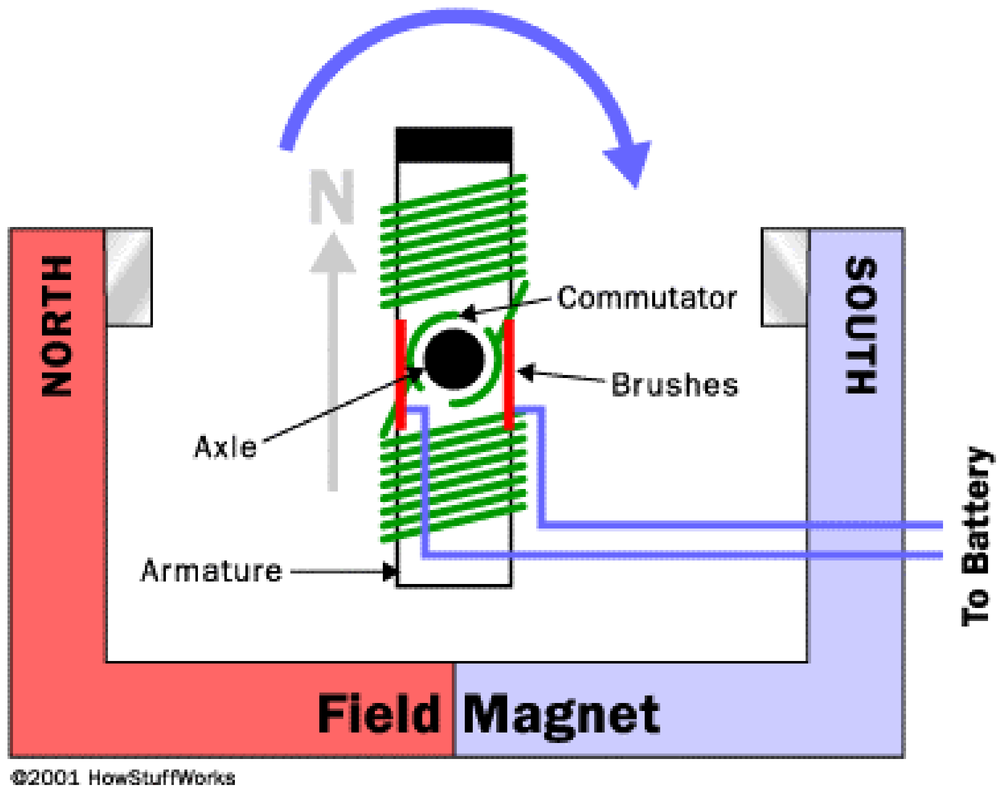
Types of Electric Motors

- AC motors: time varying voltage used to generate time-varying magnetic fields and motion
- DC motors: fixed voltage is switched to generate time-varying magnetic fields and motion
- AC induction motors
  - AC voltage applied to stator winding induces current in rotor windings and interacting magnetic fields provide motion. Commonly found in home appliances such as blenders, washers, and dryers.
- Brushless DC motors
  - Consist of permanent magnet rotor and externally switched stator windings. Lack of brushes reduces sparking and increases durability, but expensive exotic materials needed to keep small size and rotor inertia low.

