Permanent Magnet DC Brushed and Brushless Motors

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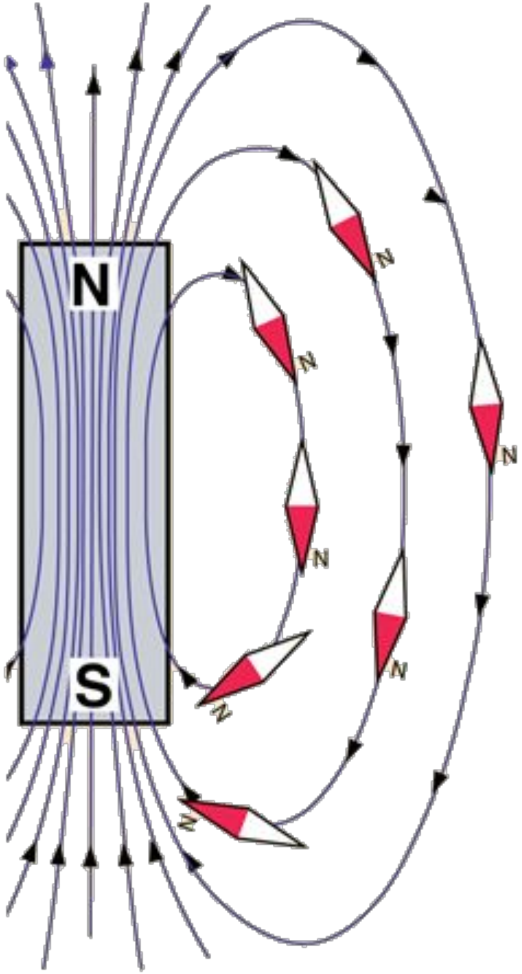
EECS 373 F19

Background Information

In a magnetic field (**B**), magnetic objects want to align their own field with the lines of the magnetic field.

See: Compass



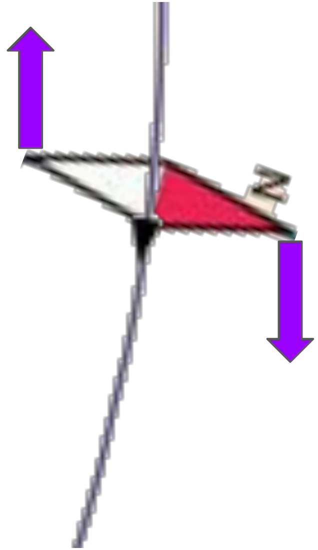
Background Information

In the compass example, both the grey bar magnet and the compass needle have their own fields.

If you turn the bar magnet, **the needle will follow in order to align its field** with the bar's field.

The needle turns because there is a **torque induced** by the misalignment of magnetic fields.

You can also create a magnetic field using a coil of conductive material...



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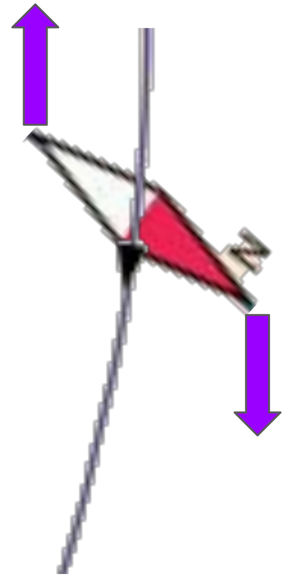

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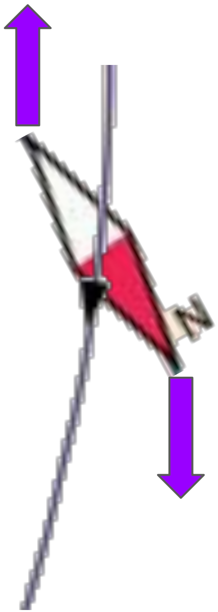

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Commutation

Recall the equation for torque on a current loop in a magnetic field:

$T = I\mathbf{A} \times \mathbf{B}$

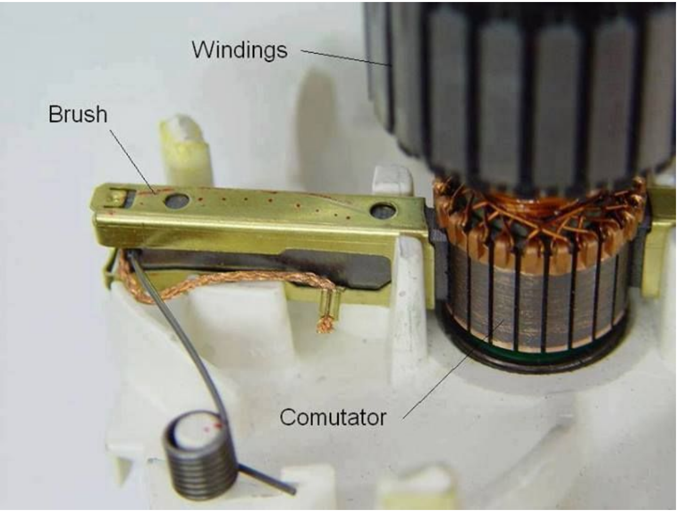
where *T* is torque, *I* is current flowing through the loop, ***A*** is the area vector of the current loop, and ***B*** is the magnetic field vector.

In an electric motor, current flows through a loop/coil on an ***armature***. If you control ***B*** or ***A*** to maintain angular separation, there will be a constant torque and the armature will spin continuously.

Keeping these fields angularly separated is a process known as ***Commutation***.

