use Zener diodes instead.

Bibliography

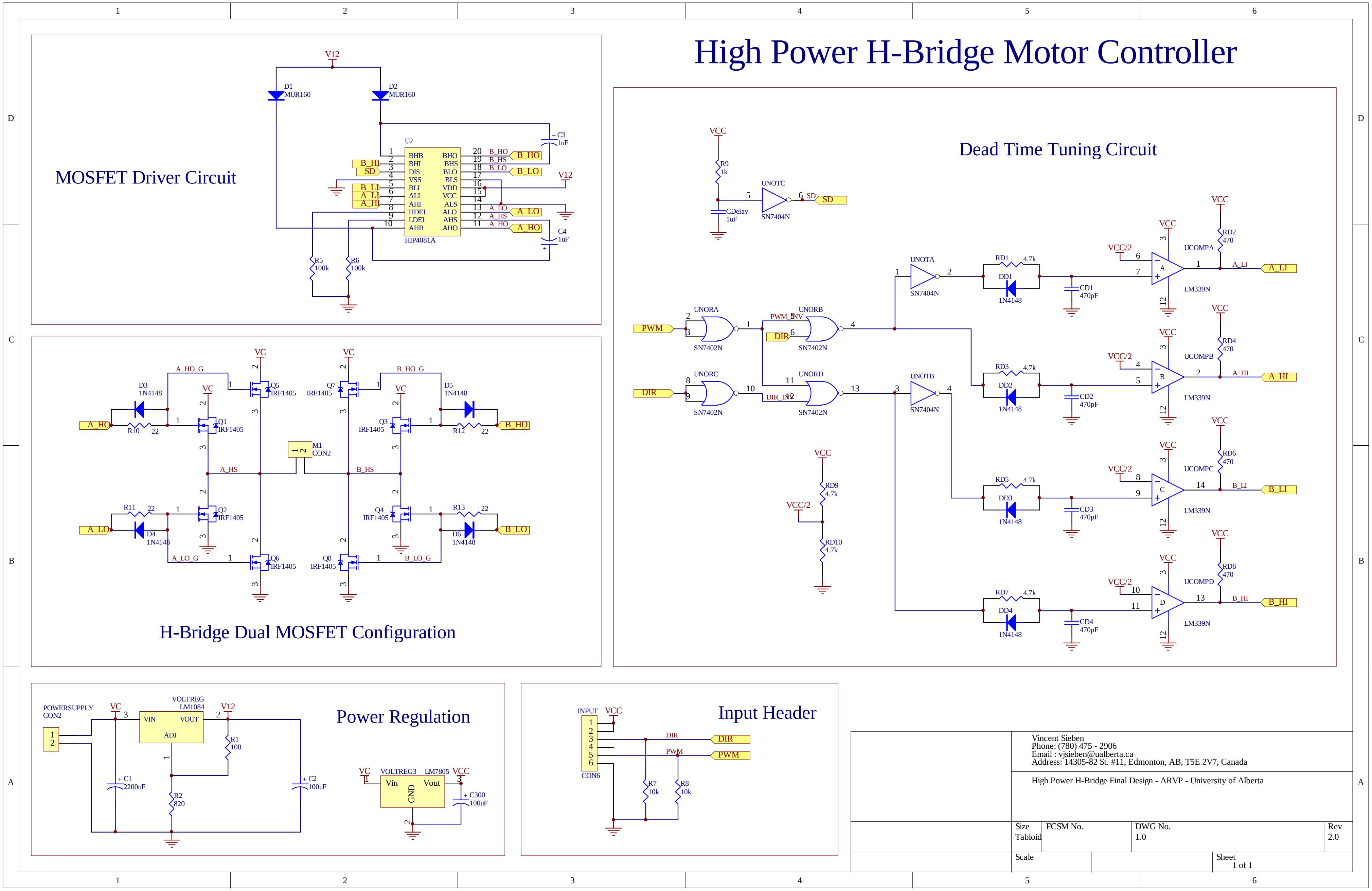
[1] 4QD. Ncc70 reference manual. Technical report. URL: `http://www.4qd.co.uk/`.

[2] Intersil. Hip4081a data sheet. Technical report. URL: `http://www.intersil.com/`.

[3] International Rectifier. Power mosfet application notes and data sheets. Technical report. URL: `http://www.irf.com/`.

