Mechatronics (Merged - DEZG516/DMZG511/ESZG511)

Lecture

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Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Actuators: Mechanical actuators like belt and chain drives, linkage mechanisms Actuators: Electric actuators like relay, contactor, solenoid, AC, DC, Stepper motors	T1: Chapter8, 9, T2: Chapter 10
Post CH			

C → A → System

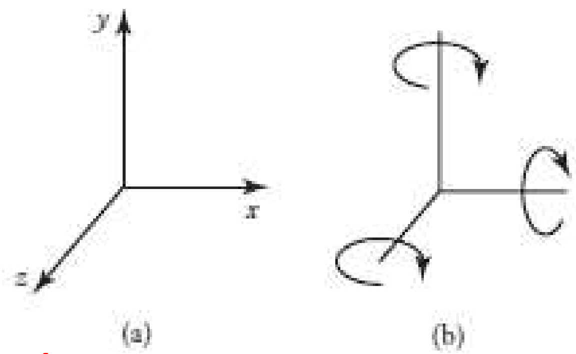
- Mech
- Ele
- Pnu
- hyd

Mechanical Actuation systems

- joint
- link → levers / Mechanism
- gear
- cam
- bearing
- Pulley / chain

Freedom and constraints

Figure 8.1 Types of motion: (a) translational, (b) rotational.



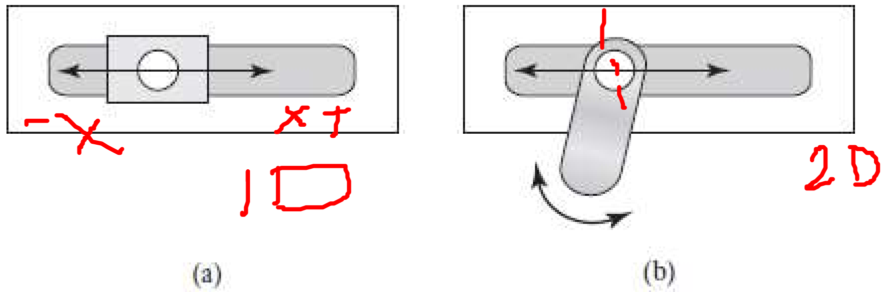
3 + 3 = 6

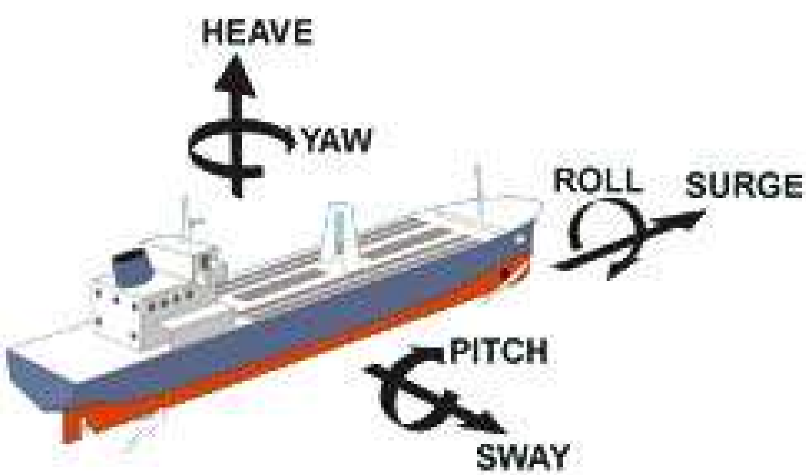
Break down the motion into combinations of translational and rotational motions so that we can design mechanisms to carry out each of these components of the motion.

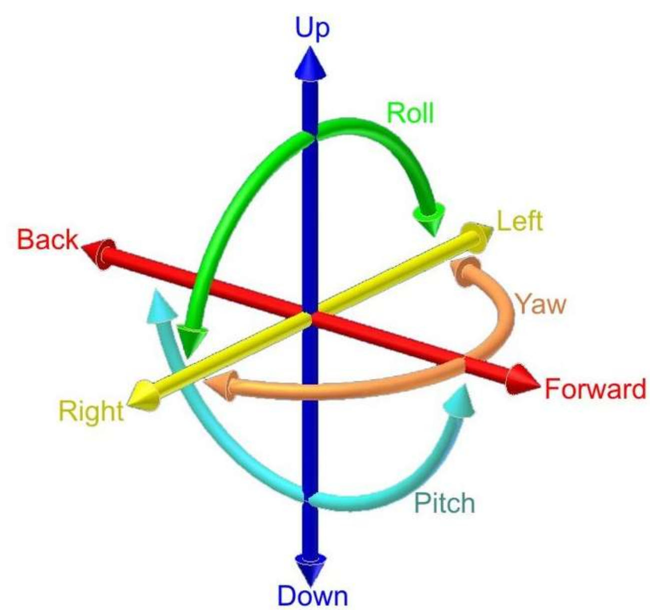
For example, among the sequence of control signals sent to a mechanism might be such groupings of signals as those to instruct joint 1 to rotate by 20° and link 2 to be extended by 4 mm for translational motion.

Freedom and constraints

Figure 8.2 Joints with: (a) one, (b) two degrees of freedom.



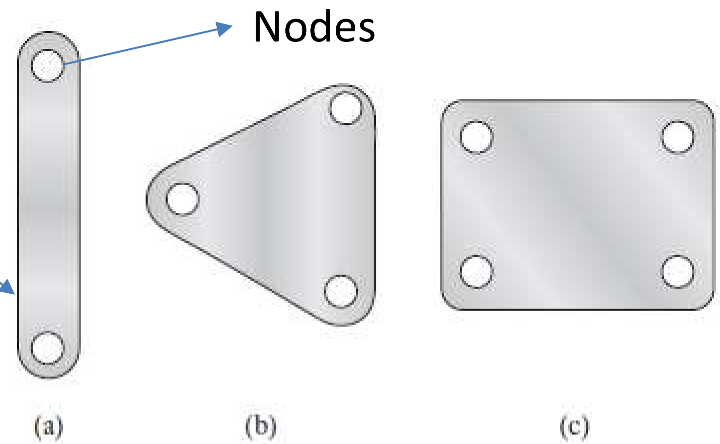


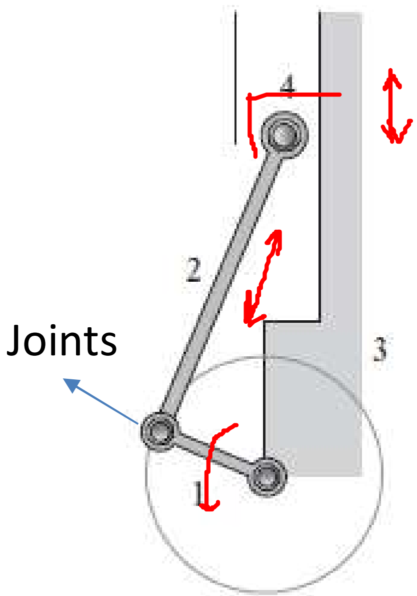


6 − number of constraints = number of degrees of freedom

Kinematic Chains (Links, Nodes Joints)

Figure 8.4 Links: (a) with two nodes, (b) with three nodes, (c) with four nodes.





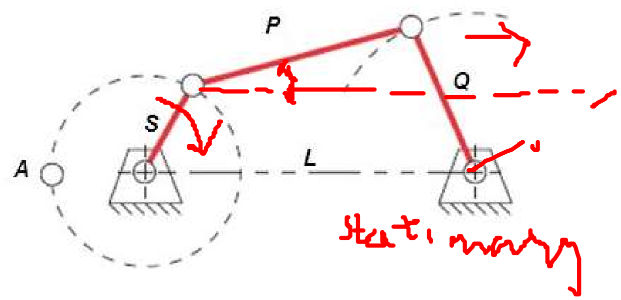
⇒ Mechanism

Four bar chain

- The Grashof condition is a simple relationship that predicts the rotation behavior or rotatability of a fourbar linkage based only on the link lengths.

  Let :

  - L = length of longest link
  - S = length of shortest link
  - P = length of one remaining link
  - Q = length of other remaining link

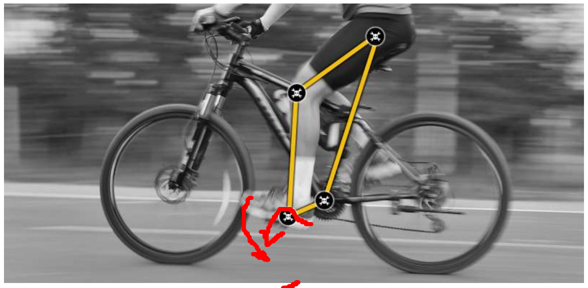


- In order for the crank to be pass through point A without locking, the sum of the lengths of the crank link and the ground link ($L+S$) must be shorter that the sum of the lengths of the two other links ($P + Q$).

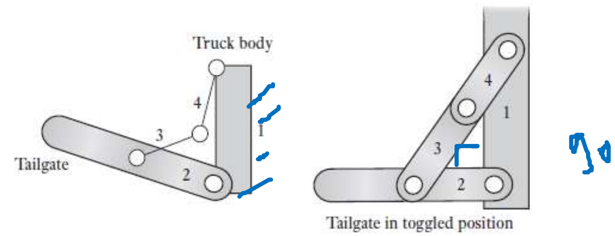
$$S + L \leq P + Q$$

Grashoff Condition

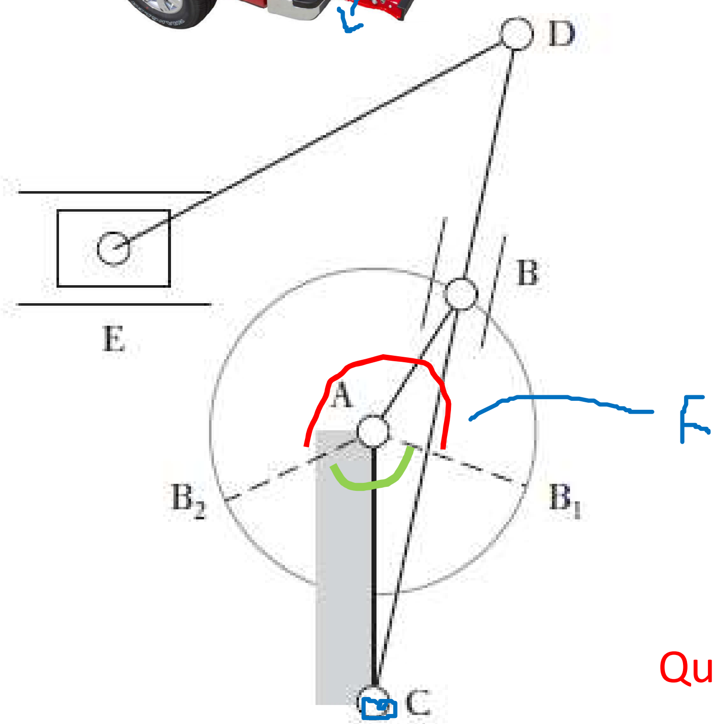
If the sum of the shortest and longest link of a **planar** quadrilateral linkage is less than or equal to the sum of the remaining two links, then the shortest link can rotate fully with respect to a neighbouring link.

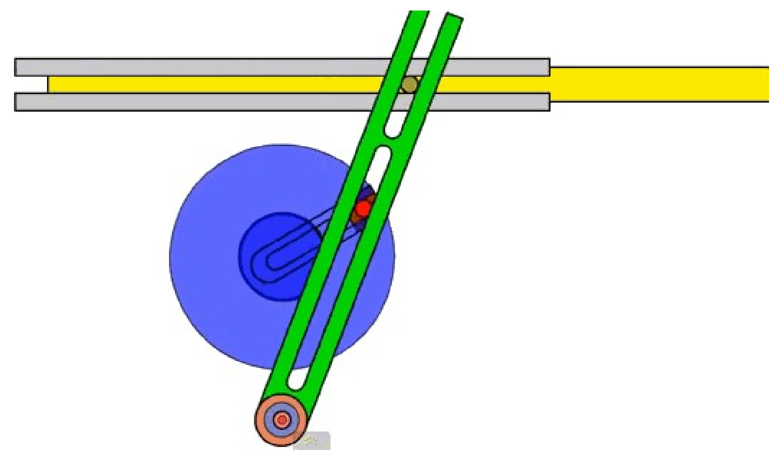


Four bar chain applications



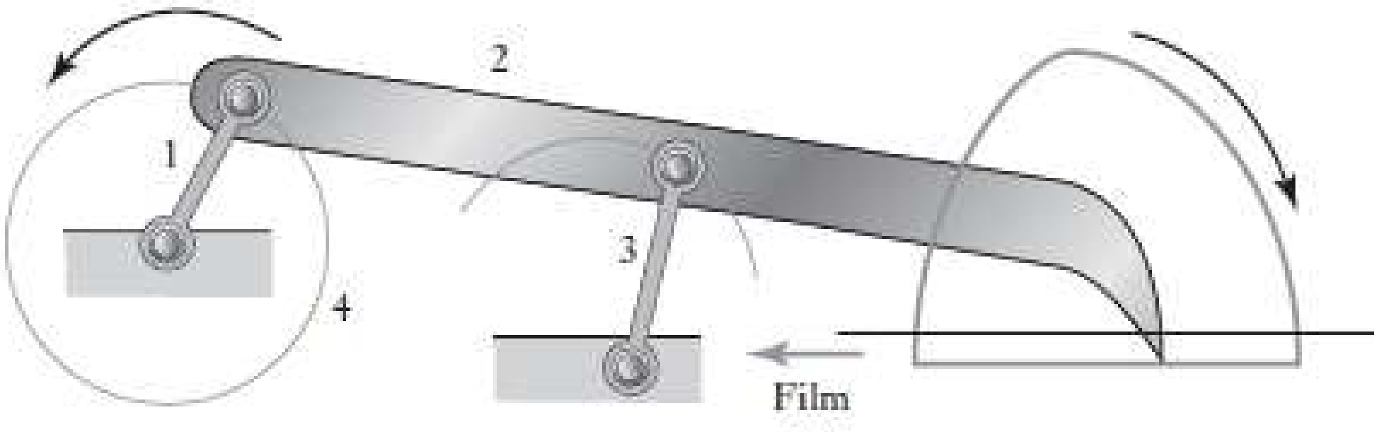
Toggle return





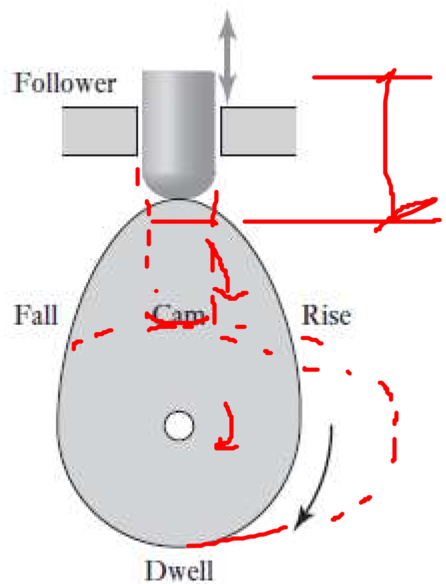
Quick return Mechanisms

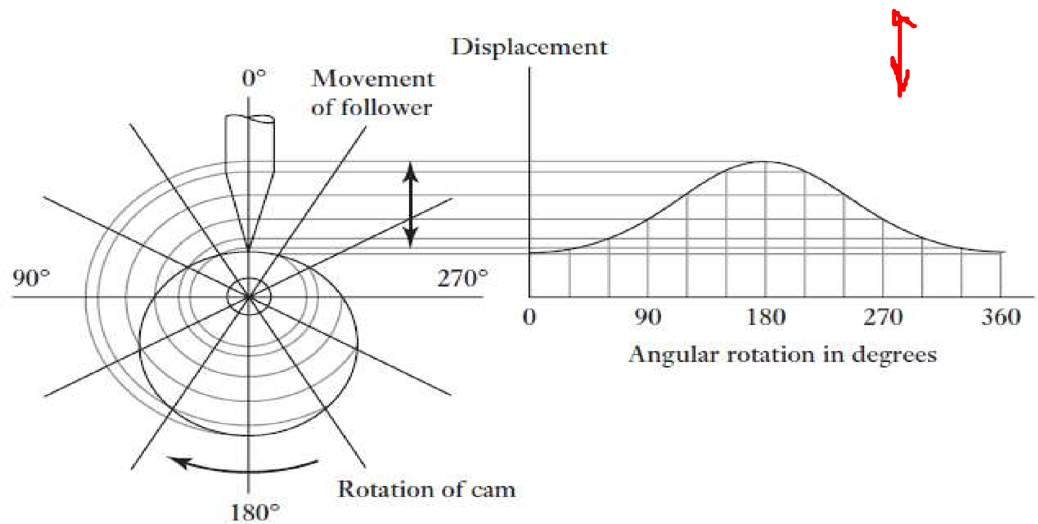
Four bar chain applications



Film Indexing mechanism

Cams





A cam is a body which rotates or oscillates and in doing so imparts a reciprocating or oscillatory motion to a second body, called the follower

Cams

Figure 8.13 Cams: (a) heart-shaped, (b) pear-shaped.

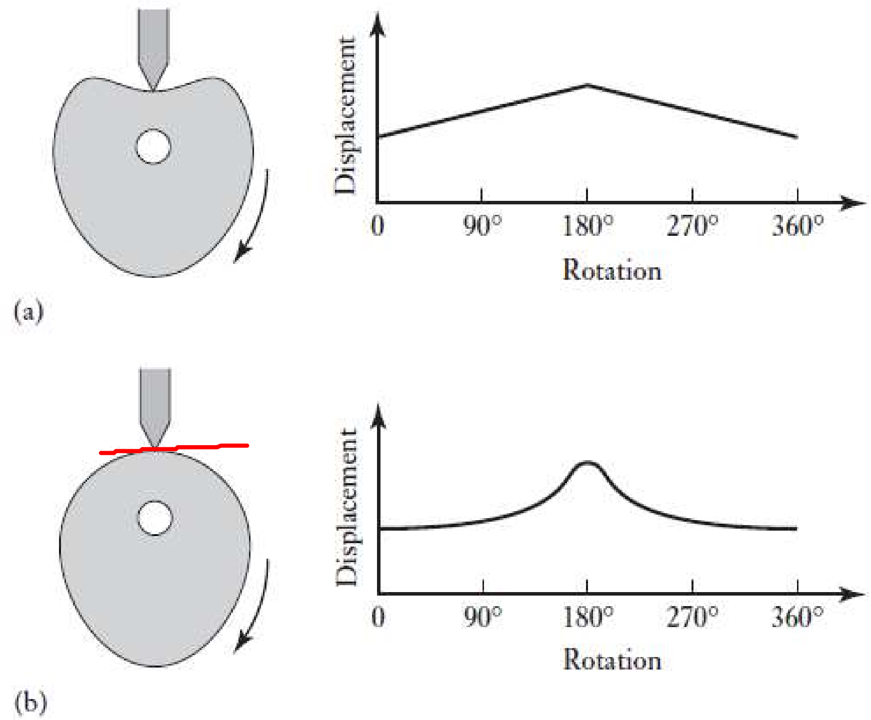
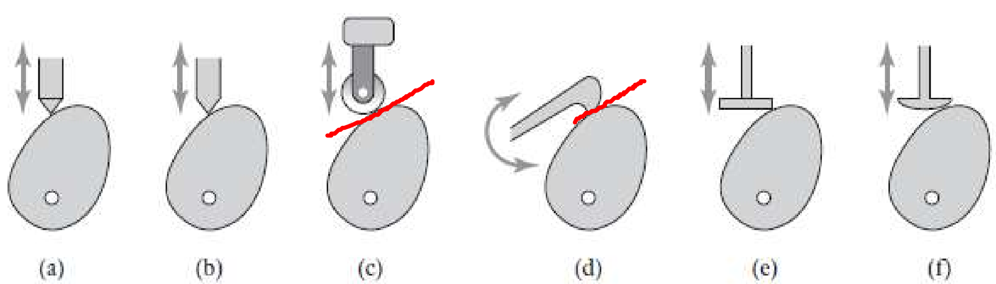
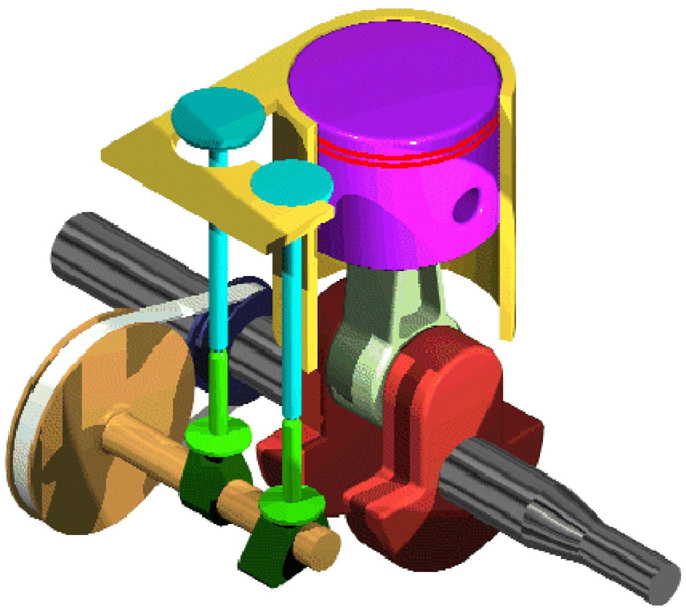
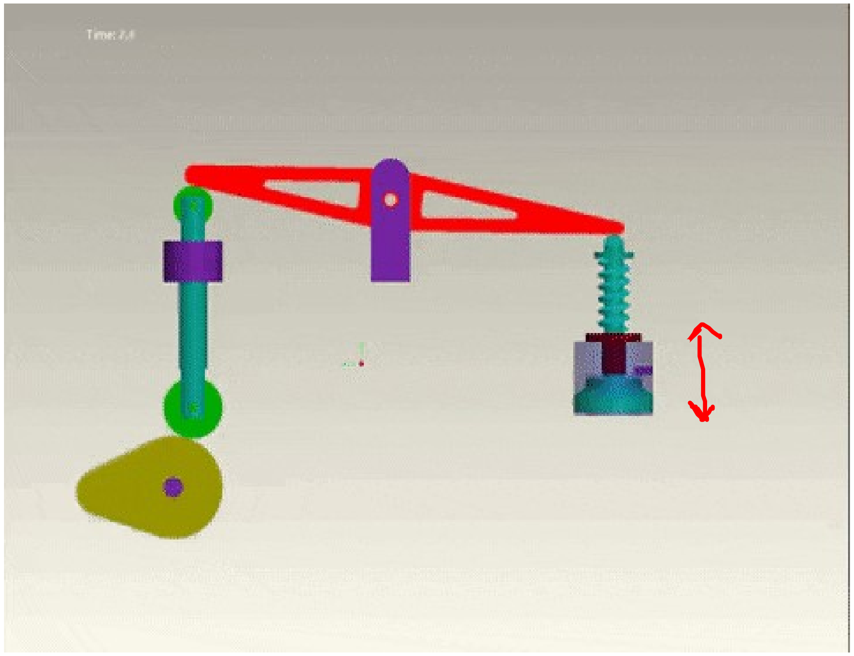


Figure 8.14 Cam followers: (a) point, (b) knife, (c) roller, (d) sliding and oscillating, (e) flat, (f) mushroom.



