EG1000 Engineering Design and Innovation

ELEC Stream Lecture 1

Introduction to Electronics

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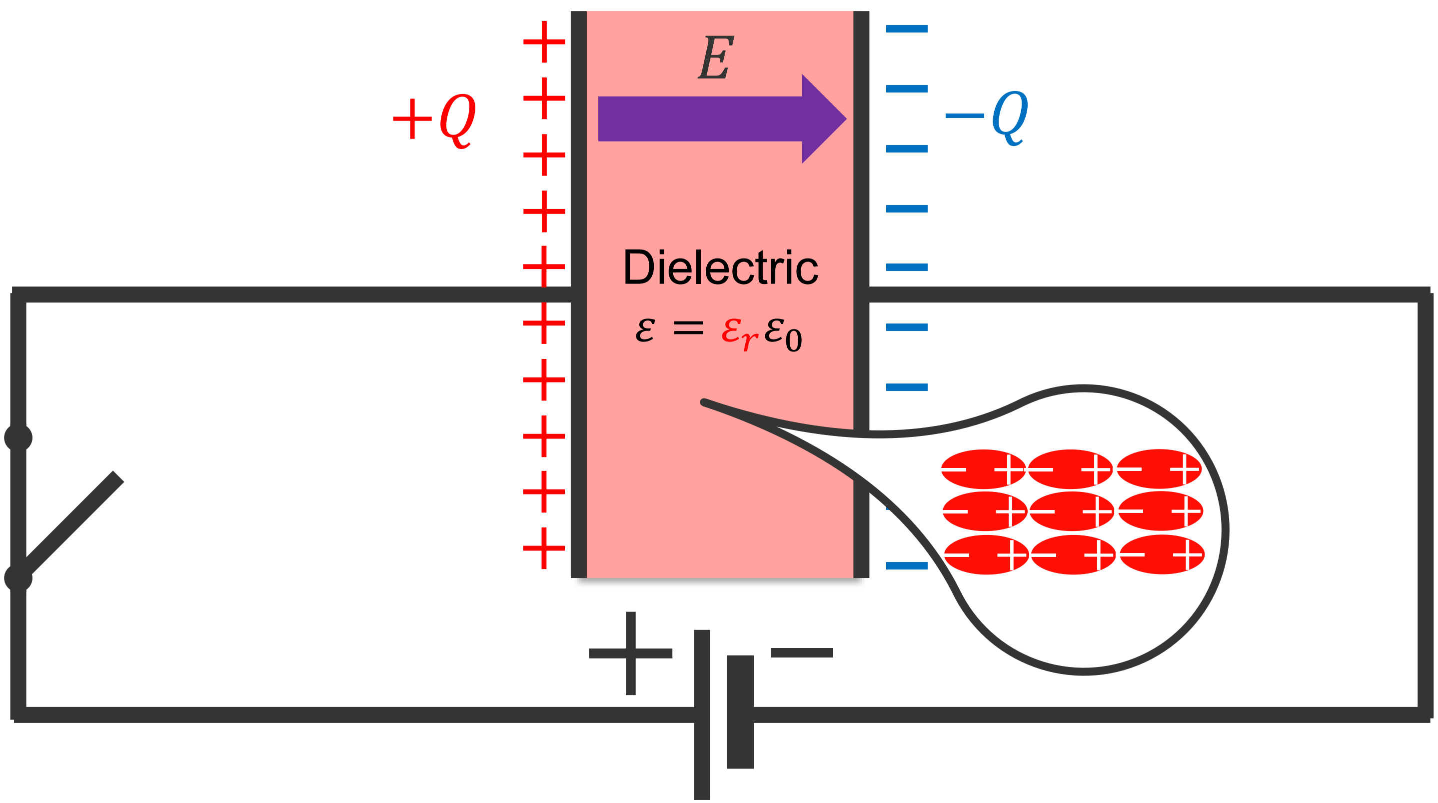
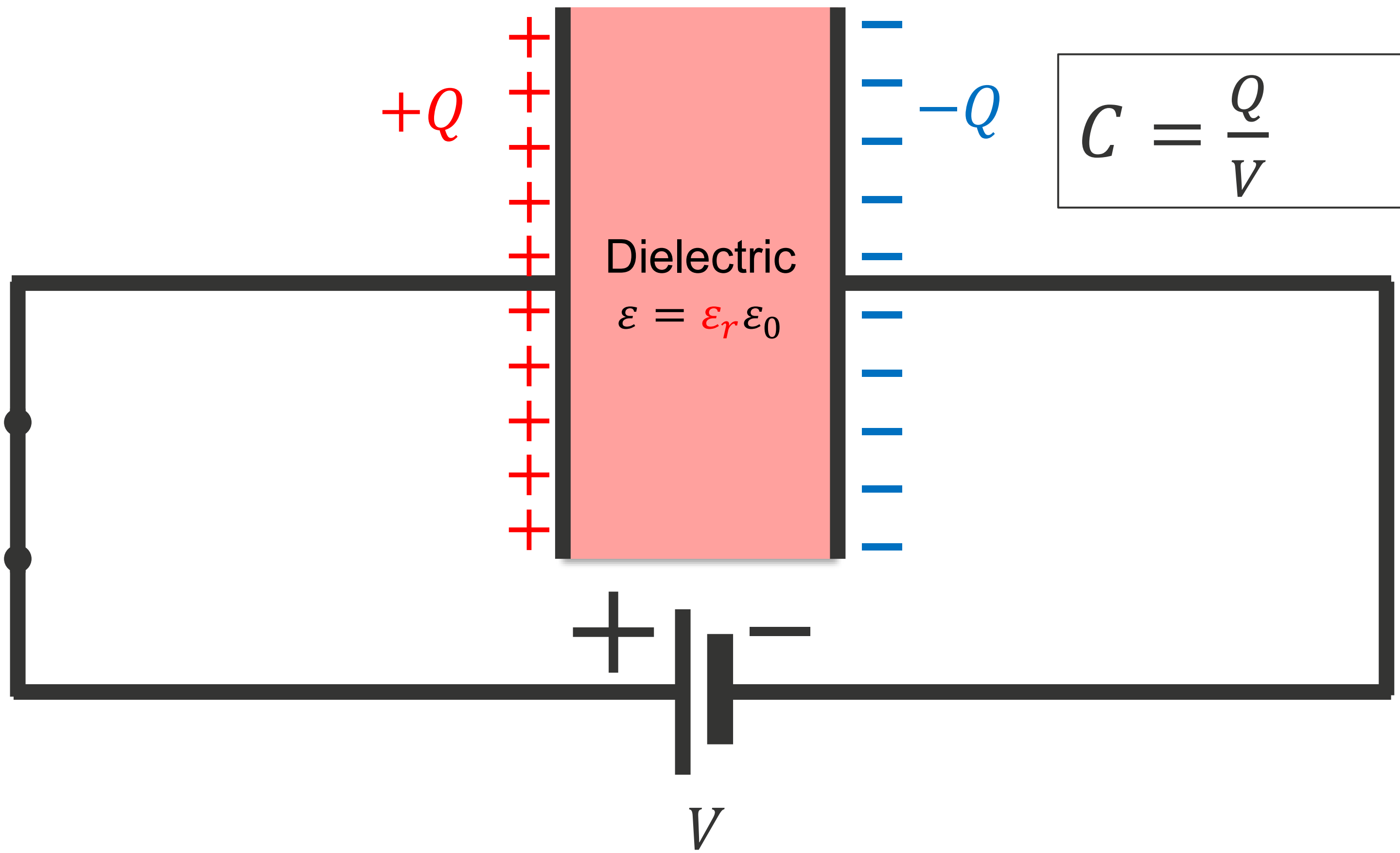
What is a capacitor?

