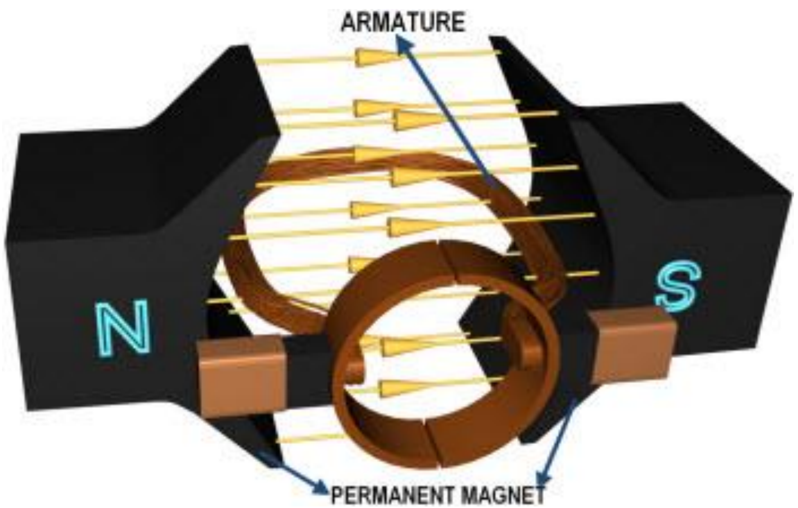
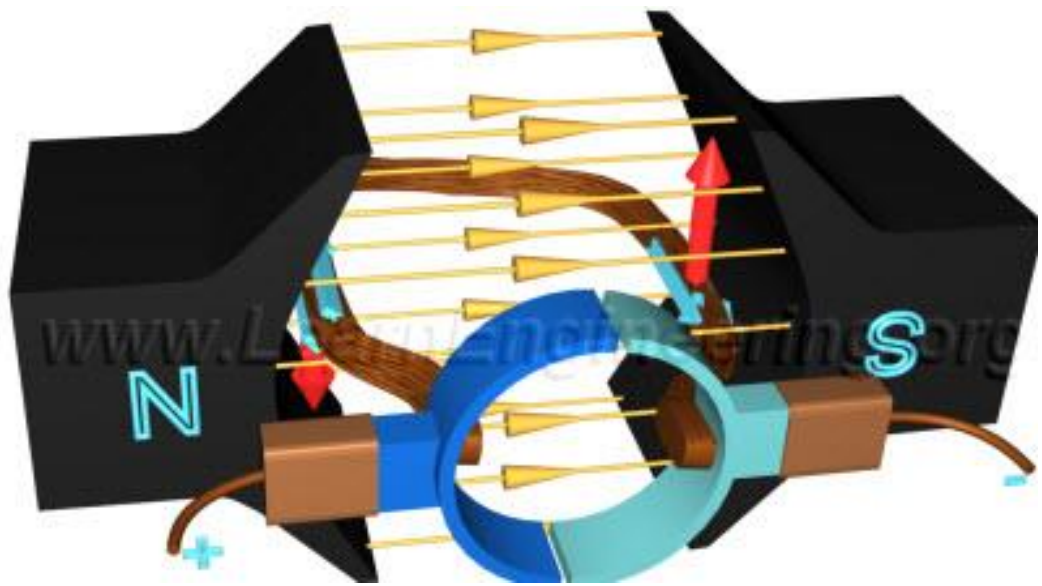
ACTUATORS AND SENSORS

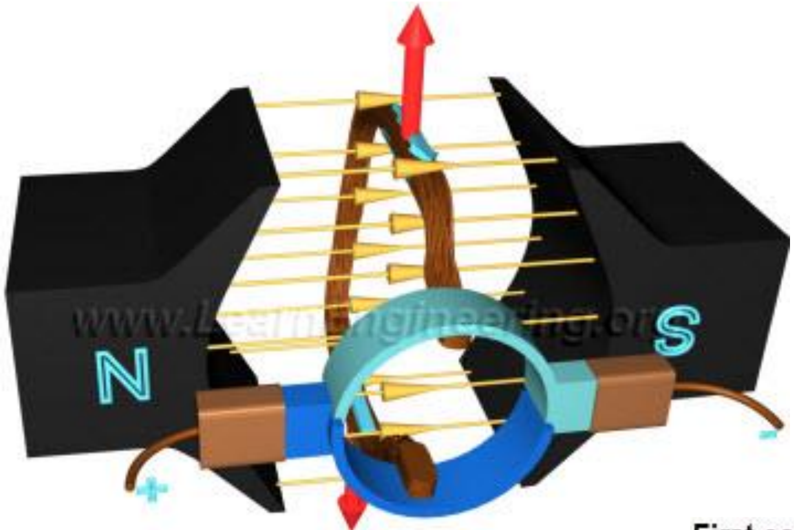
Andrea Calanca

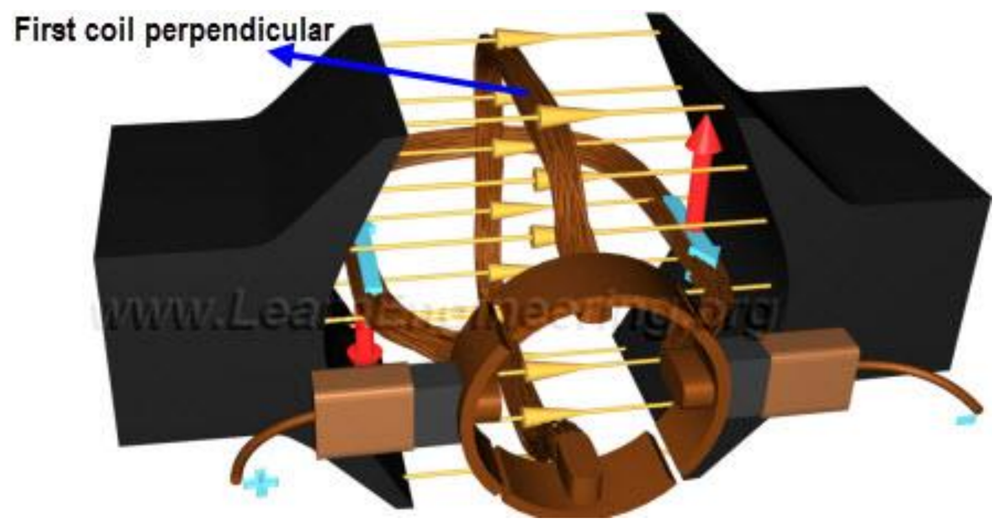
DC Motors





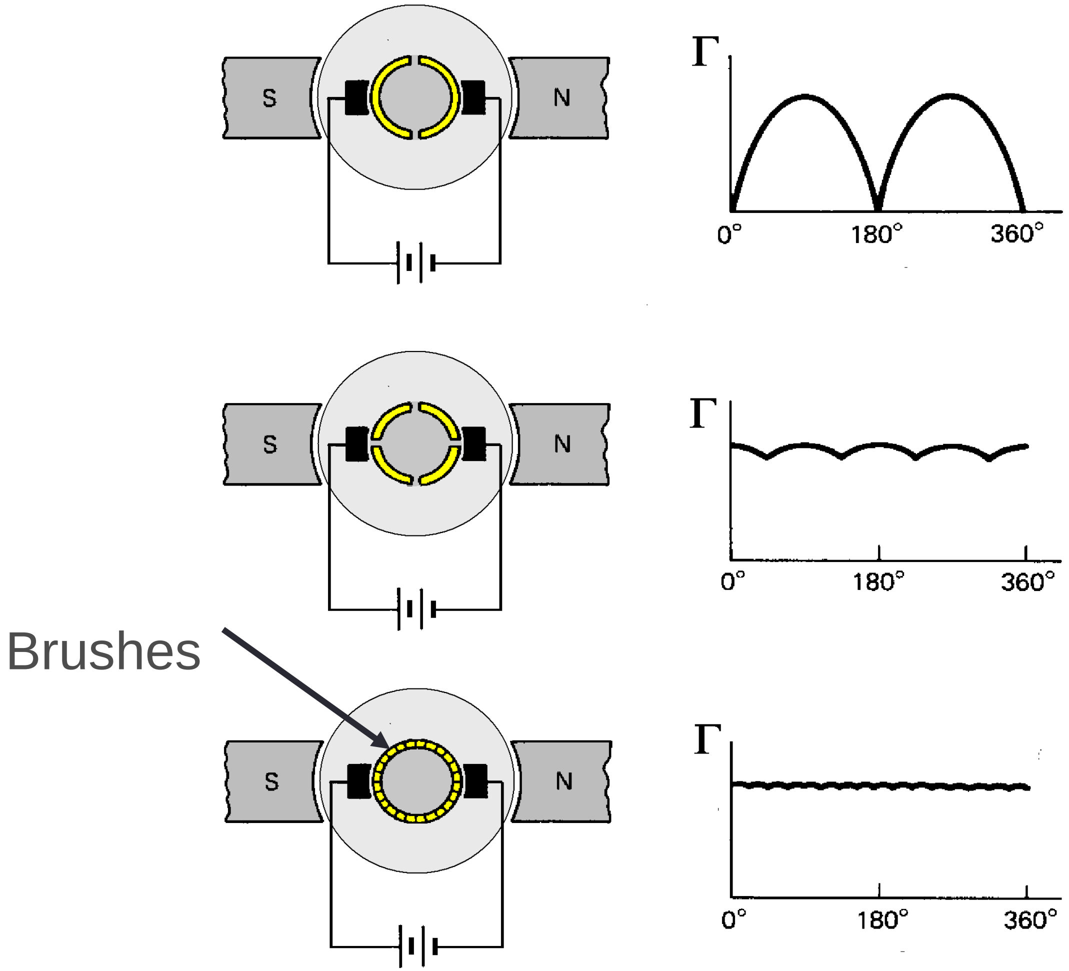
DC Motors





DC Motors

D.C. Motors.



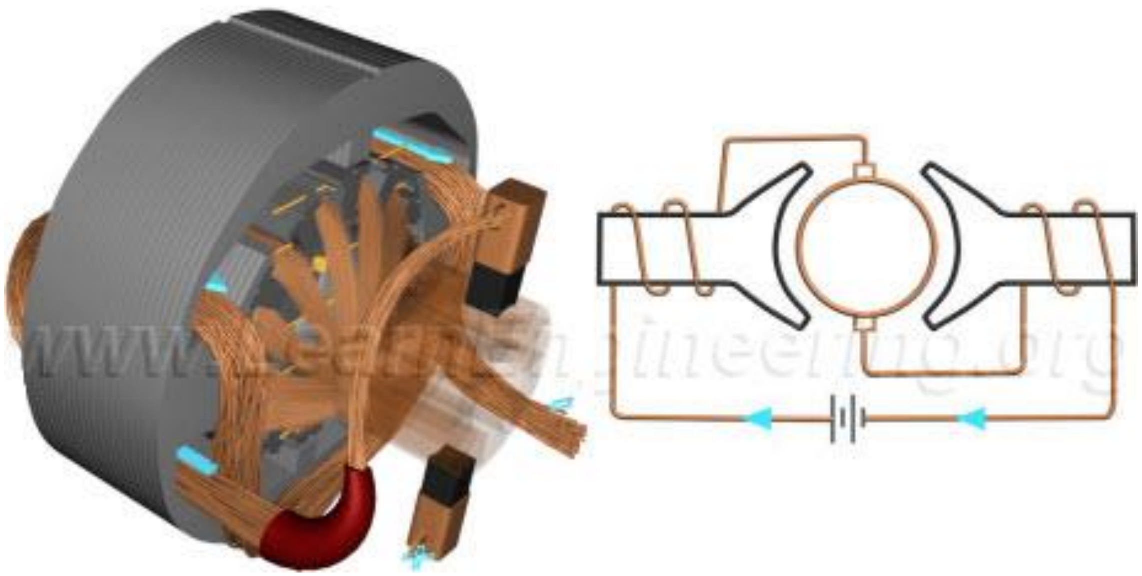
Motor torque with one turn coil

Motor torque with two turns coil

Motor torque with multiple turns coil

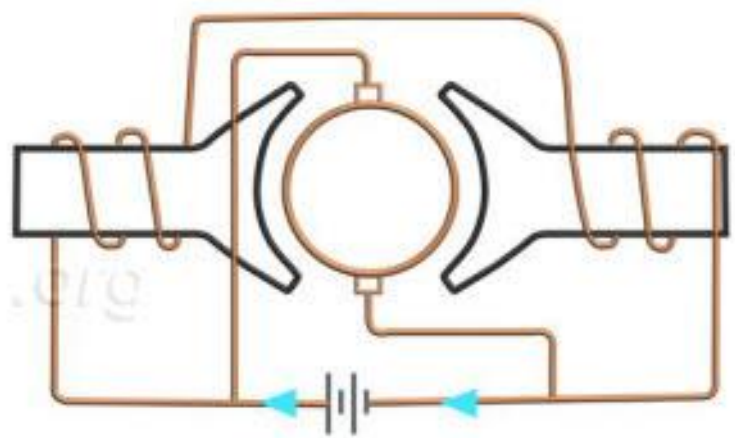
DC Motors

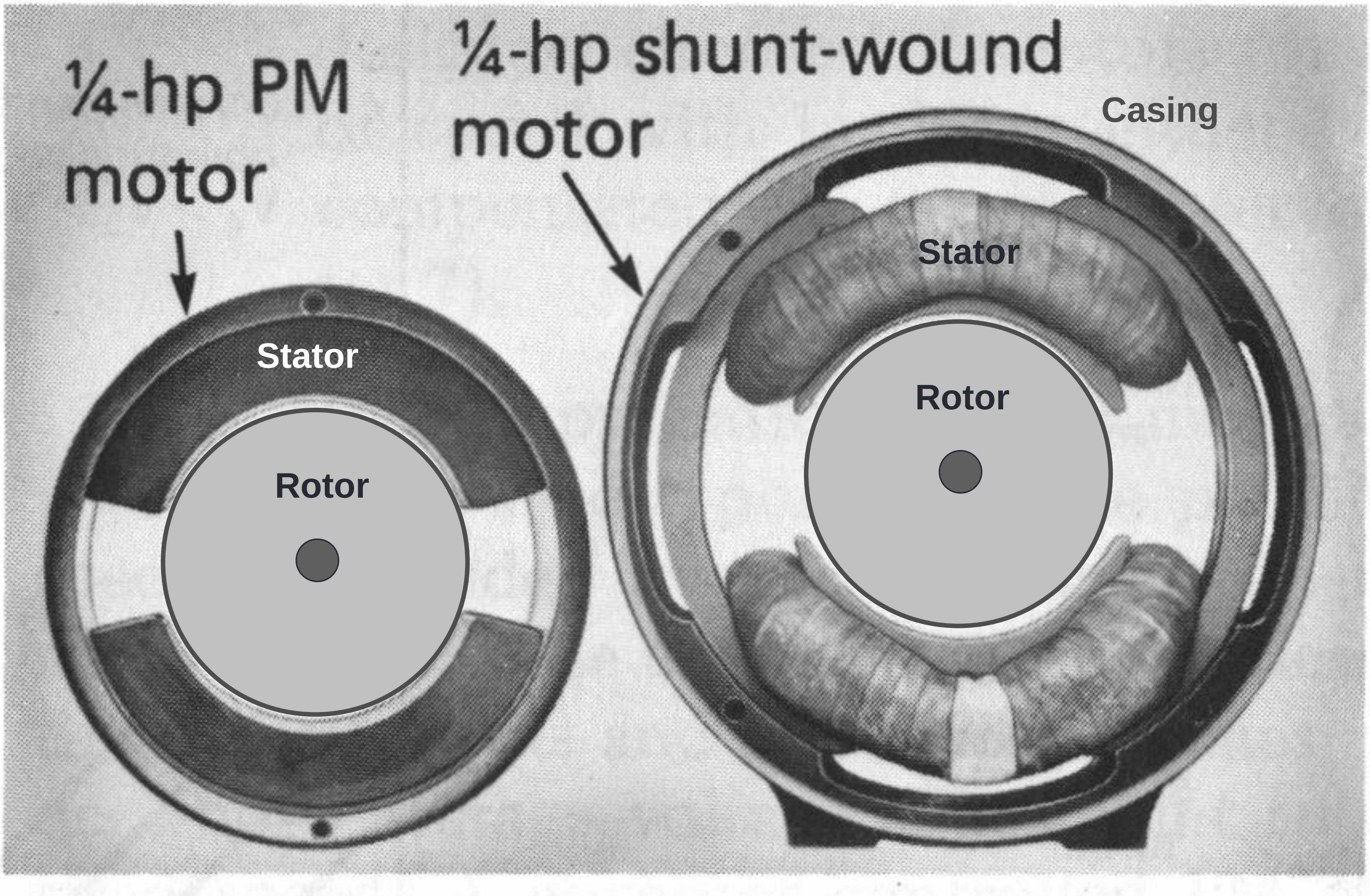
- Most of DC motors in robotics make use of permanent magnets.
- Sometimes permanent magnets are substituted with electromagnet, powered by the same DC source

