Lab 6 – Motor Driver (WALL-E)

CSE 3323 – Electronics for Computer Engineering

In this lab, we will discuss and construct the components required for a simple 2-wheeled robot: H-Bridge control for motors, variable 555-timer PWM generators, current sense resistors, and automatic forward/reverse control without the use of microcontrollers.

Students work in pairs (except one group of 3) during lab time.

What you specifically should include in your lab report is detailed at the end of this document with due dates.

Lab reports are **individual work** but include your lab partner's name in your report.

Tools Used:

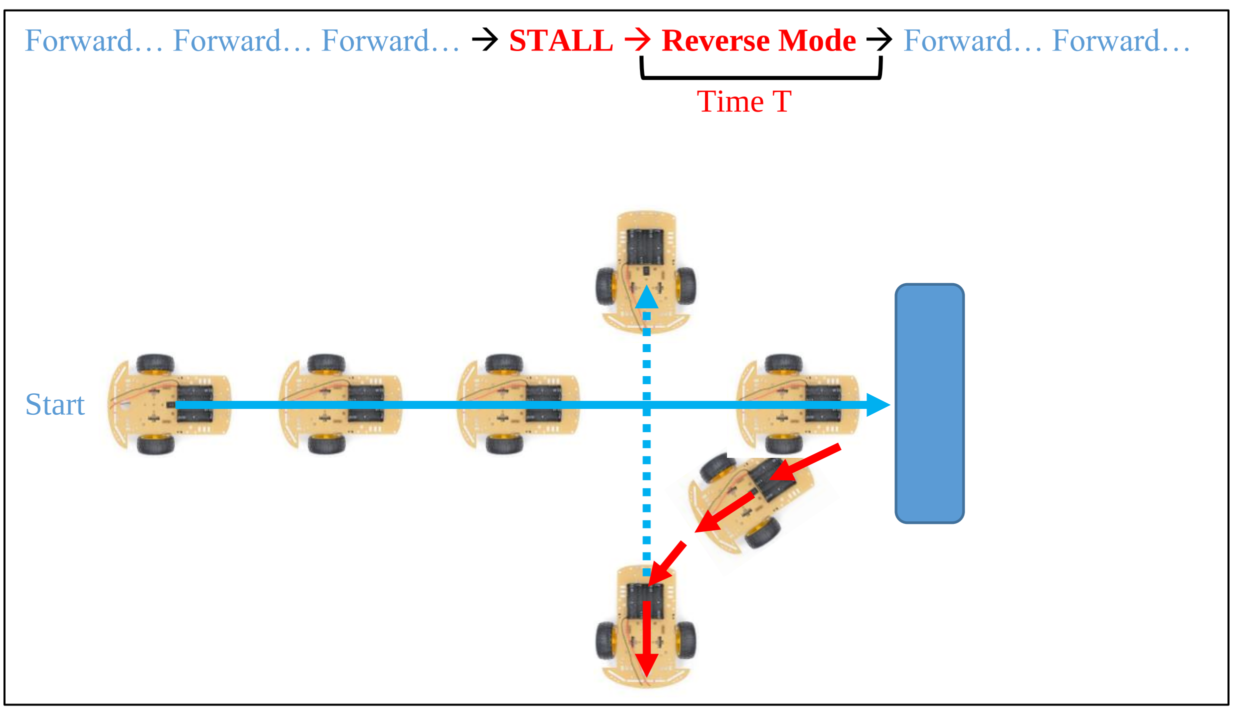
- **Digital Multimeters**
  - Thsinde 18B+ (yellow)
  - Mastech MS8268 (green)
- **Current-Limited Power Supplies**
  - DC Power Supply, Yihua YH-302D
  - DC Regulated Power Supply, Tekpower TP3005T
- **Digital Oscilloscope**
  - Siglent SDS 1202X-E, 200MHz
- **Wire cutters/strippers, probes, banana connectors, alligator clips, jumper wires, etc.**

Components Used:

No components are listed in this document, instead they are organized in a separate **Bill of Materials** document on Blackboard named **"BOM_Motor_Driver.pdf"**

Directed Part of Lab:

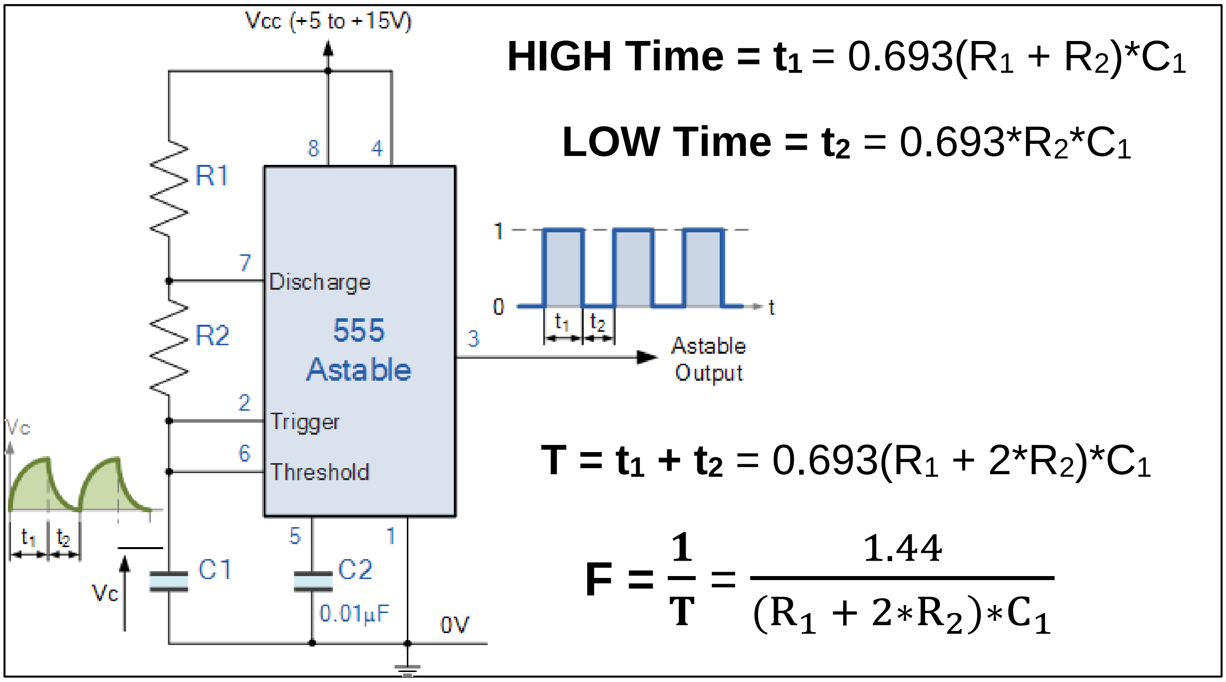
1. **WALL-E Requirements**
    a. No programmable logic (i.e. no microcontrollers)
    b. Complete circuit is mobile and battery-powered
    c. User can toggle the battery power ON and OFF
    d. Two separate motors control two separate wheels
    e. When the robot is powered ON, the wheels start rotating in the **FORWARD** direction (and the GREEN LED is turned ON)
    f. When the robot hits an obstacle or wall, the circuit will detect that the motors are stalled and automatically go into **REVERSE** Mode
    g. **REVERSE** Mode turns ON the RED LED and both motors/wheels begin rotating in the opposite direction to free itself from the obstacle
    h. In **REVERSE** Mode the motors should rotate at different speeds so it can turn away from the obstacle when it is backing up
    i. After a certain amount of time the circuit goes back into normal **FORWARD** Mode indicated by turning back ON the GREEN LED
    j. The user should be able to set and adjust the speed of each motor in the forward and reverse directions
    k. The user should be able to also set how long the robot stays in the **REVERSE** Mode before returning to normal forward motion



