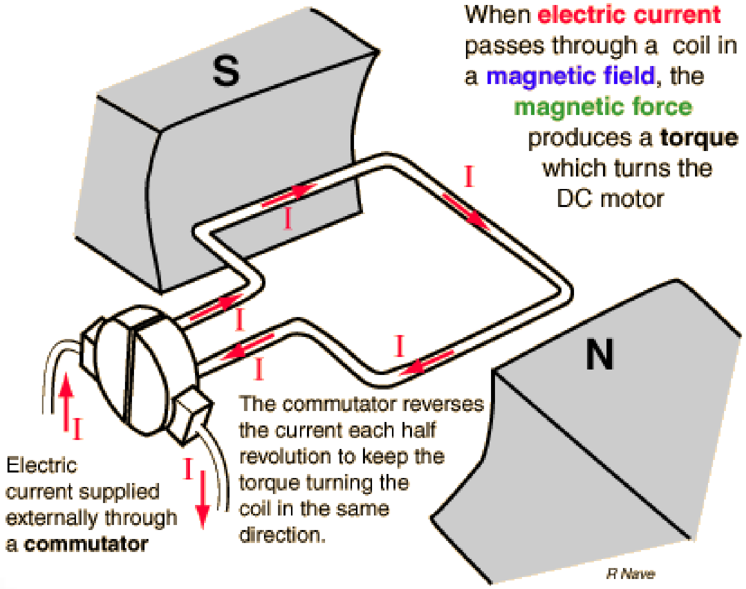
DC Motors

How DC Motor Works

Lorentz's Law

$$\vec{F} = \vec{I}L \, x \, \vec{B}$$

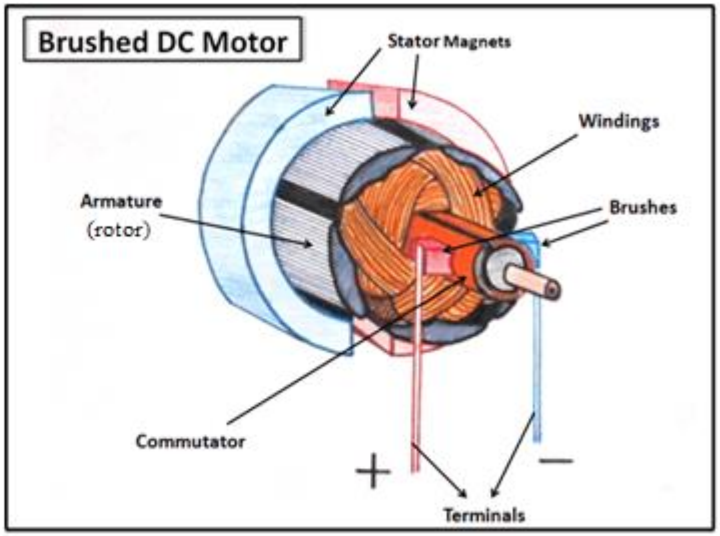
Force on straight wire of length L



Magnetic field lines travel from North to South. Using F=IL x B, the left side of the loop experiences an upward force while the right side experiences a downward force causing the rotor to spin.

The commutator causes the current to switch directions so that the current always travels in a clockwise fashion.

Brushed DC Motor Parts



Stator: Stationary part of motor. Usually just consists of the field magnet.

Rotor: Rotating part of the motor.

Armature: Coil to create alternating magnetic field. Always consist of coil windings and typically includes laminated steel to enhance magnetic field (laminated to prevent eddy currents). It is essentially an electromagnet.

Field Magnet: Creates a magnetic field to oppose or attract magnetic field in armature. Can be a permanent magnet or an electromagnet.

Brushes: Points at which the DC terminals make contact with the rotor.

Commutator: Device for reversing the direction of the current. Makes DC into AC.

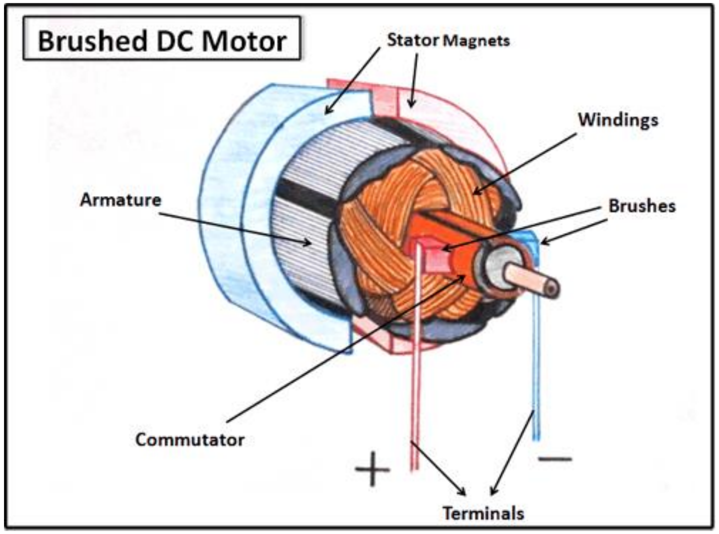
Armature Winding

https://www.youtube.com/watch?v=YUK_G2mL9_w

Great Explanation of How a DC Motor Works

https://www.youtube.com/watch?v=LAtPHANEfQo - pause at 2:35

Brushed & Brushless DC Motors



Brushed DC motors are usually built like the picture in this slide. The armature coils are part of the rotor (on the inside).