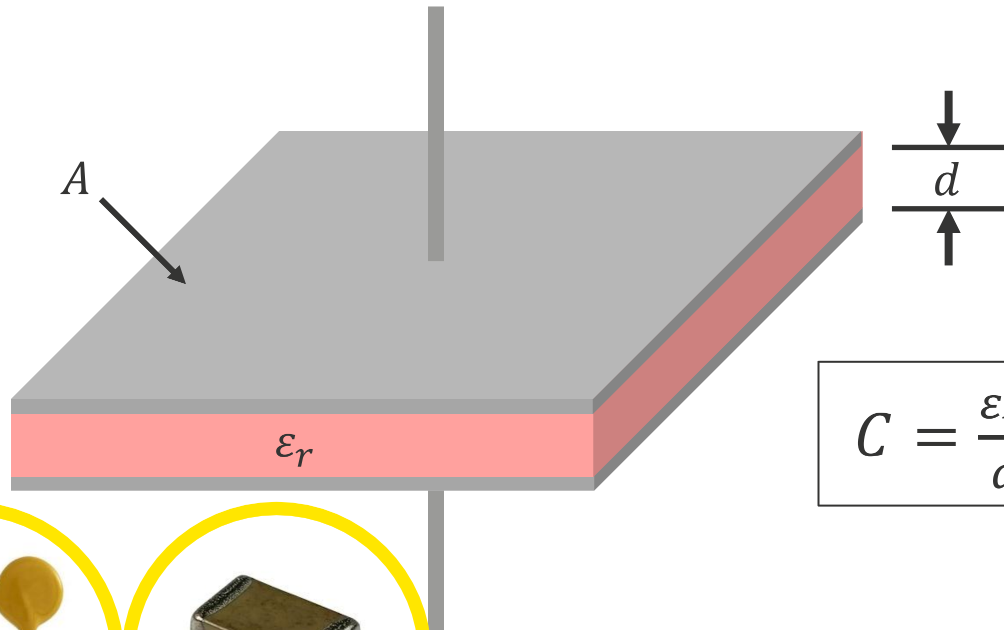


What is a capacitance?

