Mechatronic Systems Engineering
School of Engineering Science
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MSE312 PROJECT: ELECTRICAL REPORT

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Lab Demo Date:	July 2nd, 2015
Report Due Date:	June 5th, 2015

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Introduction

Our group designed and built the power interface circuitry for driving the DC motor of the mechanical arm equipped with an electromagnetic gripper. During the lab sessions, by using available power MOSFETs, Bipolar Junction Transistors, Opto-isolators, and Full-bridge Integrated Circuit, we first built circuits on the breadboard according to lecture instructions and tested it to drive the electromagnet and rotate the motor. After successful tests, we soldered the built circuit on the PCB board neatly to build a working power electronic drive. We also practiced electronic test procedures using regular measurement and test equipment such as breadboards, function generators, oscilloscopes, power supplies, and multi-meters. Finally, we successfully demonstrated the working circuit driver to a teaching assistant.

Preliminary Lab Experiments

Requirements

i. The circuit should be able to handle the DC motor and electromagnet ratings such as current, voltage, power, temperature (datasheets are posted on canvas).
ii. Appropriate protection should be included in the design.
iii. The power electronics and computer should be electrically isolated.
iv. The circuit is expected to work in the normal room temperature (20-25 degrees Celsius). Proper heat sink should be designed for the devices.

Procedure/Methodology

Full-bridge DC motor driver IC

The Full-bridge driver is given as a chip complete with some logic circuitry which allows the full-bridge driver to be controlled using only two inputs. DC motor control is primarily done through the full-bridge driver, which drives the motor using the circuit configuration shown below.

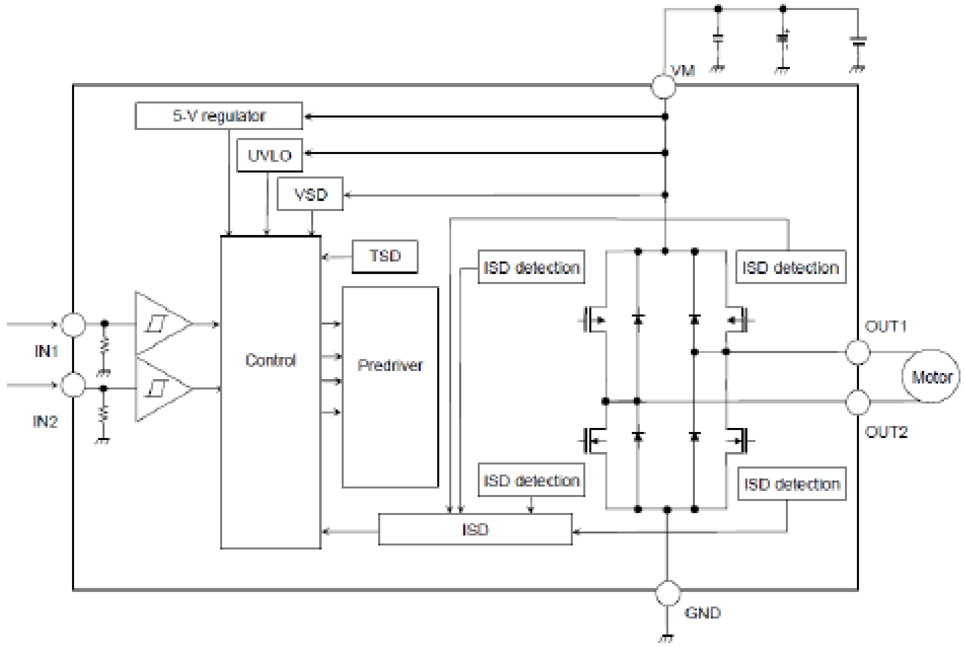


Figure 1: Full-bridge DC Motor Driver IC schematic

A full-bridge driver circuit allows for bidirectional motor control. Using all four switches, the full-bridge driver is capable of allowing current to pass through the load in either direction. In addition to being able to run the motor either clockwise or counter-clockwise, two other modes allow you to brake the motor or stop the motor. In total, these four different modes may be selected using the two logic inputs IN1 and IN2. Tables 1 and 2 below shows the inputs and outputs of this Full-bridge driver.