Types of Electric Motors

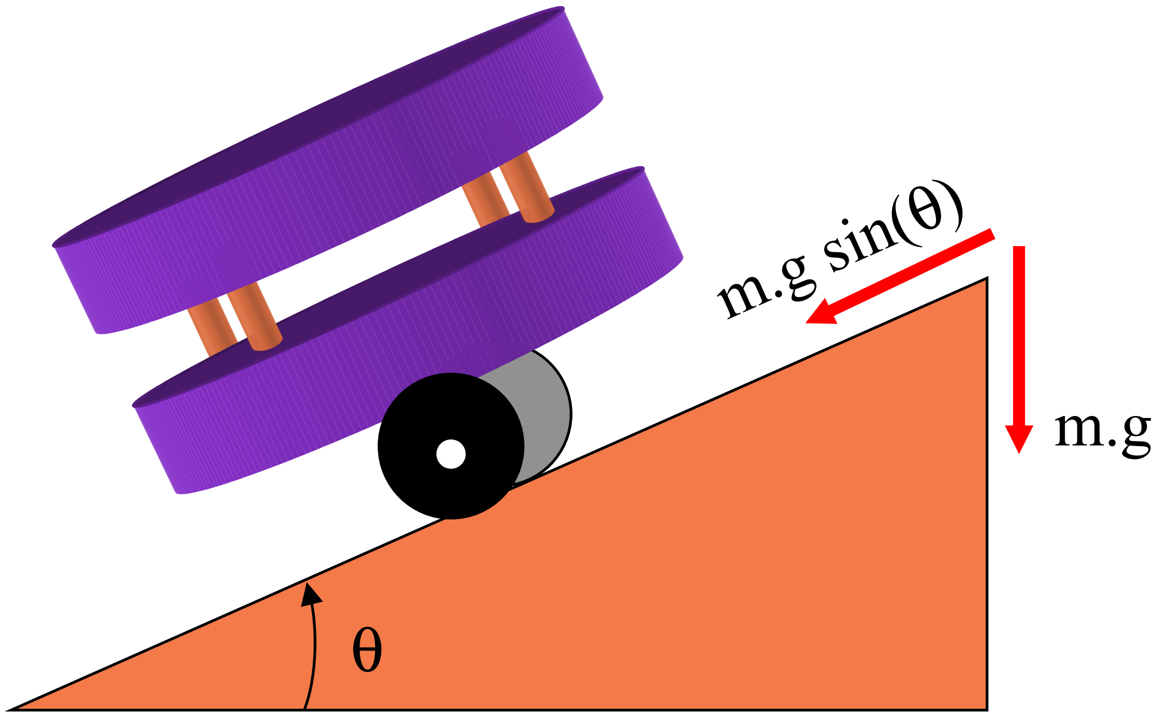
- DC stepper motors
  - Move in fixed increments by externally switched windings. Often employed to achieve accurate incremental positioning (*e.g*. hard drive and print head motors).
- Basic reversible permanent magnet DC motors
  - Normally referred to as "DC motors". These can be "cheap" (~10¢) and small, and typically offer high-speed (5,000 rpm) and low torque (1-5 oz-in).
- DC gearhead motor
  - This variant of the basic DC motor includes an integrated gear-reduction mechanism and often a built-in optical position encoder or tachometer.
- DC servo motors
  - High quality DC motor with built-in electronics to accomplish accurate closed-loop position (or speed) control. Typically, have "stops" built in to limit angular excursion of the motor shaft for applications such as RC vehicles.
- Conclusion: DC gearhead motors are a good compromise.

DC Motor Basics (Brushed)



Motor “Sizing”

- Determine motor power.



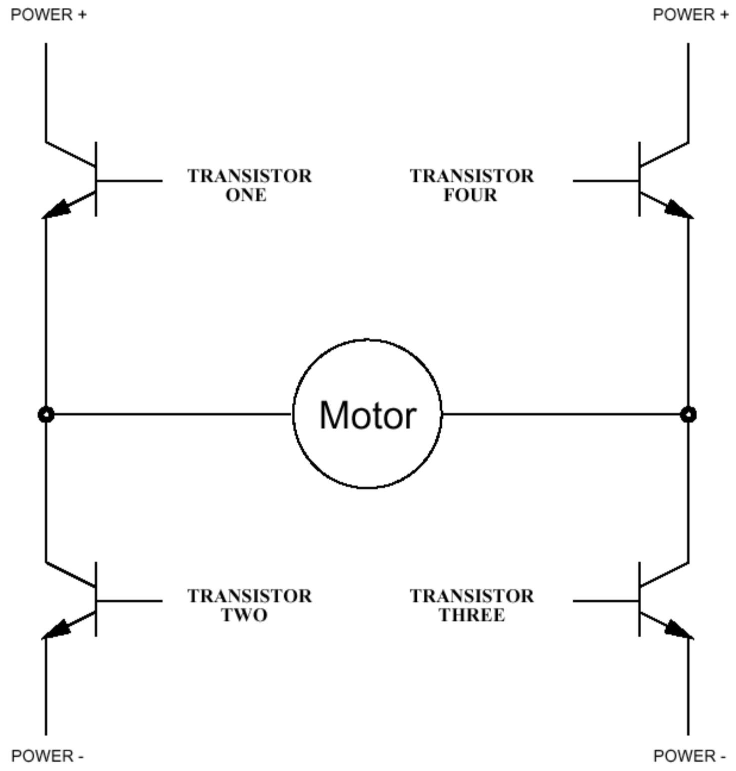
- Power = force * linear speed = torque * angular speed