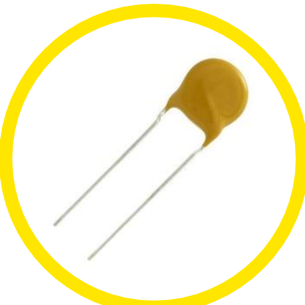


$$C = \frac{Q}{V} \qquad (1)$$

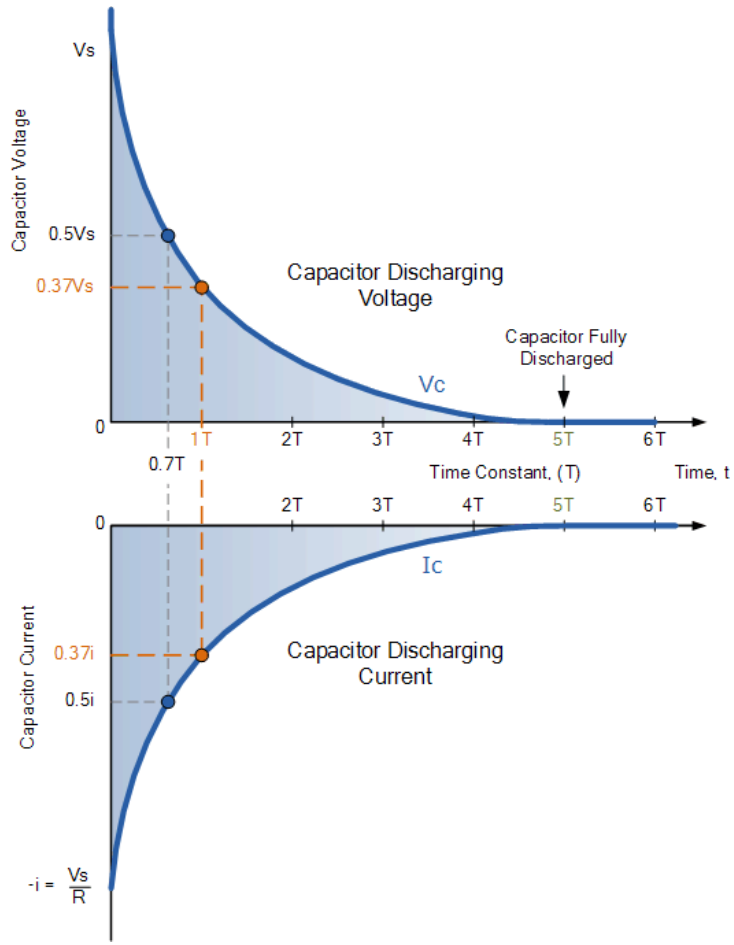
Parallel plate capacitor



$$C = \frac{\varepsilon A}{d} \qquad (2)$$



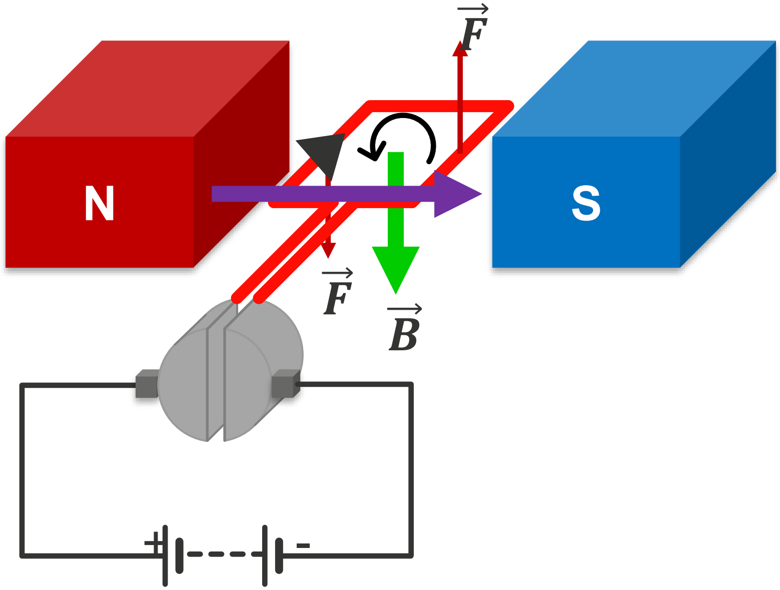
Charging & Discharging

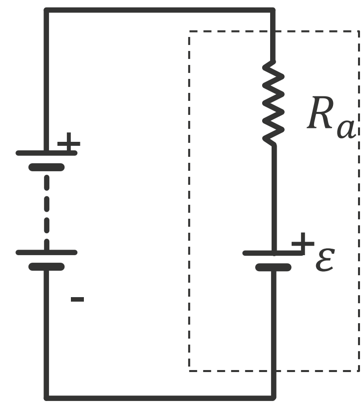


Why do we want capacitors in EG1000?

To answer this, we need to briefly look at DC motors

$$\varepsilon = -\frac{d\phi_B}{dt} \qquad (3)$$





Electric motors require more energy to start due to overcoming inertia and establishing electromagnetic fields. When starting, the motor's rotor needs to be accelerated from rest, which requires significant force and energy. Additionally, the initial state of the motor creates high inductive reactance, leading to a surge of current known as inrush current

Why do we want capacitors in EG1000?

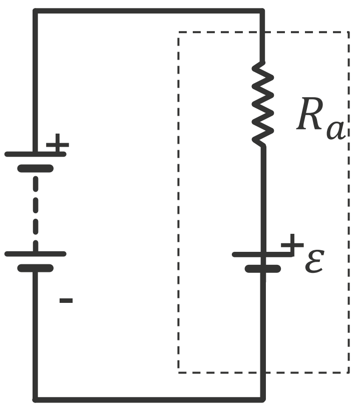
$$\varepsilon = -\frac{d\phi_B}{dt} \qquad (3)$$

$$\phi_B = \vec{B} \cdot \vec{A} = BA\cos(\theta) \qquad (4)$$

$$\theta(t) = \omega t$$

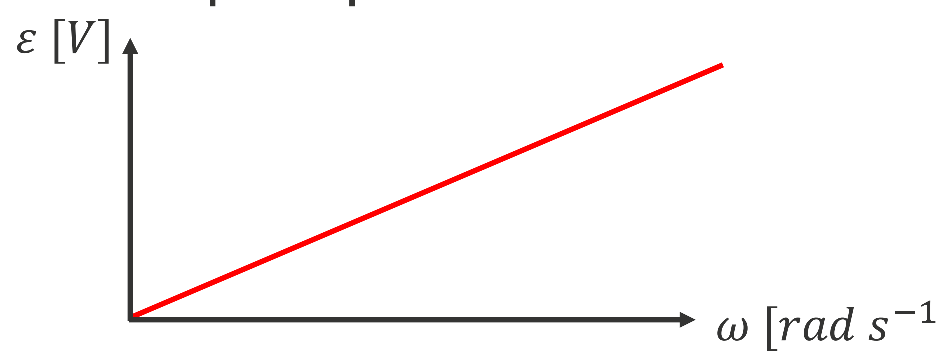
$$\Rightarrow \frac{d\phi_B}{dt} = -BA\omega \sin(\omega t)$$

$$\Rightarrow \left|\frac{d\phi_B}{dt}\right| = BA\omega$$

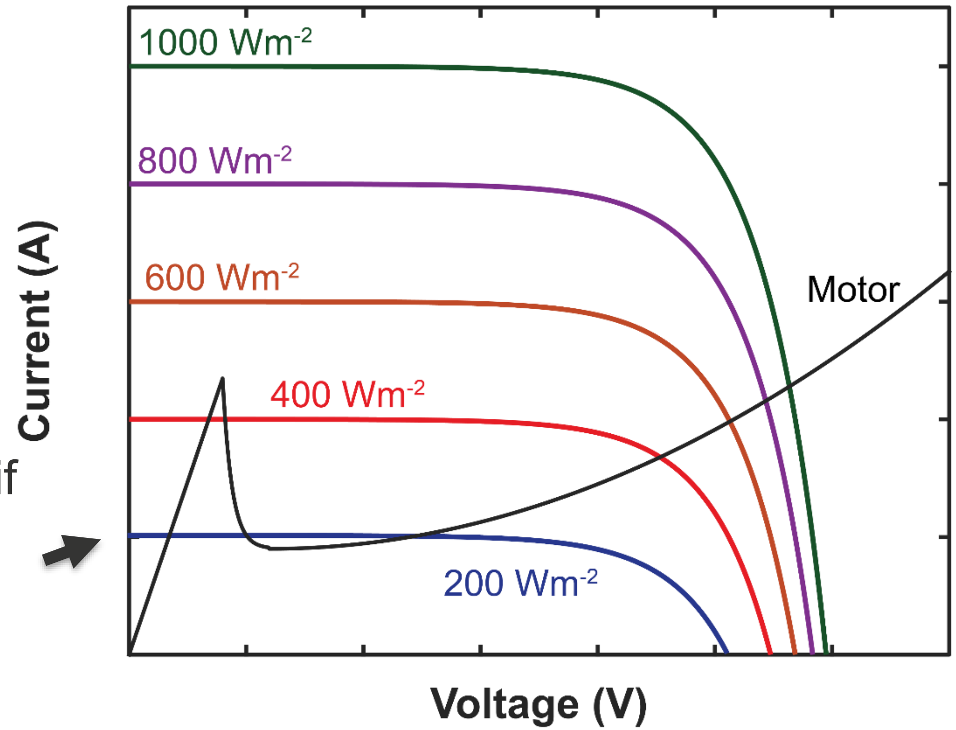


How much current do we need to start I_{start}?

$$I_{start} = \frac{V}{R_a}$$



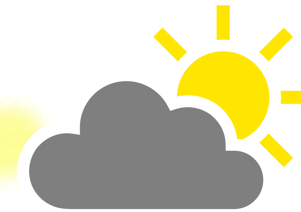
Why do we want capacitors in EG1000?



What happens if the we have these conditions?

