
KTU
NOTES

EST 130 : BEE

Module 4

Introduction to semiconductor devices

Evolution of Electronics

Early 1900's	Vacuum Tubes	First generation
1947	Transistors	Second generation
1958	Integrated circuits (I.C)	Third generation
1960's	Small scale Integration (SSI)	Less than 100 transistors per chip
1966 s	Medium scale Integration (MSI)	100 – 1000 transistors per chip
1969	Large scale Integration (LSI)	
1975	Very large scale Integration (VLSI)	Fourth generation. 10000 - 1million transistors per chip.
	Ultra large scale Integration (ULSI)	Fifth generation. more than 1million transistor / chip.

* Industrial Applications

1) Electronics circuits and systems are used in industrial automation, process control, quality control etc.

2, Digital computers are used for performing arithmatic and logical operations, for problem solving, making decisions and sharing data.

3, Plays a key role in implementation of robotic systems which are used for variety of applications.

4, Plays a major role in domestic appliances and entertainment systems. Eg: Lighting, security systems, music system etc.

5, Communication systems like radio, TV, mobile communication, internet, optical fibre etc.

6) Biomedical appliances and equipments Eg: ECG, EEG, X-ray, CT scan.

7, Defence applications Eg: RADAR, SONAR, GLA Drones etc.

Electronic Components

↳ It forms basic building blocks of an electronic circuit. They are broadly classified as below.

Electronic Component

- Active Component
- Passive Component

Active Component

Eg: (1) Tube devices like vacuum diode, Vacuum triode etc.

(2) Some P-N junction diodes

Eg: Tunnel diode, Zener diode.

(3) Bipolar junction diode (BJT)

(4) FET

(5) UJT

Passive Component

Eg: (1) Resistors

(2) Inductors

(3) Capacitors.

Active components → Capable of processing or amplifying an electrical signal. They can inject power into a circuit.

Eg: BJT

Passive components → They are not capable of amplifying or processing any signal.

→ They support operation of active component.

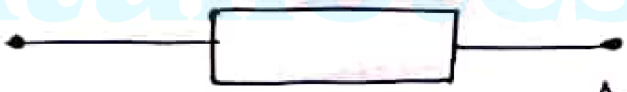
Eg : R, L, and C.

* Resistors

↳ Offer resistance to the flow of current in a circuit. Resistors is rated in ohms (Ω)

↳

According to ANSI (American National Standard Institute)



According to IEC (International Electrochemical Commision)

↳ Conductance $G = \frac{1}{\text{Resistance}}$ Unit : Siemens or mho

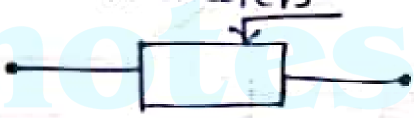
↳ ρ = Resistivity (Ωm) → depends only on material of conductor

↳ Resistance of materials may vary with temperature.

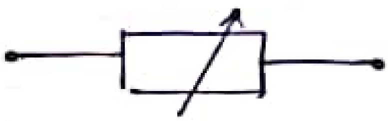
* Classification of Resistors

Resistors

- Linear (Obeys Ohm's law) $I \propto V$
  - Fixed
    - (1) Carbon composition
    - (2) wire wound
    - (3) Thin film
    - (4) Carbon film
    - (5) Metal film
    - (6) Metal oxide
    - (7) Thick film etc.
  - Variable
    - (1) Potentiometers



    - (2) Rheostats



    - (3) Trimmers

- Non Linear (R varies with V or I non-linearly)
  - (1) Thermistor.
  - (2) Photo resistor or Photo conductive cell or LDR.
  - (3) Surface Mount Technology (SMD)
  - (4) Varistor (VDR)
  - (5) Thyrite (non metallic)

* Linear Resistors :

Obey's Ohm's law ie, At a constant temperature the value of current flowing through it will be directly proportional to the voltage across it ie, $V \propto I$ $(V = IR)$

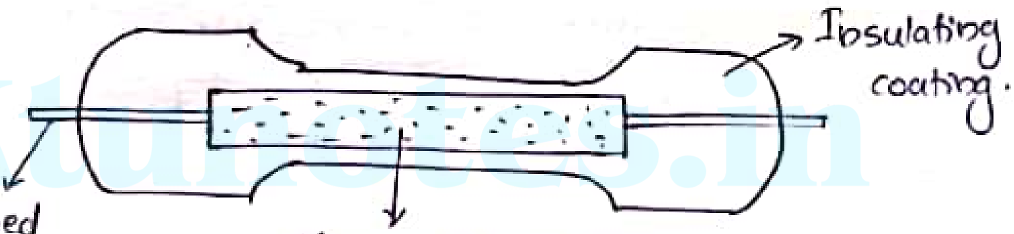
Non-Linear resistors ⟶ Doesnt obeys ohm's law

* Types of fixed resistors are.

① Carbon composition (1 Ω - 25 MΩ range
1/4 W - 5 watts)

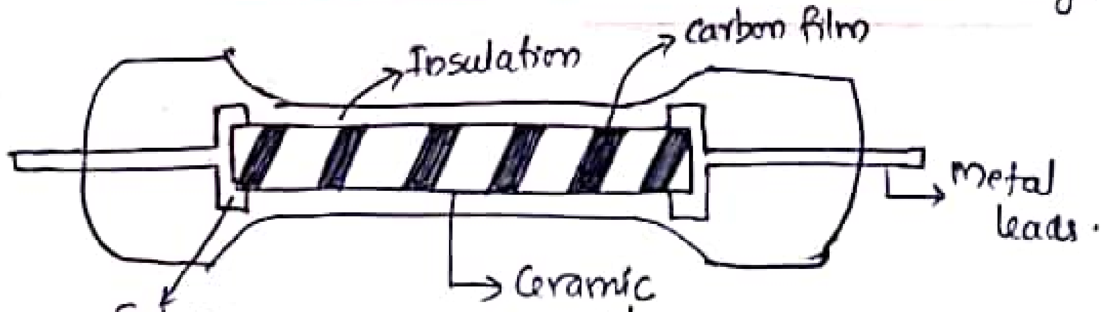
↳ Resistive material used ~~to~~ is carbon or graphite. (powdered)