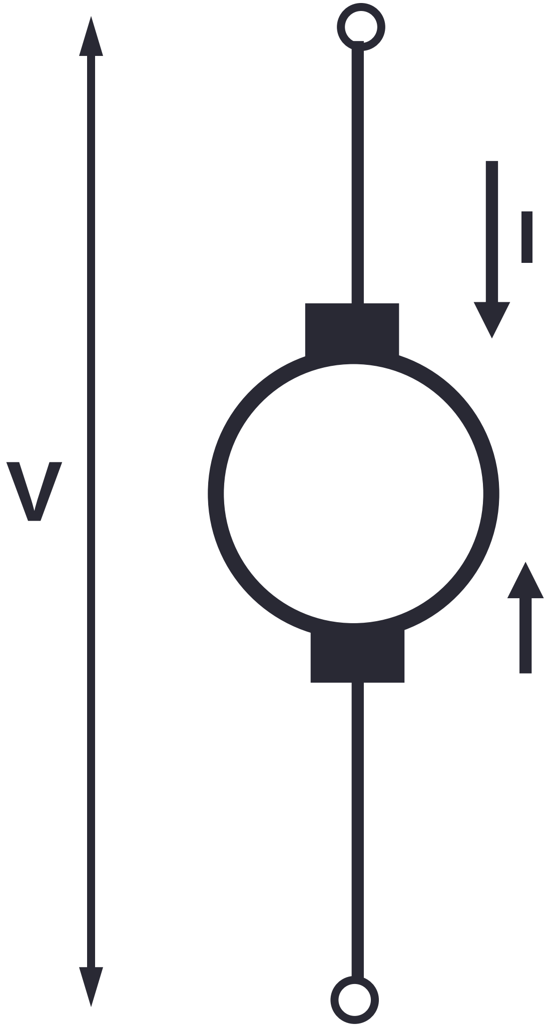


DC Motors

The electromagnet can be arranged in series or parallel



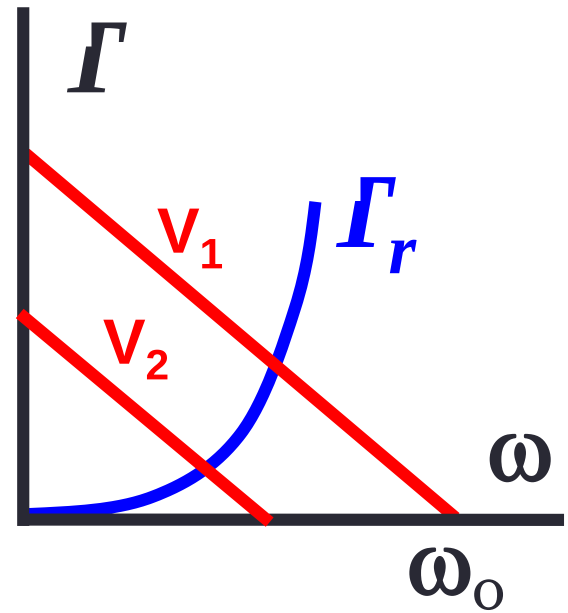

¼-hp PM motor
¼-hp shunt-wound motor
Casing
Stator
Rotor
Stator
Rotor



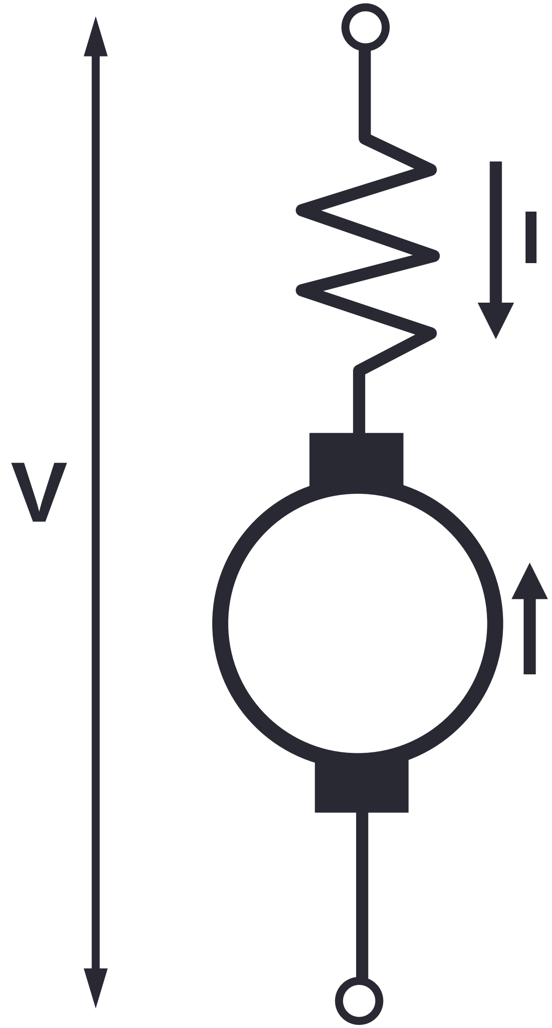
$$V = I \cdot (R_e + R_r) + V_{cem}$$

$$T = K_I \cdot I \cdot \Phi_o$$

$$V_{cem} = K_V \cdot \omega$$



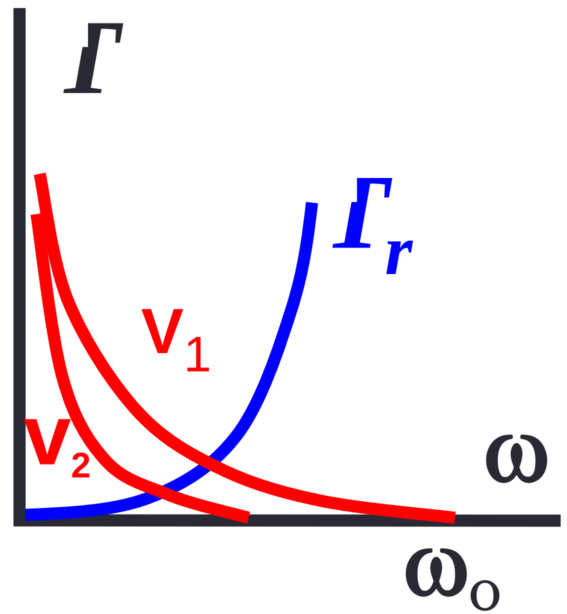
Permanent magnet
dc motor



$$V = I \cdot (R_e + R_r) + V_{cem}$$

$$\Gamma = K_I \cdot I \cdot \Phi_I$$

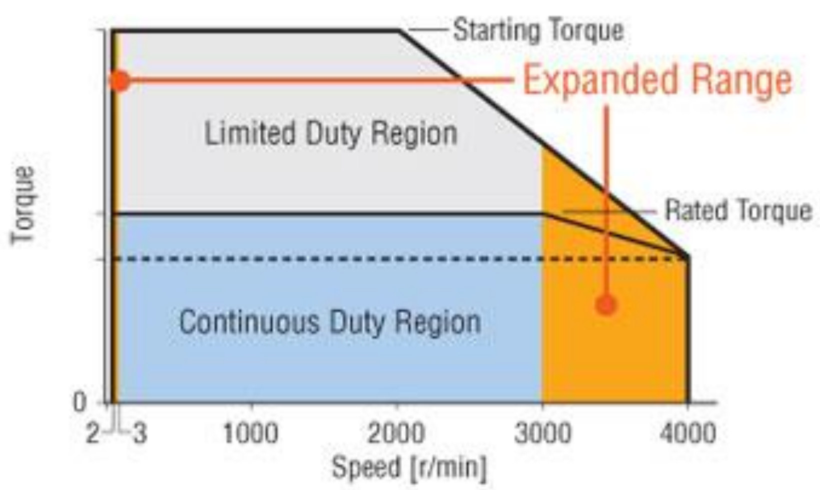
$$V_{cem} = K_v \cdot \omega$$

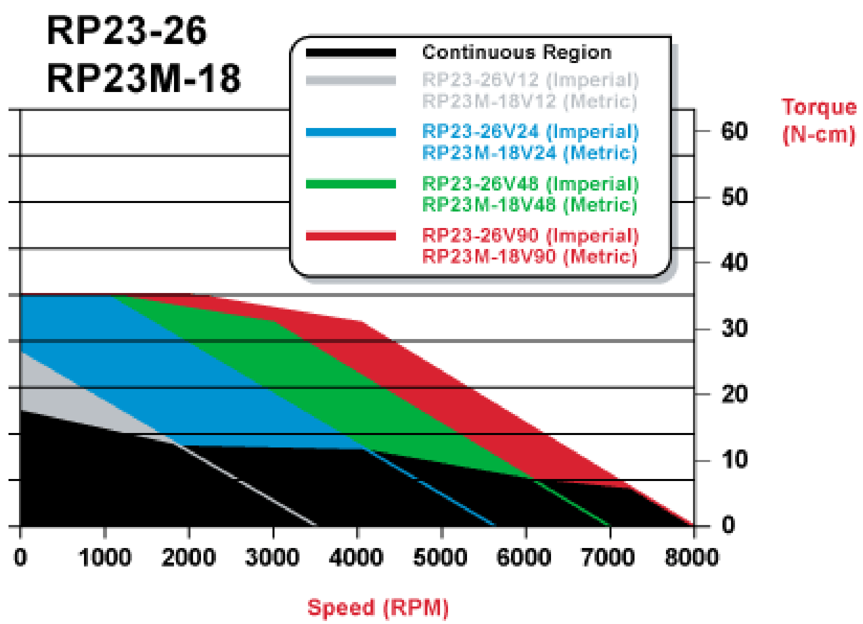


Serial excitation

DC Motors

- Maximum Torque
  - Also called starting or stall torque
- Rated Torque
- Force-Velocity Curve





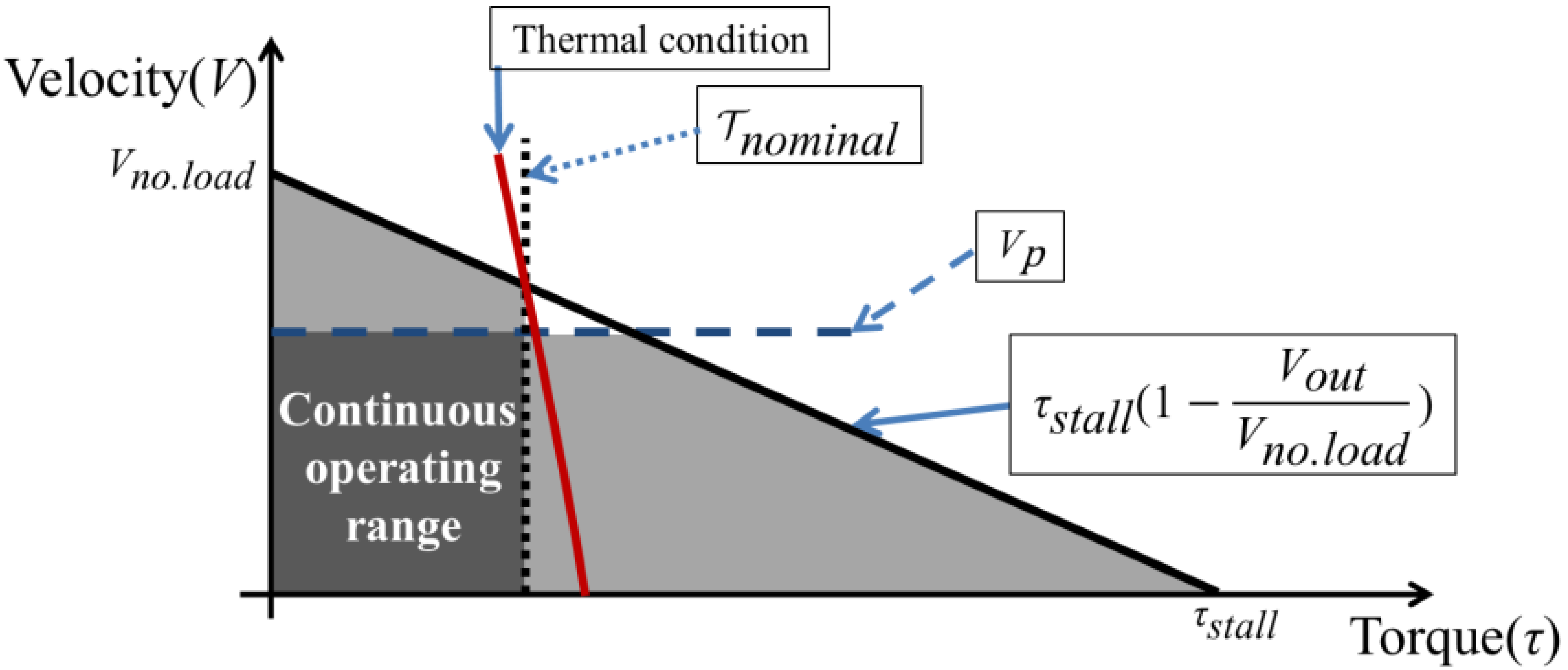
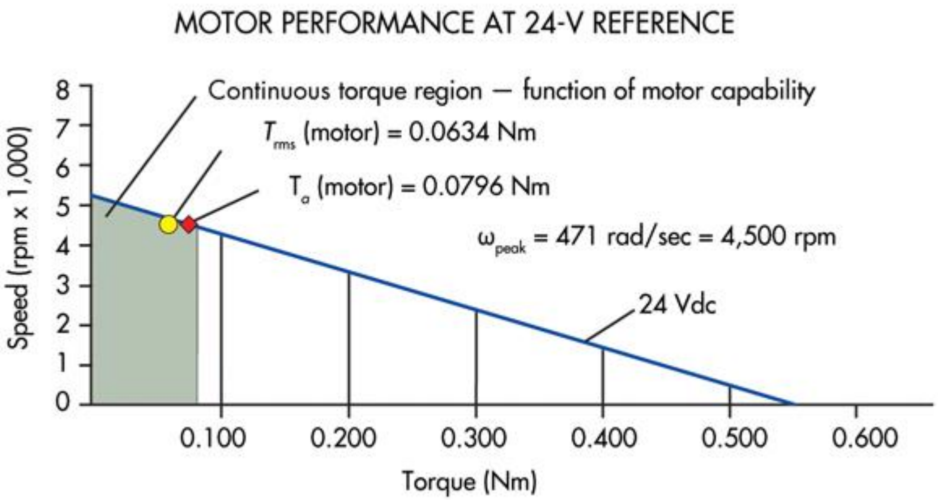
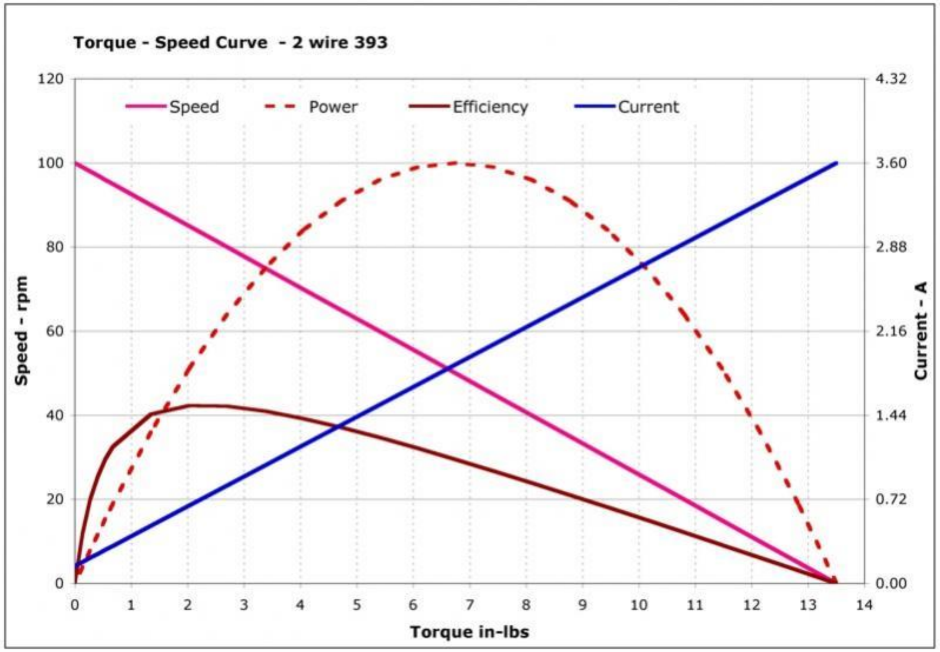