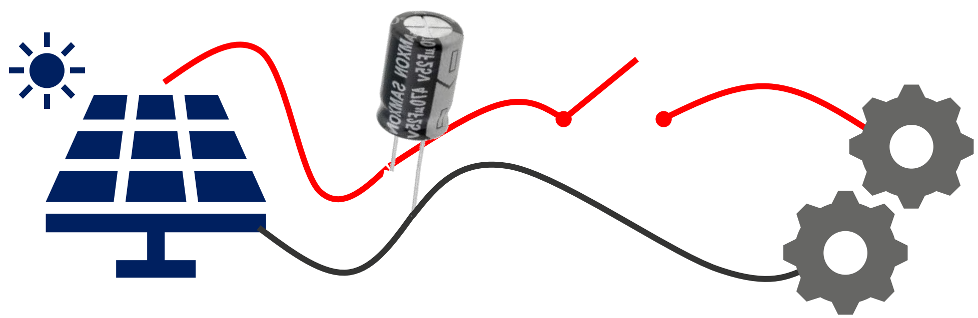
Why do we need capacitors?

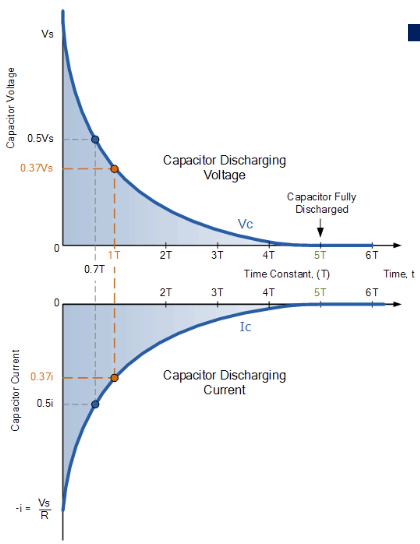
$$I_{panel} \propto Area\ of\ panel\ \&\ Solar\ irradiance$$

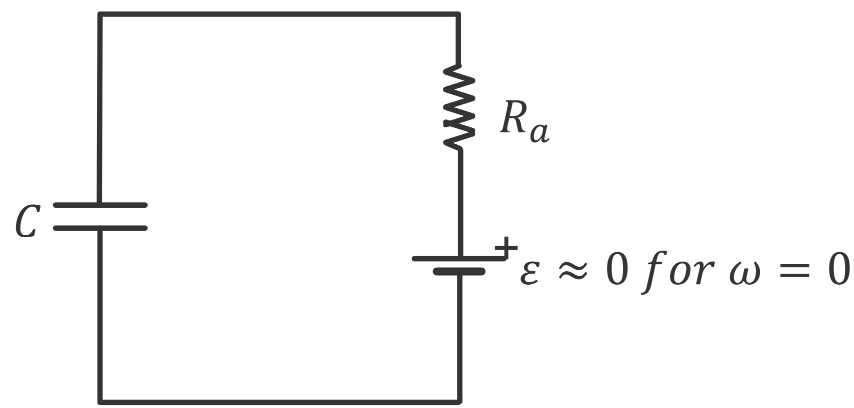


$$I_{panel} \gtrless I_{start}$$

Why do we need capacitors?







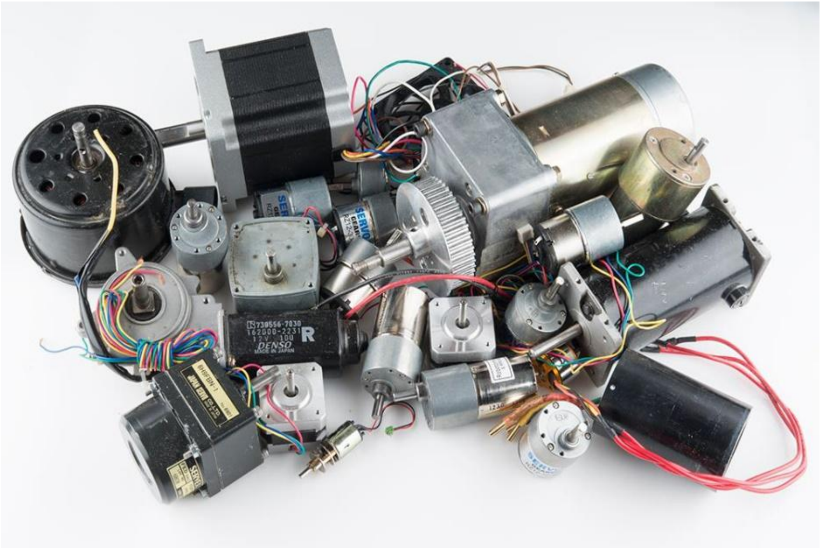
Can anyone provide an example of capacitors used in Transport?

"Wireless" light rail a reality

The Newcastle Light Rail system utilises a catenary-free operation, where each light rail vehicle houses an onboard energy storage system. A super capacitor and batteries on the roof of the vehicle enables it to travel wire free. Charging is completed through the vehicle's pantograph making contact with an elevated charge bar at each of the passenger stops.

DC motor

- DC is an acronym for **direct current**
  - A DC value can be **constant** or **variable** over time but always flows in **one direction**.
  - Unlike alternating current (AC), which **changes direction** with time and it has variable value as a result.
  - By convention we use DC and AC to characterize both current and voltage (DC voltage refers to a fixed-polarity voltage which is accompanied by a DC current).
- DC motors are electromechanical devices that works with DC voltage and current.
- There are many different types of DC and AC motors.



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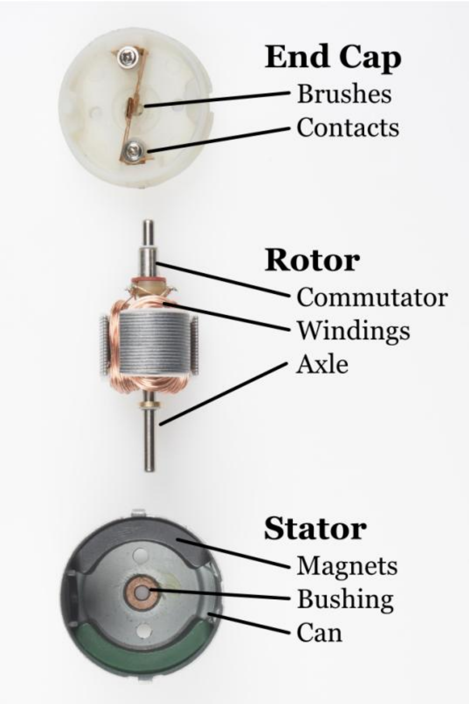
DC motor – Permanent ma