↳ Usually ceramic is used as insulater and tinned copper wires as leads



↳ Small size, rugged, low cost, suitable for high frequency applications

② Carbon film Resistors (10 Ω to 100 MΩ range)



↳ Made by depositing resistive material on to a insulating substrate Eg: over ceramic

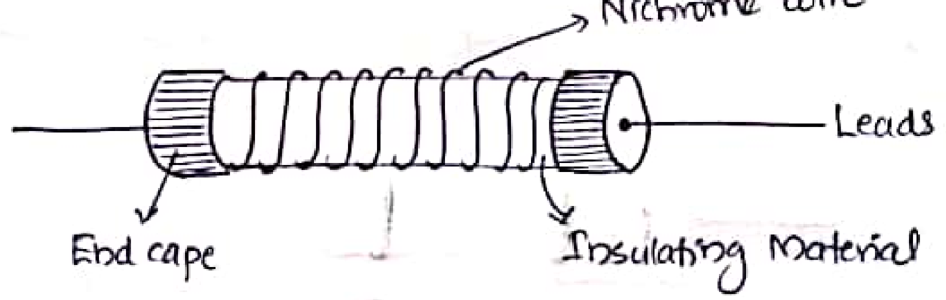
↳ They are commonly used in electronic circuits for low power applications

↳ They have better stability against temperature and humidity

③ Wire wound Resistors (1Ω to 200 kΩ up to 1000 watts)

↳ Made by winding a wire of alloy Eg: Nichrome around a ceramic or porcelain core

↳ can be used for large power applications but they are larger in size



④ Metal Film resistors

↳ Nichrome is used as resistive material. They are used when more accurate values are needed

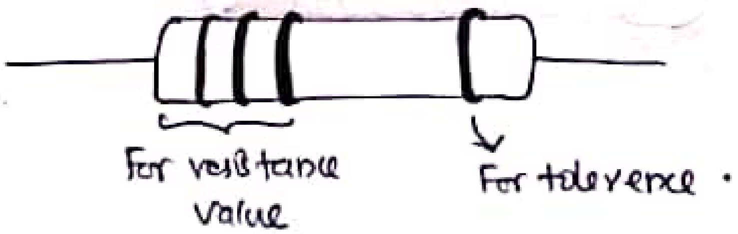
↳ Resistive material is sputtered on a cylindrical ceramic core

↳ Desired resistance obtained by cutting helical grooves on deposited nichrome film.

* Colour Coding of Resistors

↳ To identify resistance values. Small sized resistors uses colour coding Eg: in carbon film and carbon

↳ Four colour band system are widely used.



Colour	I band First value	II band Second value	III band Multiplier	IV Band
Black	0	0	$10^0 = 1$	
Brown	1	1	$10^1 = 10$	
Red	2	2	10^2	
Orange	3	3	10^3	
yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Grey	8	8	10^8	
white	9	9	10^9	
Gold	—	—	10^{-1}	±5%
Silver	—	—	10^{-2}	±10%
No colour	—	—	⋮	± 20%

Eg:- If colour code is orange, orange, yellow and gold

I band → Orange → 3
II band → Orange → 3
III band → yellow → 10^4
IV band → Gold → ±5%

$33 \times 10^4 \pm 5\% \ \Omega$

330 kΩ

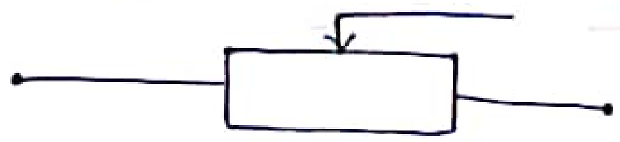
Tolerence :

It is the maximum allowed variation of resistance values from to actual value. Usually expressed in percentage.

* Variable Resistors

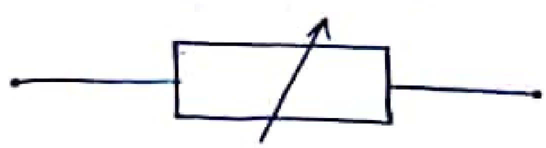
① Potentiometers :

↳ For low power applications,
↳ 3 terminals (one adjustable contact)
↳ It is a voltage devided device.
↳ Used in volume control on audio equipments, Joy sticks, Light dimmers etc.



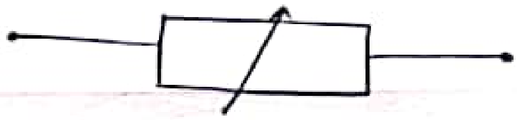
② Rheostat :

↳ Two terminal variable resistors
↳ Can be used for large power applications (electrical systems Eg: welding)



③ Trimmers :

- ↳ Never adjusted by user but set correctly while installing
- ↳ Mounted on circuit boards can be tunned using Screwdriver

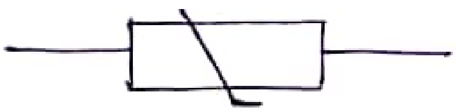


- ↳ In radio receivers, audio-Video components.

* Non Linear Resistors

① Thermistor

- ↳ Temperature sensitive resistors
- ↳ Mostly in temperature sensors and self heating elements
- ↳ Replacement for fuses, used in electrical machines for protection.
- ↳ Automotive sensors, Eg: Thermocouples, ~~Strip.~~ Bimetallic Strip.



② Varistor (VDR)

↳ Voltage Dependent Resistors

↳ Used as control or compensating element in circuits to protect excess voltage

Eg: metal oxide Varistors (MOVs).

③ LDR - Light Dependent Resistor

↳ R varies with, intensity of light

↳ Have high $M\Omega$ resistance in dark and low (100Ω) when light falls.

↳ Exhibit photo conductivity Eg: Used in Night lights
Out-door clocks
Solar street lights etc.

④ Thyrite : Has high R at low current and low R at high current. Used in lightning Arrestors

⑤ SMD : Surface Mount Technology

Used in PCB
smaller in size
η increases
faster

* Inductors

↳ Many turns of wires are wound on a magnetic core or air core. Inductor shows property of inductance

↳ It opposes change in current flowing through it.