Appendix A

Final Schematic


High Power H-Bridge Motor Controller
MOSFET Driver Circuit
Dead Time Tuning Circuit
H-Bridge Dual MOSFET Configuration
Power Regulation
Input Header
Vincent Sieben
Phone: (780) 475 - 2906
Email : vjsieben@ualberta.ca
Address: 14305-82 St. #11, Edmonton, AB, T5E 2V7, Canada
High Power H-Bridge Final Design - ARVP - University of Alberta
Size
Tabloid
FCSM No.
DWG No.
1.0
Rev
2.0
Scale
Sheet
1 of 1

Appendix B

Final PCB

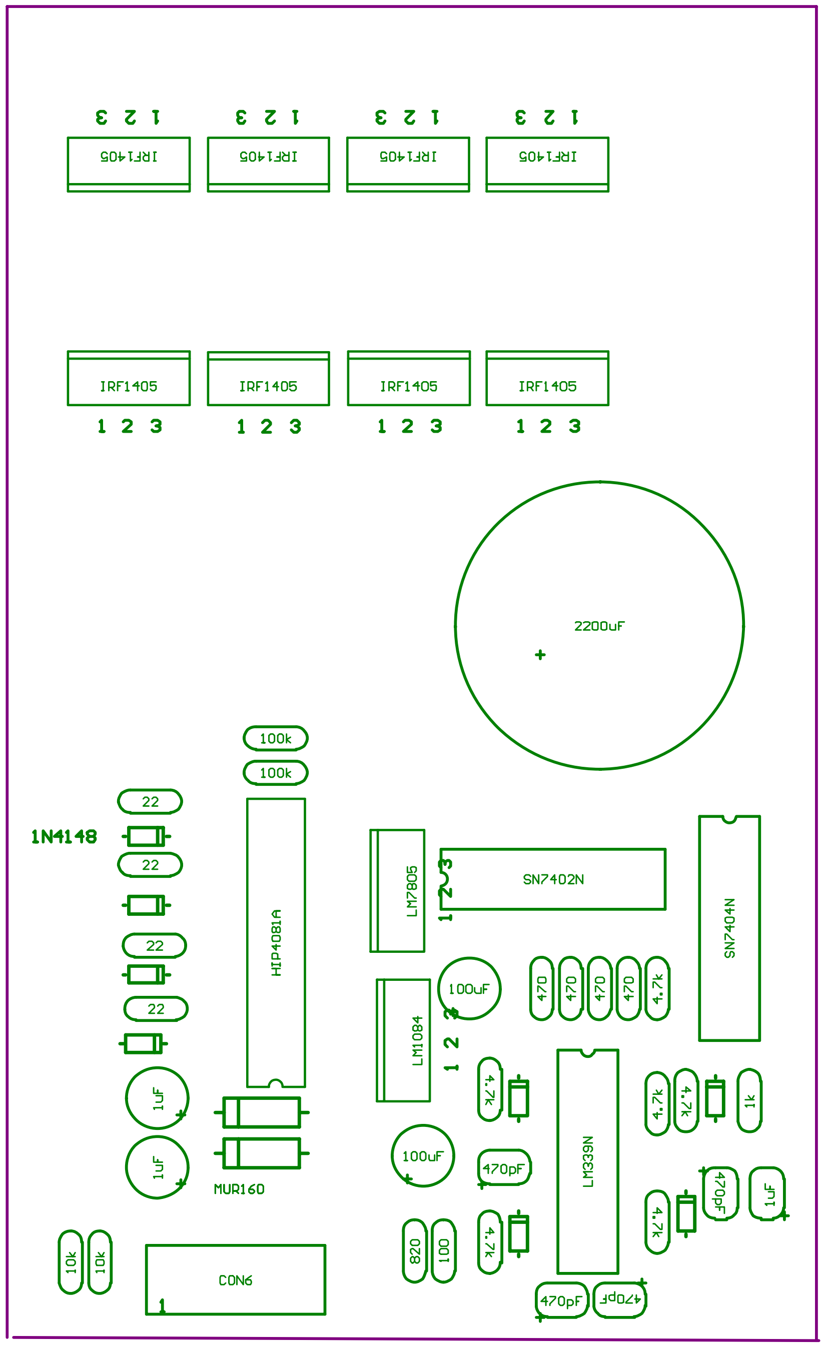


Figure B.1: Final H-Bridge PCB Top Solder Mask Layer (Not to Scale)

