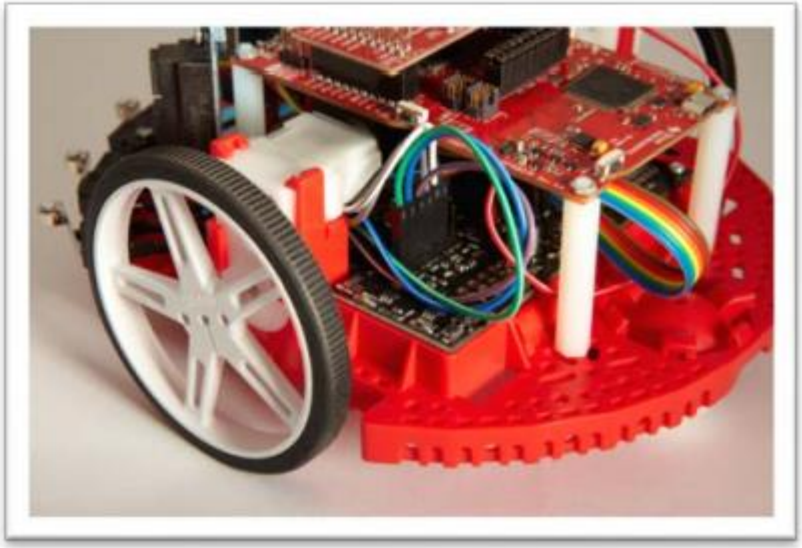
ECCS-3351
Embedded Realtime Applications (ERA)

Inductive device control

JONATHAN W. VALVANO
Modified by Drs. Kropp, Oun, and Youssfi

Objectives

- Fundamental for Electromagnetic Fields
  - Ampere’s Law
  - Faraday-Maxwell
- Brushed DC Motors



If you leave college knowing anything…

Capacitors impede changes in voltage

Inductors impede changes in current

while(1){

1) Set P5.3 high (turn on IR LED)

2) Make P7.0 an output, and set it high (charging the capacitor)

3) Wait 10 us, Clock_Delay1us(10);

4) Make P7.0 an input

5) Run this loop 10,000 times

   a) Read P7.0 (converts voltage on P7.0 into binary)

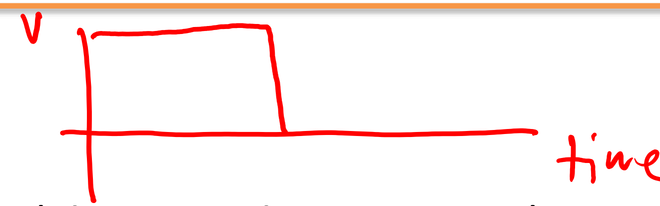
   b) Output binary to P4.0 (allows you to see binary in real time)

6) Set P5.3 low (turn off IR LED, saving power)

7) Wait 10 ms, Clock_Delay1ms(10);

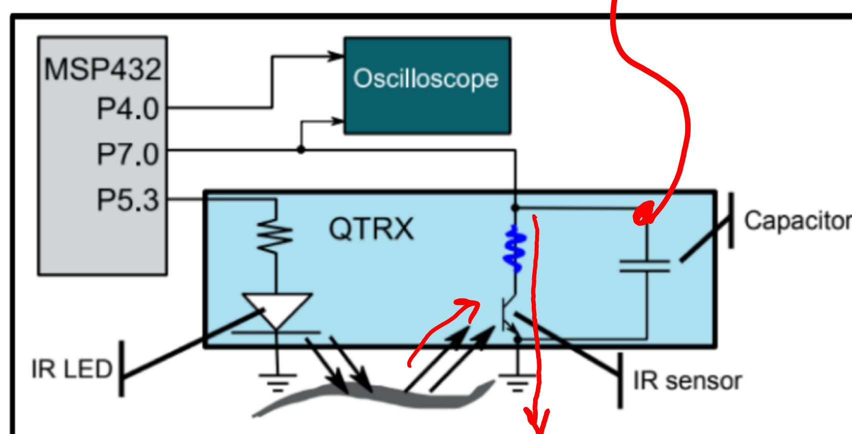
}

without a capacitor



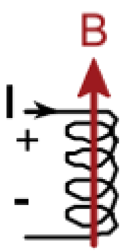
with a cap

charged to 5v

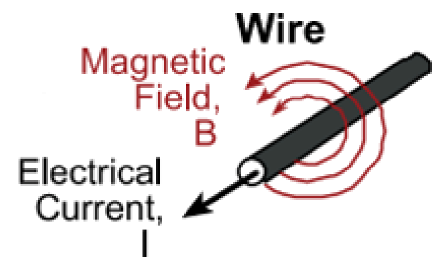


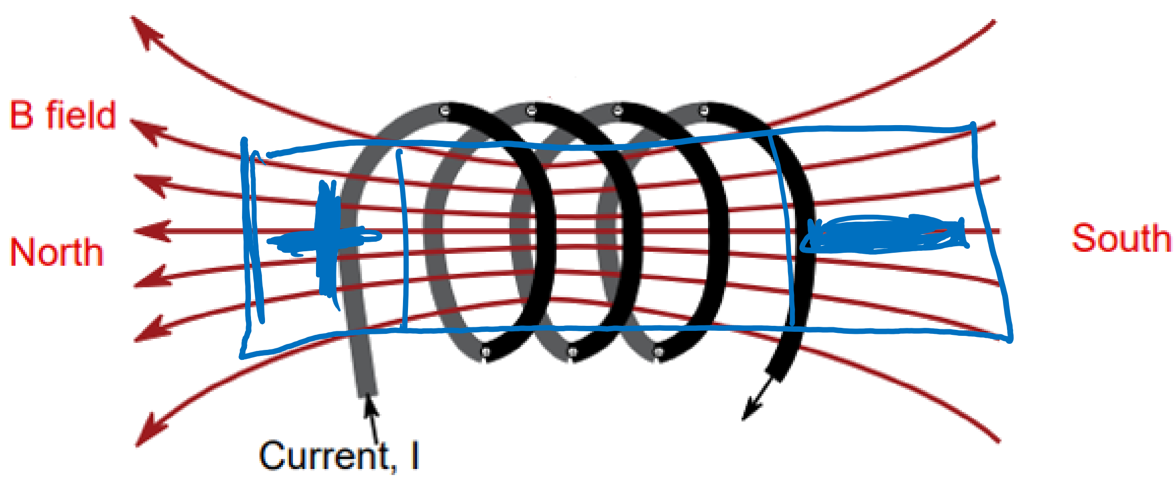
Electromagnetic Fields

Current induces a magnetic field

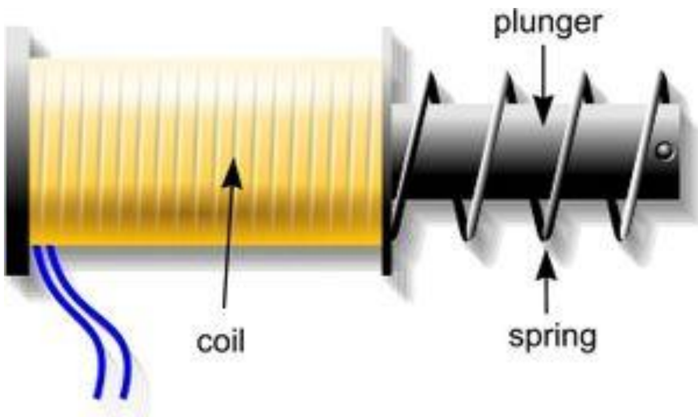


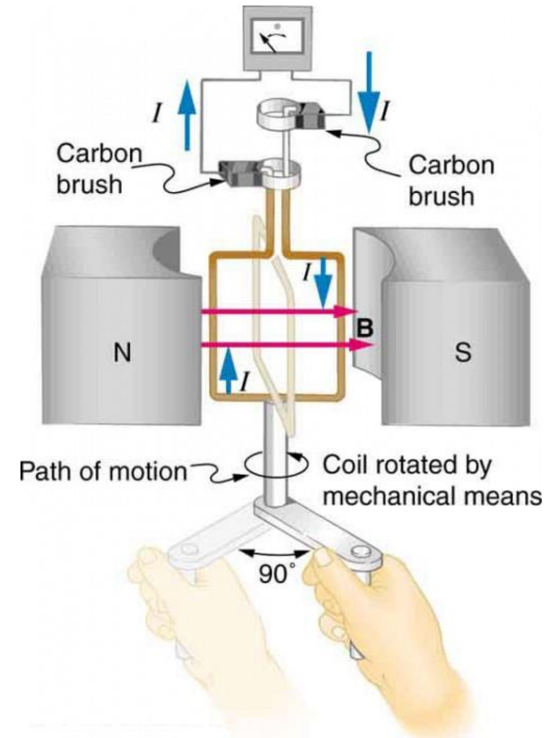
Electromagnet

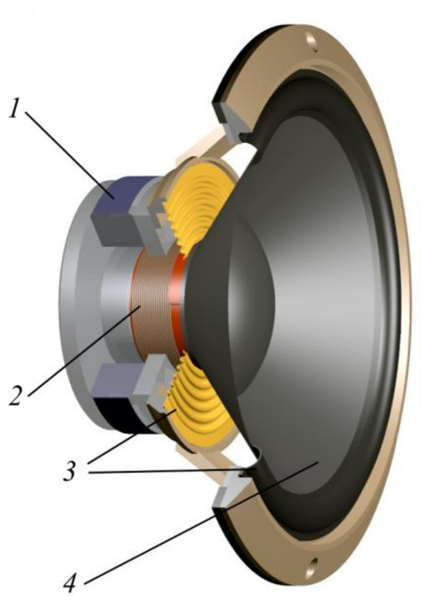


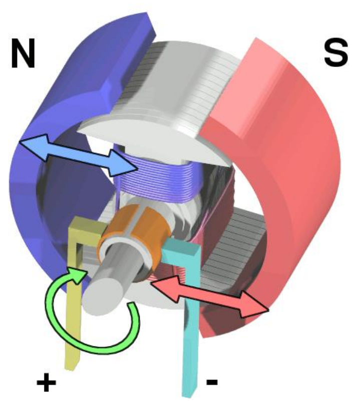


What devices use coils?