“Sizing” the motors

- Basic Specifications:
  - Maximum linear speed = 1 m/sec. (~3 ft/sec.)
  - Wheel diameter = 0.1 m (~4 inches)
  - Maximum mass = 6 Kg (~13 lbs)
  - Maximum grade (slope) = 10°
- Requirements:
  - Power = Force · Speed = m · g · sin(10°) · 1m/sec = 10.2 Watts
  - Rotational Speed = Linear Speed ÷ Wheel Radius
    = 1 m/sec · 60 ÷ (3.14159 · 0.1) ≅ 191 rpm
  - Torque = Force · Distance = m · g · sin(10°) · Wheel Radius
    = 6 · 9.81 · 0.1737 · (0.1 ÷ 2) = 0.51 N·m (~72 oz·in)
- Specs. for each motor (assuming 70% efficiency):
  - Max. Power: (10.2 ÷ 2) ÷ 0.7 = 7.3W
  - Max. Continuous Torque: (0.51 ÷ 2) ÷ 0.7 = 0.36N·m (~51oz·in)
  - Speed (after gearbox): 191rpm

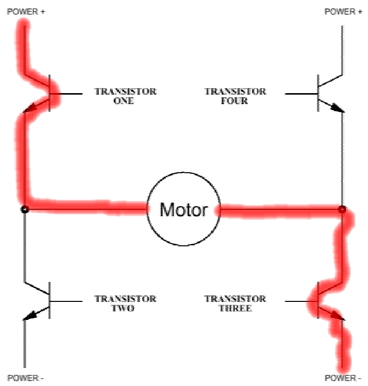
Motor Drivers

- Need for a Driver:
  - The typical digital output can supply 10-30mA while a small DC motor can draw 500-4,000 mA!! ⇒ Need an amplifier!!
  - Analog driver using microcontroller D/A and amplifier is one solution.
  - Computers in general are good at turning signals on an off, so its common to use this switching (PWM and direction) and H-bridge motor driver.

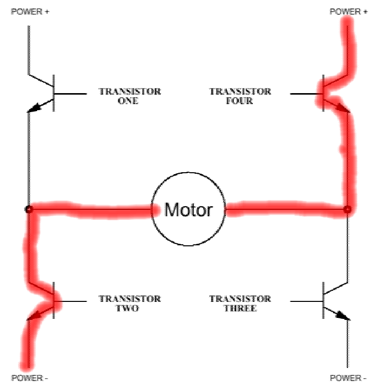


Motor Drivers: H-Bridge

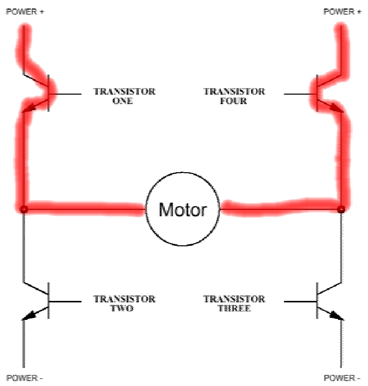
- Forward (1 & 3 ON):



Reverse (2 & 4 ON):