- Permanent magnet DC motors are modeled as an electromechanical system:
  - V_a is supply voltage (armature voltage)
  - R_a and L_a are armature resistance and inductance, respectively.
  - I_a is armature/motor current
  - θ_m and ω_m are angular/rotational position and velocity, respectively.
  - V_b is back emf (electromotive force) voltage
  - J_m and B_m and are moment of inertia and viscous damping of the mechanical parts.
  - T_m is generated motor torque.
    - » r_g, θ_g, and T_g are gearbox ratio ($r_g < 1$), angular position and generated torque after gearbox



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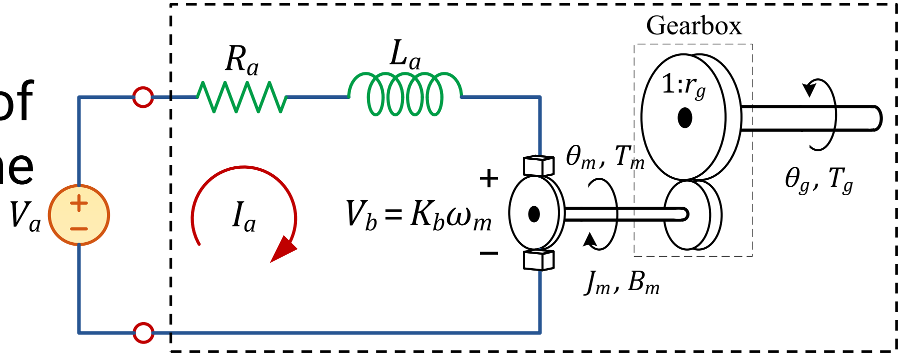

A. Khatamianfar, "Discrete-Time Servo Control of Overhead Cranes with Robust Load Swing Damping," in *Proc. 2015 European Control Conf.*, *(ECC2015)*, Linz, Austria, 2015, pp. 1106–1113.

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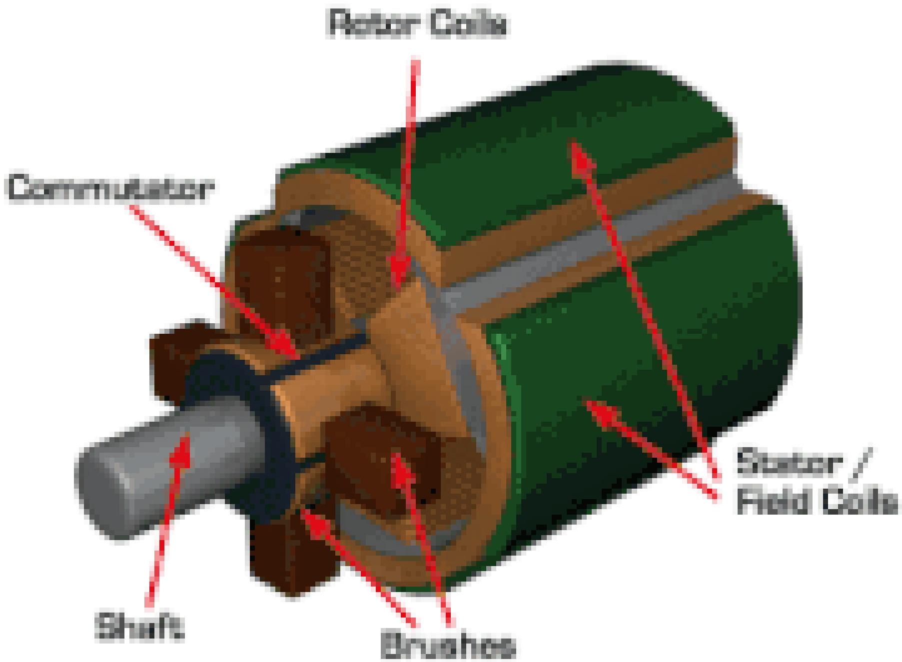
DC motor



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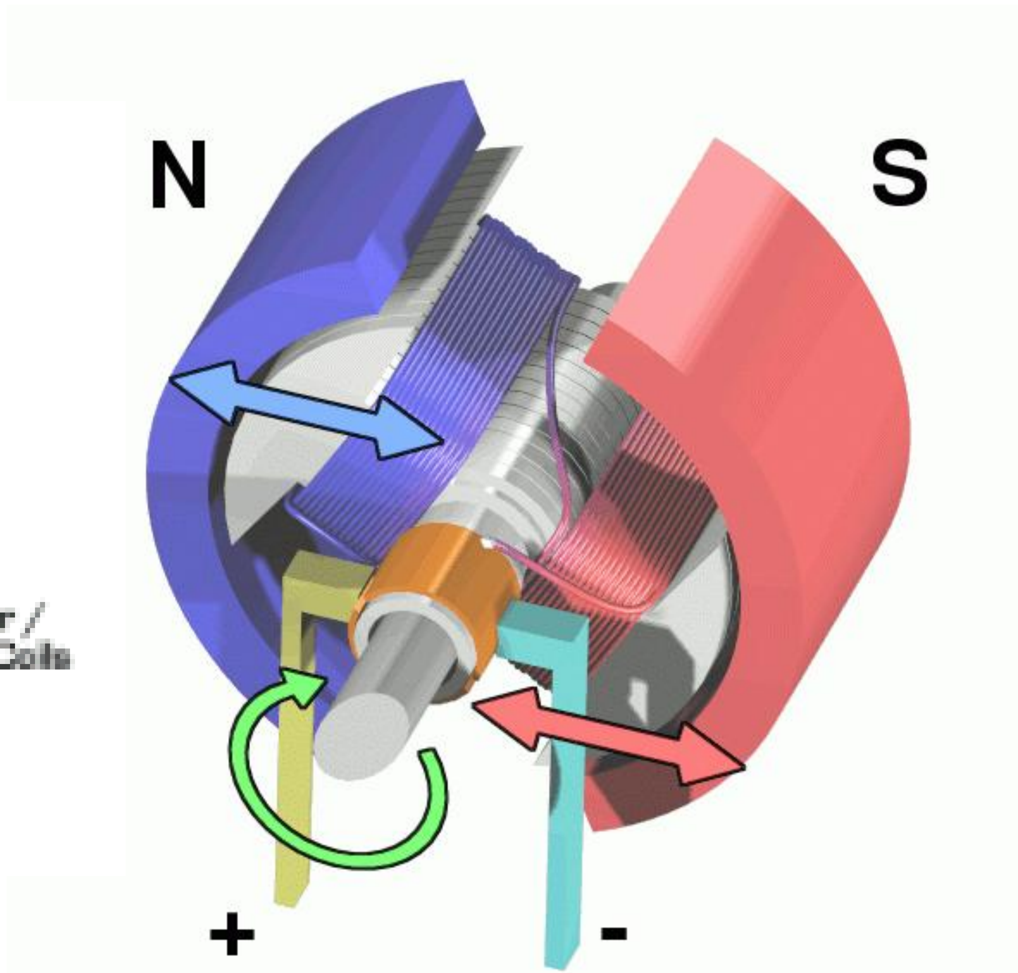