Brushed DC Motors

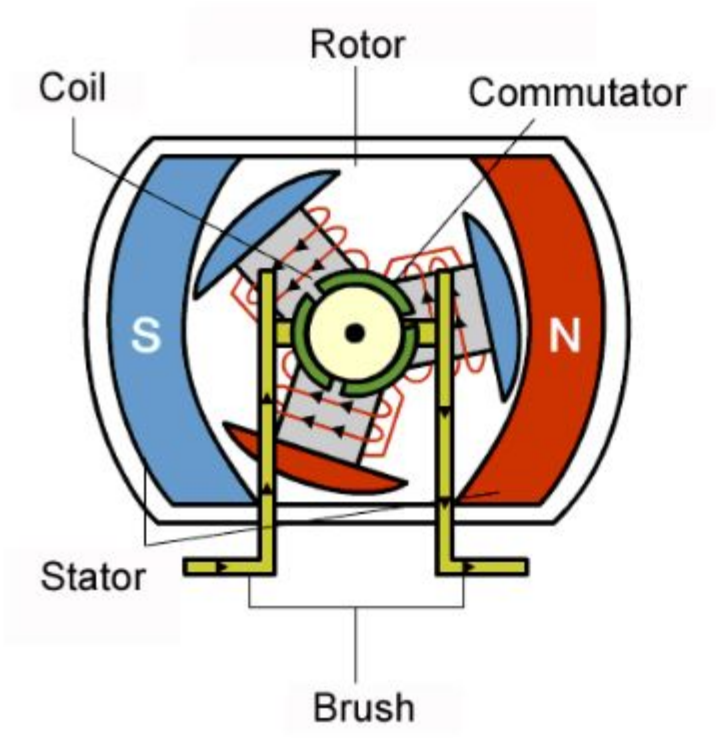
Brushed DC (BDC) motors are the category of motors that achieve commutation using ***Brushes*** -- electrical conductors that mate with other conductors in a sliding interface. It's easier to understand graphically:



Brushed DC Motors

In the figure, the brushes are fixed (attached to the ***Stator***, along with a set of permanent magnets) and they electrically mate with the ***Commutator*** in order to change how current flows in the coils that sit on the armature. The entire rotating assembly is called the ***Rotor***, which can be attached to a mechanical load to be moved.

Remember: with magnet(ic field)s, opposites attract!



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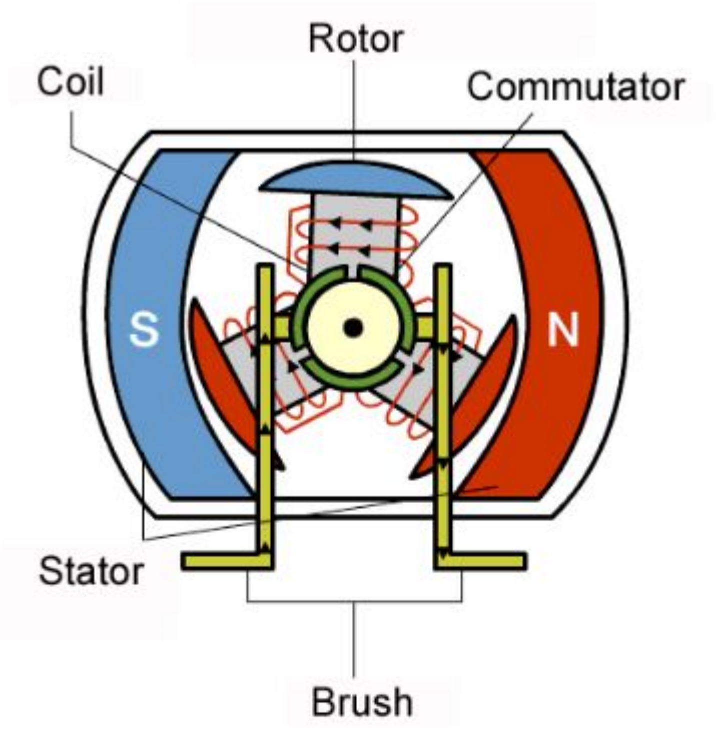

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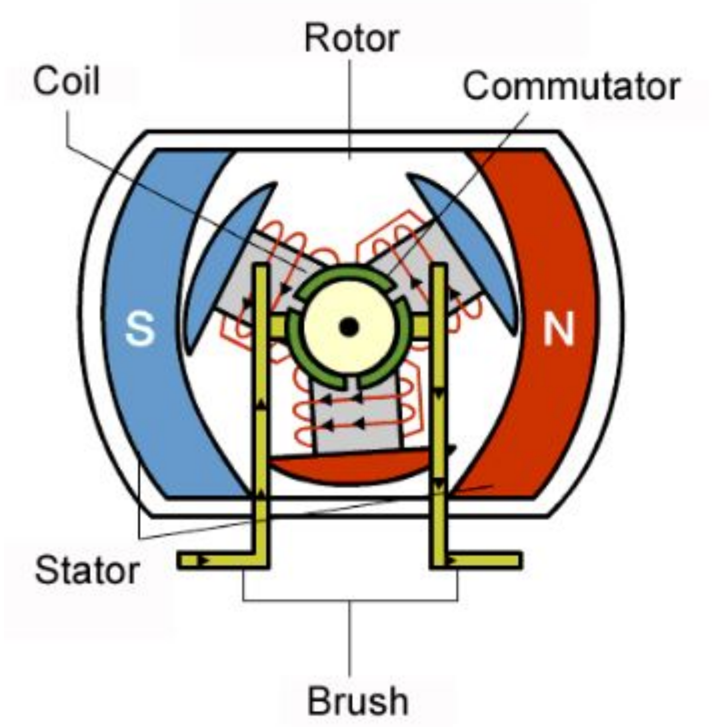