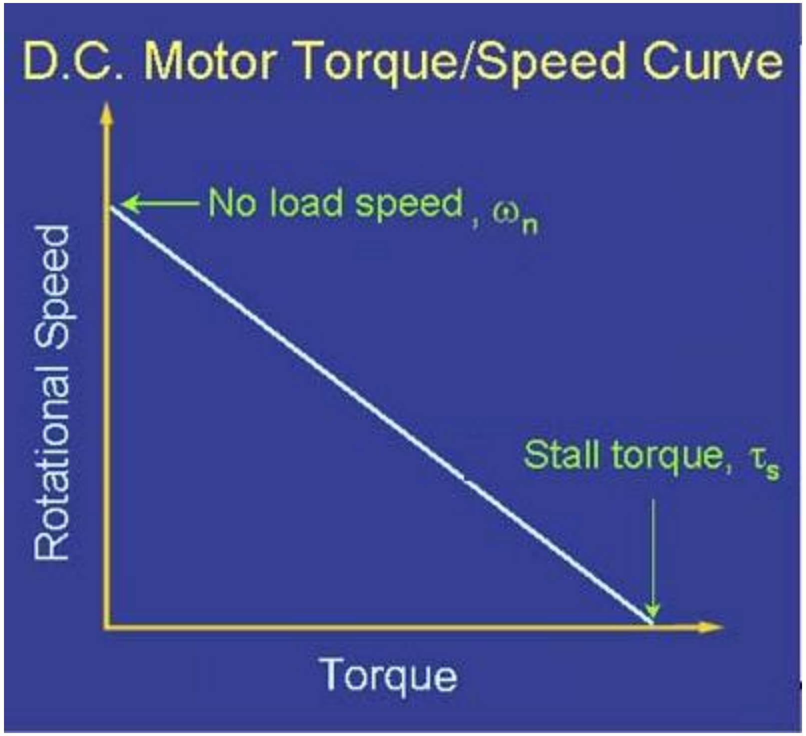
Brushless motors have the armature coils on the stator (on the outside) that causes a permanent or electromagnet to spin. Therefore, there must be a pulsed DC source to sequence the outside coils.

We'll go into more detail on brushless DC motors in a future lecture.

DC Motors Characteristics

- Very Fast (maximum speeds are typically 3000 to 8000 RPM)
- Polarity sensitive
- Two leads
- Usually uses 1.5 V to 24 V (12 V is the most common)
- Usually inexpensive.
- Not usually used for torque (unless geared and many of these motors are geared) or position controlled applications.
- Can increase speed by increasing voltage or current, but it's more efficient to control speed with pulse width modulation (PWM). Therefore, duty cycle could control speed.
- Without a load, motors draw little current. Adding a load can increase drawn current by 10 times!

Motor Torque vs. Speed



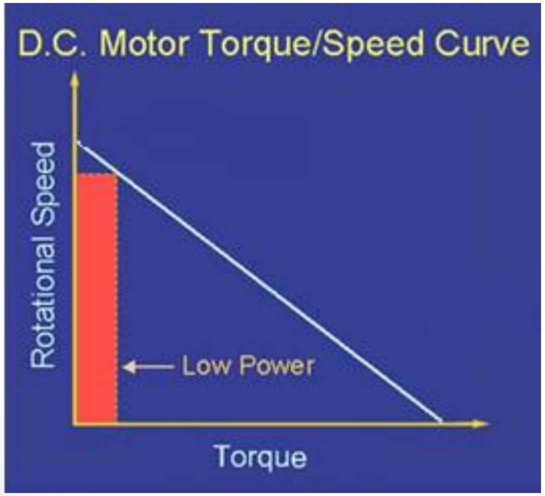
Torque and speed are inversely proportional. High torque = slow speed.

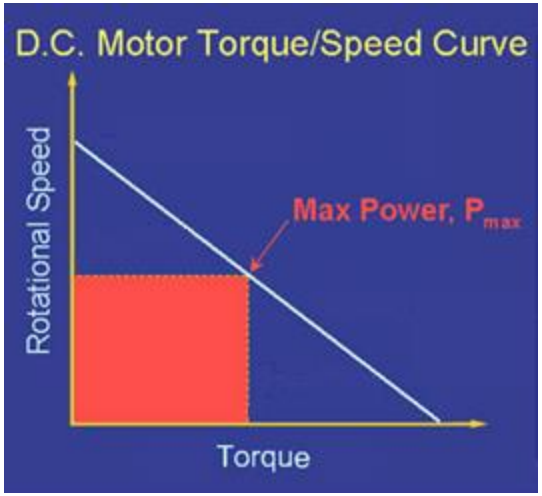
Stall torque happens when the load is so heavy that the motor no longer spins. No load speed can be thought of as the maximum speed of the motor.