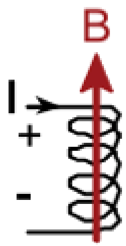




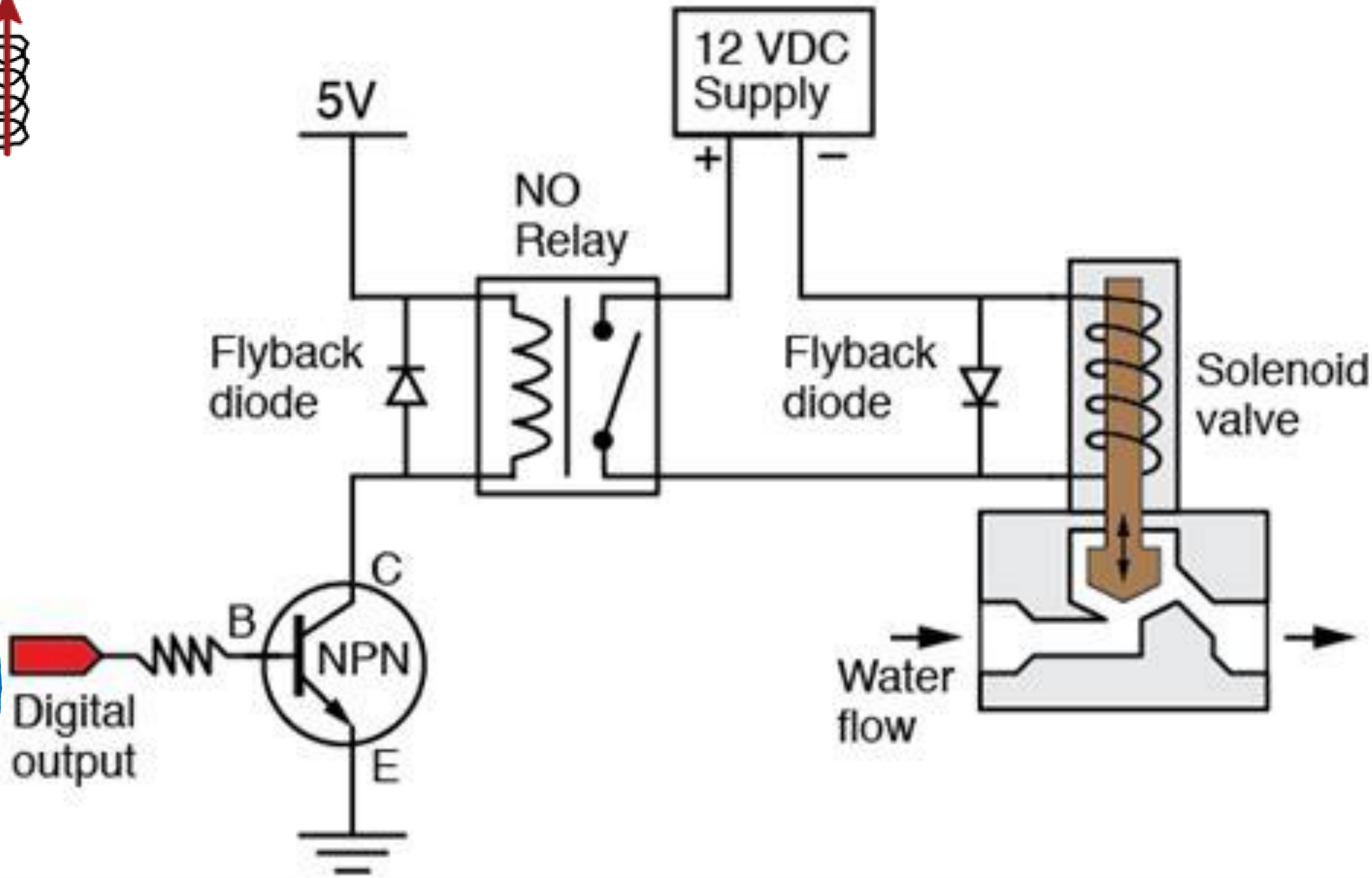
Inductive Devices

https://wiki.dtonline.org/index.php/File:Solenoid.jpg
https://en.wikipedia.org/wiki/Electric_motor#/media/File:Electric_motor_cycle_2.png
https://courses.lumenlearning.com/physics/chapter/23-5-electric-generators/
https://en.wikipedia.org/wiki/Loudspeaker#/media/File:Loudspeaker-bass.png

EF in action: Solenoid



MSP 432



Inductive Devices

Source: http://me121.mme.pdx.edu/doku.php?id=lecture:solenoid_valves

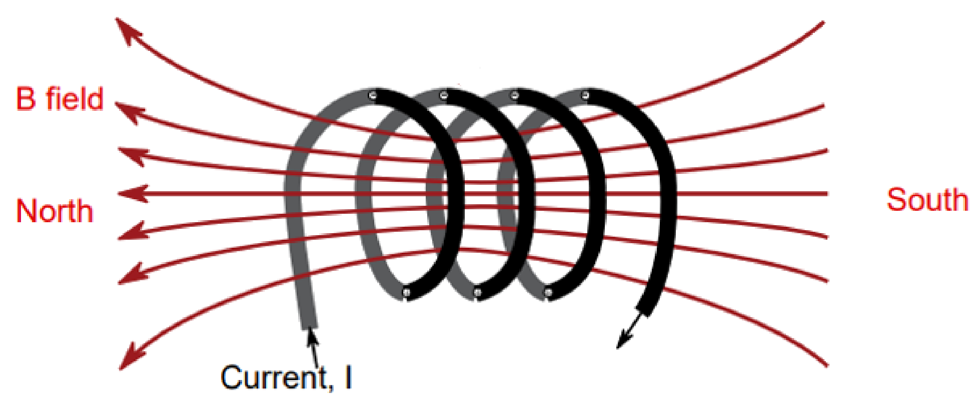
Theory of Electromagnetic Fields

Current induces a magnetic field

Derived from Ampere's Law: $B = \mu \frac{NI}{L}$

property of the conductor

- I is current (amps)
- L is the length of the coil (meters)
- N is the number of turns
- μ is the permeability (N/A^2)
- B is magnetic field (Teslas)

