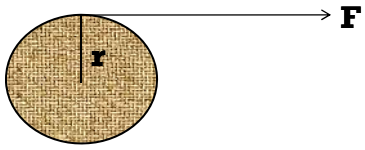
Actuators & Motors

Force, Work, Energy, Actuators, AC & DC Generators & Motors, Stepper Motors, Brushless Motors, Position Control, H Bridge.

Lecture # 10

Some Basic Stuff (To Remind Ourselves …

Torque: Torque is produced when force exerts a twisting action on a body, tending to make it rotate.



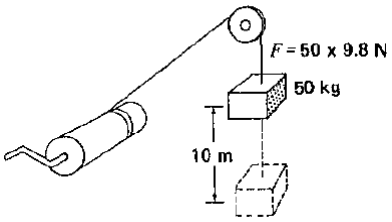
$$T = F\ r$$

Dr. D. M. Akbar Hussain
Department of Energy Technology

Some Basic Stuff (To Remind Ourselves …

Mechanical Work: Mechanical work is done whenever a force F moves a distance d in the direction of the force.

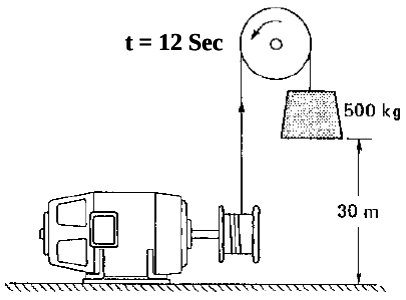
$$W = F\,d$$



Some Basic Stuff (To Remind Ourselves …

Power: Power is the rate of doing work.

$$P = W/t$$



Some Basic Stuff (To Remind Ourselves …

Power of a Motor: The mechanical power output of a motor depend upon its **rotational speed** and the **torque it develops**.

$$P = nT/9.55$$

n = Speed of rotation (r/min)
T = Torque (N.m)
9.55 a constant

Some Basic Stuff (To Remind Ourselves …

Kinetic Energy of Linear Motion: A falling stone or swiftly moving object possess kinetic energy, which is due to its motion, kinetic energy is a form of mechanical energy given by;

$$E_k = ½\ mv^2$$

Some Basic Stuff (To Remind Ourselves …

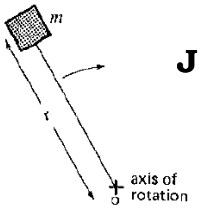
Kinetic Energy of Rotation: A revolving body also possesses kinetic energy and its magnitude depend upon the speed of **rotation**, its **mass** and the **shape of the body**.

$$E_k = 5.48 \times 10^{-3}\ Jn^2$$

J is the moment of inertia, it depend upon the **shape** and **mass** of the body ($Kg.m^2$).

Moment of Inertia

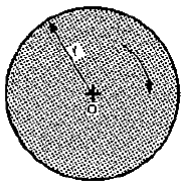
Mass m revolving at a distance r around axis 0.



$$J = mr^2$$

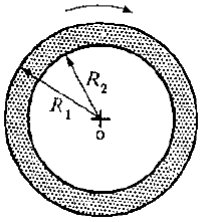
Solid Disc of mass m and radius r.

$$J = mr^2/2$$



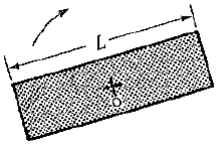
Moment of Inertia

Angular ring of mass m having rectangular cross-section.



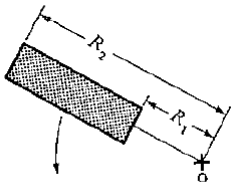
$$J = (m/2)\,(R_1^2 + R_2^2)$$

Straight bar of mass m pivoted on its center.



$$J = mL^2/12$$

Moment of Inertia



Rectangular bar of mass m revolving around axis 0.