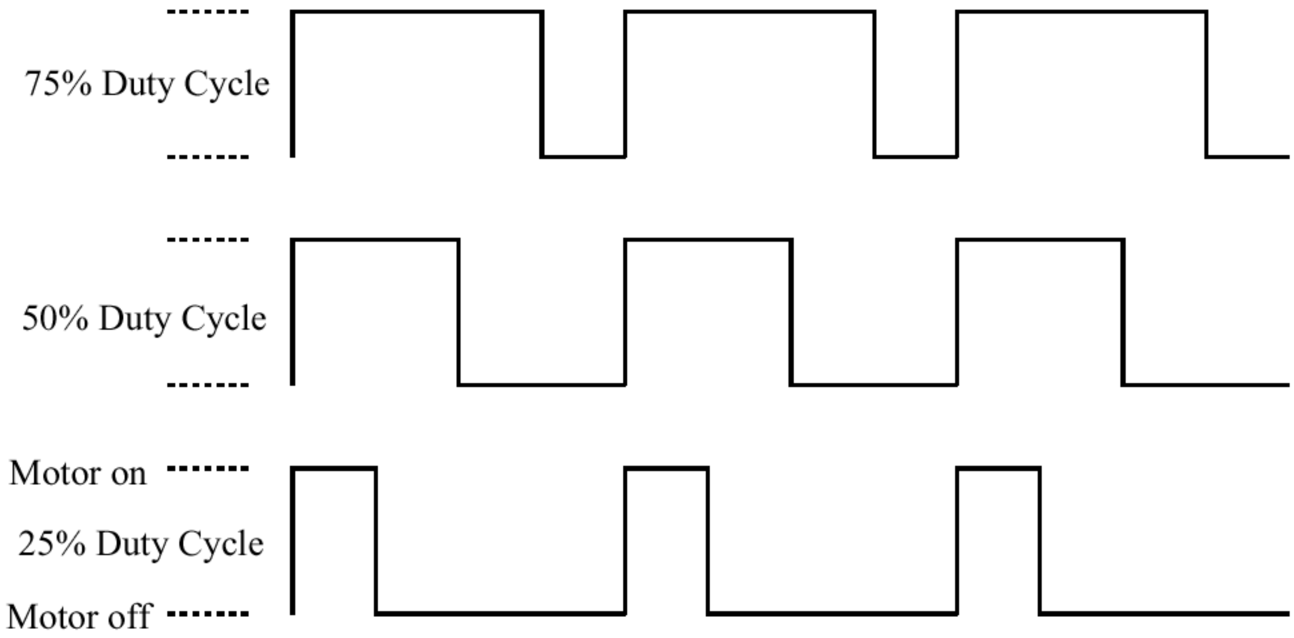


- Braking (1 & 4 ON):



Motor Drivers: PWM

- Pulse Width Modulation: Turn the motor on and off "very rapidly"

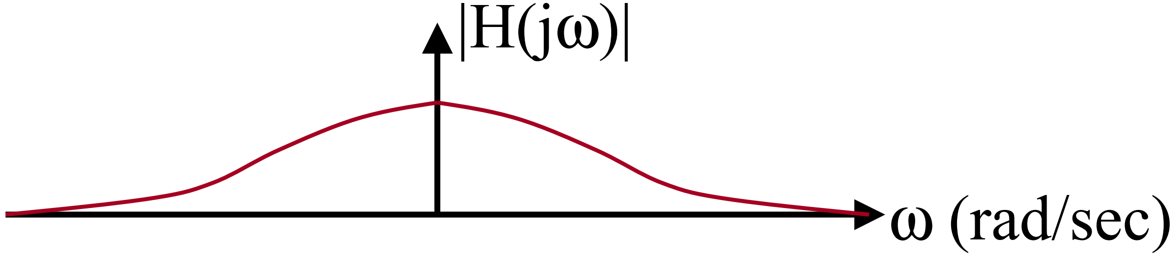


Motor Drivers: PWM

- Periodic signals (with period T and fundamental frequency $\omega_0 = 2\pi/T$) such as PWM can be written as a Fourier Series

$$v_a(t) = c_0 + \sum_{n=1}^{\infty} 2|c_n| \cos(nw_0 t + \angle c_n), \quad c_0 = \frac{V_S t_{on}}{T}$$