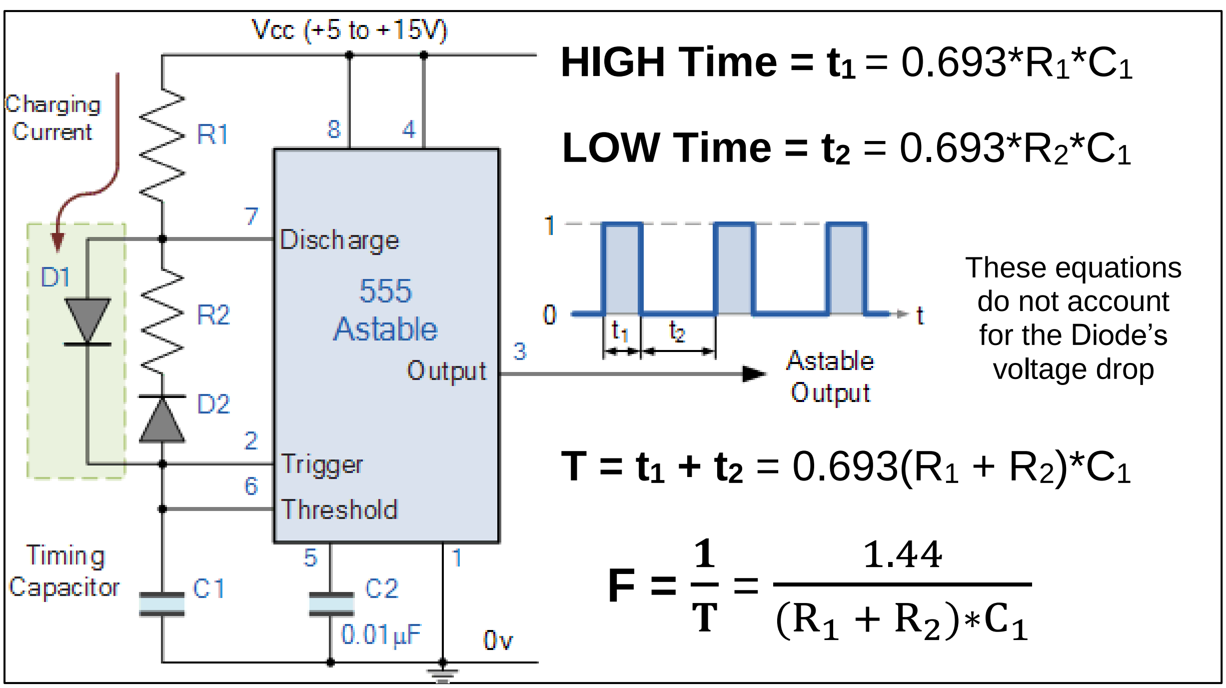
2. **Astable and Monostable 555-Timer Configurations**