↳ Stores energy temporarily as magnetic field

↳ $V \propto \frac{di}{dt}$ (or) $V = L\frac{di}{dt}$ L = Inductance in Henry (1 μH to 20H range)

* Types of Inductors

- Inductors
  - Fixed
    - Air core
    - Iron core
    - Ferrite core
  - Variable
    - Movable ferrite core
    - Ferrite slug type

↳ An inductor will block high frequency AC but allows DC to pass. They are used to seperate signals of different frequencies

↳ Used to make tuned circuits along with capacitors, in radio and TV receivers.

Fixed type Inductors

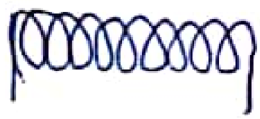
Air core inductor

↳ This type of inductor is made of thin copper wire wound over a former made of thick card-board.

↳ It has a low value of inductance. These are suitable for radio-frequency applications.

↳ It can operate at high frequency ranging up to 1GHz.

↳ Stray field radiation and pickups occurs due to electromagnetic interference which becomes substantial with increase in the diameter of the coil.



* Iron core inductor

↳ This type of inductor is made of copper wire wound on a laminated iron core.

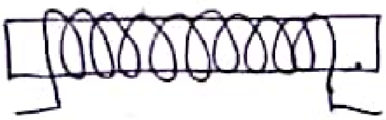
↳ Laminated core is used to avoid eddy current losses.

↳ Laminated core consists of thin iron sheets pressed together and insulated from each other

↳ Iron core inductors are very stable for audio frequency applications.

↳ They are widely used in Audio equipment, Industrial power supplies, inverter systems etc.

↳ The core assist in increasing the inductance without increasing the number of turns.



* Ferrite core inductor

↳ In this type, a coil of wire is wound on a solid core made of ferromagnetic material called ferrite.

↳ In variable type ferrite core inductors, the

— ferrite core is made movable in and out of the coil.

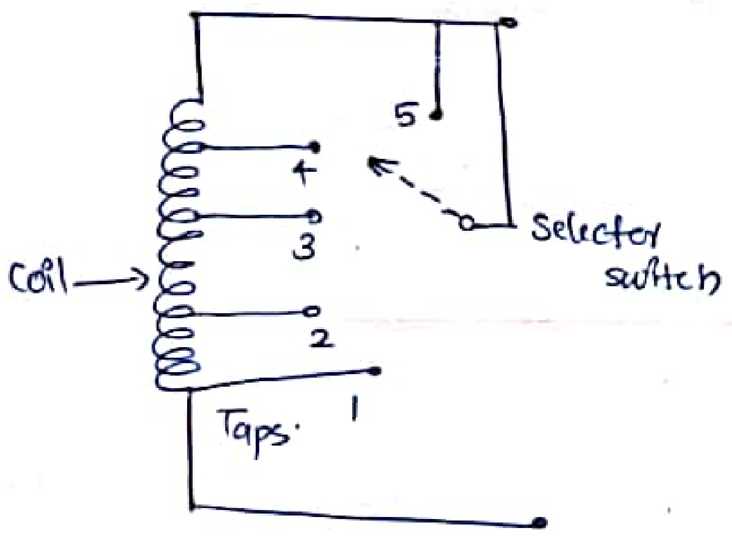
* Variable Inductors

Tapped Inductor

↳ It is a type of variable inductor

↳ It consists of a coil having large number of turns and wound on a magnetic core with a desired number of tappings.

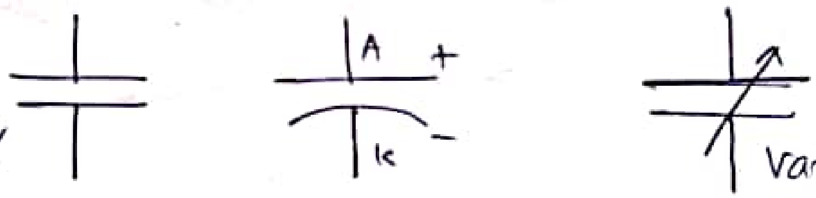
↳ Where tap is a conducting wire taken out from coil at a desired distance due to which different mutual inductance can be achieved over the same inductor.



Capacitors

- Consists of two parallel plates seperated by a dielectric material or air
- It opposes change in voltage across the parallel plates.
- $\boxed{i = C\dfrac{dv}{dt}}$ where C = capacitance in Farad (F)
- They store energy as elecstatic energy
- Usually capacitor of values μF are used.

Symbol



Fixed capacitor

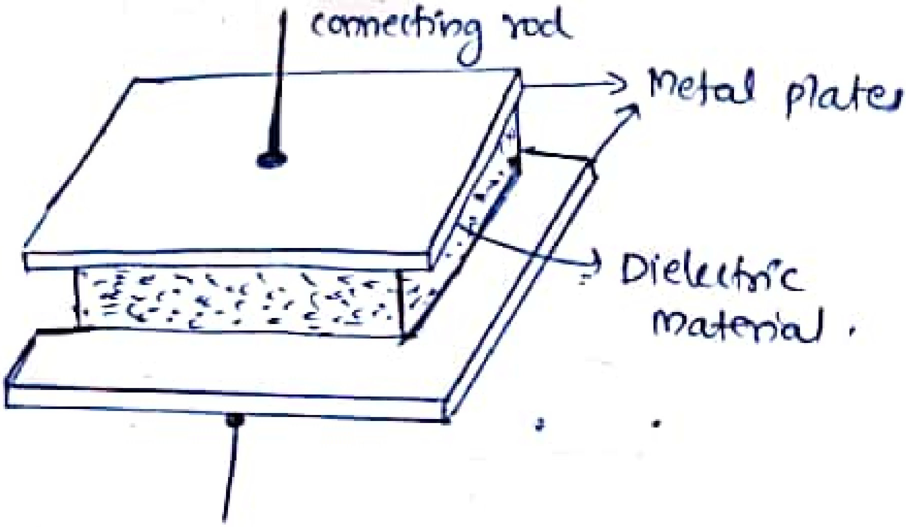
Polarised capacitor

Variable capacitor

- A capacitor act as open circuit for DC (blocks DC low frequency) and allows higher frequency signals to pass.