Cams

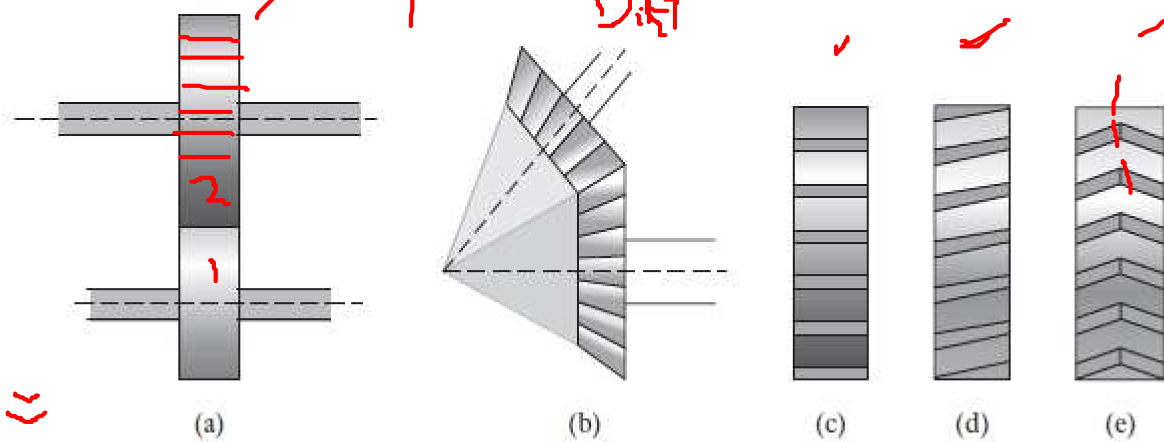




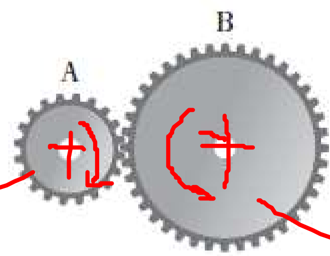
Gears

Figure 8.15 (a) Parallel gear axes, (b) axes inclined to one another, (c) axial teeth, (d) helical teeth, (e) double helical teeth.

Spur Diff



$\pi D_1 N_1 = \pi D_2 N_2 \Rightarrow \frac{N_1}{N_2} = \frac{D_2}{D_1}$



Driver

driven

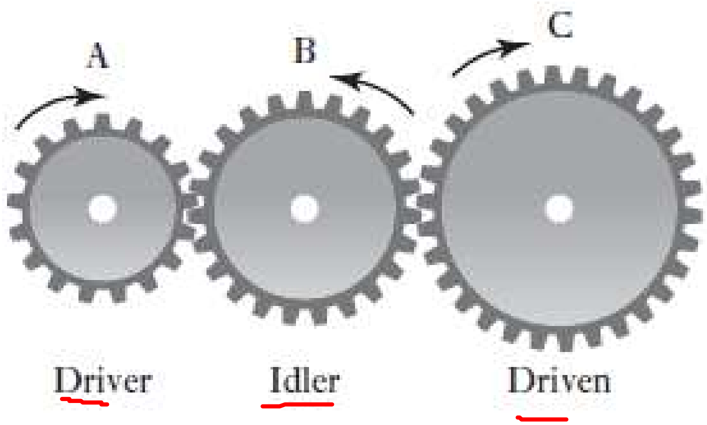
$$\frac{\omega_A}{\omega_B} = \frac{\text{number of teeth on B}}{\text{number of teeth on A}} = \frac{80}{40} = 2$$

$\frac{\omega_{Driver}}{\omega_{driven}}$

40 teeth on wheel A and 80 teeth on wheel B,

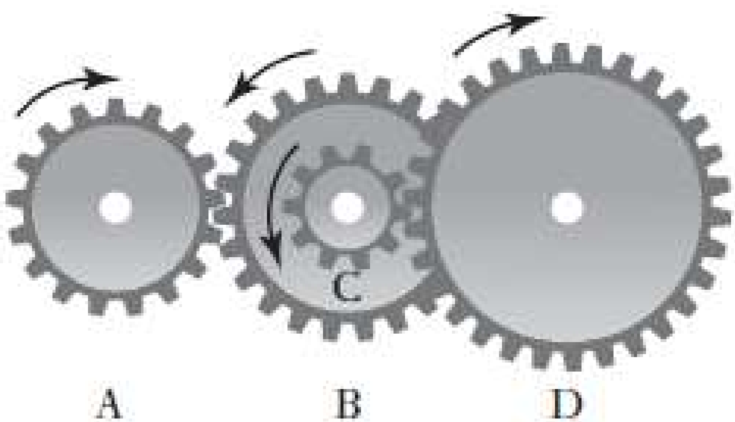
$\frac{D_1}{D_2} = \frac{N_2}{N_1}$

Gears



$$G = \frac{\omega_A}{\omega_C} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C}$$

$\omega_B = \omega_C \quad . \quad \frac{\omega_B}{\omega_C} = 1$



$$G = \frac{\omega_A}{\omega_D} = \frac{\omega_A}{\omega_B} \times \boxed{\frac{\omega_B}{\omega_C}} \times \frac{\omega_C}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_C}{\omega_D}$$

1

Rotational to translational motion

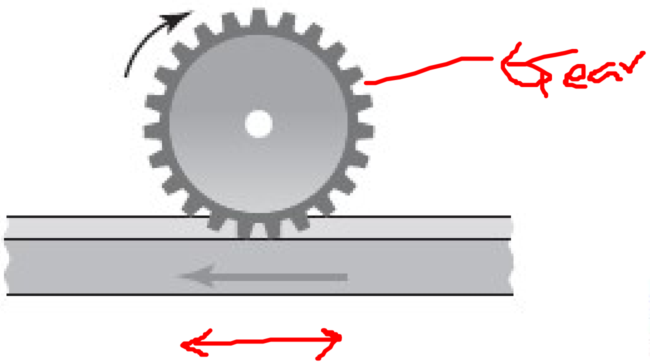
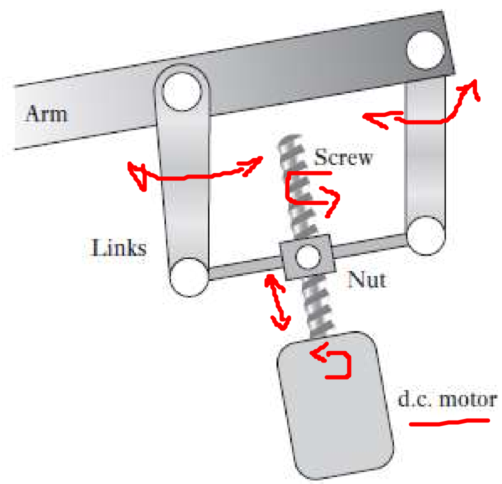
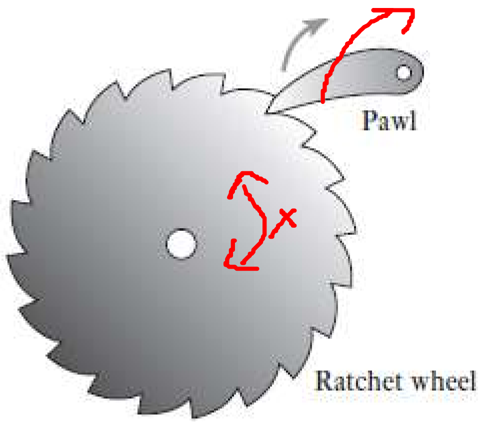


Figure 8.20 Ball screw and links used to move a robot arm.

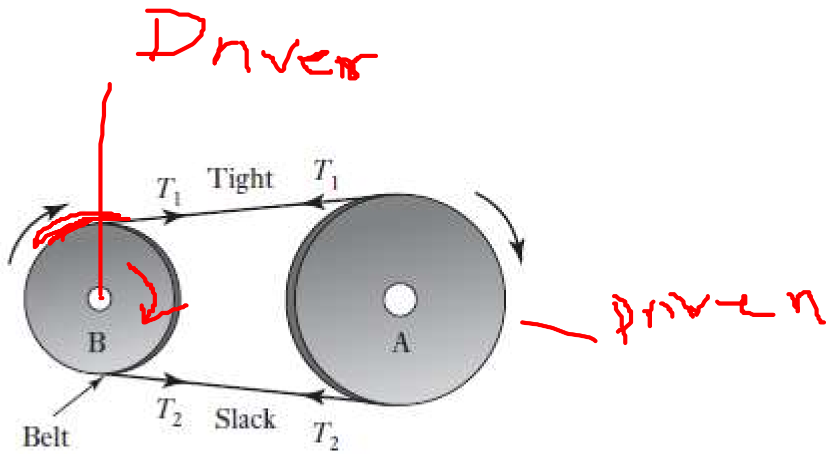


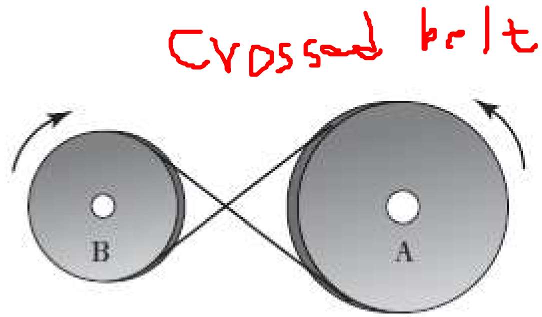
Ratchet and Pawl



Rotation of the ratchet wheel in a clockwise direction is prevented by the pawl and can only take place when the pawl is lifted

Belts



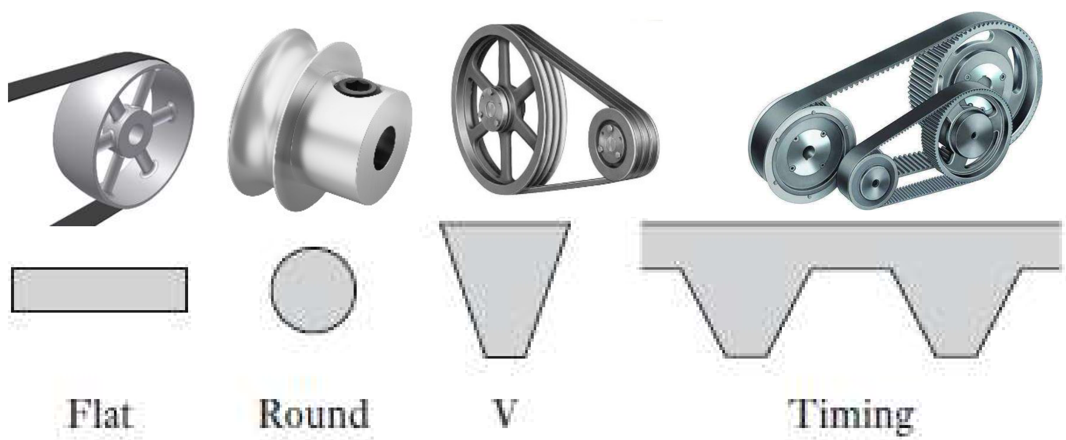


(a)

torque on A $= (T_1 - T_2)r_A$

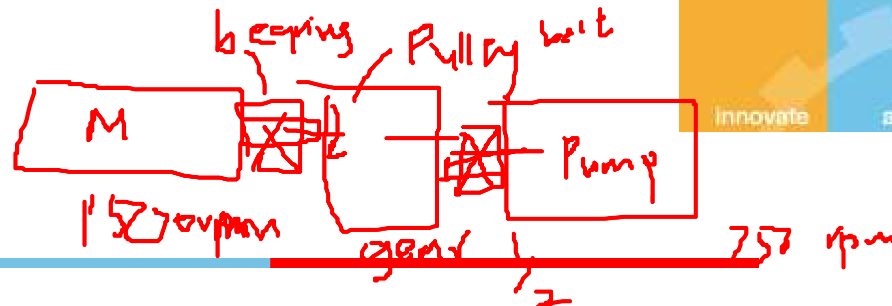
torque on B $= (T_1 - T_2)r_B$

power $= (T_1 - T_2)v$



Types of belt.

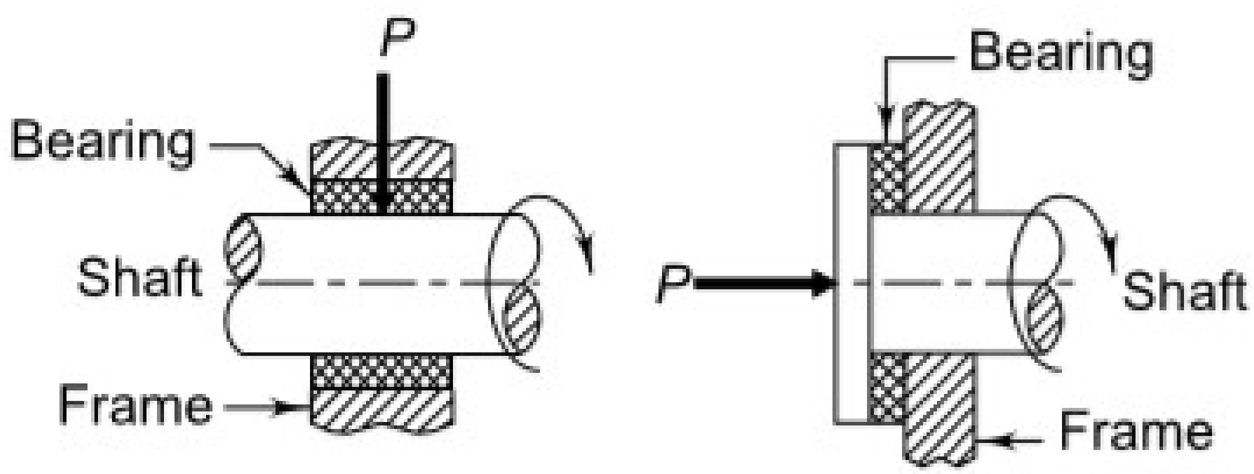
Bearings



- Bearing is a mechanical element that permits relative motion between two parts, such as the shaft and the housing, with minimum friction.
- The functions of the bearing are
  – The bearing ensures free rotation of the shaft or the axle with minimum friction.
  – The bearing supports the shaft or the axle and holds it in the correct position.
  – The bearing takes up the forces that act on the shaft or the axle and transmits them to the frame or the foundation.

Classification of bearings and terminology

- Depending upon type of load
  - Radial bearing
  - Thrust bearing

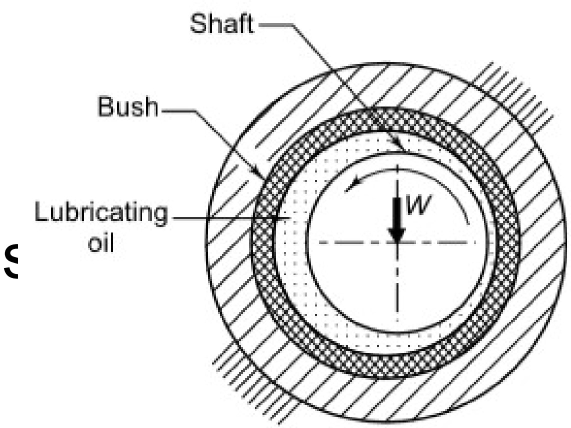


(a) Radial bearing (b) Thrust bearing

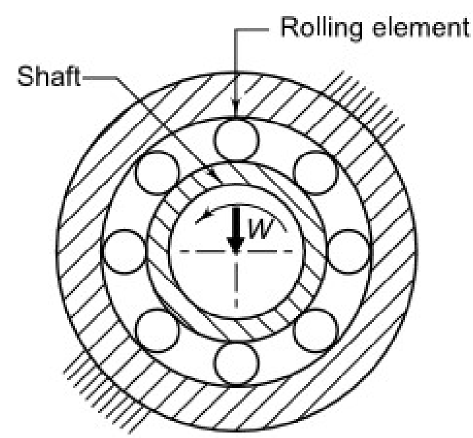
Classification of bearings and terminology

- Depending upon the type of friction
  - sliding contact bearings
    - plain bearings,
    - journal bearings or sleeve bearings
  - rolling contact bearings

  (also called antifriction bearings)
    - balls bearing
    - rollers bearing



(a) Sliding contact bearing



(b) Rolling contact bearing

Applications of Sliding contact bearings

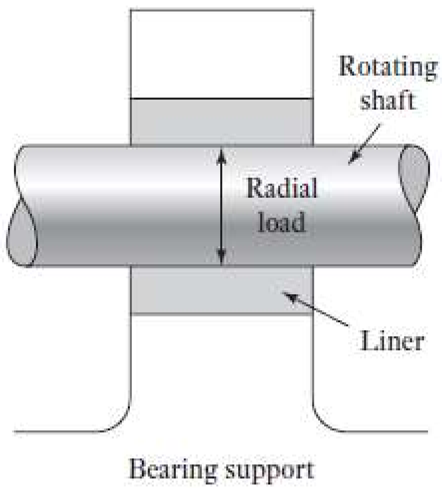
- Crankshaft bearings in petrol and diesel engines
- Centrifugal pumps
- Large size electric motors
- Steam and gas turbines;
- Concrete mixers, rope conveyors and marine installations.

Applications of rolling contact bearings

- machine tool spindles
- automobile front and rear axles
- gear boxes;
- small size electric motors
- rope sheaves, crane hooks and hoisting drums.

Bearings

Journal Bearing (Suited for radial load)



The insert may be a white metal, aluminium alloy, copper alloy, bronze or a polymer such as nylon or polytetrafluoroethylene (PTFE).

Types –

- Hydrostatic
- Hydrodynamic
- Solid film
- Boundary layer

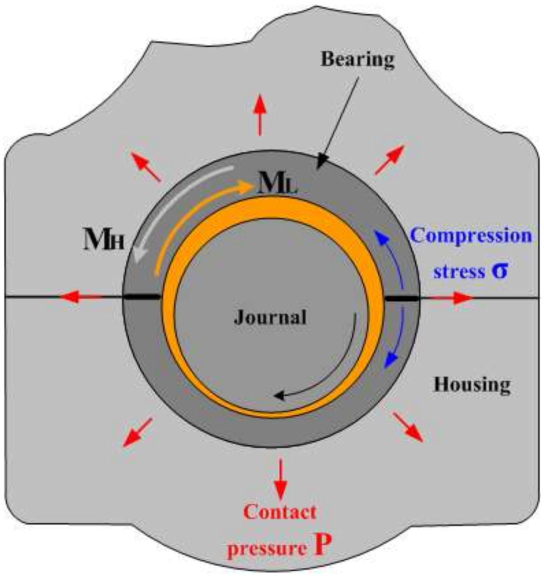


Fig. 1 Bearing assembly

Bearing type comparison

Features \ Bearing Types		Deep Groove Ball Bearings	Magneto Bearings	Angular Contact Ball Bearings	Double-Row Angular Contact Ball Bearings	Duplex Angular Contact Ball Bearings	Four-Point Contact Ball Bearings	Self-Aligning Ball Bearings	Cylindrical Roller Bearings	Double-Row Cylindrical Roller Bearings	Cylindrical Roller Bearings with Single Rib
Load Capacity	Radial Loads	◯	○	⊙	⊙	⊙	○	◯	⊙	◎	⊙
	Axial Loads	⟷ ◯	⟵ ○	⟵ ⊙	⟷ ⊙	⟷ ⊙	⟷ ⊙	⟷ ○	×	×	⟵ ◯
	Combined Loads	◯	○	⊙	⊙	⊙	◯	○	×	×	◯
High Speeds		◎	⊙	◎	◯	⊙	⊙	⊙	◎	⊙	⊙
High Accuracy		◎		◎		◎	⊙		◎	◎	
Low Noise and Torque		◎							⊙		
Rigidity						⊙			⊙	◎	⊙
Angular Misalignment		⊙	○	○	○	○	○	◎	◯	○	◯
Self-Aligning Capability								☆			
Ring Separability			☆				☆		☆	☆	☆
Fixed-End Bearing		☆			☆	☆	☆	☆			
Free-End Bearing		★			★	★	★	★	☆	☆	

× Impossible ⟵ One direction only ⟷ Two directions

action/elongation at fitting surfaces of bearings.