a. **Normal Astable Mode**

From: https://www.electronics-tutorials.ws/waveforms/555_oscillator.html

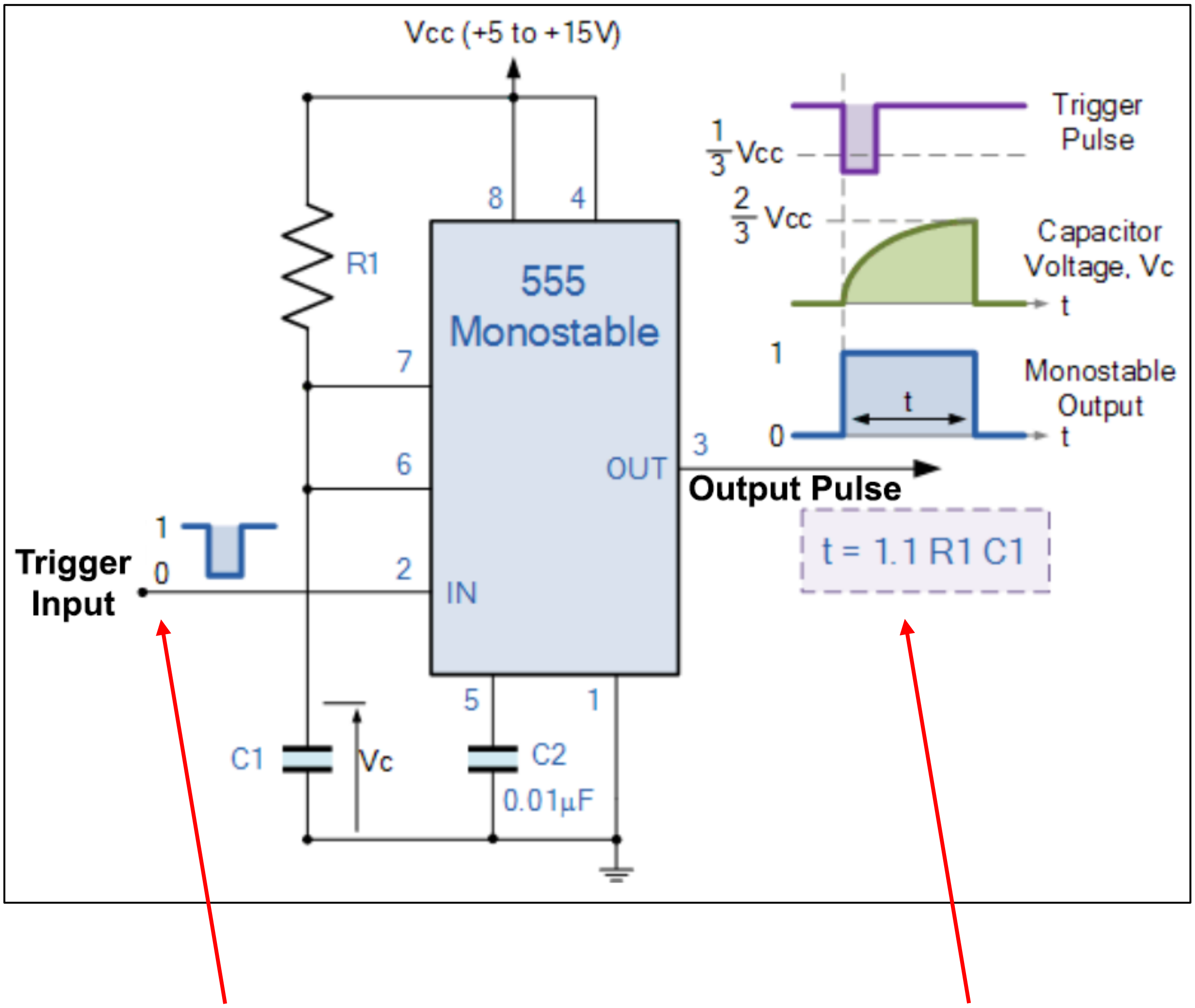


b. **Modified Astable Mode (Greater Duty Cycle Range)**



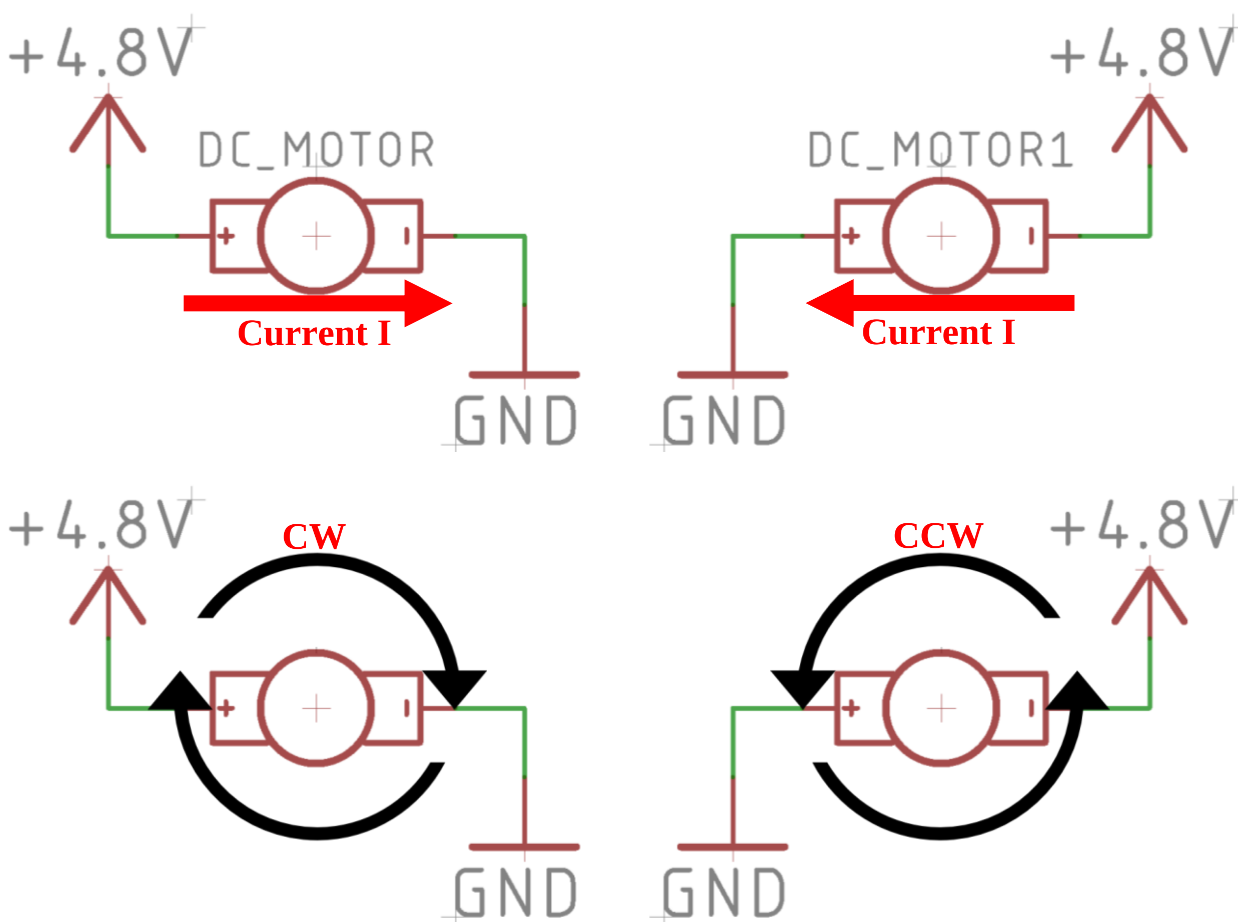
c. **Normal Monostable Mode**

From: https://www.electronics-tutorials.ws/waveforms/555_timer.html

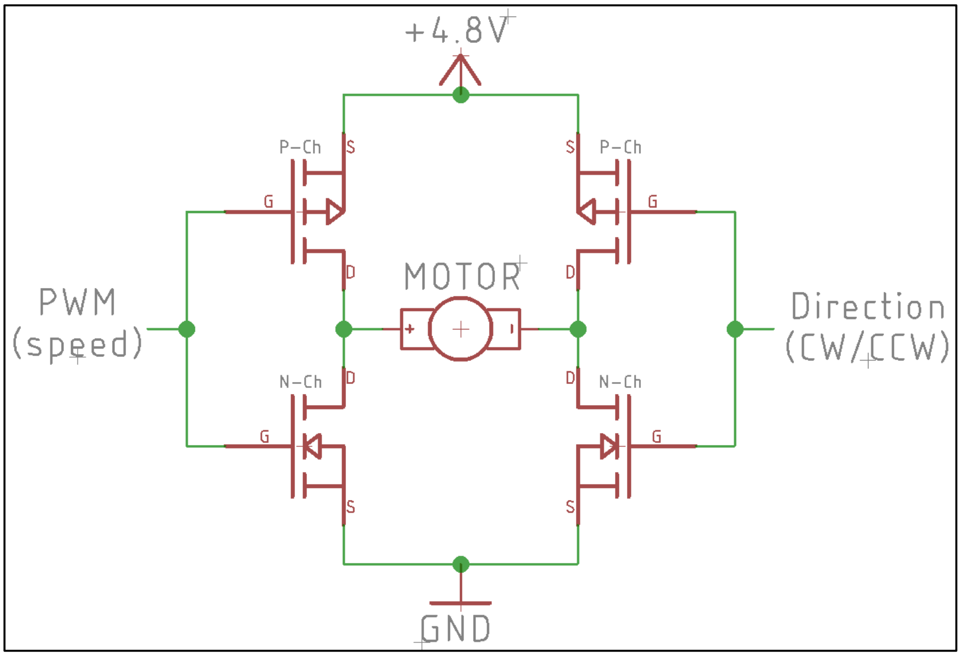


Make a Quick Input Pulse turn into a Long Output Pulse

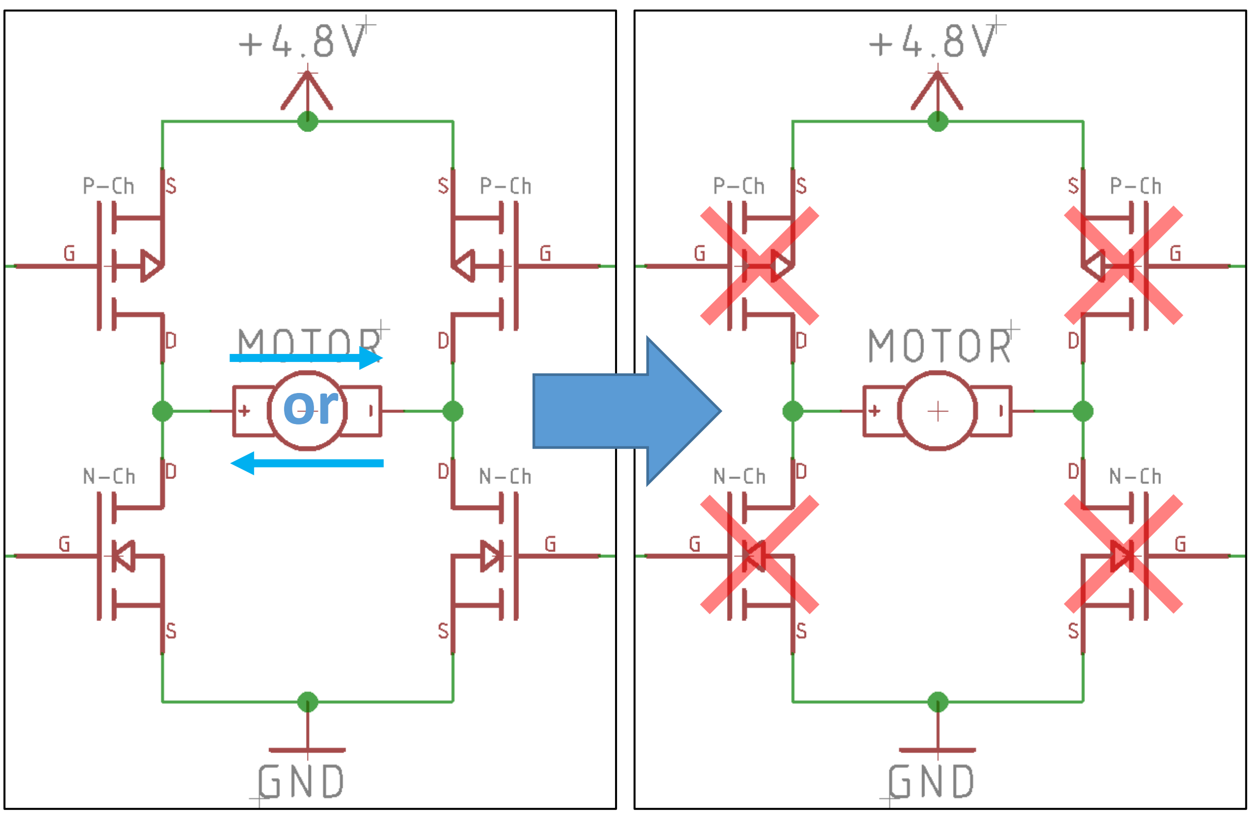
3. **DC Motor Basics**
    a. When you place a large enough voltage (potential difference) across the terminals of a DC motor, it automatically begins to rotate in one direction. If you reverse the polarity of the voltage, the motor rotates in the other direction. If you can limit or vary the voltage below its nominal or rated voltage, then you can control the rotational speed of the motor since you are essentially controlling the amount of current the motor has to utilize.
    b. You do not have to provide current-limiting protection for simple DC motors (like you have to do with LEDs). DC Motors only draw the current they require to meet their rotational needs.