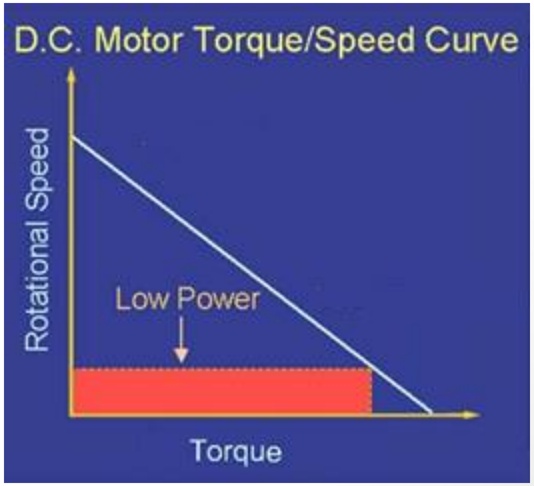
Motor Power

$P = \tau * \omega$

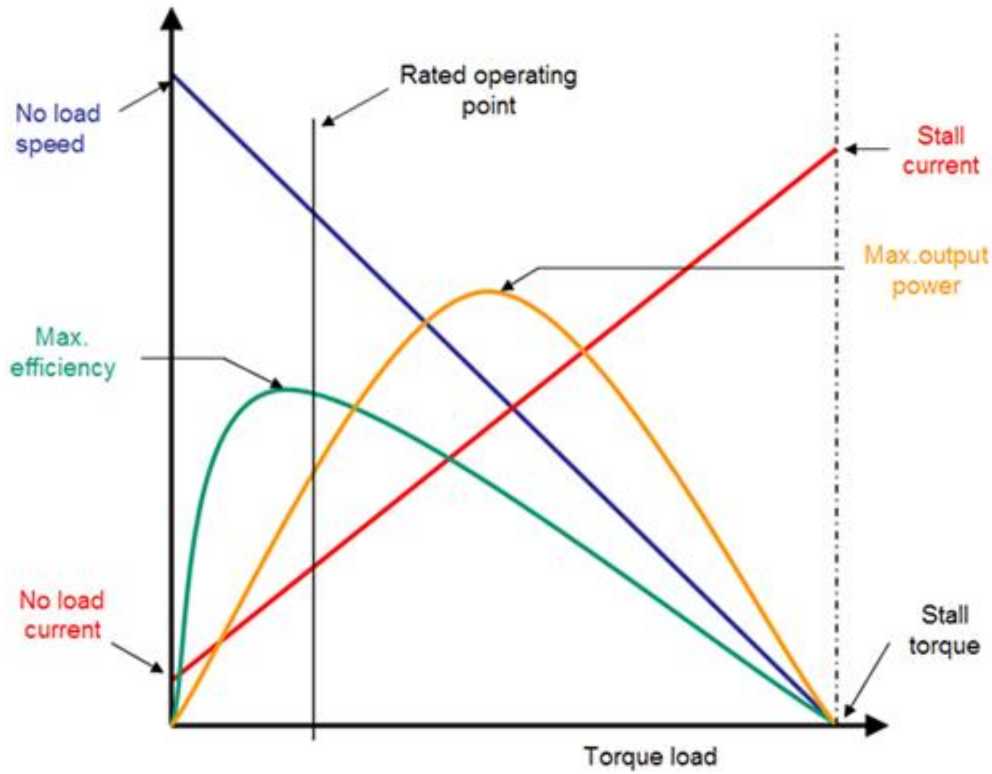
Maximum power occurs when you are at ½ of the stall torque and ½ of the motor's maximum angular velocity.







Motor Characteristics



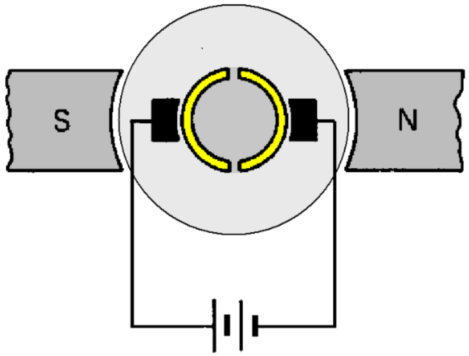
Notice that the motor runs the most efficient when a slight load is added and the speed is around 85% its maximum speed.

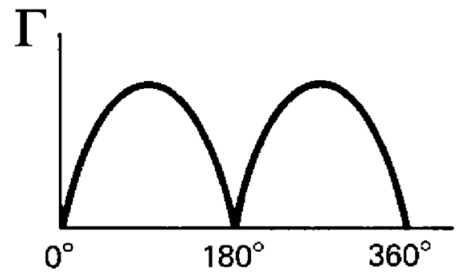
Also notice that current increases with larger loads.