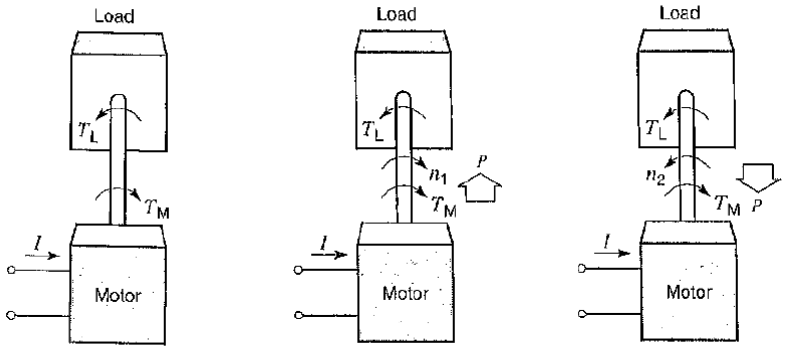
$$J = (m/3)(R_1^2 + R_2^2 + R_1R_2)$$

Speed of Motor/Load System

We see many applications where a motor drives a mechanical load, so if we are designing such a system, we must consider 3 main things:

- **Torque developed by the motor.**
- **Torque exerted by the load.**
- **Speed.**

Speed of Motor/Load System



Load to turn clockwise at a speed n_1. What we should do ?

At this moment $T_M = T_L$ (Motor state is Stopped)

Actuator

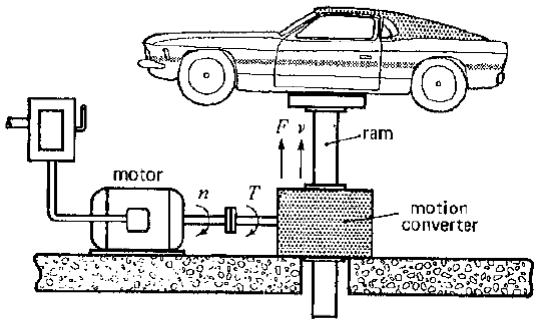
Actuator converts energy into motion. It can also be used to apply a force.

Actuator typically, is a mechanical device that takes energy, usually created by air, electricity, or liquid, and converts that into some kind of motion.

That motion can be anything from blocking to clamping to ejecting.

Actuators are used in manufacturing and industrial applications.

Is this an Actuator ?

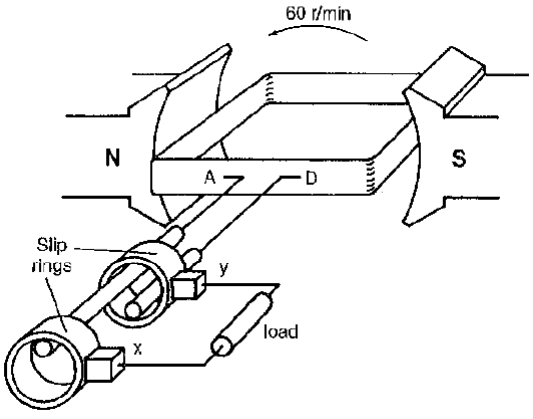


Generator

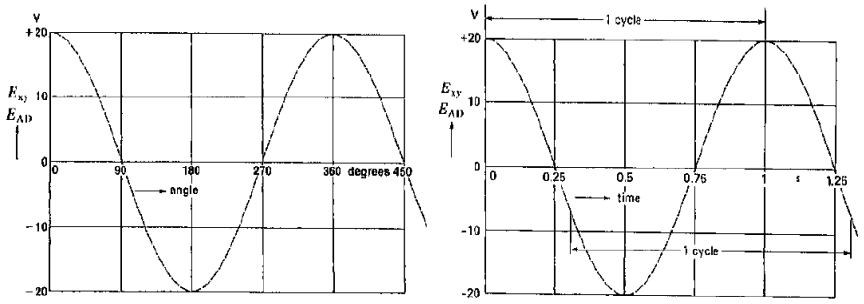
The study of generators is important as it represents logical introduction to the behavior of motors. Typically, a generator consists of an electromagnet, an armature, two slip rings, two brushes and a resistive load.

An armature is any number of conductive wires wound in loops which rotates through the magnetic field and we know that when a conductor moves through a magnetic field, voltage is induced in the conductor, causing the current to flow. Slip rings are attached to the armature so they rotate with it, carbon brushes ride against the slip rings to conduct current from the armature.