    c. If nothing is obstructing or resisting the rotating shaft, then the motor should rotate at a constant speed (RPM) and draw a somewhat constant current.
    d. When some type of resistance or friction slows the shaft's rotational speed, the motor will try to overcome this by drawing more current to compensate.
    e. If the shaft is completely forced to stop rotating (STALLED) then the motor will draw maximum current trying to fight against the shaft resistance.
        i. If the max stalled current is very high, then you should implement automatic power cutoff or reduction in your circuit to avoid power supply damage (or blowing batteries).



4. **H-Bridge for Bi-Directional Motor Control and Speed Control**



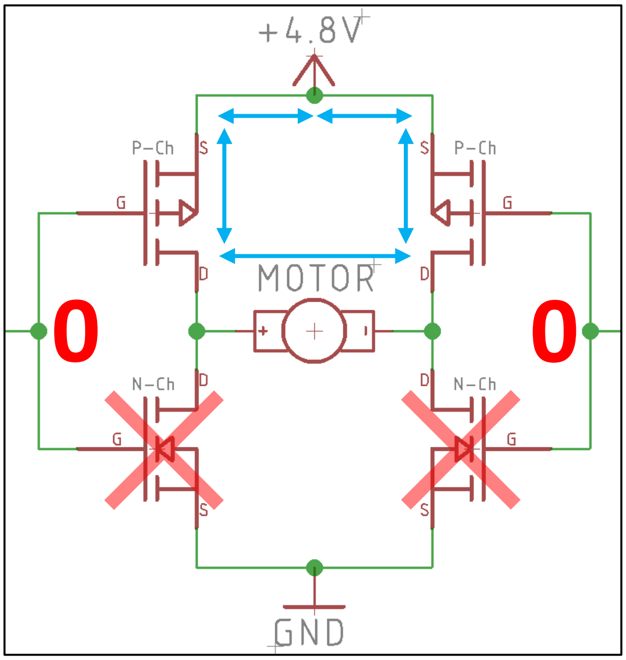
Coast or Roll-off State



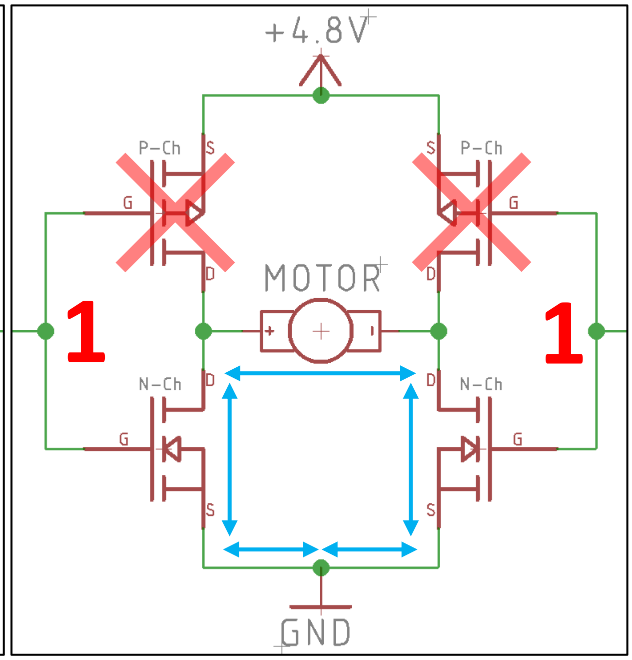
If the Motor is rotating (either direction) and then all MOSFETs turn OFF, then the Motor is now “floating” and the Motor will dissipate its local energy and slowly come to a stop

Note: 0 = 0.0V and 1 = +4.8V for this example

Stopped



Stopped



No voltage difference across the Motor (same potential on motor terminals) in both cases

