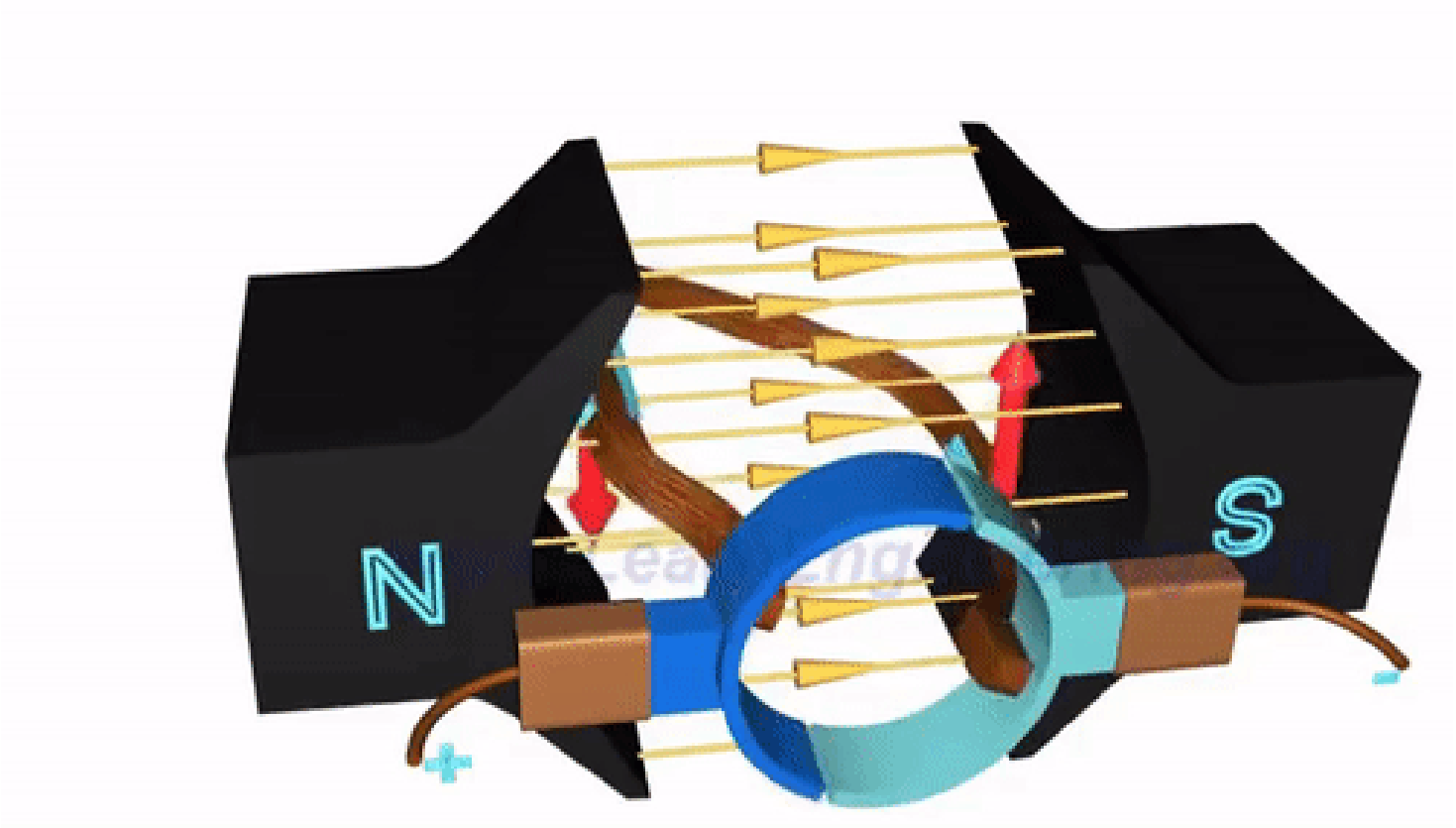
Motor control

Agenda

- How a DC motor works
- Speed control with PWM
- Direction control using an H-Bridge
- Stepper motors
- Servo motors

How a DC motor works

https://www.youtube.com/watch?v=LAtPHANEfQo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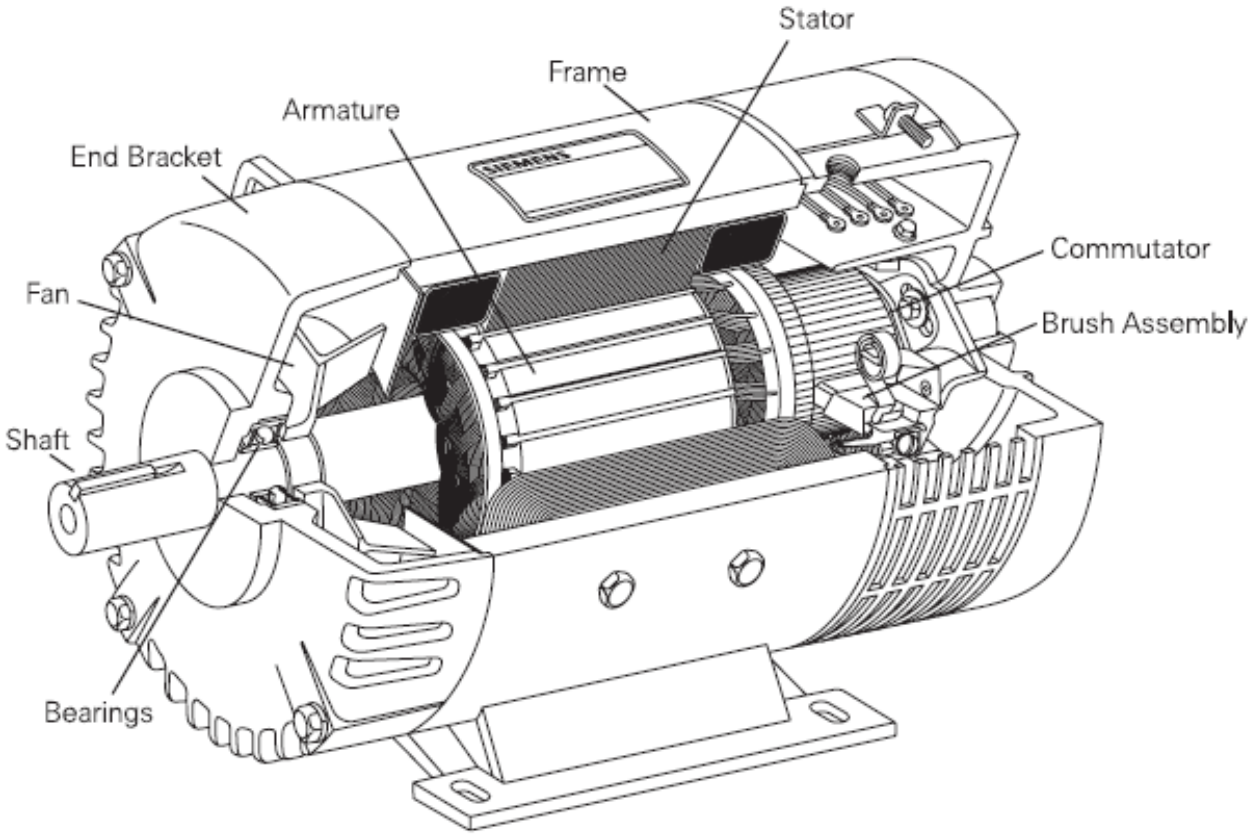
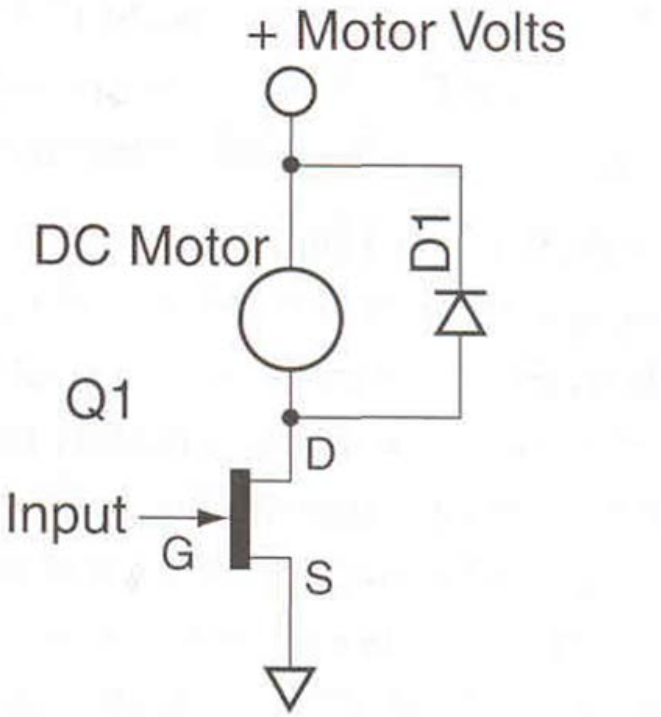
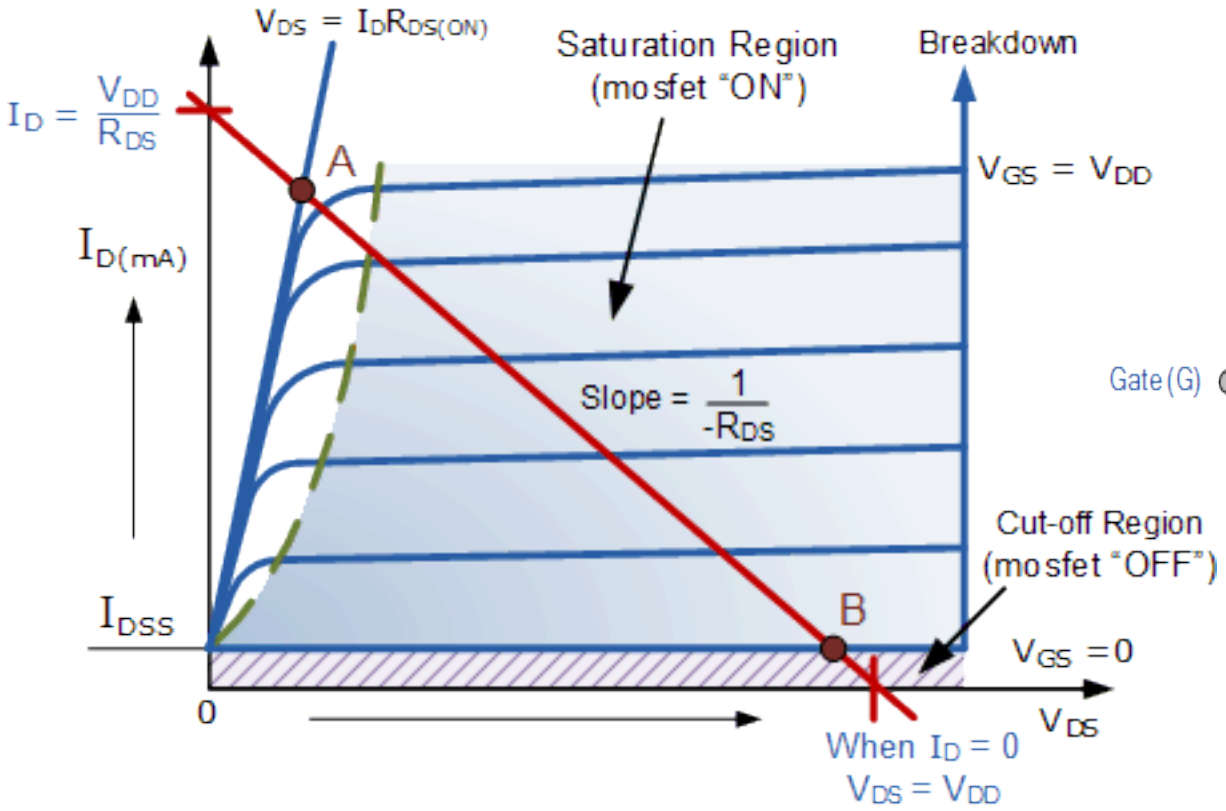
A complete DC motor

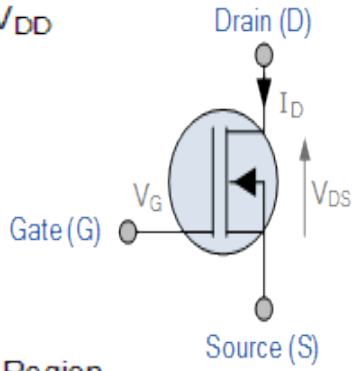


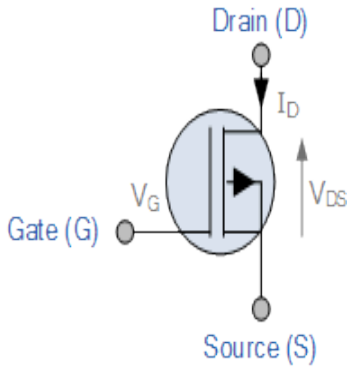
Switching on/off using a transistor



The MOSFET as a switch



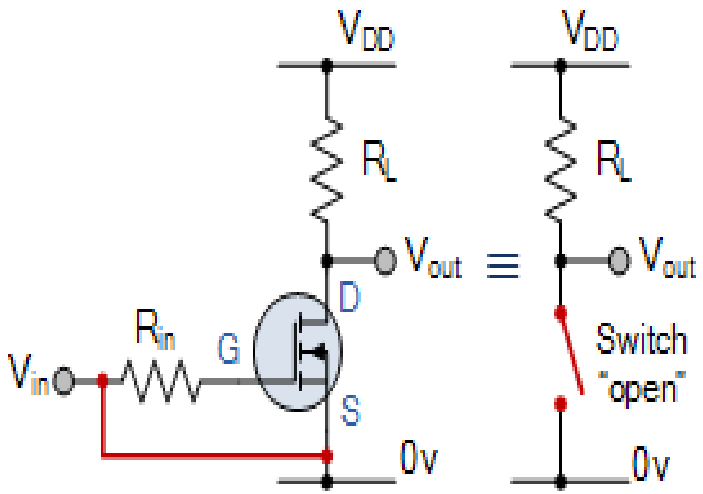




- When we use the MOSFET as a closed switch, we want it to operate in the linear region, i.e. when we increase the power supply voltage, we increase the current.
- So the voltage applied to the Gate must be 'high enough' (see the datasheet!)

Open switch

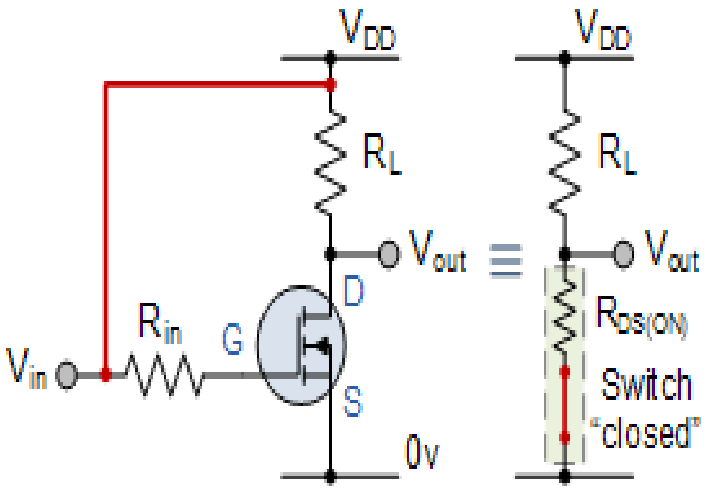
N-Channel Cut-off



- Gate-source voltage less than threshold voltage $V_{GS} < V_{TH}$
- MOSFET is “fully-OFF” (Cut-off region)
- No Drain current flows ($I_D = 0$)
- $V_{OUT} = V_{DS} = V_{DD}$
- MOSFET operates as an “open switch”

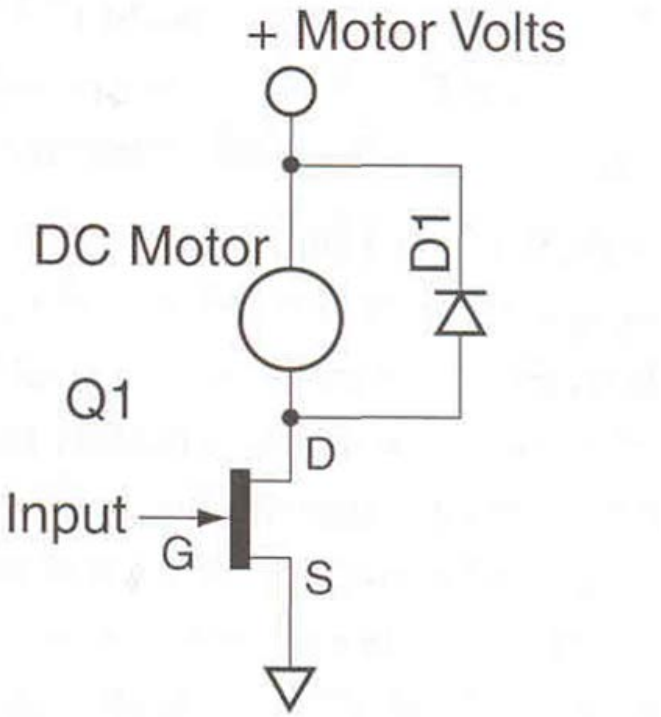
Closed switch

N-Channel Saturation



- Gate-source voltage is much greater than threshold voltage: $V_{GS} > V_{TH}$
- MOSFET is “fully-ON” (linear region)
- $I_D = (V_{DD} - V_{DS}) / R_L$
- $V_{OUT} = V_{DS} = R_{DS(on)} * I_D$
- Min channel resistance $R_{DS(on)} < 0.1\Omega$ (typical)
- MOSFET operates as a low resistance “closed switch”

Switching on/off using a transistor

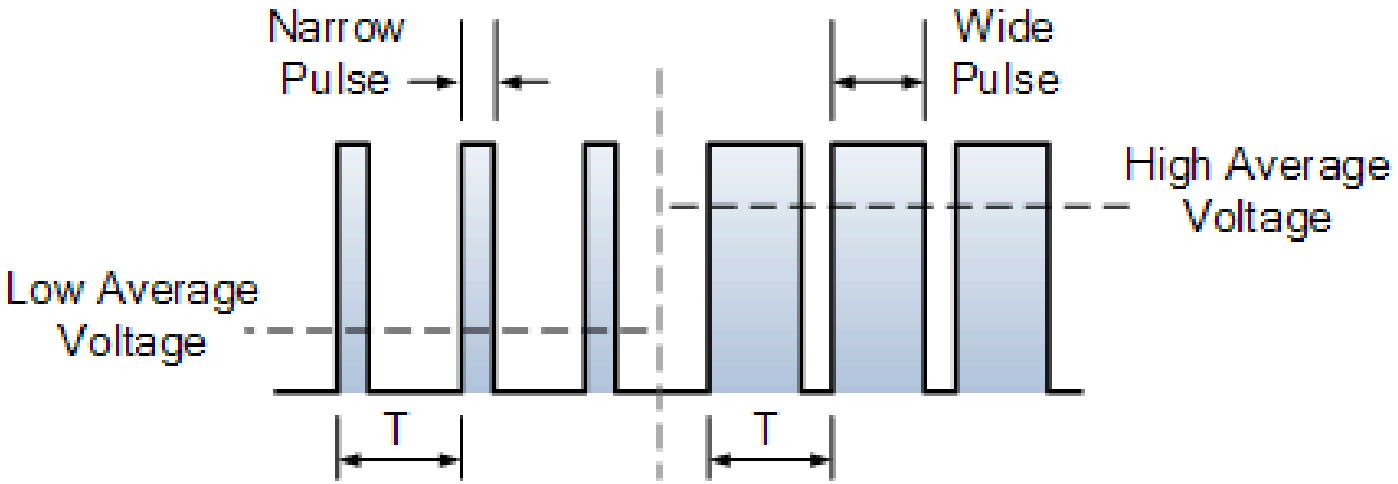


- The diode protects the transistor, when the power to the inductive load (ex. a motor) is turned off.