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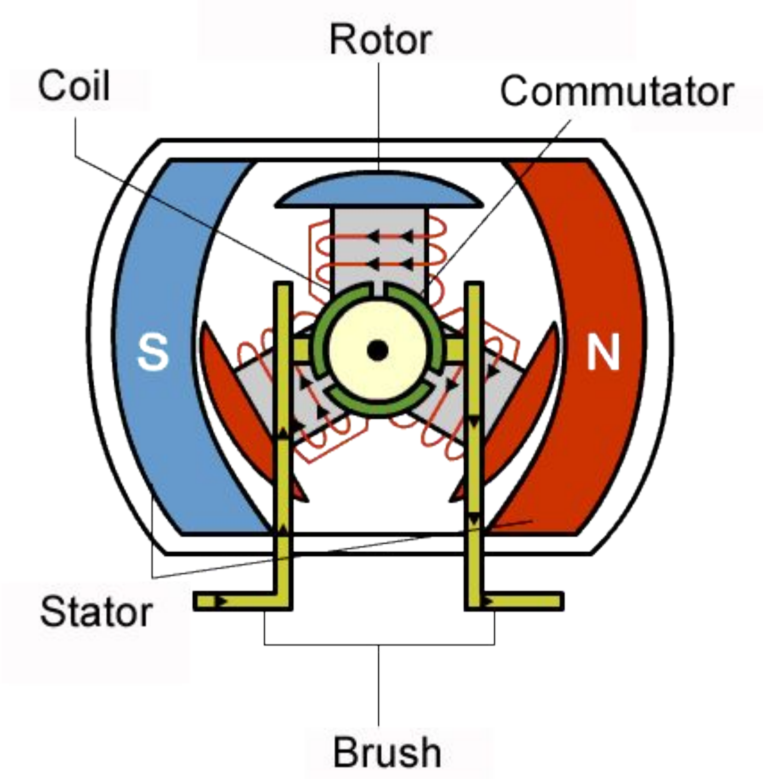
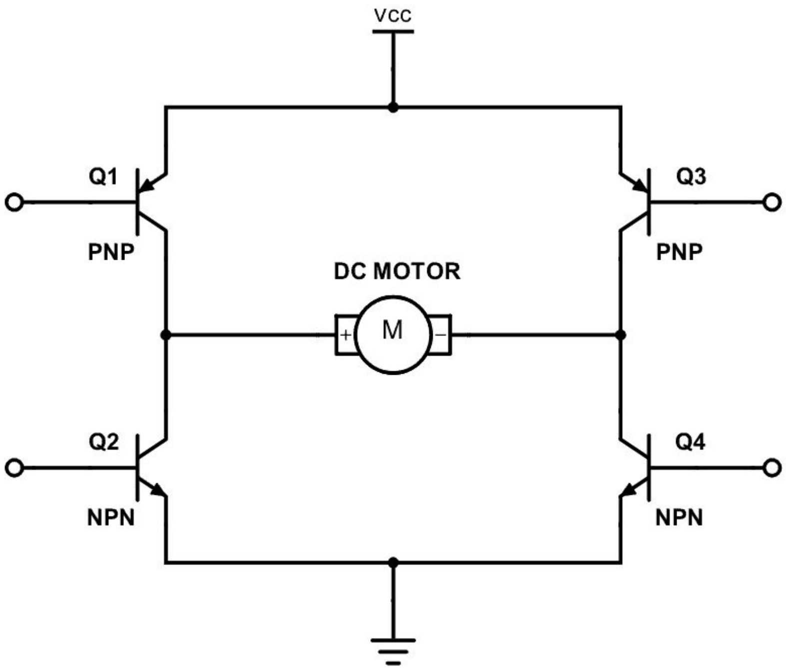


How to Use BDC Motors

To control a brushed DC motor, you need hardware for a **Power stage** between your processor and the terminals of the motor.

Two **half-bridges** can be combined to form an **H-bridge**, which when combined with your power supply and a PWM signal can control a brushed DC motor speed and direction.

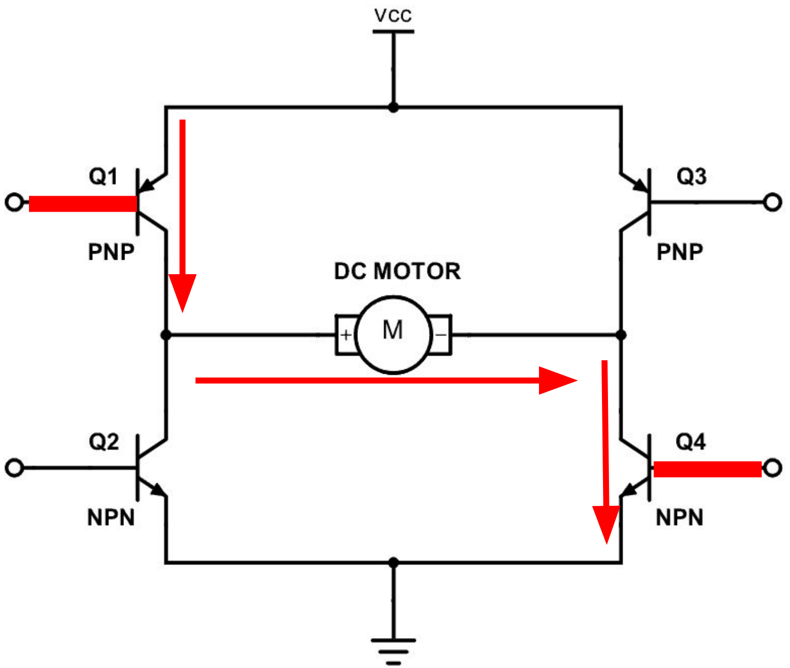


How to Use BDC Motors

If you turn on transistors Q1 and Q3, current will flow across the DC Motor in one direction, turning it via the process described earlier.

By turning on transistors Q2 and Q4, the current flows in the reverse direction and spins the motor in reverse.

By controlling the duty cycle of the PWM wave applied to the transistors, you change the apparent voltage across the motor and thus the motor speed.