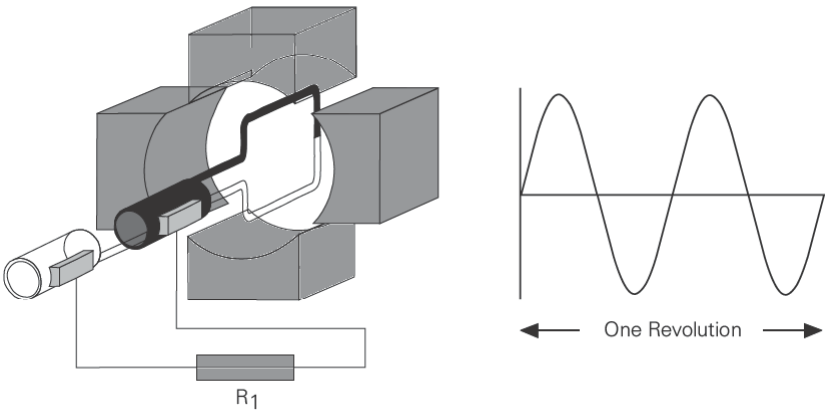
AC Generator



Voltage Induced

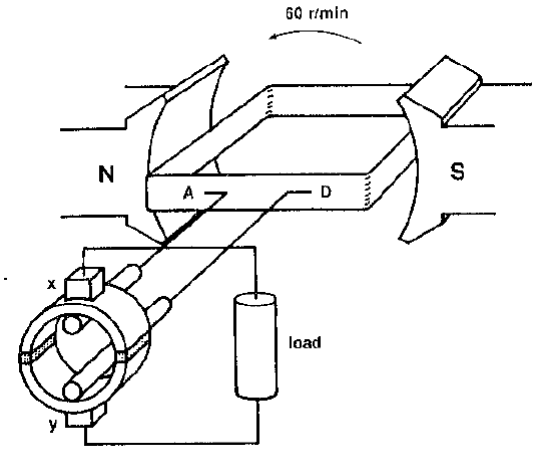


What is the result for this setup ?

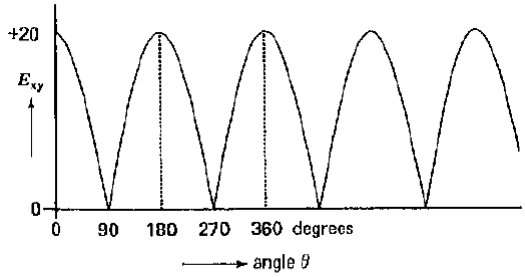


DC Generator

The study of DC generator is important as it represents logical introduction to the behavior of DC motors.

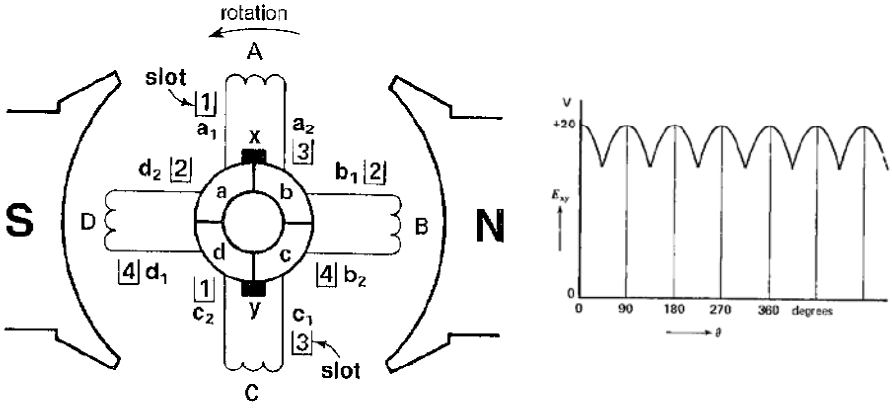


Pulsating DC



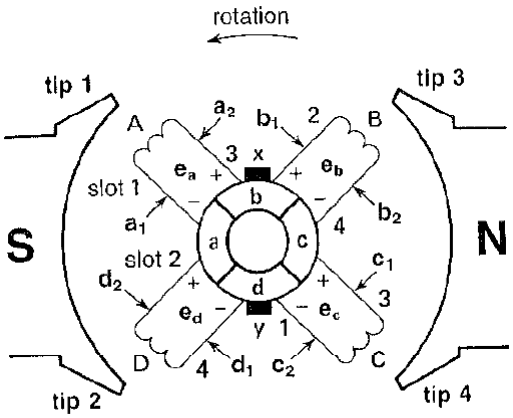
These have Identical Windings, can they be used as AC, DC or both Type ?