◎ Excellent ⊙ Good ◯ Fair ○ Poor

☆ Applicable ★ Applicable, but it is necessary to allow shaft con

Bearing type comparison

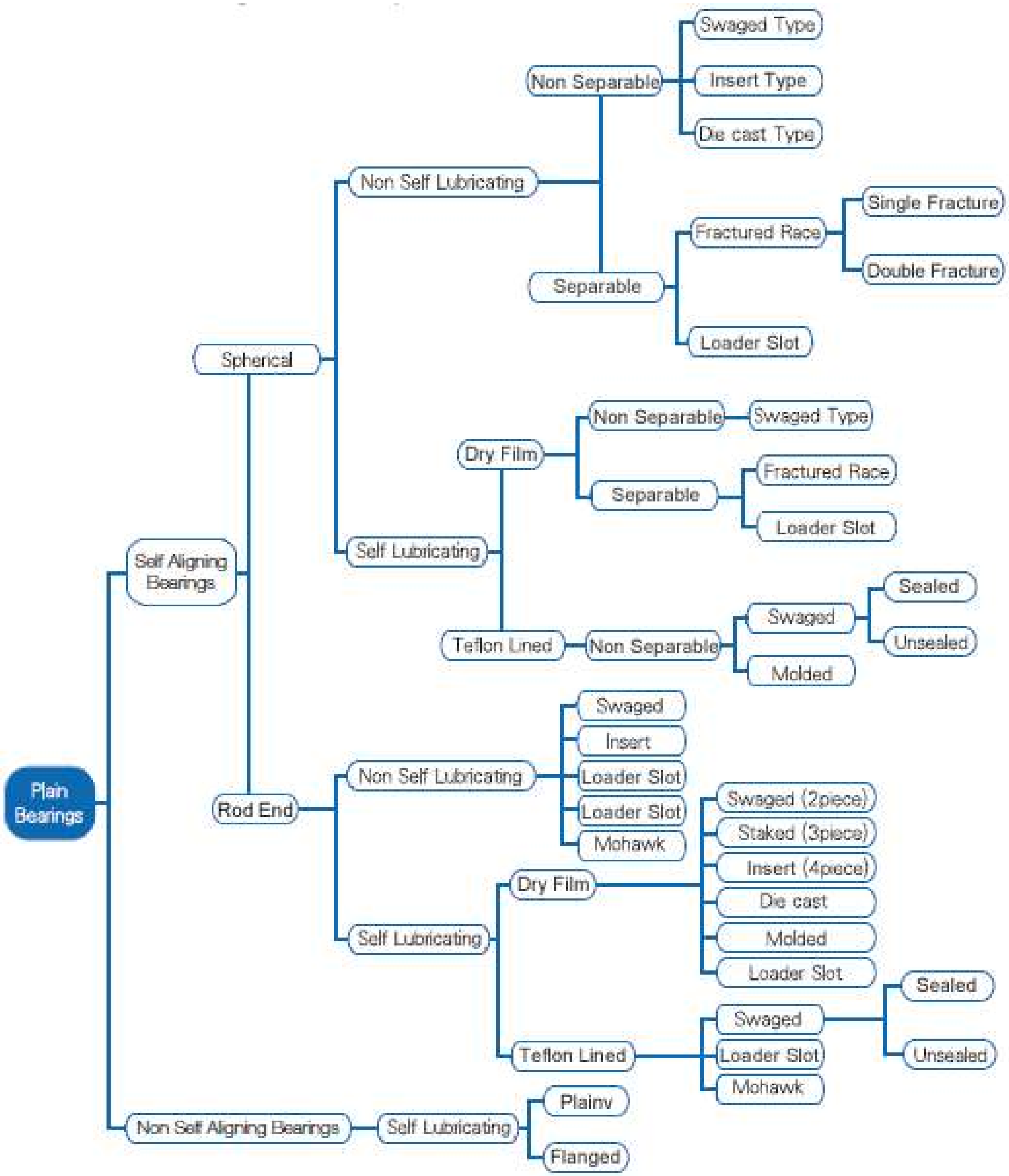
Features \ Bearing Types		Cylindrical Roller Bearings with Thrust Collars	Needle Roller Bearings	Tapered Roller Bearings	Double-and Multiple-Row Tapered Roller Bearings	Spherical Roller Bearings	Thrust Ball Bearings	Thrust Ball Bearings with Aligning Seat	Double-Direction Angular Contact Thrust Ball Bearings	Cylindrical Roller Thrust Bearings	Tapered Roller Thrust Bearings	Spherical Thrust Roller Bearings
Load Capacity	Radial Loads	Good	Good	Good	Excellent	Excellent	×	×	×	×	×	Poor
	Axial Loads	↔ Fair	×	← Good	↔ Good	↔ Fair	← Good	← Good	↔ Good	← Excellent	← Excellent	← Excellent
	Combined Loads	Fair	×	Good	Excellent	Good	×	×	×	×	×	Poor
High Speeds		Good	Good	Fair	Fair	Fair	×	×	Fair	Poor	Poor	Poor
High Accuracy				Good			Good		Excellent			
Low Noise and Torque												
Rigidity		Good	Good	Good	Excellent				Good	Excellent	Excellent	
Angular Misalignment		Fair	Poor	Fair	Poor	Excellent	×	Excellent	×	×	×	Excellent
Self-Aligning Capability						☆		☆				☆
Ring Separability		☆	☆	☆	☆		☆	☆	☆	☆	☆	☆
Fixed-End Bearing		☆			☆	☆						
Free-End Bearing			☆		★	★						
Tapered Bore in Inner Ring						☆						

× Impossible ← One direction only ↔ Two directions

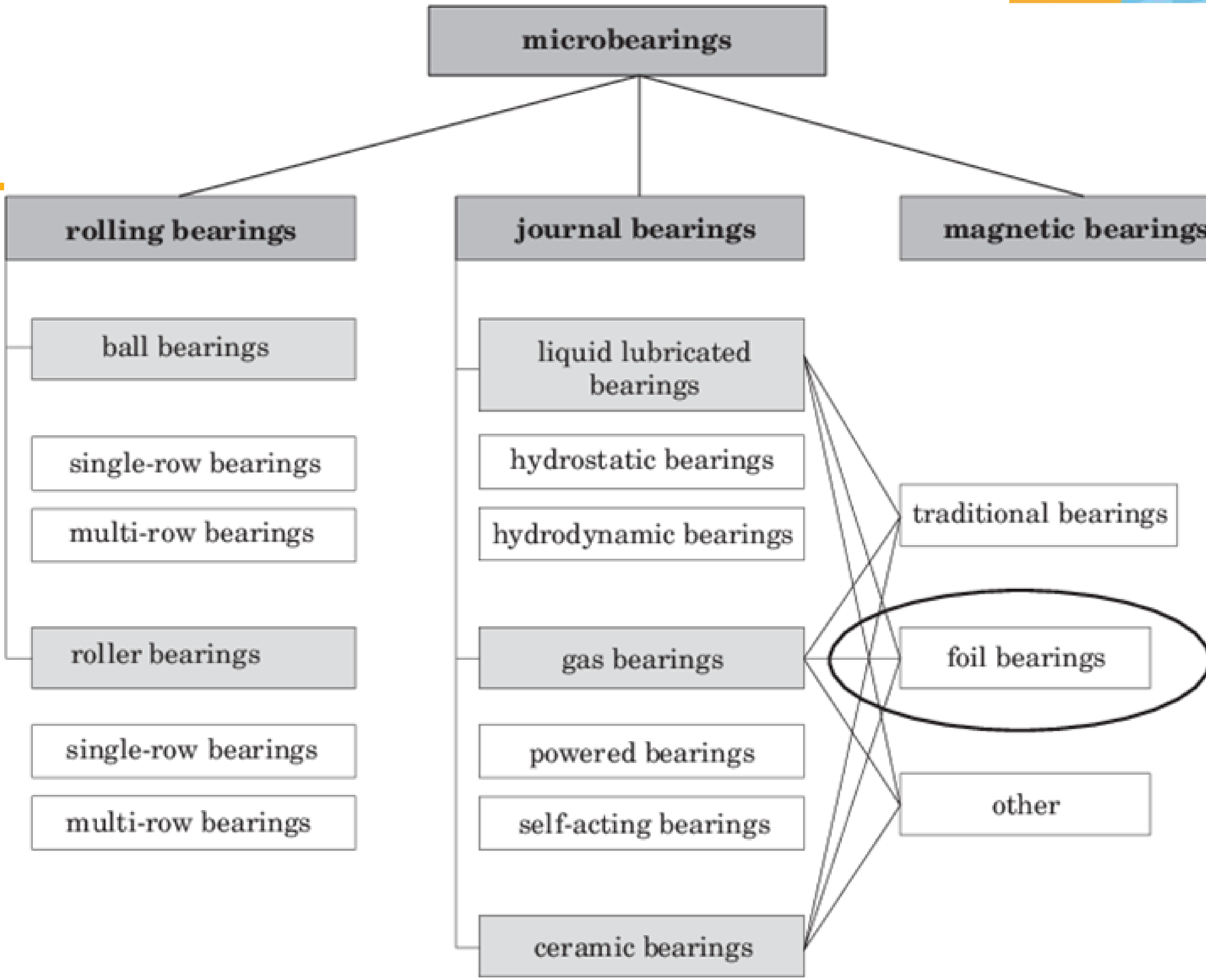
action/elongation at fitting surfaces of bearings.

Excellent Good Fair Poor

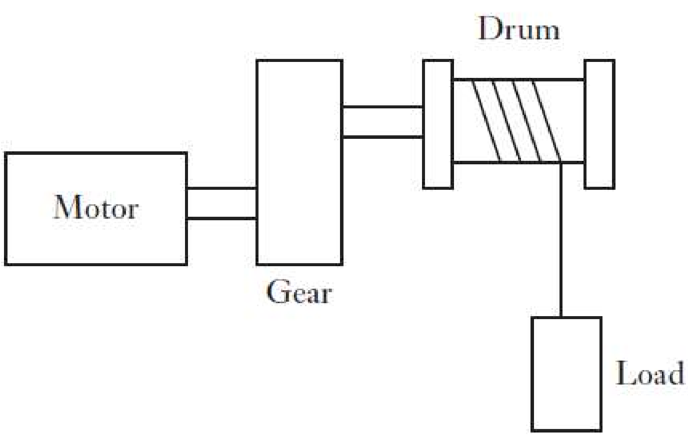
☆ Applicable ★ Applicable, but it is necessary to allow shaft con



Plain Bearings
Self Aligning Bearings
Spherical
Non Self Lubricating
Non Separable
Swaged Type
Insert Type
Die cast Type
Separable
Fractured Race
Single Fracture
Double Fracture
Loader Slot
Self Lubricating
Dry Film
Non Separable
Swaged Type
Separable
Fractured Race
Loader Slot
Teflon Lined
Non Separable
Swaged
Sealed
Unsealed
Molded
Rod End
Non Self Lubricating
Swaged
Insert
Loader Slot
Loader Slot
Mohawk
Self Lubricating
Dry Film
Swaged (2piece)
Staked (3piece)
Insert (4piece)
Die cast
Molded
Loader Slot
Teflon Lined
Swaged
Loader Slot
Mohawk
Sealed
Unsealed
Non Self Aligning Bearings
Self Lubricating
Plainv
Flanged


microbearings
rolling bearings
journal bearings
magnetic bearings
ball bearings
single-row bearings
multi-row bearings
roller bearings
single-row bearings
multi-row bearings
liquid lubricated bearings
hydrostatic bearings
hydrodynamic bearings
gas bearings
powered bearings
self-acting bearings
ceramic bearings
traditional bearings
foil bearings
other

Motor selection



Drum Dia =0.5 m
Mass (Load) =1000 Kg
Speed of hoist = 0.5 m/s

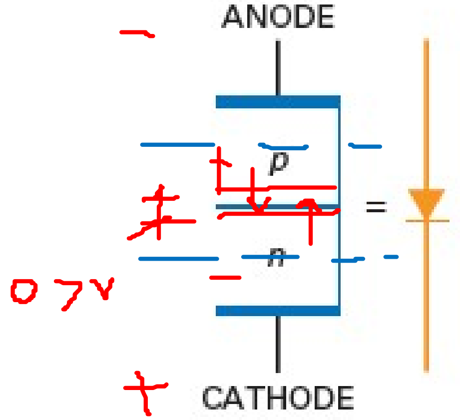
Tension in cable = 1000 x 9.81 N

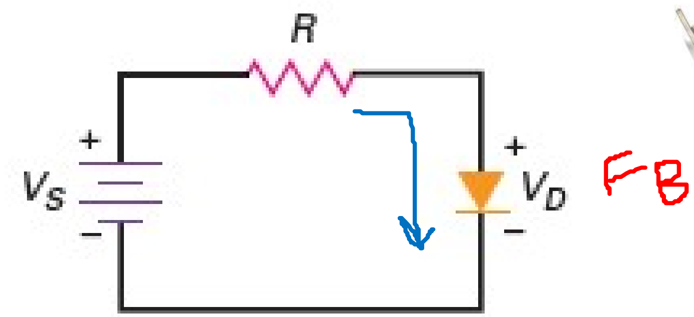
Torque = 9810 x 0.25 ® = 2.5 KN-m
Angular velocity of drum = 0.5 / 0.25 = 2 rad/s
Rotation per second w=2*pi*f , then f=0.32 rev/s

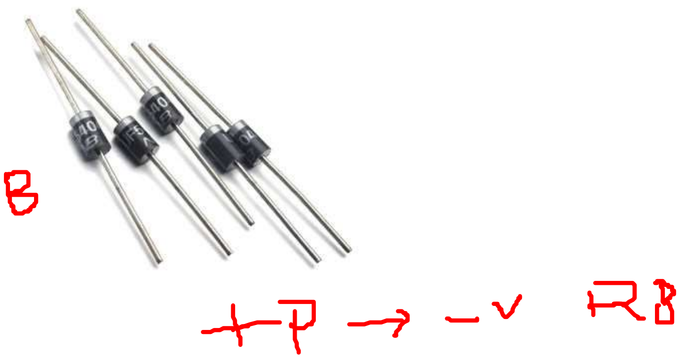
Assume 1500 RPM motor or 25rev/s
The gear ratio : 25/0.32 = 80:1
Load torque on motor = 2.5KN-m/80 = 31.25 N-m
With friction etc = 35 N-m

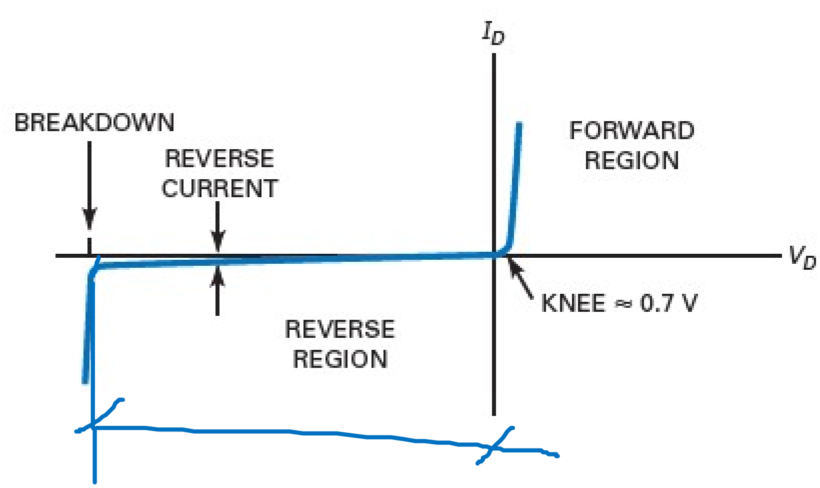
Electrical Actuation systems

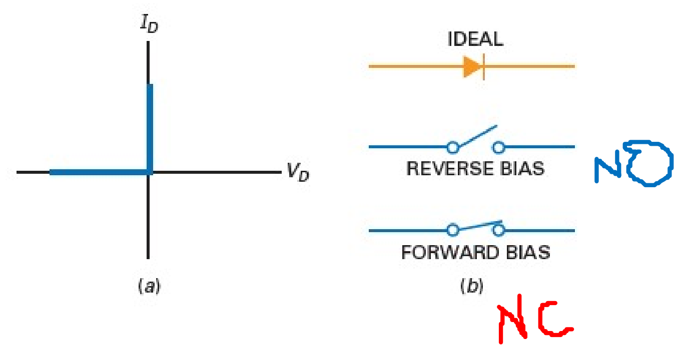
Diodes – (Electronic check valve) Unidirectional Current flow











Diodes

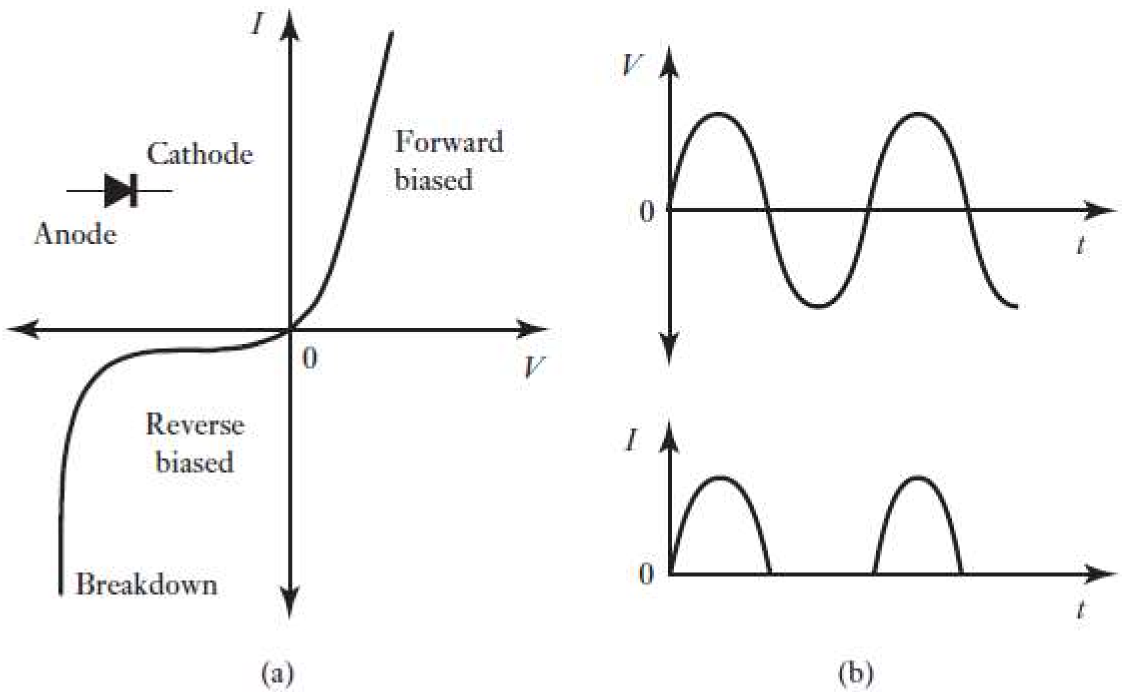


Figure 9.3 (a) Diode characteristic, (b) half-wave rectification.

What is a Transistor?

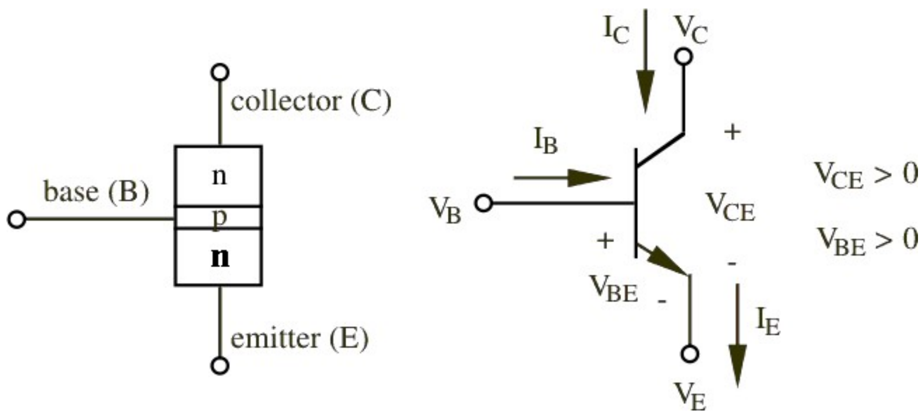
NPN
PNP

Switch
Amplifier

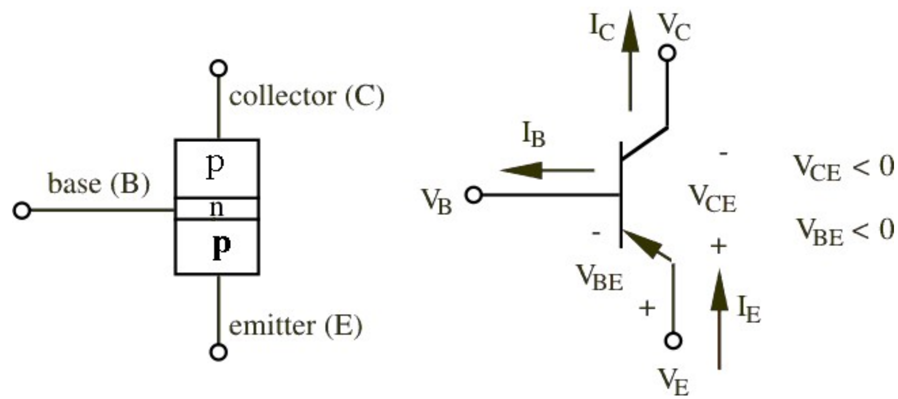
- Semiconductors: ability to change from conductor to insulator
- Can either allow current or prohibit current to flow
- Useful as a switch, but also as an amplifier
- Essential part of many technological advances

Bipolar Junction Transistor (BJT)

- 3 adjacent regions of doped Si (each connected to a lead):
  - Base. (thin layer, less doped).
  - Collector.
  - Emitter.
- 2 types of BJT:
  - NPN
  - PNP
- Most common: NPN (focus on it).



npn bipolar junction transistor



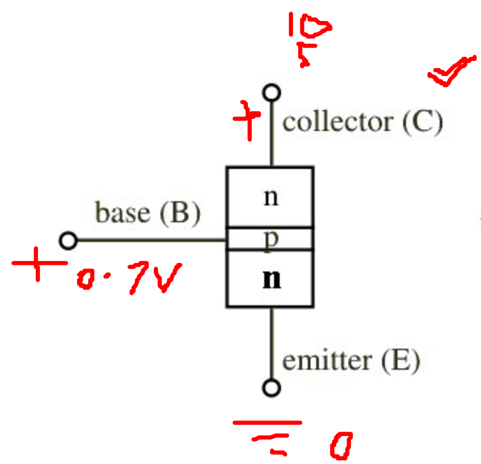
pnp bipolar junction transistor

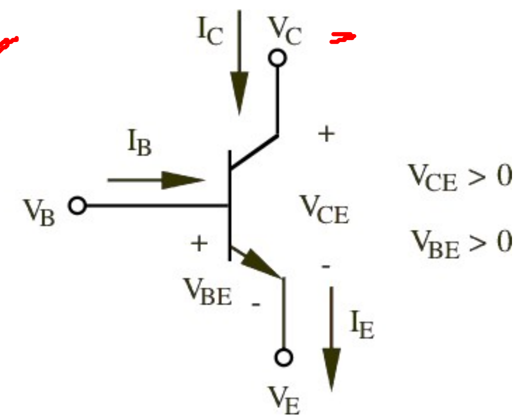
BJT NPN Transistor

- <u>1 thin layer of p-type</u>, sandwiched between <u>2 layers of n-type</u>.
- N-type of emitter: <u>more heavily doped</u> than collector.
- <u>With $V_C>V_B>V_E$:</u>
  - <u>Base-Emitter</u> junction <u>forward biased</u>, <u>Base-Collector</u> <u>reverse biased</u>.
  - Electrons diffuse from Emitter to Base (from n to p).
  - There's a <u>depletion layer</u> on the Base-Collector junction → no flow of e^- allowed.
  - **BUT** the <u>Base is thin and Emitter region is n^+ (heavily doped)</u> → electrons have enough momentum to cross the Base into the Collector.
  - The small base current I_B controls a large current I_C

$$V_C > V_B > V_E$$

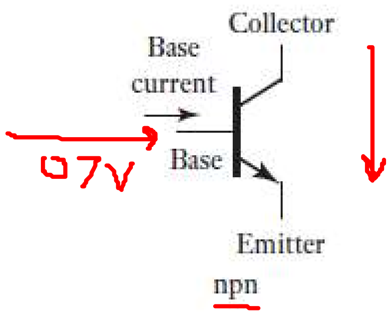
$$\begin{aligned} I_E &= I_C + I_B \\ V_{BE} &= V_B - V_E \\ V_{CE} &= V_C - V_E \\ I_C &= \beta I_B \end{aligned}$$

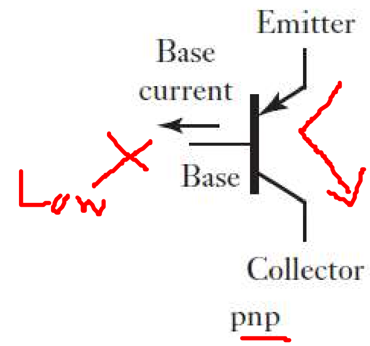




NPN Vs PNP

The main difference between the NPN and PNP transistor is, an NPN transistor turns on when the current flows through the base of the transistor. In this type of transistor, the current flows from the collector (C) to the emitter (E).





A PNP transistor turns ON, when there is no current at the base of the transistor. In this transistor, the current flows from the emitter (E) to the collector (C).