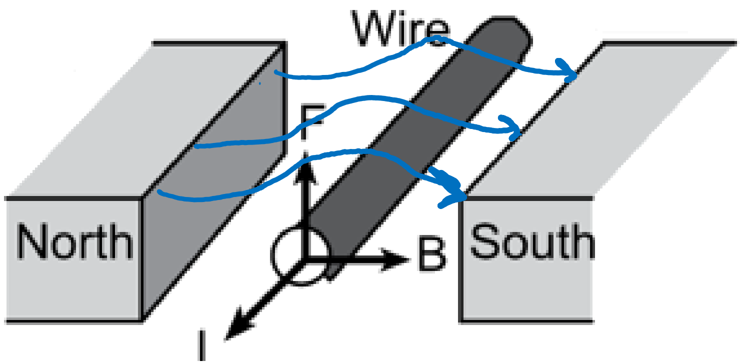


DC Motor Physics

- **Faraday-Maxwell Law:**

Force = Current × Length × Magnetic Field

$$F = ILB$$

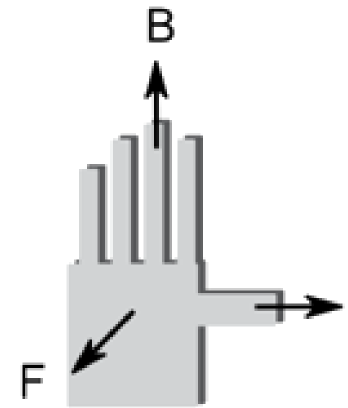


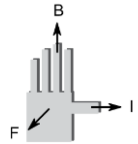
- **Right hand rule**

Thumb = direction of current

Fingers = direction of magnetic field

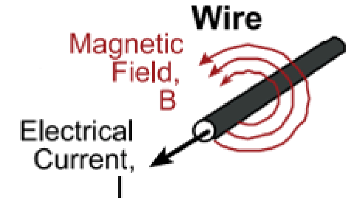
Palm = direction of force

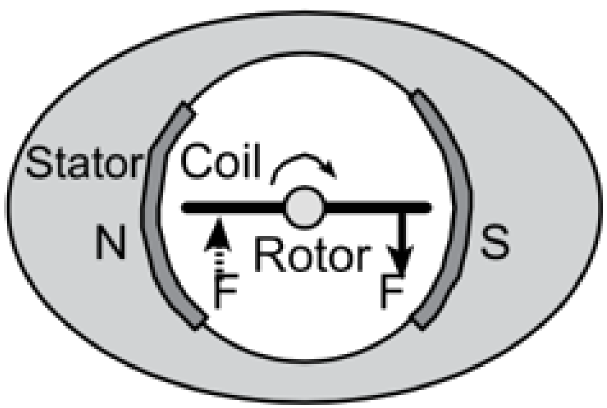


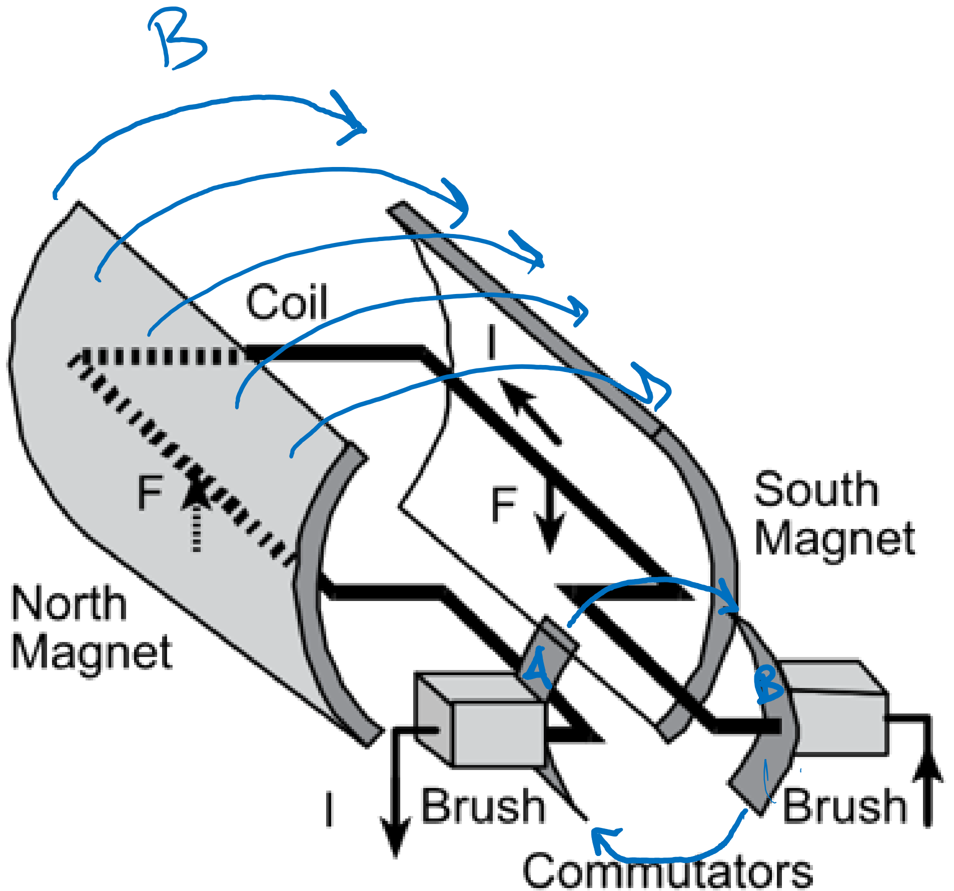


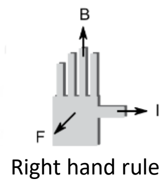
Right hand rule

Magnetisms to Movement

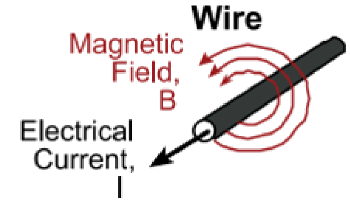


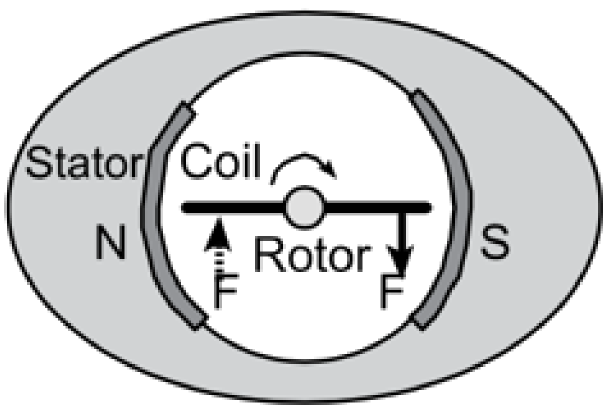


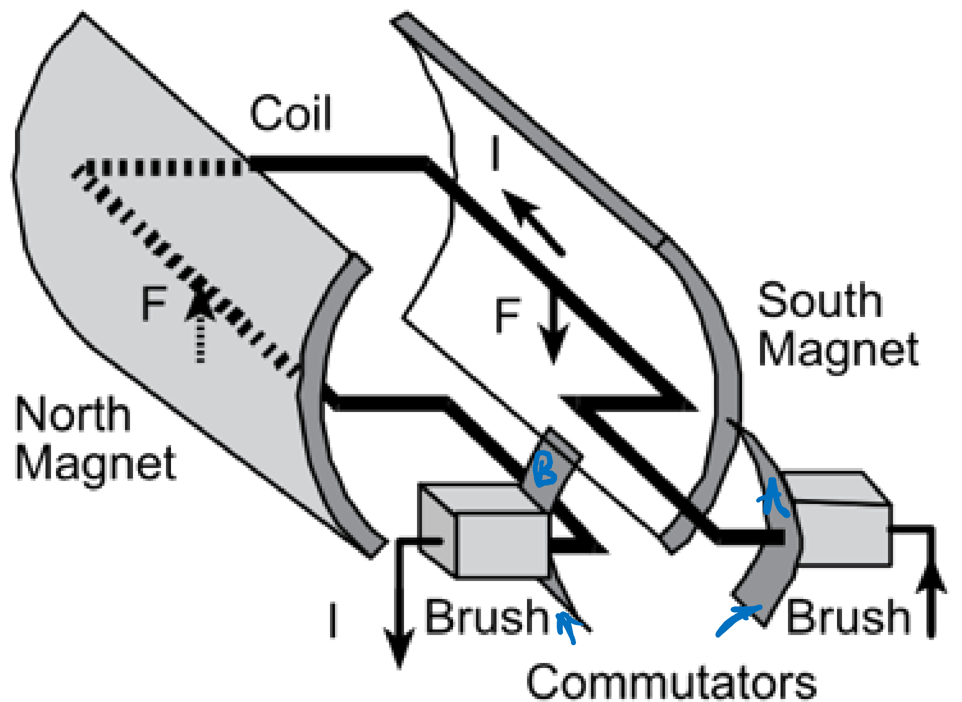




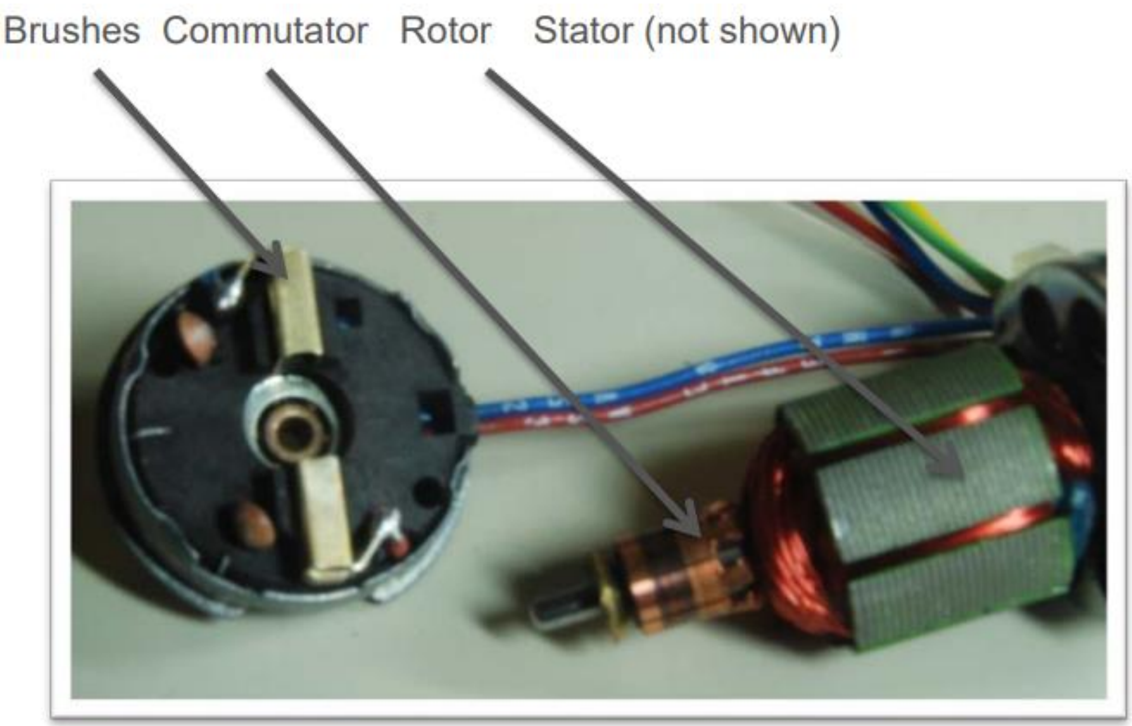
Magnetisms to Movement

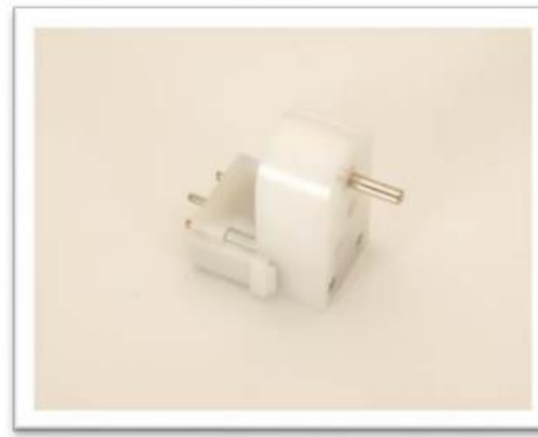




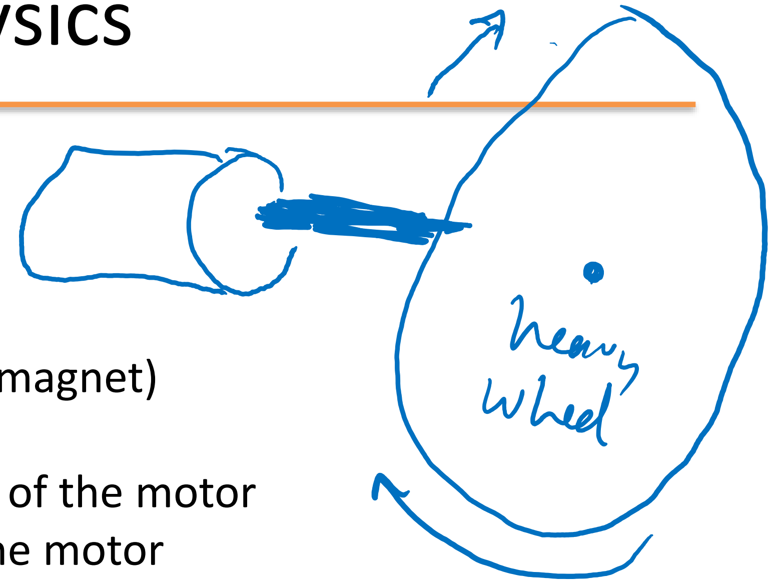


Components





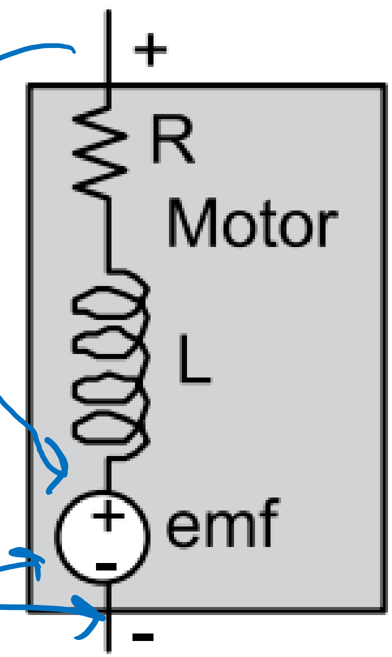
DC Motor Physics



Electrical Model

- R Resistance from long wires
- L Inductance because wires are coil (electromagnet)
- emf electromotive force
  - a function of the ultimate speed and torque of the motor
  - Opposite polarity of the voltage powering the motor

opposite polarity

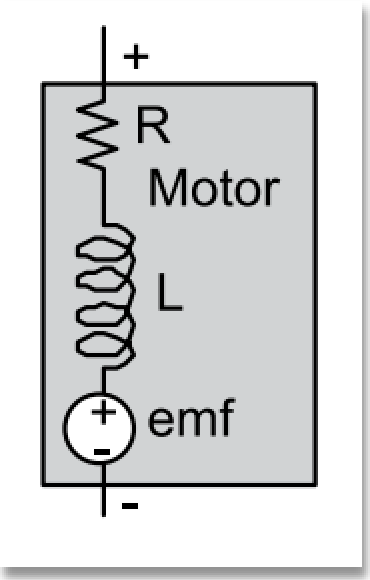


opposite polarity

Basic Model for a DC motor

Considerations

- Voltage (V)
- Current (A)
- Power (W = V*A = J/sec)
- Force (N=kg*m/sec2)
- Torque (N-m)
- Inductance (H)
- emf (V)
- Friction (coefficient)
- Speed (rps)