DC Generator More Smooth Output ?

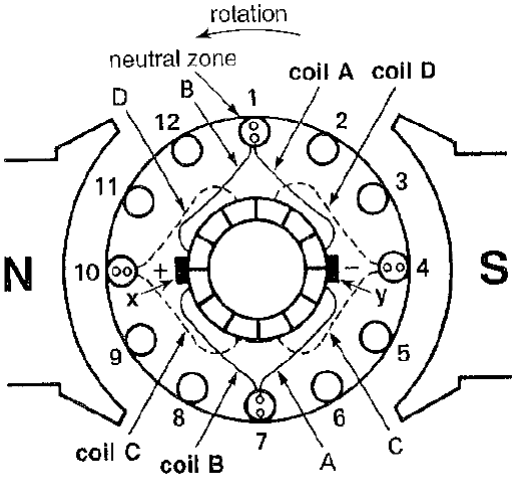


We can get a more smooth output by increasing the number of coils and commutator segments, here we have 4 coils and 4 commutator segments.

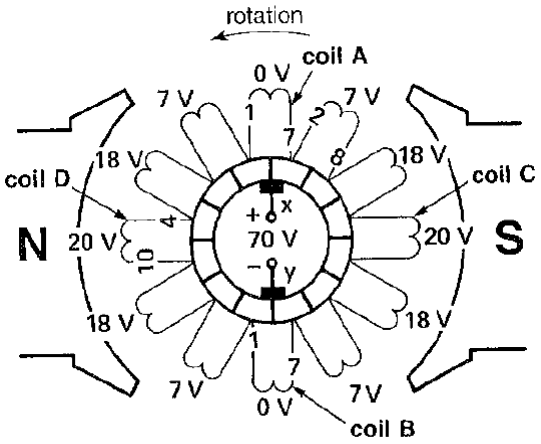
Position of the coils when it moves 45°



DC Generator 12 Coils and 12 Commutator Segments



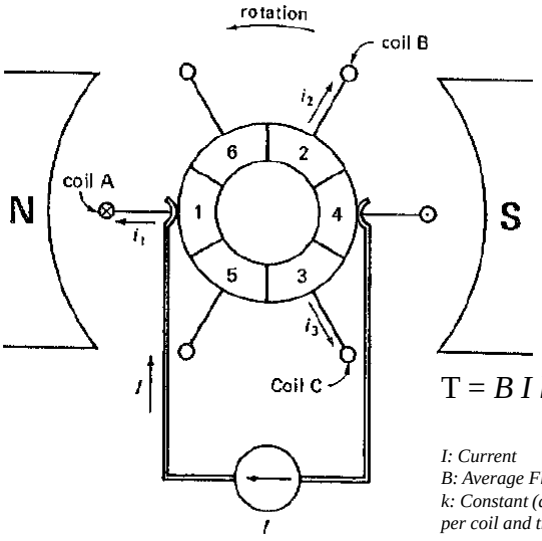
Voltages Induced in the Coils



Motor

It is a machine, which creates a motion: A machine that converts energy into motion and can be used as a power source, e.g., to drive another machine or to move a vehicle.