PNP transistor turns ON by a low signal (ground), where NPN transistor turns ON by a high signal (current).

Transistor as a switch

NPN

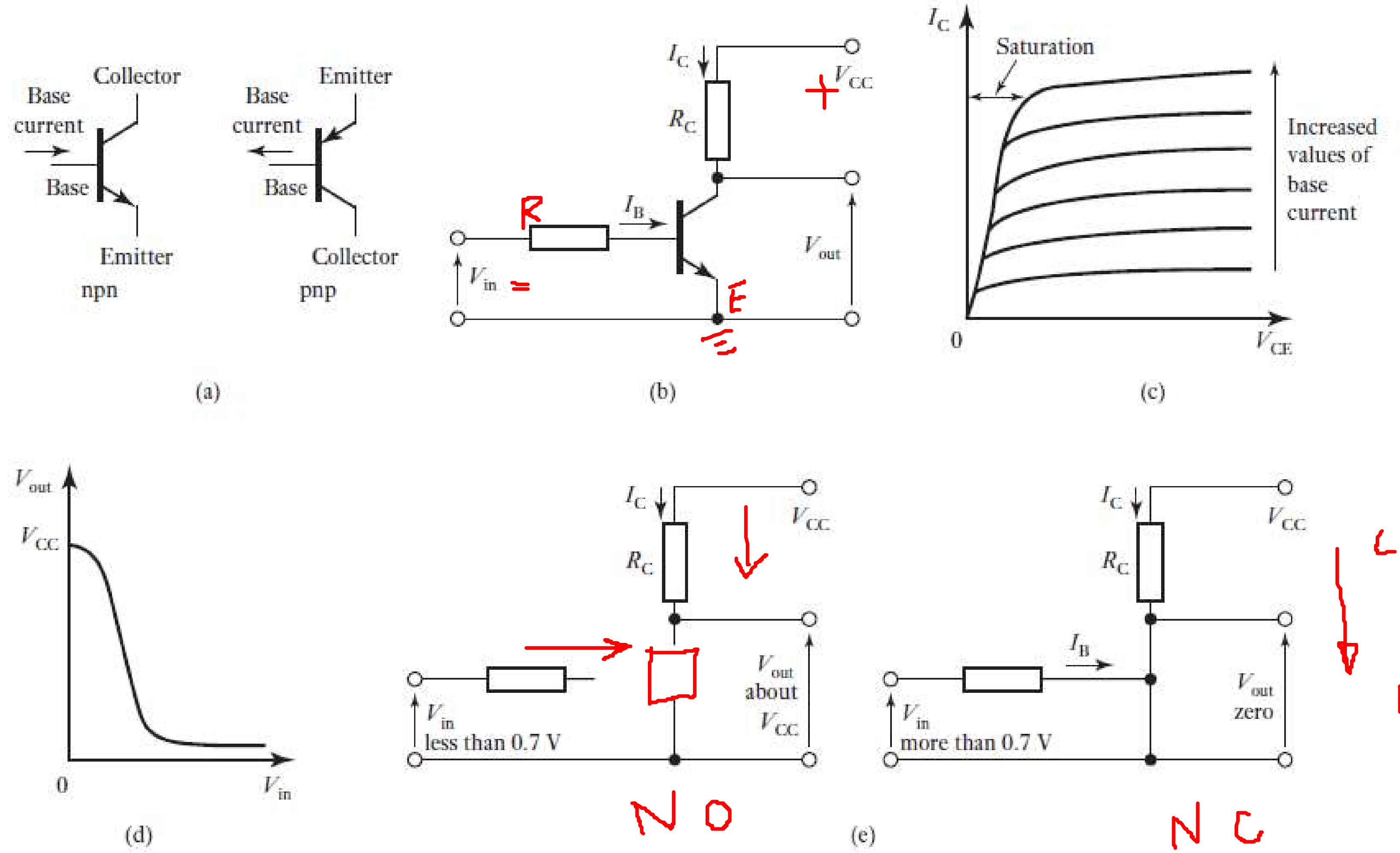
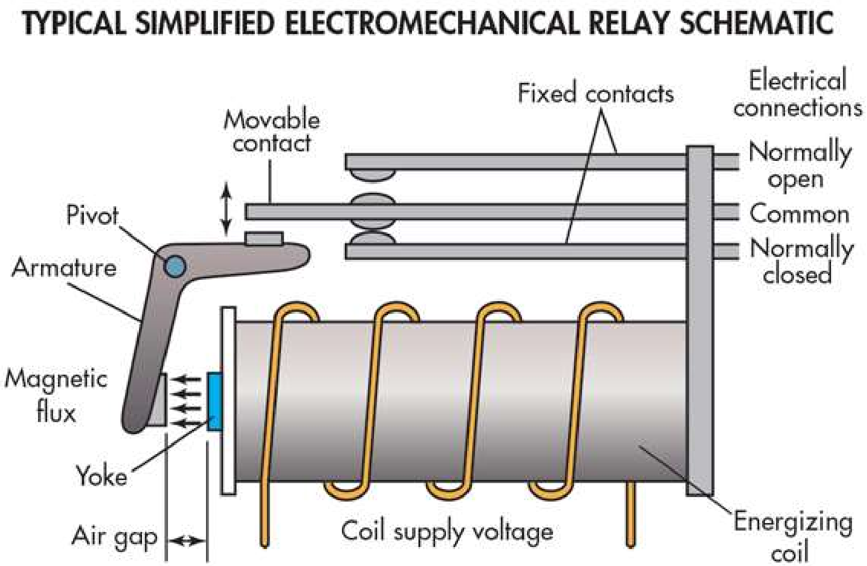
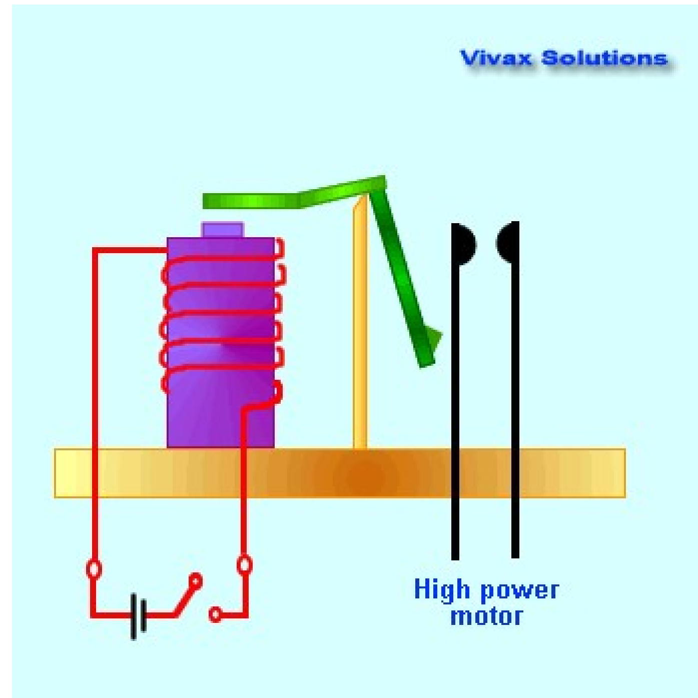


Figure 9.9 (a) Transistor symbols, (b), (c), (d), (e) transistor switch.

Relays



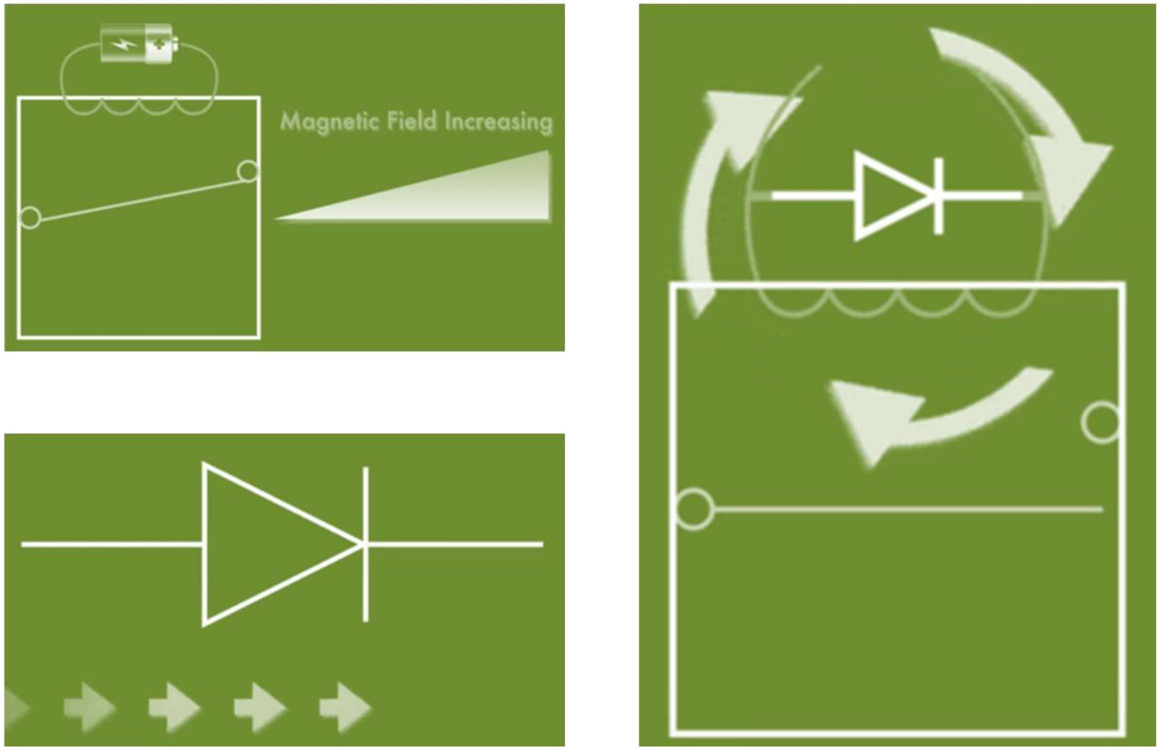


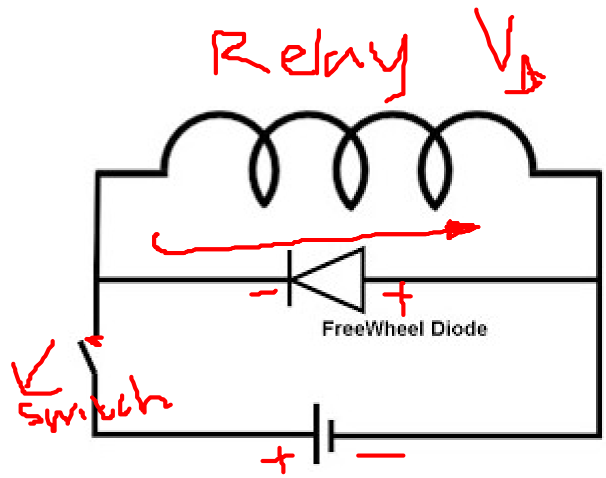
Inductance

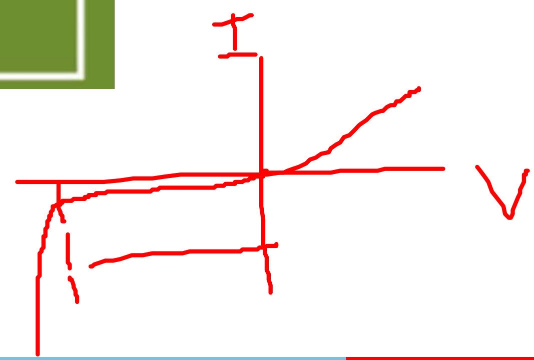
Free-wheeling or fly back diode

- Relays are inductances, they can generate a back voltage when the energising current is switched off or when their input switches from a high to low signal.
- Damage can occur in the connecting circuit.
- To overcome this problem, a diode is connected across the relay.
- When the back e.m.f. occurs, the diode conducts and shorts it out
- Such a diode is termed a free-wheeling or fly back diode.

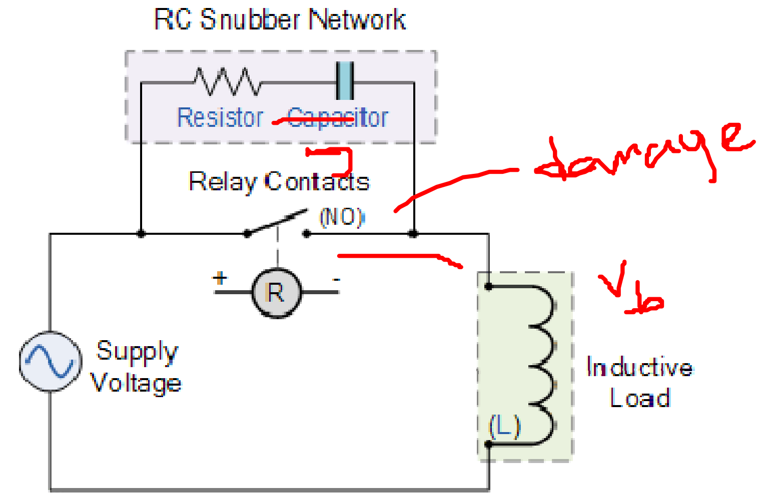
Free-wheeling or fly back diode







Contactors RC Snubber Network



Extending the life of relay tips by reducing the ~~amount of arcing~~ generated as they open is achieved by connecting a Resistor-Capacitor network called an **RC Snubber Network** electrically in parallel with an electrical relay contact tips.

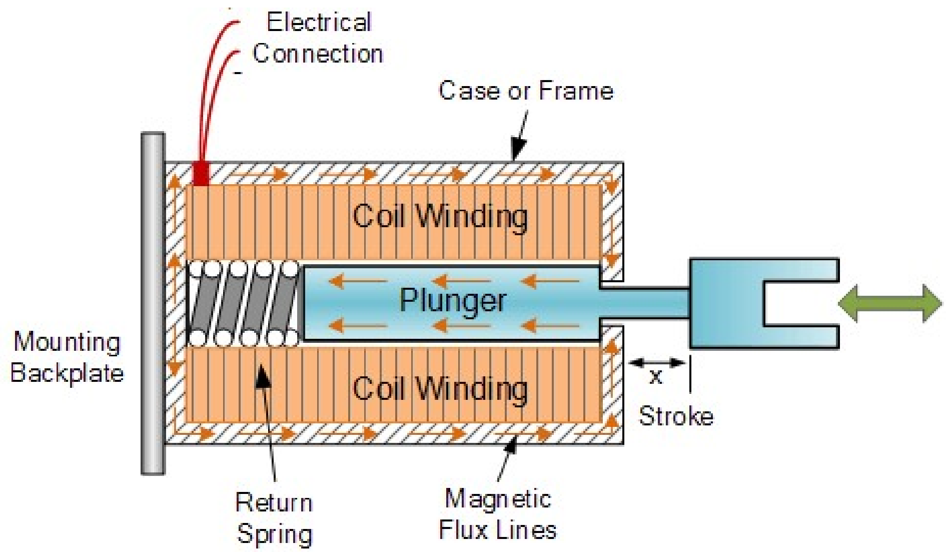
The voltage peak, which occurs at the instant the contacts open, will be safely short circuited by the RC network, thus suppressing any arc generated at the contact tips.

Solenoids

Energised

Disenerged

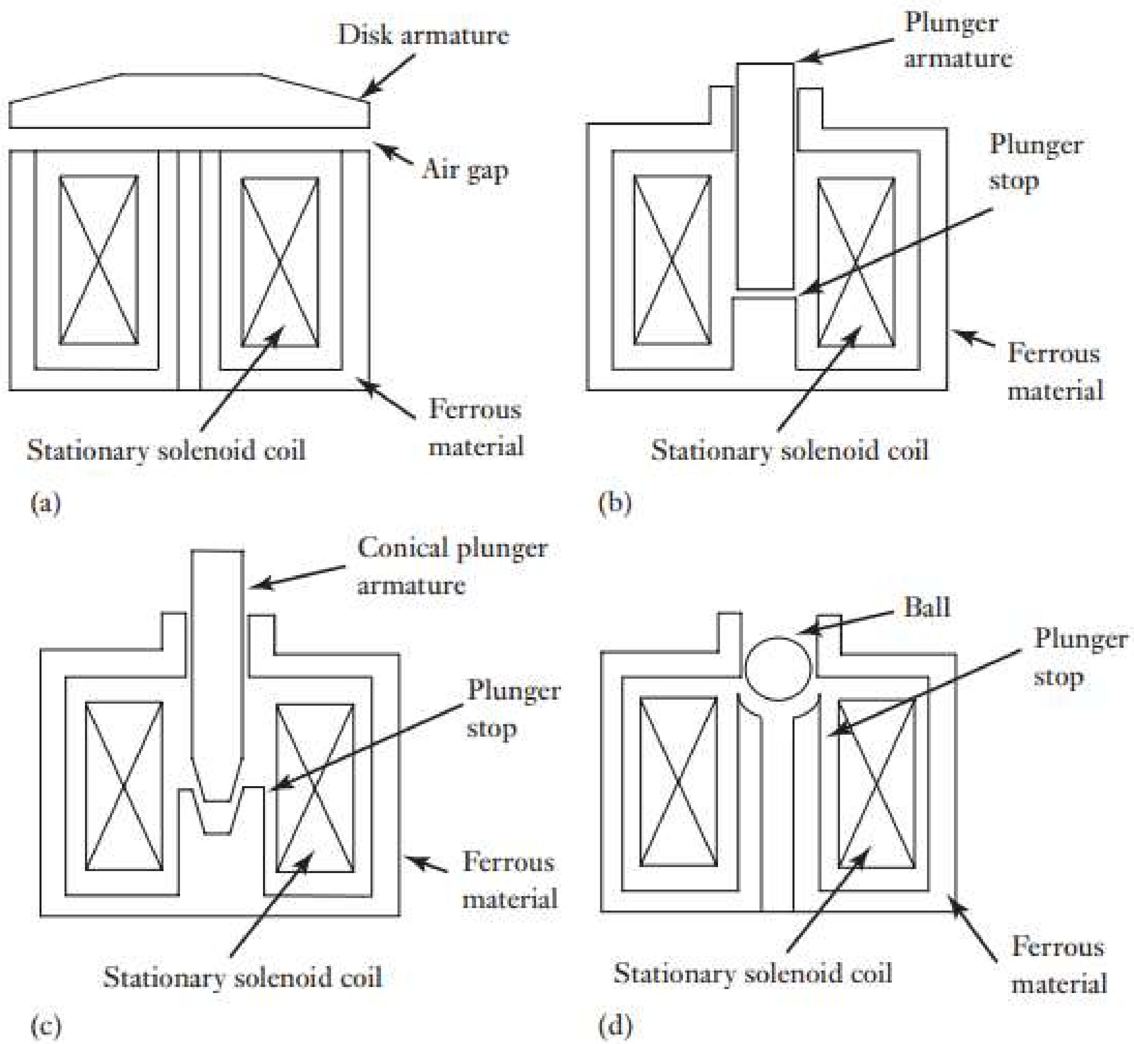
- Solenoids consist of a coil of electrical wire with an armature which is attracted to the coil when a current passes through it and produces a magnetic field.
- The movement of the armature contracts a return spring which then allows the armature to return to its original position when the current ceases.



Solenoids

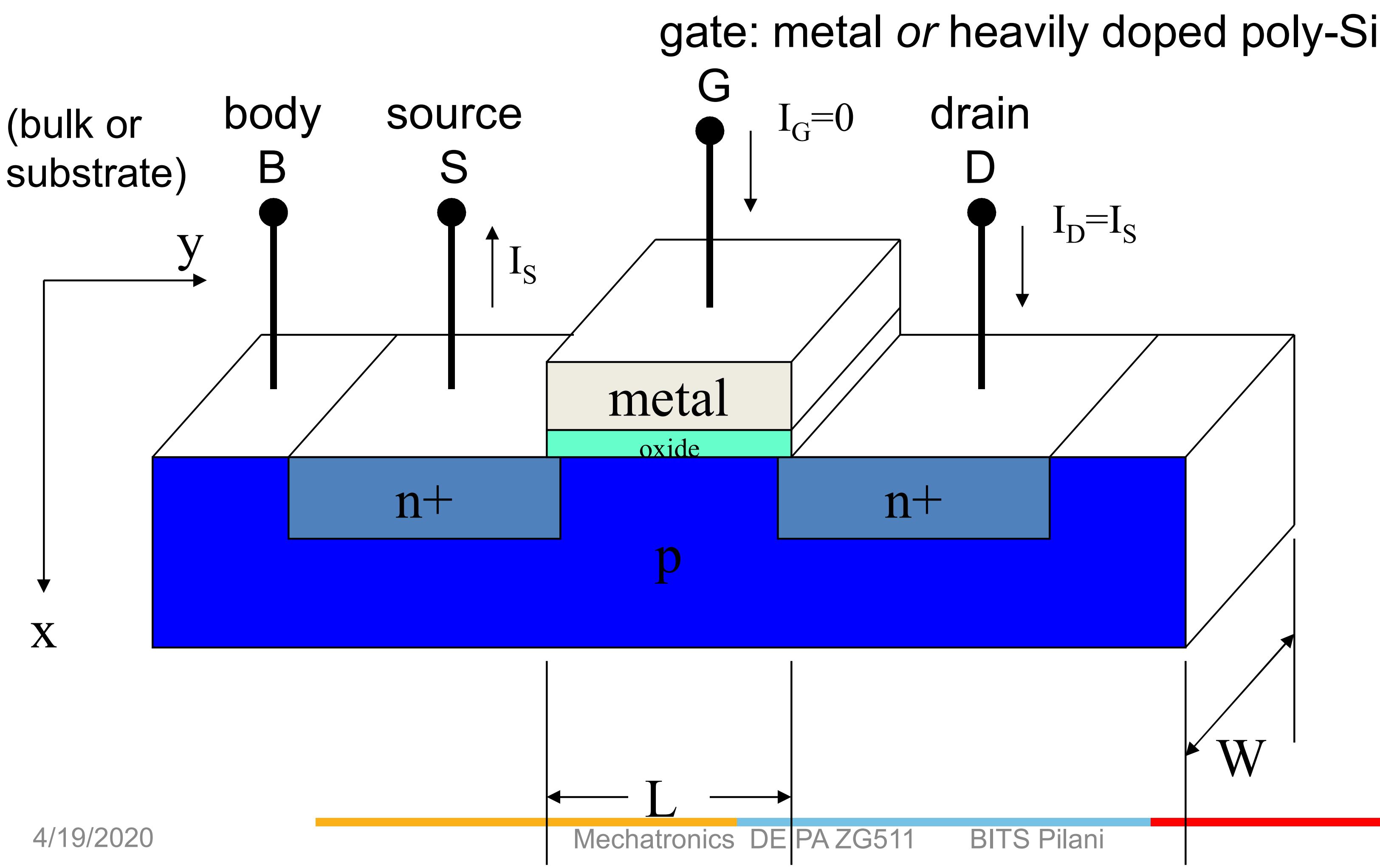
- Types of Solenoids
  - Based on power supply
    - A.C. or D.C.
  - Based on types of Actuation
    - Disk, Plunger, conical, ball type
  - Based on Actuation motion
    - linear or rotary,
    - on/off or
    - variable positioning

Solenoids


Disk armature
Air gap
Ferrous material
Stationary solenoid coil
(a)
Plunger armature
Plunger stop
Ferrous material
Stationary solenoid coil
(b)
Conical plunger armature
Plunger stop
Ferrous material
Stationary solenoid coil
(c)
Ball
Plunger stop
Stationary solenoid coil
Ferrous material
(d)

Structure: *n-channel* MOSFET (NMOS) (Metal-Oxide-Semiconductor Field Effect Transistors)

The gate voltage is the controlling signal unlike gate current in transistor.