Pin No.	Pin Name	Functional Description
1	IN1	Control signal input pin 1
2	IN2	Control signal input pin 2
3	OUT1	Output pin 1
4	GND	Ground pin
5	OUT2	Output pin 2
6	N.C.	No-connect
7	VM	Power supply voltage pin

Table 1: Pin Functions

Input		Output		
IN1	IN2	OUT1	OUT2	Mode
H	H	L	L	Short Brake
L	H	L	H	CW/CCW
H	L	H	L	CCW/CW
L	L	OFF (Hi-Z)		Stop (caused by a release of TSD/ISD)

Table 2: Full-bridge inputs and modes

Opto-Isolator

In order to separate the high power circuitry from the low power circuitry, two opto-isolators were implemented for each input to the Full-bridge. This separation is necessary to protect the more sensitive low power circuitry from being destroyed by the higher voltages and current generated in the high power circuitry. The opto-isolator functions using a light emitting diode and a phototransistor. The diode is turned on when connected to the low power circuitry, which in turn activates the phototransistor which lets current through on the high power circuitry side, as shown below:

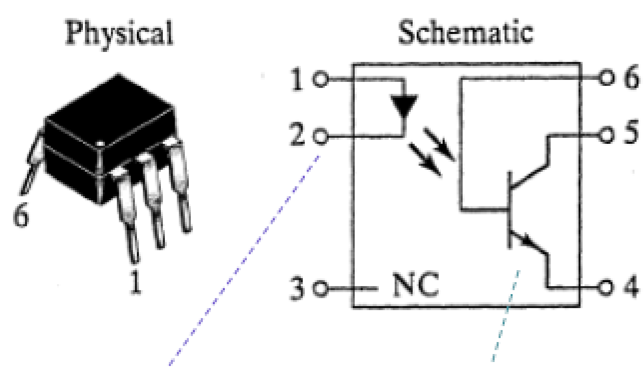


Figure 2: Opto-isolator image and circuit schematic

The isolation effectively disconnects the high power circuitry from the low power circuitry; therefore the opto-isolator is to isolate both signal inputs on the Full-bridge from the signal.

DC Motor Control

During the circuit development stages, we follow the DC Motor Power Drive Design to build our circuit controlling DC Motor, which is shown below:

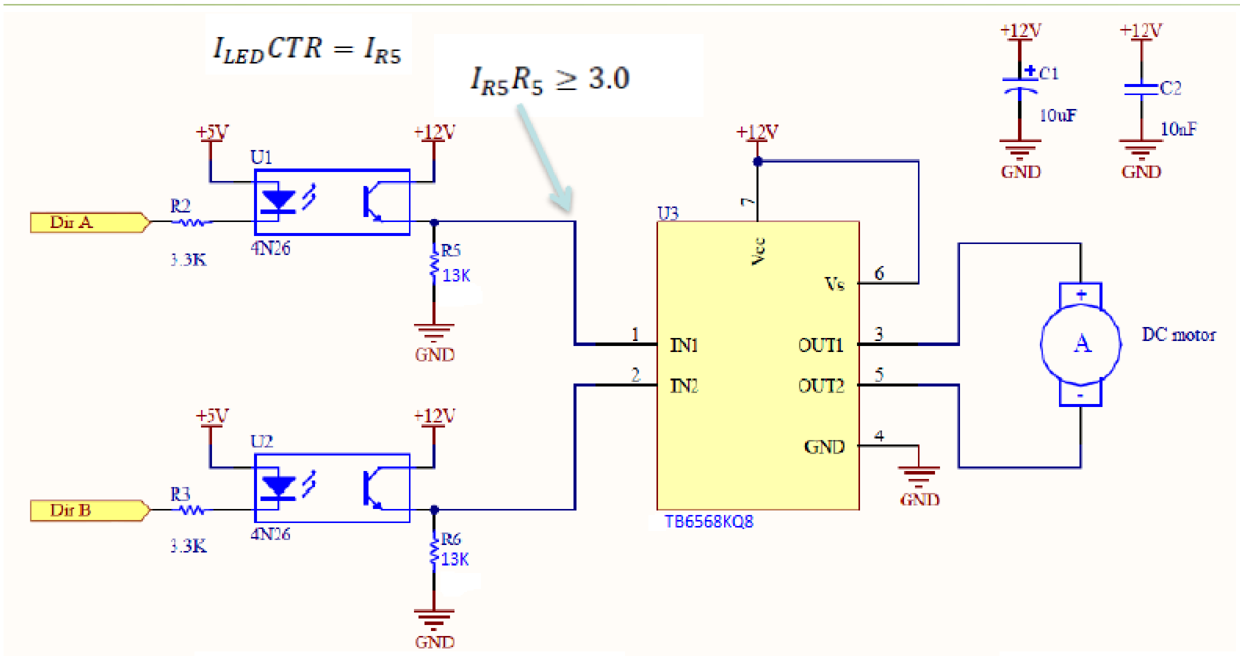


Figure 3: DC Motor Power Drive Design

By utilizing the equation

$$\frac{V_{cc} - V_{LED}}{R_2} CTR \geq \frac{3.0}{R_5} \quad (1)$$

We get the relationship

$$\frac{R_5}{R_2} \geq 3.5 \quad (2)$$

It should be noted capacitors C_1 and C_2 are used for voltage stabilization from the 12V source.

Electromagnet

We also followed the Electromagnet Drive Circuit Design shown in Fig. 2 to build the electromagnet control circuit.

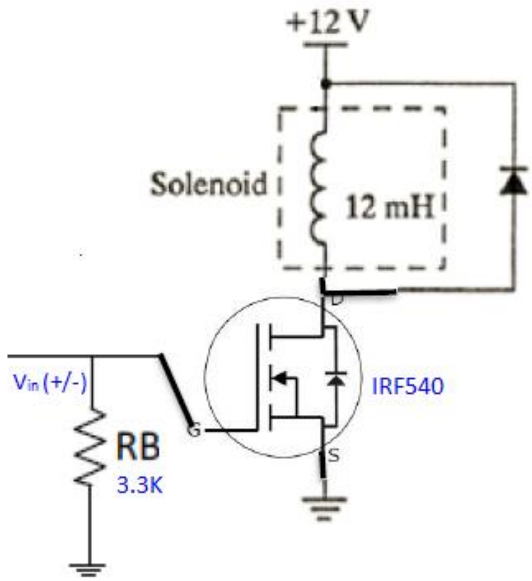


Figure 4: Electromagnet Drive Circuit

It should be noted by supplying a positive voltage to the MOSFET, it turns on allowing the solenoid in the electromagnet to be energized and once this supply voltage is cut-off the MOSFET turns off hence de-energizing the electromagnet. In reality, the MOSFET acts as a capacitor and even when disconnected from power will hold charge keeping the MOSFET temporarily on thus keeping the electromagnet energized. To prevent this from happening in our circuit for quick response, we add the resistor R_B to aid in power dissipation from the MOSFET.

Final circuit design and analysis

The final design for our protoboard can be seen below and the list of components used for the motor and electromagnet circuits can be seen in Table 3.