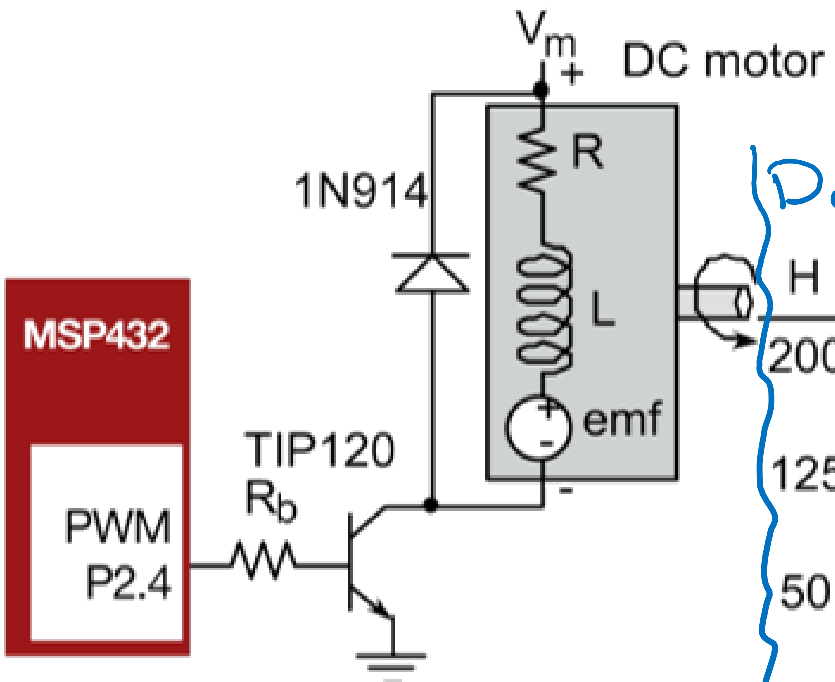
$P = V*I$

$F = m*a$

$\tau = F*d$

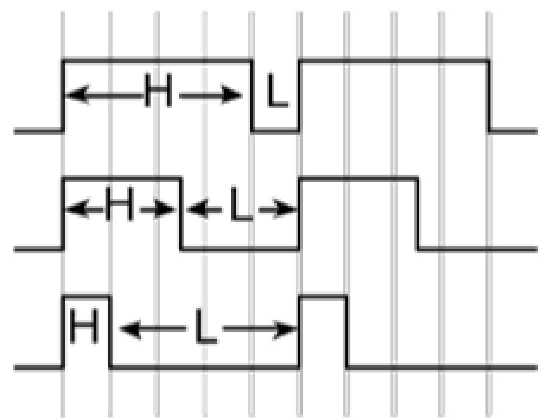
$V = L\, dI/dt$

Basic Drive Circuits for DC Motors



Duty Cycle

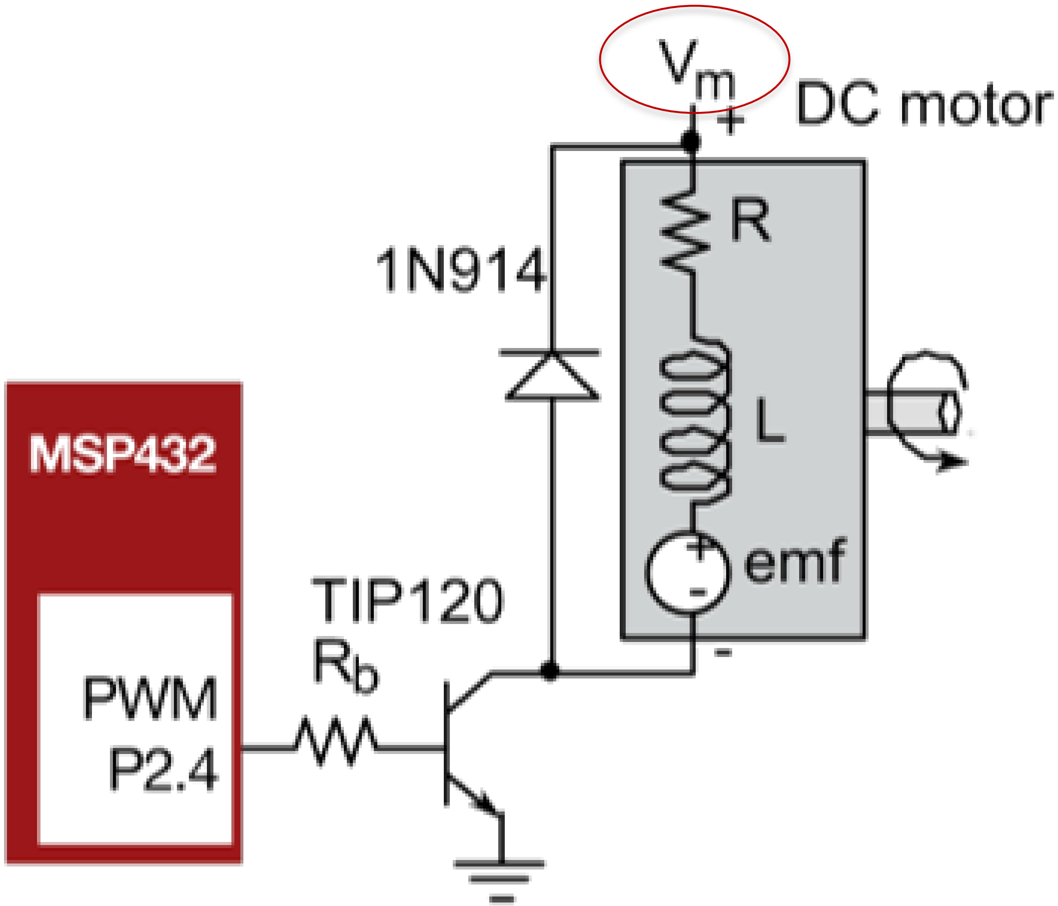
H	L	
200	50	P2.4
125	125	P2.4
50	200	P2.4



Basic Drive Circuits for DC Motors

Voltage

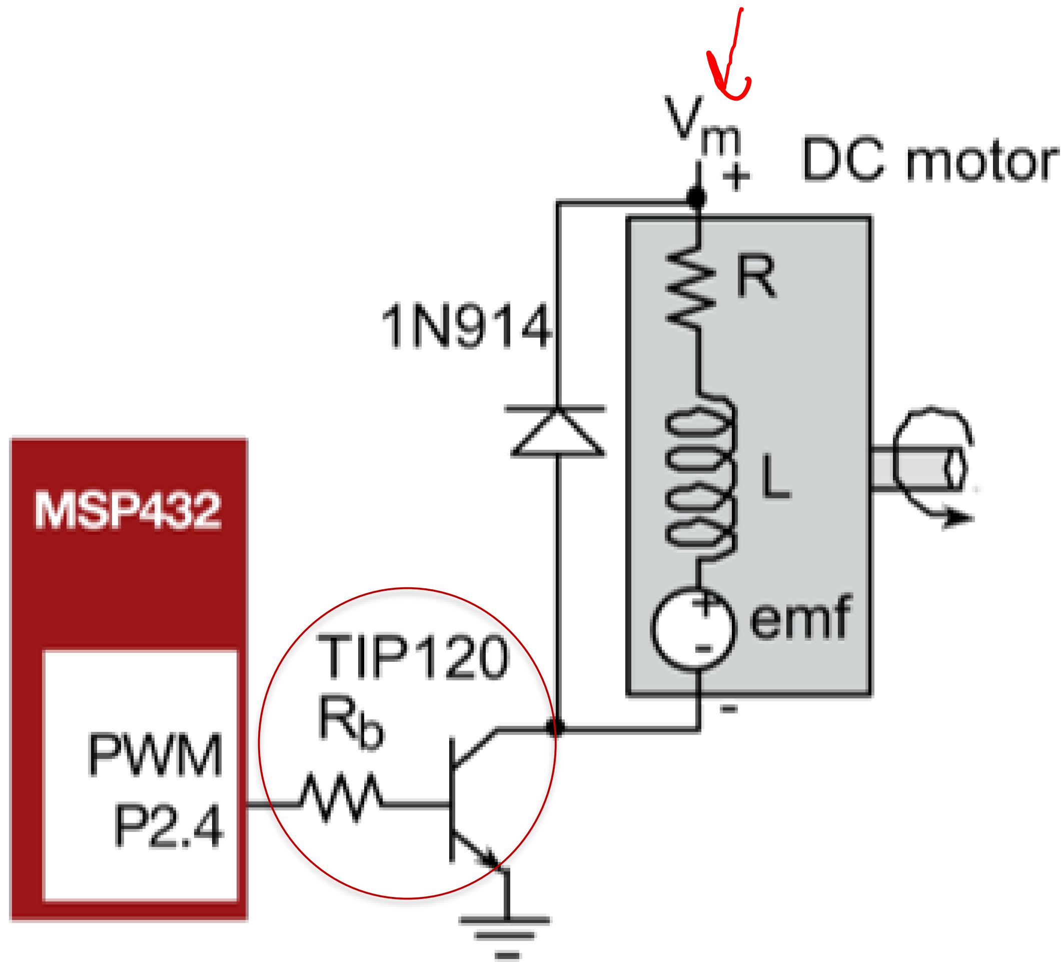
- Look up the required voltage of the motor, and supply it (V_m)
- Regulate the voltage source if necessary



Basic Drive Circuits for DC Motors

Controlling by current

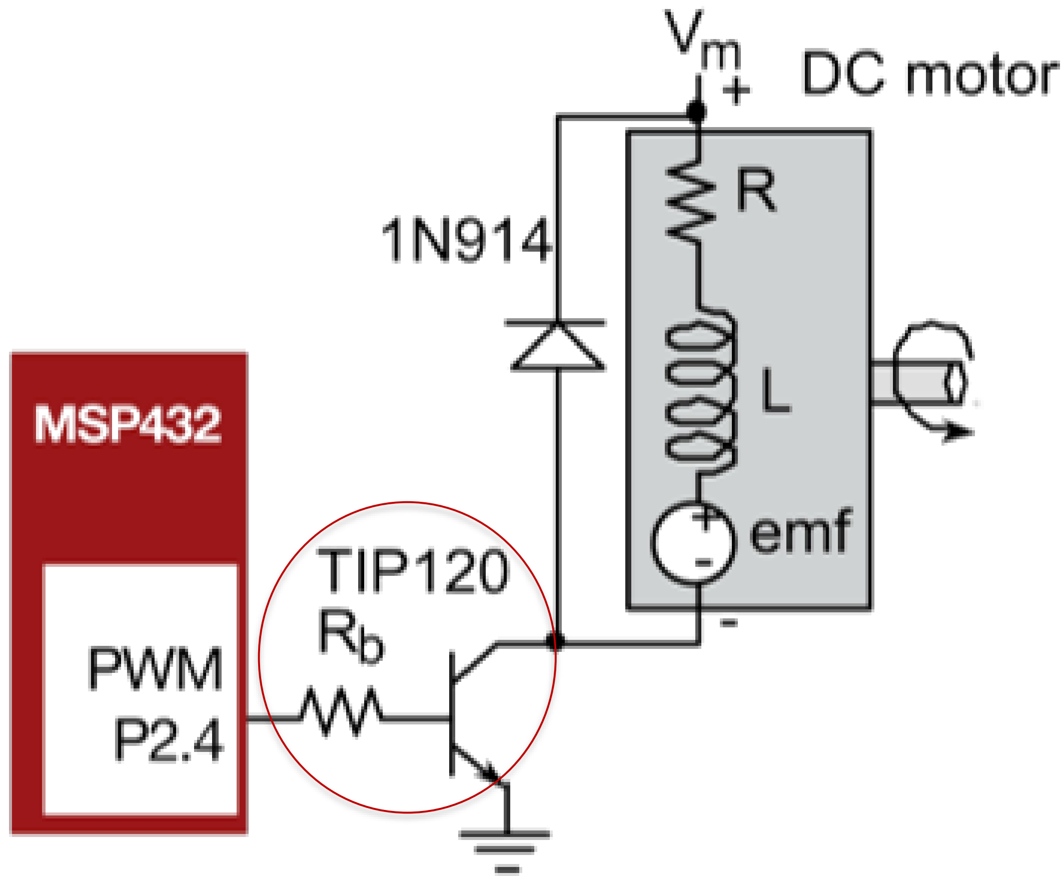
- In this example, we provide a transistor to control the current of the motor
    - Bipolar junction transistor
    - These transistors can handle high current
- Driven by a GPIO pin
- Choose a driver pin with twice the required current of the motor