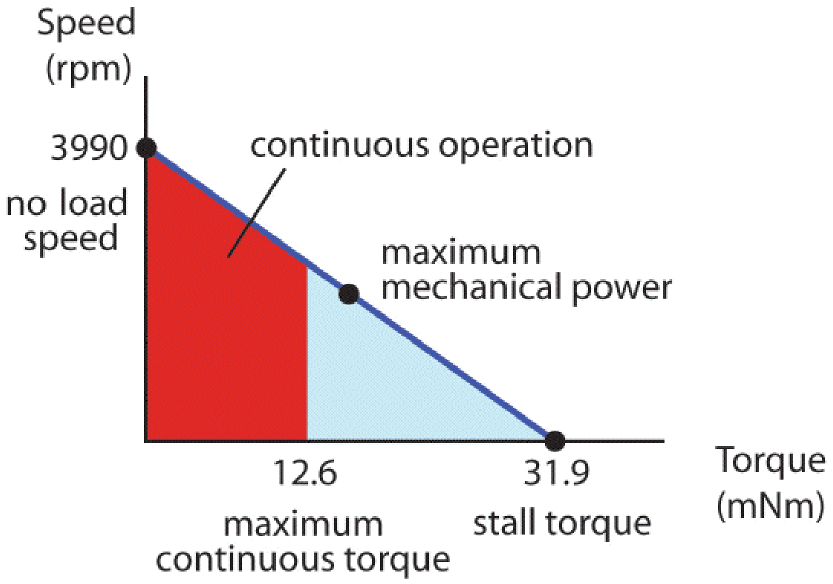
Fig. 2: Continuous operating range of a DC motor considering various conditions. The nominal current value is determined by the intersecting point between the torque/speed curve and the thermal curve. The maximum continuous torque of motor is determined by the nominal current multiplied by the torque constant. The motor speed v_m is limited due to various reasons: the mechanical wear and the electro-erosion of brushed and commutators of a brushed DC motor, and the service life of the bearings[26].

DC Motors

- Power
- Power to weight ratio
- Efficiency







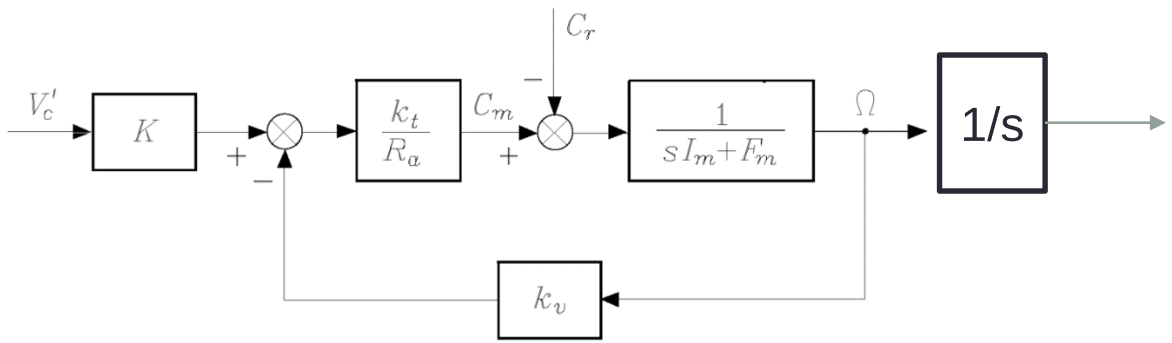
DC Motors

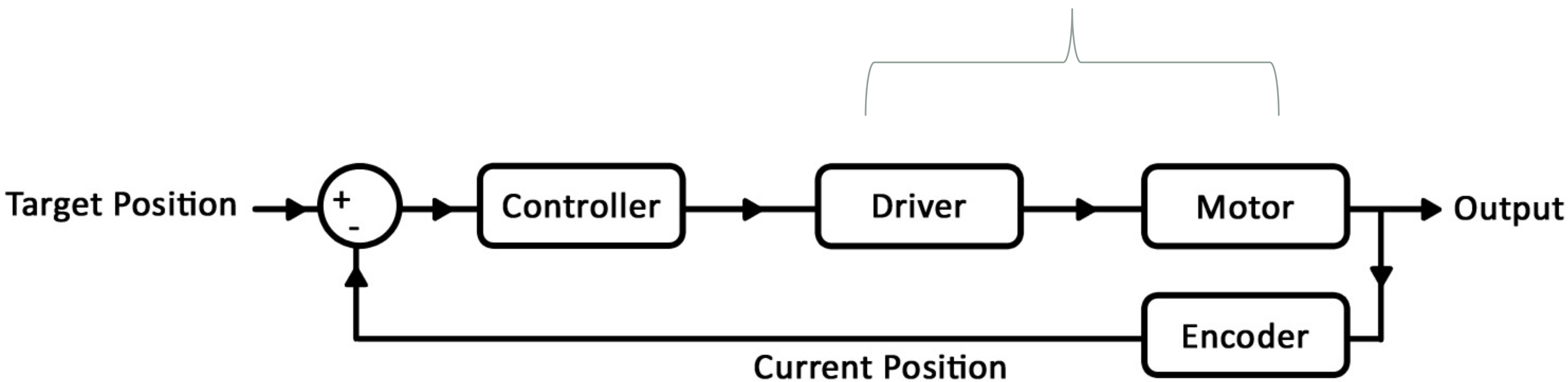
Bandwidth

Can the motor follow a 100Hz sinusoid?

- In electric motors the bandwidth depends on
  - Maximum force
  - Maximum velocity (strongly related to voltage saturation)
  - Motor inertia
  - Load impedance
  - Control Algorithm

Position Control

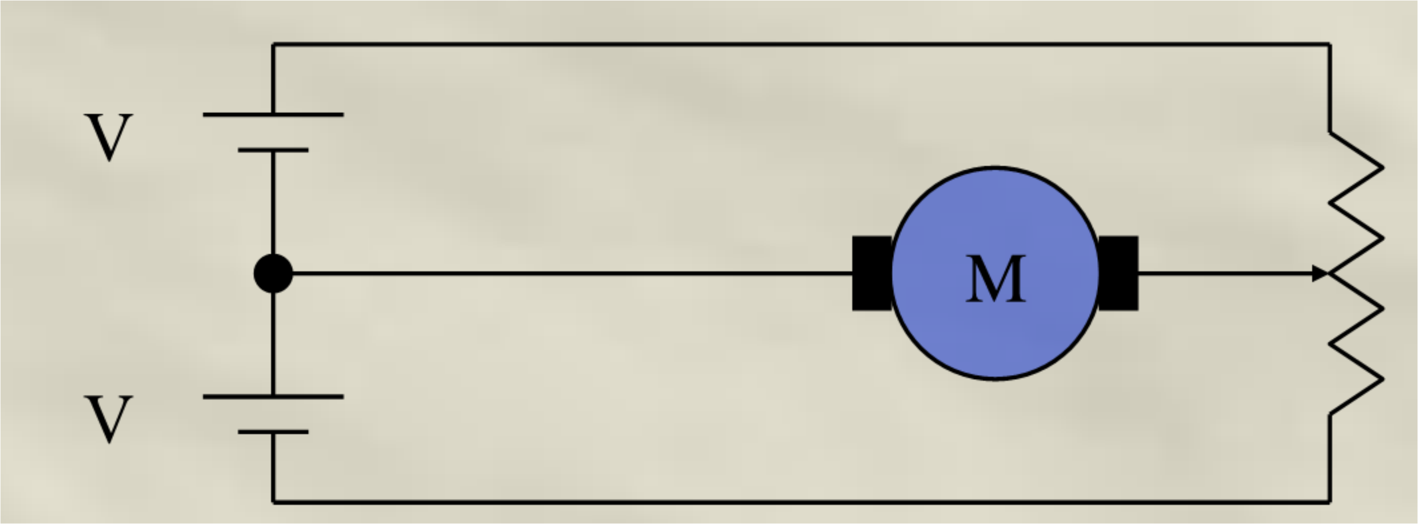




Power Electronics (DC Motors)

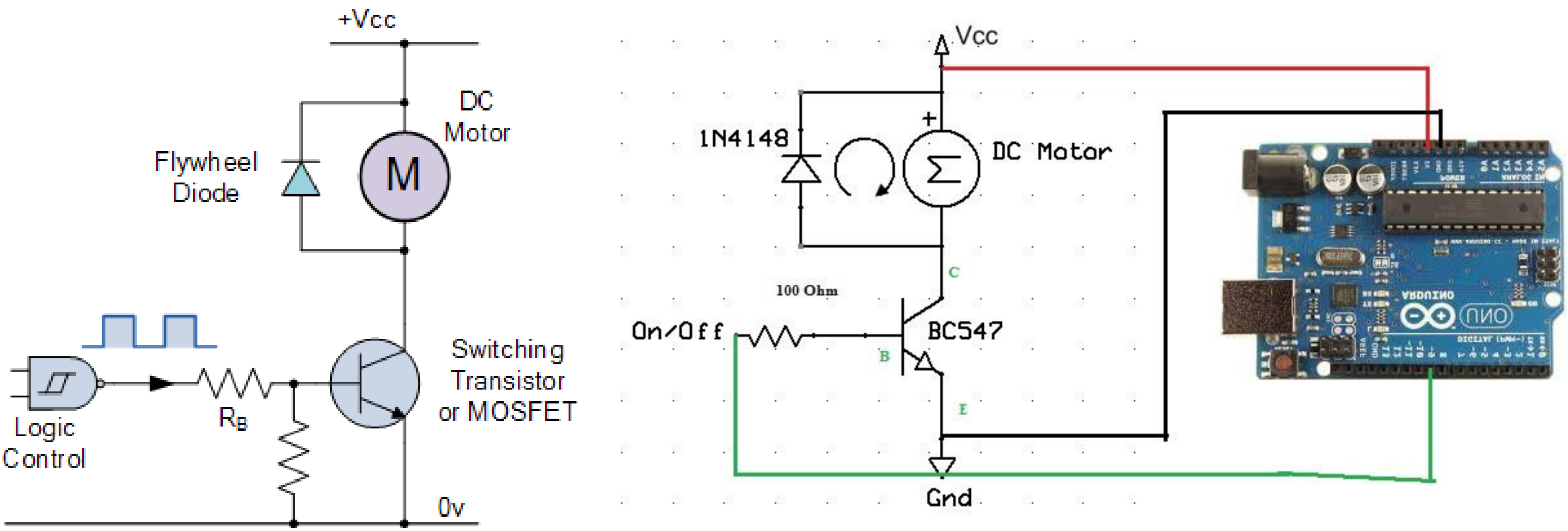
Voltage Control

- The circuits below can apply a desired voltage but implies power dissipation



Power Electronics

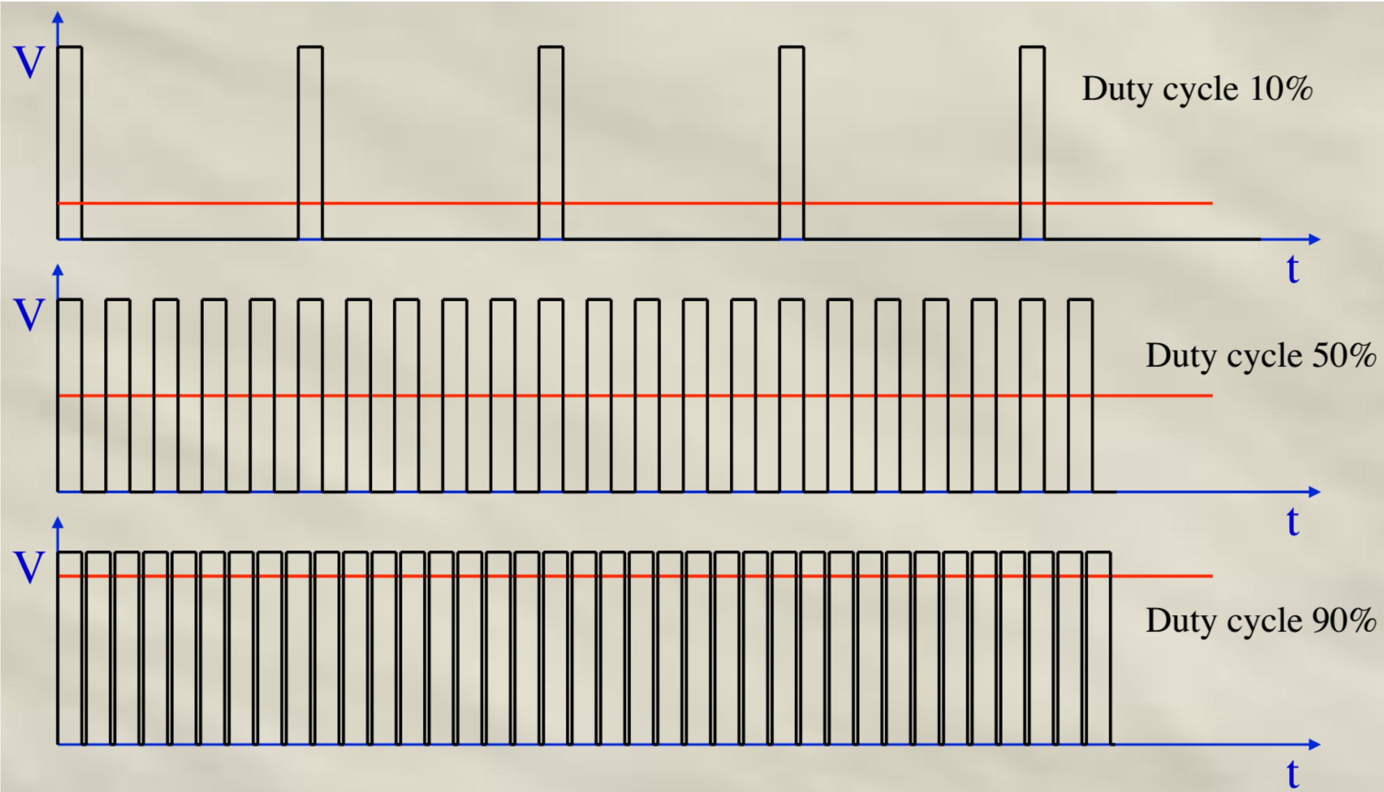
- Use a switching mechanism (i.e. on-off transistor) to partialize the current.
- Use a desired logic to switch on and off the transistor