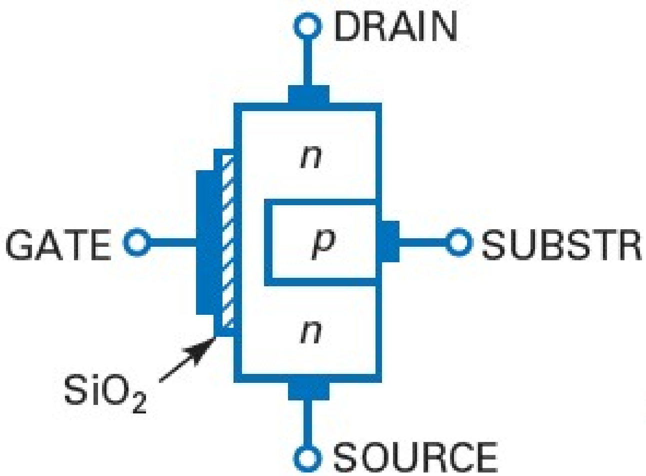


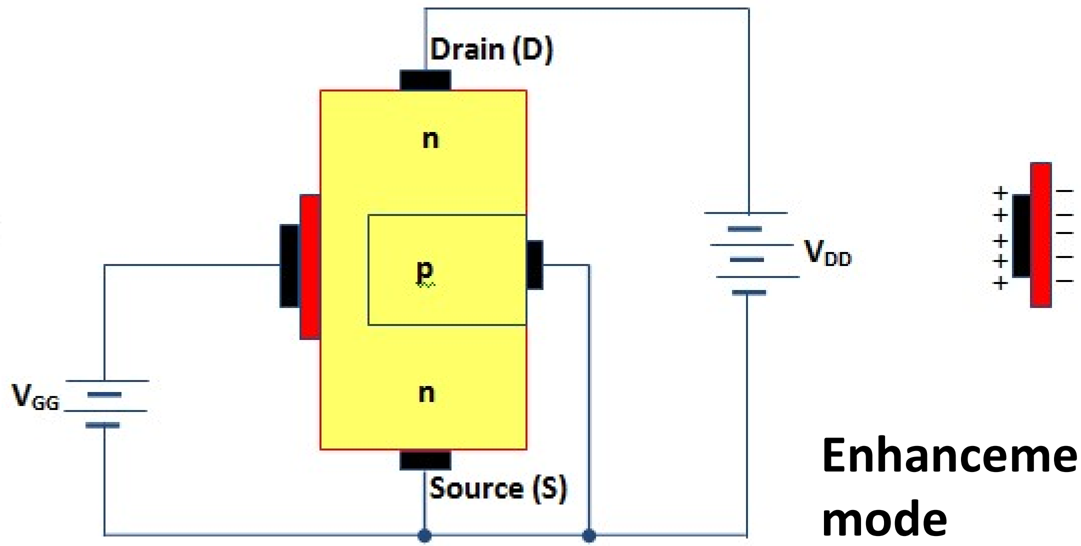
MOSFETs

- Enhancement mode
- Also known as Normally Off transistors.
  - A voltage must be applied to the gate of the transistor, at least equal to the threshold voltage, to create a conduction path between the source and the drain of the transistor before current can flow between the source and drain.

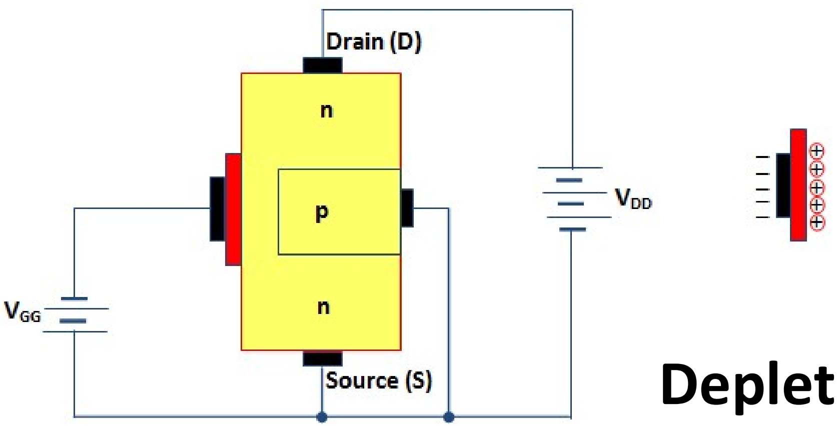
- Depletion mode
- Also known as Normally On transistors.
  - A voltage must be applied to the gate of the transistor, at least equal to the threshold voltage, to destroy a conduction path between the source and the drain of the transistor to prevent current from flowing between the source and drain.

MOSFET (Metal-Oxide-Semiconductor Field Effect Transistors)





Enhancement mode



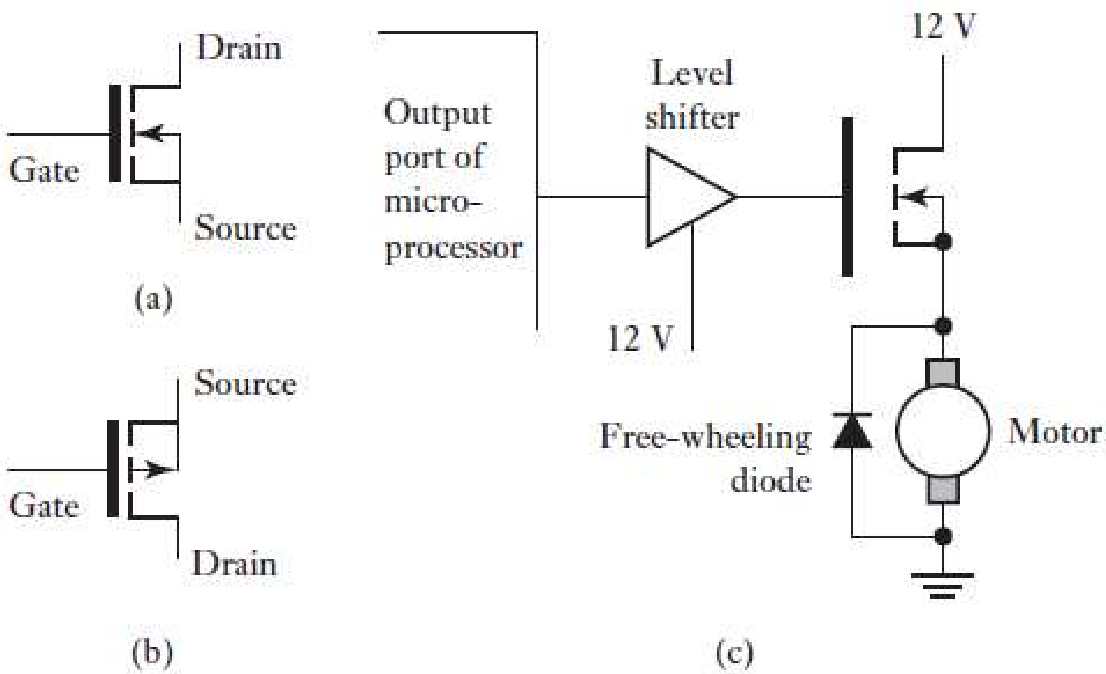
INPUT IMPEDANCE- VERY HIGH

SIZE – VERY SMALL

LESS NOISY THAN BJT

Depletion mode

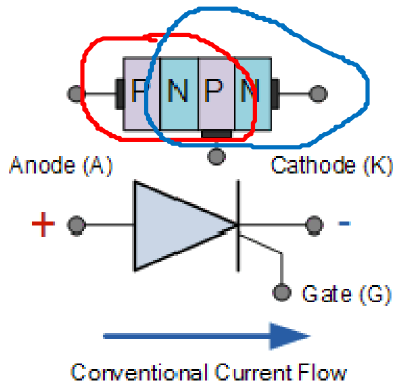
MOSFETs

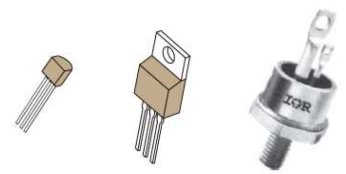


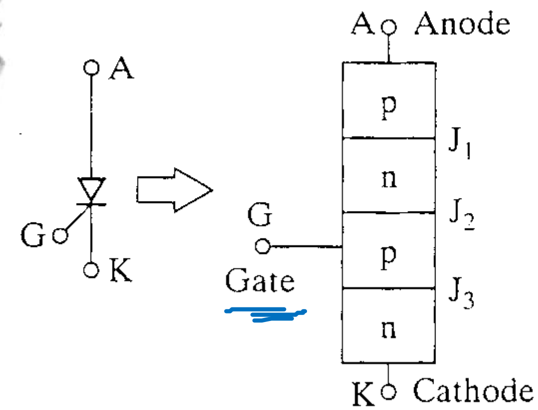
(a) n-channel, (b) p-channel,
(c) used to control a d.c. motor.

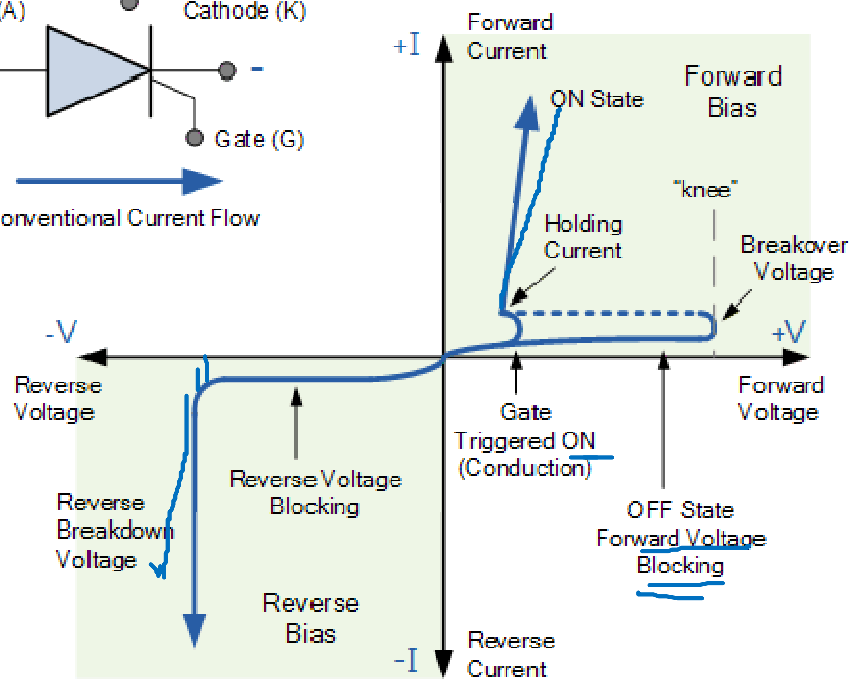
Level shifter bridges domain between low-power application processors running at 1.8 V and other system functions like sensors or other analog intensive applications running at 3.3 or 5V.

Thyristor (silicon-controlled rectifier)









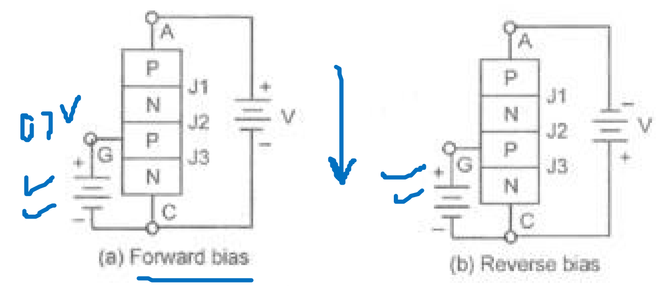


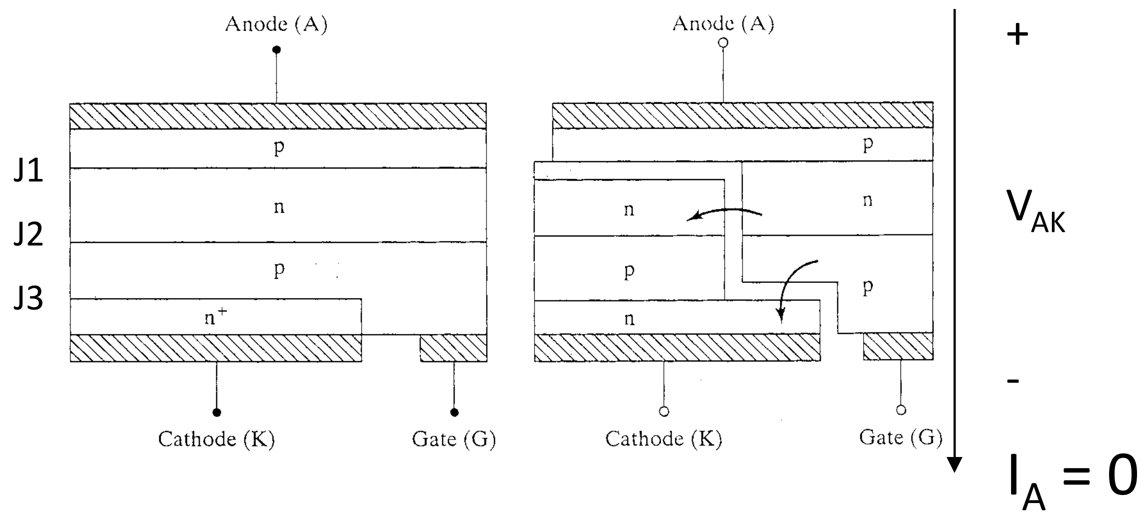
Figure 2 Biasing for SCR

A Thyristor is basically an on-off switch to control the output power of an electrical circuit by switching on and off the load circuit in intervals of time.

Applications of thyristor

- Mainly used in variable speed motor drives AC motors, lights, welding machines.
- Used in electric fan speed control.
- Used in car ignition switches

Cross-section of the pnpn structure



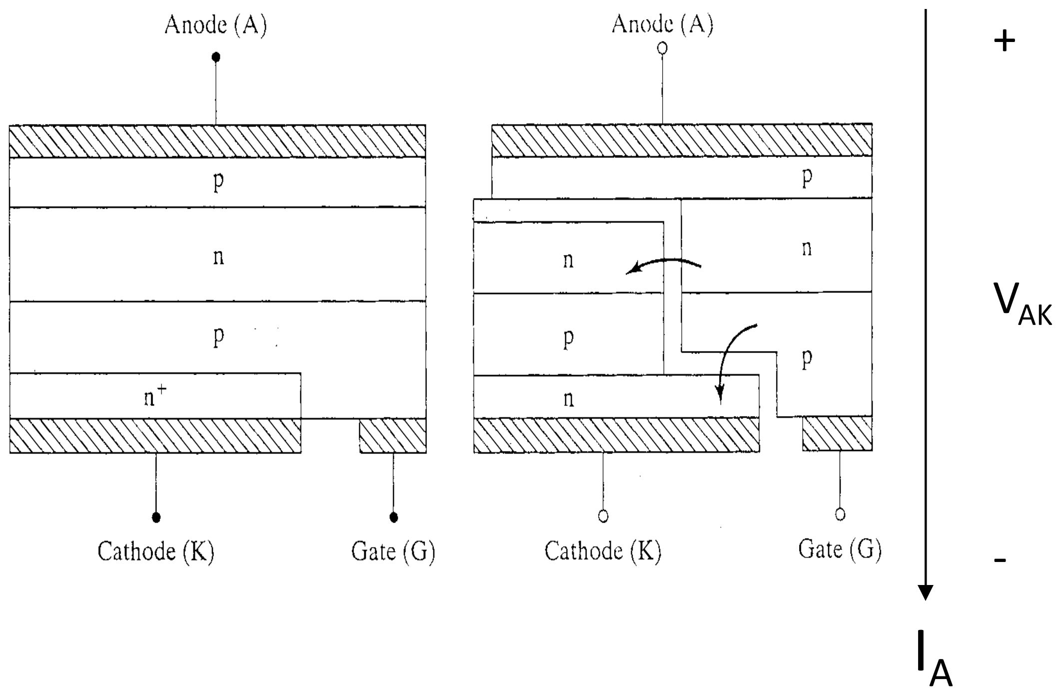
Apply a forward bias voltage to the Anode-Cathode
Junctions J1 and J3 are forward biased

Junction J2 is reverse biased

Only a small amount of current flows from A to K

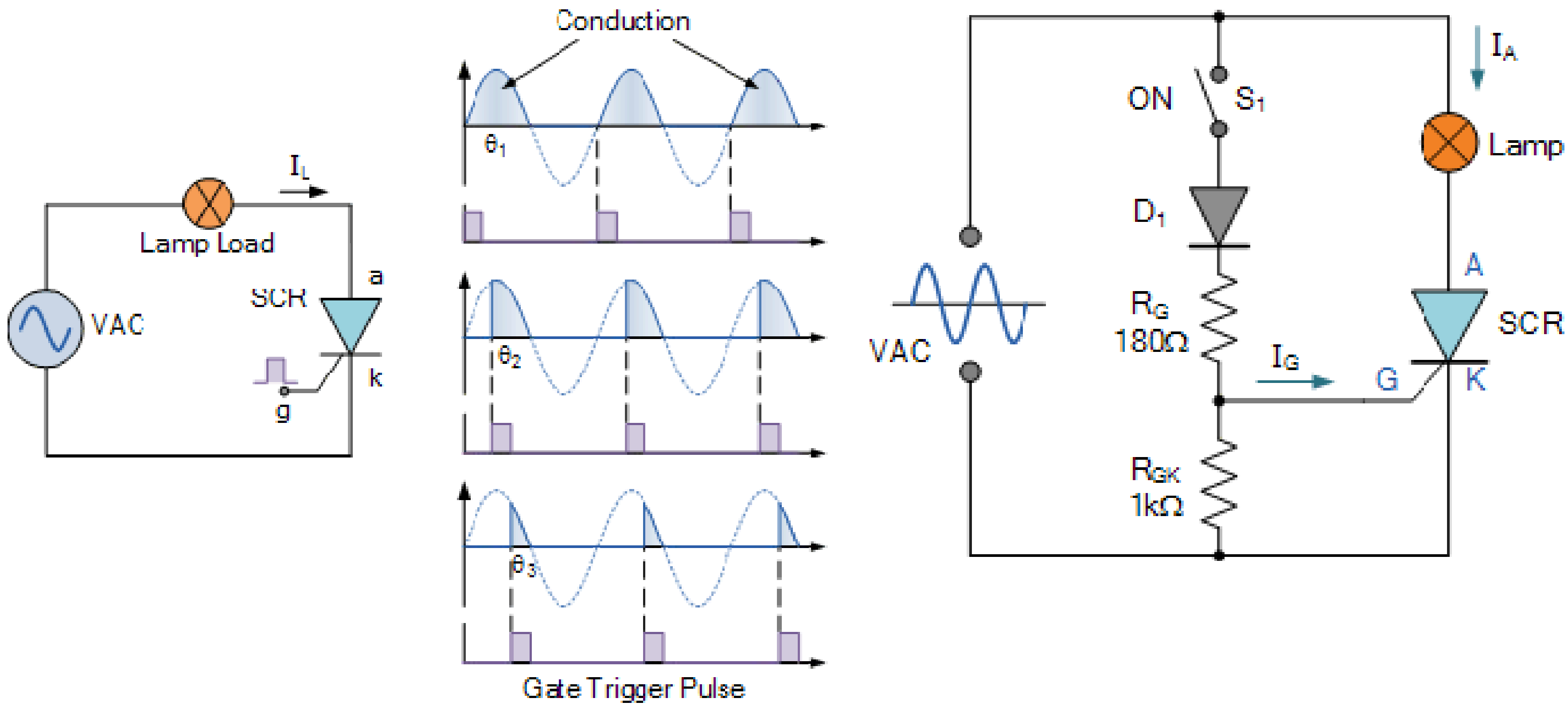
The device is in it’s OFF or “Forward Blocking” State

SCR/Thyristor (continued)



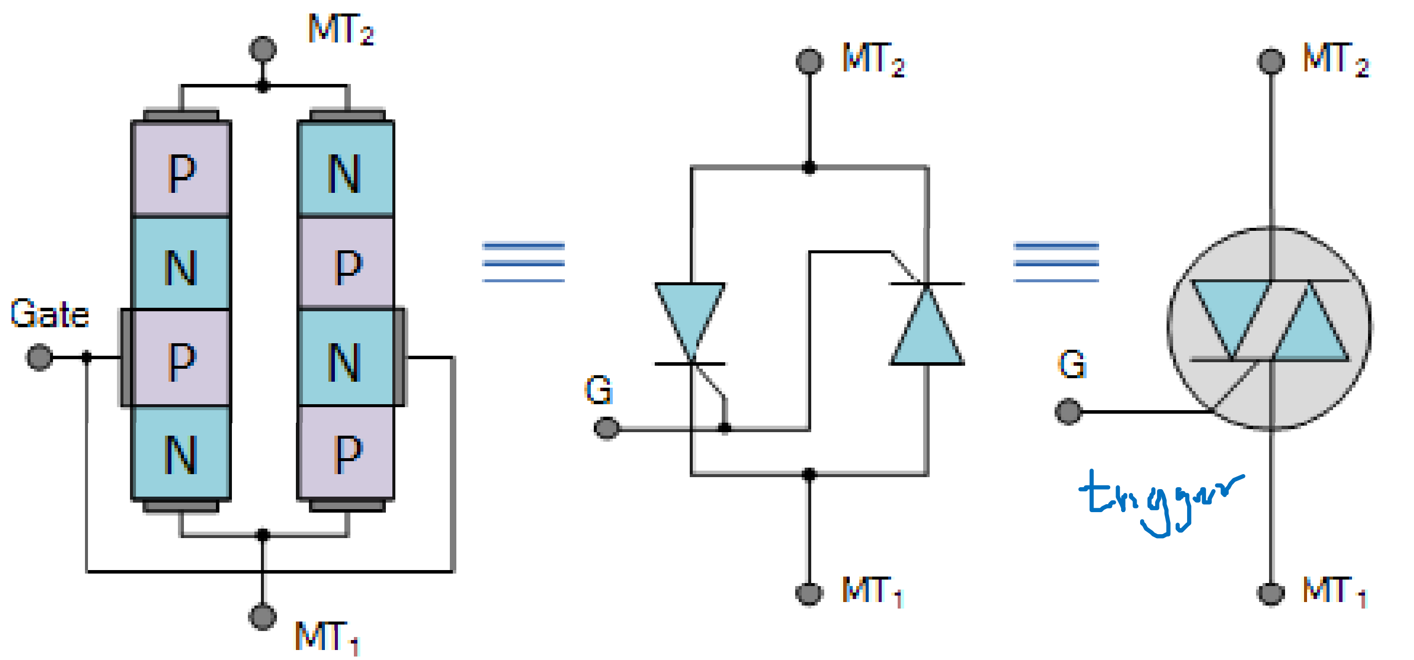
Increase the Anode-Cathode voltage until "breakdown" occurs. Anode current increases. "Conducting state"