Some Motor Specifications

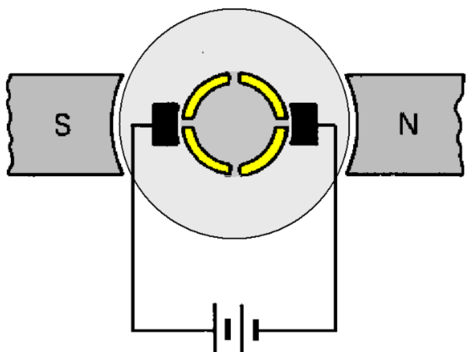
- Stall Current: Amount of current drawn when a load applied and is big enough to stop the motor from rotating.
- Starting Current: Amount of current required to start the shaft spinning. Can be 20x nominal current.
- Peak (Stall) Torque: Amount of torque applied when the motor shaft is stalled due to a large load.
- Full-load (Rated) Torque: Maximum amount of torque that the motor can handle before it decreases rapidly in performance and starts to slip. This value is less than peak torque.
- RPM: Revolutions per minute when the motor is fully loaded.
- No-Load (Max) Speed: Speed of shaft when no load is attached.
- Efficiency: Ratio of mechanical horsepower to incoming electrical power.

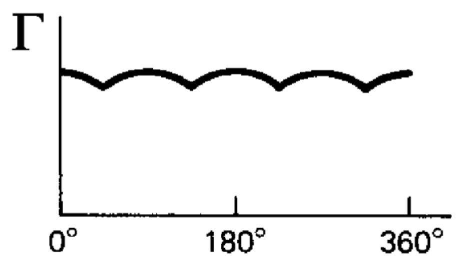
Torque vs. Number of Coil Turns





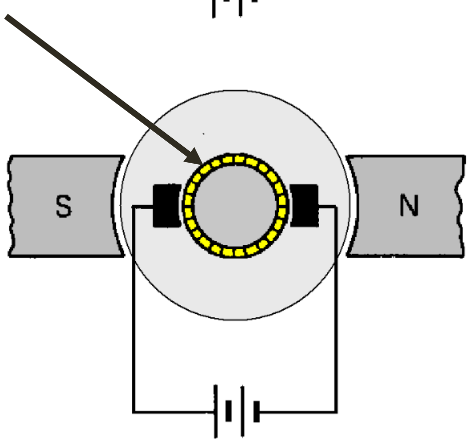
Motor torque with two coils

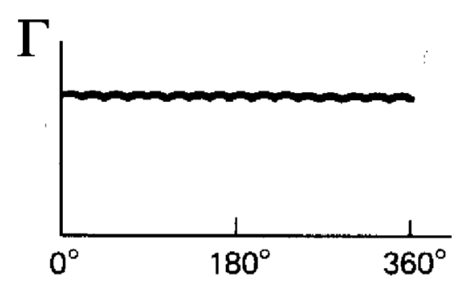




Motor torque with four coils

Brushes





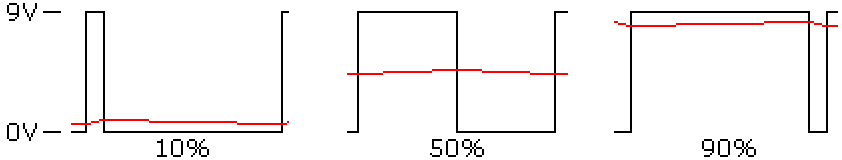
Motor torque with multiple coils

Pulse Width Modulation (PWM) to Control Motor Speed

PWM uses the fact that when voltage and current are both zero, then the supplied power will be zero. The motor only experiences power when it's on the high part of the cycle, which is more efficient than just lowering the voltage. *On a side note: This is why switching power supplies are popular even though they are noisy.*

Since there are periods of time when no power is supplied, there is a little bit of time for the motor to cool so PWM controlled motors tend to run a little bit cooler than the linearly regulated motors.

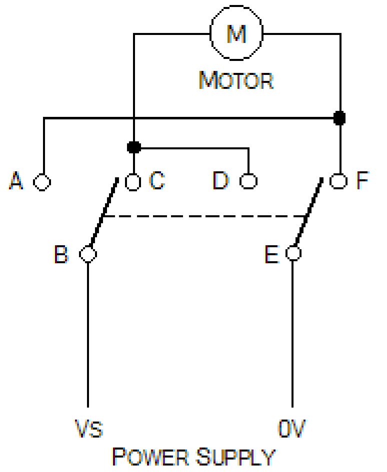
25% duty cycle is about the minimum duty cycle for motors since they start to drastically lose rotational momentum at that point.



Examples of PWM Waveforms

DC Motor Direction Control

The following circuit can be found on my car window switch. If you want the motor to roll the window up, then you apply 12V across the motor. If you want the window to roll down, then you switch the polarity so -12V is across the motor. The following switch is known as a double-pole, double-throw (DPDT) switch.



This works fine, but it requires a mechanical switch. An electrical version of this would be nice!