- DC motors act as low-pass filters, $H(j\omega) = \Omega(j\omega)/V_a(j\omega)$



- Motor speed (output) is also a Fourier Series

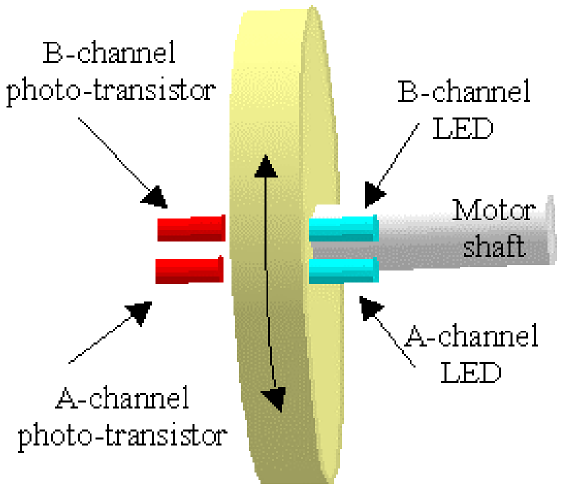
$$\omega(t) = c_0|H(0)| + \sum_{n=1}^{\infty} 2|c_n||H(nw_0)| \cos(nw_0 t + \angle c_n + \angle H(nw_0))$$

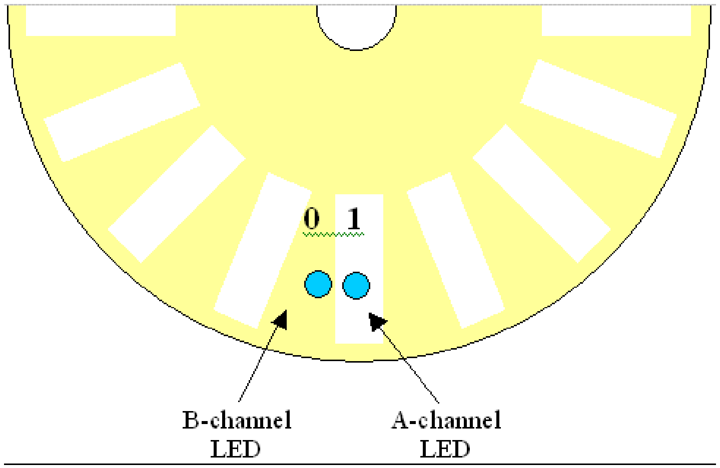
Choosing ω_0 "large enough" that $|H(n\omega_0)|$ is small results in approximately constant motor speed determined by t_{on}

$$\omega(t) = c_0|H(0)|$$

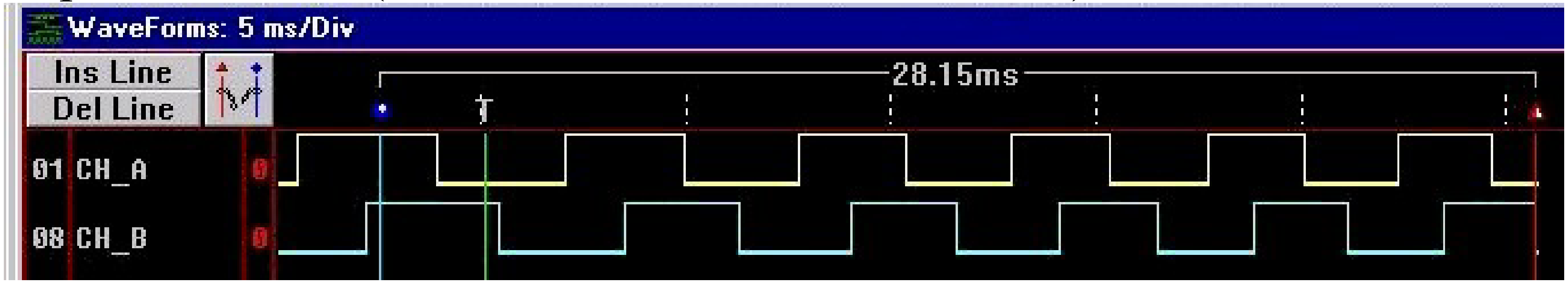
Encoders

- Optical Encoders:





- Output Waveform (see EE231 Labs 12 for more info.):



Encoders

- Direction of motor rotation:
  - 90° phase shift in channels allows direction to be determined via
    - Using one signal as a clock and other as direction
    - State machine
- Position feedback:
  - Pulse counting can be achieved via
    - Pulse accumulator/input capture on microcontroller
    - Counter built out of discrete components or in PLD
- Velocity feedback:
  - Pulse frequency can be achieved via
    - Frequency-to-voltage converter (differentiation)
    - Counting pulses over a fixed amount of time to find pulses/second