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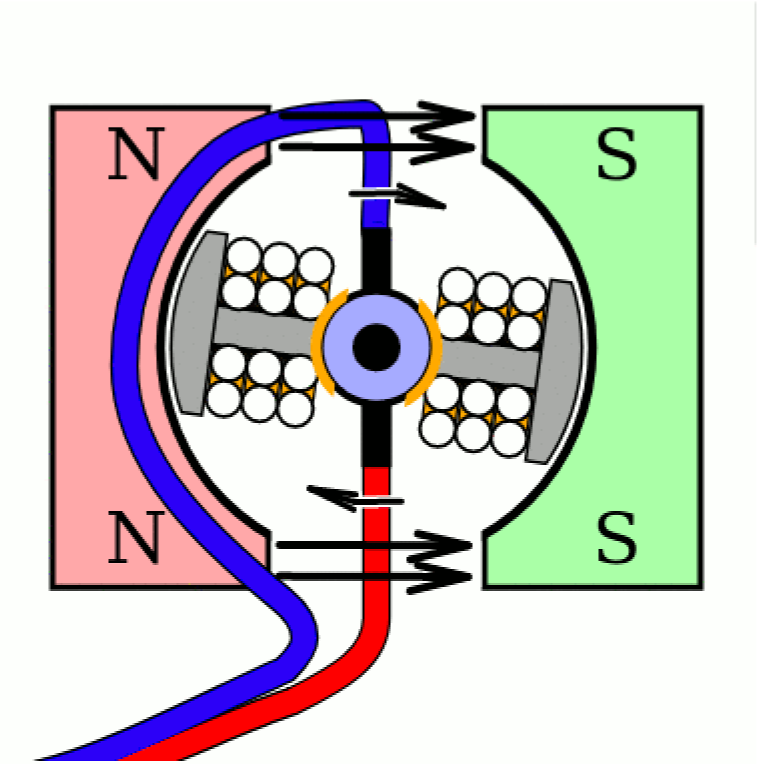
DC motor



DC motor – Permanent magnet Equations of motion (no gearbox)

- KVL in the loop:

$$V_a = R_a I_a + L_a \frac{dI_a}{dt} + V_b$$

- Angular speed is proportional to back emf voltage:

$$V_b = K_b \omega_m$$

  - K_b is back emf constant which is also denoted by K_e

- Motor torque is proportional to armature current:

$$T_m = K_m I_a$$

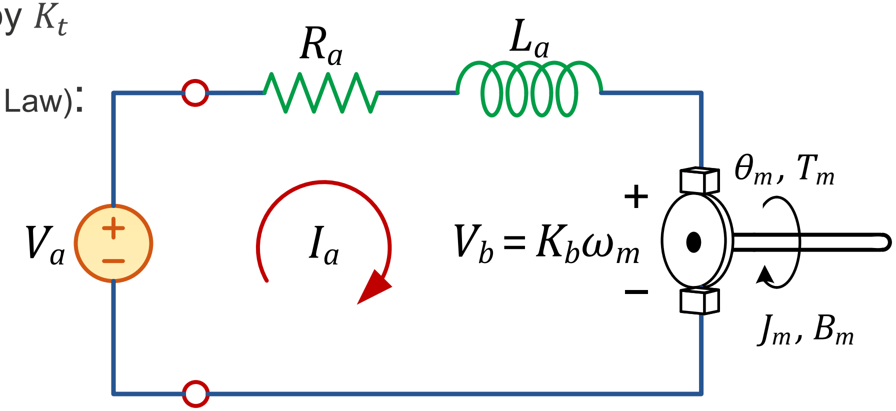
  - K_m is torque constant which is also denoted by K_t

- Mechanical rotational equation (2nd Newton's Law):

$$J_m \frac{d^2\theta_m}{dt^2} + B_m \frac{d\theta_m}{dt} = T_m - T_{load}$$

$$J_m \frac{d\omega_m}{dt} + B_m \omega_m = T_m - T_{load}$$

  - T_{load} is load torque (like wheel)



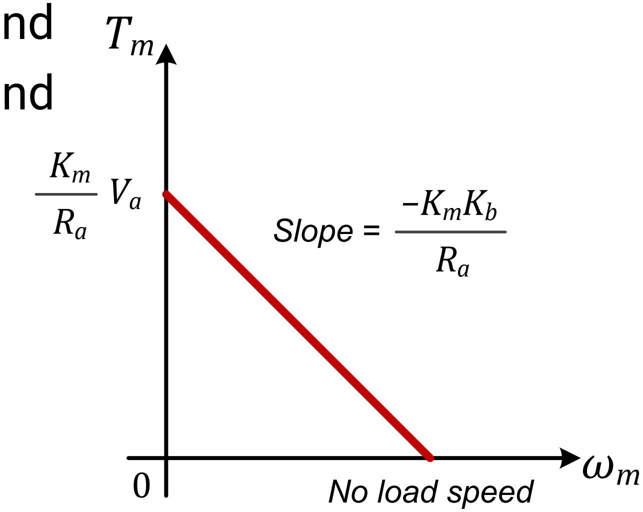
DC motor – Torque/Speed Characteristic

- At steady state, motor rotates with constant velocity, which means constant torque and subsequently constant current, i.e., $\frac{d\omega_m}{dt} = 0$ and $\frac{dI_a}{dt} = 0$, thus:

  $V_a = R_a I_a + K_b \omega_m$ (1)

  $T_m = K_m I_a$ (2)

  $B_m \omega_m = T_m - T_{load}$ (3)



- Combining Eq. (1) and Eq. (2):

$$T_m = -\frac{K_m K_b}{R_a}\omega_m + \frac{K_m}{R_a} V_a$$

or $T_m = -c_1 \omega_m + c_2 V_a$

V_a and I_a are the design variables to achieve a particular torque/speed operating point.

- $T_{stall} = \frac{K_m}{R_a} V_a$ is the **stall torque** required to initiate the motor motion when V_a is the **nominal voltage** V_{an}.
  - Note that motor will not start turning without a small current: "**stall current**".