∴ It can be used as a filter.

* Parallel plate Capacitor



Capacitance value $\boxed{C = \frac{\varepsilon A}{d}}$ Farads.

where ε = Permittivity of dielectric medium

A = Area of plate

d = distance between plates.

$\varepsilon = \varepsilon_0 \varepsilon_r$ where ε_0 = Permittivity of free space.

$= 8.84 \times 10^{-12}$ F/m

ε_r = Relative permittivity.

Types of Capacitors

Capacitors are classified mainly based on the type of dielectric material used.

① Fixed capacitors

Eg: Ceramic capacitor
Paper capacitor
Electrolyte capacitor
Mica capacitors etc.

② Variable capacitors

Eg: 1, Gang capacitor
2, Trimmer
3, Padder

* ① Ceramic Capacitor (PF to few μF)

↳ Also called disc capacitor. made by coating two sides of a ceramic or porcelain disc with silver.

↳ Can be made very small in size with high value ε

↳ 3 digit code will be printed on it to identify value. Eg: 103 = 10×10^3 pico farads

$= 10 \times 10^3$ PF

(2) **Electrolytic Capacitor:**

↳ A semi-liquid electrolyte solution serves as a one electrode usually cathode.

↳ When very large C is required this type is used.

↳ They are usually polarized capacitor and hence not to be used in AC

↳ Usually available in 1 μF to 47 μF range.

(3) **Gang capacitor**

↳ It is a variable capacitor, capacitor value can be changed mechanically / electronically

↳ They are often used in LC circuit to set resonant frequency (radio tuning), called tuning capacitor

↳ Air or plastic foil is used as dielectric material

(4) **Trimmer Capacitor:**

↳ Small values variable capacitor

↳ Never adjusted after factory settings or during installation.

↳ Air / plastic / ceramic as dielectric.

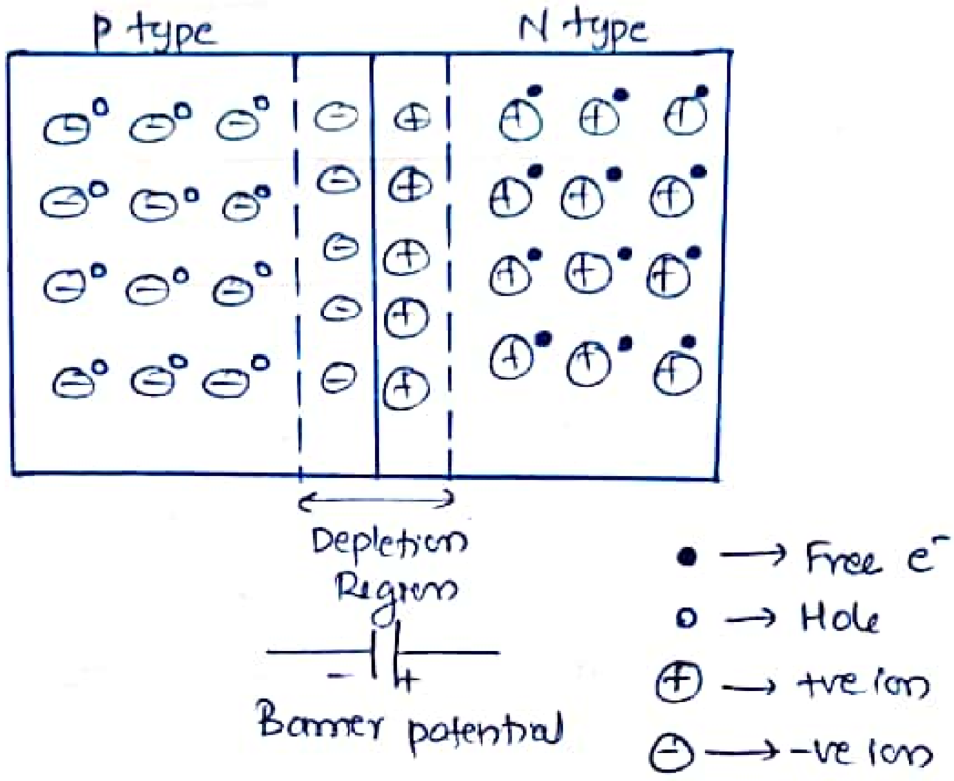
* ↳ P-N Junction Diode.

Principle of operation:

↳ When P-type semiconductor and N type semiconductor are brought together, than some free electrons from the inside are attracted across the junction to fill adjecent holes in p-side. Thus diffusion takes place across the junction.

↳ Free electrons crossing the junction creates negative ions on P side by giving some atoms ~~are~~ one or more e^- than their no. of protons. The electron also leave positive ion behind them on the n-side. Thus it creates an electric field from N side to P side.

↳ Thus initial diffusion of charge carriers creates a barrier voltage at the junction which is -ve on P side and +ve on n side. It is also known as space charge potential.



↳ N type Semiconductor → Obtained by adding pentavalent impurity in intrinsic semiconductor

Eg: As, Sb, Pb etc.

There will be free e^- ∴ They are called donor impurity.

↳ P type semiconductor → obtained by adding trivalent impurity in intrinsic semiconductor

Eg: Al, Bo, Ga, In

It creates extra holes (absence of e^-) and hence called acceptor impurity.

↳ Barrier voltage or Cut in voltage or Knee voltage = { 0·6 to 0·7 in silicon diodes; 0·2 to 0·3 in Germanium diodes }

↳ The region of a P-N junction which contains only immobile ions and devoid of free carriers is called depletion region. In a PN junction without external supply a barrier voltage is developed across junction and no current flows through junction.

* VI Characteristics:

Forward Biasing

+ve terminal of supply → P region
-ve terminal of supply → N region.

↳ when it is forward biased, the holes got repelled from +ve terminal of source and it moves towards junction. Similarly e^- get repelled from -ve terminal and moves towards junction.

↳ Electrons and holes crosses depletion region and recombine themselves. that is width of depletion region reduces and hence potential barrier is reduced.