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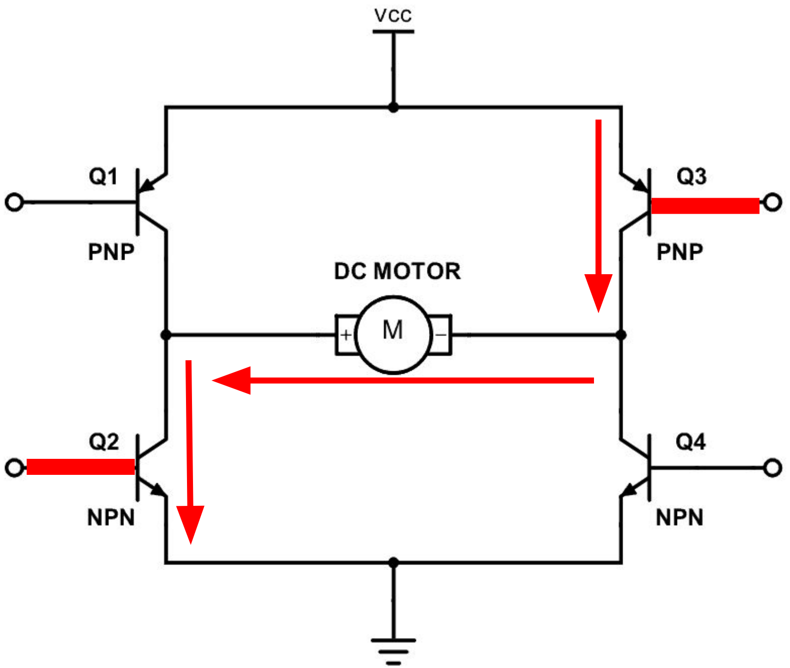

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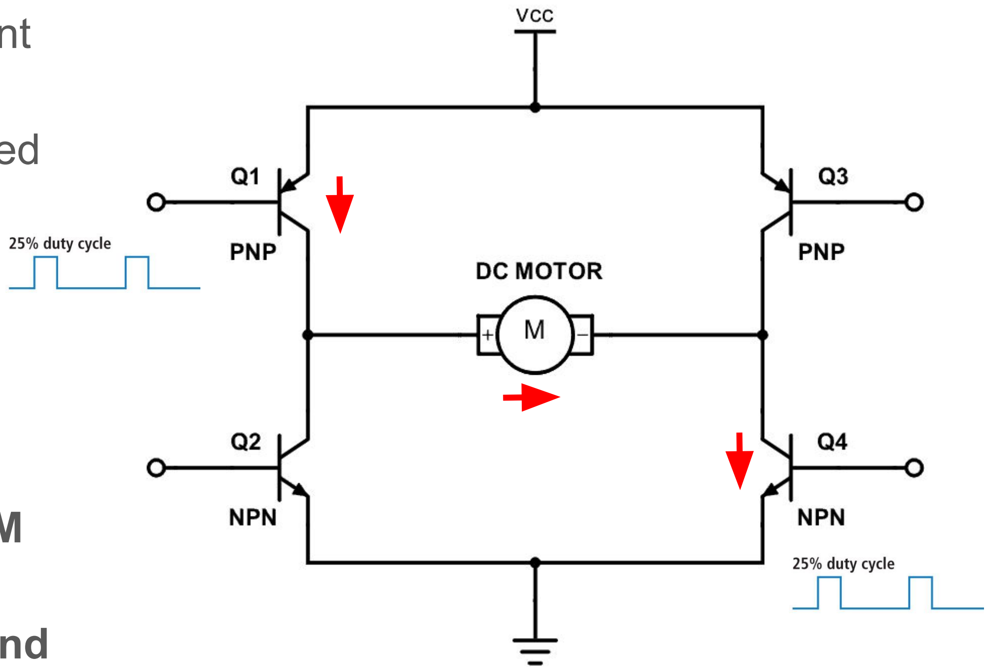

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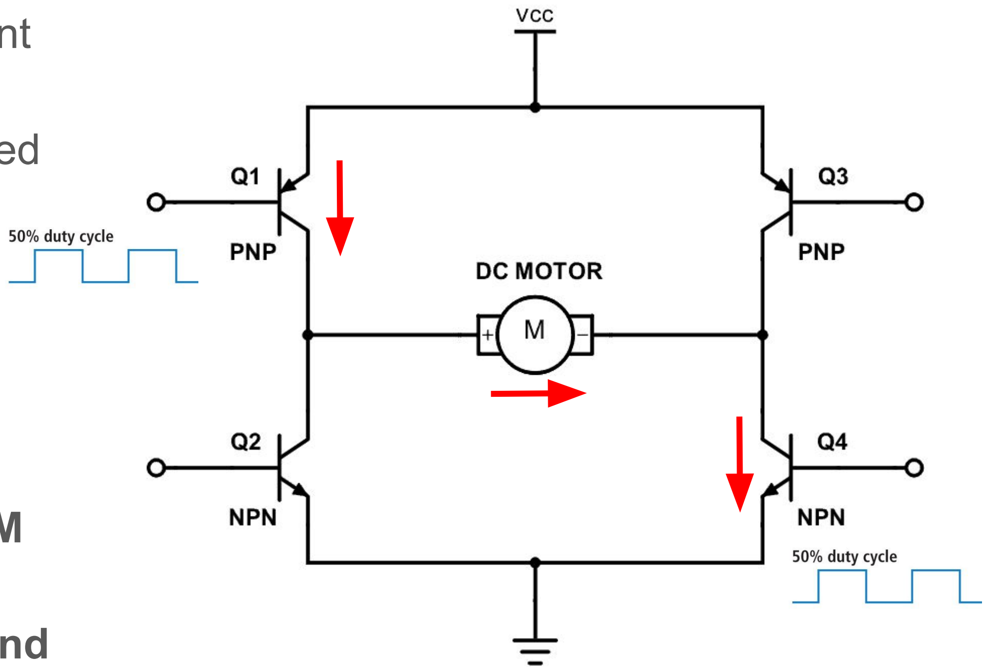