Power Electronics

(Voltage) Control

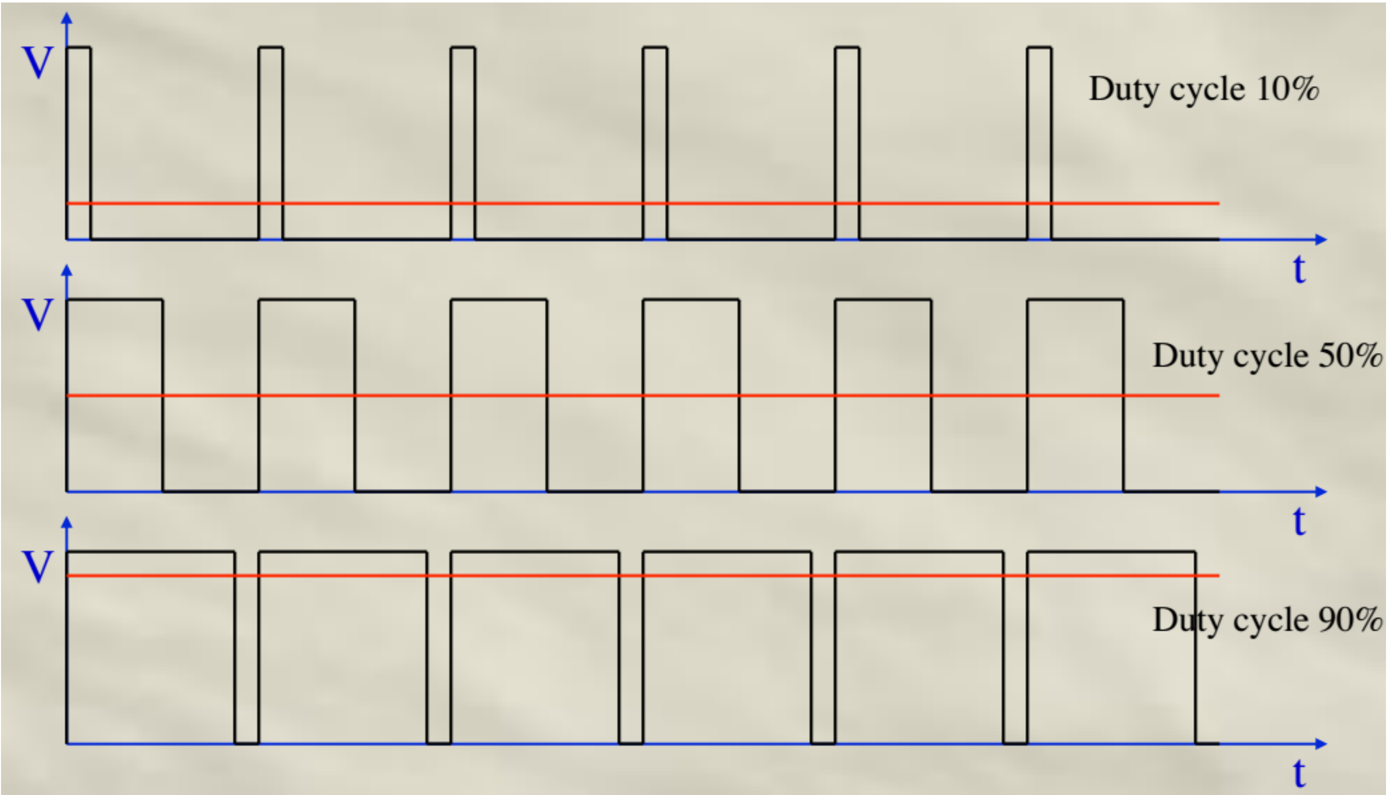
- Logic: Pulse Frequency Modulation



Power Electronics

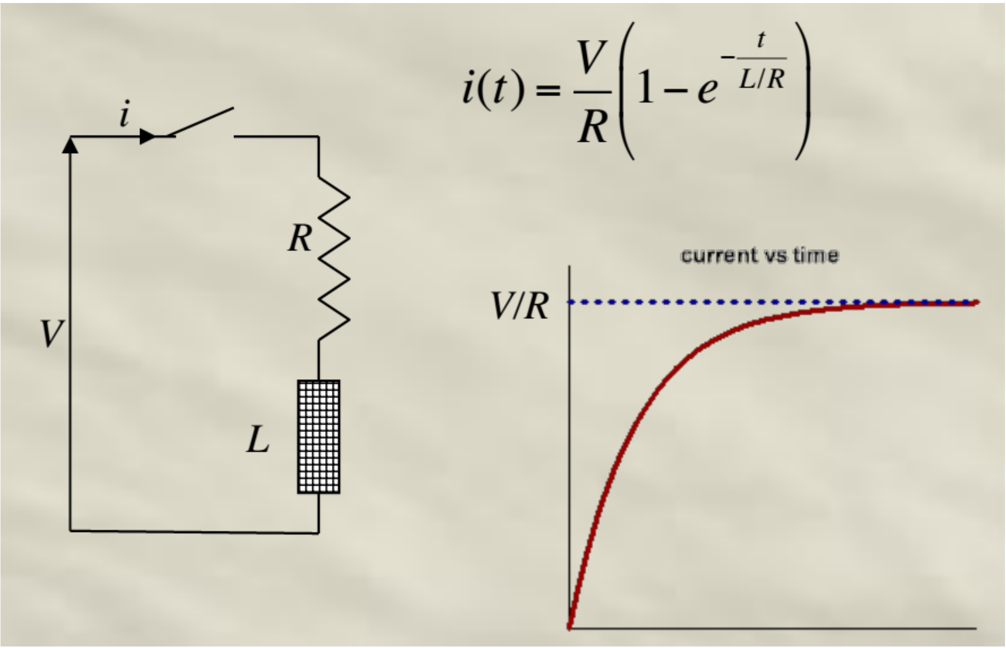
(Voltage) Control

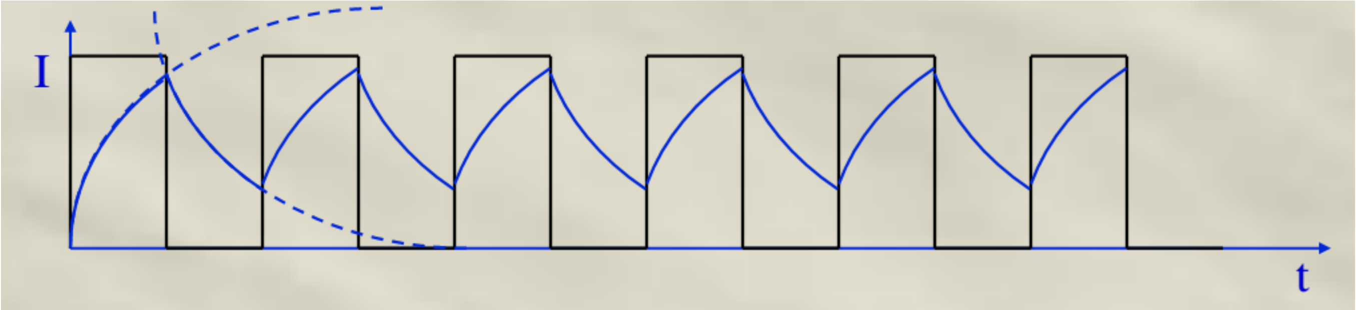
- Logic: Pulse Width Modulation



Power Electronics

Voltage Control

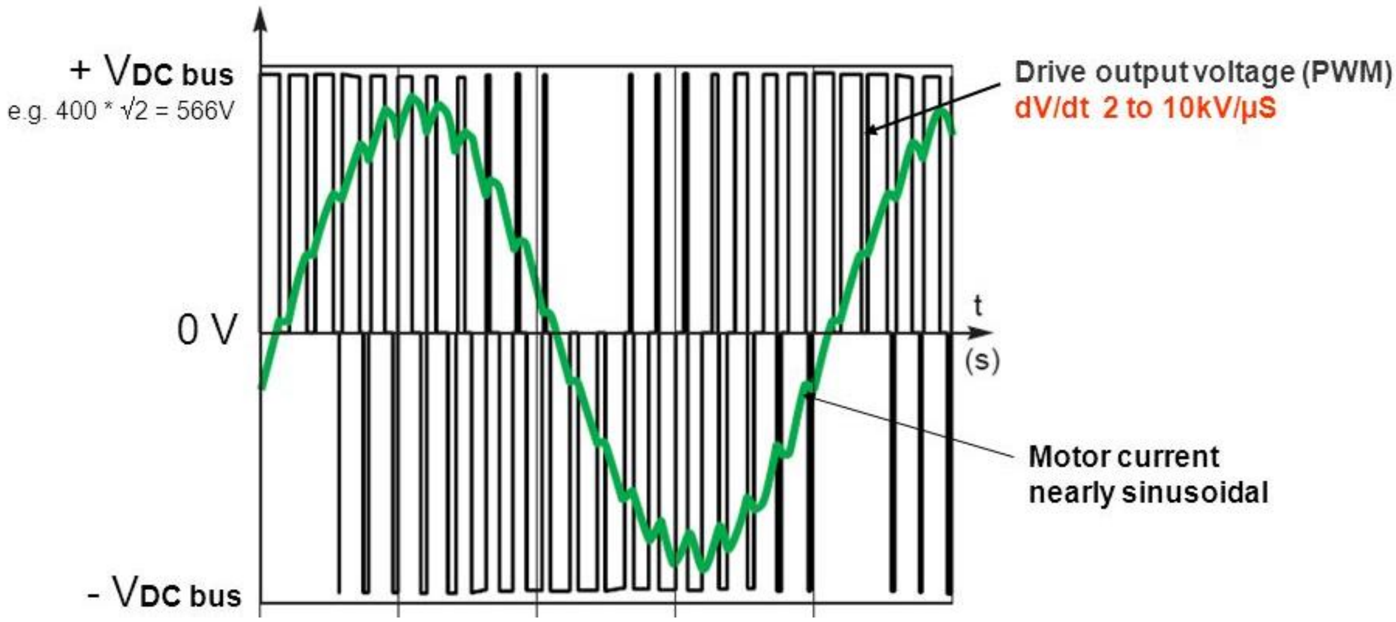




Power Electronics

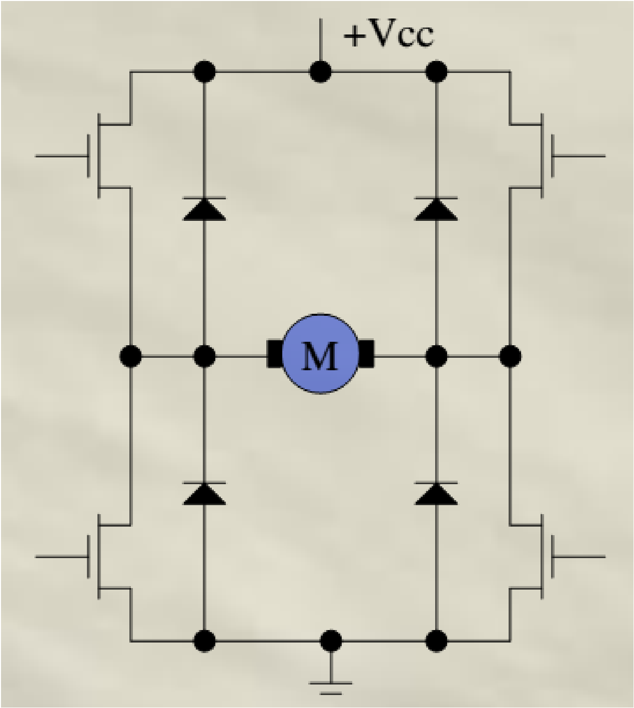
- Voltage Control

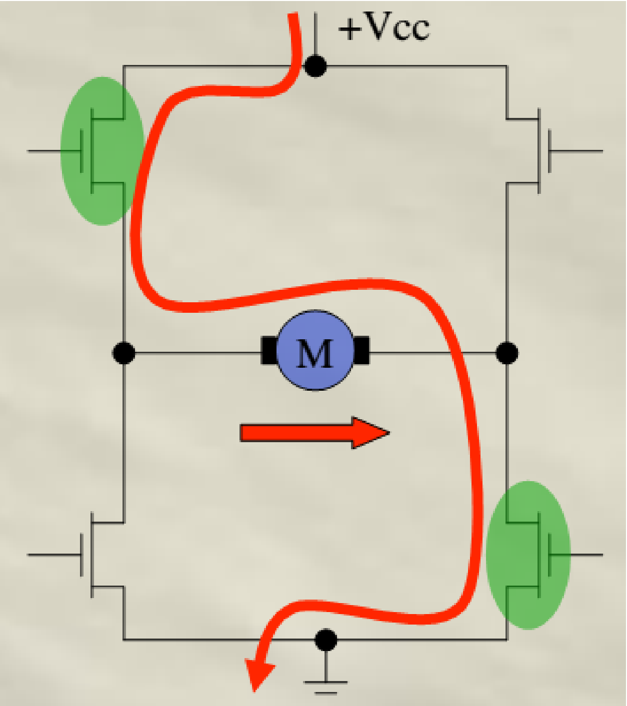
- The switching of the output voltage on the output of a drive by the IGBT bridge generates rapid variations in voltage (dV/dt).