Thyristor (SCRs)



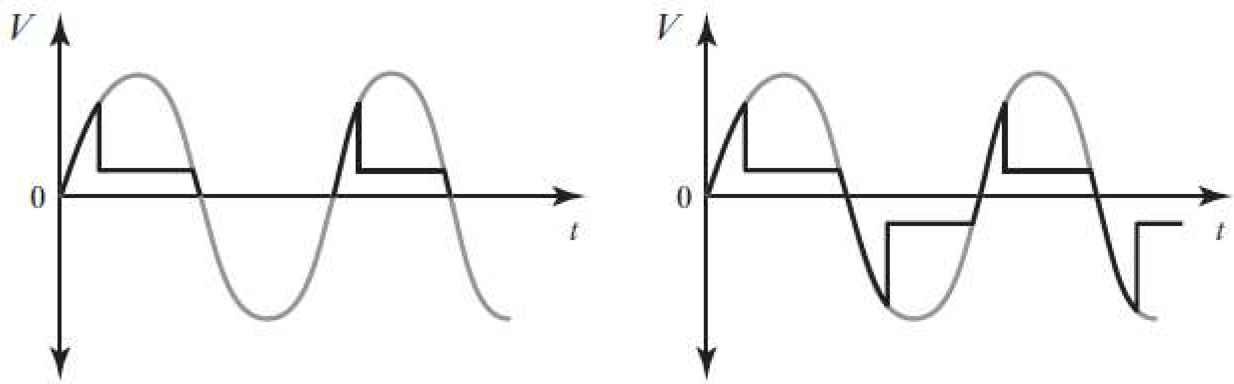
By accurately varying the timing relationship between the Gate pulse and the positive half-cycle, the **Thyristor** could be made to supply any percentage of power desired to the load, between 0% and 50%

Triacs



Physical Construction Two-Thyristor Analogy Circuit Symbol

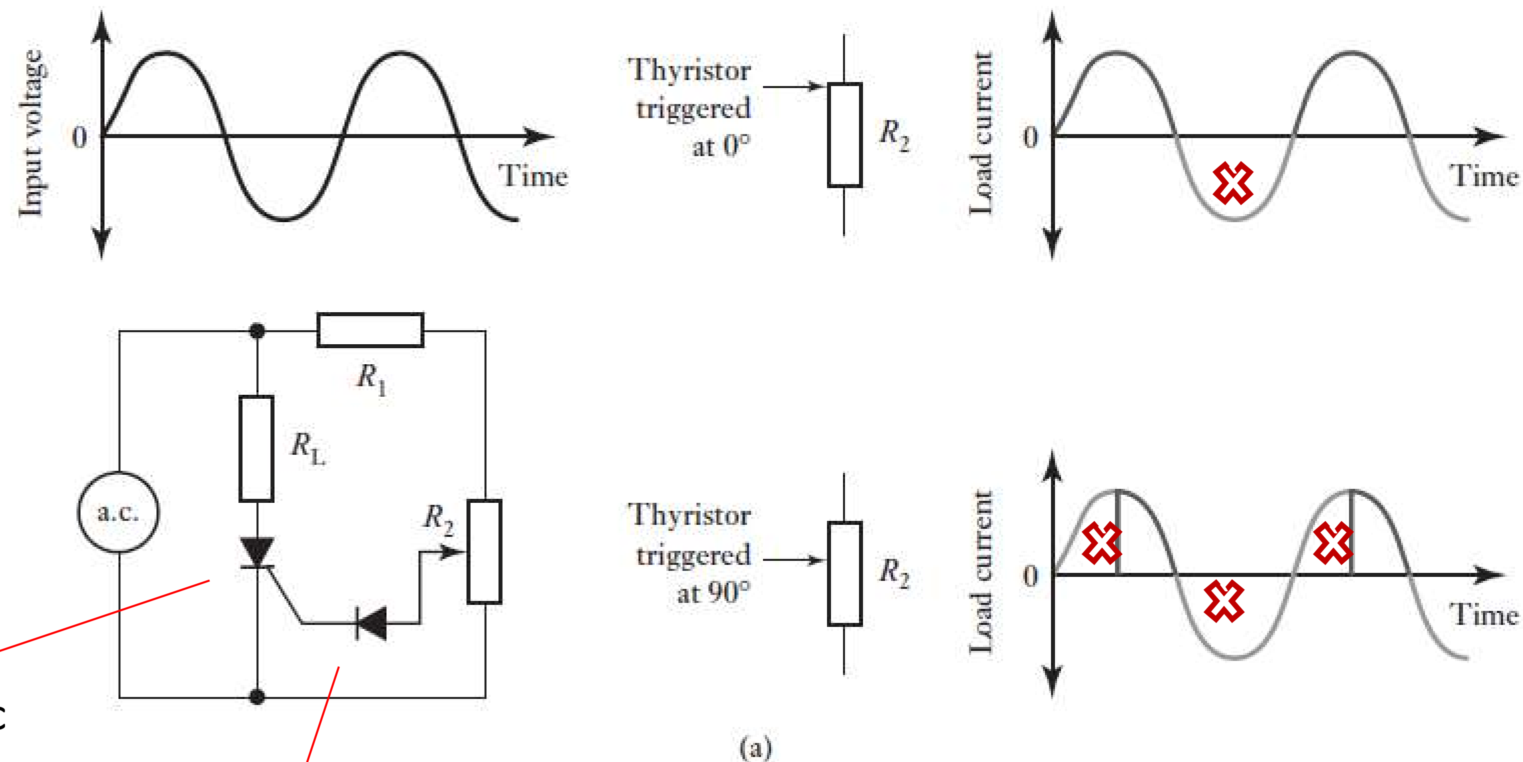
Voltage control



(a)   (b)

Thyristor   **Triac**

AC control



Triac

The diode is to prevent the negative part of the alternating voltage cycle being applied to the gate

Motor types

Stator

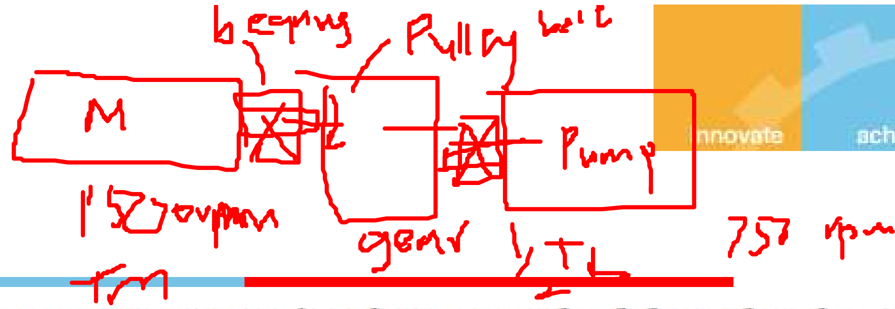
Field V_f

Armature V_a

- DC Motors
  - Permanent Magnet
  - Series Wound
  - Shunt Wound
  - Compound Wound
- AC Motors
  - Single-Phase (LP)
    - Induction
      - Squirrel Cage
        - Split-Phase
        - Capacitor-Start
        - Permanent Split Capacitor
        - Capacitor Start/Run
        - Shaded Pole
      - Wound Rotor
        - Repulsion
        - Repulsion Start
        - Repulsion Induction
    - Synchronous
      - Shaded Pole
      - Hysteresis
      - Reluctance
      - Permanent Magnet
  - Polyphase (HP)
    - Induction
      - Wound Rotor
      - Squirrel Cage
    - Synchronous
  - Universal Motors

Single-phase motors tend to be used for low-power requirements while polyphase motors are used for higher powers.

Motor selection



The torque T_m required from a motor is that needed by the load T_L, or T_L/n for a geared load with gear ratio n, and that needed to accelerate the motor $I_m\alpha_m$, where I_m is the moment of inertia of the motor and α_m its angular acceleration:

$$T_m = \frac{T_L}{n} + I_m\alpha_m$$

$T_M - (\text{inertia}_{I_m \alpha_m} + \text{losses}_{T_f}) = T_L$

The angular acceleration of the load α_L is given by

$$\alpha_m = n\alpha_L$$

speed ratio

Because there will be torque T_f required to overcome the load friction, the torque used to accelerate the load will be $(T_L - T_f)$ and so

$$T_L - T_f = I_L\alpha_L$$

Thus we can write

$T_M + T_{iL}$

$$\boxed{T_m = \frac{1}{n}[T_f + \alpha_L(I_L + n^2 I_m)]}$$

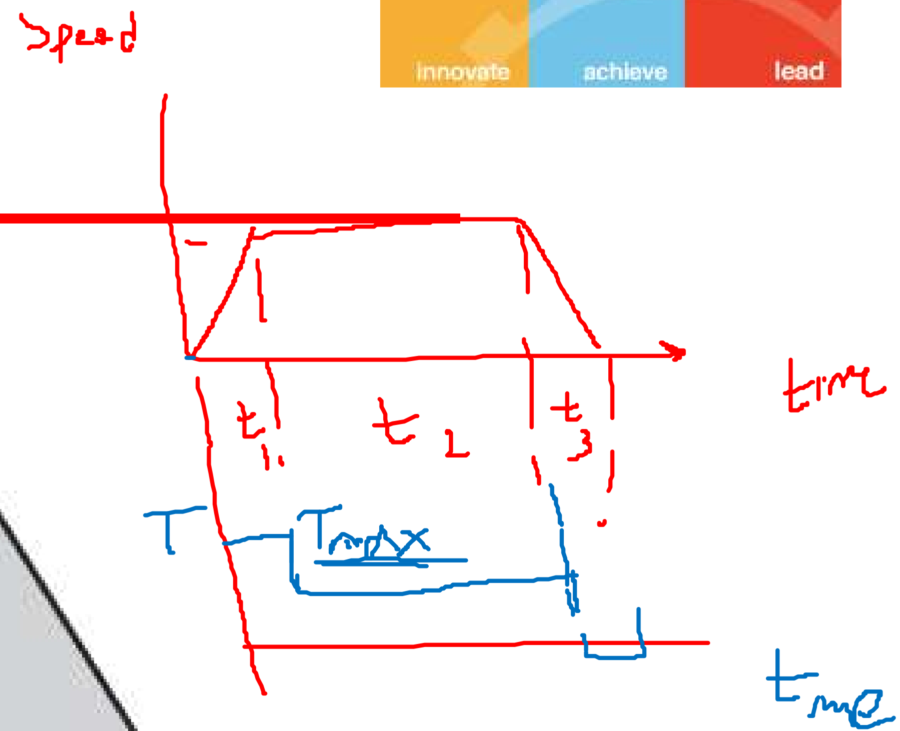
And Power is $P = T_f\omega + I_L\alpha\omega$

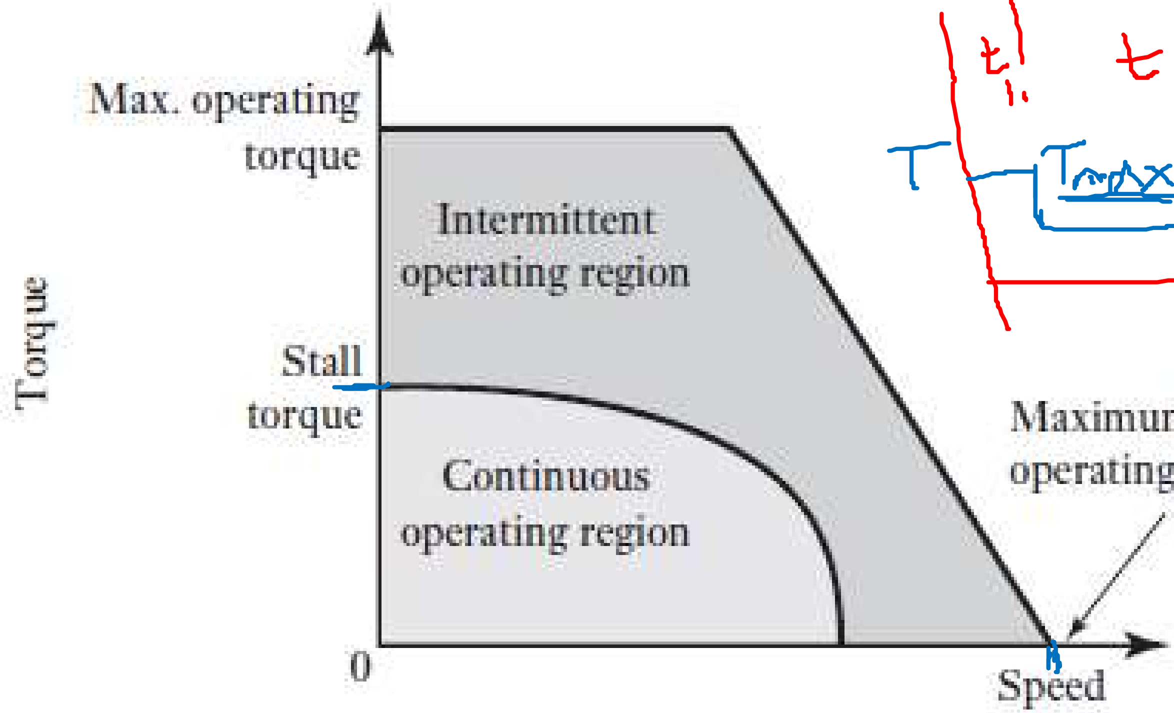
Motor selection

The motor needs to be able to run at the maximum required velocity without overheating. The total power P required is the sum of the power required to overcome friction and that needed to accelerate the load. As power is the product of torque and angular speed, then the power required to overcome the frictional torque T_f is $T_f\omega$ and that required to accelerate the load with angular acceleration α is $(I_L\alpha)\omega$, where I_L is the moment of inertia of the load. Thus:

$$P = T_f\omega + I_L\alpha\omega$$

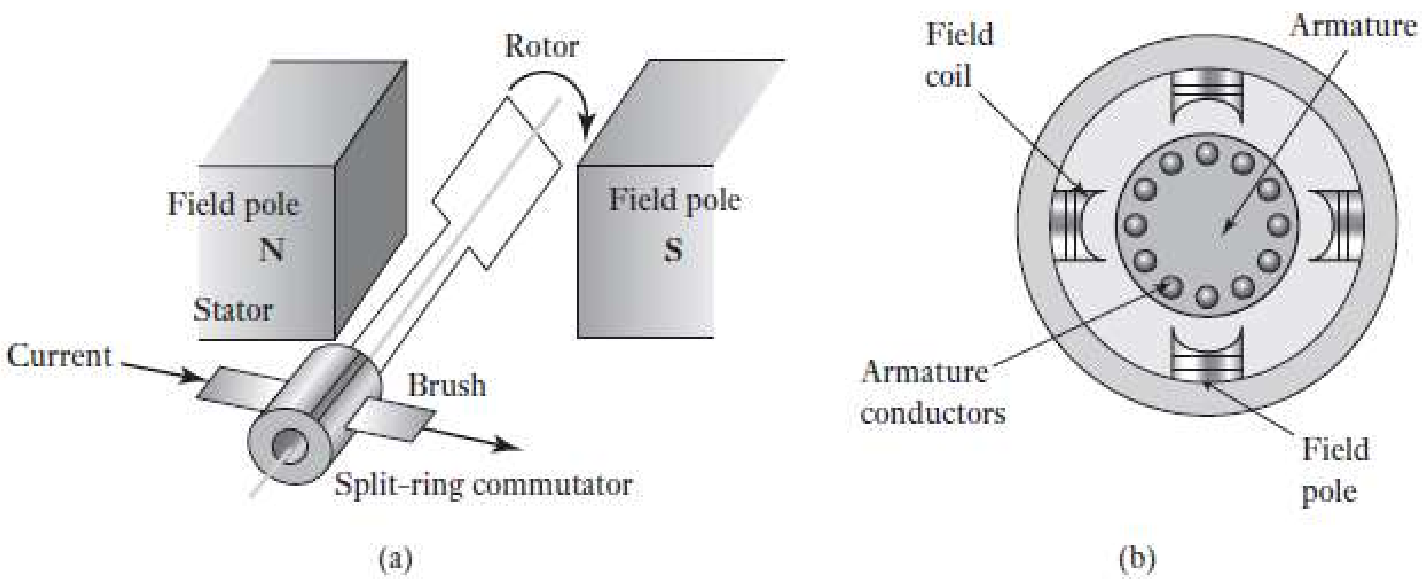
Motor selection





Stall torque is the **torque** produced by a mechanical device whose output rotational speed is zero

DC motors (Brush type)

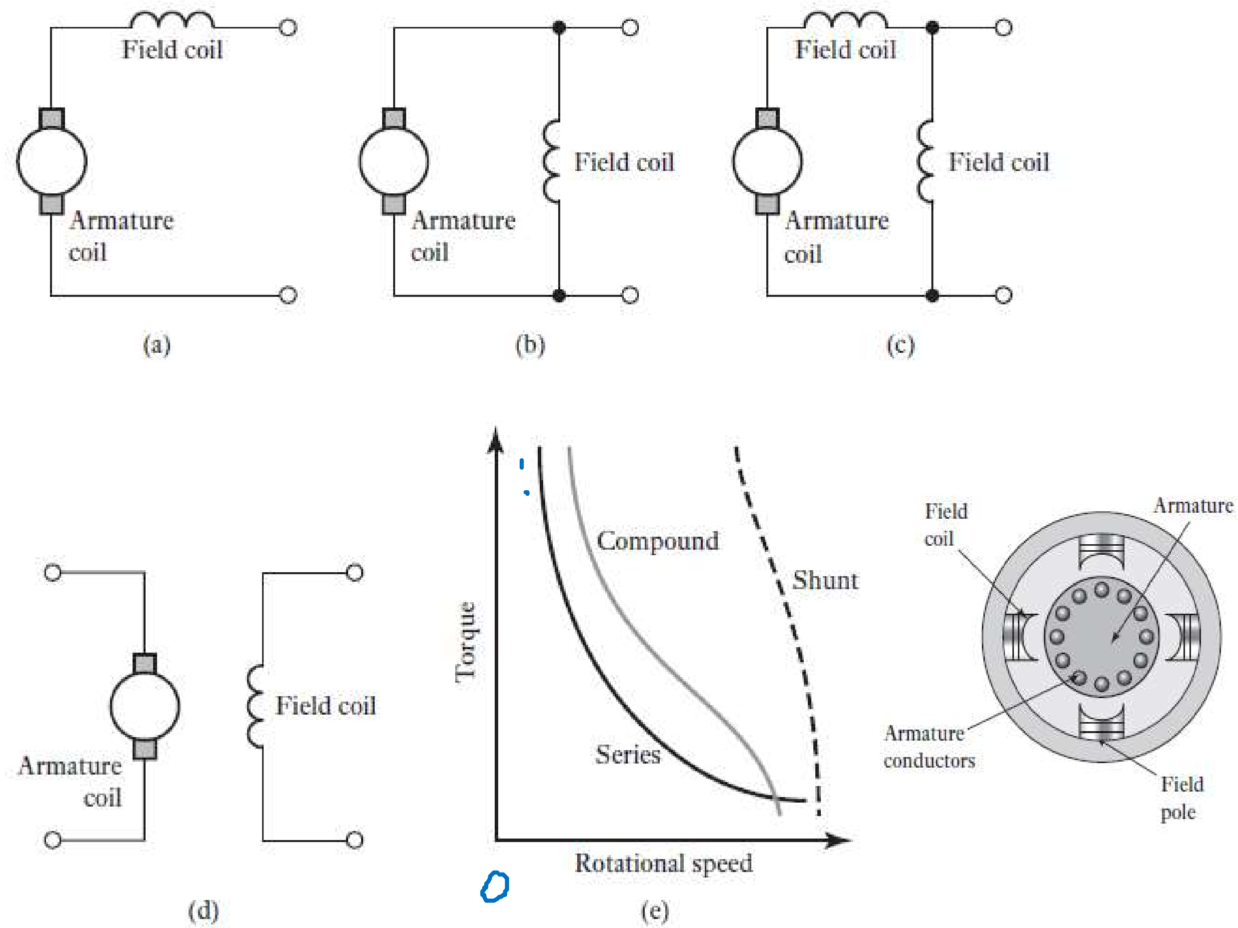


Stator is magnet – Stationary magnetic field

Rotor has coil winding.

Types

Figure 9.17 Direct current motors: (a) series, (b) shunt, (c) compound, (d) separately wound, (e) torque–speed characteristics.



Series motor: Provides high starting torque

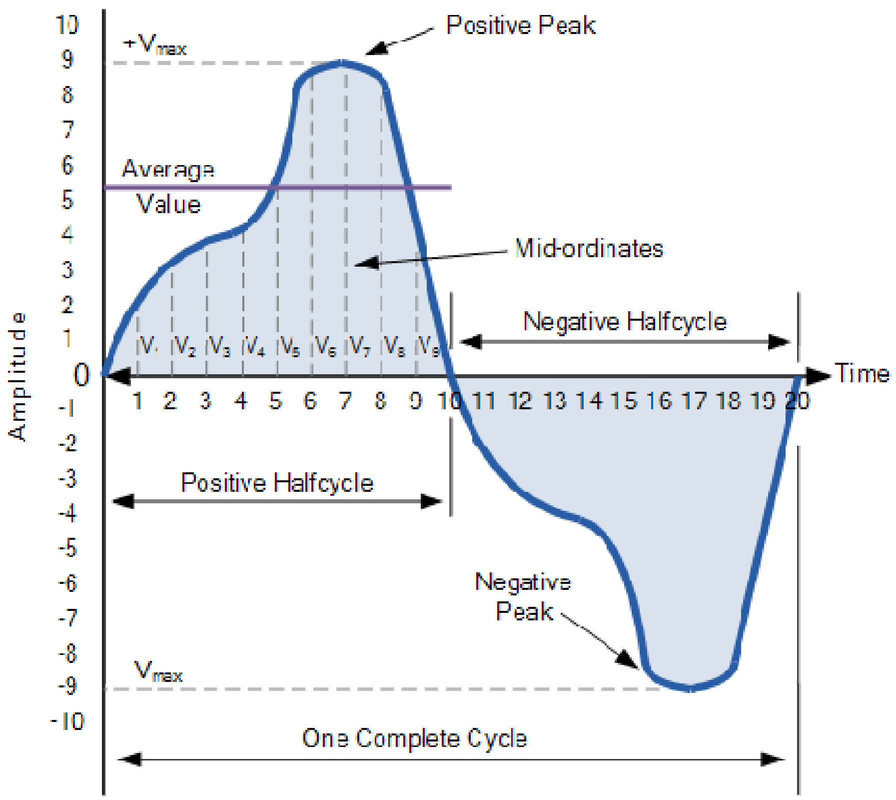
Shunt motor : Provides low starting torque- Constant torque-speed motor.