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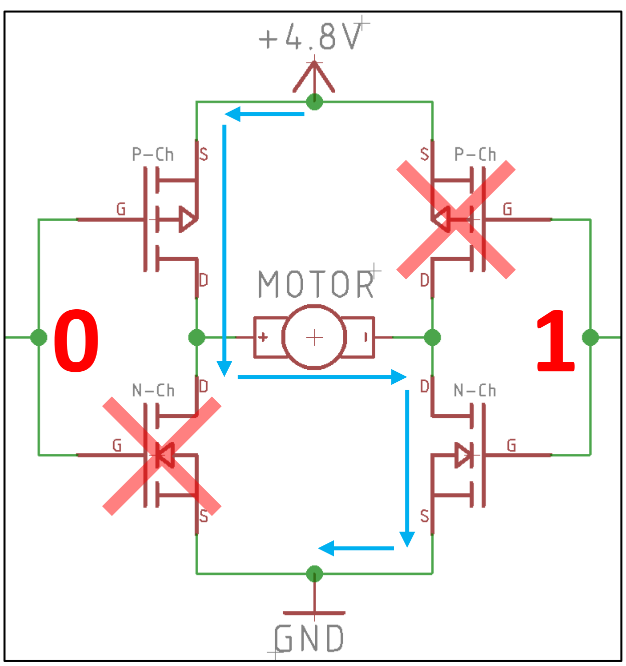
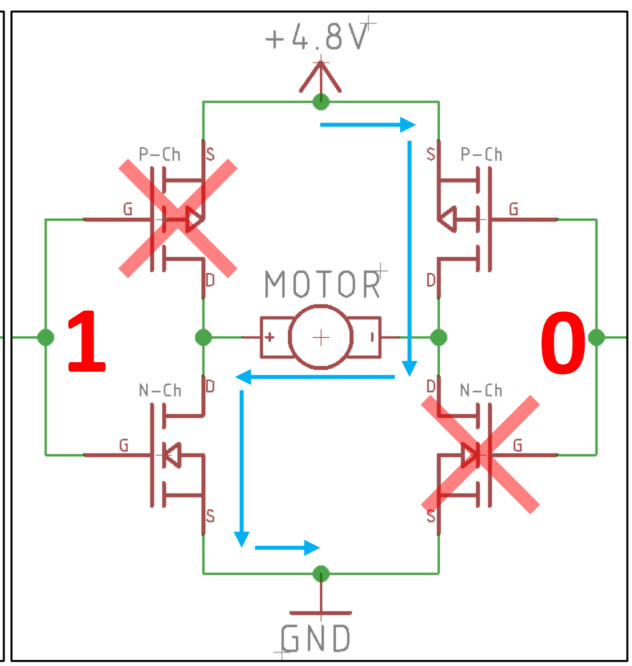
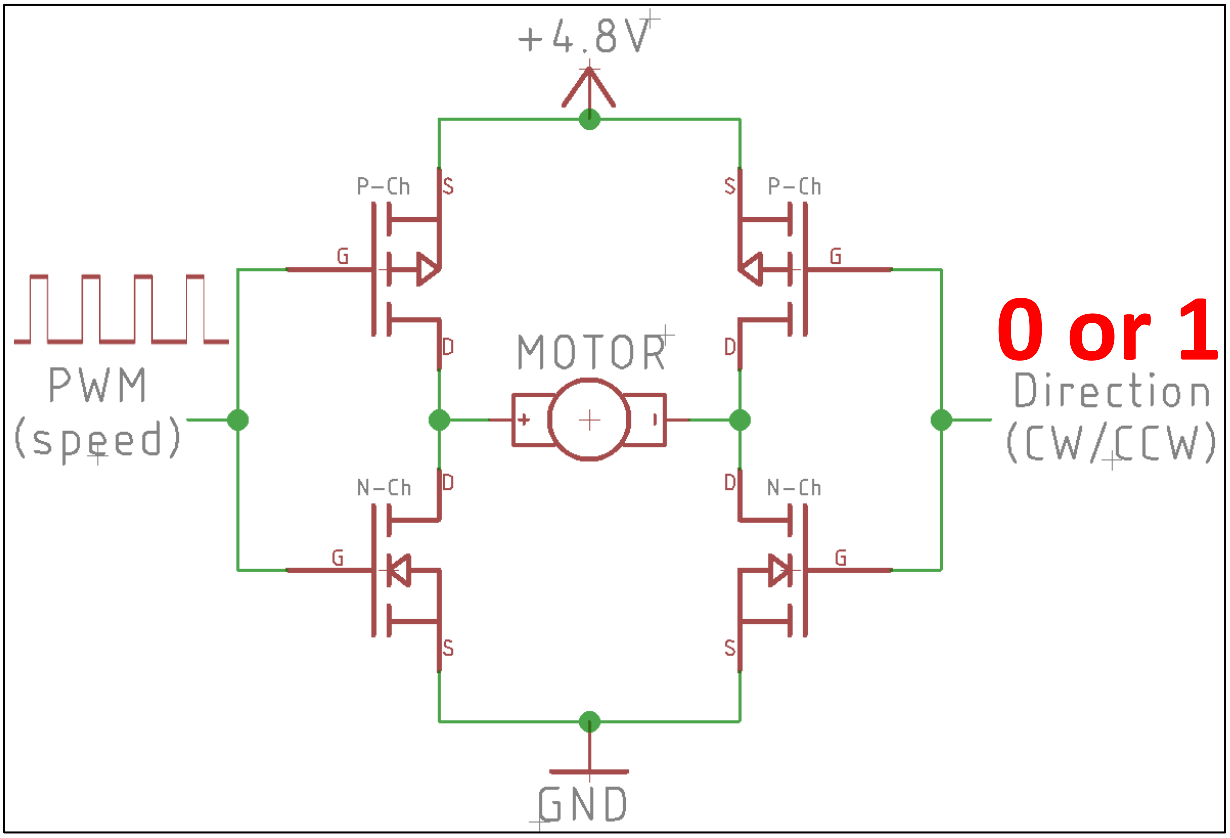
Clockwise (CW)



Counterclockwise (CCW)

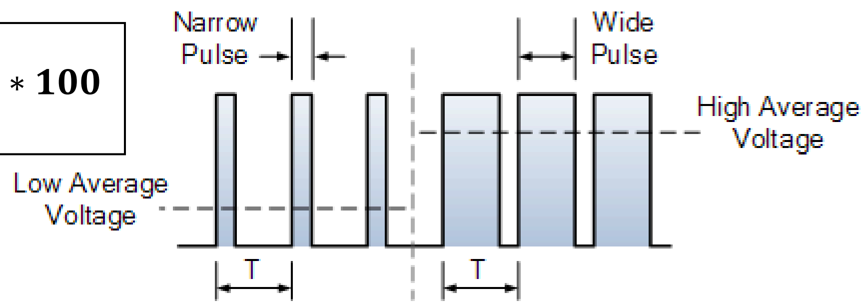


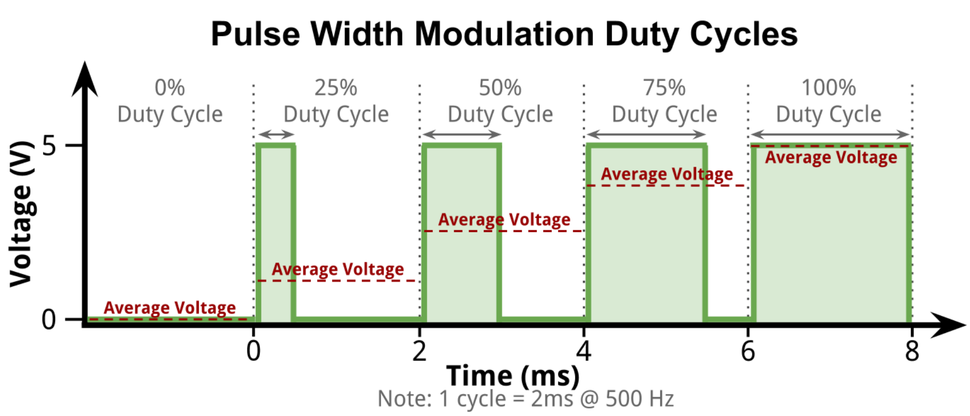
Motor now sees different voltage levels (potentials) across its terminals and rotates



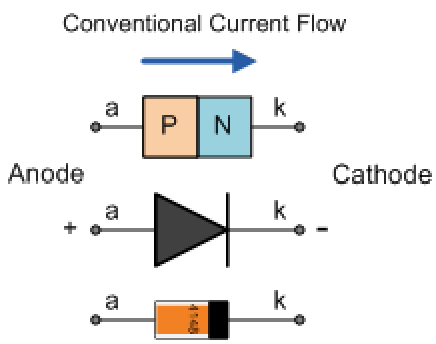
Due to the PWM signal, the Motor will see an "Average Voltage" across it and if you vary a Motor's voltage it changes its rotational speed (RPM). To change the "Average Voltage" you need to change the <u>Duty Cycle</u> of your PWM signal.