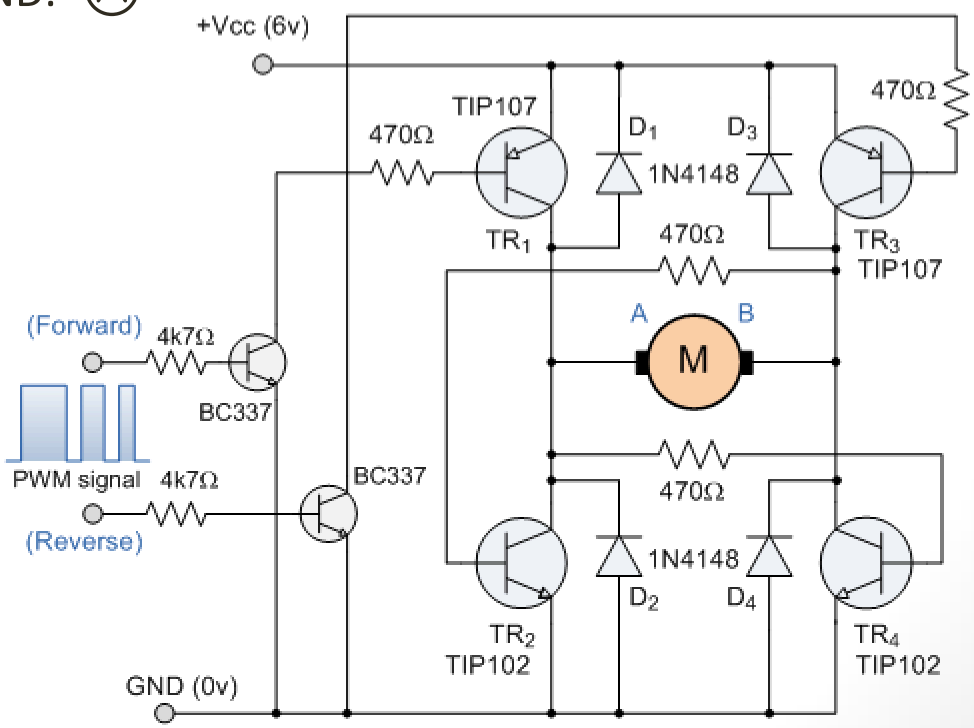
DC Motor Direction Control

The following circuit is known as a H Bridge. Think of each transistor as a switch.

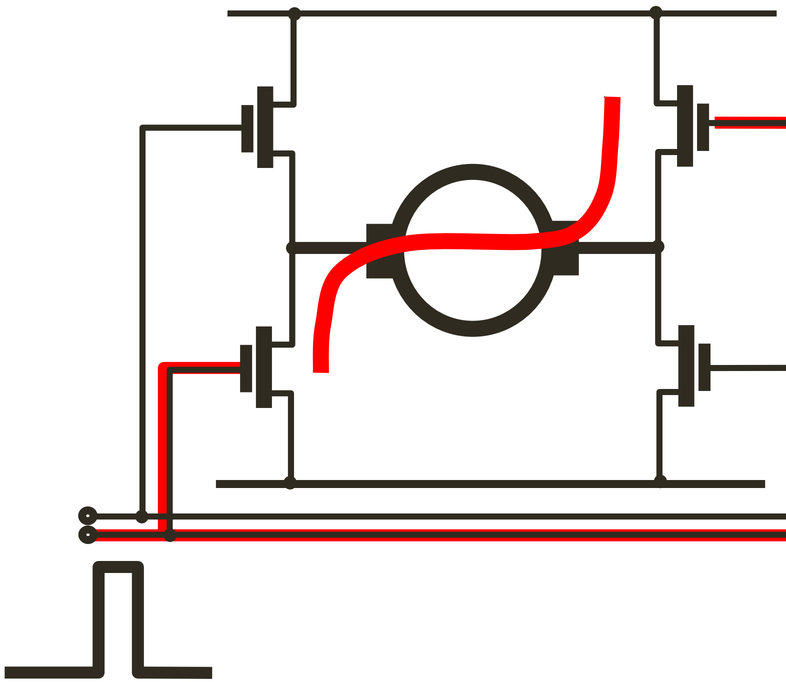
If forward = high and reverse = low, then current flows from A to B.
If forward = low and reverse = high, then current flows from B to A.
If forward = low and reverse = low, then all transistors are off and no current flows.
If forward = high and reverse = high, then all transistors are on and you have a direct short from Vcc to GND. ☹

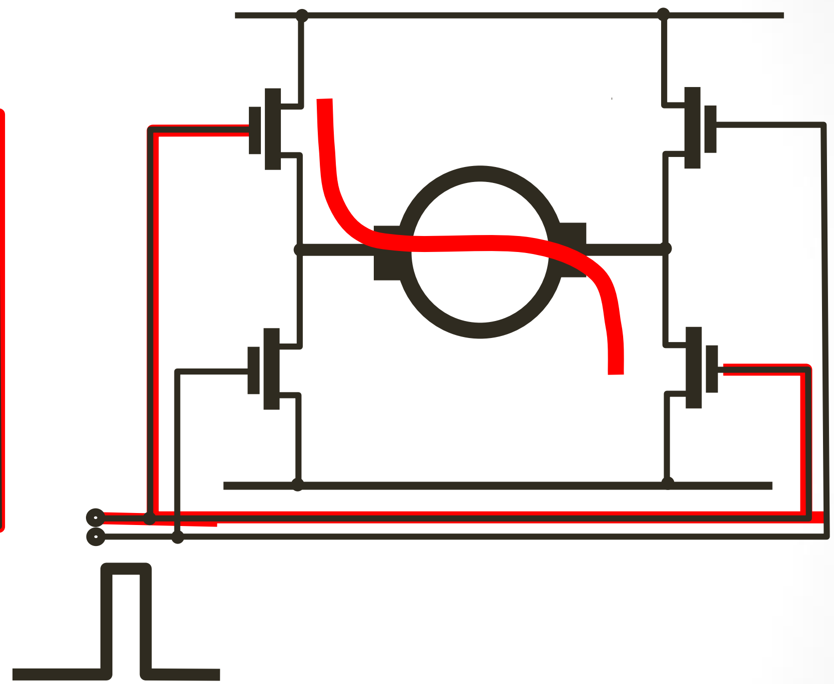
This circuit replaces the DPDT switch on the previous slide.