Basic Drive Circuits for DC Motors

Controlling by voltage

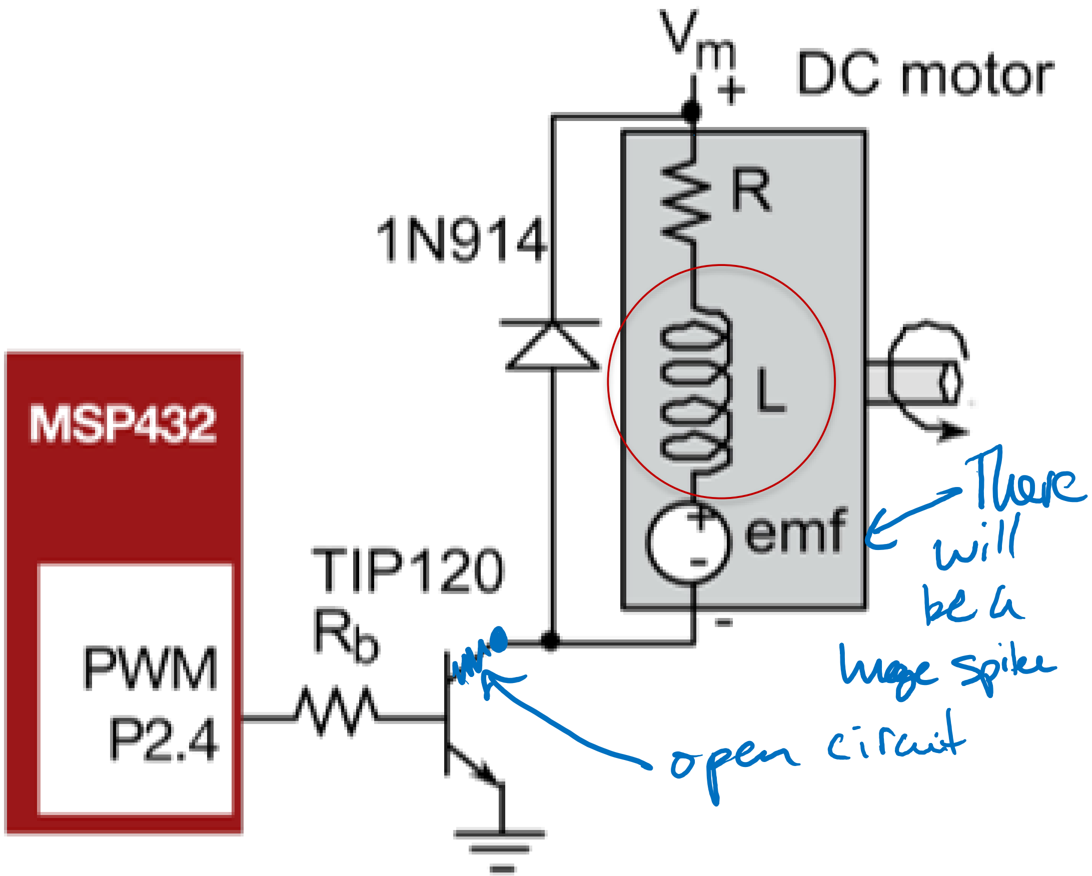
- The TIP120 is controlled by current
- Use a MOSFET to control the motor by a voltage signal



Basic Drive Circuits for DC Motors

Dealing with inductance

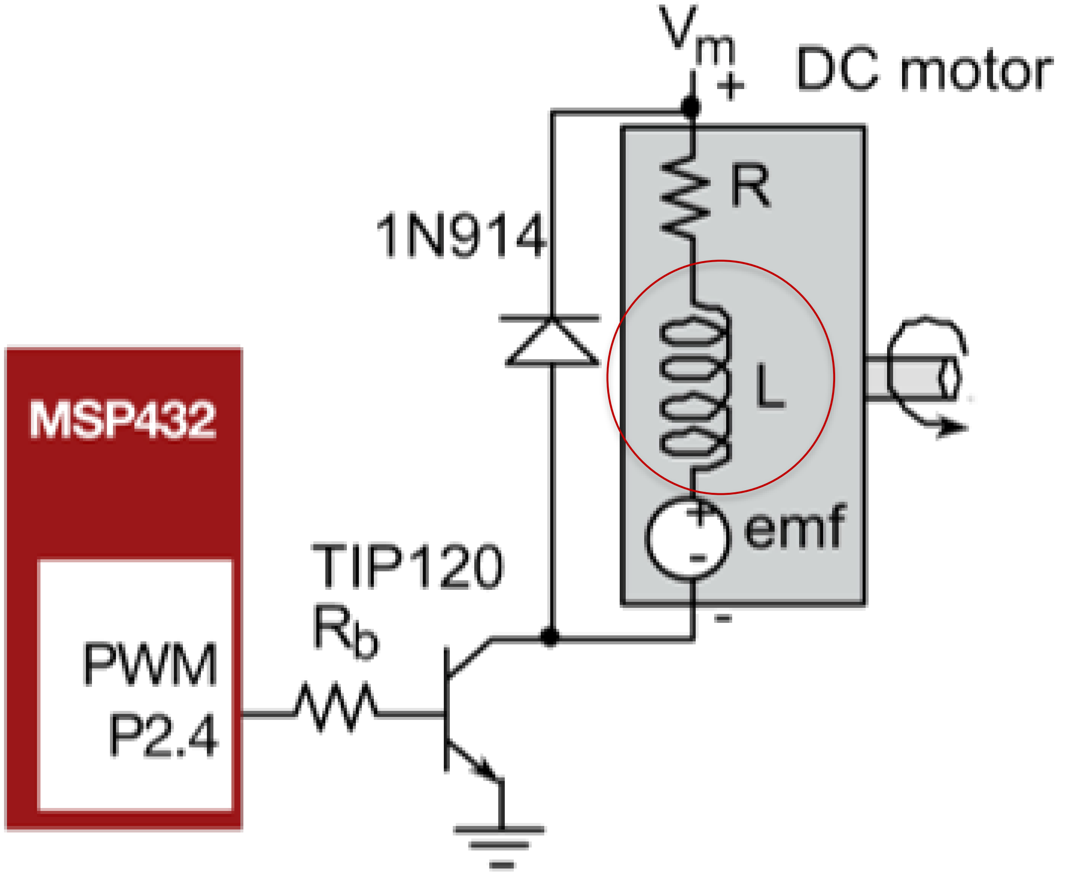
- All motors contain an inductance, since it's comprised of coiled wire
- When you switch off the motor, the motor is still spinning
- This is just like a small generator, which creates a voltage called *back emf*



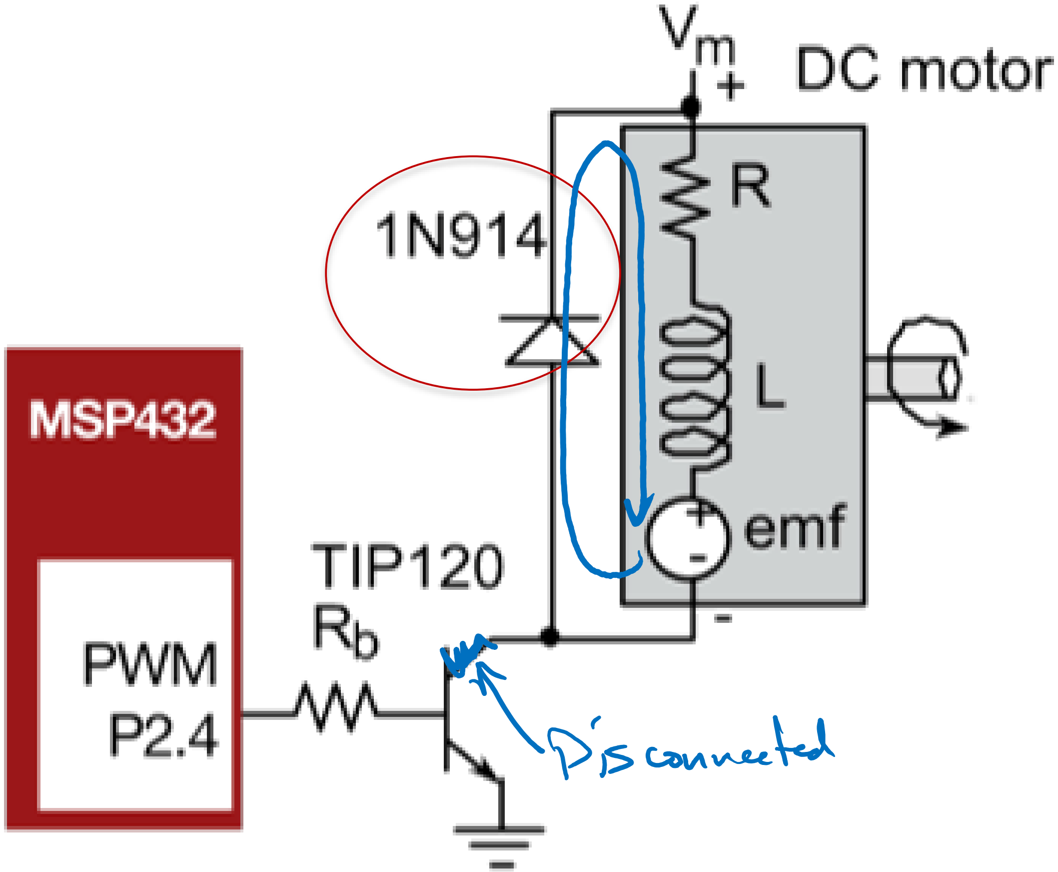
Basic Drive Circuits for DC Motors

Dealing with inductance

- All motors contain an inductance, since it's comprised of coiled wire
- When you switch off the motor, the motor is still spinning
- This acts just like a small generator, which creates a voltage called *back emf*
- This can send current into your MCU, possibly frying it!!