* ## Reverse biased P-N junction

+ve terminal of battery ⟶ N region
−ve terminal of battery ⟶ P region

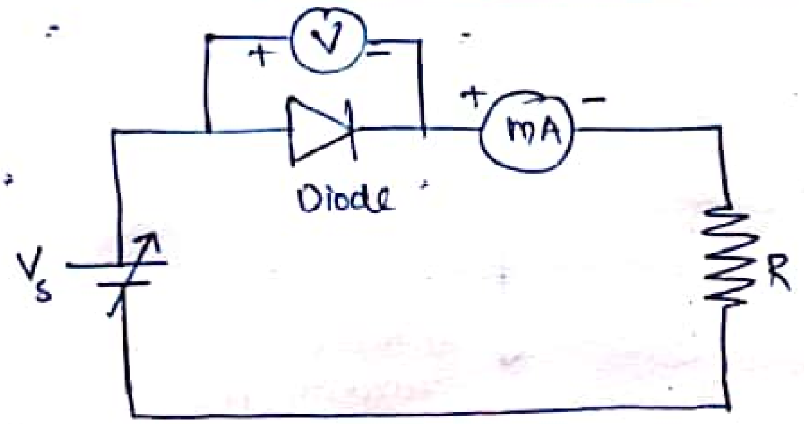
↳ Then holes in P region are attracted towards the −ve terminal of the voltage source. Similarly e^- in the 'n' region are attracted towards +ve terminal

↳ This widens the depletion region and increases the barrier potential. Increase barrier potential prevents diffusion of majority carrier through junction.
∴ No current flow due to majority carriers.

↳ But the barrier potential helps the minority carriers to cross the junction (holes in n side and e^- in p side) hence small amount of current flows through reverse biased P-N junction (in μA)

⟹ VI characteristics is a graph between voltage applied across the terminals of a P-N junction diode and current flowing through it.

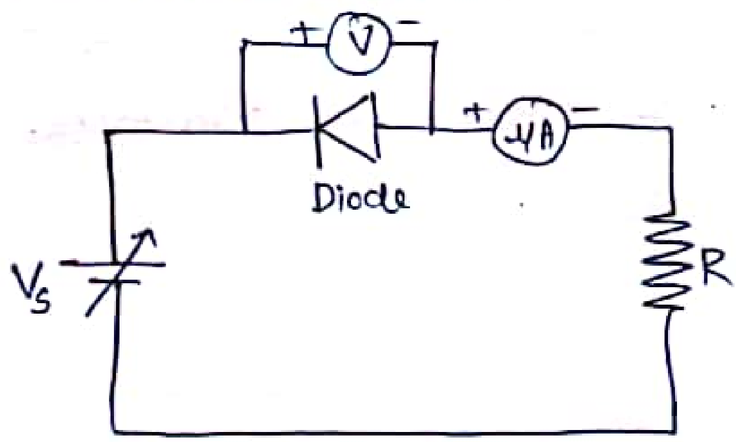
(i) Forward biased diode.



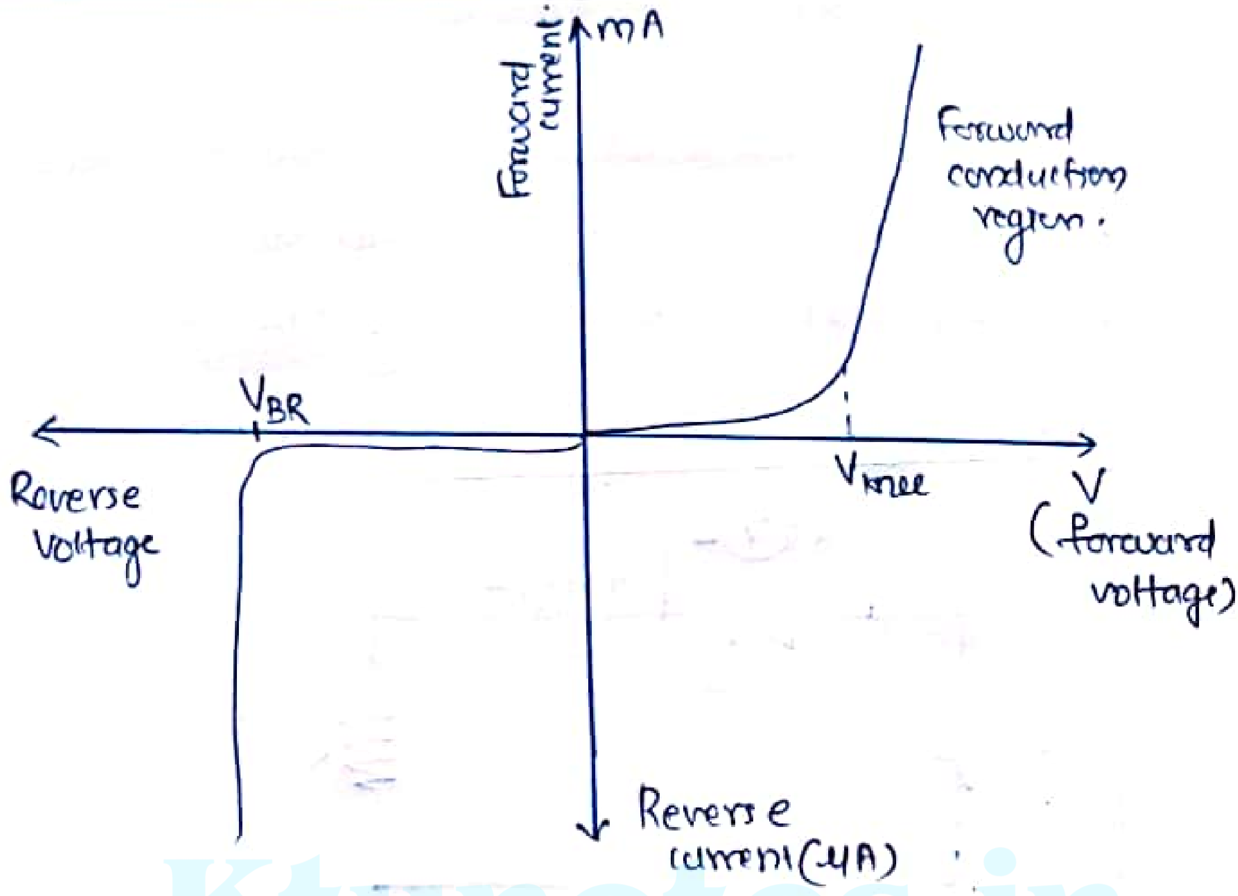
↳ R limits current

↳ If we increase voltage then V increases above knee value it conducts.