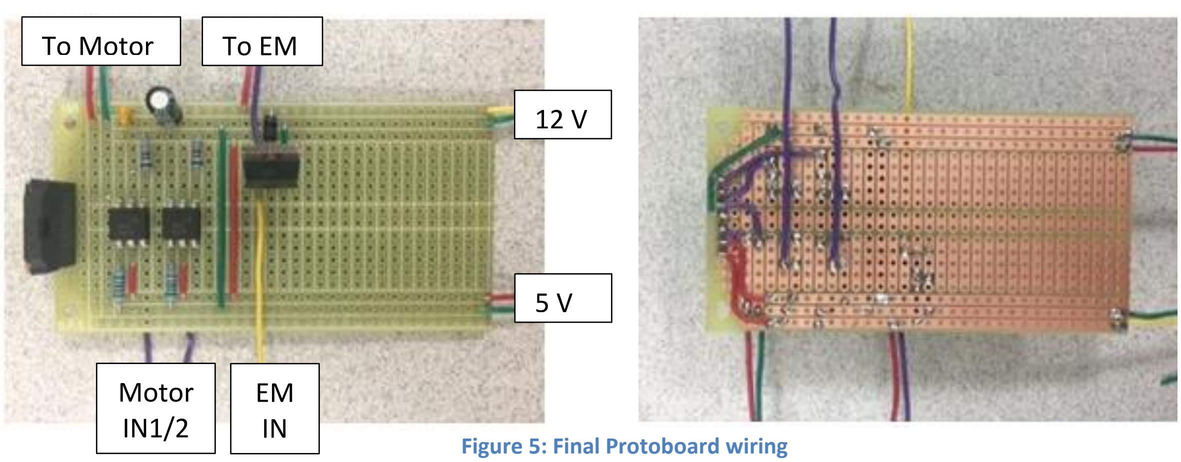


Figure 5: Final Protoboard wiring

Figure 6: Final Design of Motor and Electromagnet Circuit on Prototype Board

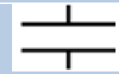
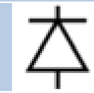
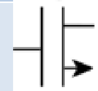
Name	Type	Value	Quantity	Symbol
R1	Resistor	13KΩ	2	
R2		3.3KΩ	3	
C1	Capacitor	10μF	1	
C2		0.1μF	1	
D1	Diode	0.7V (across)	1	
IRF540	MOSFET	n/a	1	
4N25	Opto-isolator	n/a	2	See Fig. 2
TB6568KQ	Full-Bridge DC Motor Driver IC	n/a	1	See Fig. 1

Table 3: Table of Components and measured values

Heat Sink Analysis

Most electronic circuits/chips have a specific temperature range of optimal operation and if exceeded, the circuit/chip can perform poorly or be destroyed thus compromising the integrity of any other circuit it is a part of. It was therefore necessary for us to study the bounds of operation of our device and design a heat sink around it should our analysis proof this as a necessity. The diagram below characterizes the thermal performance of our full-bridge DC motor IC driver.

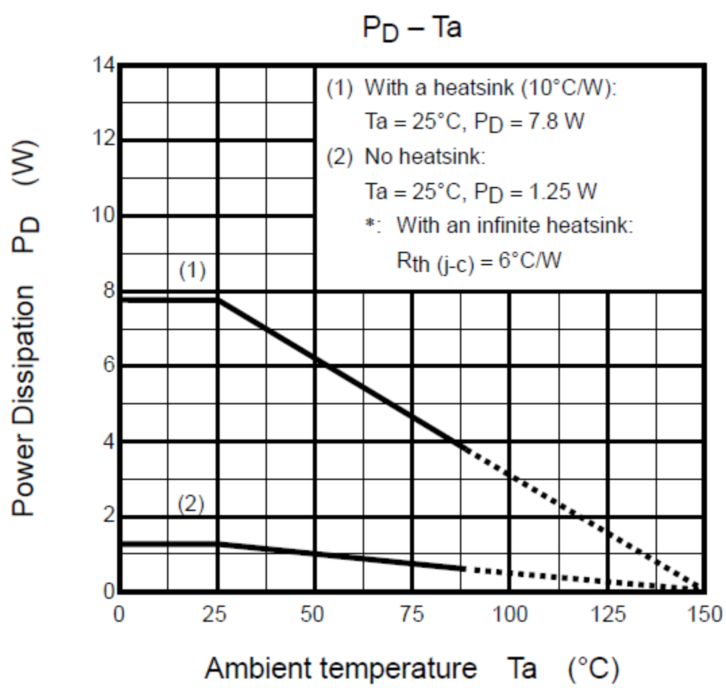


Figure 7: Thermal Characteristic of Full-Bridge DC Motor driver

From Fig. 7 we can extrapolate the following data:

Maximum allowable temperature:	150 ^oC
Ambient temperature:	25 ^oC
Power Dissipation (P_D):	1.25 W

$$T_{junction} - T_{ambient} = \theta_{Junction} * P_{Dissipation} \quad (3)$$

$$T_{ambient} + (\theta_{jc} + \theta_{ca}) * P_D < 150°C \ (Maximum\ allowable\ temperature) \quad (4)$$

$$T_{ambient} + (\theta_{jc} + \theta_{ca}) * P_D < 150°C \quad (5)$$

$$25 + (6 + \theta_{ca}) * 1.25 < 150°C \quad (6)$$

$$(6 + \theta_{ca}) < \frac{150 - 25}{1.25} \quad (7)$$

$$(\theta_{ca}) < 94°C/W \quad (8)$$

Area of Heat Sink = $(\frac{50}{\theta_{ca}})^2 = (\frac{50}{94})^2 = 0.28\ cm^2$

Given the size of the heat sink calculated, it is sufficient to ignore adding a heat sink to our device.