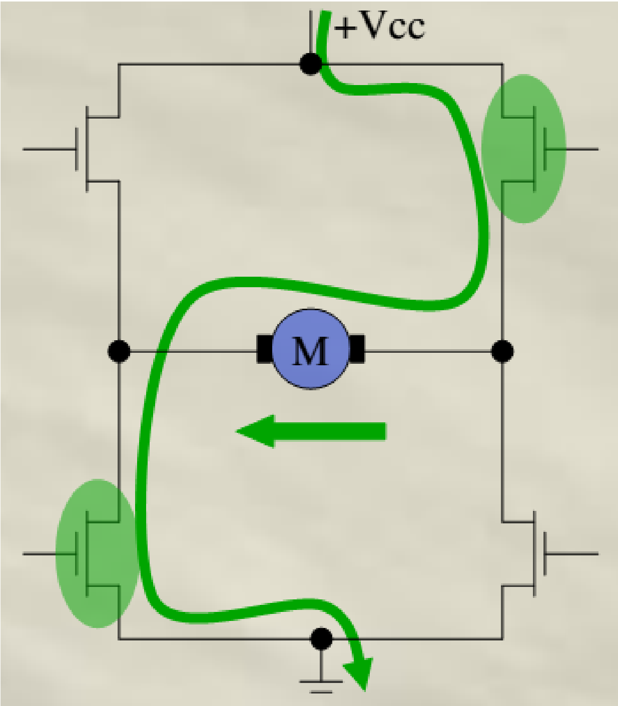


Power Electronics

H-Bridge



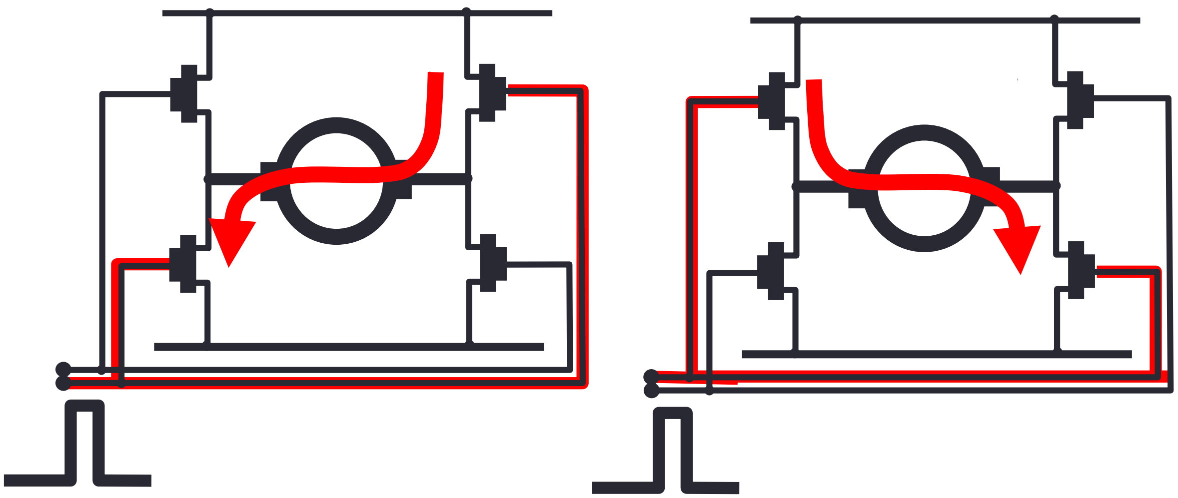




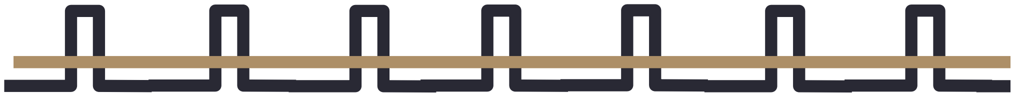
Power Electronics

Voltage Control

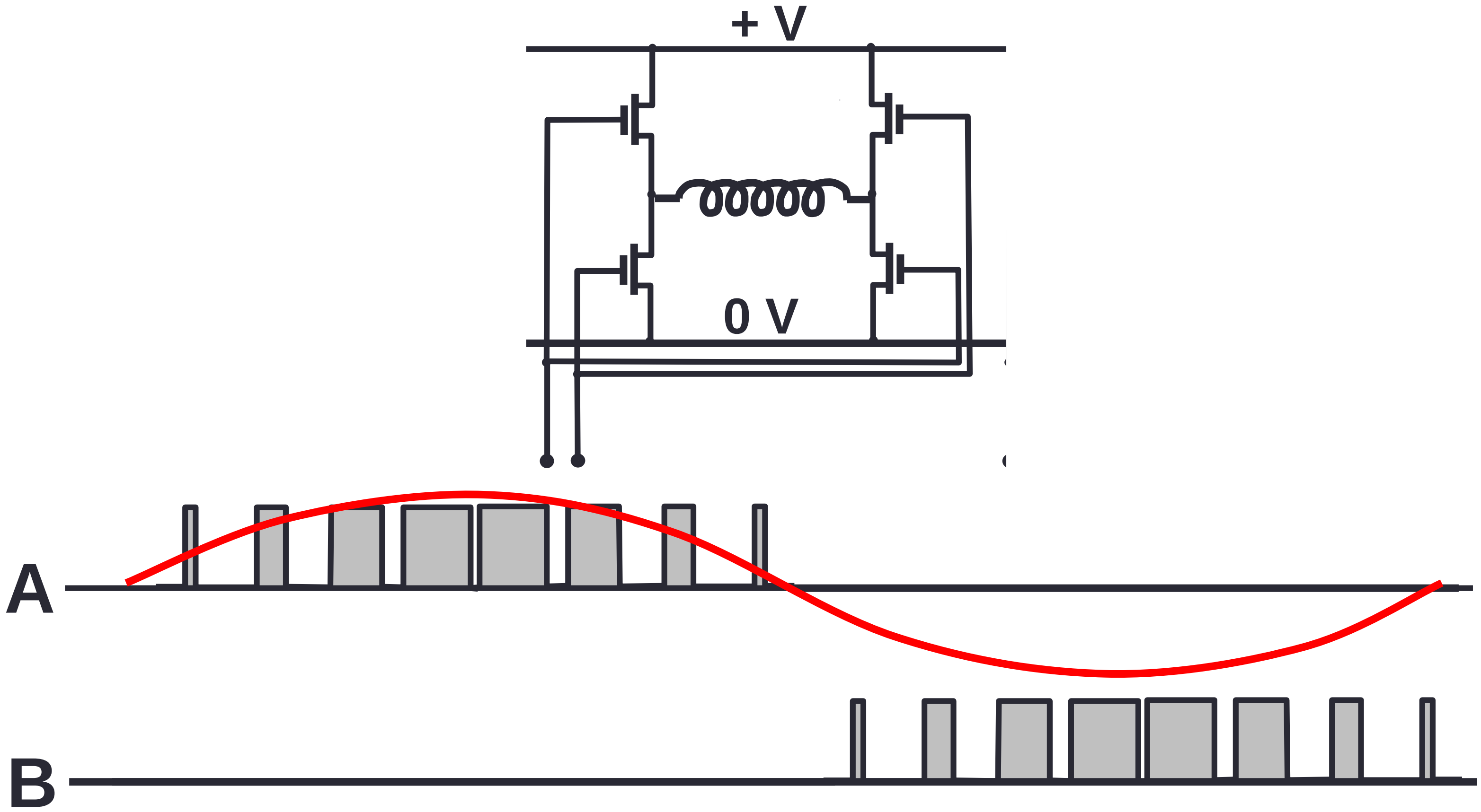
- H-Bridge



PWM

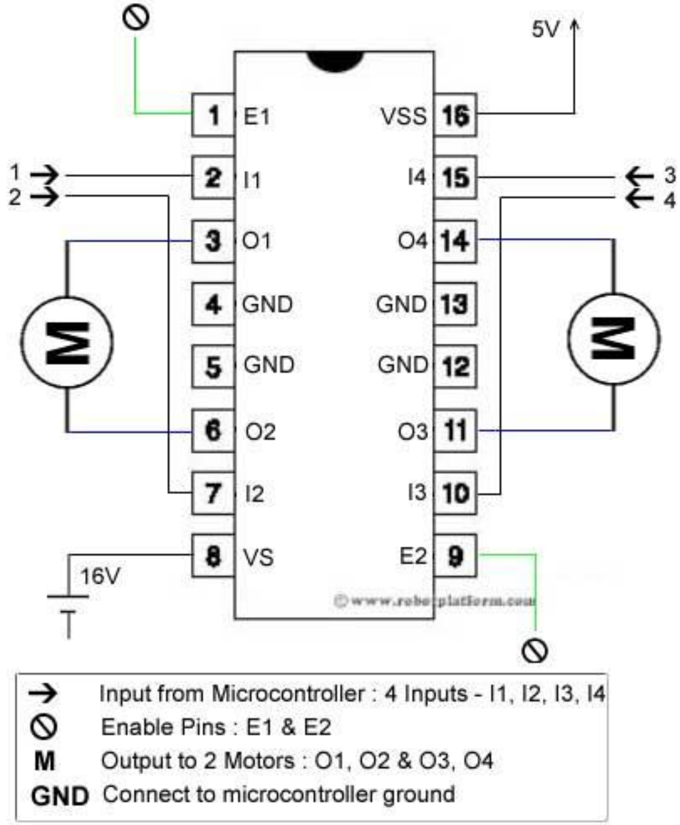


Power Electronics



Power Electronics

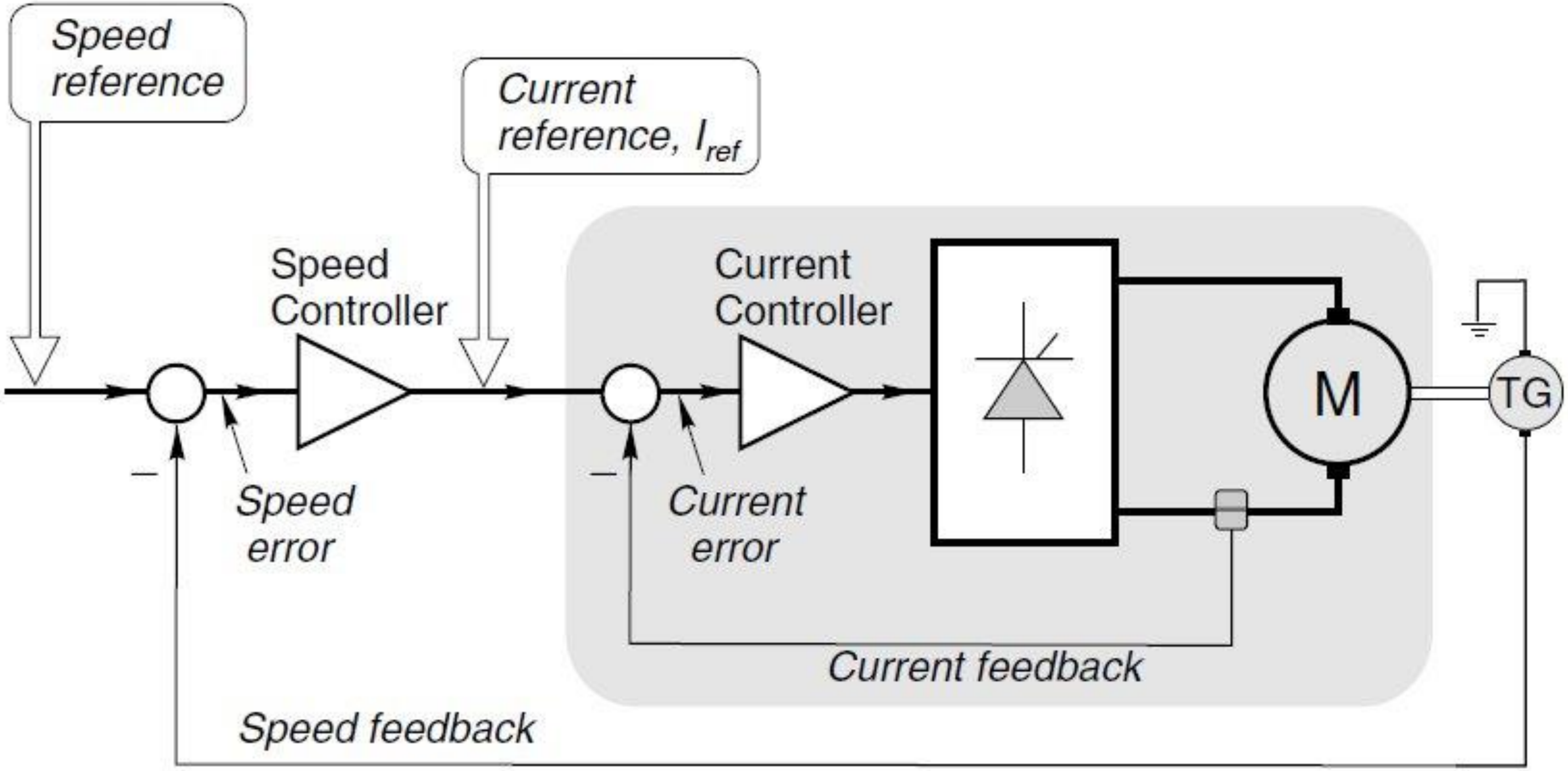
H-Bridge



- E.g. L293D
- 600mA OUTPUT CURRENT CAPABILITY PER CHANNEL
- 1.2A PEAK OUTPUT CURRENT (non repetitive) PER CHANNEL

Power Electronics

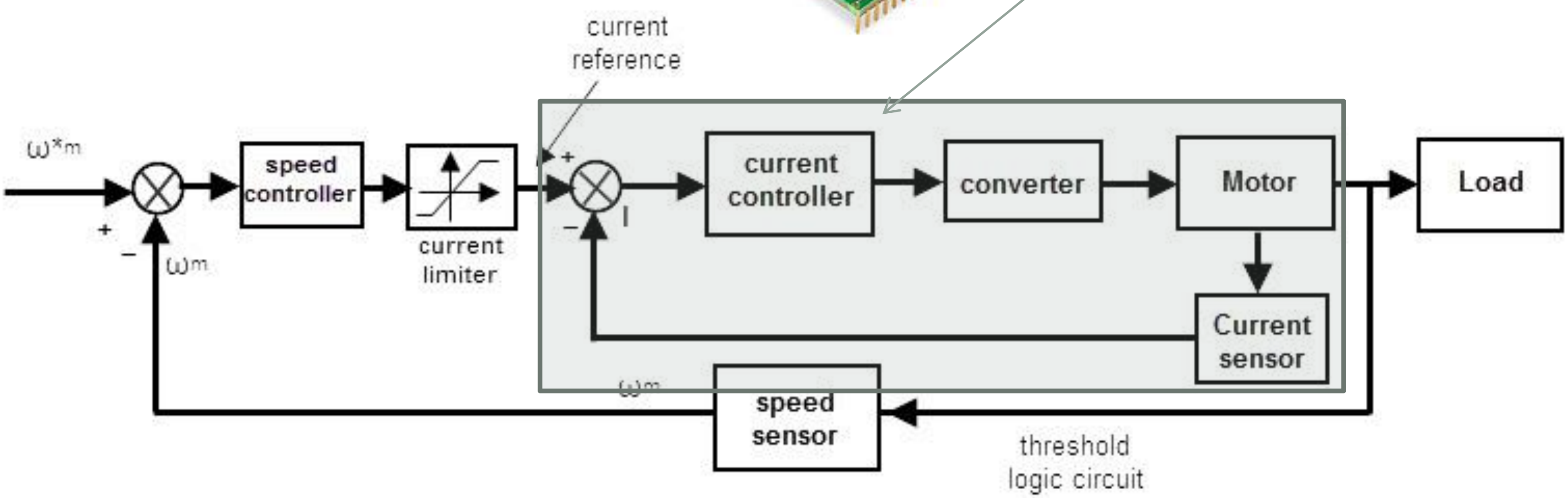
Current Control



Power Electronics

Current Control

May need
the motor position



Brushless DC Motors (BLDC)