H-Bridge chips…
LMD18200 (~$17) for 3A of current
L293 (~$4) for 1A of current
L298 (~$4) for 2A of current. Has a dual H-bridge, so can run each H-bridge in parallel and achieve 4A of current.

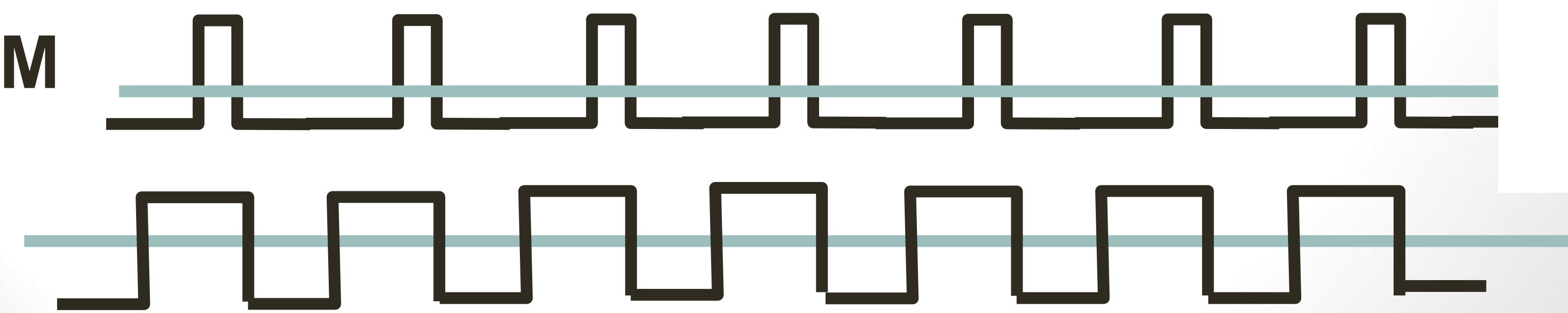


Current Through H Bridge





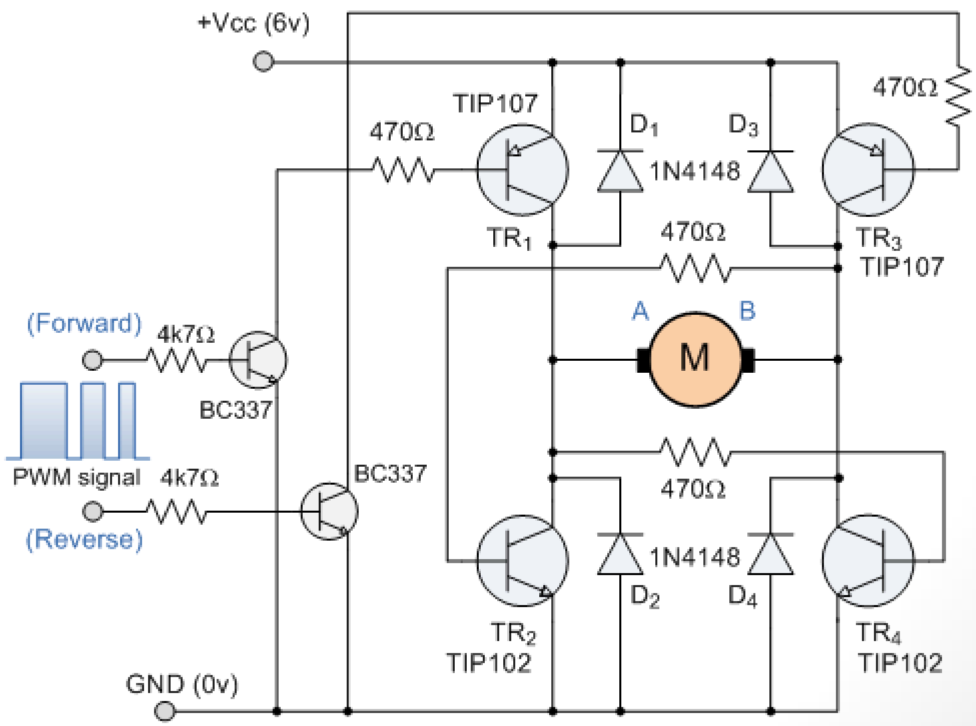
PWM



DC Motor Direction Control

Going back to the idea that if forward = high and reverse = high, then all transistors are on and you have a direct short from Vcc to GND ☹ . . .

There could be a time that when the transistors are switching, that all 4 transistors are ON for a brief period of time (which is also bad). To prevent this, one could add a driver or something to delay the input of the bottom half of the transistors by a few ns to prevent this from happening.