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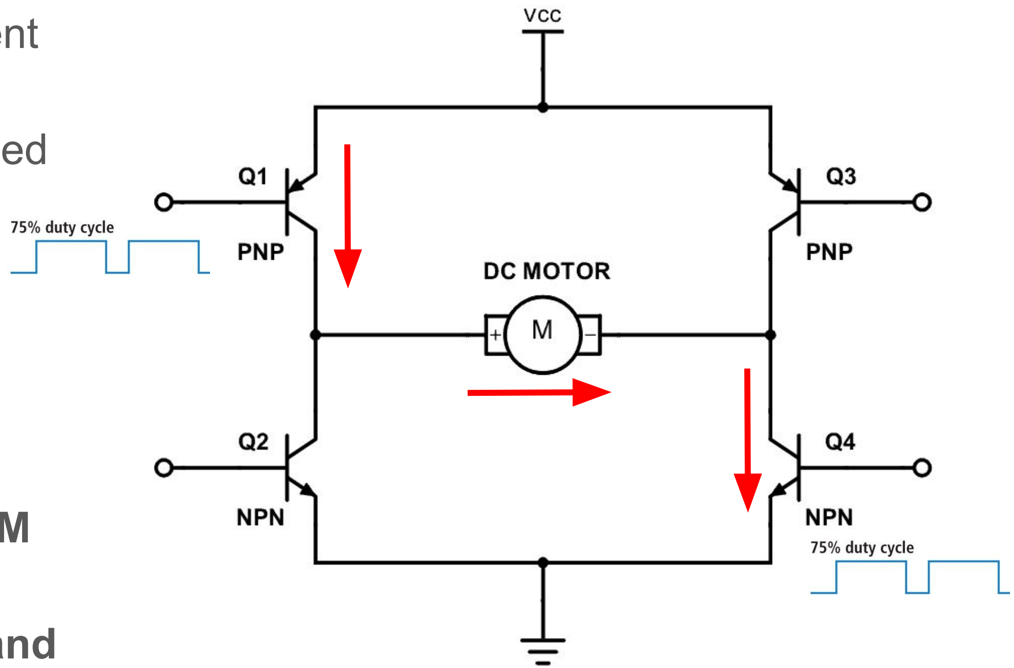


Brushed DC Motors

Pros:

- Inexpensive
- Easy to control
- Simple to model

Cons:

- Large
- Heavy
- Wear from brushes
- Linear Torque Speed curve

Applications:

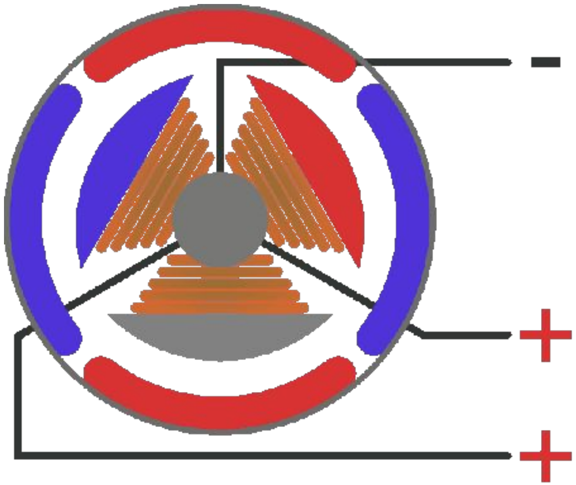
- Old electric vehicles
- DIY
- Low cost, low power applications

Brushless DC Motors

Brushless DC (BLDC) motors don’t have brushes to handle commutation -- it must be done electronically!

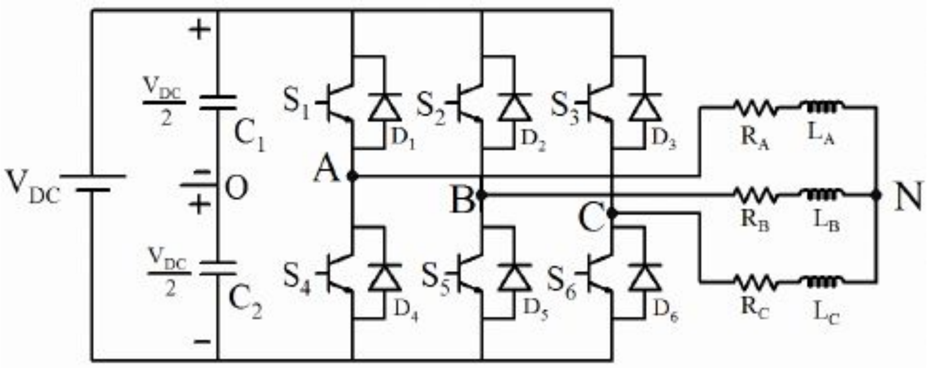
The current through the coils is commutated electrically order to generate torque to spin on the rotor.

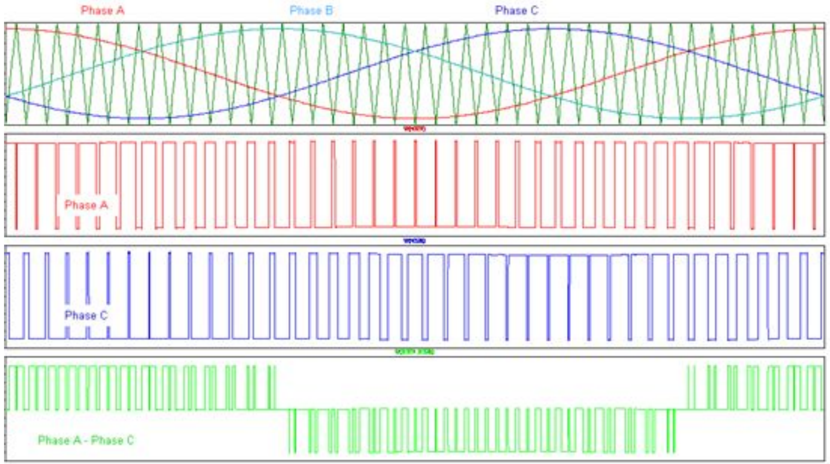
The current on three inputs (known as ***Phases***) can be controlled using solid state power electronics (MOSFETs, IGBTs, BJTs).