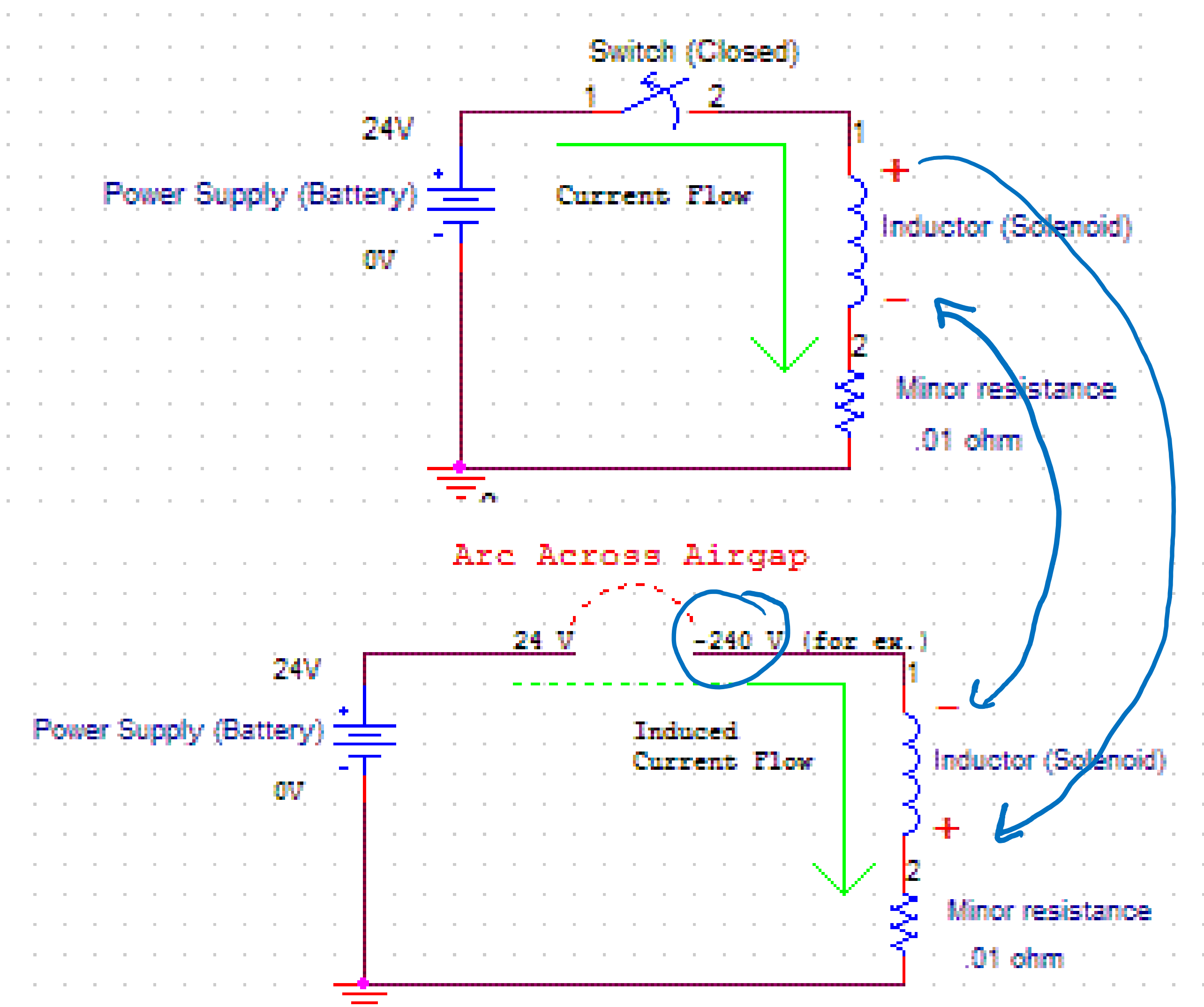
Basic Drive Circuits for DC Motors



Dealing with inductance

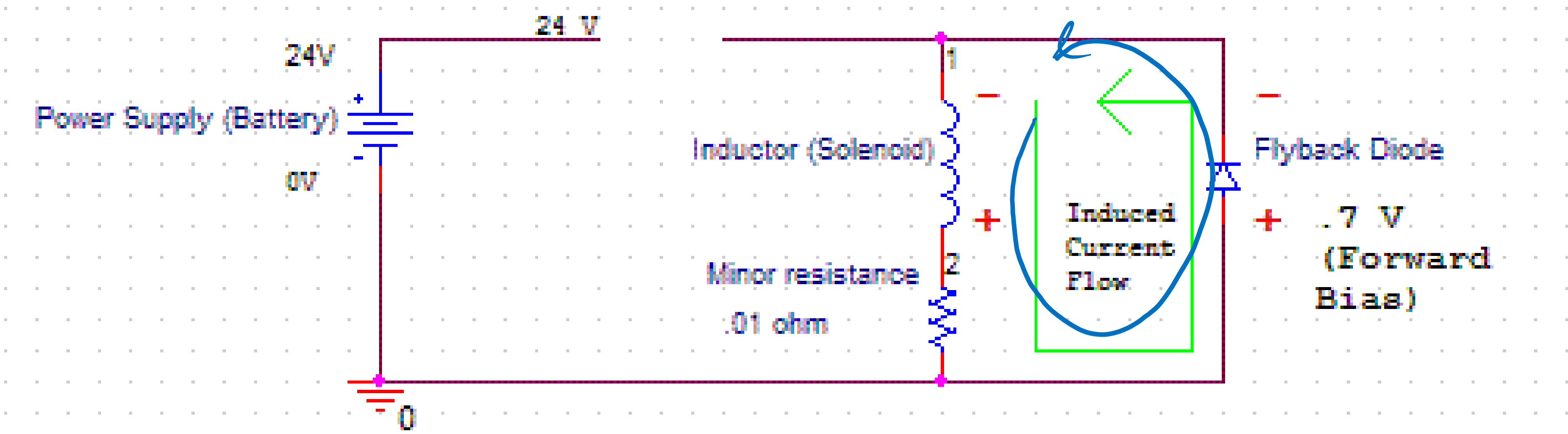
- Using a *snubber diode* prevents unwanted current from frying your MCU driver

Flyback (or snubber) diodes



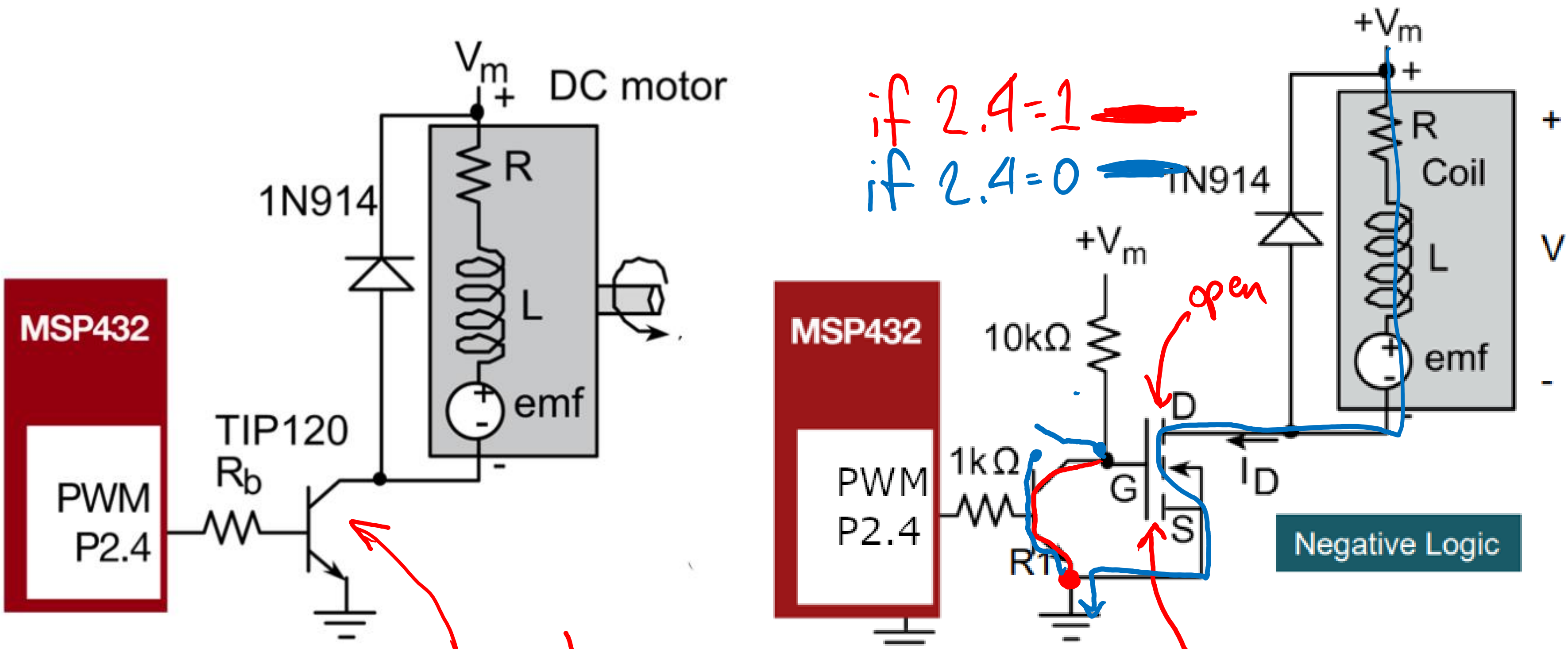
https://upload.wikimedia.org/wikipedia/commons/7/76/FlybackExample.GIF

Flyback (or snubber) diodes



https://upload.wikimedia.org/wikipedia/commons/7/76/FlybackExample.GIF

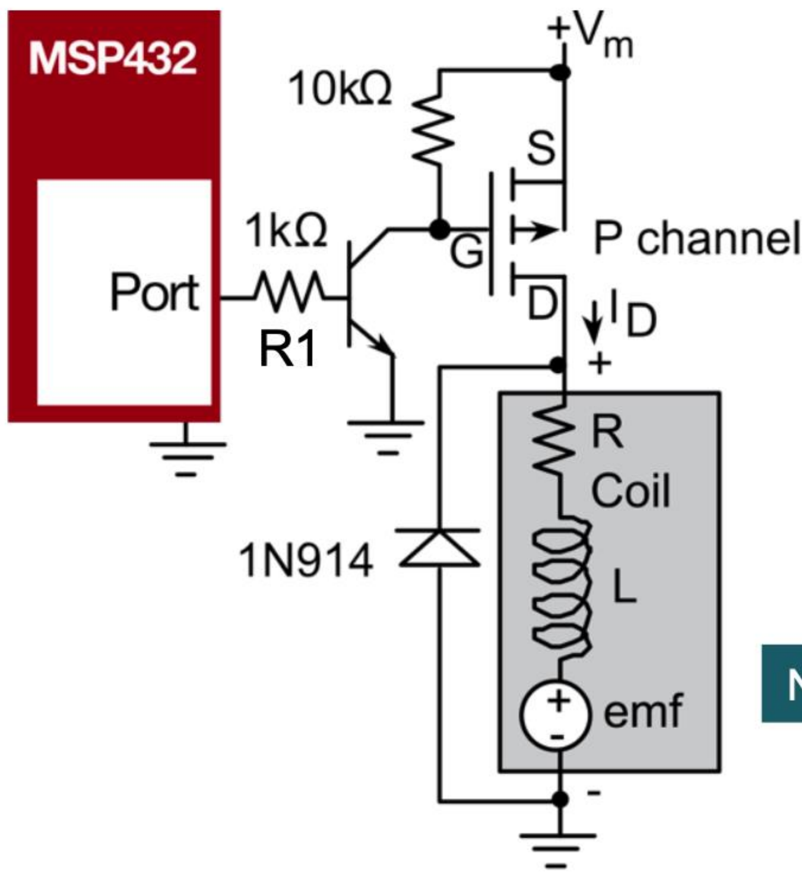
MOSFET Drive Circuit



Darlington transistor are typically rated for a lower current

mosFET (rated for higher currents)