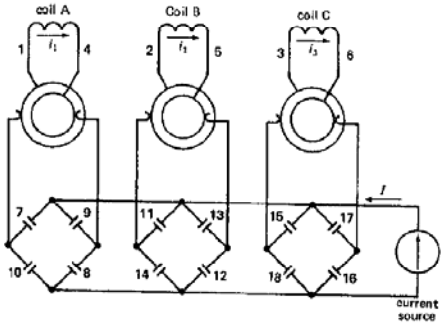
Motor with 3 Coils

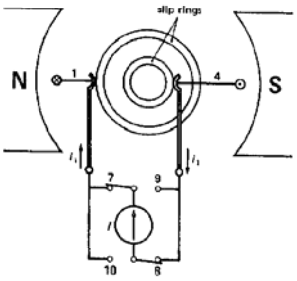


$$T = B\,I\,k$$

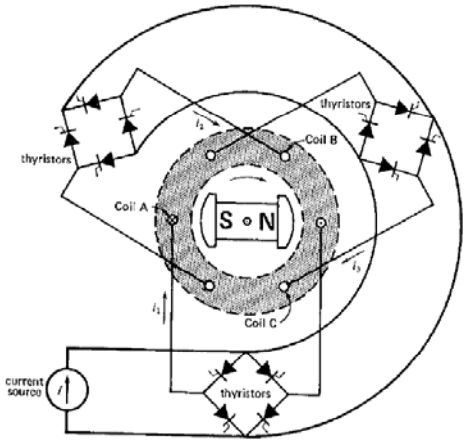
I: Current
B: Average Flux Density
k: Constant (dependent upon number of turns per coil and the size of armature)

Commutator Replaced with Switches





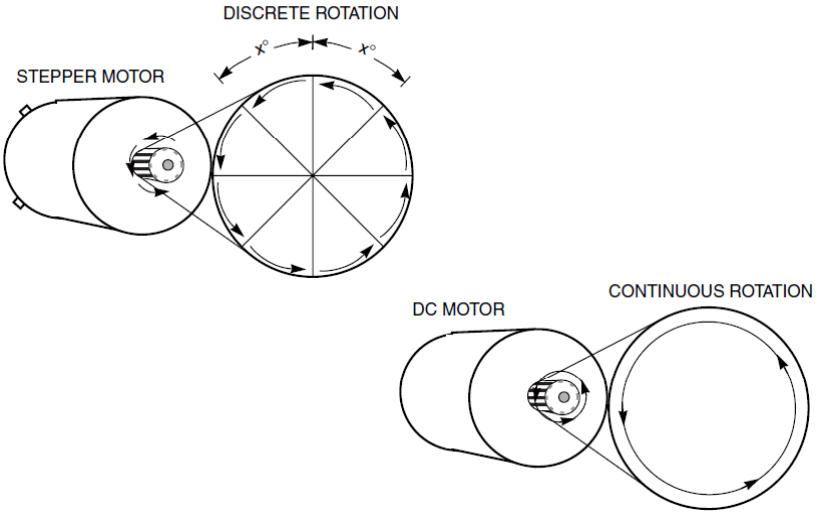
Brushless Motor



Stepper Motor

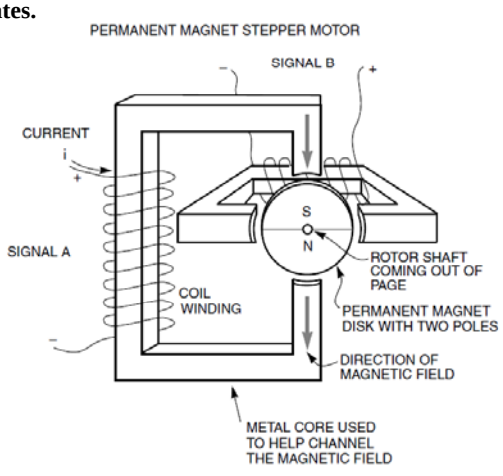
A stepper motor is a small brushless synchronous electric motor that can divide a full rotation into a large number of steps. If it is electronically connected to the MCU, the motor's position can be controlled with precision without any feedback mechanism.