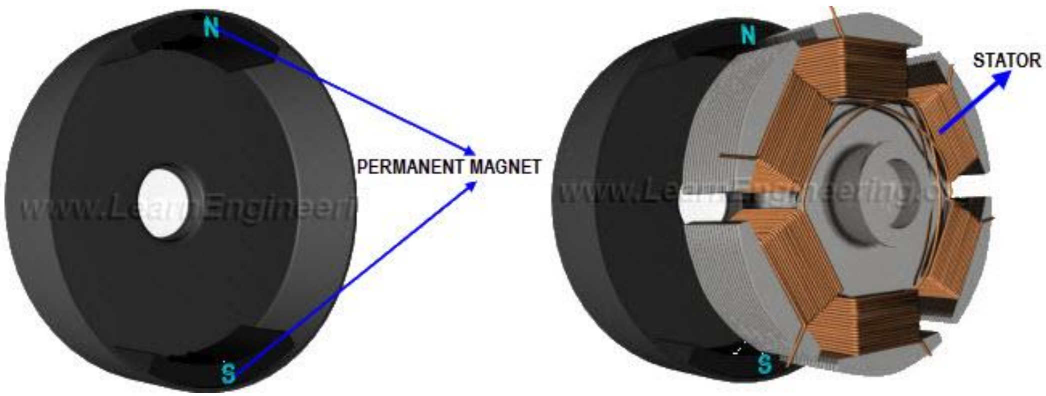
BLDC Motor

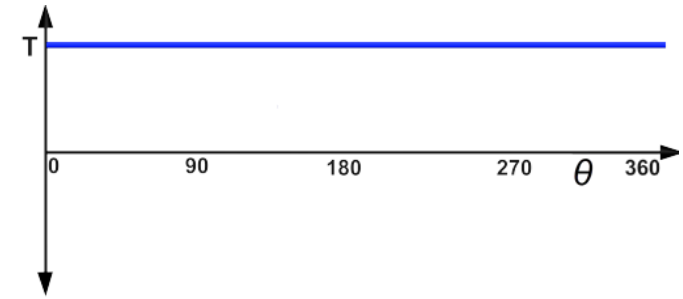
- uses the same principle of standard DC motors

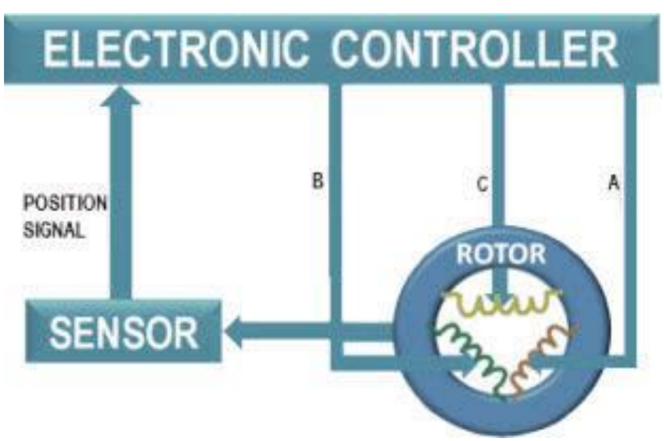
but

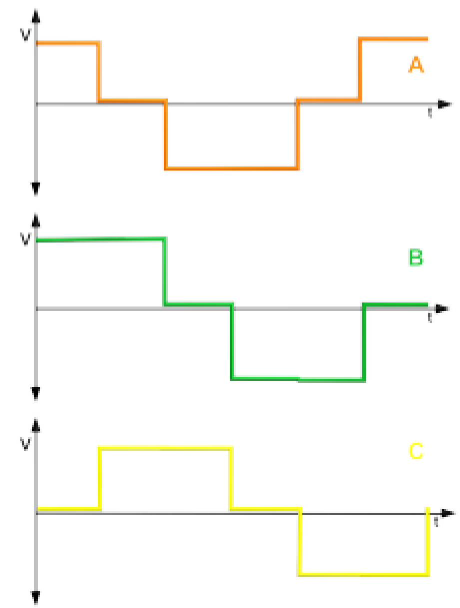
- the commutation is not given by brushes, instead it is implemented in firmware algorithms
- The computation is based on position measurements (or estimation)
  - FOC algorithm (based on position measurements, e.g. encoders)
  - Sensorless FOC algorithm
  - 6-steps algorithm (based on position measurements e.g. hall sensors)
- Chapter on BLDC motor Control

Brushless DC Motors (BLDC)





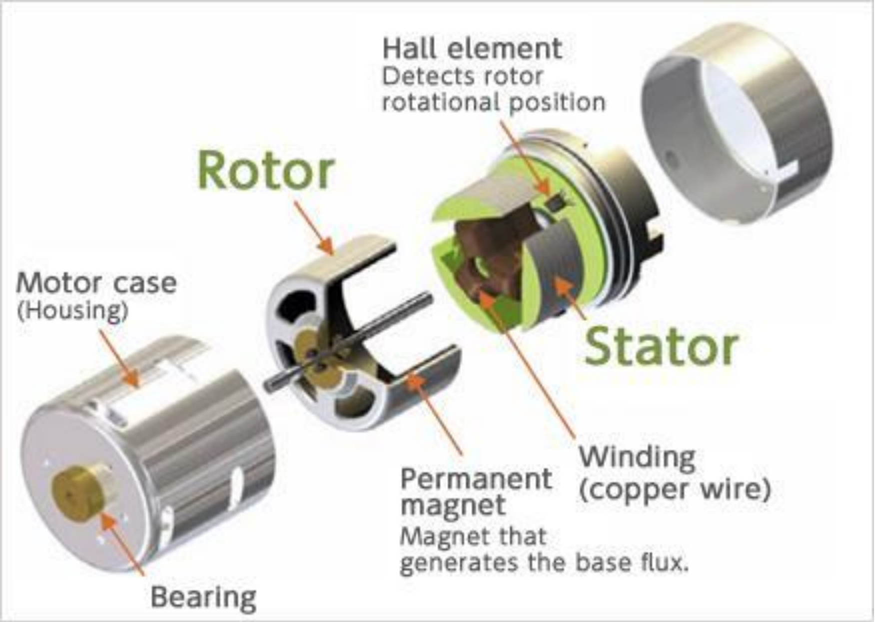




Brushless DC Motors (BLDC)

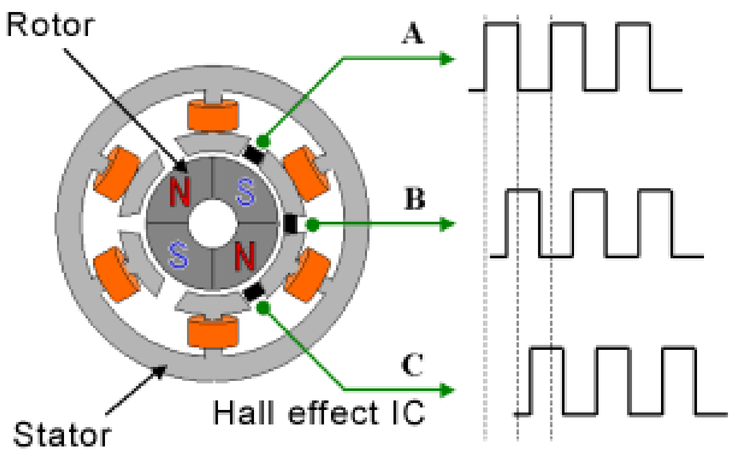
Mechanics

- The rotor is usually “outside”
- There exist also “inside” rotors

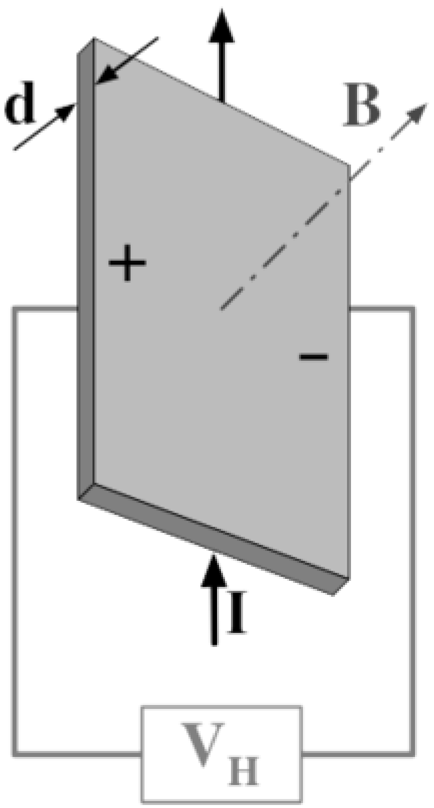


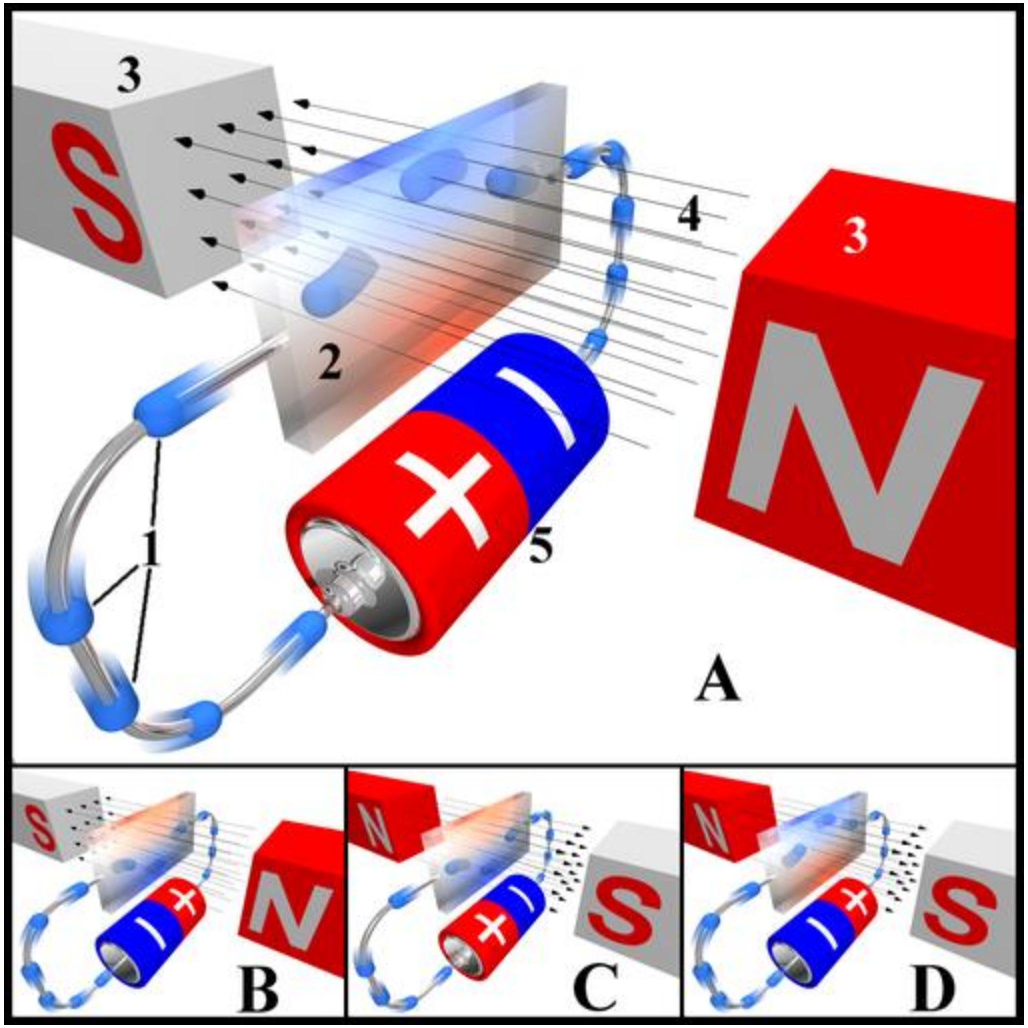
Sensors

- BLDC usually includes hall sensors, otherwise an external sensor must be provided for the FOC



Hall Effect



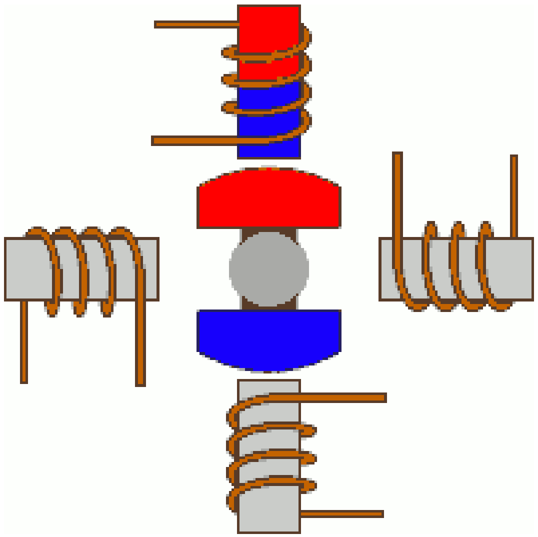


Six-Step algorithm

- https://www.youtube.com/watch?v=ZAY5JInyHXY

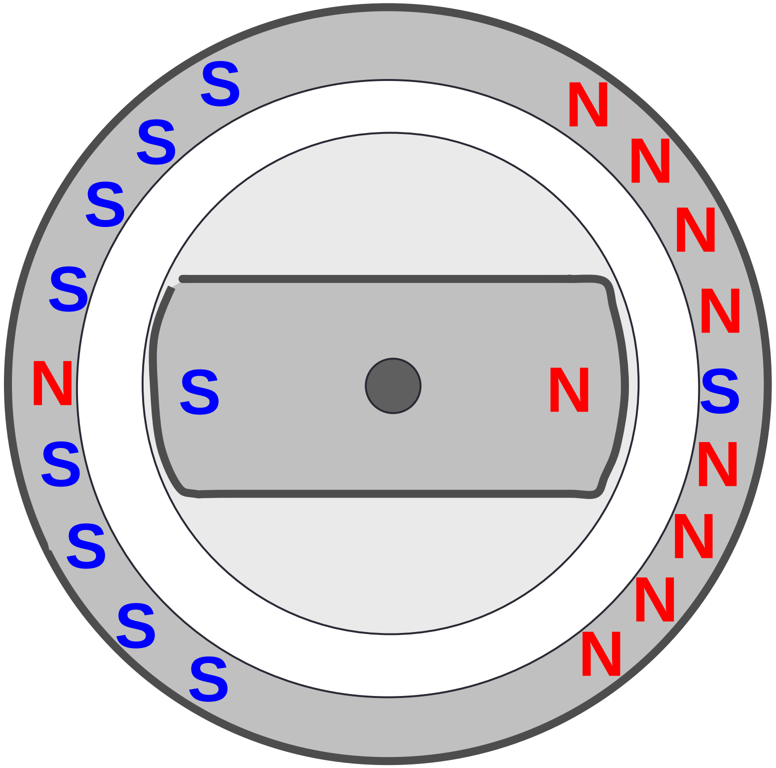
Stepper Motors

- Inherently position controlled
- Sensorless (open loop positioning)