(ii) Reverse biased.



↳ If we increase voltage small current (minority carriers) only flows.



↳ In reverse bias condition, if the applied voltage increases to large values then at some poit, breakdown (Sharp increase in current) takes place and this voltage is known as reverse breakdown voltage. This phenomenon is known as Avalanche Breakdown.

* Bipolar Junction Transistors (BJT)

↳ Transistors are main building blocks of modern electronic circuits and devices.

↳ They are mainly two major categories

(1) Bipolar Junction transistor (BJT)
(2) Field Effect transistor (FET).

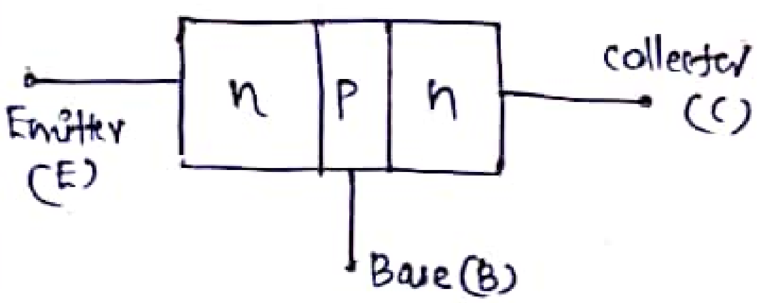
* Construction of BJT

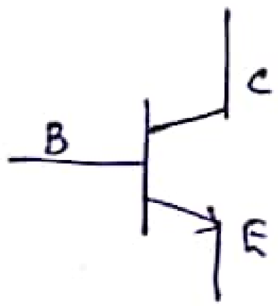
↳ It is a 3 terminal device containing semi-conductors.

↳ Current conduction is due to both electrons and holes and hence called Bipolar.

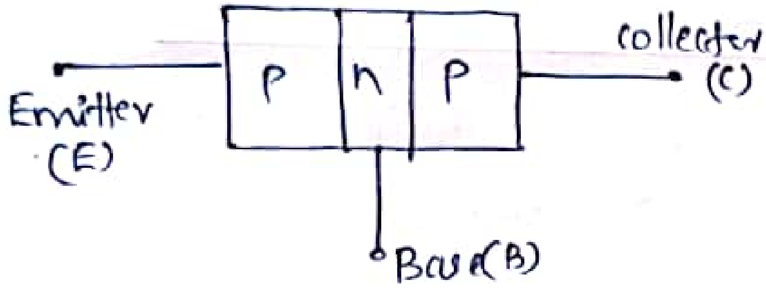
↳ There are two different configurations of BJT

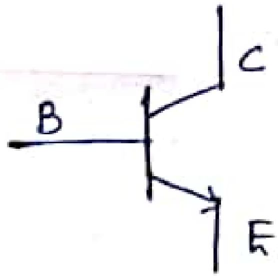
(1) NPN Configuration





(ii) PNP configuration





- Emitter (E) ⟶ Heavily doped compared to C and B to supply charge carrier to the collector via base. Size of E is more than base but less than collector

- Base (B) ⟶ Size is extremely small, charge carrier from E is directed towards collector and only a few recombines in base. Lightly doped region.

- Collector (C) ⟶ Moderately doped, size of C is more than E to collect charge carriers ~~to~~ and to dessipate heat.

* ## Operation of BJT

↳ Transistors can operate in three different modes namely Active mode, Saturation mode and cut off mode.

Mode	Emitter Base Junction	Collector Base Junction	Behaviour.
Active	Forward	Reverse	Amplifier
Saturation	Forward	Forward	ON switch
cut off	Reverse	Reverse	OFF switch
Reverse active	Reverse	Forward	Rarely used

* ## Configuration of BJT

There are mainly 3 configurations of BJT based on its circuit connections, They are

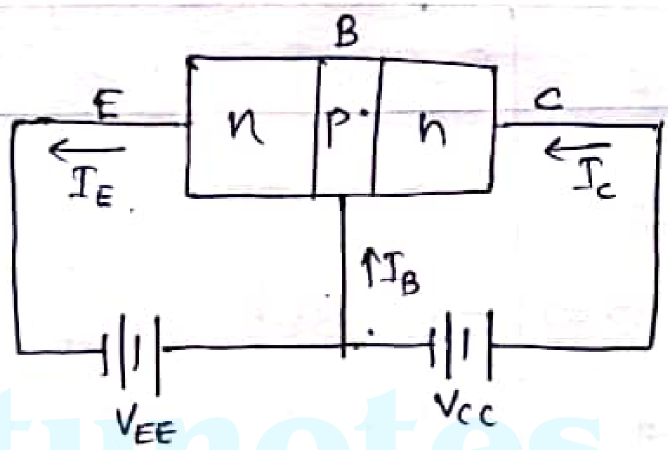
(i) common base configuration → B common to i/p and o/p.

(ii) Common Emitter configuration → E common to i/p and o/p

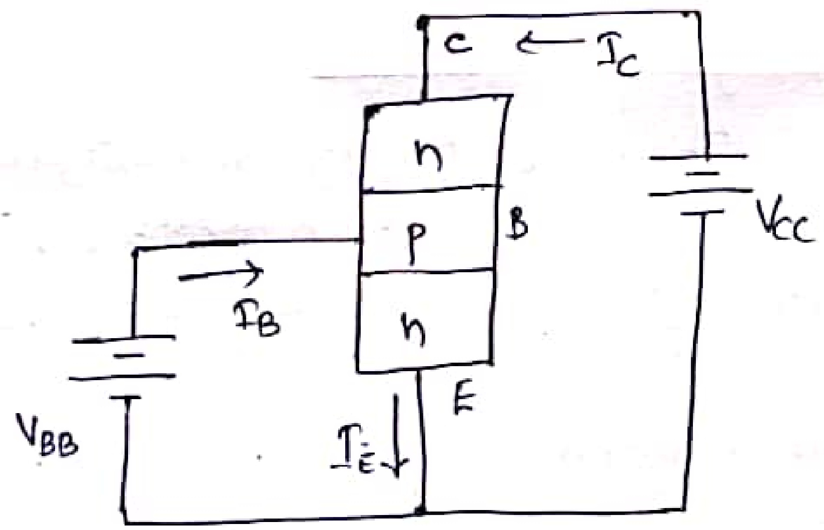
(iii) Common collector configurations → C common to i/p and o/p.