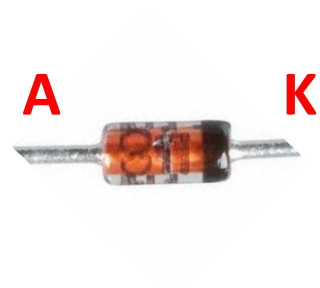
$$DC\% = \frac{T_{High}}{T_{High} + T_{Low}} * 100$$

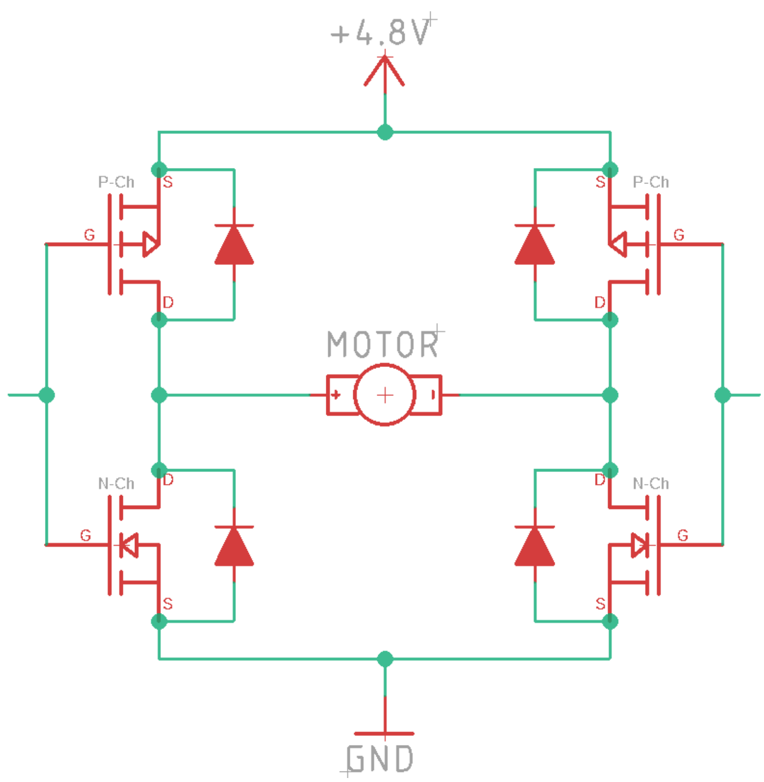




5. **Flybak Diodes** (also called Freewheeling Diodes or Snubber Diodes)
    a. When an inductor (i.e. a motor) is suddenly deprived of current by a switch opening or a MOSFET turning off, the inductor resists the current drop by creating a large voltage. This voltage spike can be extremely large and can damage other components and power supplies if not properly handled.
    b. Flyback diodes provide the inductor (motor) a “route or path” for its stored energy to travel. Allowing the current to flow drastically reduces the voltage spike and protects other components.
    c. For an H-Bridge, we use 4 diodes to protect the MOSFETs and the motor itself. If one side of the motor has a very high voltage spike, the diodes provide a path for the energy to loop through and dissipate throughout the larger circuit’s power connections. The diodes do not negatively affect the H-Bridge for normal operation, since they only conduct current in 1 direction.



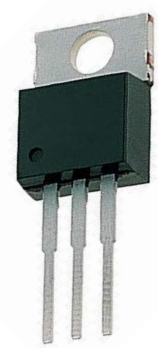




6. **Power MOSFETs**
    a. When using MOSFETs in an H-Bridge that contains a motor, you can't simply pick any random MOSFET to do the job. In an H-Bridge, the MOSFETs are directly in the path of current that the motor draws. If 1Amp goes through the motor, then 1Amp goes through the MOSFETs.
    b. If you use a regular transistor that can't handle the current/power, then you'll have smoke and fire.
    c. Power MOSFETs are a special subset of FETs that are specifically designed to handle large current levels. They usually have a protruding metal backing (TAB connected to Drain) that can easily be attached to a Heat Sink if required to help dissipate heat and prevent MOSFET damage.
    d. Normal Gate/Drain/Source pin control applies the same as they did with the low power logic-level MOSFETs.
    e. Reference the datasheets of our Power MOSFETs to learn their pinouts.

Small Signal
Low Power MOSFET

(TO-92 Package)



Power MOSFET

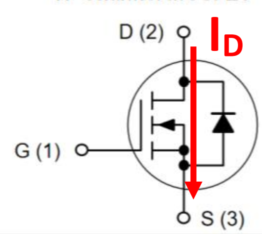
(TO-220 Package)

ABSOLUTE MAXIMUM RATINGS (T_J = 25°C unless otherwise noted)

Parameter	Symbol	NDD	NDT	Unit
Drain−to−Source Voltage	V_{DSS}	400		V
Gate−to−Source Voltage	V_{GS}	±20		V
Continuous Drain Current $R_{\theta JC}$ Steady State, T_C = 25°C (Note 1)	I_D	1.7	0.4	A
Continuous Drain Current $R_{\theta JC}$ Steady State, T_C = 100°C (Note 1)	I_D	1.1	0.25	A
Power Dissipation – $R_{\theta JC}$ Steady State, T_C = 25°C	P_D	39	2.0	W
Pulsed Drain Current	I_{DM}	6.9	1.6	A

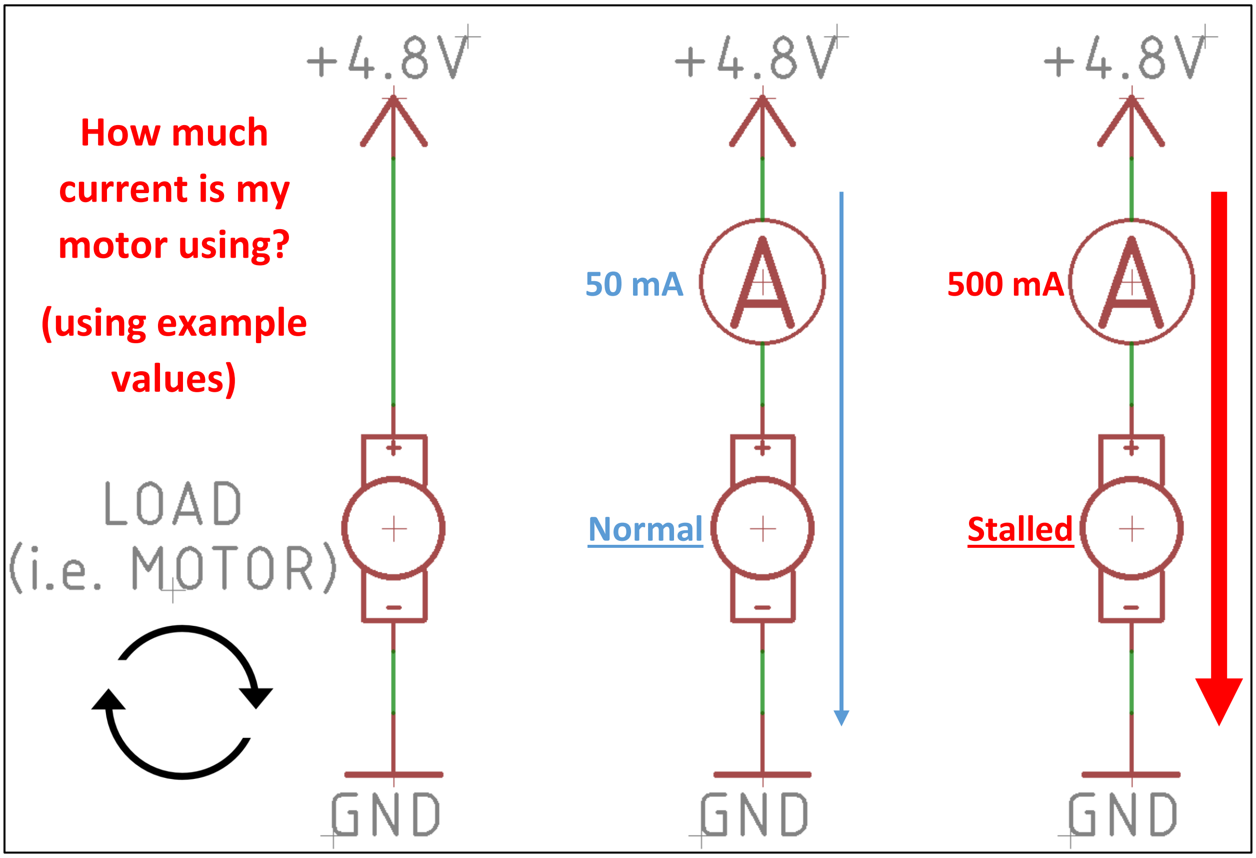
$V_{(BR)DSS}$	$R_{DS(ON)}$ MAX
400 V	5.5 Ω @ 10 V