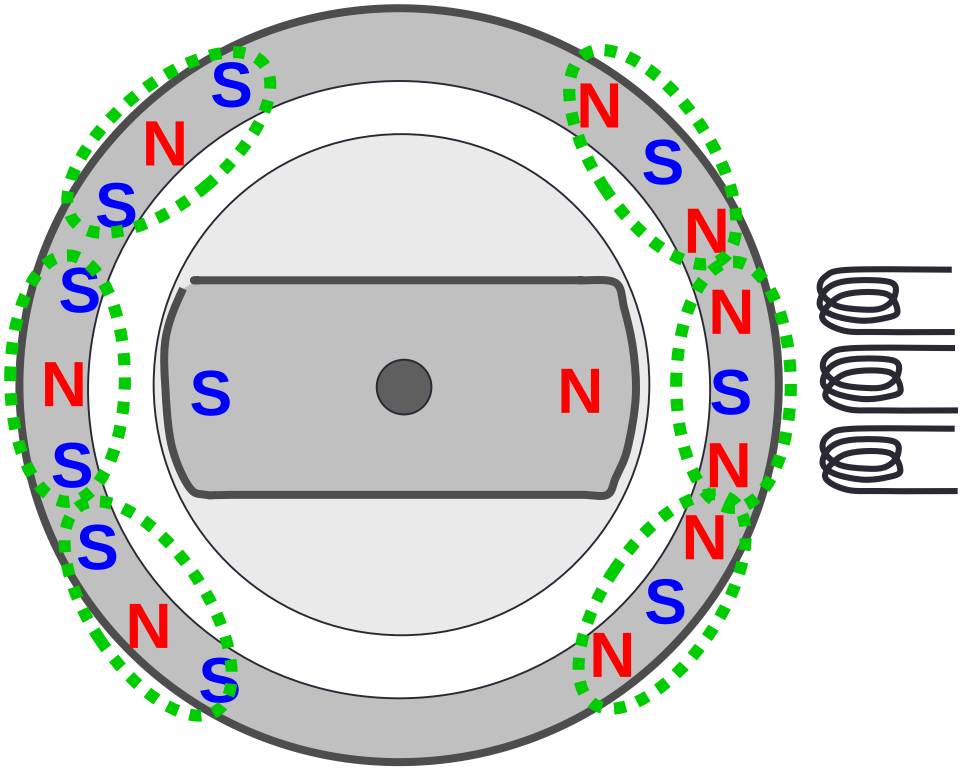
- Advantages:
  - Lightweight
  - Low Cost
- Disadvantages
  - Limited forces
  - May loose some step
  - Unprecise positioning in case of loads
  - Resolution (micro-steps can augment resolution)

Stepper Motors



Control of the position of the rotor in a stepper motor using multiple pole pairs

Stepper Motors

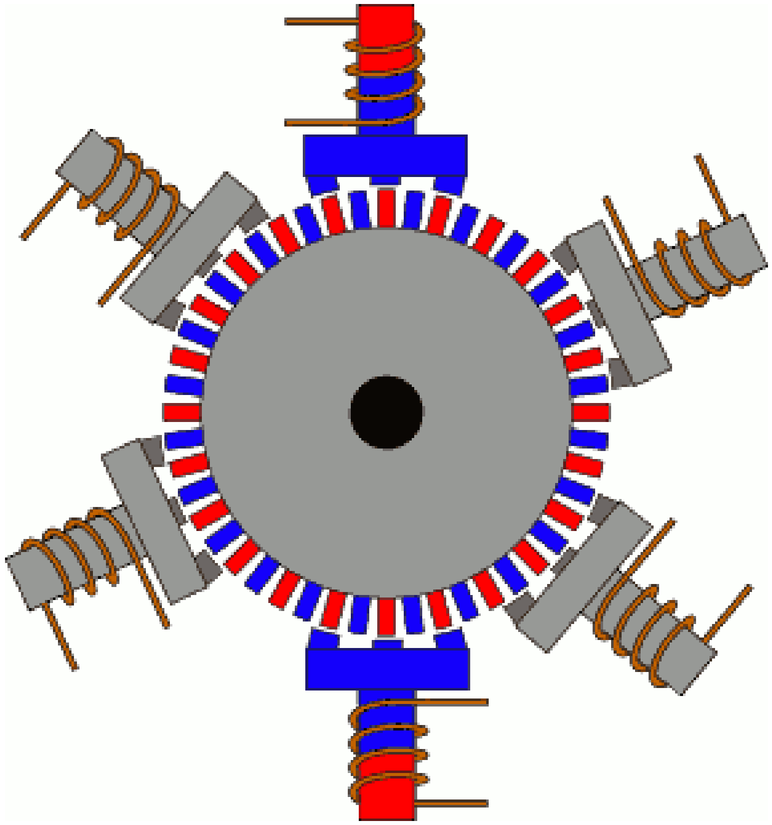


Reduction of the number of pole pairs to a minimum, groups of three that share the same coils:

Three phases stepper motor

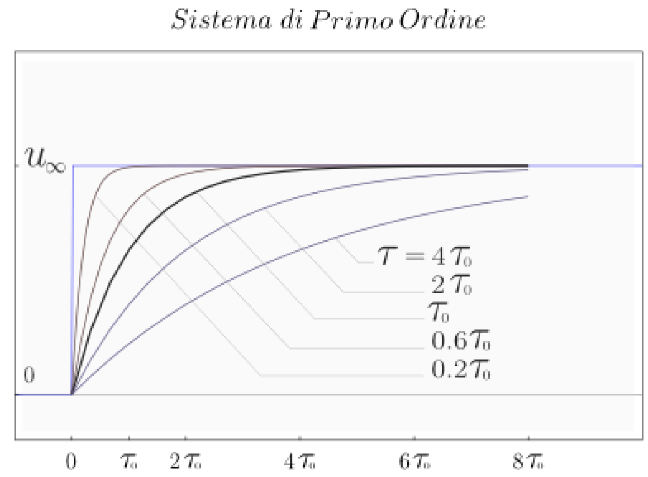
Stepper Motors

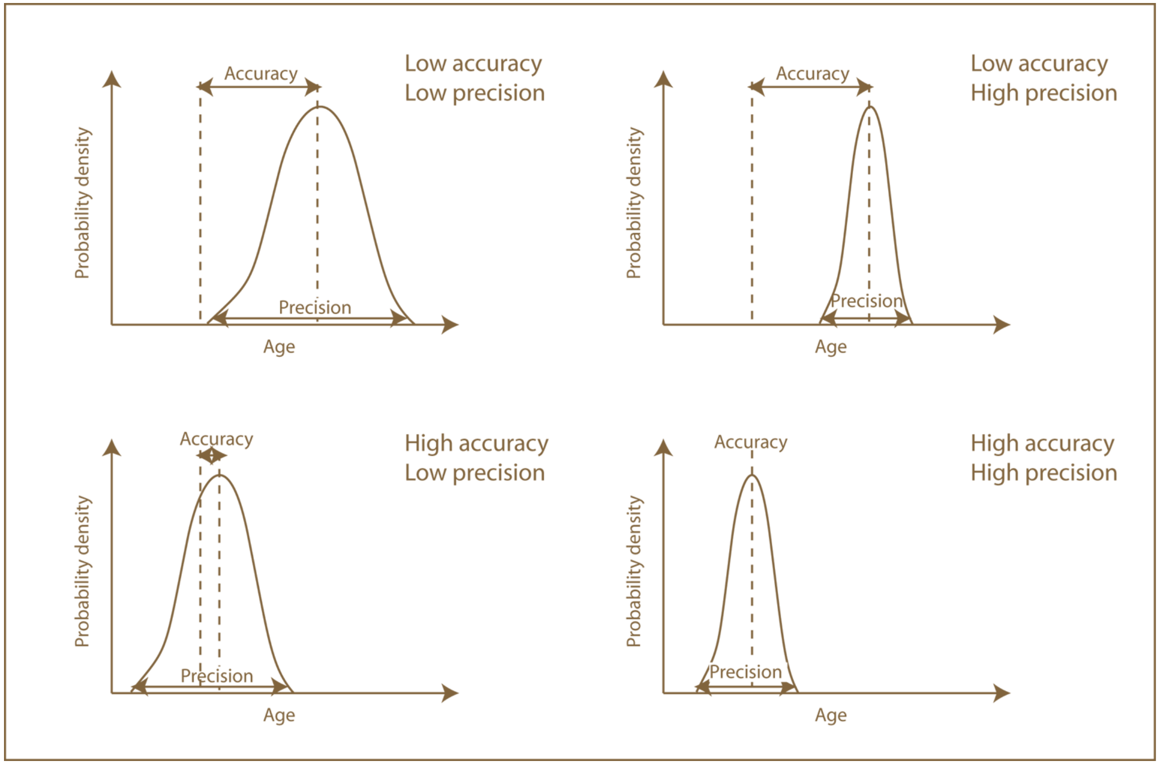
- Micro-step System



Sensors

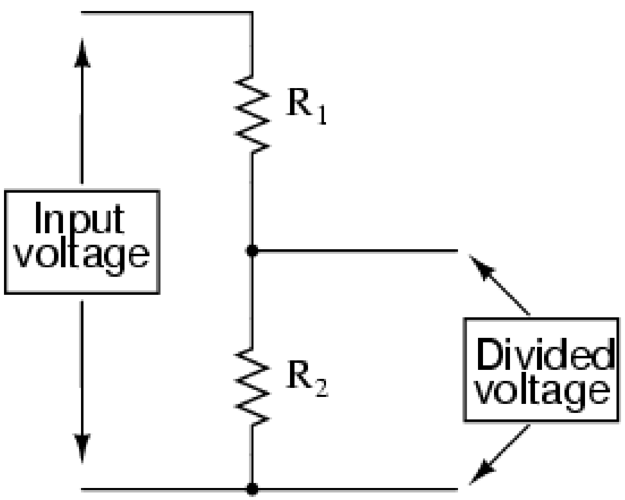
- Precision & Accuracy
- Dynamics
- Robustness
- Conditioning

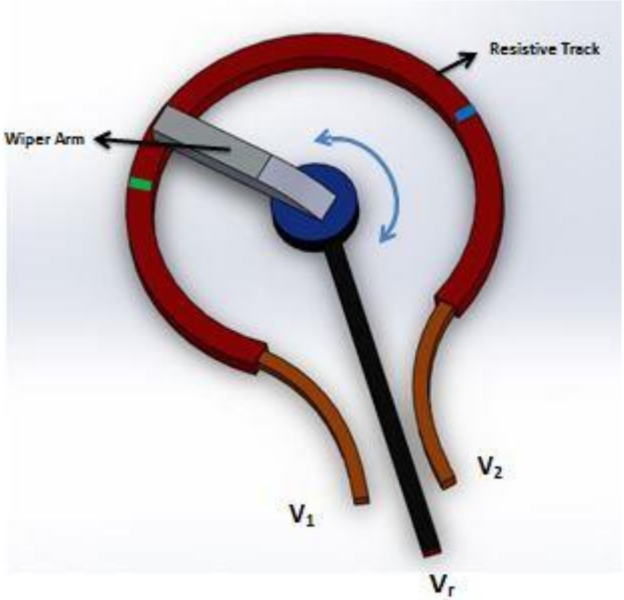




Position Sensors

- Potentiometer
  - Simple and low cost
  - Deterioration because of sliding friction
  - Depending on the power supply, can be noisy
    The noise is at higher frequencies (not derivable!!)
  - Dissipative (choose high R!!)