Speed control with PWM

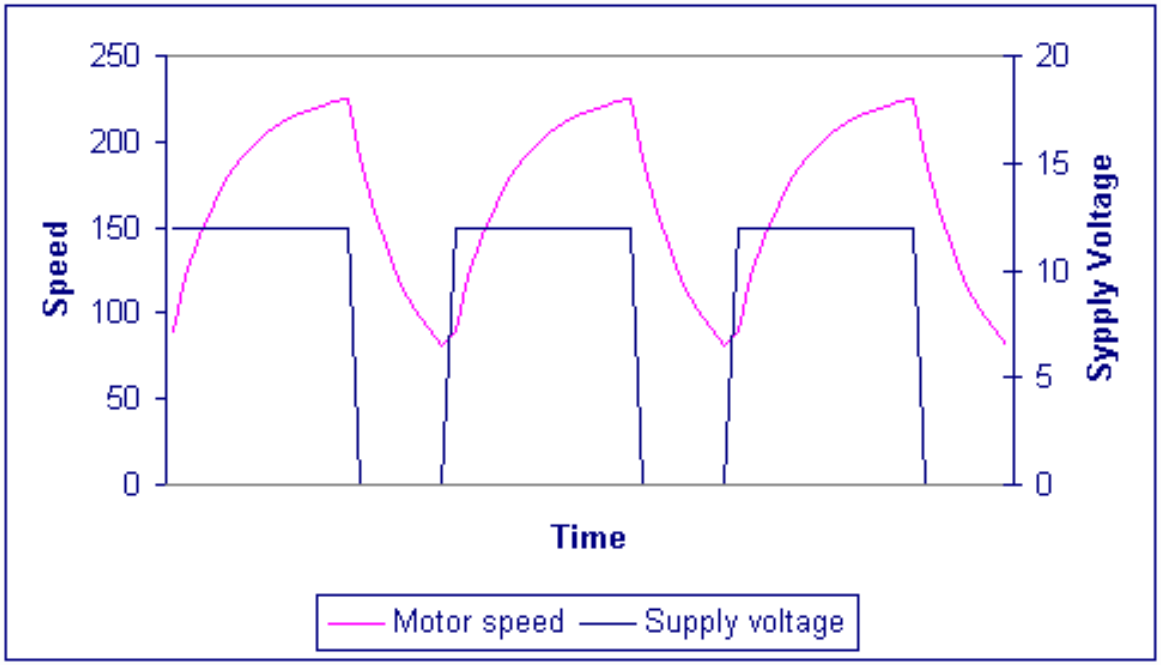
- The rotation speed depends on the magnetic field generated by the coils and the load on the motor.
- The magnetic field depends on the current flow in the coil (and thus indirectly on the voltage applied to the motor).
- But we normally have a fixed supply voltage (e.g. the battery), so how do we control the rotation speed?

PWM



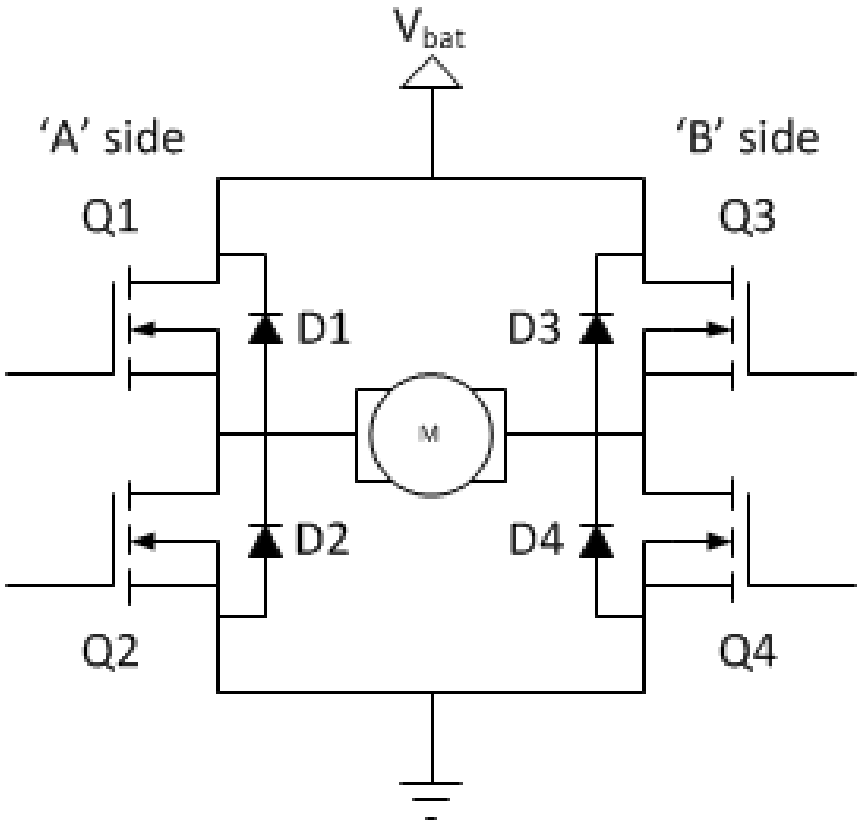
- We can control the speed by changing the pulse width instead of the voltage.

PWM



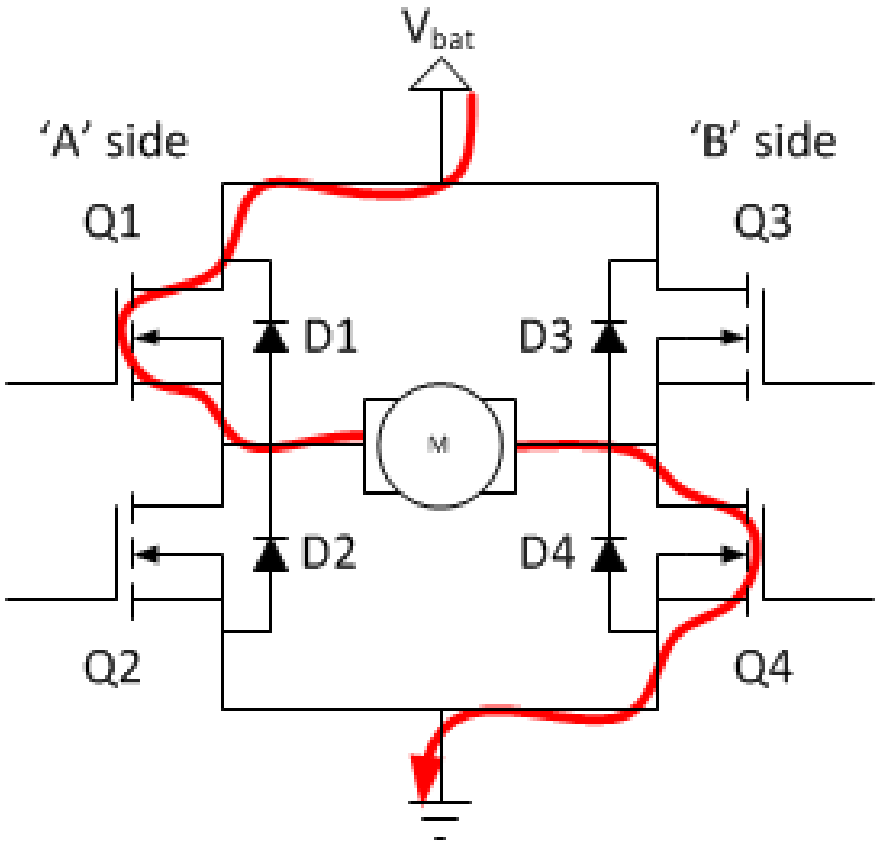
- At a high frequency, the motor will behave as if we had applied a constant voltage equal to the mean voltage of the PWM signal.
- Avoid frequencies between 20 Hz and 20 kHz!

Direction control using an H-Bridge



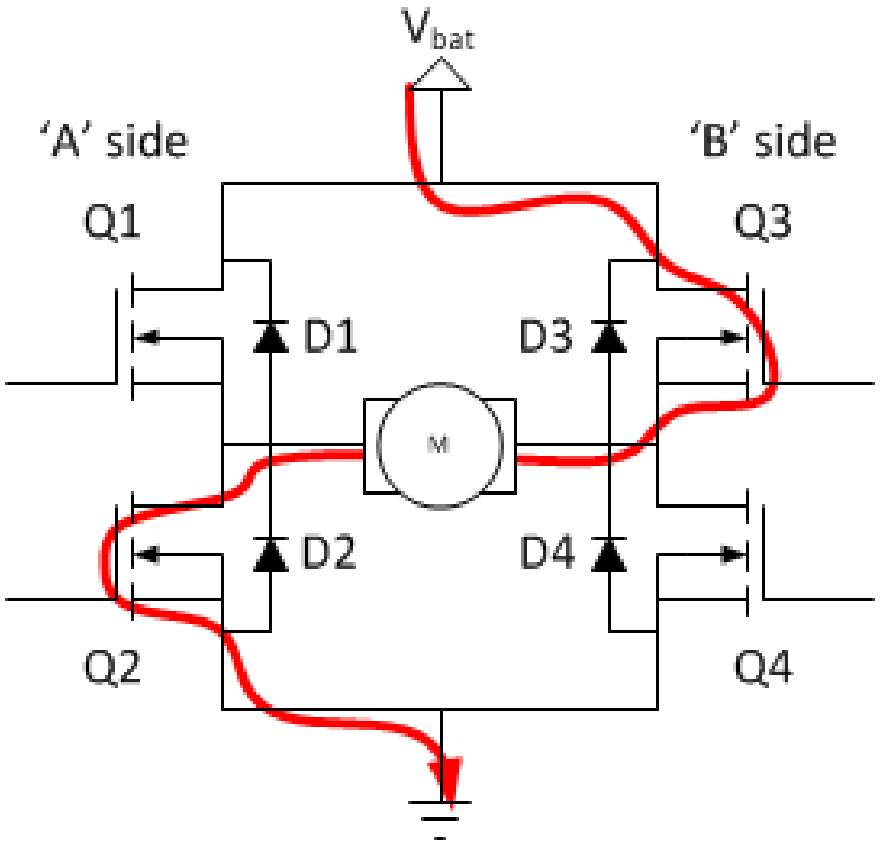
- Four MOSFETs which can be controlled independently.

Direction control using an H-Bridge



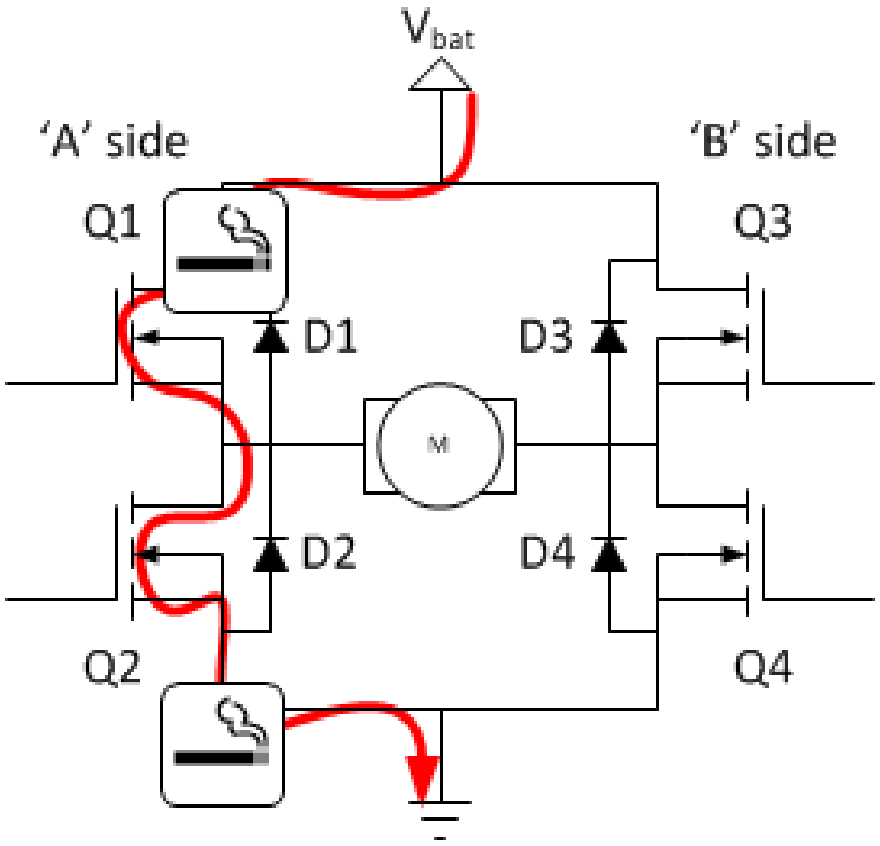
- Q1 and Q4 closed will drive the motor in one direction.

Direction control using an H-Bridge



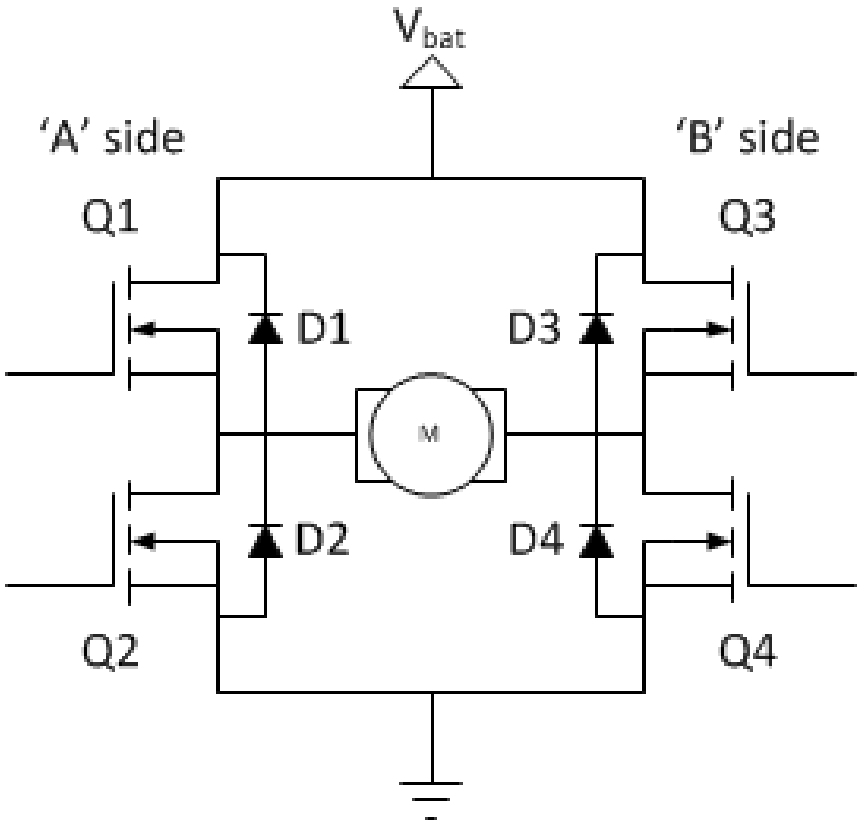
- Q3 and Q2 closed will drive the motor in the opposite direction.