How to Drive Brushless Motors

- Add another half bridge (three phases)
- Each half bridge controls a single phase
- Transistors switch on and off (PWM) to modulate current
- Capacitor and motor act and low pass filter.
    - PWM -> Sine wave

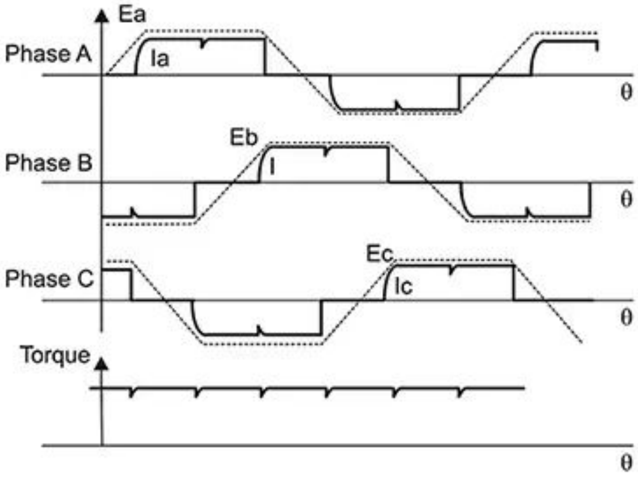




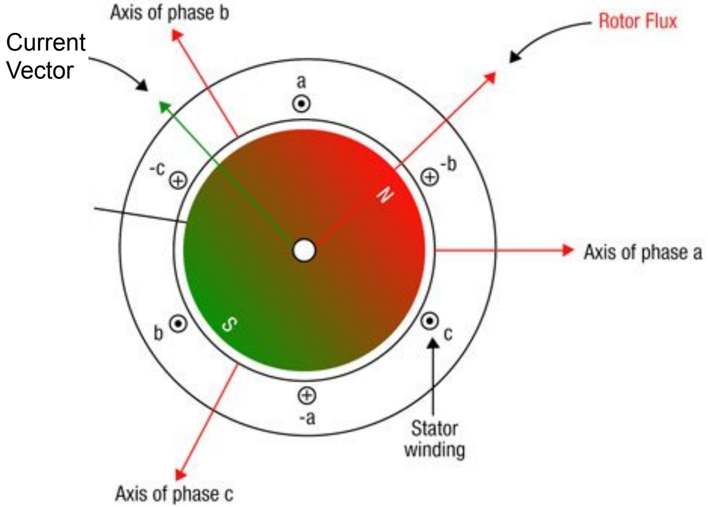
Brushless DC Motors: Control Strategies

Brushless motors require electrical commutation that can be achieved with a variety if control strategies.

Trapezoidal Control



Field-Oriented Control (FOC)



Brushless DC Motors: Control Strategies

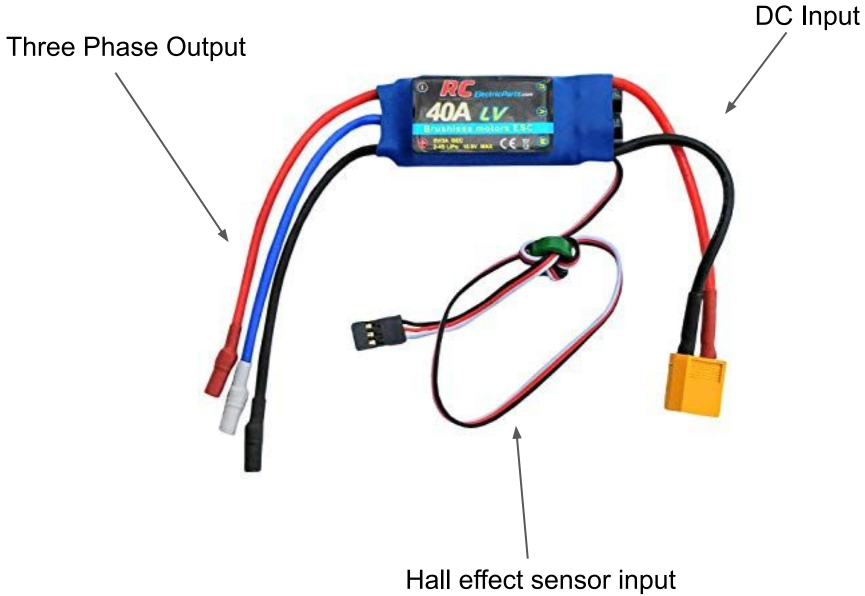
Trapezoidal Control

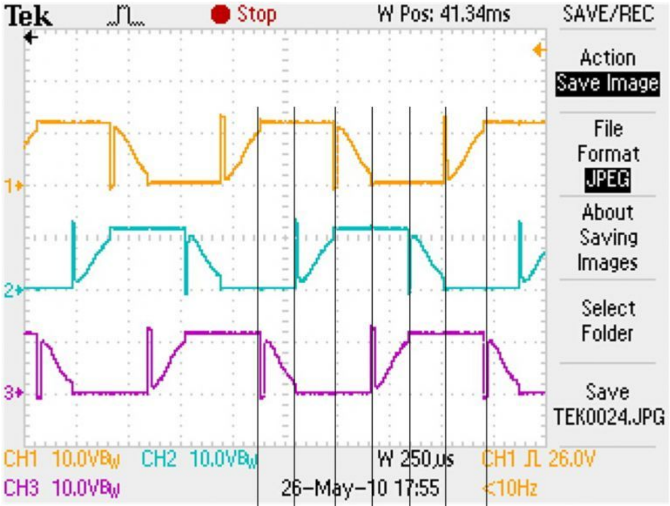
- Uses 3 digital sensor with 60 degree resolution
- Commutates the phases to maintain a ***B*** lead of 60-120 degrees (before jumping to the next state)
- This variable lead angle can cause ***Torque Ripple***.
- The algorithm is simple, but does not provide optimal performance