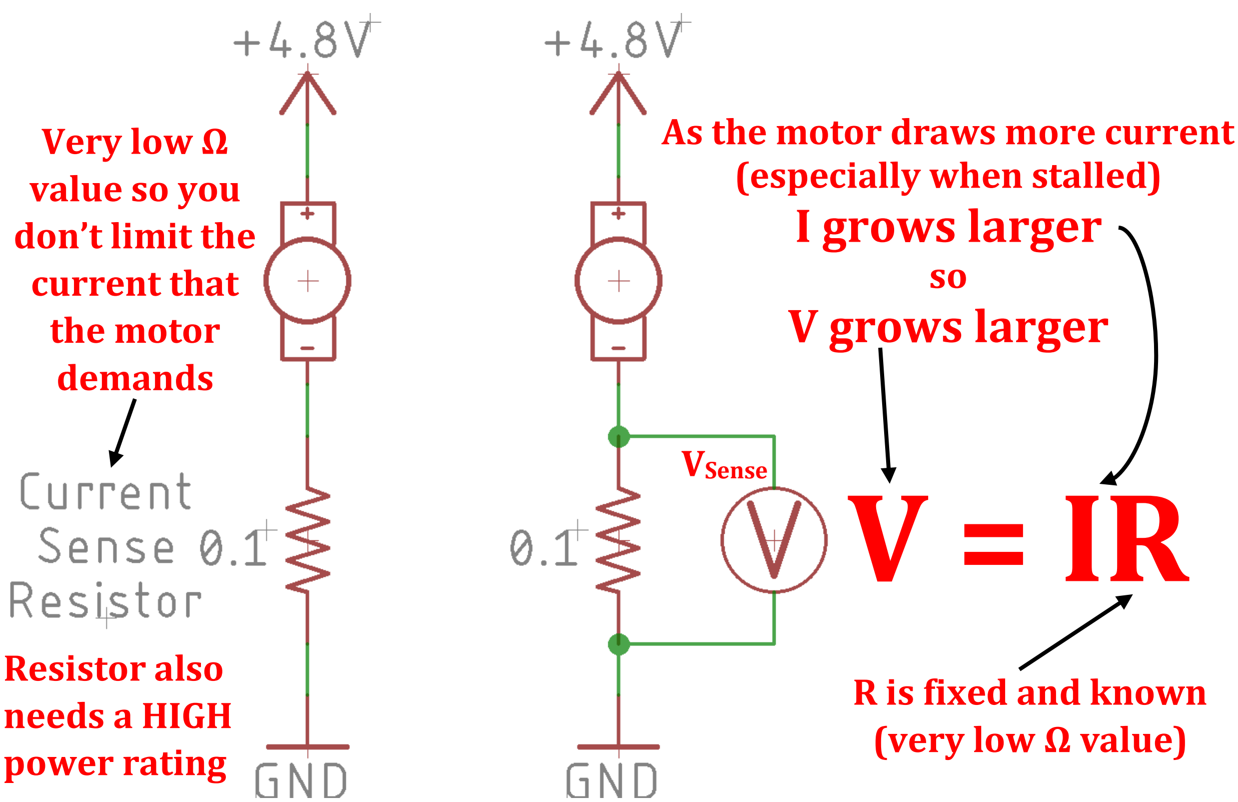
N−Channel MOSFET



MARKING DIAGRAMS

7. **Current Sensing** (using Current Sense Resistors)





Individual Part of Lab:

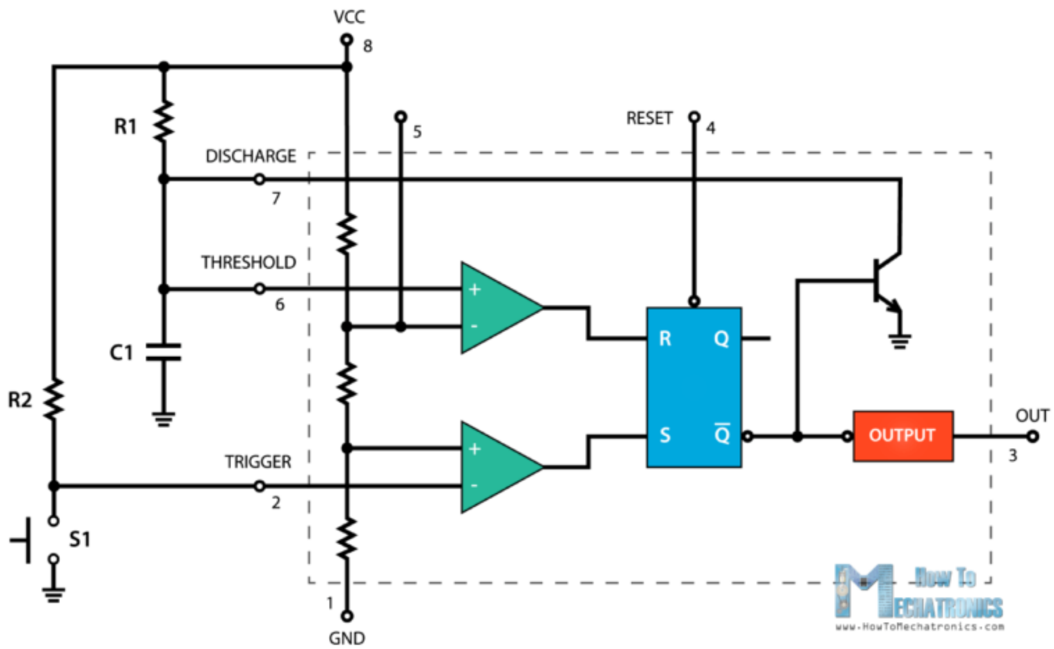
1. **Breadboard** (Work in Pairs)
   a. Breadboard the circuit **"Motor_Driver.sch"**
   b. All components are included in the SCH but there are **13 missing connections** intentionally left disconnected. You need to determine how to finish up wiring the circuit to make it function correctly.
   c. **Demo your working circuit when it is fully complete**

Additional Submission Details:

1. **Part 1** (Due 4/19/2019) - **Lab Report (.pdf)**
   a. Perform the Astable and Monostable calculations for the 555-timers. Using the exact circuit layout and component values shown in the Motor schematic show all of the math for calculating the following...