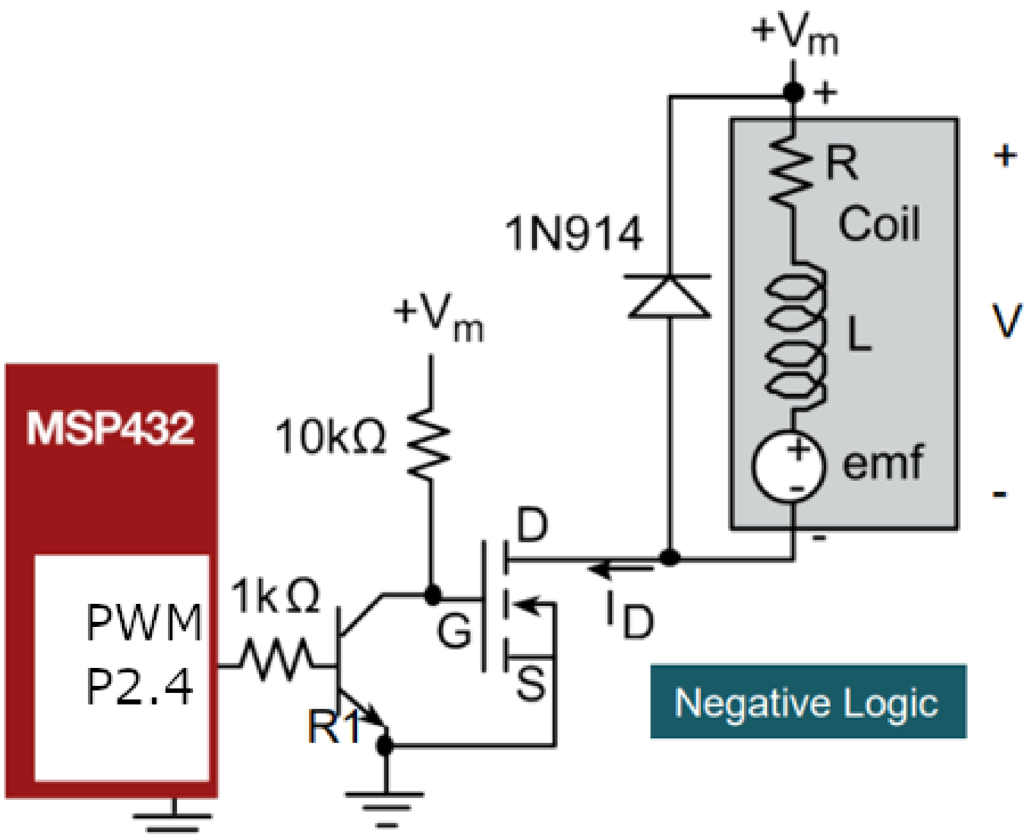
Alternative MOSFET Driver Circuit



Negative Logic

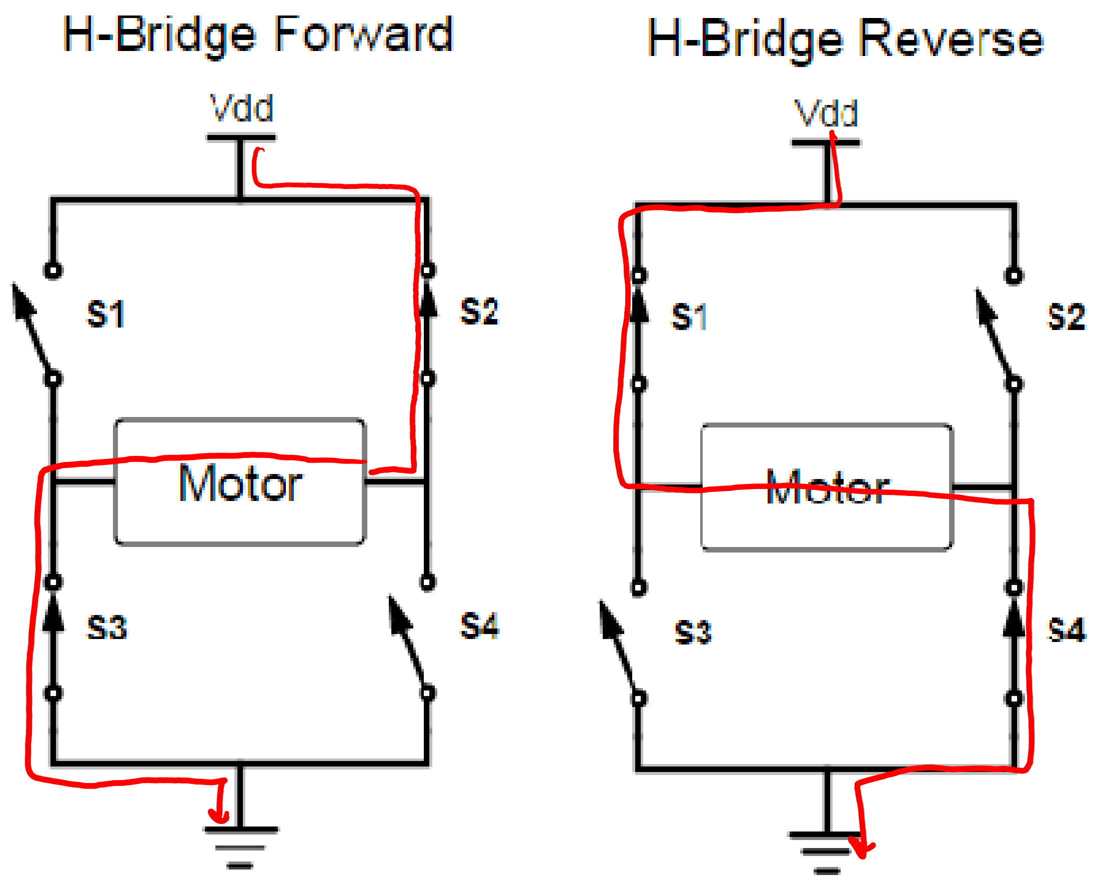
MOSFET Drive Circuit

What's a missing feature of this set up?



Going forward and backwards: H Bridge

Basic circuit inside the DRV8838



S1=0 S3=1
S2=1 S4=0

S1=1 S3=0
S2=0 S4=1

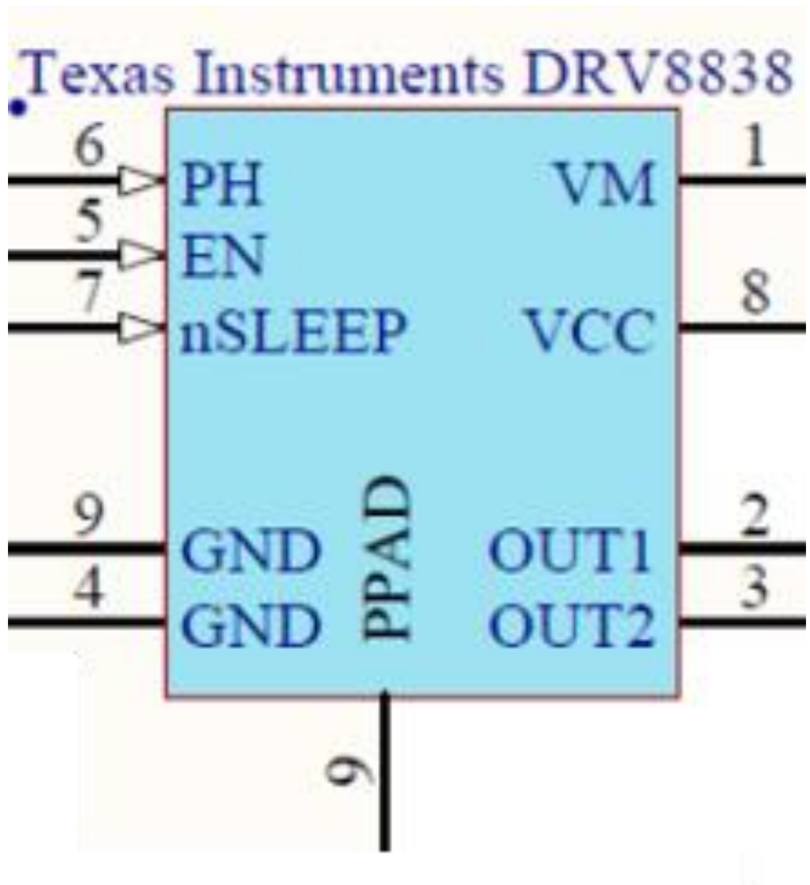
Inductive Devices

Image from *An integrated H-bridge circuit in a HV technology*, Bellini et al.