Common Base configuration → Input is applied between emitter and base terminal and the o/p is taken between collector and base

DC current gain, $\boxed{\alpha = \frac{I_C}{I_E}}$

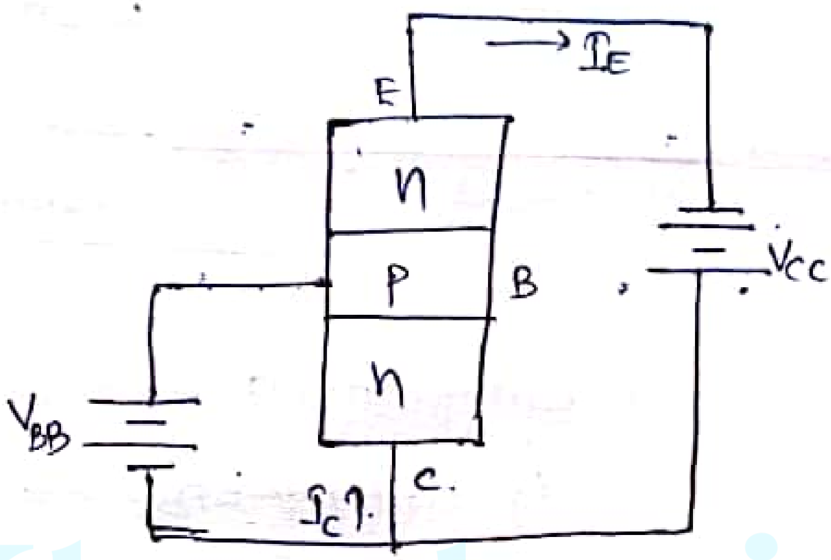


Common emitter configuration → Input is applied between base and emitter and o/p is taken between C and E



DC current gain $\boxed{\beta = \frac{I_C}{I_B}}$ $\quad 20 < \beta < 500$

* Common collector configuration → Input is applied between base and collector, and the output is taken between emitter and collector.



DC current gain $\boxed{\gamma = \frac{I_E}{I_B}}$

Relation between current gains.

$$\boxed{\alpha = \frac{\beta}{1+\beta}} \qquad \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

$$\boxed{\gamma = \beta + 1 = \frac{1}{1-\alpha}}$$

* Common Emitter configuration input and output characteristics

→ Input characteristics : Input voltage Vs input current when o/p voltage is constant

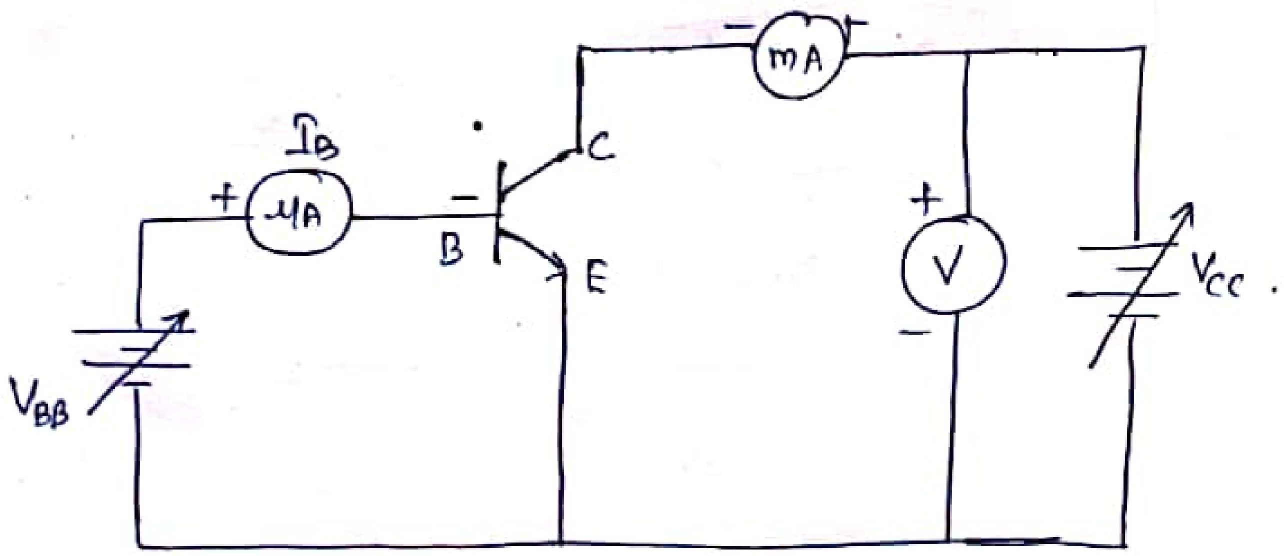
→ Output characteristics : Output voltage Vs o/p current when i/p current is constant