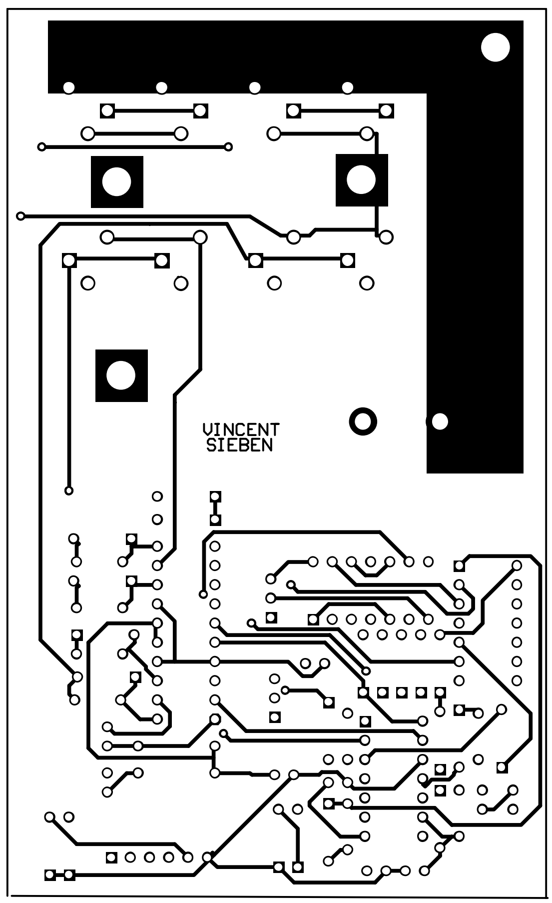


Figure B.2: Final H-Bridge PCB Top Layer

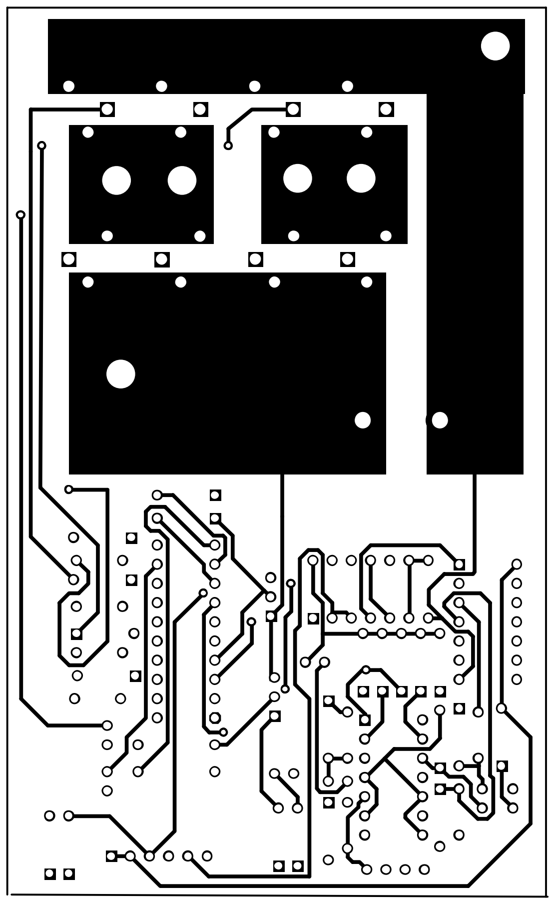


Figure B.3: Final H-Bridge PCB Bottom Layer

Bill of Material - BOM

Part Type	Designator	Footprint	Description
1N4148	D4	SDIODE	Diode
1N4148	D3	SDIODE	Diode
1N4148	D5	SDIODE	Diode
1N4148	D6	SDIODE	Diode
1N4148	DD4	SDIODE	Diode
1N4148	DD3	SDIODE	Diode
1N4148	DD1	SDIODE	Diode
1N4148	DD2	SDIODE	Diode
MUR160	D1	DIODE0.4_V	Diode
MUR160	D2	DIODE0.4_V	Diode
1k	R9	resistor	resistor
4.7k	RD5	resistor	resistor
4.7k	RD10	resistor	resistor
4.7k	RD3	resistor	resistor
4.7k	RD9	resistor	resistor
4.7k	RD7	resistor	resistor
4.7k	RD1	resistor	resistor
10k	R8	resistor	resistor
10k	R7	resistor	resistor
22	R10	resistor	resistor
22	R11	resistor	resistor
22	R13	resistor	resistor
22	R12	resistor	resistor
100	R1	resistor	resistor
100k	R6	resistor	resistor
100k	R5	resistor	resistor
470	RD2	resistor	resistor
470	RD4	resistor	resistor
470	RD6	resistor	resistor
470	RD8	resistor	resistor
820	R2	resistor	resistor
1uF	C4	cap5mm	Capacitor
1uF	C3	cap5mm	Capacitor
1uF	CDelay	ceramic	Capacitor
100uF	C300	cap5mm	Capacitor
100uF	C2	cap5mm	Capacitor
470pF	CD1	ceramic	Capacitor
470pF	CD3	ceramic	Capacitor
470pF	CD2	ceramic	Capacitor
470pF	CD4	ceramic	Capacitor
2200uF	C1	caplarge	Capacitor
CON6	INPUT	jtag	Connector
HIP4081A	U2	DIP-20	FET DRIVER IC
IRF1405	Q5	TO1	HEXFET Power MOSFET
IRF1405	Q3	TO1	HEXFET Power MOSFET
IRF1405	Q1	TO1	HEXFET Power MOSFET
IRF1405	Q7	TO1	HEXFET Power MOSFET
IRF1405	Q8	TO2	HEXFET Power MOSFET
IRF1405	Q6	TO2	HEXFET Power MOSFET
IRF1405	Q4	TO2	HEXFET Power MOSFET
IRF1405	Q2	TO2	HEXFET Power MOSFET
LM339N	UCOMP	DIP-14/D19.7	Quad Differential Comparator
LM1084	VOLTREG	TOG	Voltage Regulator
LM7805	VOLTREG3	TOG	Voltage Regulator
SN7402N	UNOR	DIP-14/D19.7	Quadruple 2-Input Positive-NOR Gate
SN7404N	UNOT	DIP-14/D19.7	Hex Inverter

Figure C.1: Bill of Materials