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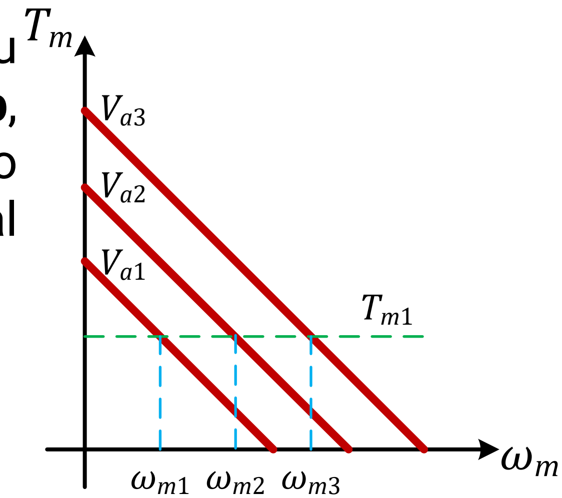
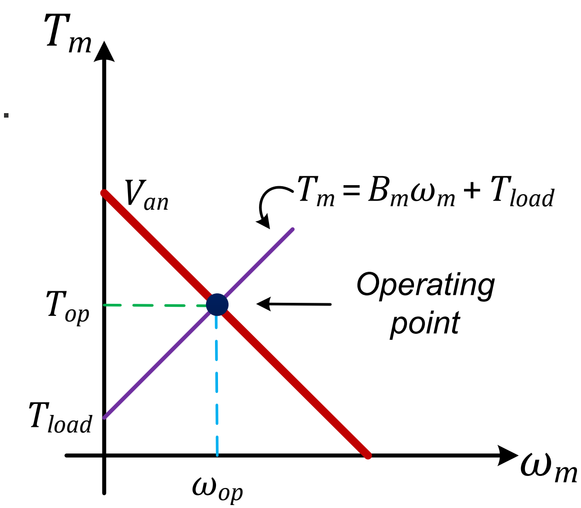
DC motor – Load effect

- If there is **no extra load** attached to the motor, as you **increase input voltage** V_a, the **velocity** ω_m **goes up**, since there is no need for extra current and torque to be provided except for rotating internal mechanical parts
  - ω_m is proportional to V_a in steady state.



- If a constant load is attached (T_{load}), the **velocity drops** to allow for **more current** to be drawn and consequently to generate **more torque**.
  - Plot both Mechanical torque-speed $T_m = B_m\omega_m + T_{load}$ and Electrical torque-speed curves $T_m = -c_1\omega_m + c_2V_a$.
  - Intersection of these curves is the **operating point**.
  - ω_m is still proportional to V_a at constant load.



- Always use these curves to determine the required speed and torque at nominal voltage.
- Following the analogy to electric power, the **mechanical power** supplied is obtained as the product of torque (current) to velocity (voltage):

$$\boxed{P_m = T_m\omega_m}$$

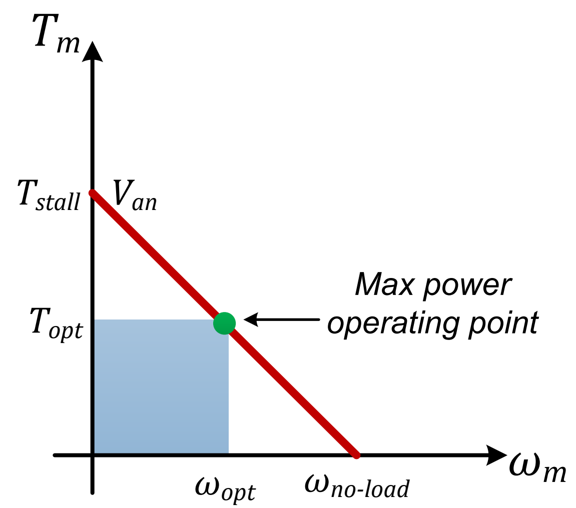
DC motor – Load effect

- Varying supply voltage will move operating point
- To find the **optimum operating point** at nominal voltage, we use maximum power transfer theorem, which results in the following:

$$T_{opt} = \frac{1}{2} T_{stall}$$

$$\omega_{opt} = \frac{1}{2} \omega_{no-load}$$

- Power transfer is the area under the torque-speed curve.



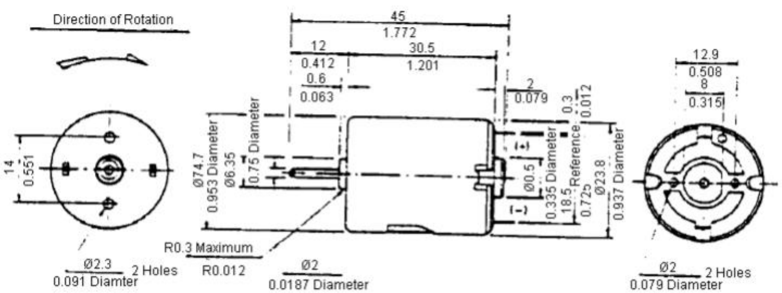
DC motor – Datasheet

- Always read the datasheet for maximum allowable current, voltage and power rating, and nominal values, as well as torque-speed curve.

Miniature Motors

multicomp

Model MM28

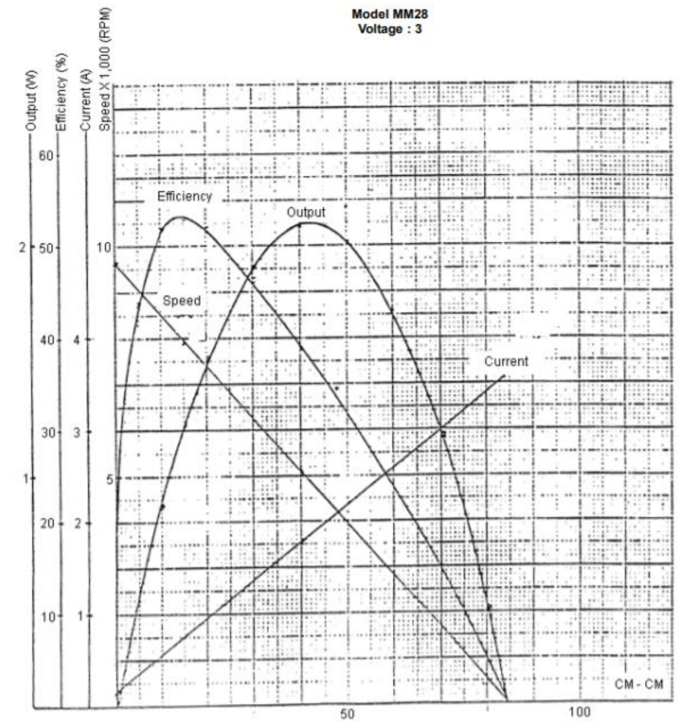


Dimensions : Millimetres (Inches)