Fuse test using an H-Bridge



- Q1 and Q2 closed will let the smoke out.
- Q3 and Q4 closed will let the smoke out.

Braking with an H-Bridge



- To brake, turn on Q1 and Q3.
- Or turn on Q2 and Q4.

Stepper motors

https://learn.adafruit.com/assets/16352

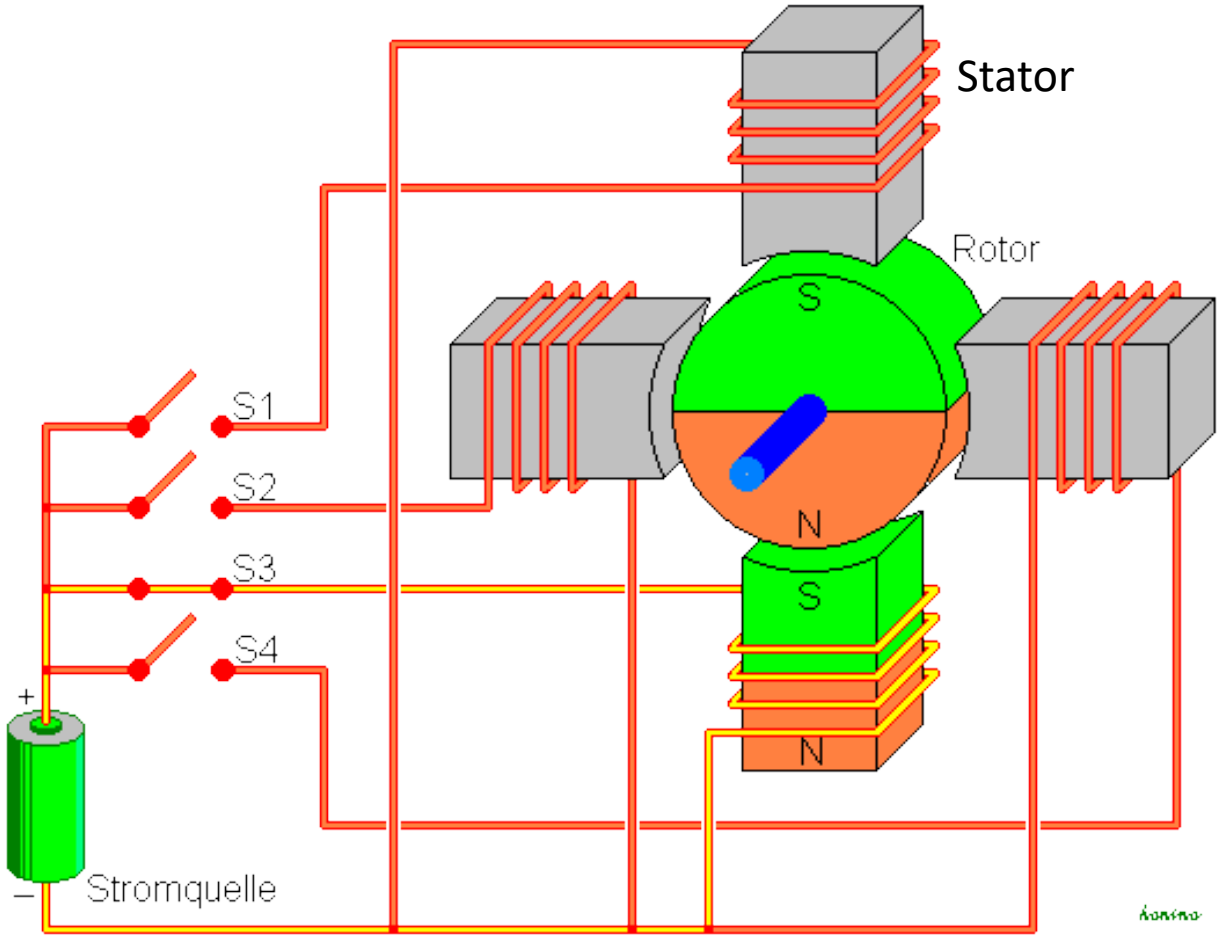
Advantages

- Movement is controlled in steps of a given angle.
- Full torque when rotation is stopped.
- Precise open-loop positioning and repetition without additional tracking (open-loop control).
- Quick starts, stop, and reverse capability.
- High reliability because there is no brush or physical contact required for commutation.
- A wide speed range can be controlled by varying the drive signal timing.

Drawbacks

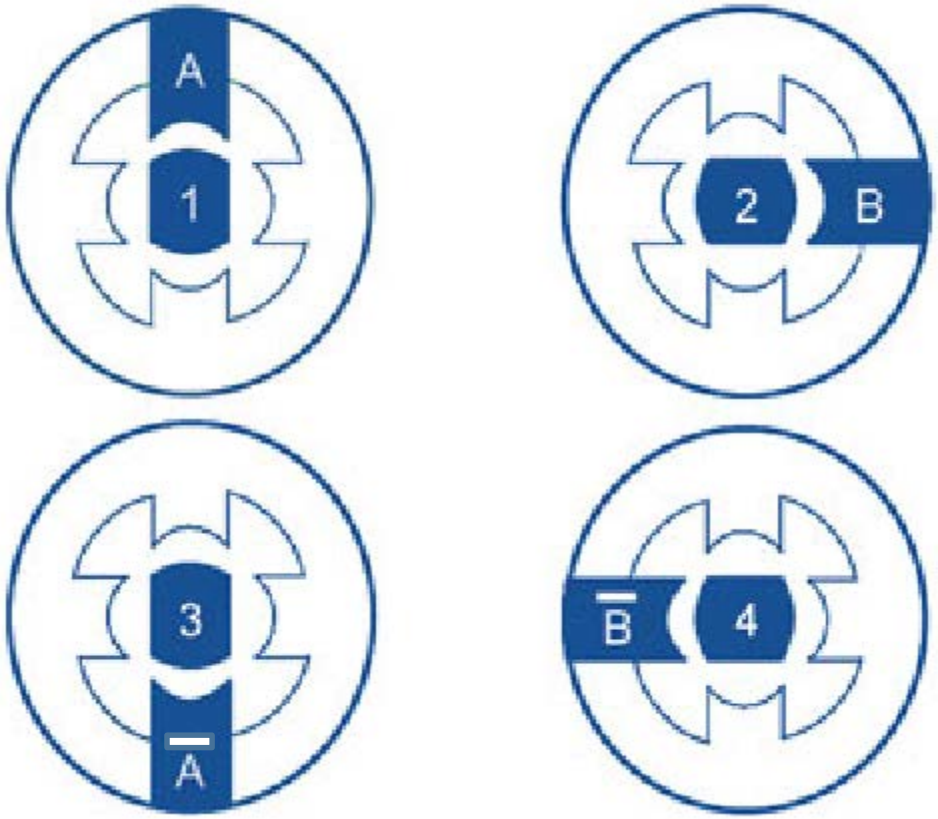
- It is possible to lose position control in some situations, because no feedback is natively provided.
- Power consumption does not decrease to zero, even if load is absent.
- Stepping motors have low power density and lower maximum speed compared to brushed and brushless DC motors. Typical loaded maximum operating speeds for stepper motors are around 1000 RPM.

Basics of a stepper motor



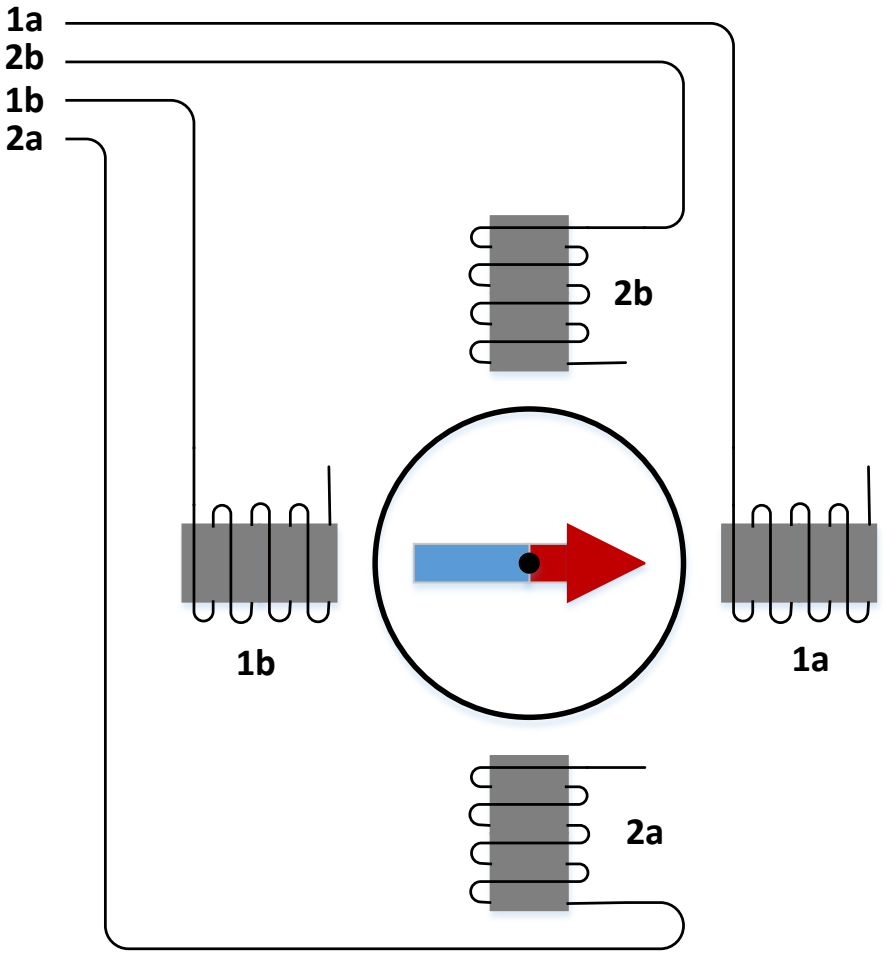
- Each stator is an individually controlled electromagnet.
- The rotor is a permanent magnet or electromagnet.

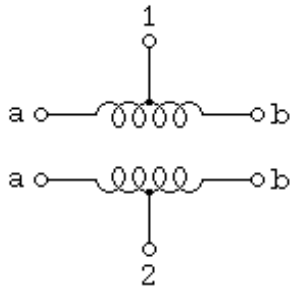
Wave drive (full step)



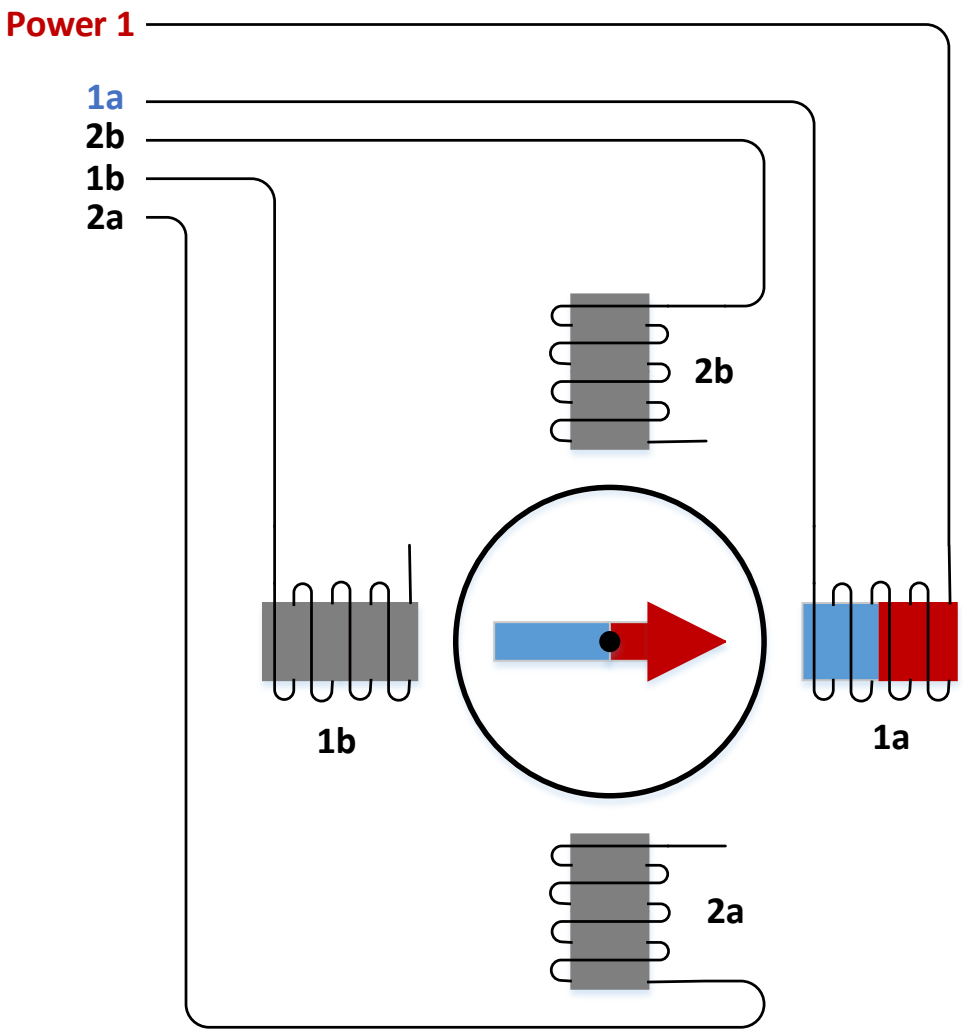
- Full step drive, exciting one stator at the time.