In CE configuration

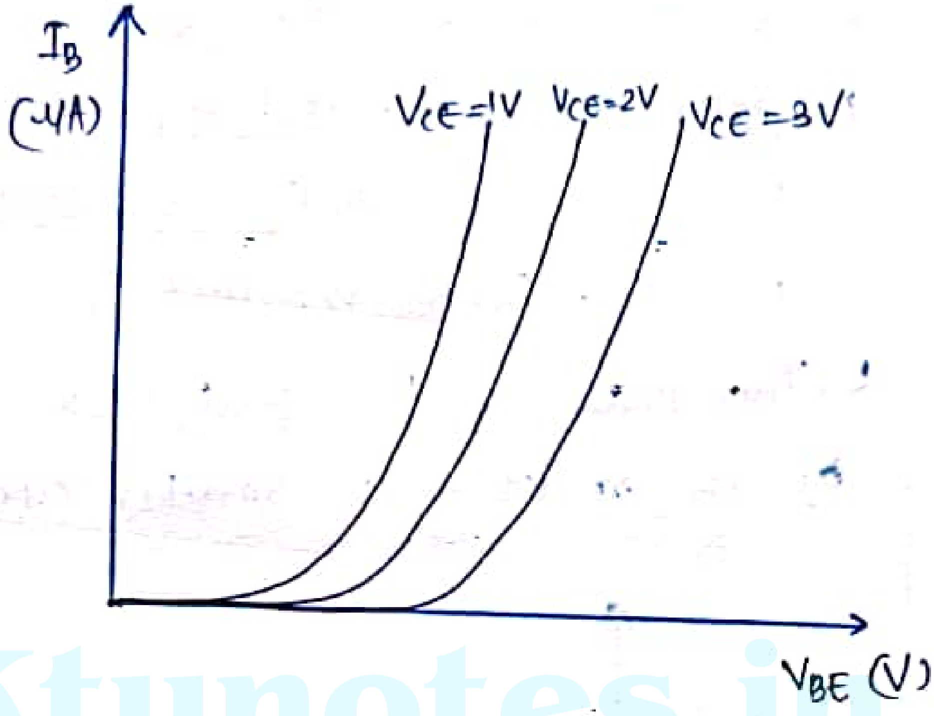
i/p characteristics → V_{BE} Vs I_B for a constant V_{CE}

o/p characteristics → V_{CE} Vs I_C for a constant I_B.

→ The circuit arrangement for obtaining characteristics.



* Input characteristics



→ Set V_{CE} as a constant value (say 1V) then V_{BE} is varied in small steps by changing power supply and corresponding base current is noted. Then plot V_{BE} Vs I_B

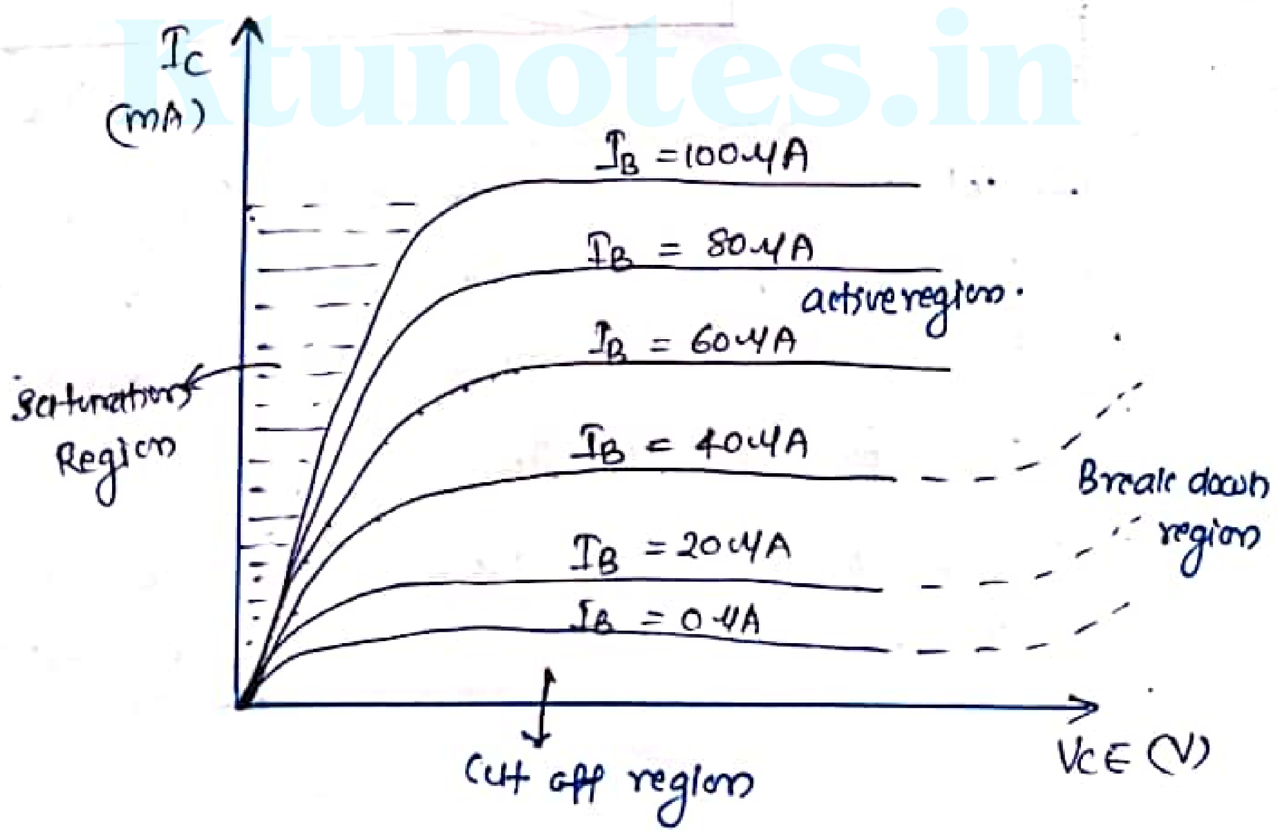
↳ This procedure is repeated for different values of V_{CE} (say 2V, 3V etc) resulting in similar curves.

* Output characteristics

↳ Set base current at a constant value (Say 40μA) by adjusting emitter to base voltage

↳ Then V_{CE} is varied by changing the power supply voltage and corresponding collector currents are noted. Then V_{CE} and I_C is plotted.

↳ This procedure is repeated for different values of I_B resulting in similar curves



↳ When $I_B = 0$, a small I_c which is known as leakage current I_{CEO} flows from collector to emitter.

↳ The region below $I_B = 0$ is known as cutoff region.

↳ In active region the curves for I_B are nearly straight and equally spaced.

↳ The region to the left of $V_{CE\,sat}$ is called saturation region.