Field-Oriented Control (Vector Control)

- Uses a high-resolution rotary position sensor
- Samples phase currents to calculate and control current vector.
- Runs a feedback control loop to maintain a specified ***B*** lead current vector by 90 degrees
- Complex algorithm and hardware, but higher performance

Electronic Speed Controllers (ESCs)



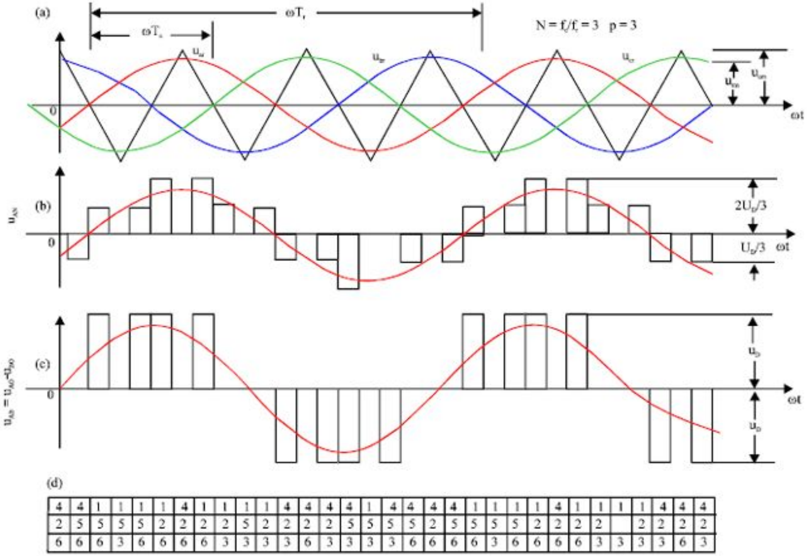


ESC Waveforms
E Flite 32
Part Load
with PWM

	STEP	1	2	3	4	5	6
PHASE	A	Hi	Hi	Off	Lo	Lo	Off
	B	Lo	Off	Hi	Hi	Off	Lo
	C	Off	Lo	Lo	Off	Hi	Hi

AC Inverters

Tractive Inverter from RMS



Brushless DC Motors

Pros:

- High power density
- Non linear torque speed curve
- No wear from brushes
- Efficient

Cons:

- Expensive
- Hard to control

Applications:

- RC products
- Modern Electric Vehicles
- Industrial machines and drives

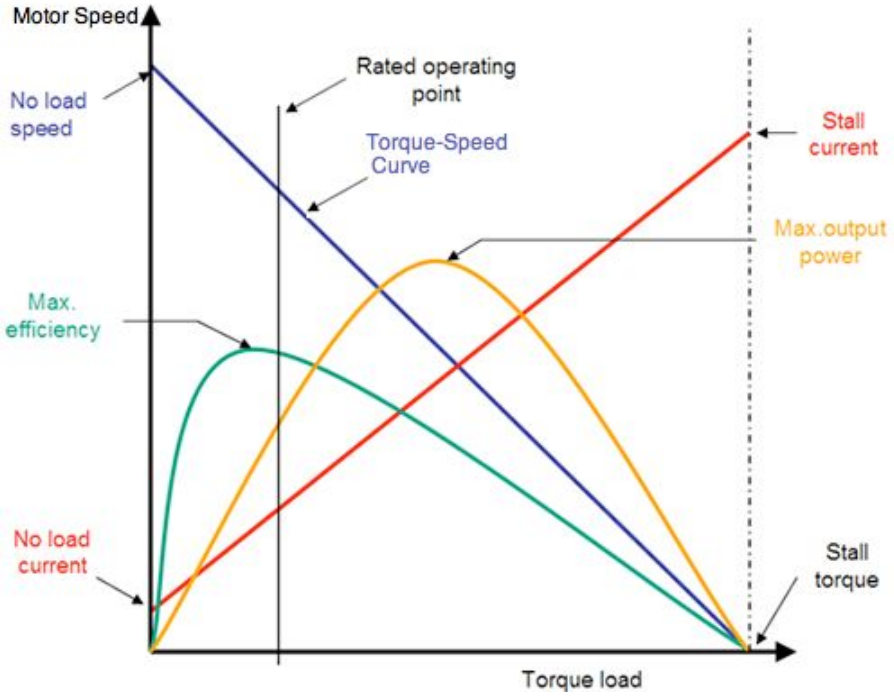
Basic Analysis for Motor Sizing (BDC)

Avoid thinking of your problem in terms of speed.

It takes **torque** to move things. **Power** is how fast you can spin while applying that torque.