Operational parameters of a motor

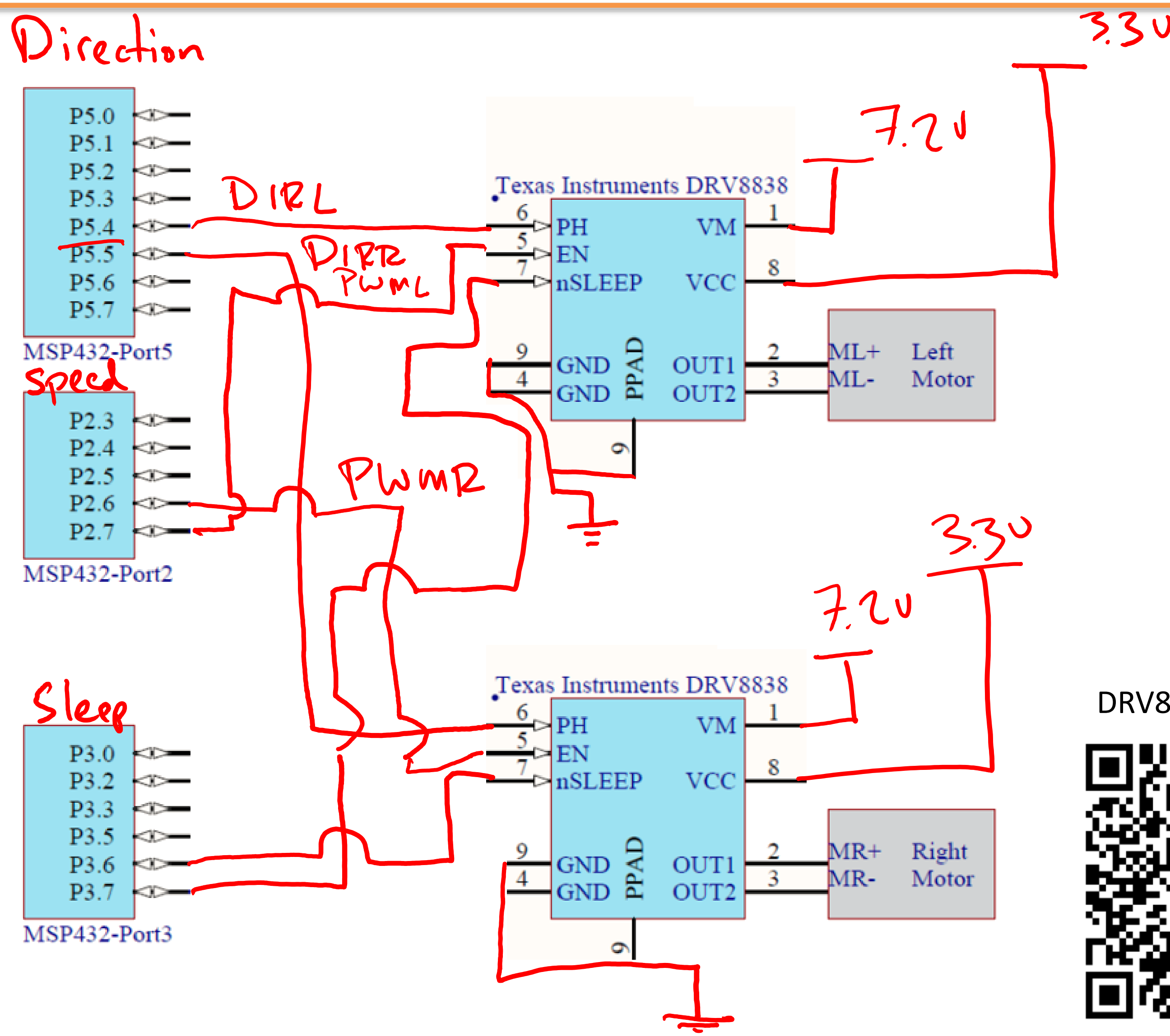
- Speed (using PWM)
- Direction of robot (varying the speed of the left and/or right motors)
- Direction of motor

Integrated Version of an H bridge



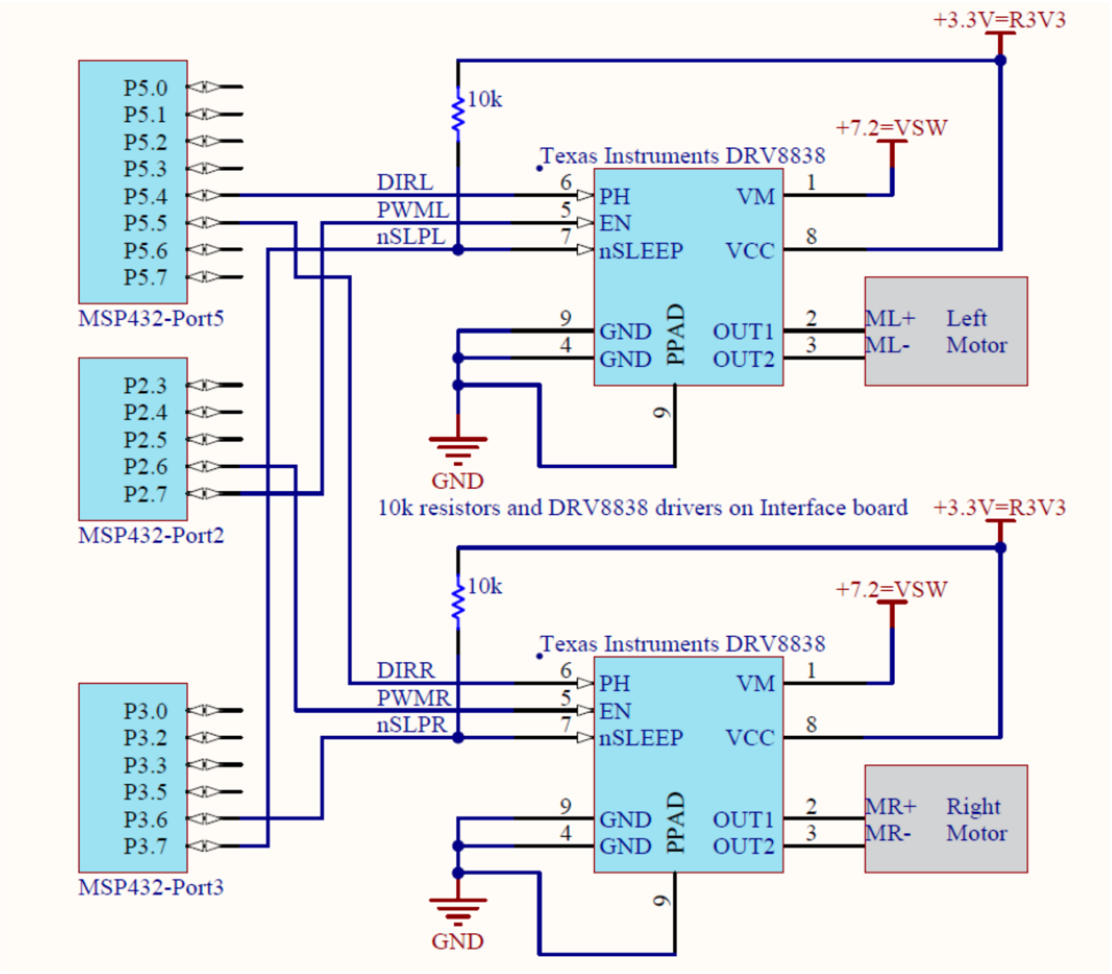
What do all of these pins do?

Let's hook everything up!

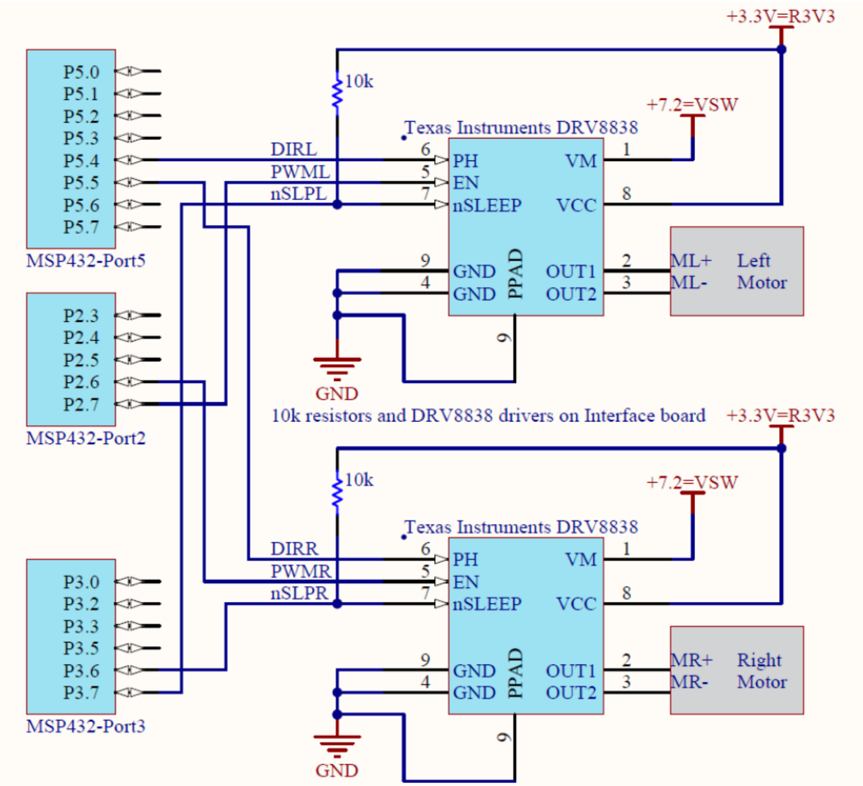


DRV8838 datasheet

Motor Interface on TI-RSLK Chassis Board



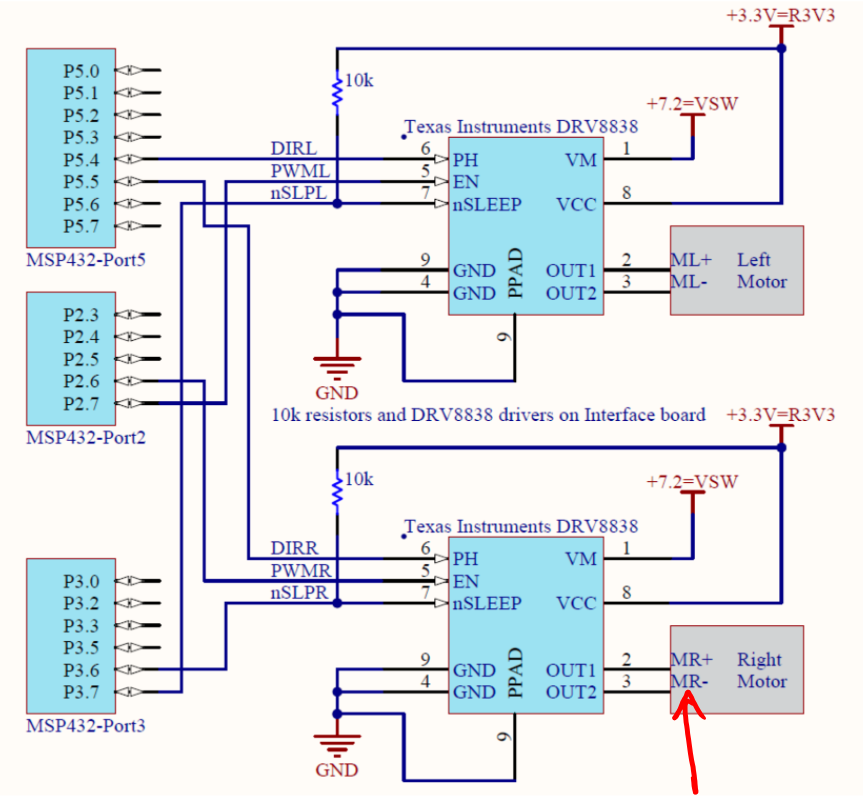
Motor Interface on TI-RSLK Chassis Board



PH/DIRL/P5.4	EN/PWML/P2.7	Left wheel action
1	0	Stop
0	0	Stop
0	1	Forward
1	1	Back

PH/DIRL/P5.5	EN/PWML/P2.6	Right wheel action
1	0	Stop
0	0	Stop
0	1	Forward
1	1	Back

Motor Interface on TI-RSLK Chassis Board



PH/DIRL/P5.4	EN/PWML/P2.7	Left wheel action
0	0	Stop
1	0	Stop
0	1	Forward
1	1	Back

PH/DIRL/P5.5	EN/PWML/P2.6	Right wheel action
0	0	Stop
1	0	Stop
0	1	Forward
1	1	Back

Drive circuit waveforms for DC Motors

DRV8838

Times < 200ns