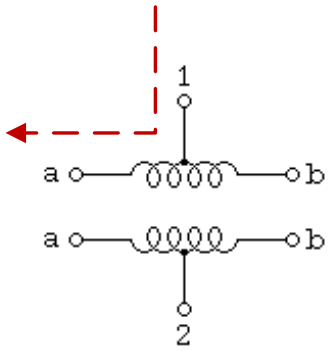
Unipolar wiring



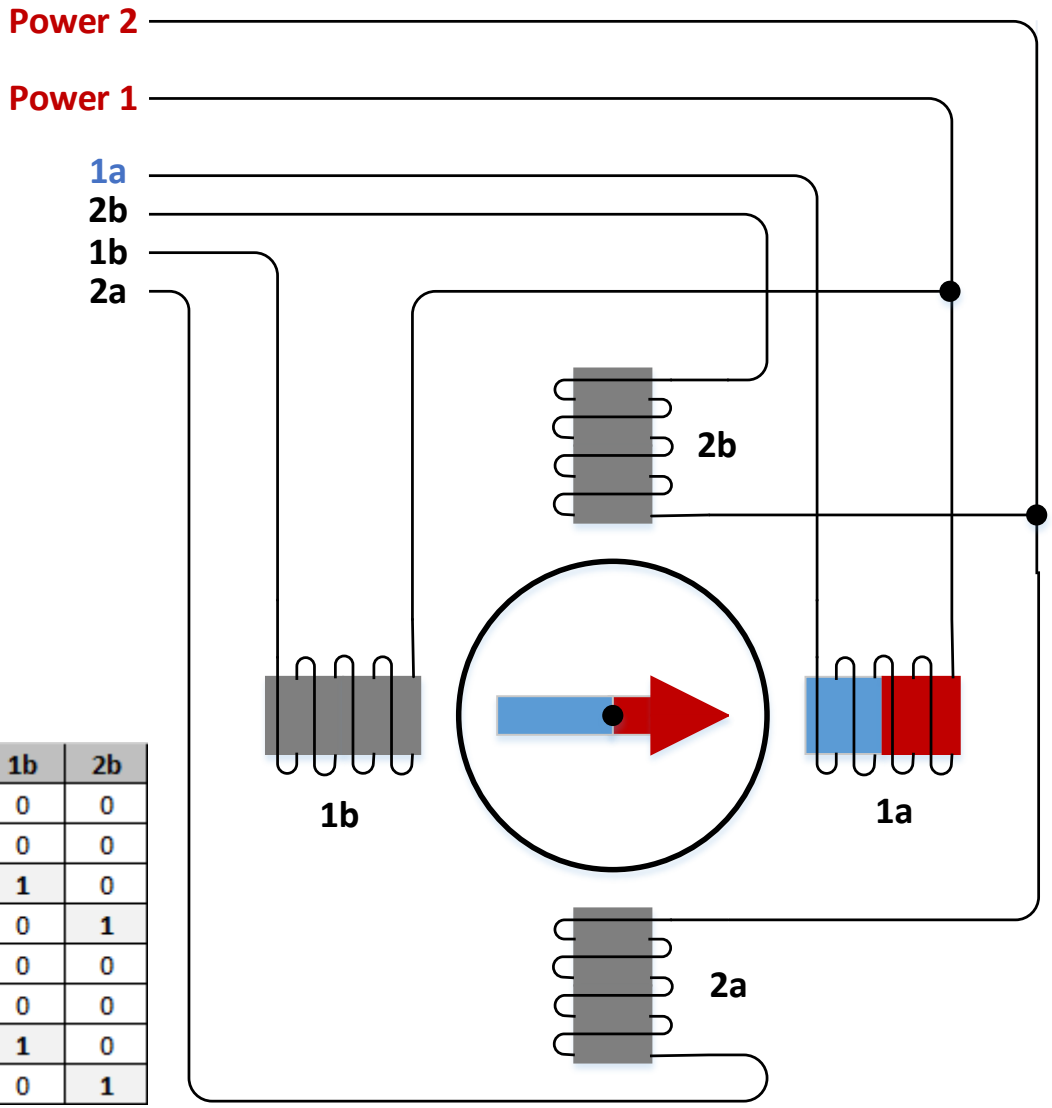


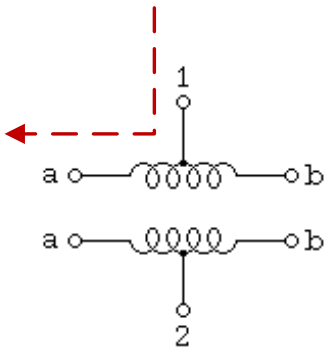
Unipolar wiring





Wave drive





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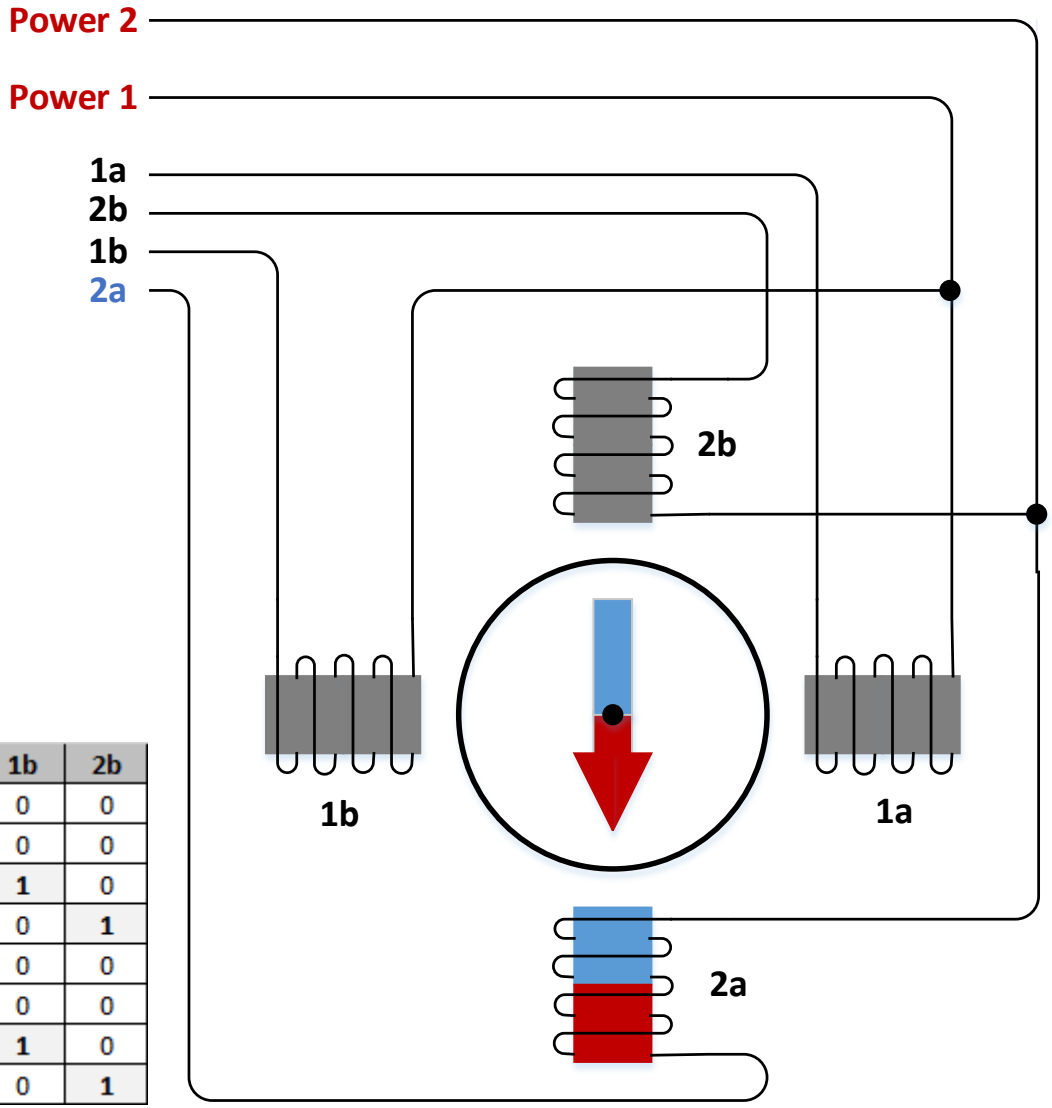
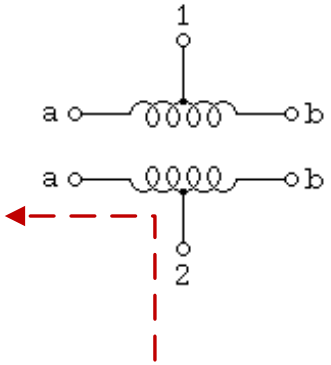
8	0	0	0	1

Wave drive





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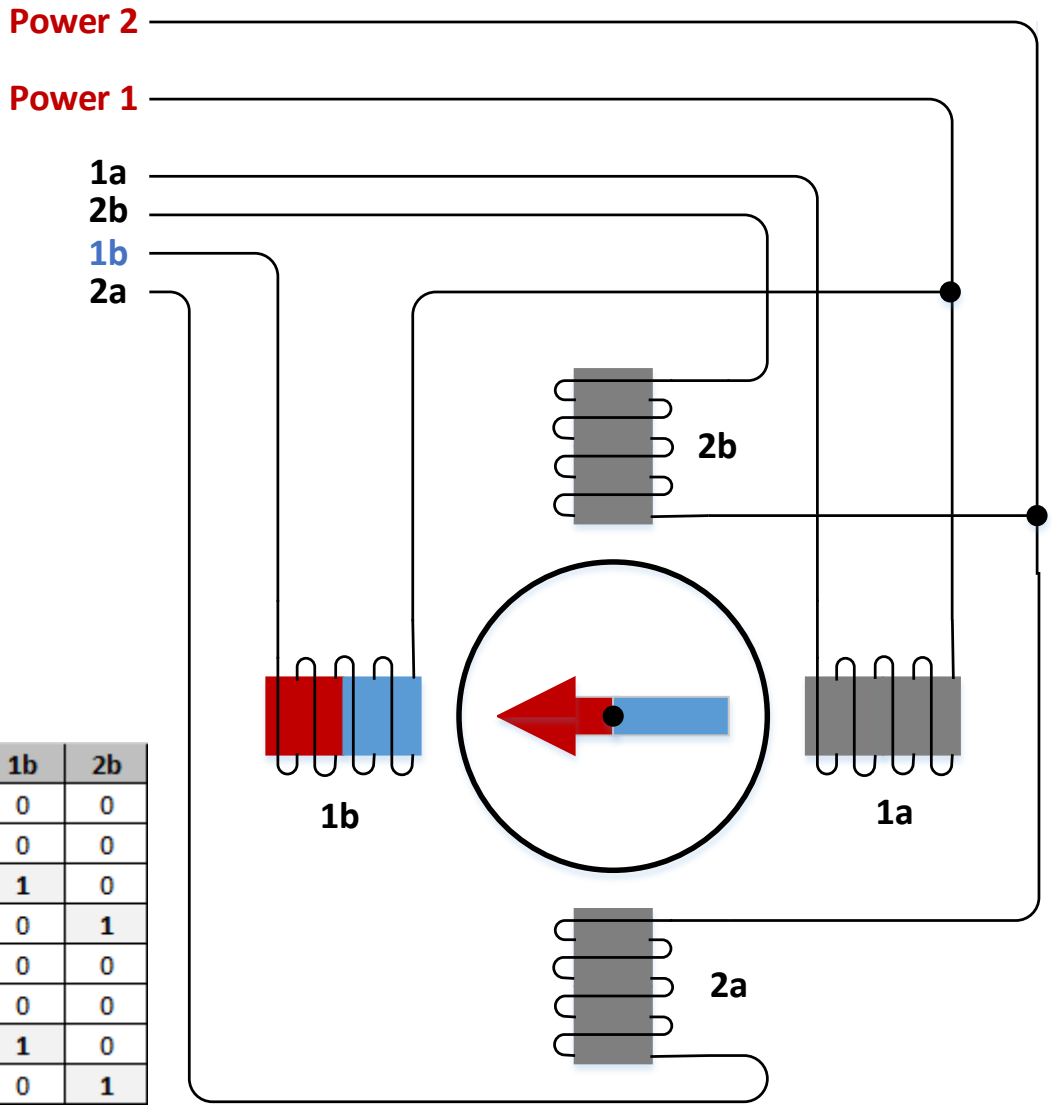
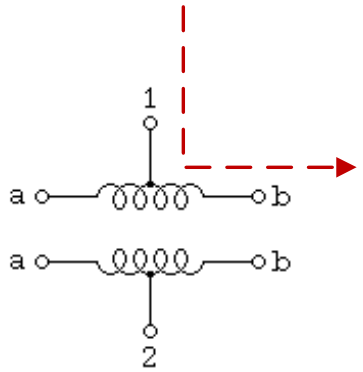
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

Wave drive





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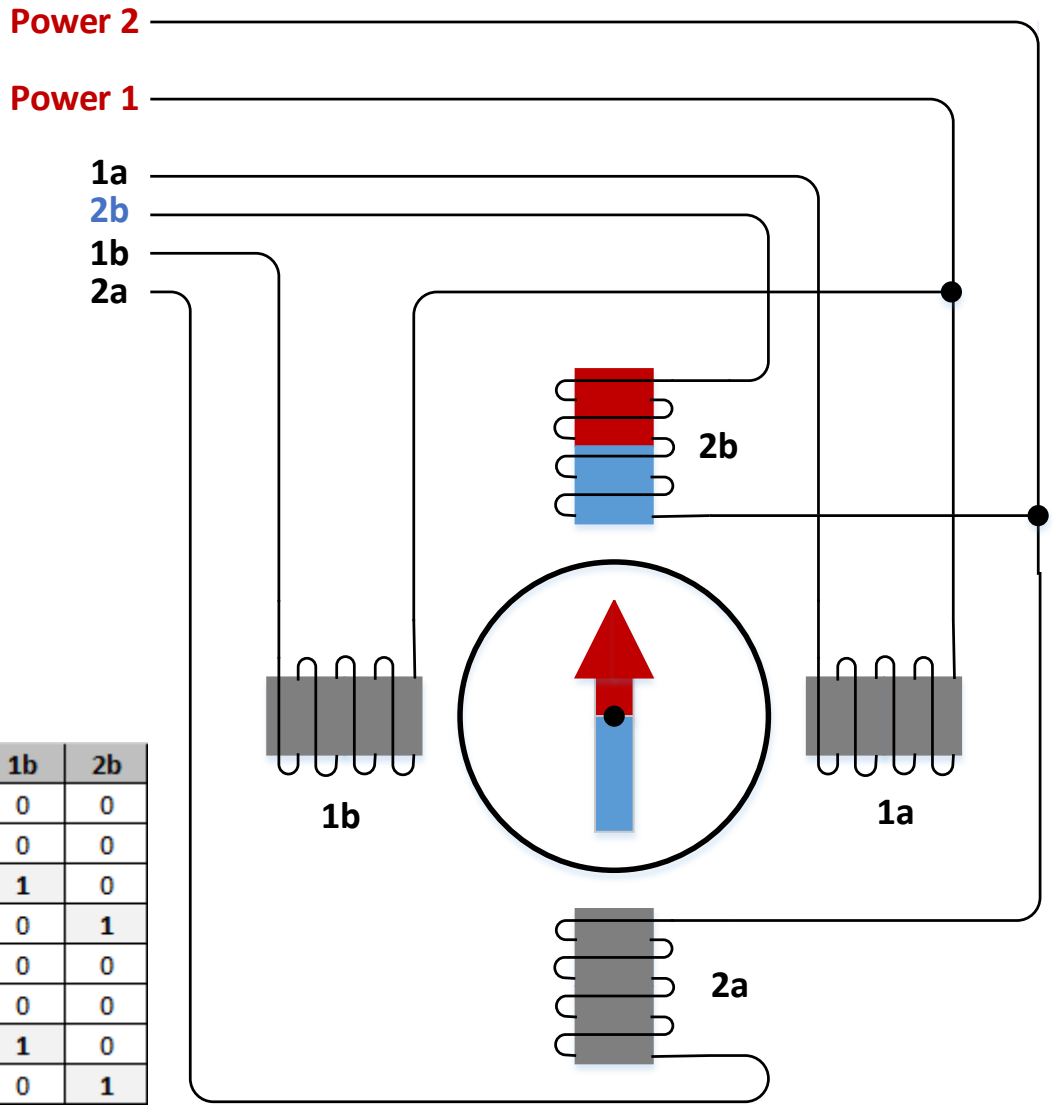
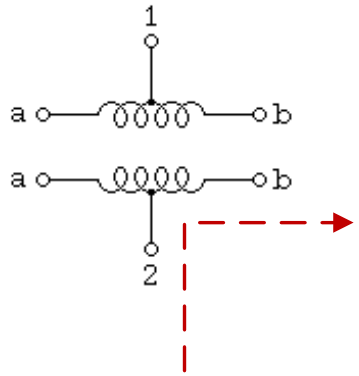
7	0	0	1	0
8	0	0	0	1

Wave drive





Index	1a	2a	1b	2b
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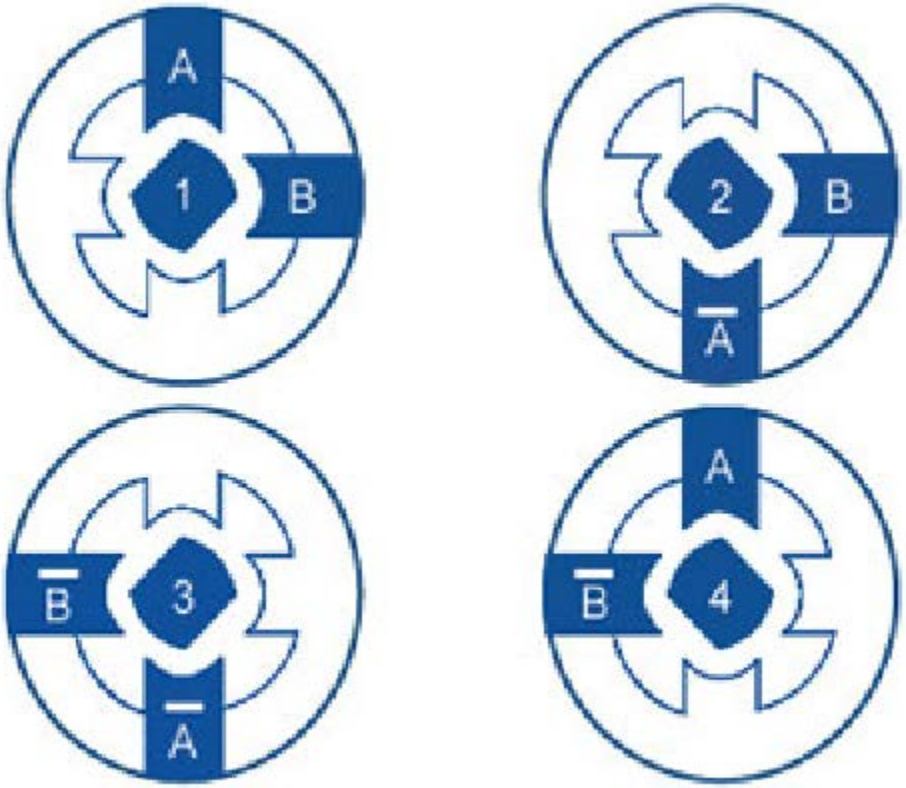
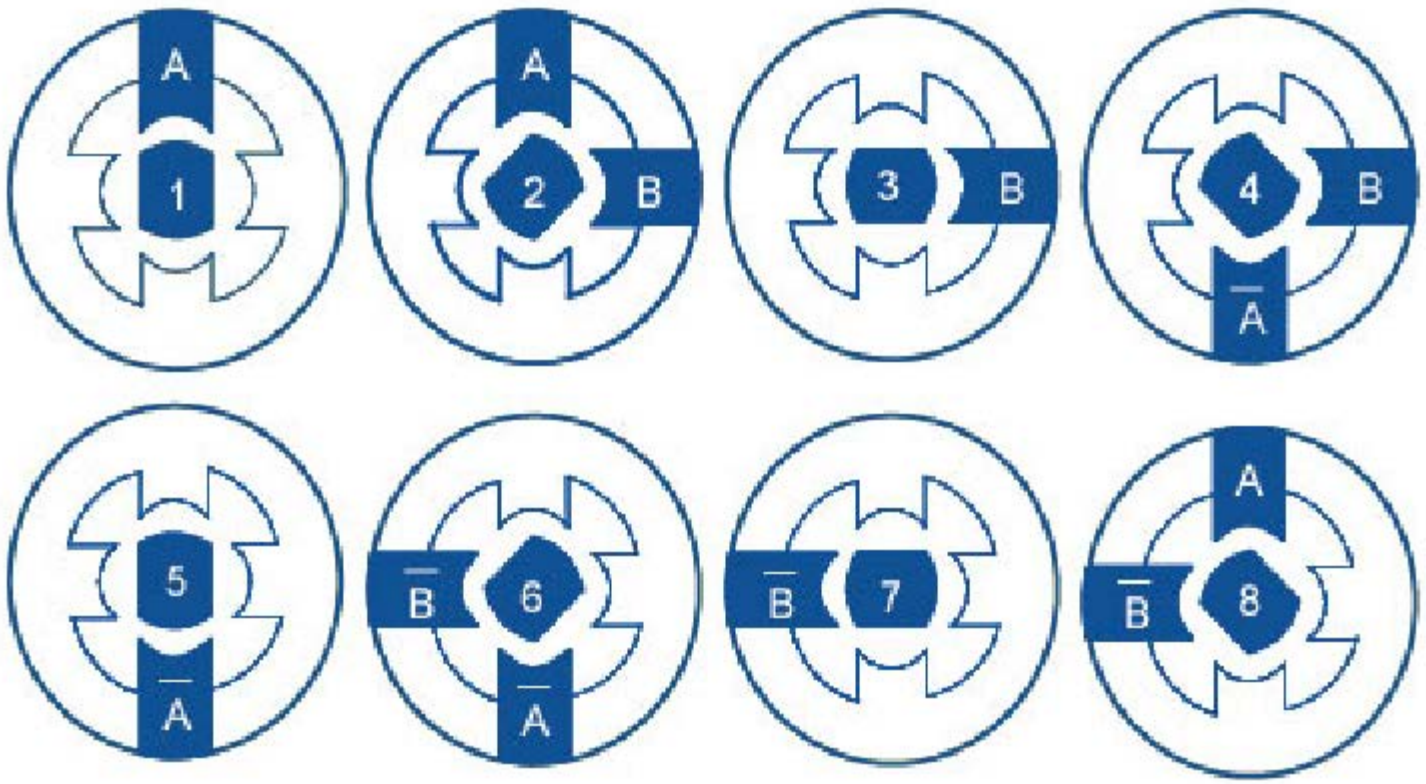
4	0	0	0	1
5	1	0	0	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