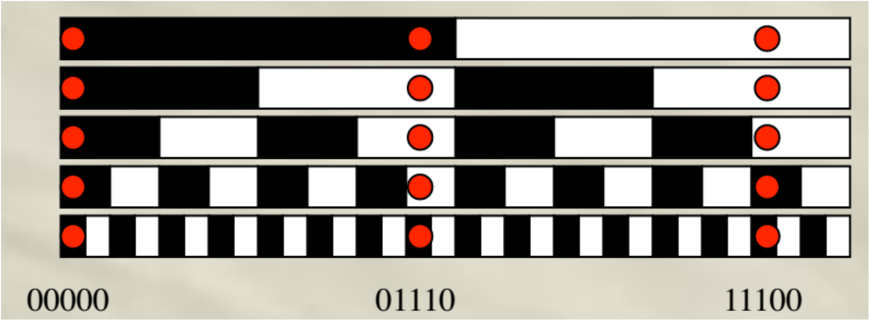


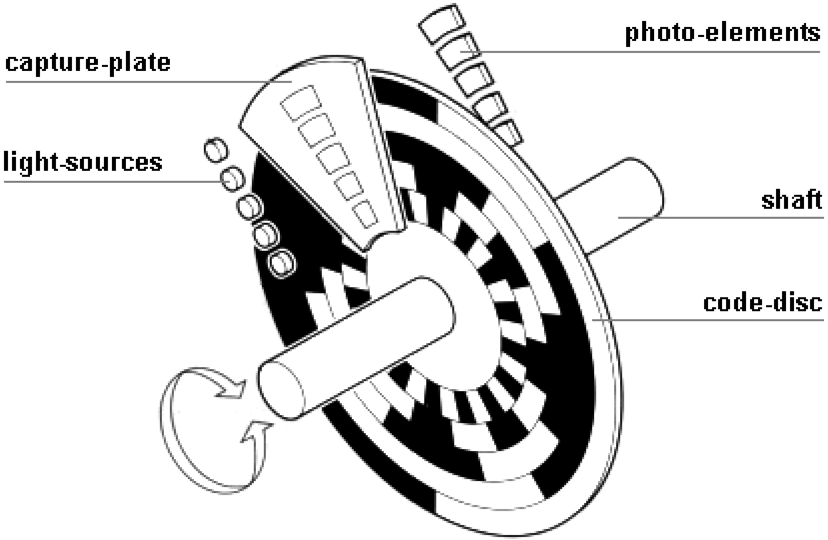


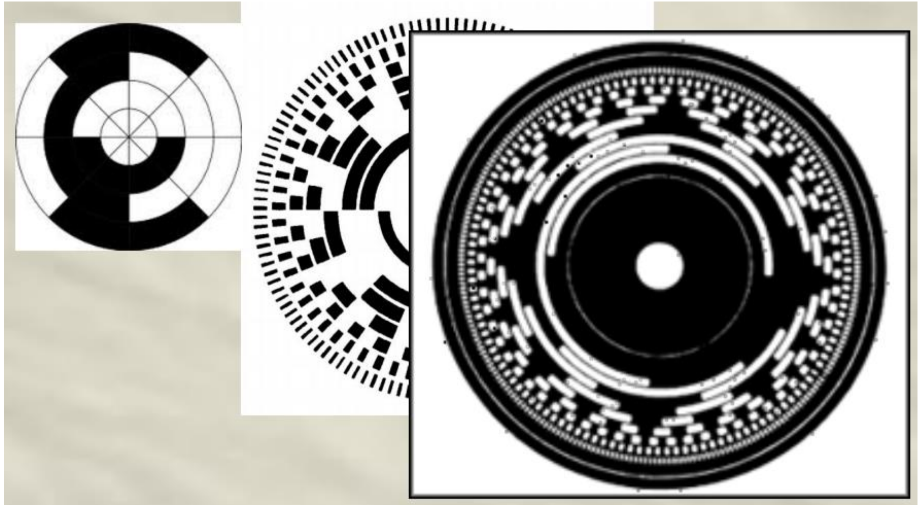
$$P = \frac{V^2}{R}$$

Digital Encoders

- Absolute Encoders
  - Optical
  - Magnetic

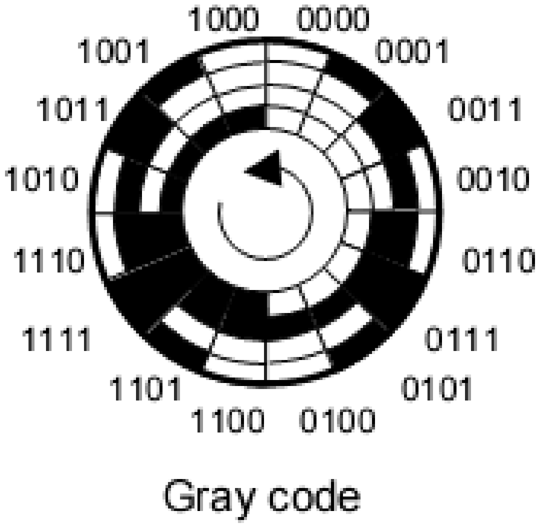


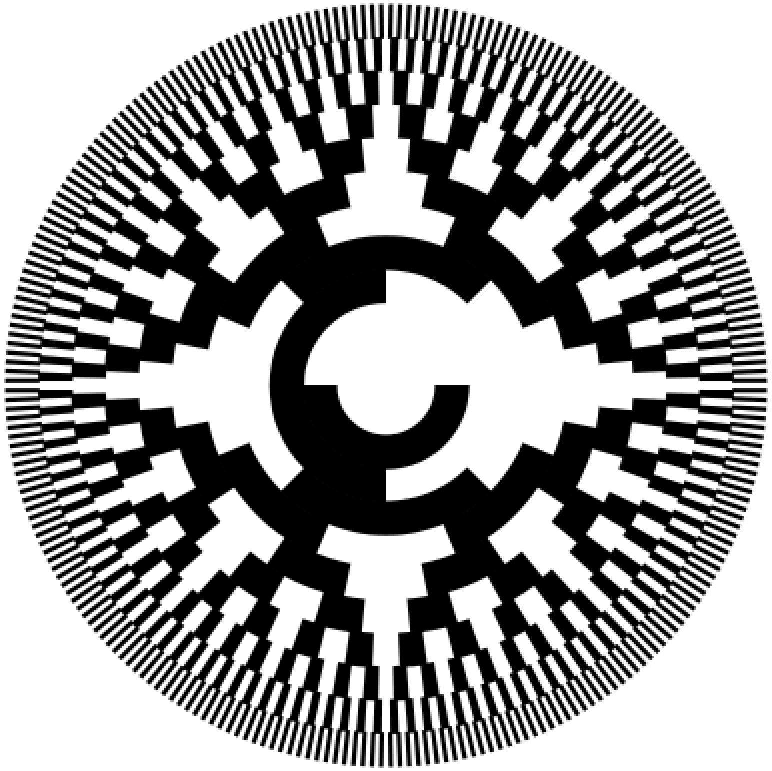




Digital Encoders

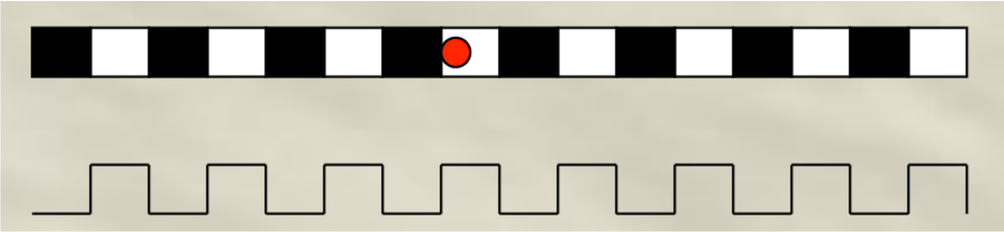
- Absolute Encoders
  - Gray Code



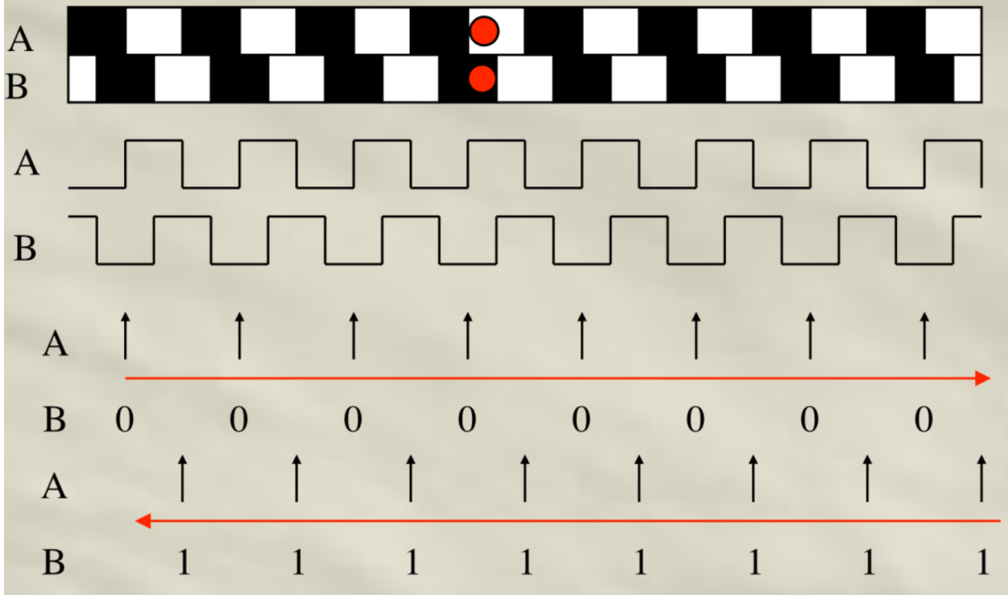


Digital Encoders

- Incremental Encoders
  - The electronics counts the pulses

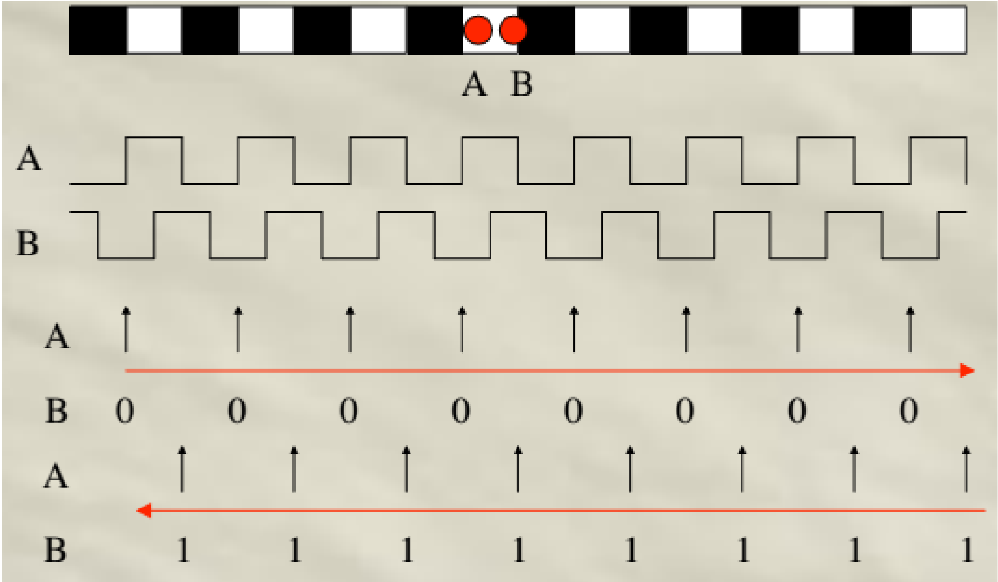


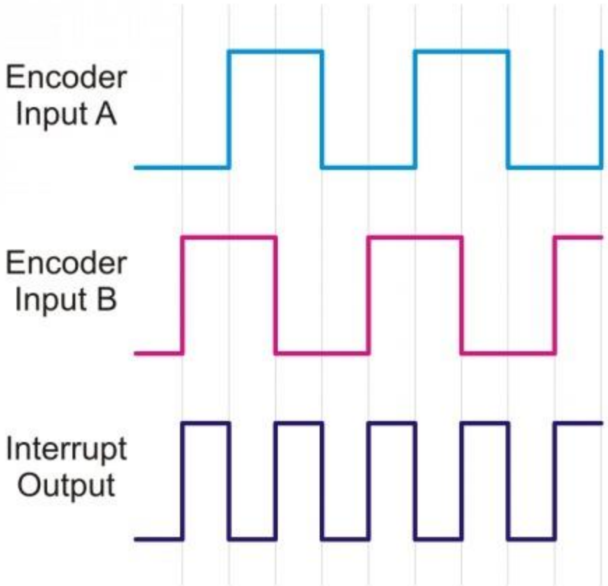
  - What about the direction?



Digital Encoders

- Incremental Encoders
  - A smarter manufacture
  - Resolution

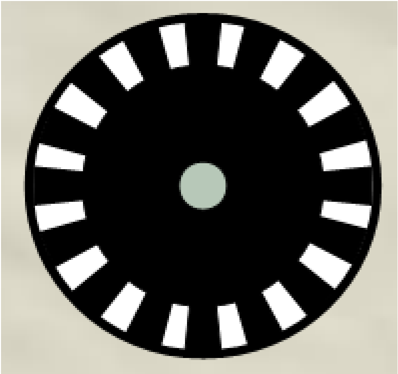


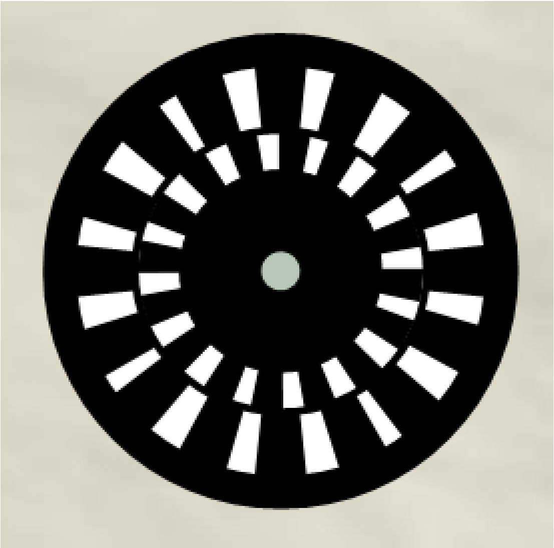


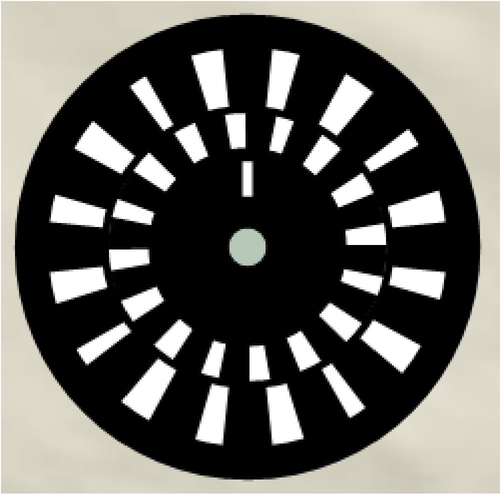
Encoder reading is interrupt based!!
Signal reading and counting is usually provided by dedicated electronics.
Could Hard RT software be an option?

Digital Encoders

- Incremental Encoders



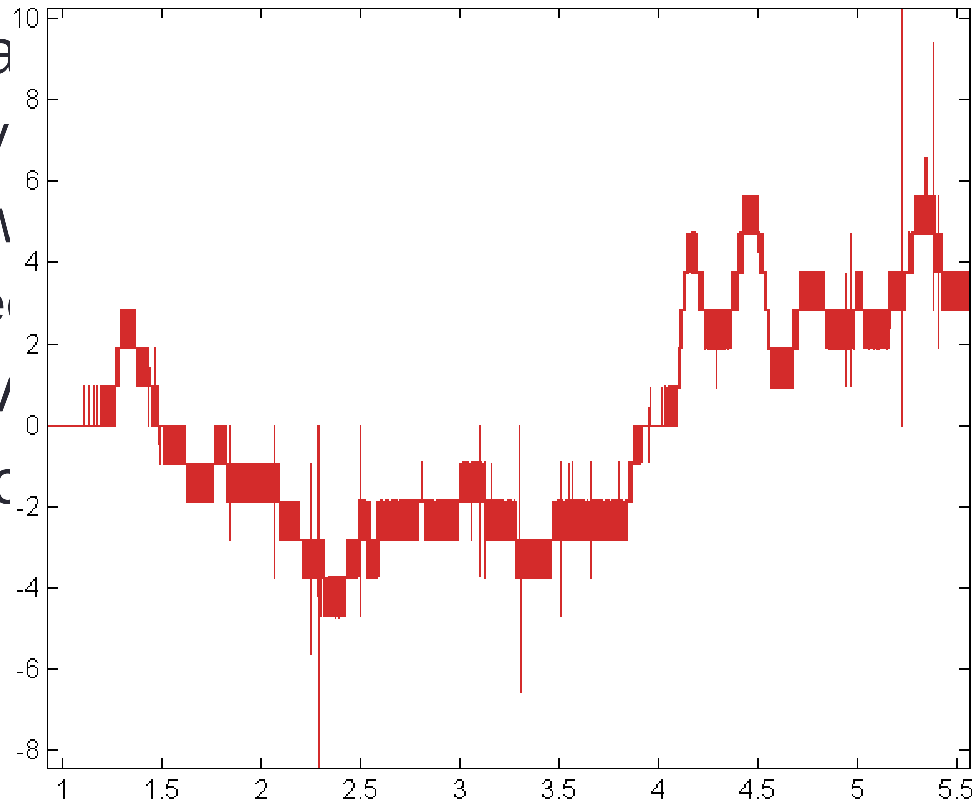




Digital Encoders

Incremental Encoders

- Can we use them for estimating the velocity?
- The position signal is digital (discontinuous)
- The signal is more informa
  - In a sampling time we can av
- And less informative al low
  - In a sampling time we just se
- The velocity resolution is v
- The position resolution is c



Digital Encoders

Incremental Encoders

- Instead of counting the pulses within a period, lets measure the period inter-pulse duration!
  - You need a timer in the electronics