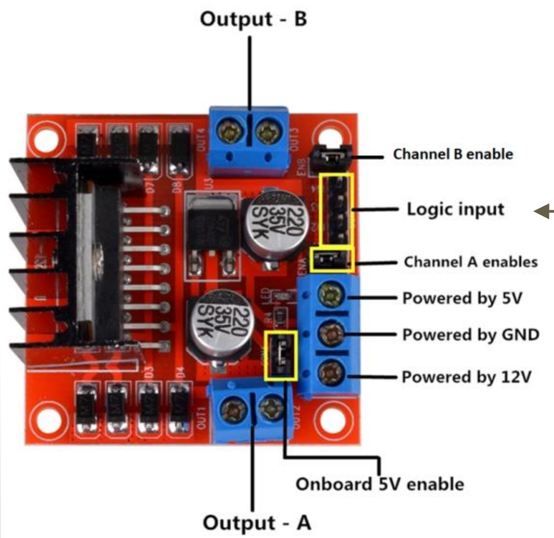


L298 Motor Driver

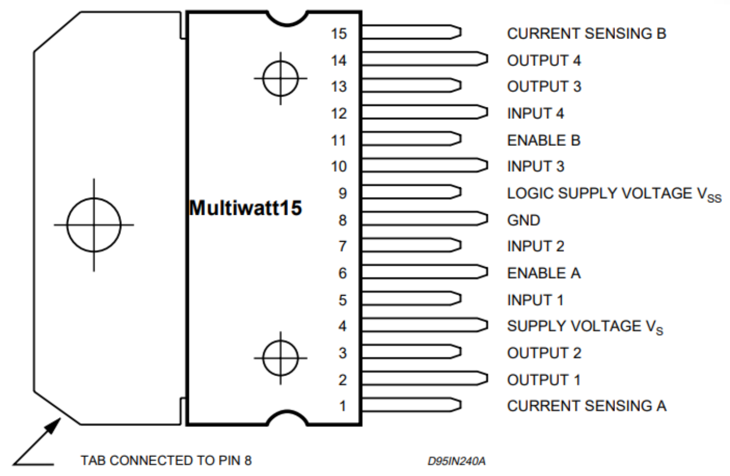
The L298 Motor Driver is a dual H-Bridge circuit that can handle 46V and 2A of continuous current. Because there exist 2 H-Bridges, the user can run these in parallel and the chip can handle 4A of continuous current.

For each of the 2 motor outputs, there are 2 TTL compatible inputs (IN1 and IN2) that control the motor state and direction of the motor.

- IN1=high, IN2=low spins the motor in one direction
- IN1=low, IN2=high spins the motor in the other direction
- IN1=IN2 performs a fast motor stop
- IN1=Hi-Z or IN2=Hi-Z performs a free running motor stop



"Logic input" contains IN1, IN2, IN3, IN4



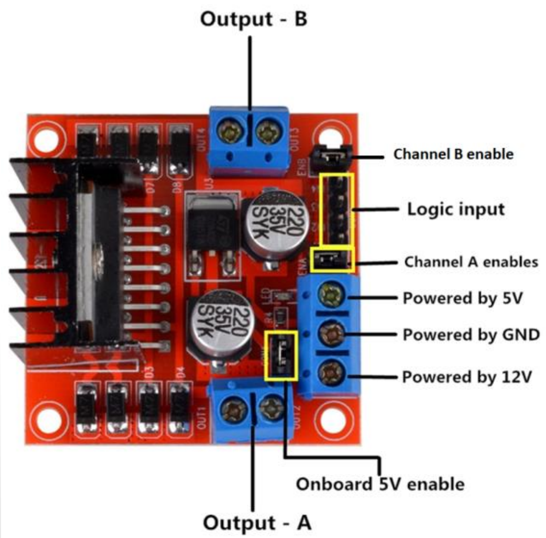
L298 Motor Driver

The L298 Motor Driver also has a Motor A enable and a Motor B enable. Enable=HIGH enables the individual motor driver.

We can control the speed of motor A two different ways…

1. PWM on IN1 and GND on IN2 (or vice versa to switch direction) ← We'll do in lab
2. PWM on the enable.

In the lab, we'll leave the motor enabled and use PWM on the logic input pins.



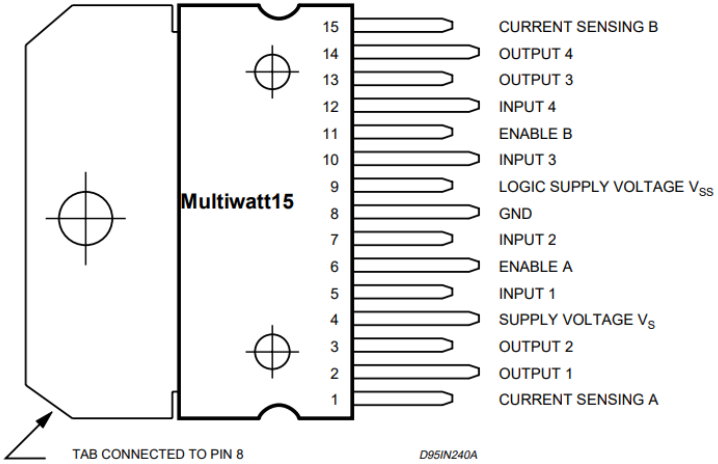
"Logic input" contains
IN1, IN2, IN3, IN4

L298 Motor Driver

The L298 Motor Driver has current sensing outputs on each driver (pin 1 and 15) where a non-inductive resistor can be tied to ground to measure the current going through the motor.