Measurement of Voltage/Duty Cycle

Clockwise		Counter clockwise	
Duty Cycle	**DC Voltage (V)**	**Duty Cycle**	**DC Voltage (V)**
20	3.5	20	-3.8
30	5.53	30	-5.43
40	7.2	40	-7.34
50	8.63	50	-8.9
60	9.5	60	-9.67
70	10.01	70	-10.31
80	10.34	80	-10.55

Table 4: Output Voltage vs. Duty Cycle from Full-Bridge Rotating Motor

Fig. 8 below shows the obtained graph from the measuring of the output voltage versus Duty cycle from the Full-bridge.

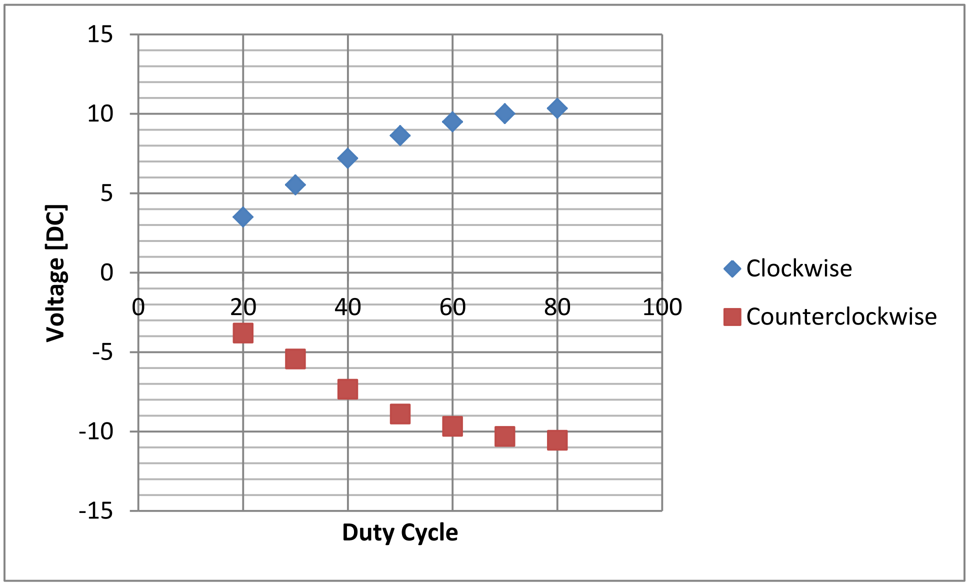


Figure 8: Voltage vs. Duty Cycle of Rotating DC Motor

Task Division

The step undertakes towards the deliverables for this project were divided as follows:

Tasks	Description
Circuit Design	With given circuit design, performed wiring validity and component substitution where needed.
Bread Board Testing	Team was subdivided into two: Team 1 (Ane Tendo, Zheng Wang) wired and tested electromagnet control circuit. Team 2 (Rame Sherro, Sohail Sangha) wired and tested motor control circuit.
Circuit Soldering, Testing & Data Collection	Component soldering and circuit testing done by respective sub teams on the same proto-board.
Report	Collective composition and editing performed by the group.

Table 5: Task Division

Conclusion

During the electrical part of this project we designed and built a circuit on a proto-board to drive and control a DC motor as well as an electromagnetic solenoid by using PWM signals. By varying the duty cycle and inverting the input of the PWM signal to the motor, we were able to change the speed of the DC motor and its direction respectively. We then performed heat sink calculations to ensure safe operations of our circuit at room temperature without overheating and determined it will without an additional heat sink. This project was very valuable to us as we were able to get hands on experience with electronic test equipment such as function generators, oscilloscopes and power supplies, as well as practice soldering.