Astable Mode			Monostable Mode	
5k POT Setting	**Output Frequency**	**Output Duty Cycle %**	**100k POT Setting**	**Output Pulse HIGH Time**
0%	**?**	**?**	**0%**	**?**
25%	**?**	**?**	**25%**	**?**
50%	**?**	**?**	**50%**	**?**
75%	**?**	**?**	**75%**	**?**
100%	**?**	**?**	**100%**	**?**

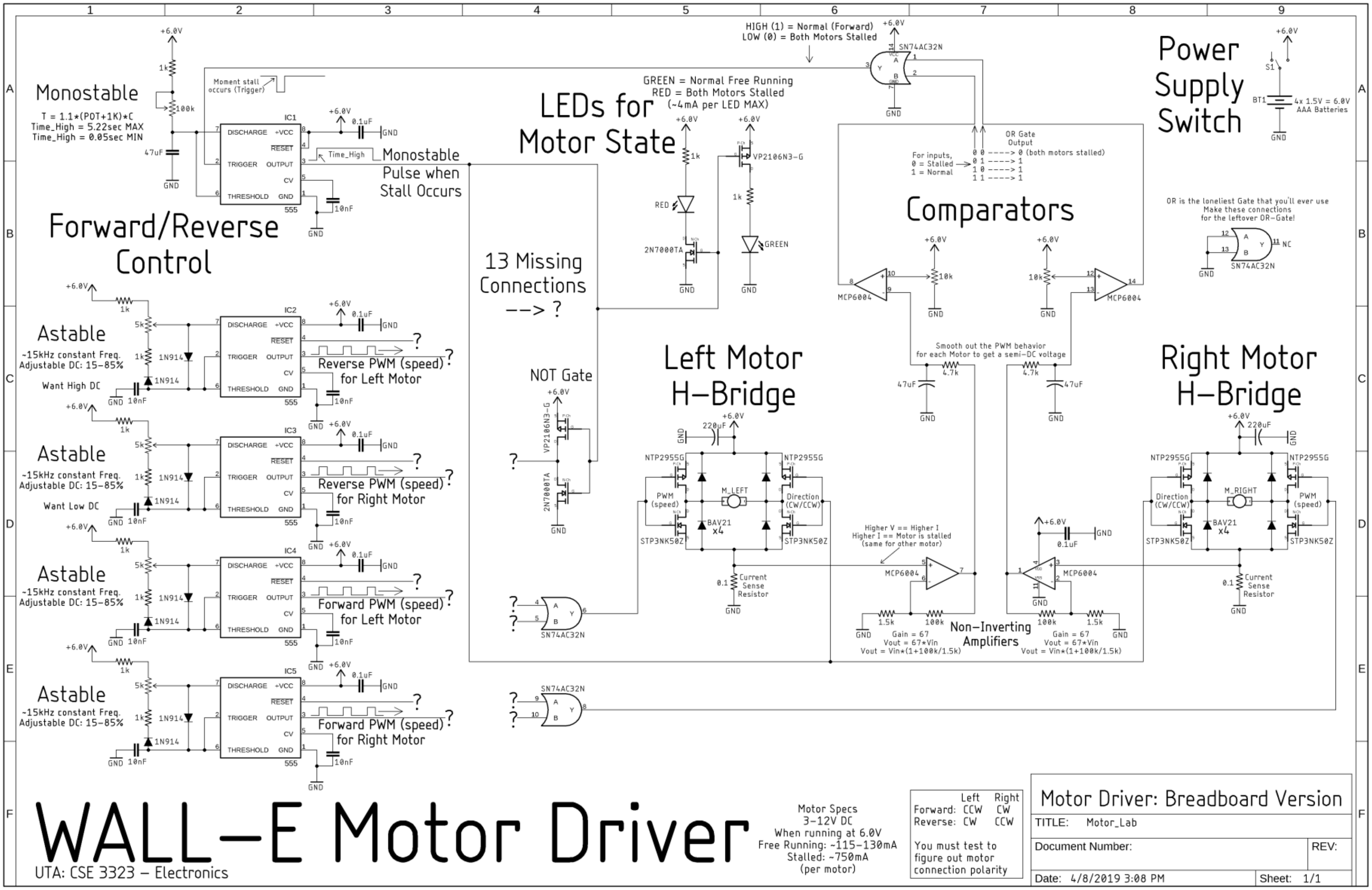
   b. Using a detailed image of a 555-timer (below), explain IN DETAIL how Monostable Operation works. Use a combination of text, drawings, input vs. output graphs, etc. to thoroughly explain the internal operation when the switch S1 is pressed, what the output looks like, and what happens in between to create the output.



2. **Part 2** (Due 4/26/2019) - **Lab Report (.pdf)**
   a. Explain the roles of the "Non-Inverting Amplifiers" and the "Comparators".
      i. What purpose do they serve for this circuit?
      ii. List and discuss measurements taken of the input of the amplifiers, the output of the amplifiers, the smoothing RC segment, the input to each opamp comparator, and the output of each comparator.
      iii. **Explain in detail. Be sure to take measurements during lab time.**

   b. When the Motors/H-Bridges are fully implemented make the following measurements and include them in your report…
      i. Current drawn by LEFT motor in normal CW rotation (max speed)
      ii. Current drawn by LEFT motor in normal CCW rotation (max speed)
      iii. Current drawn by LEFT motor when it is fully stalled
      iv. Current drawn by RIGHT motor in normal CW rotation (max speed)
      v. Current drawn by RIGHT motor in normal CCW rotation (max speed)
      vi. Current drawn by RIGHT motor when it is fully stalled

3. **Part 3** (Due by end of lab 4/26/2019) – **Demo in Lab**
   a. If you successfully implement and demo the working robot, you will receive a grade of 100% for the Part 3 lab grade.



Monostable
T = 1.1*(POT+1K)*C
Time_High = 5.22sec MAX
Time_High = 0.05sec MIN
Moment stall occurs (Trigger)
Monostable Pulse when Stall Occurs
Forward/Reverse Control
Astable
~15kHz constant Freq.
Adjustable DC: 15-85%
Want High DC
Want Low DC
Reverse PWM (speed) for Left Motor
Reverse PWM (speed) for Right Motor
Forward PWM (speed) for Left Motor
Forward PWM (speed) for Right Motor
13 Missing Connections --> ?
NOT Gate
LEDs for Motor State
GREEN = Normal Free Running
RED = Both Motors Stalled
(~4mA per LED MAX)
HIGH (1) = Normal (Forward)
LOW (0) = Both Motors Stalled
For inputs,
0 = Stalled
1 = Normal
OR Gate Output
0 0 ----> 0 (both motors stalled)
0 1 ----> 1
1 0 ----> 1
1 1 ----> 1
Comparators
Smooth out the PWM behavior for each Motor to get a semi-DC voltage
Power Supply Switch
4x 1.5V = 6.0V AAA Batteries
OR is the loneliest Gate that you'll ever use
Make these connections for the leftover OR-Gate!
Left Motor H-Bridge
Right Motor H-Bridge
Current Sense Resistor
Higher V == Higher I
Higher I == Motor is stalled
(same for other motor)
Non-Inverting Amplifiers
Gain = 67
Vout = 67*Vin
Vout = Vin*(1+100k/1.5k)
WALL-E Motor Driver
UTA: CSE 3323 - Electronics
Motor Specs
3-12V DC
When running at 6.0V
Free Running: ~115-130mA
Stalled: ~750mA
(per motor)
Left Right
Forward: CCW CW
Reverse: CW CCW
You must test to figure out motor connection polarity
Motor Driver: Breadboard Version
TITLE: Motor_Lab
Document Number:
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Date: 4/8/2019 3:08 PM
Sheet: 1/1