This can be used in conjunction with the motor enable to have the motor turn off if too much current is being drawn. Automobiles have this to automatically stop the motor when the window rolls all the way up or down. This is a nice feature because if someone's fingers are in the window as the window rolls up, then the motor will automatically shut off.

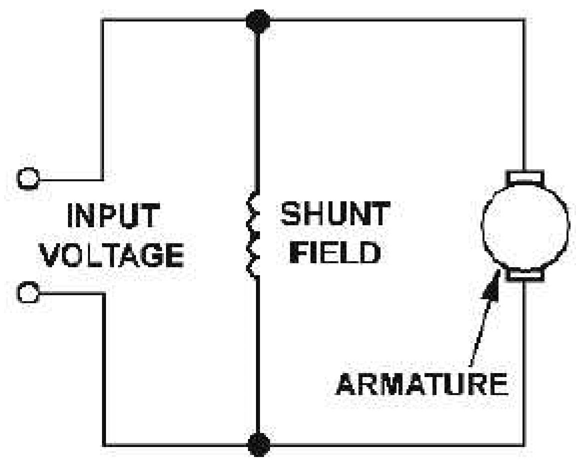
We won't use this feature in the lab.



Shunt, Series, and Compound Motor Configurations

Shunt motors have the field electromagnet windings and the armature electromagnet windings wired in parallel. This allows a lot more current to travel through the armature windings, which usually means that the windings consist of fewer turns and heavy gauge wire. This high current isn't affected as much by back EMF (that is caused by the spinning of the armature) and does well to keep the current constant.

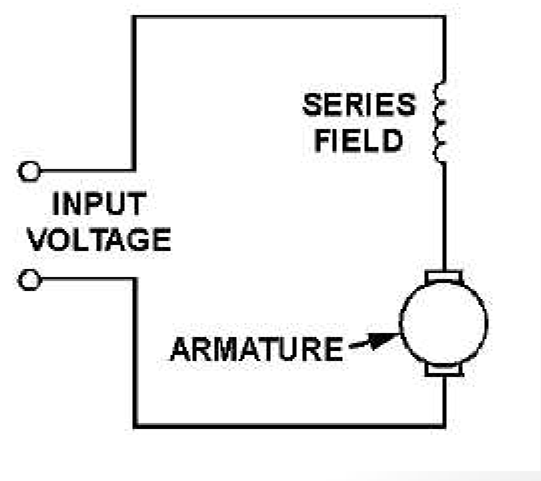
This configuration is used for motors that need a **constant speed** (ex: water pump).
Note that the difference between the no load speed and the full load speed is seldom more than 5%.



Shunt, Series, and Compound Motor Configurations

Series motors have the field windings and armature windings wired in series. Remember when the load is full, the current increases causing the magnetic field to increase which creates a high torque/low speed (useful to move **large loads**). This current can be so large that the motor will overheat and damage. The other boundary is when no load is attached and the magnetic field is weak causing low torque/high speed.

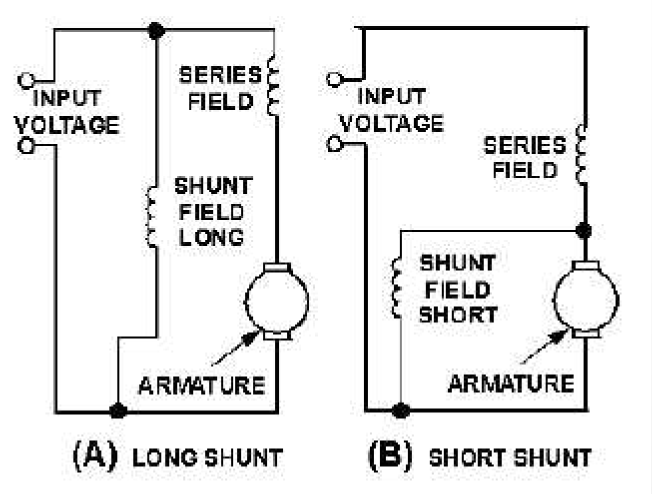
In fact, some series motors destroy themselves (and possibly other people around it) because they spin so fast when no load is attached!



Shunt, Series, and Compound Motor Configurations

Compound motors combine characteristics of series and shunt motors, so you get higher torque and more constant speed. This means that some of the electric field is in series with the armature windings and some of the electric field is parallel to the armature windings. This allows you to operate the motors with no load without problems.

FYI, the long shunt configuration is more similar to shunt configuration (constant speed). The short shunt configuration is more similar to series configuration (high torque). The Long shunt is more popular.



Shunt, Series, and Compound Motor Configurations

Back to the DC motor video…
https://youtu.be/LAtPHANEfQo?t=155