Speed Control of DC Motor

- The speed of a permanent magnet motor depends on the current through the armature coil.
- With a field coil motor the speed can be changed by varying either the armature current or the field current;
- generally it is the armature current that is varied.
- Thus speed control can be obtained by controlling the voltage applied to the armature.

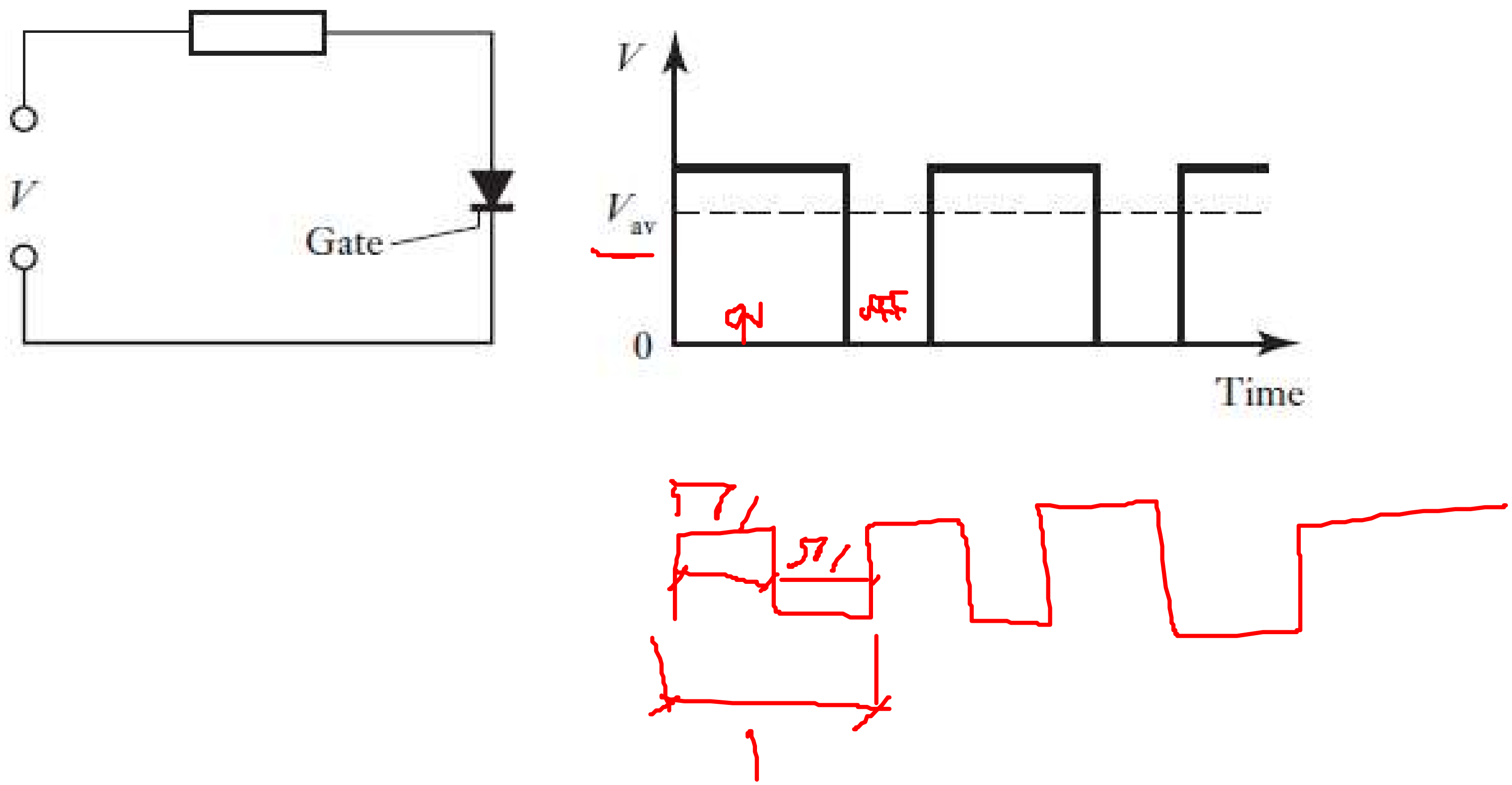
$S \propto V$

Voltage chopping

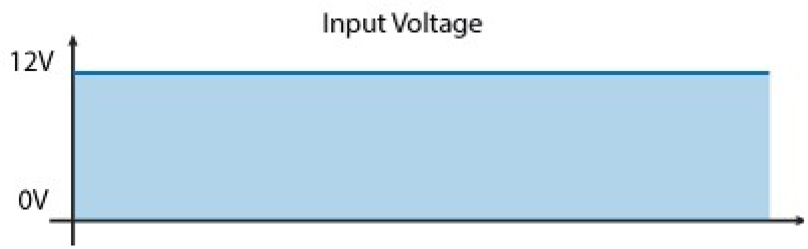


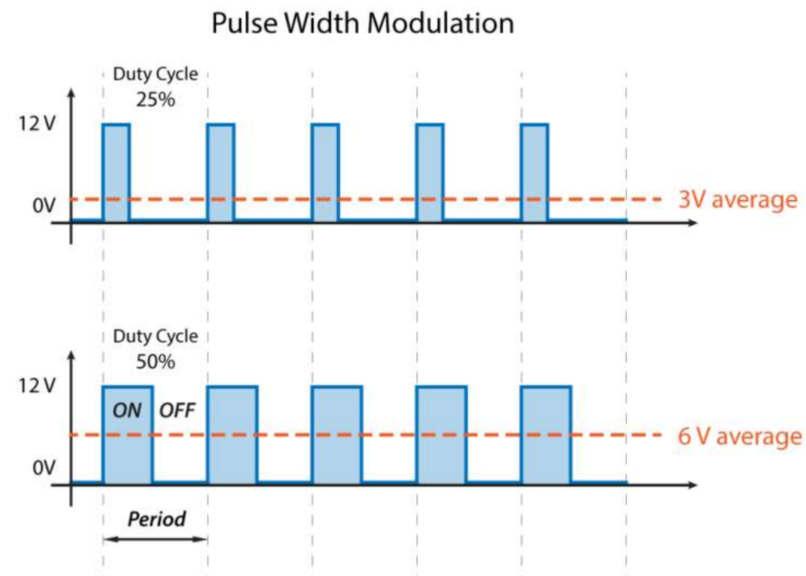
$$V_{average} = \frac{V_1 + V_2 + V_3 + V_4 + \ldots + V_n}{n}$$

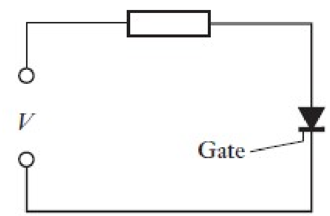
DC control

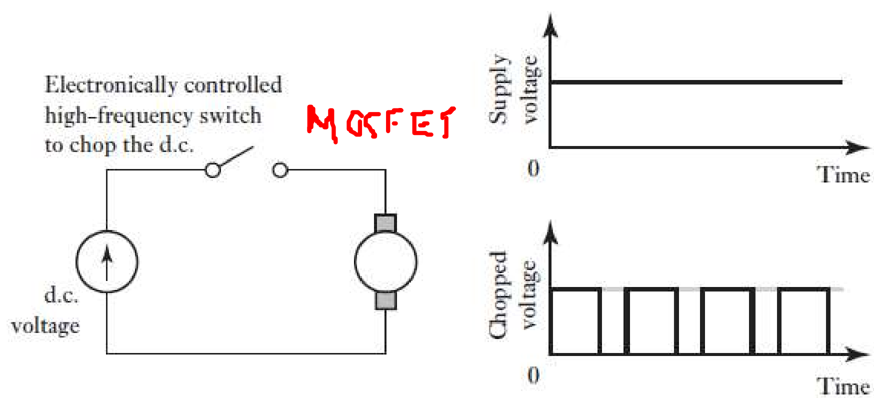


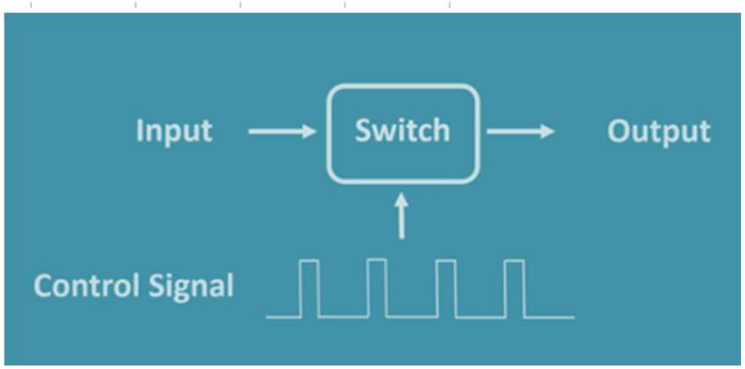
PWM modulation of DC motor







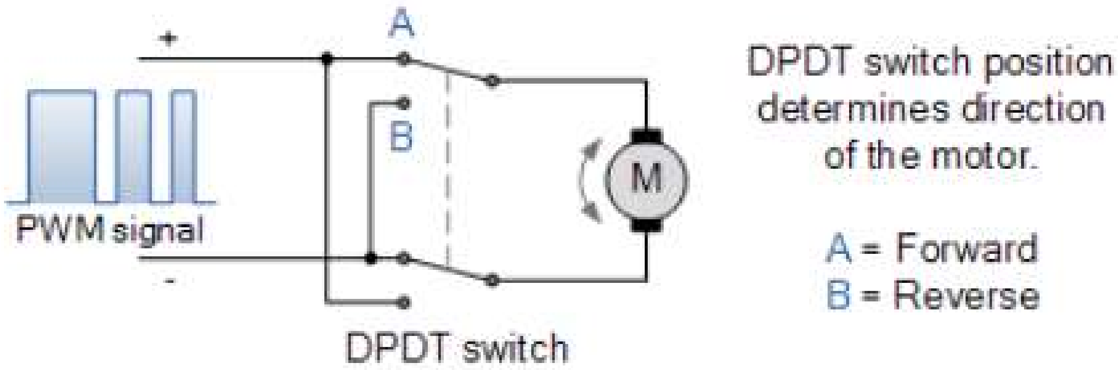


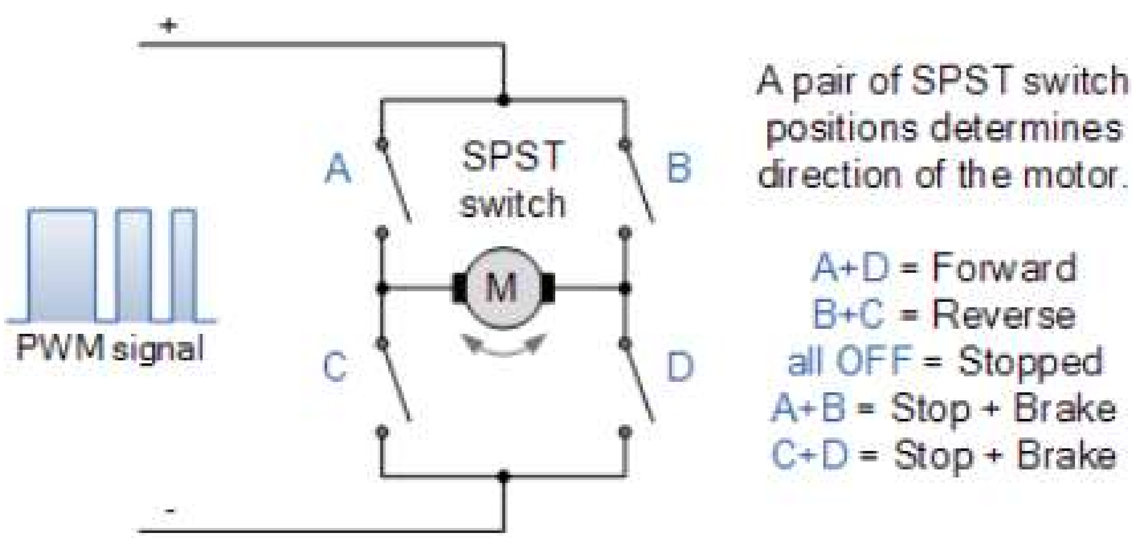


Pulse width modulation

- Pulse width modulation speed control works by driving the motor with a series of “ON-OFF” pulses and varying the duty cycle, the fraction of time that the output voltage is “ON” compared to when it is “OFF”, of the pulses while keeping the frequency constant.
- The power applied to the motor can be controlled by varying the width of these applied pulses and thereby varying the average DC voltage applied to the motors terminals

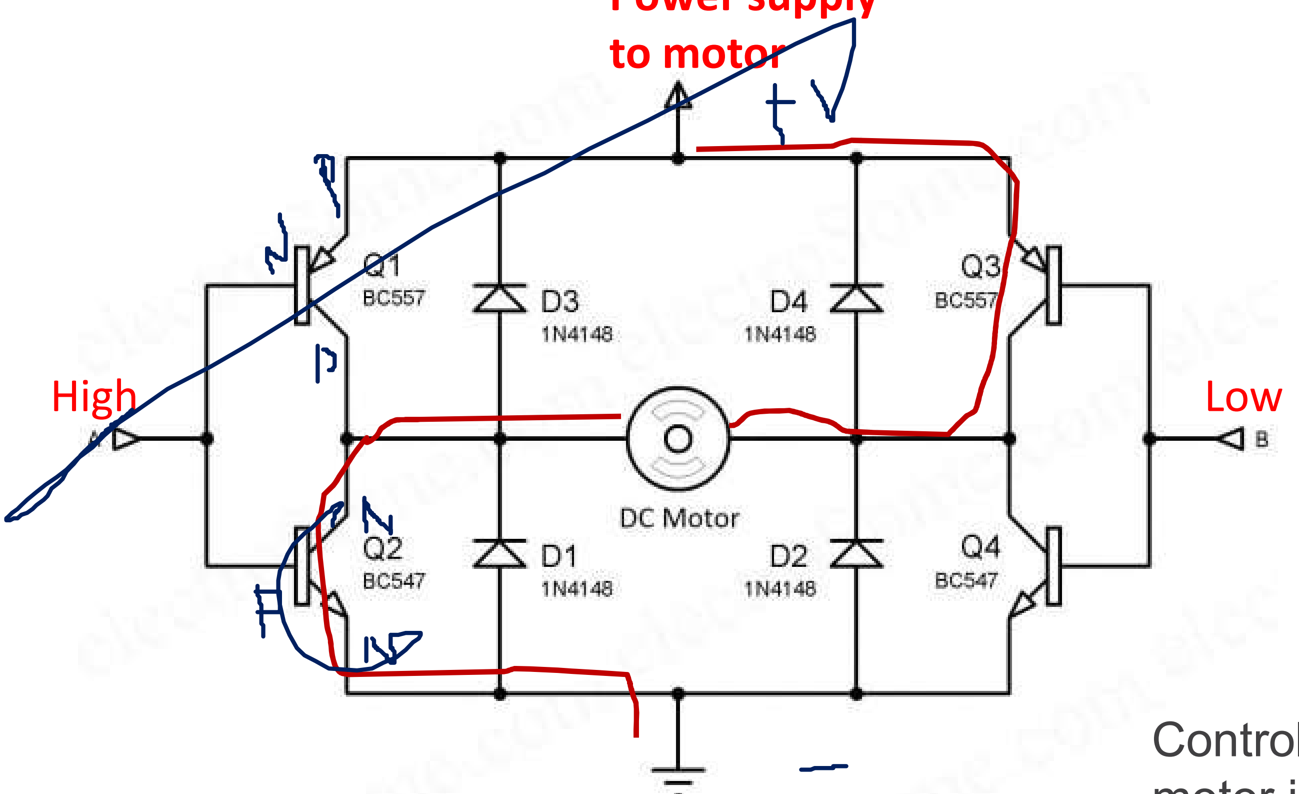
DC motor direction control





Double-pole, double-throw (DPDT) single-pole, single-throw (SPST)

Transistorized DC motor control



If A is high, B is low, then Q2 and Q3 are ON

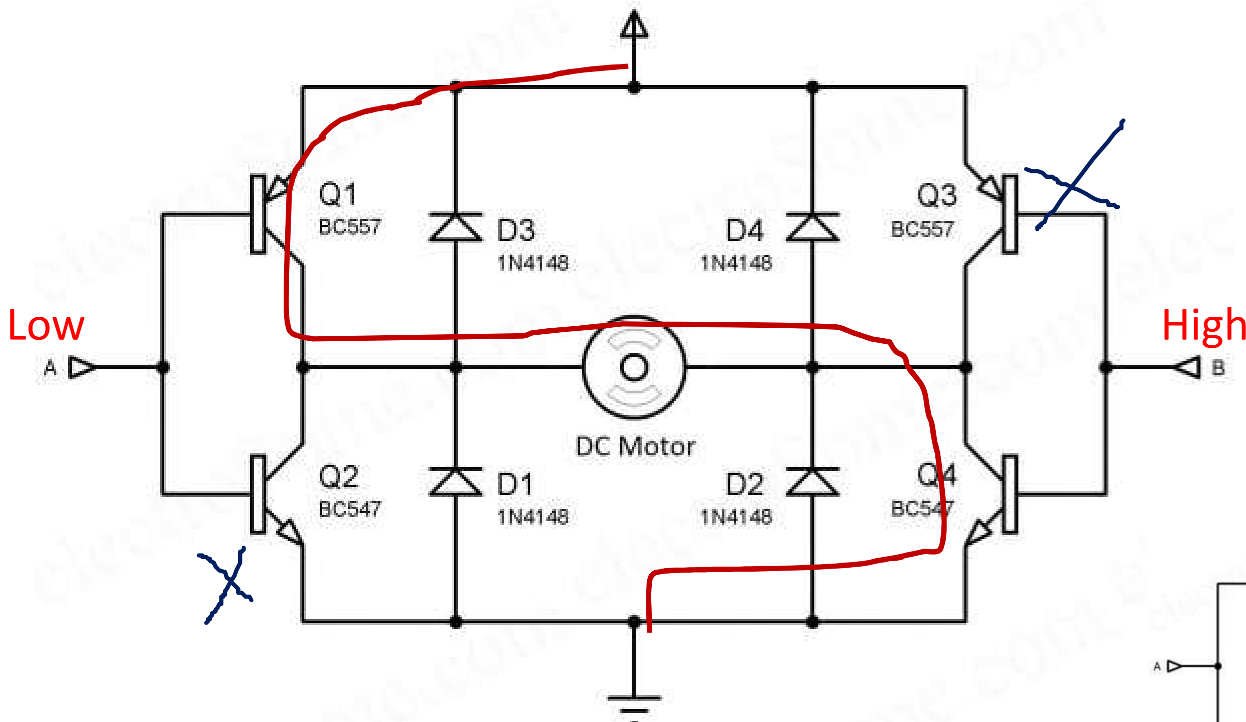
Q1 and Q3 are PNP

Q2 and Q4 are NPN

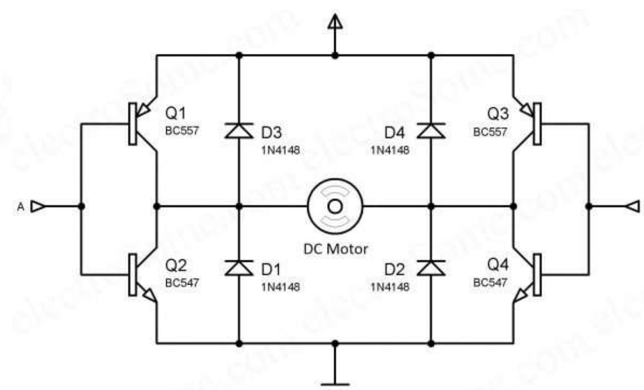
Say motor rotates anti clockwise

Control input A operates the motor in one direction ie, Forward rotation while input B operates the motor in the other direction ie, Reverse rotation.