Stepper Motor

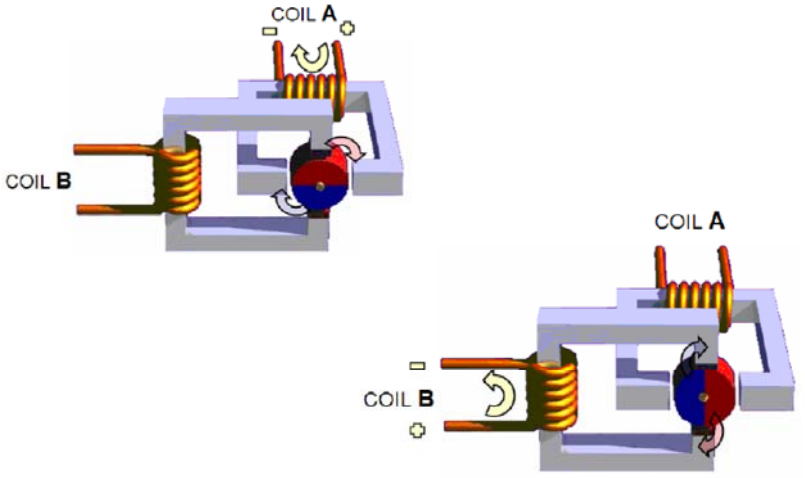


Stepper Motor Construction

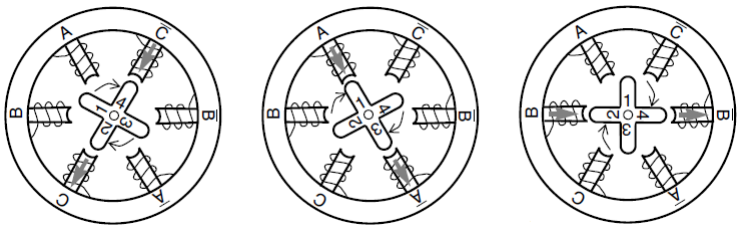
Typically, a stepper motor consists of a stator, a rotor with a shaft, and coil windings. The stator is a surrounding casing that remains stationary and is part of the motor housing, while the rotor is a central shaft within the motor that actually spins/rotates.



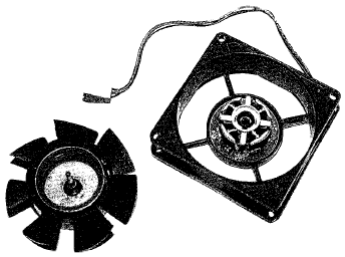
Motor Rotation



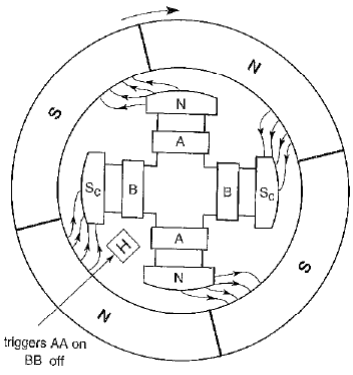
VR Stepper Motor



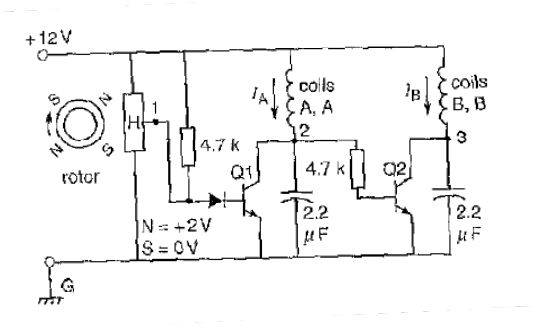
Practical Application of Brushless DC Motor



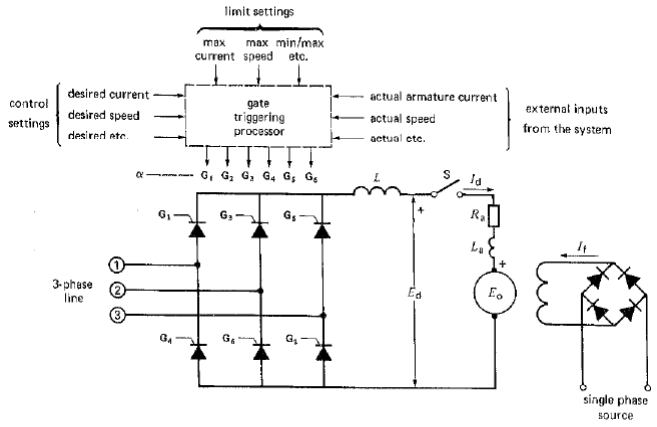
Practical Application of Brushless DC Motor



Practical Application of Brushless DC Motor

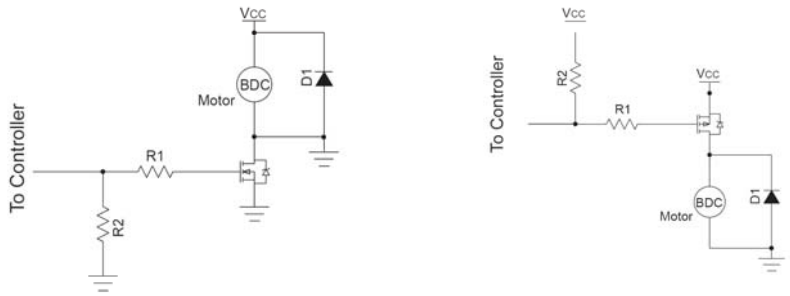


Speed Control of a DC Motor



The field excitation is fixed which is provided by a single phase source and the speed is varied by changing the armature voltage.