Full step drive (2 phases on)



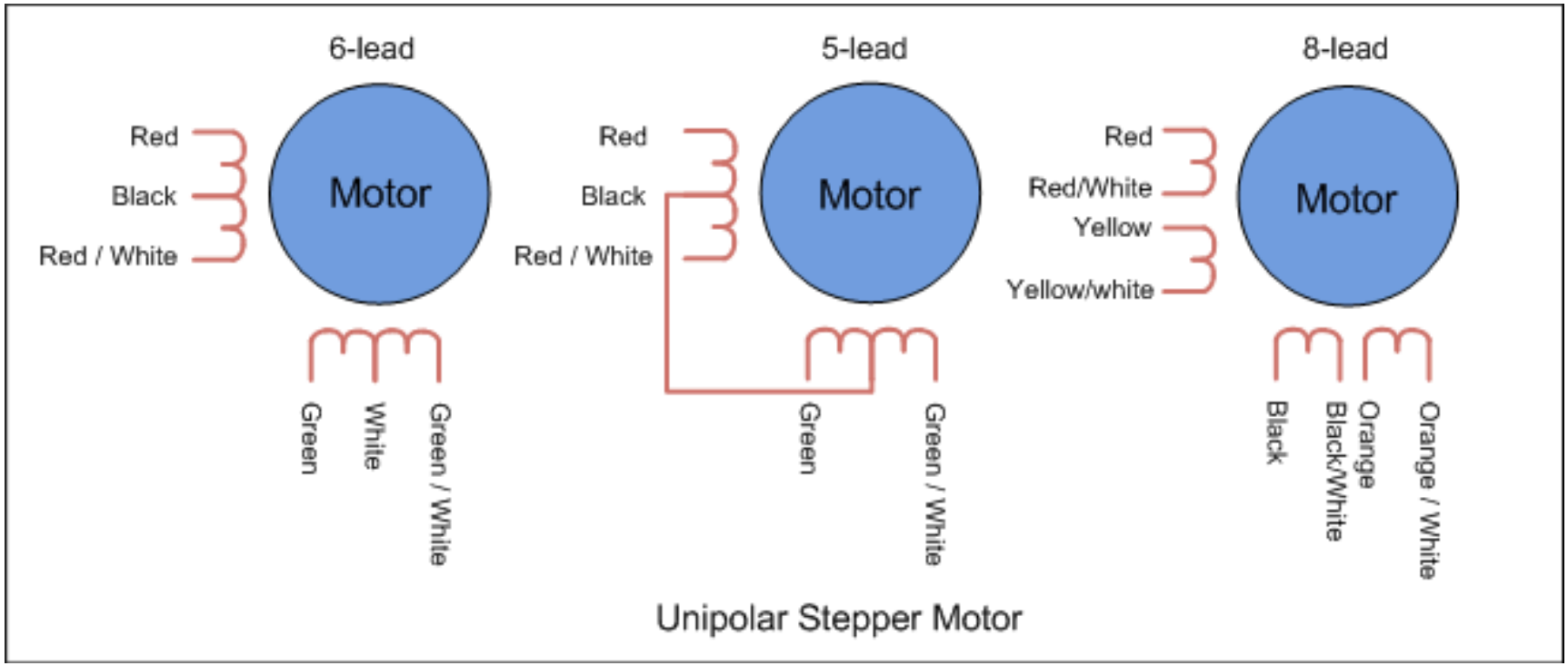
- Full step drive, exciting 2 stators at the time.
- Produces more torque.

Half step drive



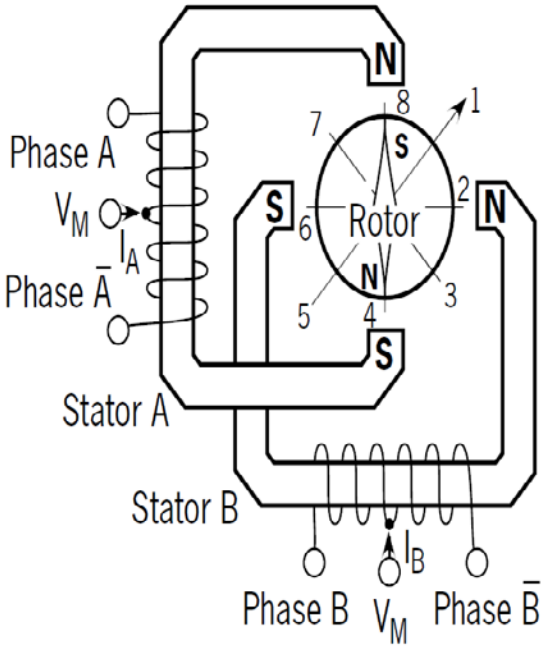
- Half step drive gives us double the resolution.
- Stator excitation alternates between 1 and 2 stators excited.

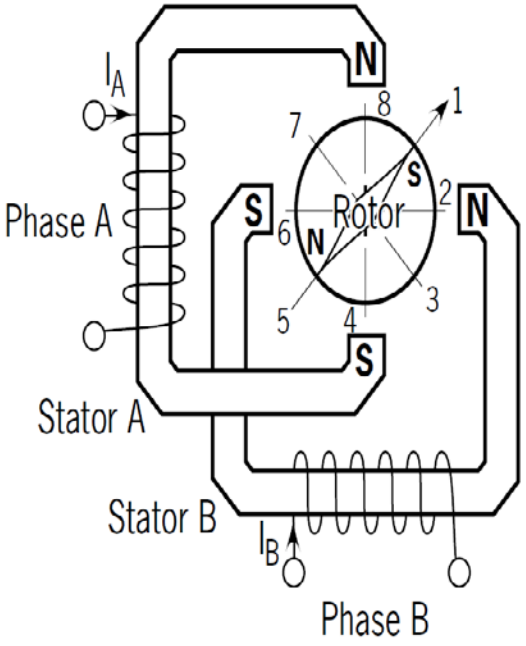
Unipolar stepper motor wiring



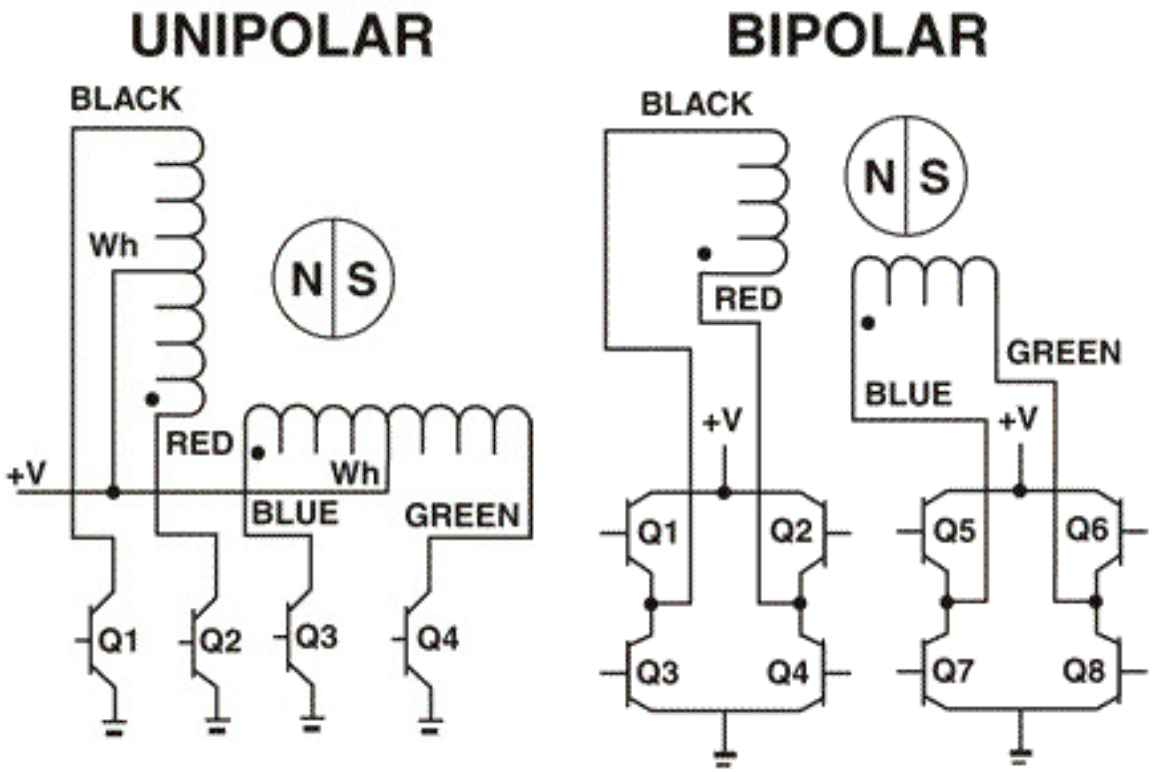
- A unipolar stepper motor can have 5, 6 or 8 leads.
- We have 5-wire and 6-wire versions in lab.

Unipolar versus Bipolar





- A bipolar stepper motor provides a stronger field, but you need external circuity (e.g. an H-bridge) in order to reverse the magnetic fields.

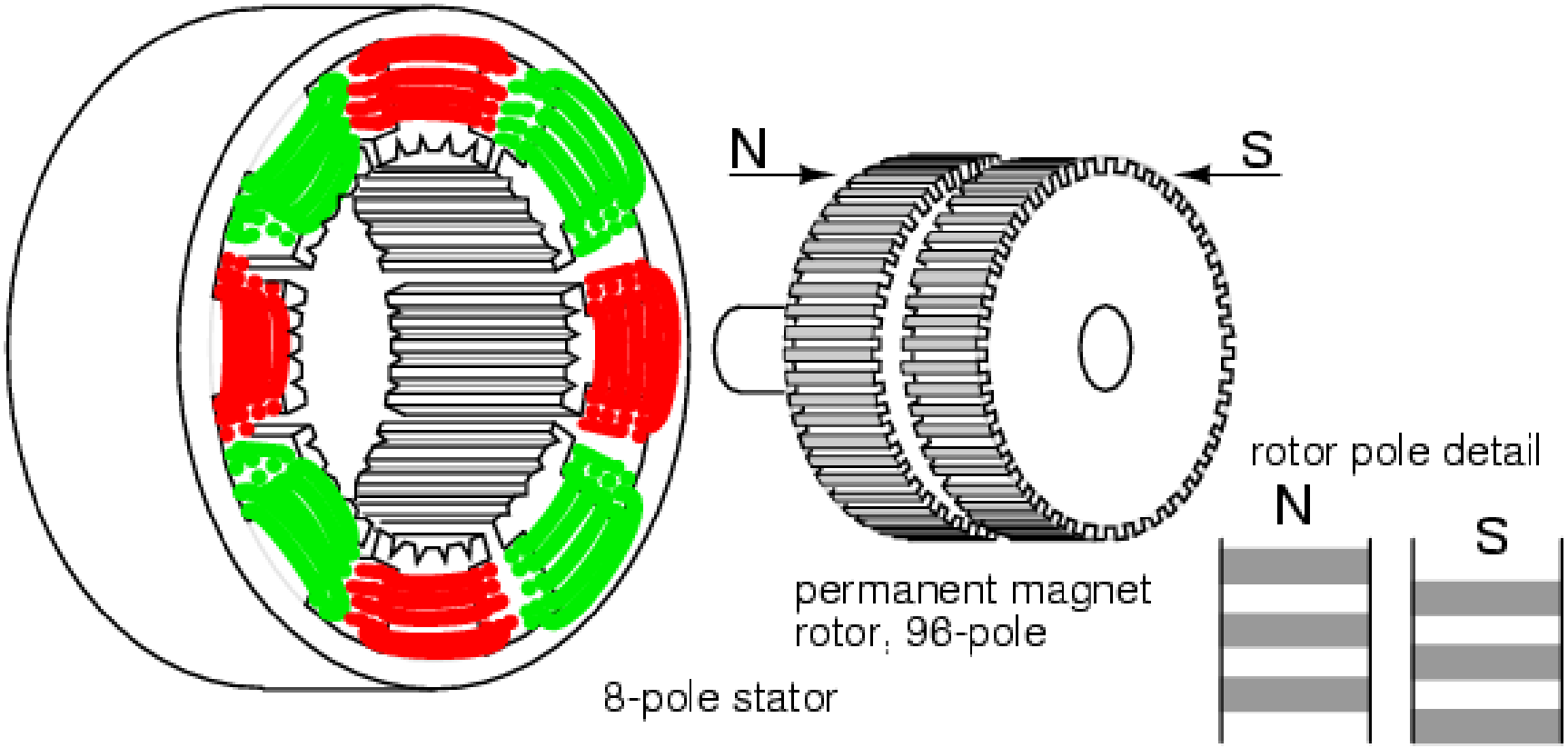

UNIPOLAR
BLACK
Wh
N
S
RED
Wh
+V
BLUE
GREEN
Q1
Q2
Q3
Q4
BIPOLAR
BLACK
N
S
RED
GREEN
BLUE
+V
+V
Q1
Q2
Q5
Q6
Q3
Q4
Q7
Q8

Hybrid Stepper Motors

- Hybrid stepper motors incorporate the qualities of both the Variable Reluctance, VR and Permanent Magnet, PM stepper motor designs
  - Smaller step angles in comparison to VR and PM stepper motors
  - Rotor is made of a permanent magnet with fine teeth
  - Increase in detent, holding and dynamic torque
  - 1.8° is the most common step angle

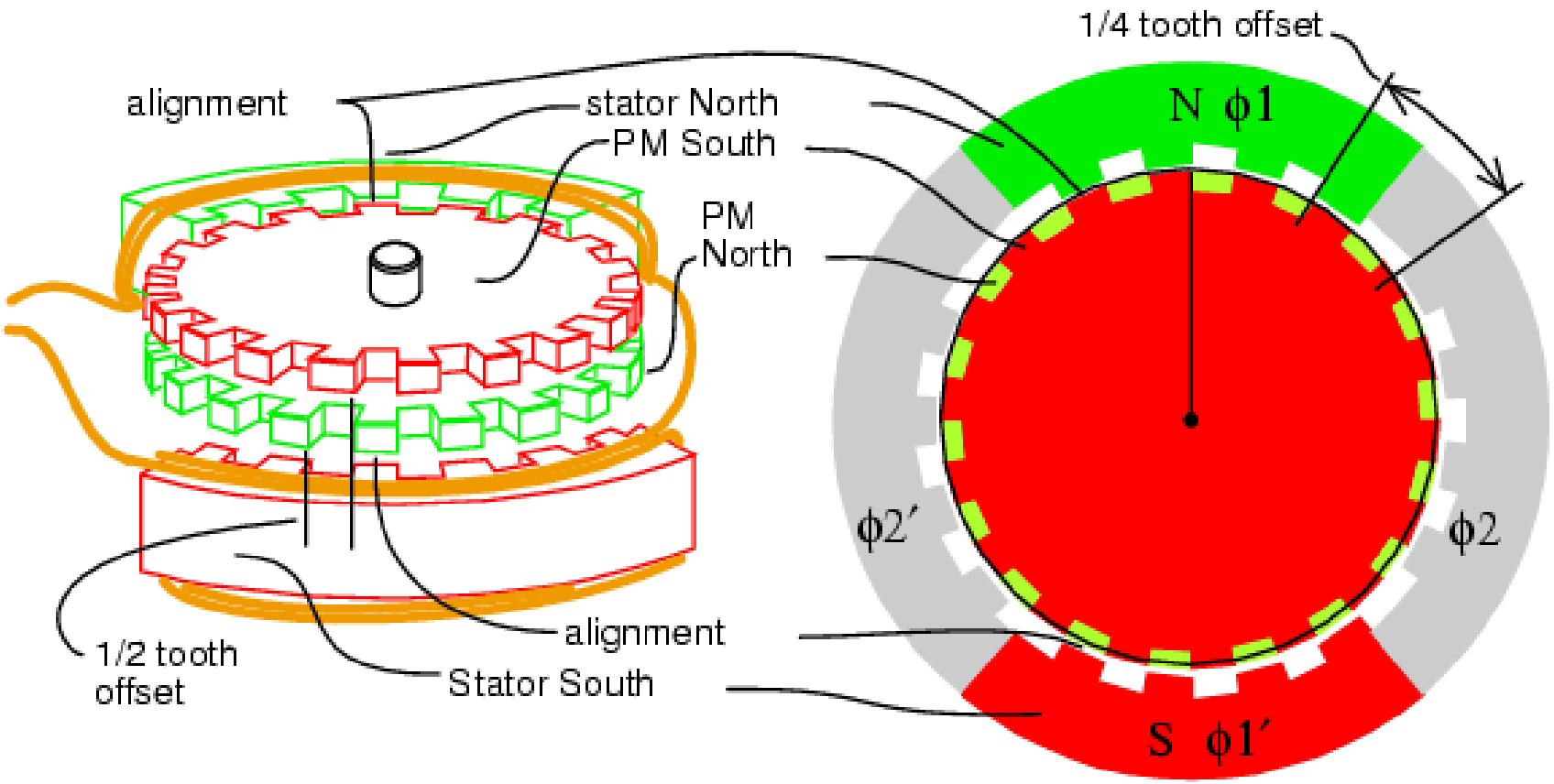
- https://www.youtube.com/watch?v=eyqwLiowZiU
- From 2:35