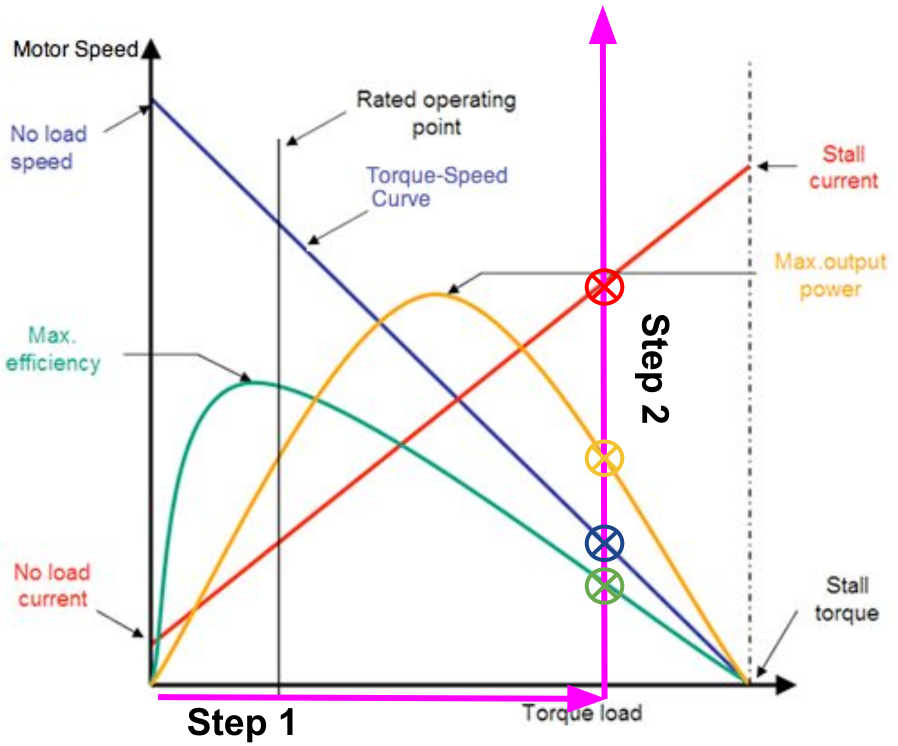
Power = **Torque** ⨉ Speed

Think of these two parameters first!



Basic Analysis for Motor Sizing (BDC)

1. Find the location of your application torque
2. Trace upwards and take note of the intersections with the speed, power, efficiency, and current curves
3. Evaluate if the values at those intersections meet your criteria

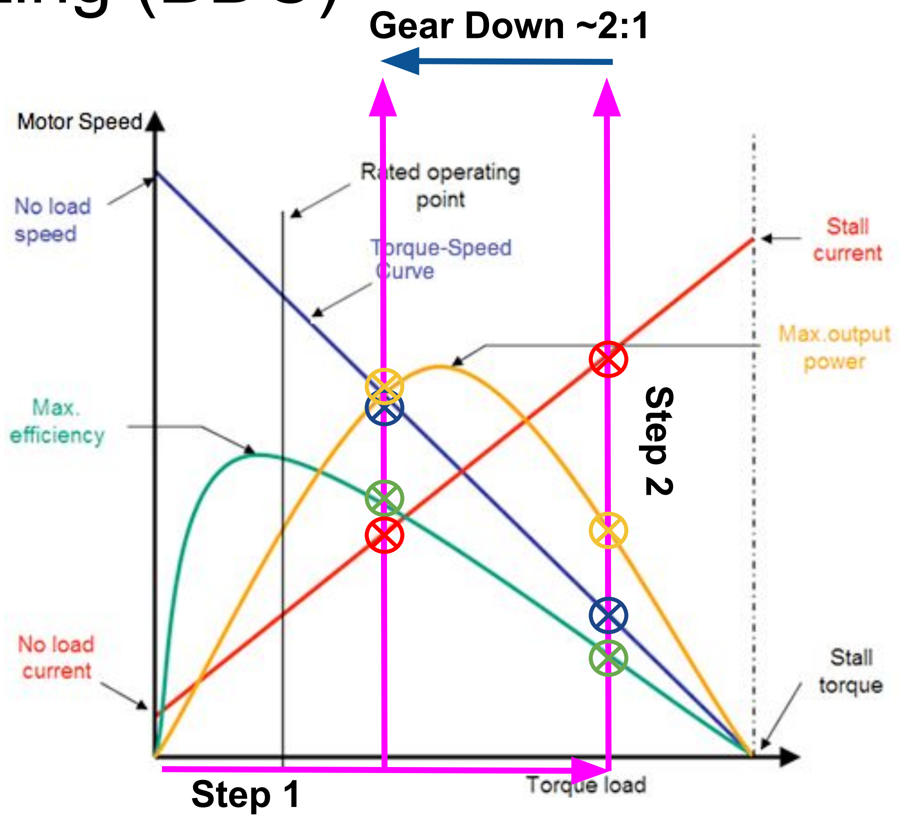


Basic Analysis for Motor Sizing (BDC)

Not fast enough?
Not efficient enough?
Can't sustain current draw?

- Get a bigger motor OR
- Gear your motor towards peak power (if to the right -> gear down and vice versa)
- (or gear towards peak efficiency)

Ex: Gear down 2:1 -- Torque from motor is halved; speed *more* than doubles; efficiency increases (motor runs cooler)



Selection Guide

Numbers are a relative scale -- higher is better

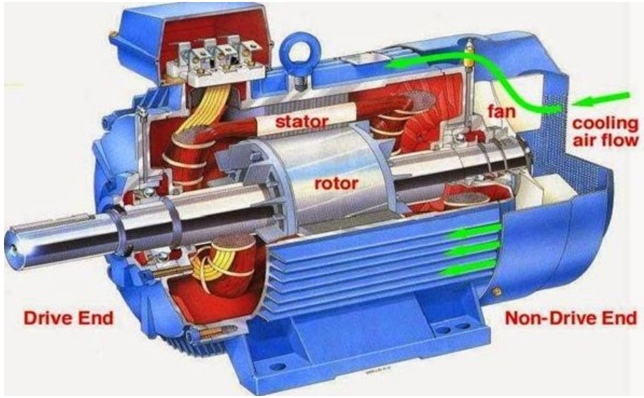
Property	BDC	BLDC - Trapezoidal	BLDC - FOC
Simplicity/Affordability	3	2	1
Power/$ at low power	3	2	1
Power/$ at high power	1	2	3
Power/Mass	1	2	3
Speed	1	2	2
Torque at low power	3	1	2
Torque at high power	1	2	3

Questions?

Appendices

PMSM

Induction Motors



Switched Reluctance