Basic Drive Circuit



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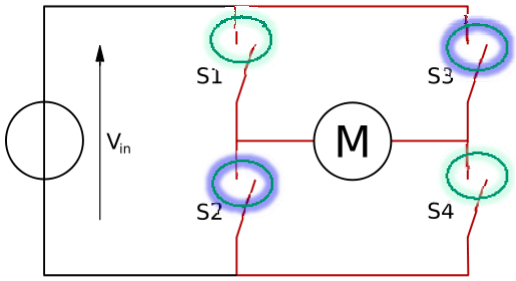
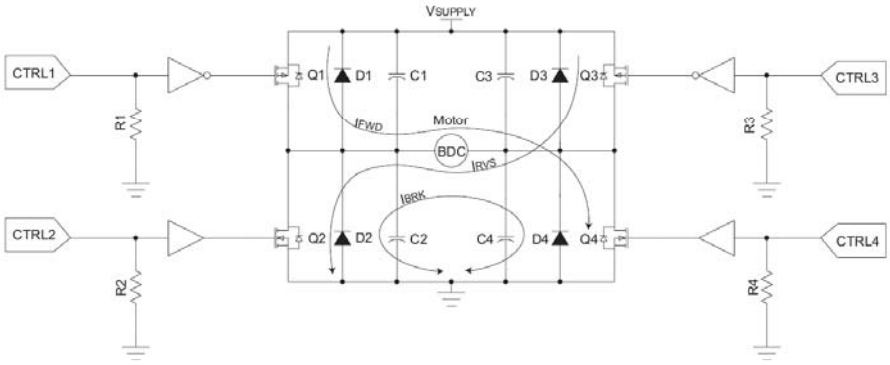
H Bridge



H Bridge



Speed & Duty Cycle

	Q1 (CTRL1)	Q2 (CTRL2)	Q3 (CTRL3)	Q4 (CTRL4)
Forward	on	off	off	on
Reverse	off	on	on	off
Coast	off	off	off	off
Brake	off	on	off	on

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Important: Frequency of PWM

The frequency of the PWM waveform is an important consideration. Too low a frequency will result in a noisy motor at low speeds and sluggish response to changes in duty cycle. Too high a frequency lessens the efficiency of the system due to switching losses in the switching devices. A good rule of thumb is to modulate the input waveform at a frequency in the range of 4 kHz to 20 kHz. This range is high enough that audible motor noise is attenuated and the switching losses present in the MOSFETs (or BJTs) are negligible. Generally, it is a good idea to experiment with the PWM frequency for a given motor to find a satisfactory frequency.

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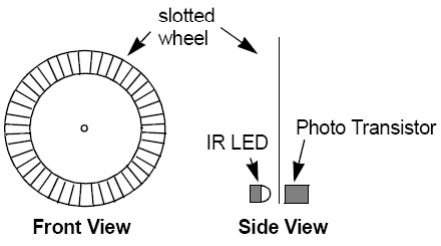
Feedback

Typically, the speed can be control through duty cycle and it is pretty accurate, but still may not be ideal so the solution could be using a feedback mechanism.

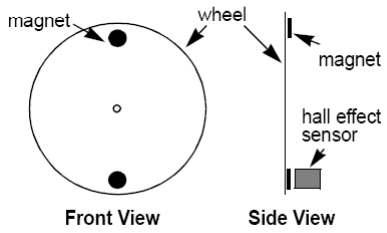
Many factor contribute for this inaccuracy, for example, Heat, Commutator wear & tear and may be load as well.

Sensors For Feedback



This setup can be sued for dual purpose not only for determining speed but also positioning.

Hall Effect Sensor



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