Hybrid Stepper Motors

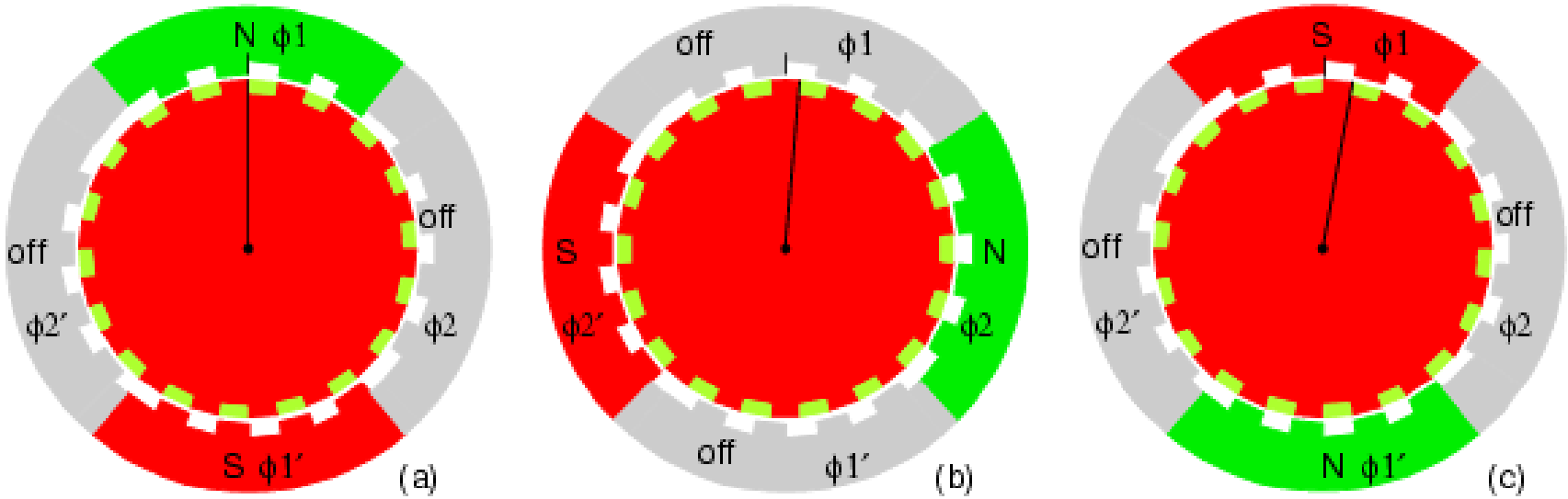


Note: Normally 4 pole stator!

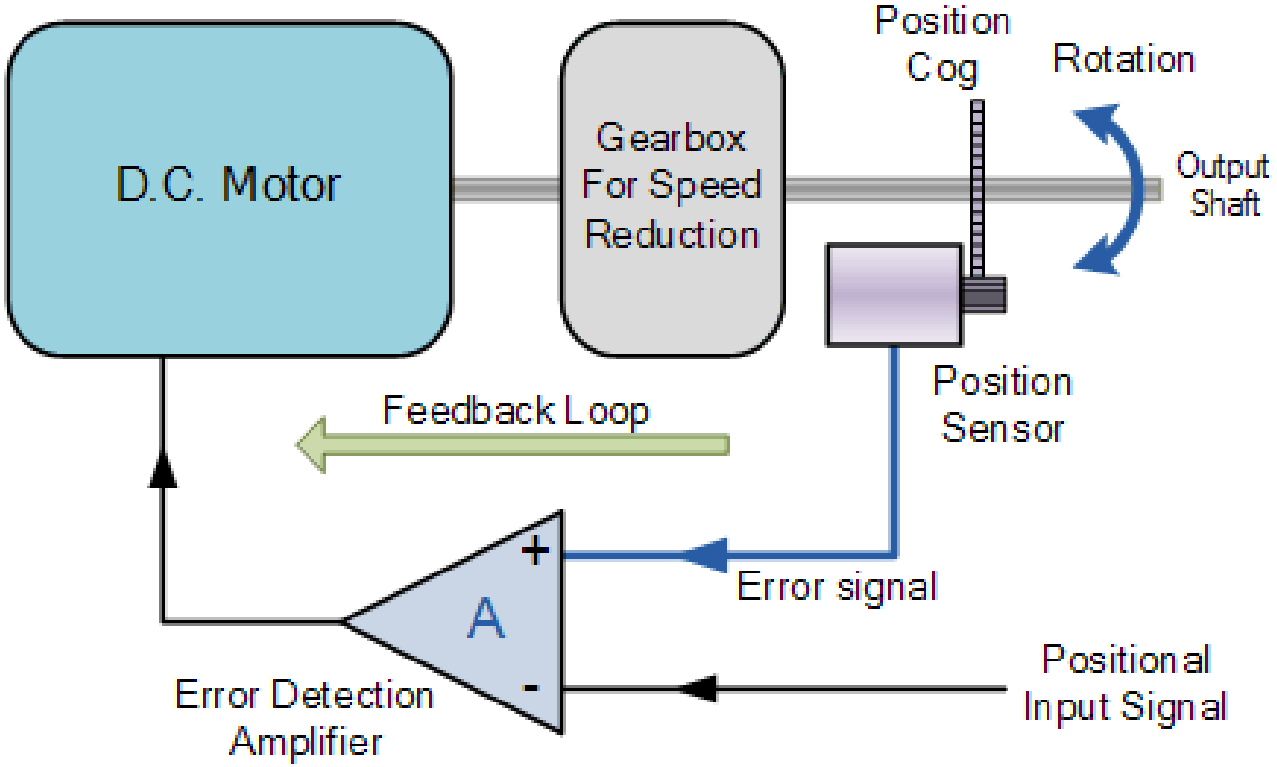
Hybrid Stepper Motors Schematic



Hybrid Stepper Motor Rotation Sequence



Servo Motors

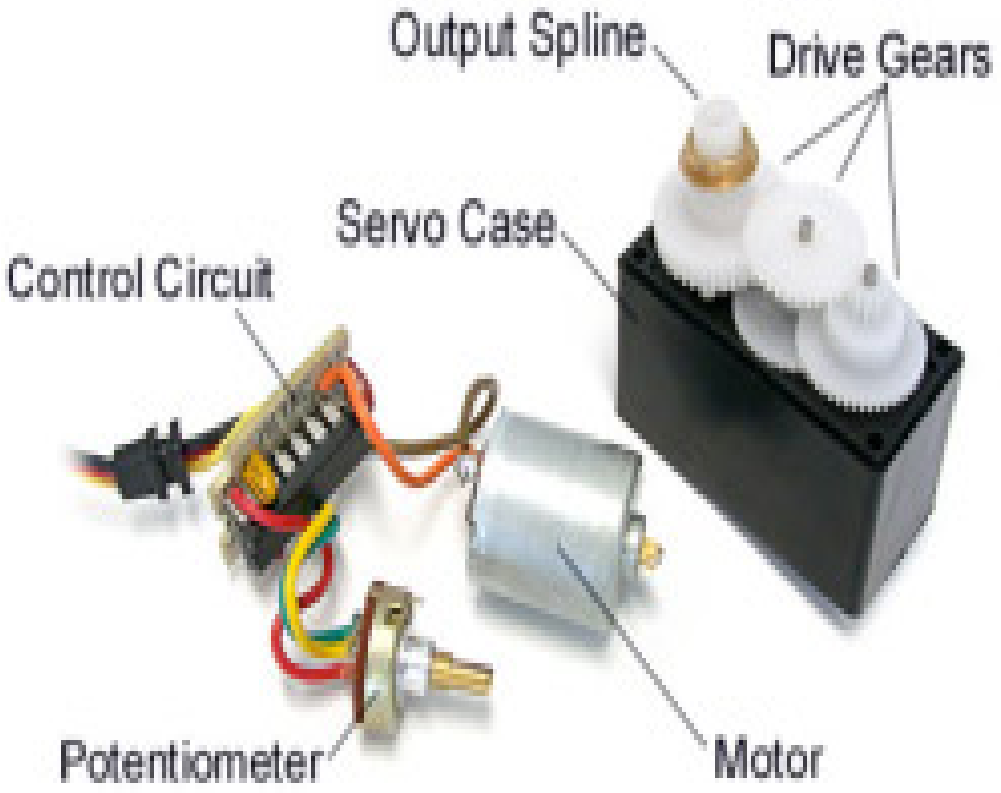


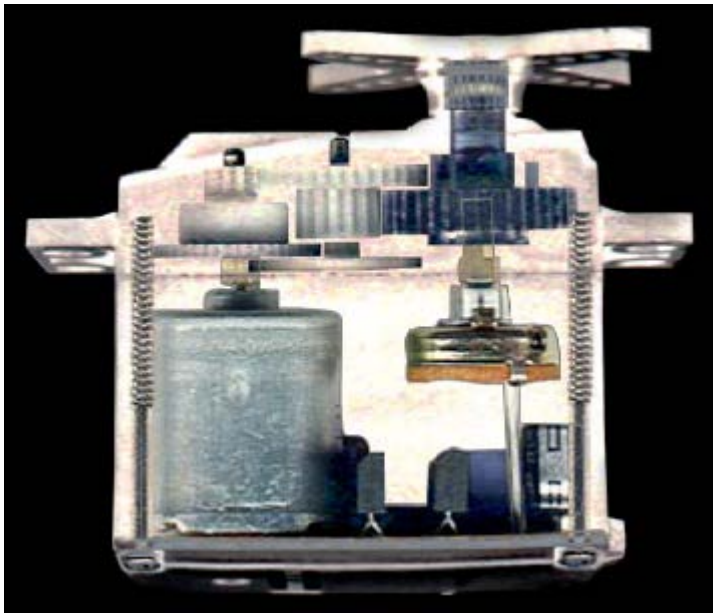
source: https://www.electronics-tutorials.ws/io/io_7.html

Servo Motors

- A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position.
- It consists of a suitable motor coupled to a sensor for position feedback.
- It requires a controller
- Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.

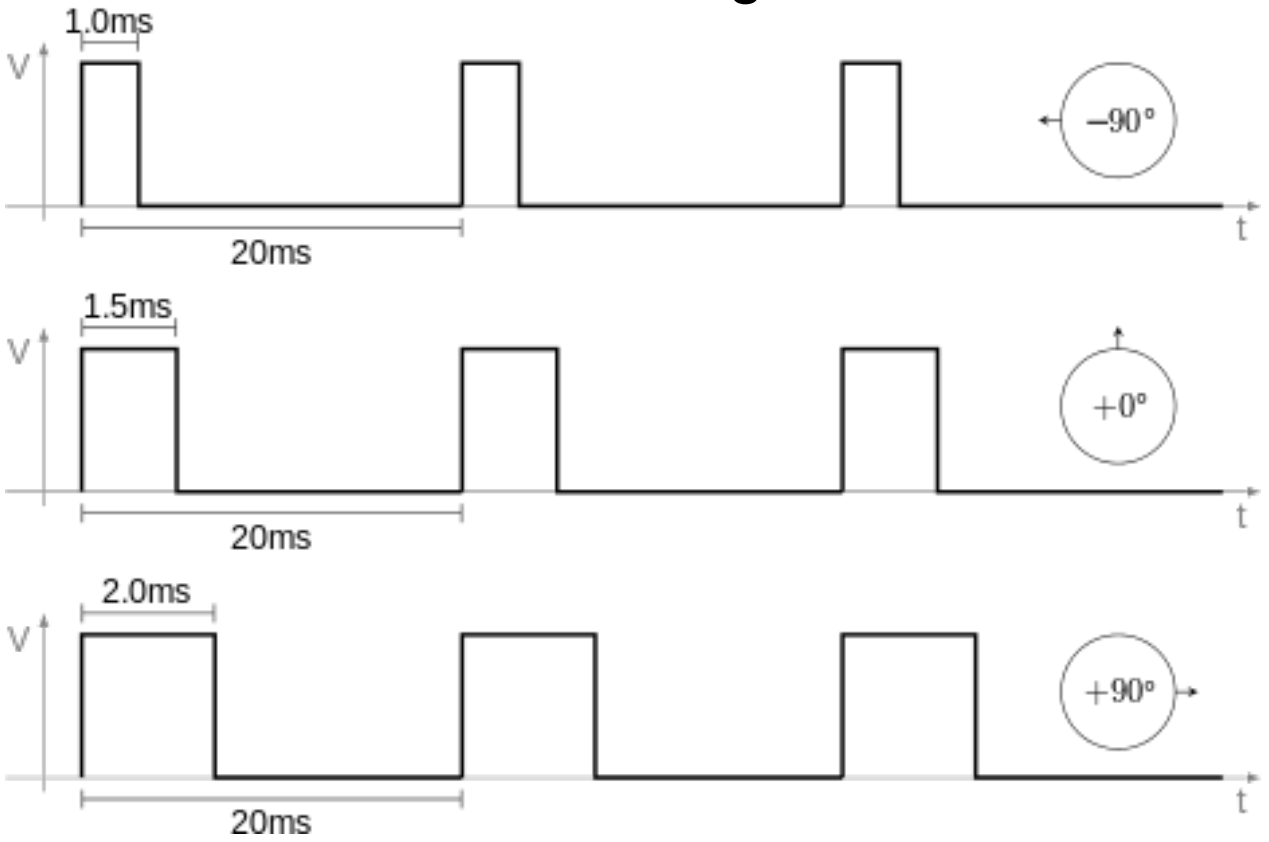
Servo Motors





Servo Motors

- Typically controlled with a PWM signal:



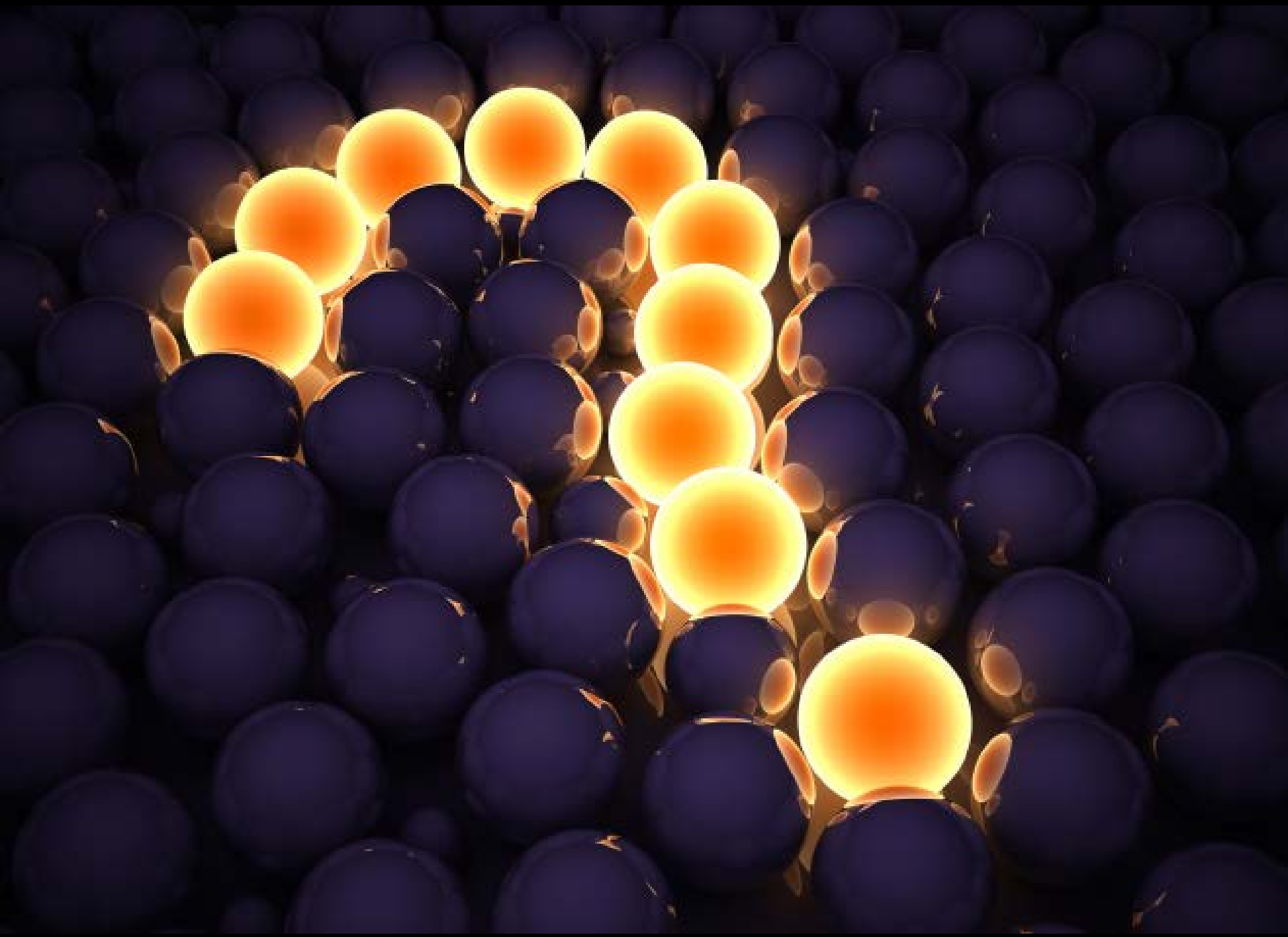


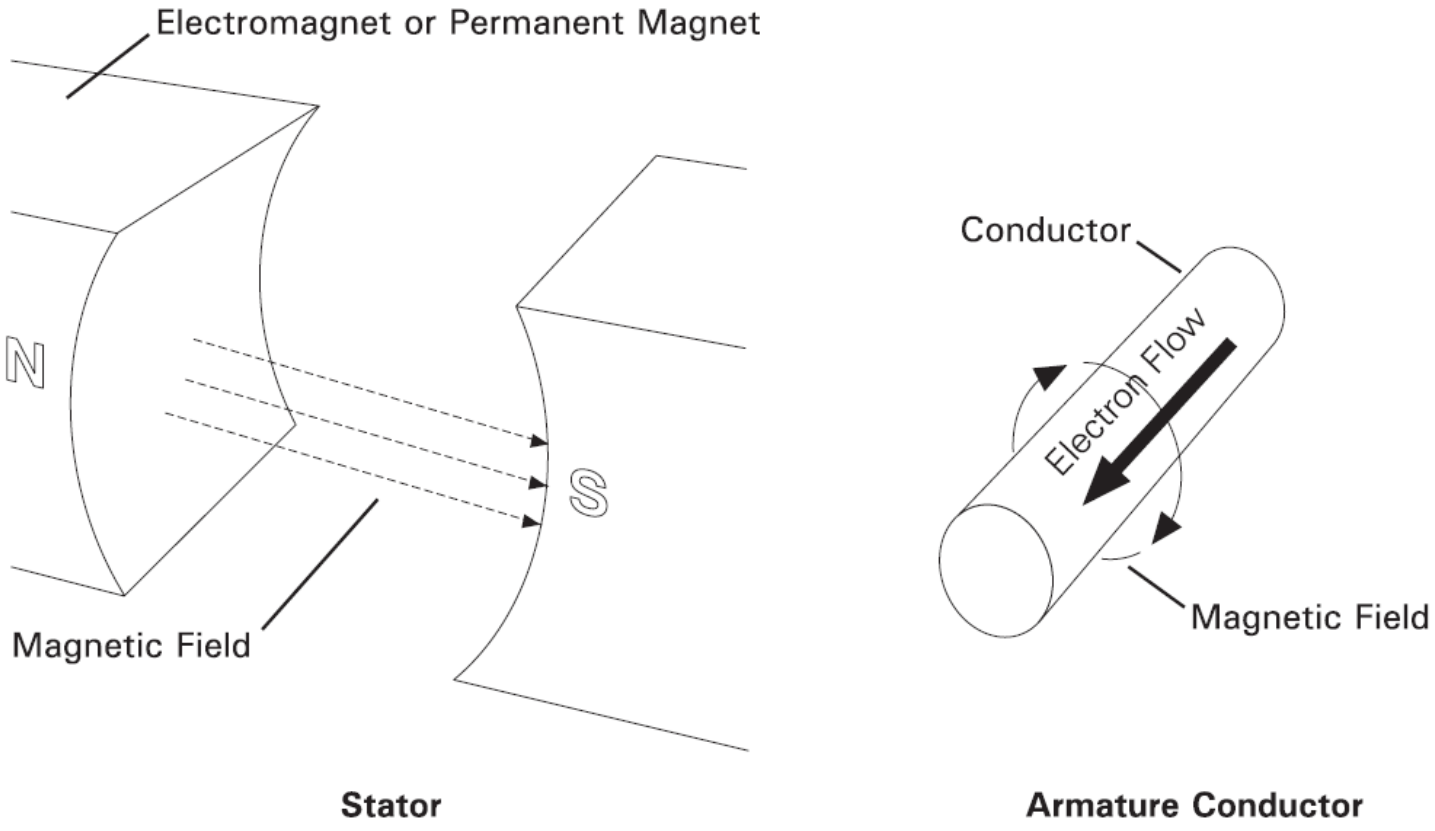
Image resources

- DC Motor explanations: Siemens DC drives pdf http://electrical-engineering-portal.com/res/Siemens-Basics-of-DC-drives.pdf (the one on blackboard)
- Rotating DC motor: https://thumbs.gfycat.com/UnacceptableSeriousCanine-size_restricted.gif
- DC Motor: http://www.learnengineering.org/2014/09/DC-motor-Working.html
- PWM: http://www.electronics-tutorials.ws/blog/pulse-width-modulation.html
- H-Bridge: http://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridges-the-basics/
- Step motor drive modes: http://www.robotpark.com/Stepper-Motor-Working
- Unipolar stepper motor wiring: https://www.circuitspecialists.com/blog/unipolar-stepper-motor-vs-bipolar-stepper-motors/
- Unipolar vs bipolar: https://www.circuitspecialists.com/blog/unipolar-stepper-motor-vs-bipolar-stepper-motors/

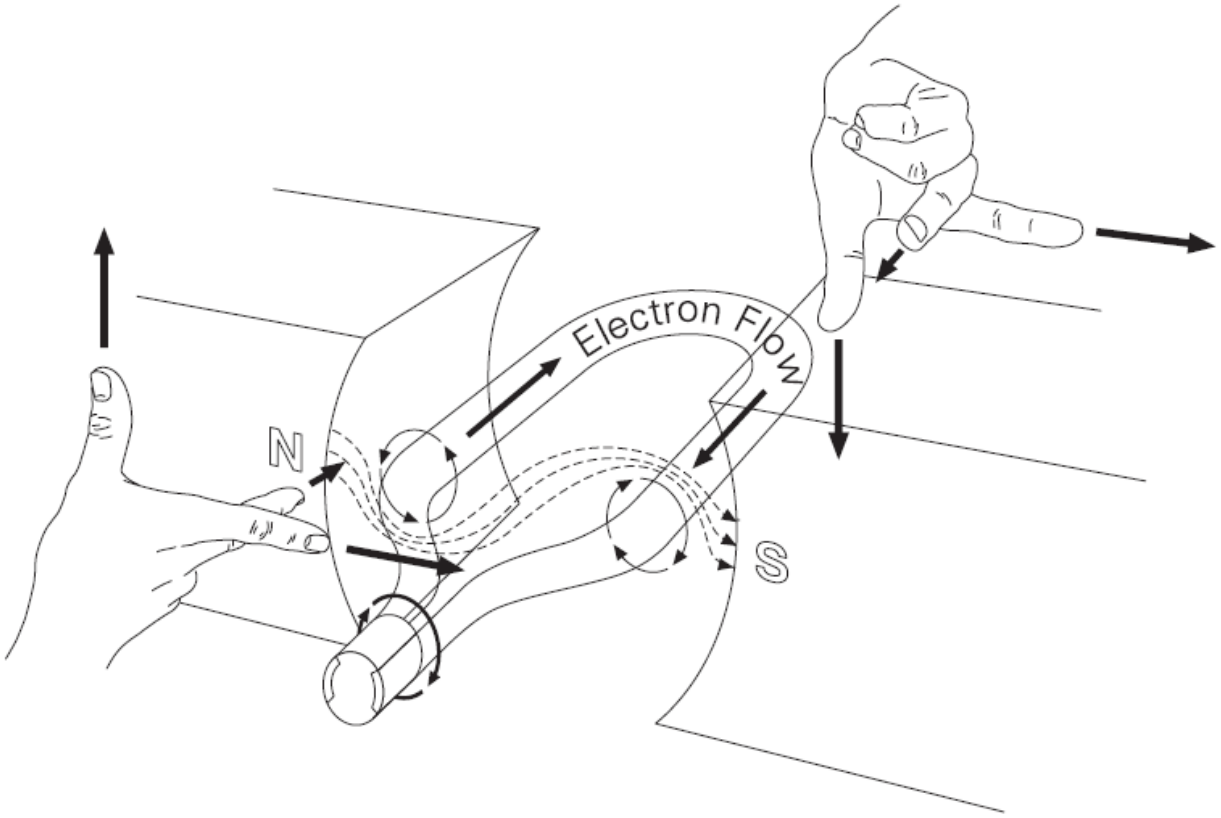
- Question mark: https://wall.alphacoders.com/big.php?i=437563

Background material

How a DC motor works

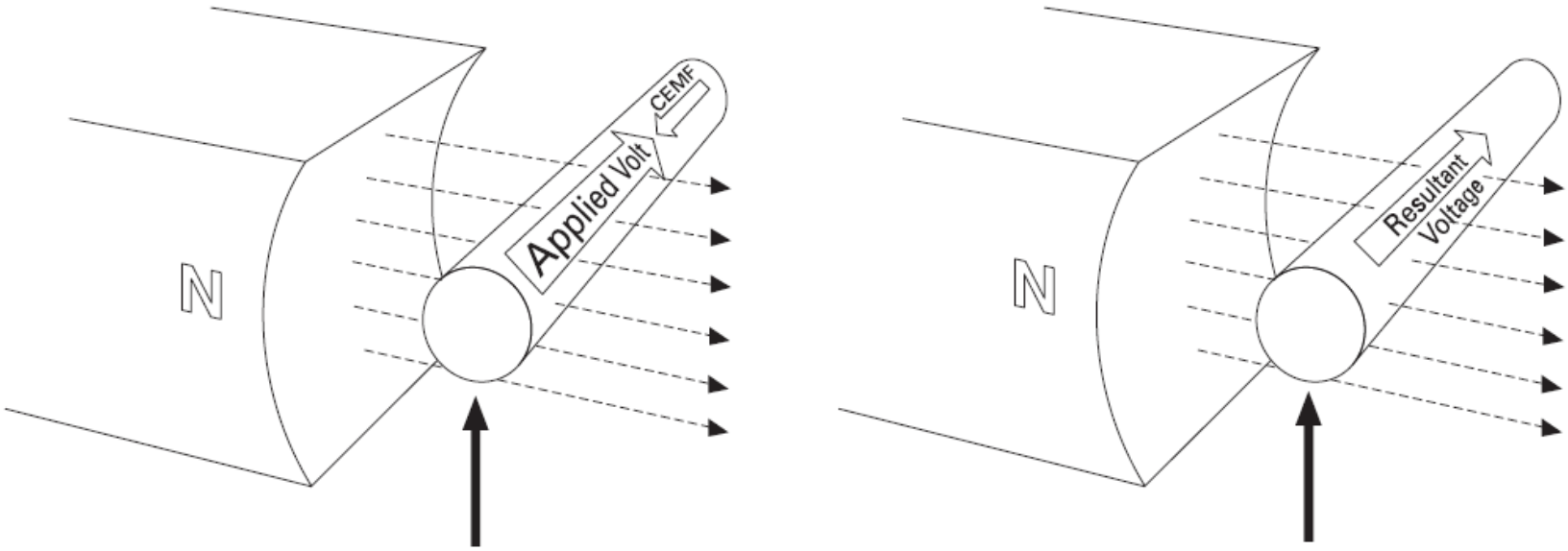


- We have a stationary magnetic field (permanent or electromagnet).
- And a non-stationary conductor, in which the electron flow generates a magnetic field.



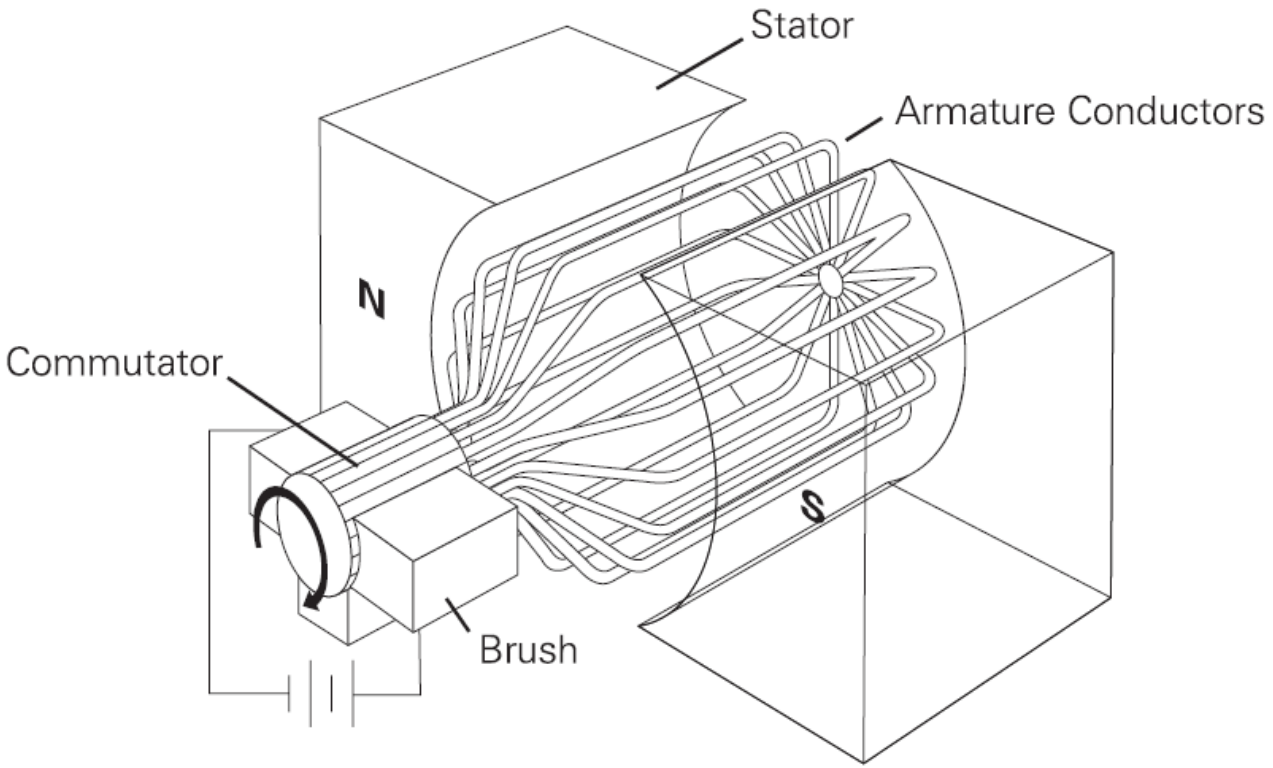
- The main field from the stator interacts with the secondary field from the rotor.
- The right-hand rule tells us which way the motor will rotate.

Counter electromotive force (CEMF)



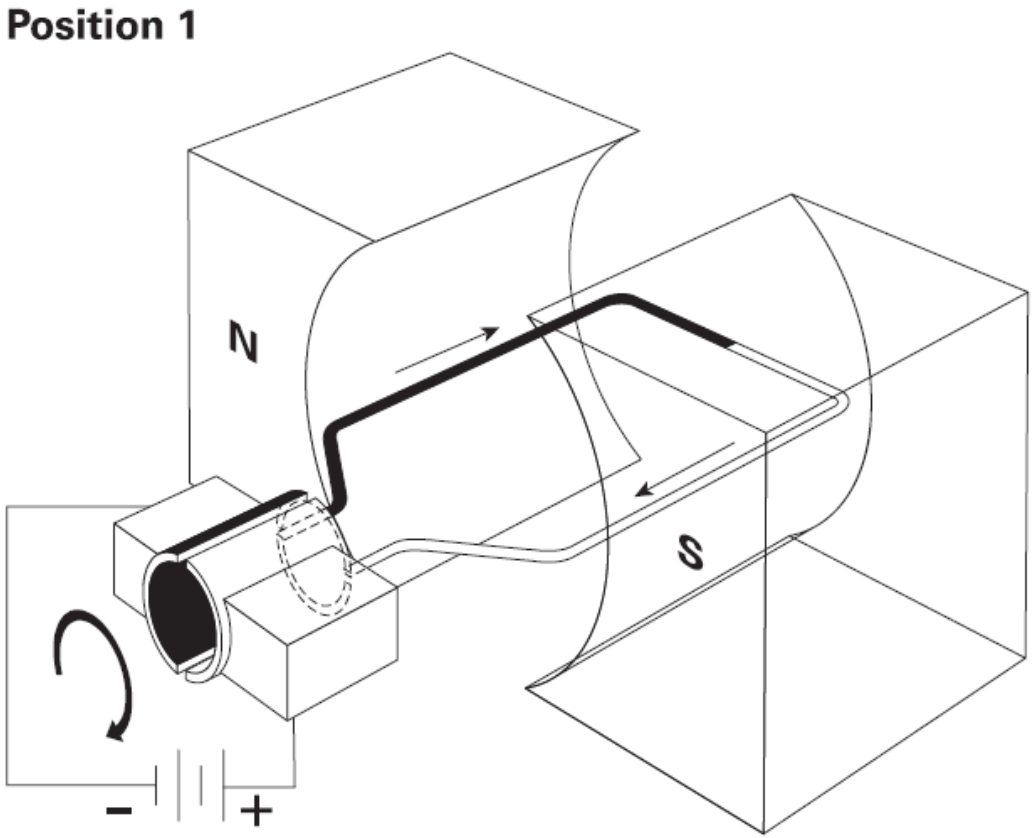
- When the conductor moves in the main field, it will generate a voltage in the opposite direction of the applied voltage.
- I.e. a DC motor is also a generator.