Specification Table

Model	Operating Range	Approximately Weight
MM28	3 - 6 V	42 g

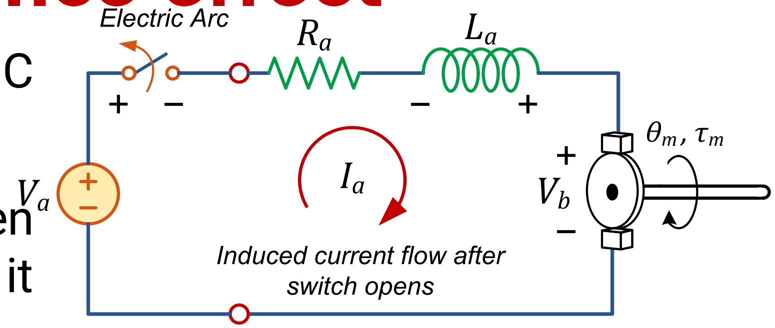
Nominal	No Load		At Maximum Efficiency					Stall Torque
Constant V	Speed rpm	Current A	Speed rpm	Current A	Torque g-cm	Output W	Efficiency %	g-cm
3 V	9,600	0.22	8,000	0.99	20	1.64	55.2	112

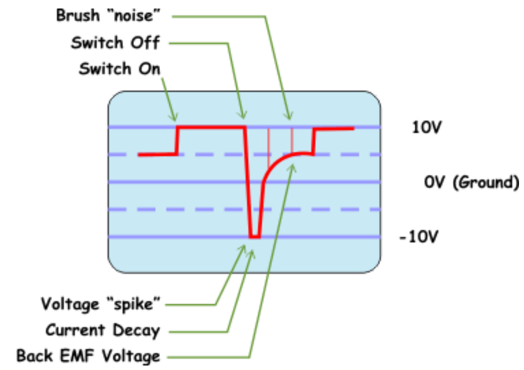


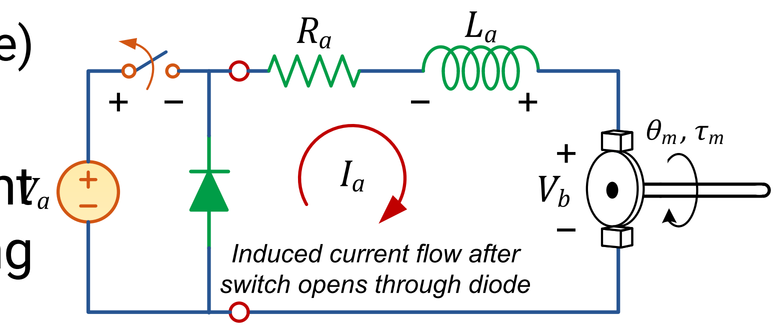
Description	Current A	Speed RPM	Torque CM - CM	Output W	Efficiency %
No Load	0.15	9,638	-	-	-
Maximum Efficiency	0.76	7,926	15	1.22	53.3
Maximum Output	1.78	5,072	40	2.08	38.9

DC motor – Inductance effect

- Recall that there is an inductance effect in DC motor due to armature wirings.
- Inductor naturally resists against sudden changes in current (similar to capacitor as it resists to sudden changes in voltage).
- When switch opens, the current tends to drop very quickly but the inductor resists this drop by developing a very large induced voltage.
- This voltage appears across the switch and can be much higher than the voltage source, causing a momentary **electric arc**.
- **Flyback diode** (also called free-willing diode) can be used to prevent that.
  - It limits voltage surge to 1.1V (current will discharge through conducting diode).

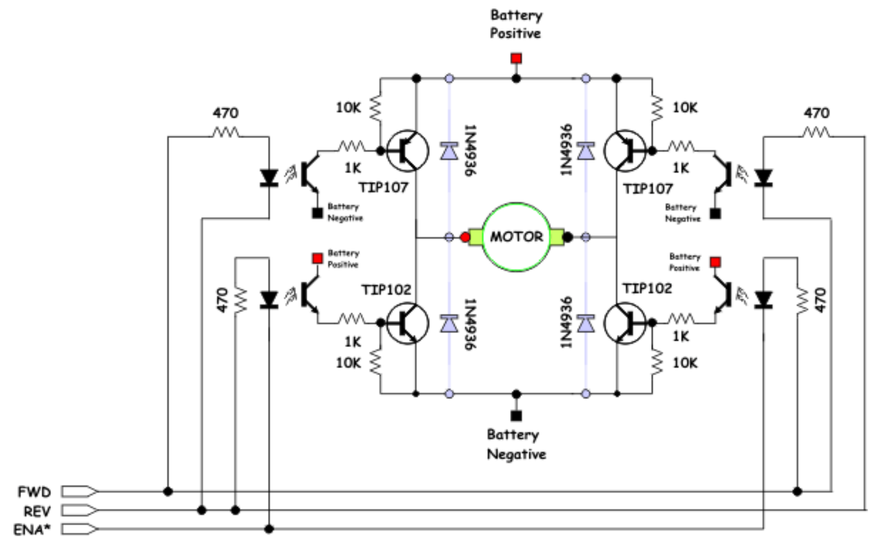






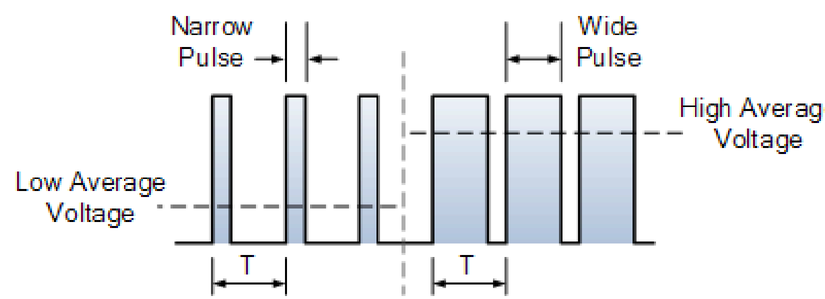
DC motor – Motor drives

- We'll consider two popular motor drive circuits:
  - **H-bridge**
  - **PWM**
- Check these websites on how to design them:
  - H-Bridges – the Basics
  - Pulse Width Modulation (PWM)
  - Motors and Selecting the Right One
  - Arduino DC Motor Control Tutorial



H-bridge example to be driven by logic circuit or microcontroller

Source: http://www.mcmanis.com/chuck/robotics/tutorial/h-bridge/bjt-circuit.html]



PWM signal that can be generated via 555 Timer or microcontroller like Ardunio

Simulation Software

https://www.tinkercad.com/circuits