Transistorized DC motor control



If A is Low, B is High, then Q1 and Q4 are ON

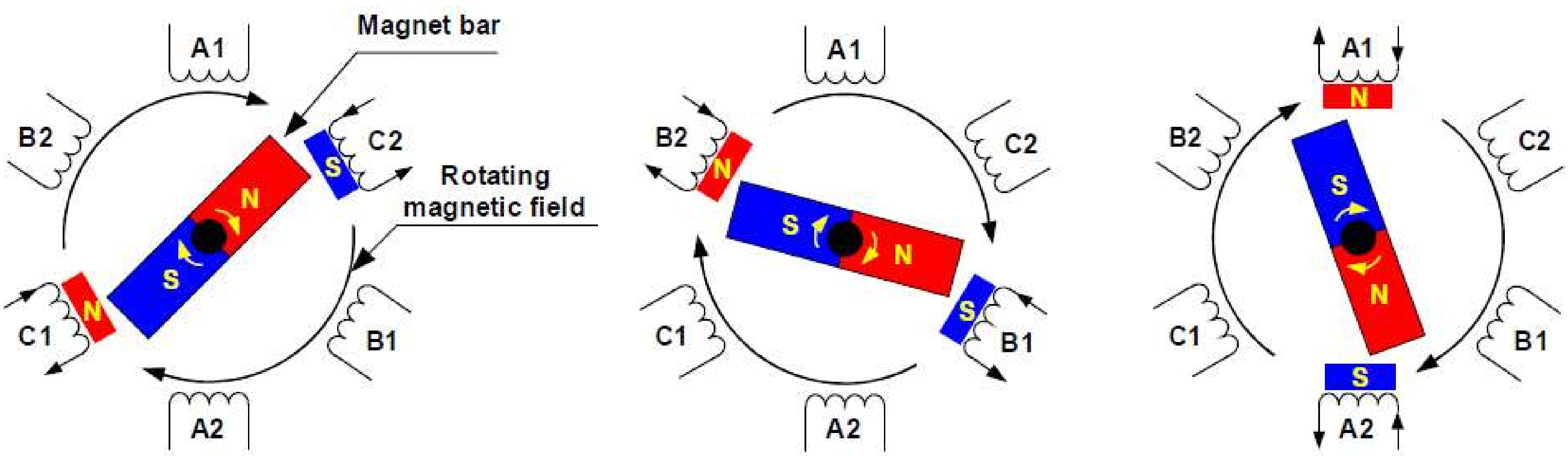


Q1 and Q3 are PNP

Q2 and Q4 are NPN

Say motor rotates clockwise

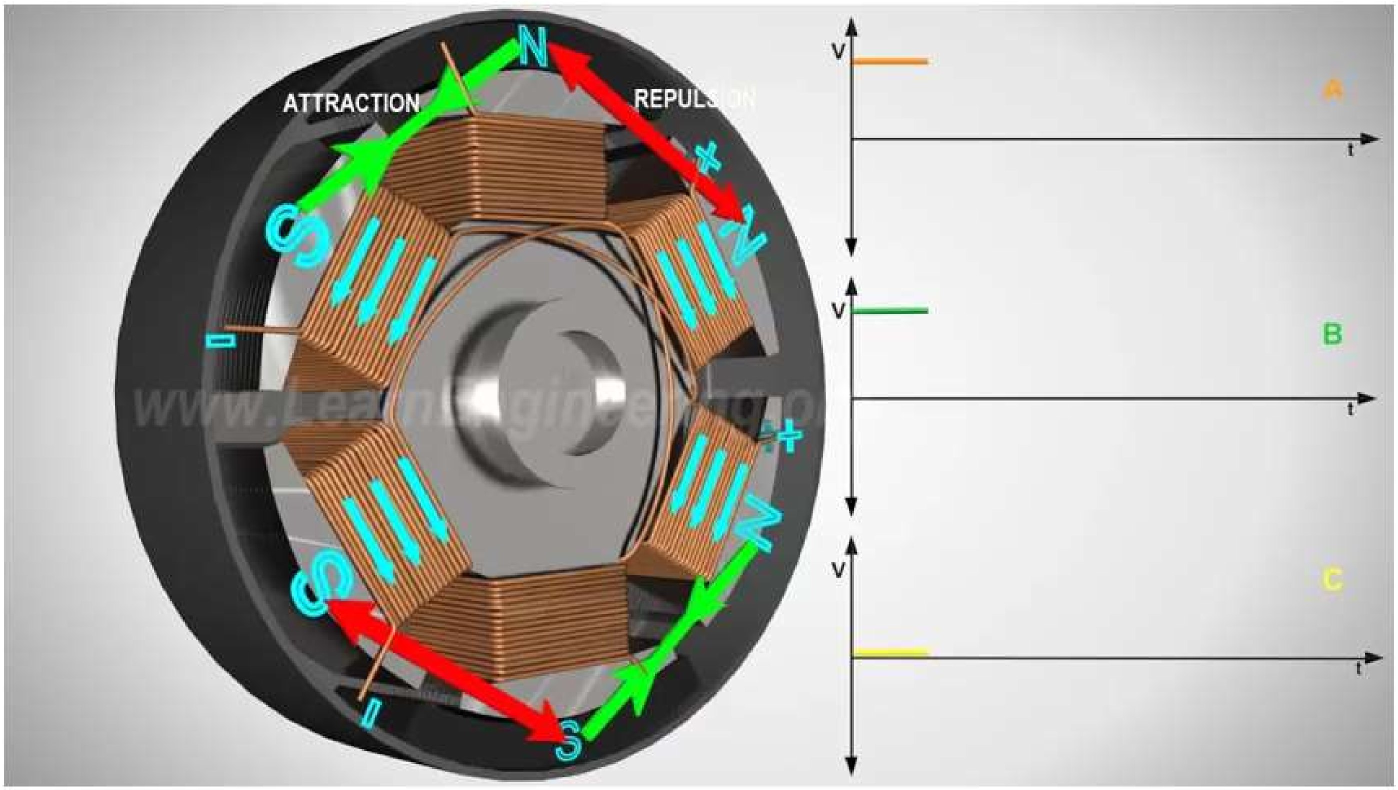
DC motors (Brushless type - BLDC)



Rotor is magnet –Rotating magnetic field - Permanent

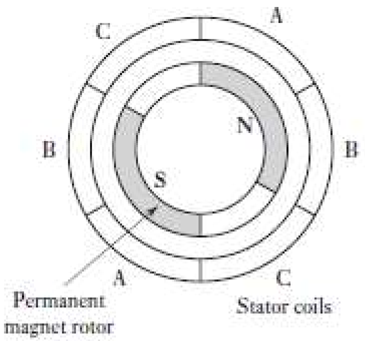
Stator has coil winding.

DC motors (Brushless type - BLDC)

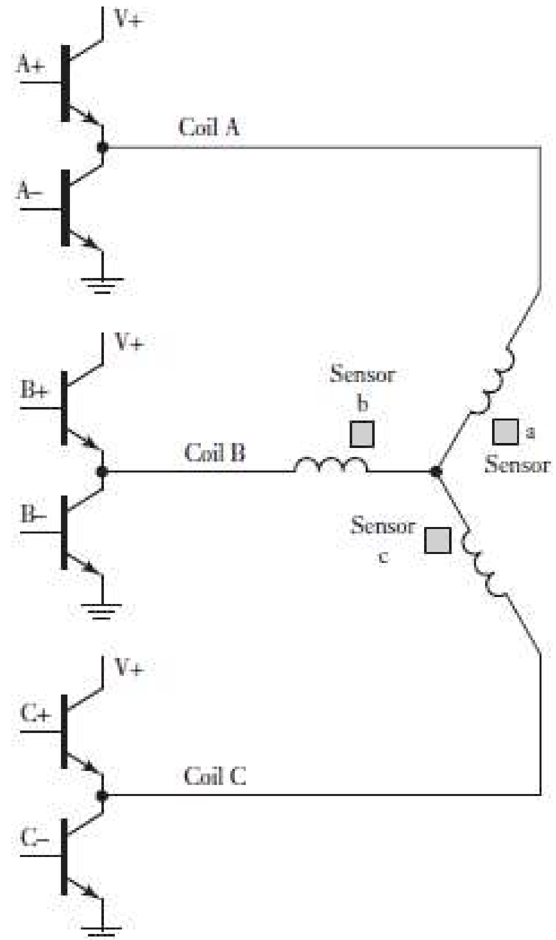


https://www.youtube.com/watch?v=bCEiOnuODac

DC motors (Brushless type - BLDC)



Rotor position	Sensor signals		
	a	b	c
0°	0	0	1
60°	0	1	1
120°	0	1	0
180°	1	1	0
240°	1	0	0
360°	1	0	1



DC motors (BLDC Vs Brushed DC)

Feature	BLDC Motor	Brushed DC Motor	Actual Advantage
Commutation	Electronic commutation based on rotor position information	Mechanical brushes and commutator	Electronic switches replace the mechanical devices
Efficiency	High	Moderate	Voltage drop on electronic device is smaller than that on brushes
Maintenance	Little/None	Periodic	No brushes/commutator maintenance.
Thermal performance	Better	Poor	Only the armature windings generate heat, which is the stator and is connected to the outside case of the BLDC.;The case dissipates heat better than a rotor located inside of brushed DC motor.
Output Power/ Frame Size (Ratio)	High	Moderate/Low	Modern permanent magnet and no rotor losses.
Speed/Torque Characteristics	Flat	Moderately flat	No brush friction to reduce useful torque.
Dynamic Response	Fast	Slow	Lower rotor inertia because of permanent magnets.
Speed Range	High	Low	No mechanical limitation imposed by brushes or commutator
Electric Noise	Low	High	No arcs from brushes to generate noise, causing EMI problems.
Lifetime	Long	Short	No brushes and commutator

Special motors

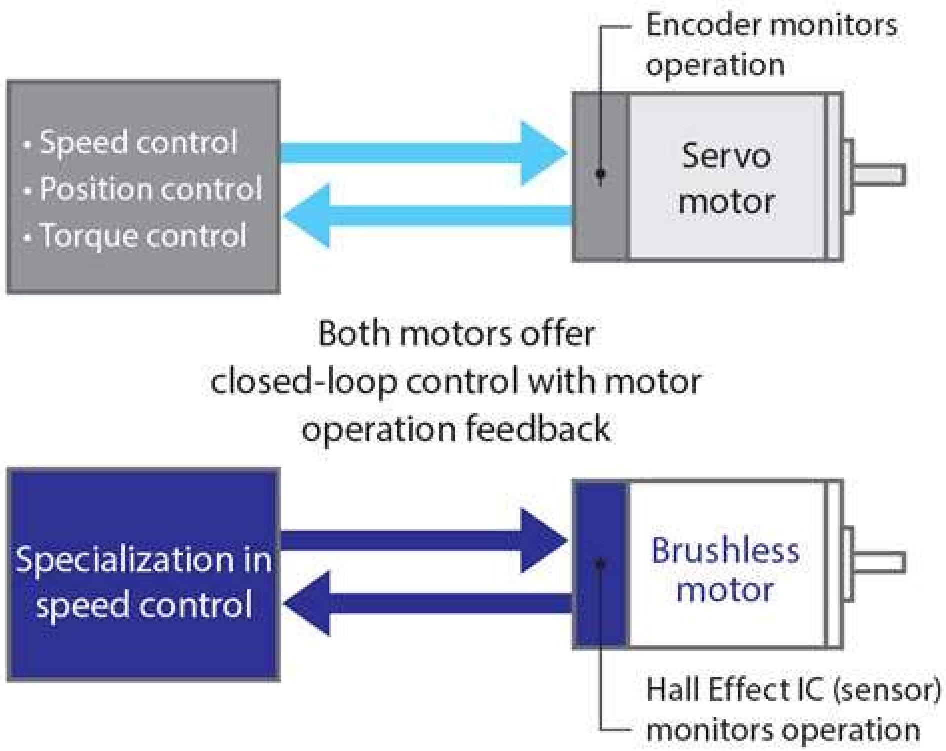
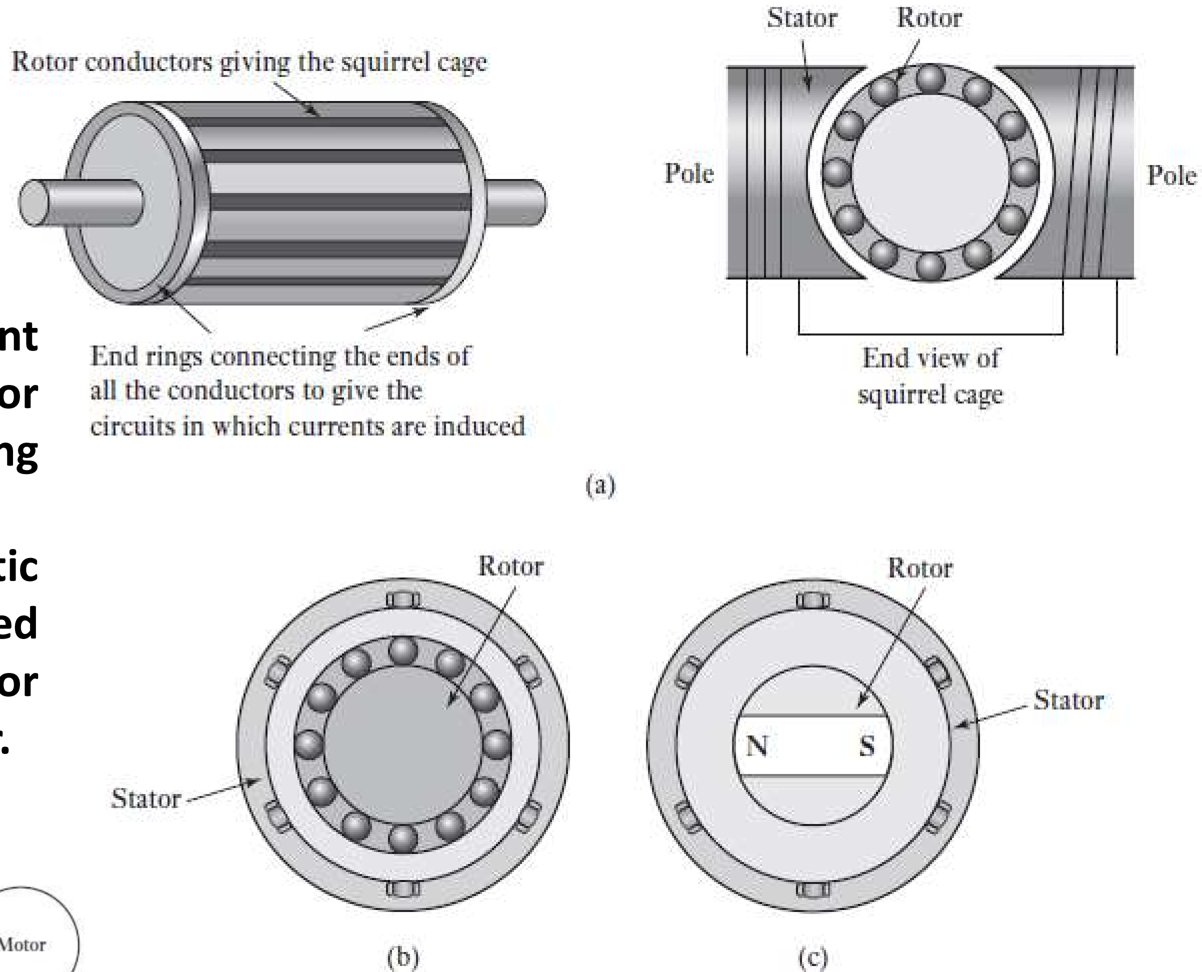


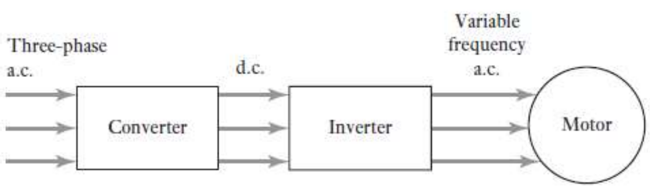
Figure 3 The Brushless Motor Structure and Characteristics are Similar to Those of the Servo Motor

AC motors (Induction /Synchronous)

Figure 9.22 (a) Single-phase induction motor, (b) three-phase induction motor, (c) three-phase synchronous motor.



When an alternating current passes through the stator windings an alternating magnetic field is produced. As a result of electromagnetic induction, e.m.f.s are induced in the conductors of the rotor and currents flow in the rotor.



Induction motors tend to be cheaper than synchronous motors and are thus very widely used.

AC Vs DC Motor

Sl. No.	Differentiating Property	AC Motor	DC Motor
1	Definition	AC motors can be defined as an electric motor which is driven by an alternating current (AC).	DC motors is also a rotatory electric motor which converts Direct current (DC energy) into mechanical energy.
2	Types	AC motors are mainly of two types which are synchronous AC motors and induction motors.	DC motors are also mainly of two types which are namely DC motors with brushes and DC motors without brushes.
3	Current Input	AC motors only run when an alternating current is given as input.	DC motors will only run when DC supply is given. In case of DC series motor, the motor might run with AC supply. But, for shunt motors, the motor never runs on AC supply.
4	Commutators and Brushes	Commutators and brushes are absent in AC motors.	Commutators and carbon brushes are present in the DC motors.
5	Input Supply Phases	AC motors can run on both single phase and three phase supplies.	DC motors can run only on single phase supply.
6	Starting of Motor	A three-phase AC motor is self-starting but a single-phase AC motor requires a starting mechanism.	DC motors are always self-starting in nature.

AC Vs DC Motor

7	Armature Characteristics	In AC motors, the armature is stationary while the magnetic field rotates.	In DC motors, the armature rotates while the magnetic field remains stationary.
8	Input Terminals	In AC motors, three input terminals (RYB) is present.	In DC motors, two input terminals (positive and negative) are present.
9	Speed Control	The speed of an AC motor can be changed by varying the frequency.	In case of DC motors, speed can be controlled by changing the armature winding's current.
10	Load Change	AC motors show a slow response to the change in load.	DC motors show a quick response to the change in load.
11	Life Expectancy	Since AC motors do not have brushes and commutators, they are very rigged and have a high life expectancy.	The brushes and commutators in DC motors limit the speed and reduce the life expectancy of the motor.
12	Efficiency	Due to induction current loss and motor slip, the efficiency of AC motor is less.	The efficiency of DC motor is high as there is no slip and induction current loss.
13	Maintenance	AC motors require less maintenance as brushes and commutators are absent.	DC motors require excessive maintenance due to the presence of brushes and commutators.

AC motors (Induction /Synchronous)

BASIS OF DIFFERENCE	SYNCHRONOUS MOTOR	INDUCTION MOTOR
Type of Excitation	A synchronous motor is a doubly excited machine.	An induction motor is a single excited machine.
Supply System	Its armature winding is energized from an AC source and its field winding from a DC source.	Its stator winding is energized from an AC source.
Speed	It always runs at synchronous speed. The speed is independent of load.	If the load increased the speed of the induction motor decreases. It is always less than the synchronous speed.
Starting	It is not self starting. It has to be run up to synchronous speed by any means before it can be synchronized to AC supply.	Induction motor has self starting torque.

AC motors (Induction /Synchronous)

BASIS OF DIFFERENCE	SYNCHRONOUS MOTOR	INDUCTION MOTOR
Operation	A synchronous motor can be operated with lagging and leading power by changing its excitation.	An induction motor operates only at a lagging power factor. At high loads the power factor becomes very poor.
Usage	It can be used for power factor correction in addition to supplying torque to drive mechanical loads.	An induction motor is used for driving mechanical loads only.
Efficiency	It is more efficient than an induction motor of the same output and voltage rating.	Its efficiency is lesser than that of the synchronous motor of the same output and the voltage rating.
Cost	A synchronous motor is costlier than an induction motor of the same output and voltage rating	An induction motor is cheaper than the synchronous motor of the same output and voltage rating.

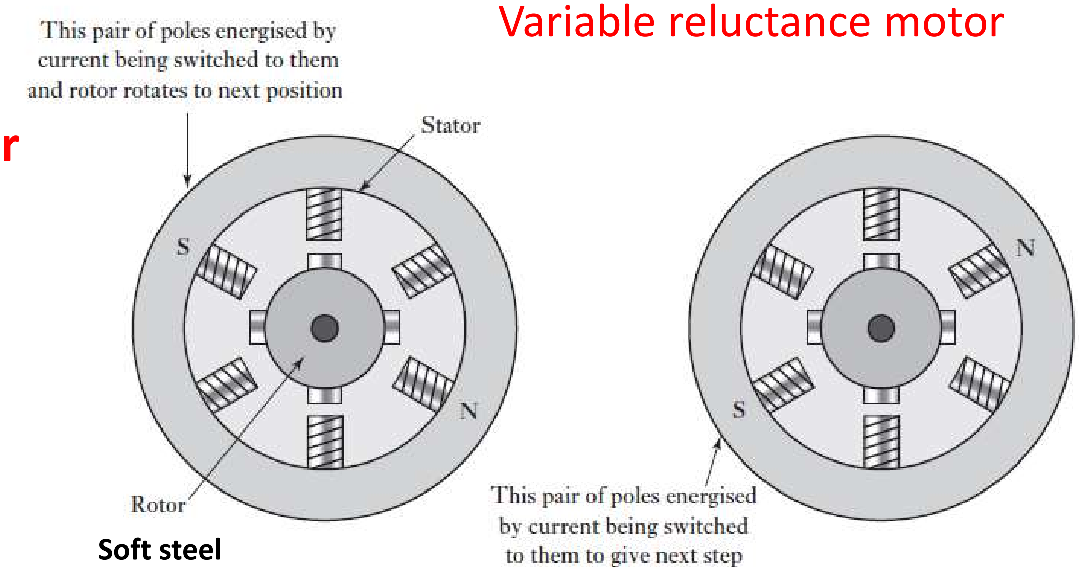
Stepper Motor (Variable reluctance/ Hybrid Motor)

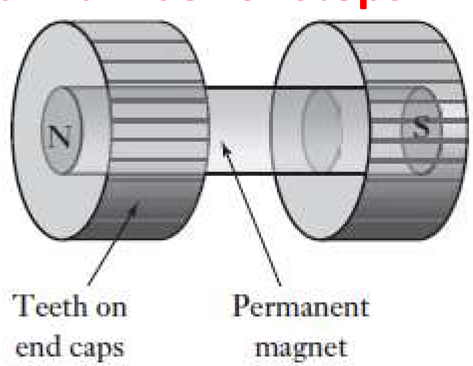
Stepper Motors are also electromechanical actuators that convert a pulsed digital input signal into a discrete (incremental) mechanical movement are used widely in industrial control applications.

Figure 9.24 Variable reluctance stepper motor.

Variable reluctance motor

If there are n phases on stator and m teeth on rotor, then total number of steps = n x m

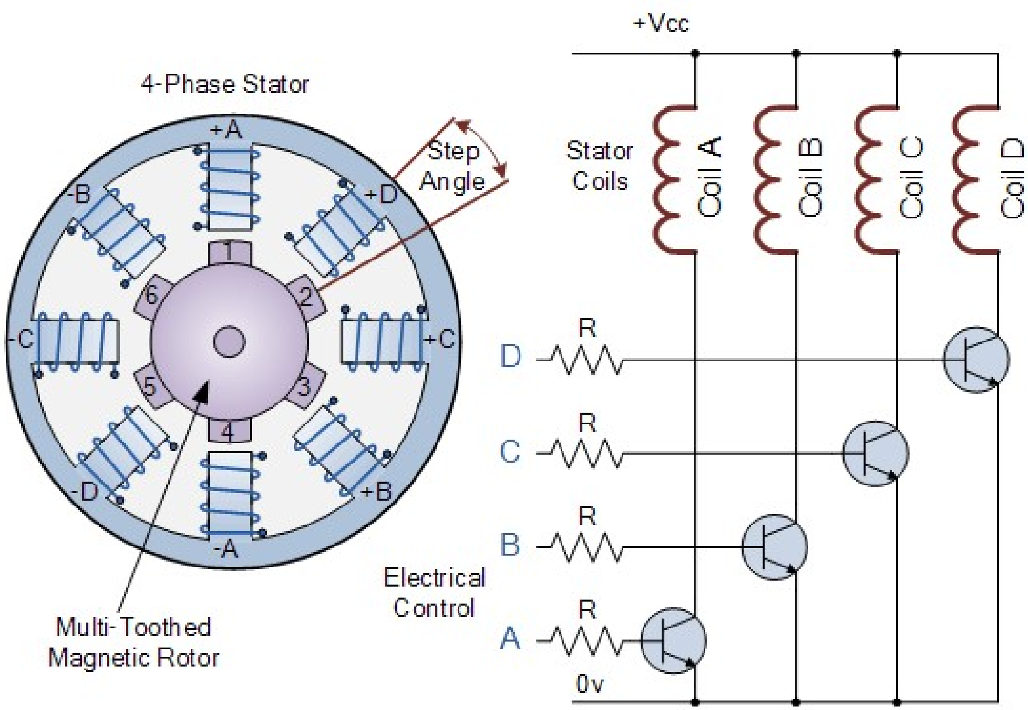




Hybrid motor rotor.

https://www.youtube.com/watch?v=eyqwLiowZiU

Stepper Motor (Permanent Magnet)



The motor consists of a central rotor surrounded by four electromagnetic field coils labelled A, B, C and D.

By applying power to each set of coils in turn the rotor can be made to rotate or "step" from one position to the next by an angle determined by its step angle construction, and by energising the coils in sequence the rotor will produce a rotary motion.

There are 24 (6 teeth x 4 coils) possible positions or “steps” for the rotor to complete one full revolution. Step angle above is given as: $360^o/24 = 15^o$.

Stepper Motor (Problem)

If a stepper motor has a step angle of 7.5°, what digital input rate is required to produce a rotation of 10 rev/s?

For one complete revolution (360° / 7.5°) = 48 pulses

For 10 revolutions = 48 *10 =480 Pulses per second digital input rate is required.

Thank you