Commutation

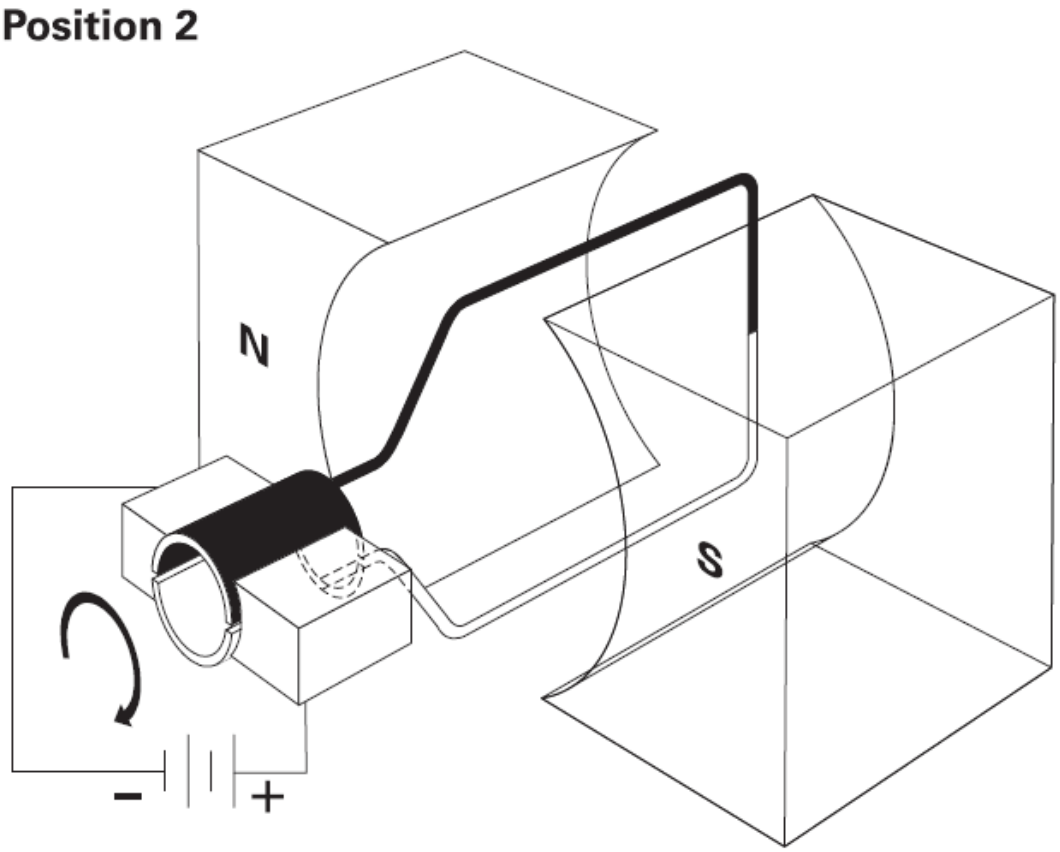


- The brushes (danish ‘kul’) connects to the commutator and causes the electron flow to reverse in a conductor, when it is at a 90 degree angle with respect to the main field.

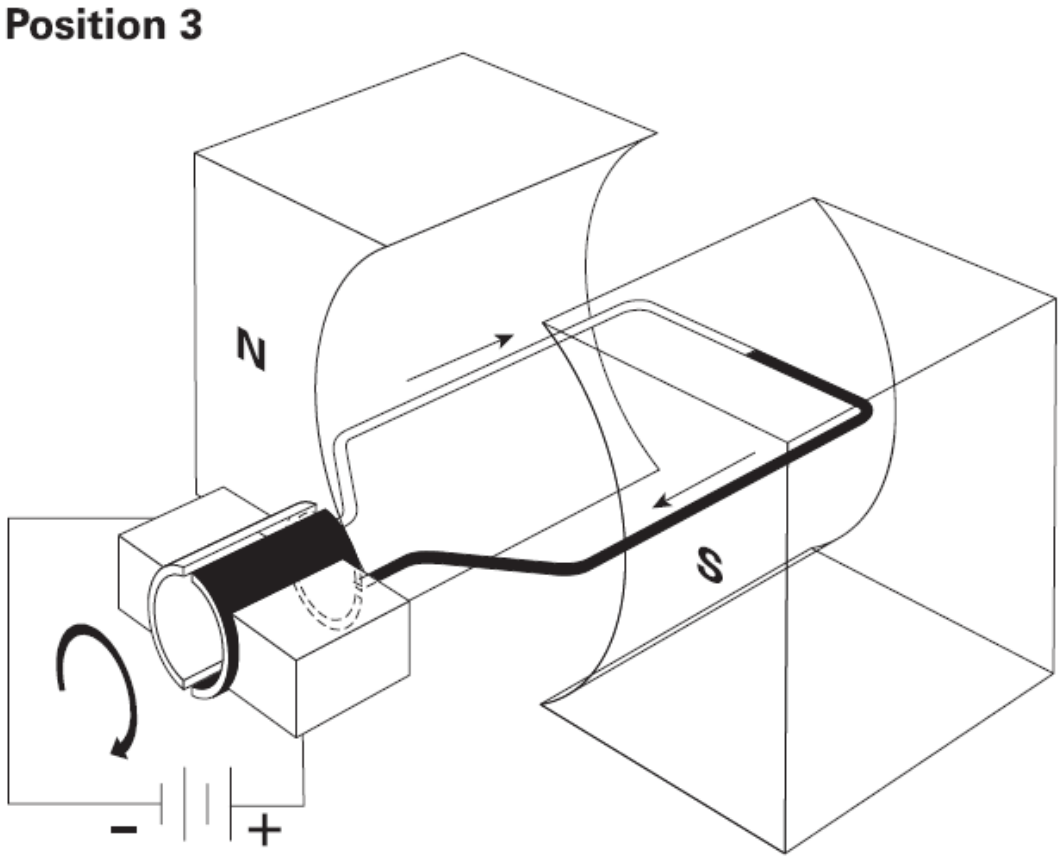
Commutation

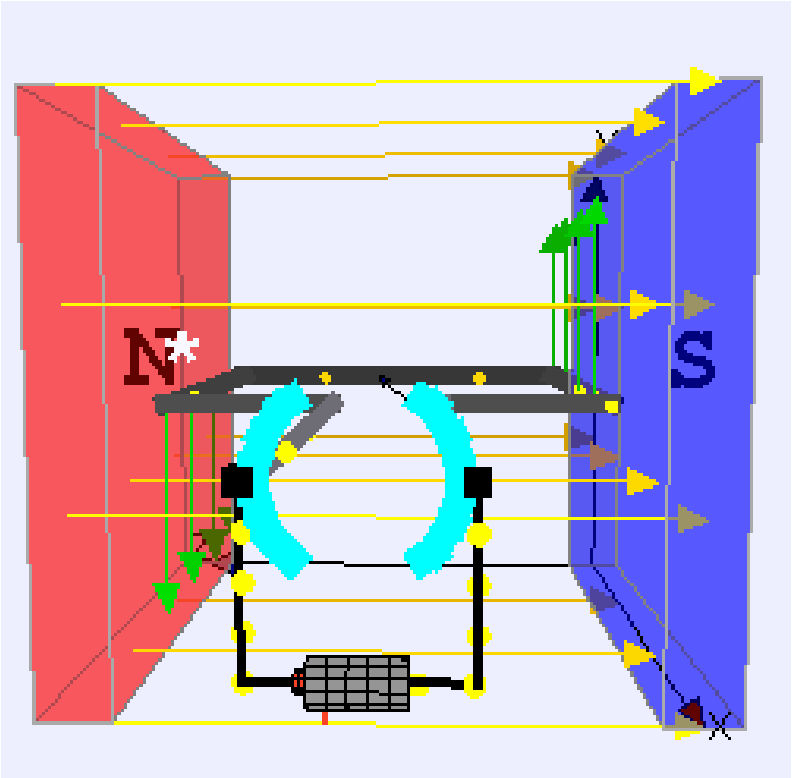


Commutation

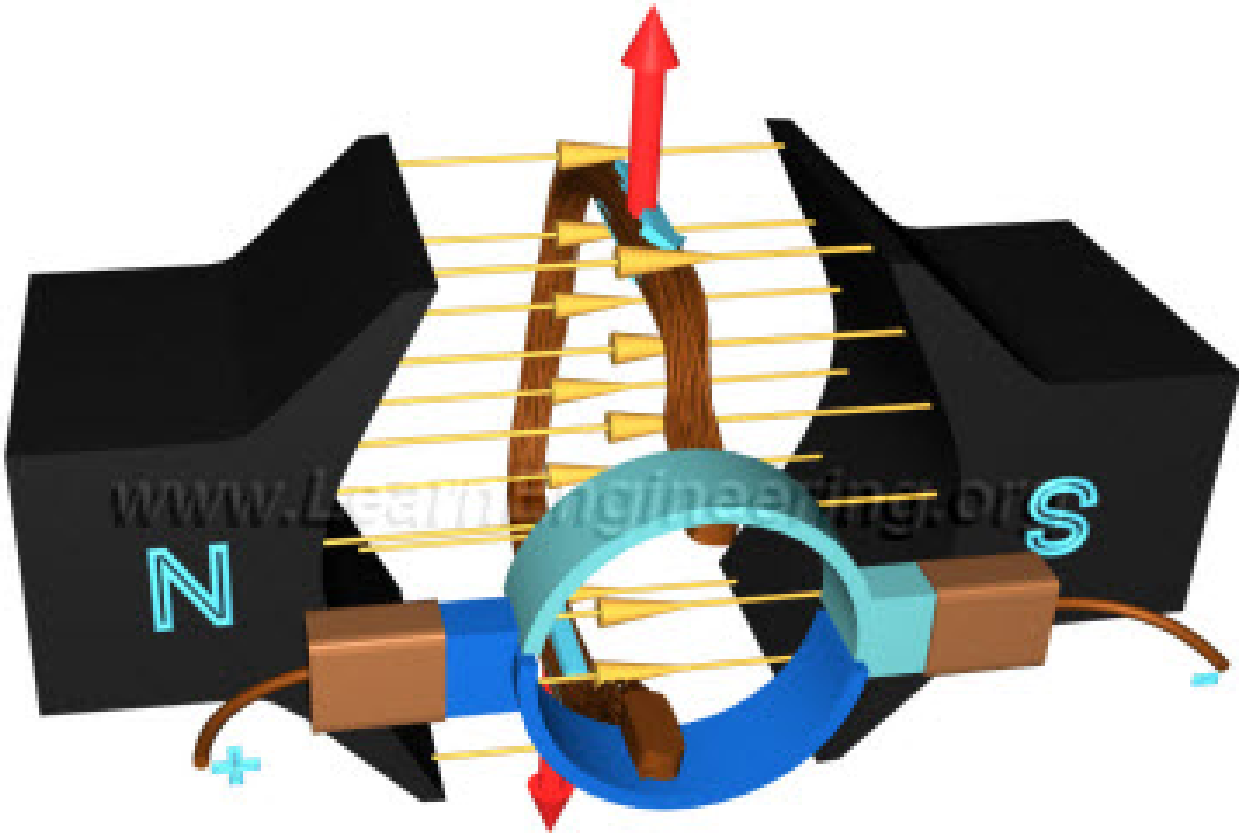


Commutation





https://upload.wikimedia.org/wikipedia/commons/f/f8/Ejs_Open_Source_Direct_Current_Electrical_Motor_Model_Java_Applet_%28_DC_Motor_%29_50_degree_split_ring.gif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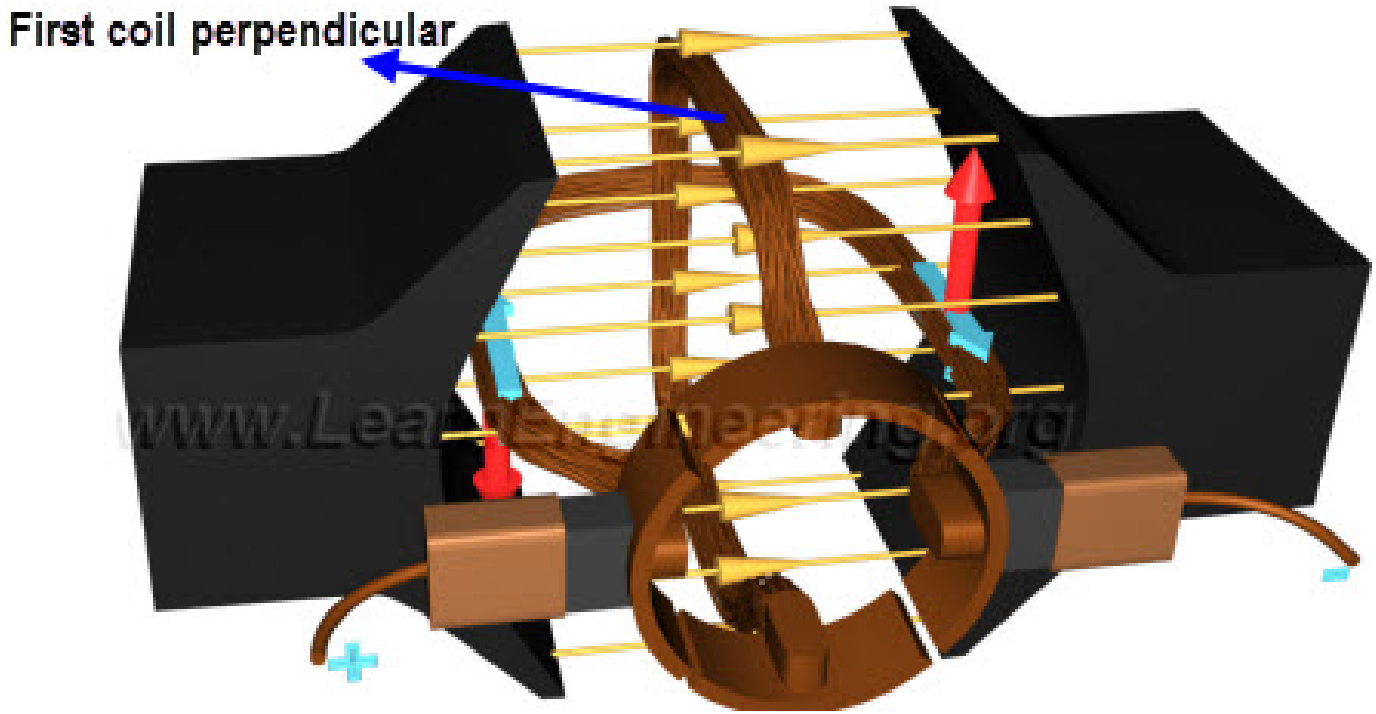
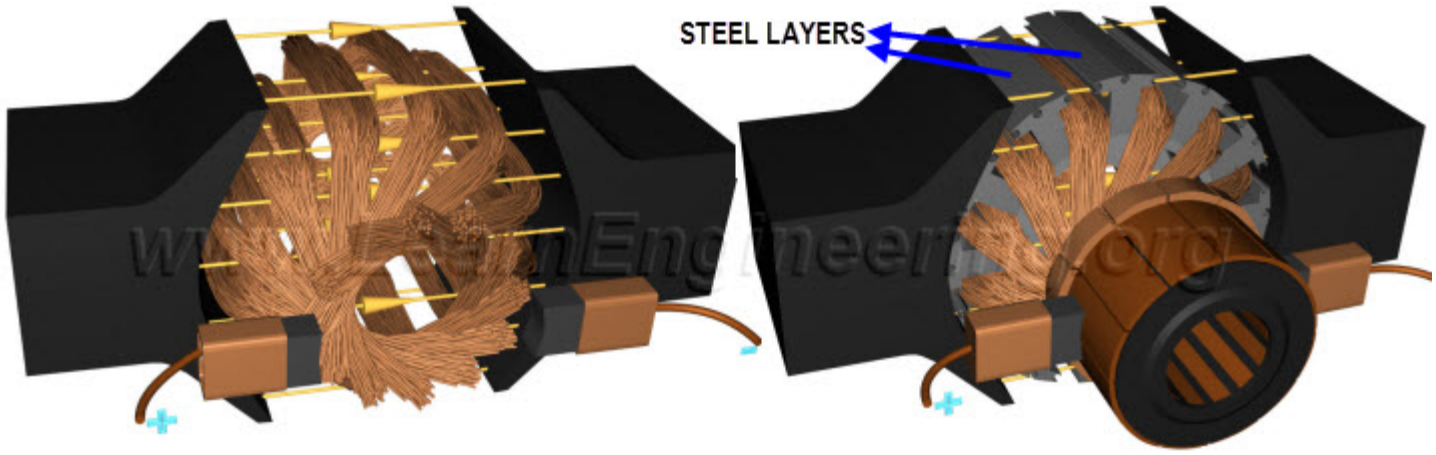

First coil perpendicular



- More coils makes the motor run smoother.
- More coils and steel layers between the coils makes the motor stronger.