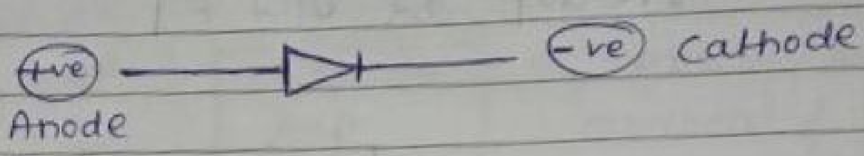
# Module - 01



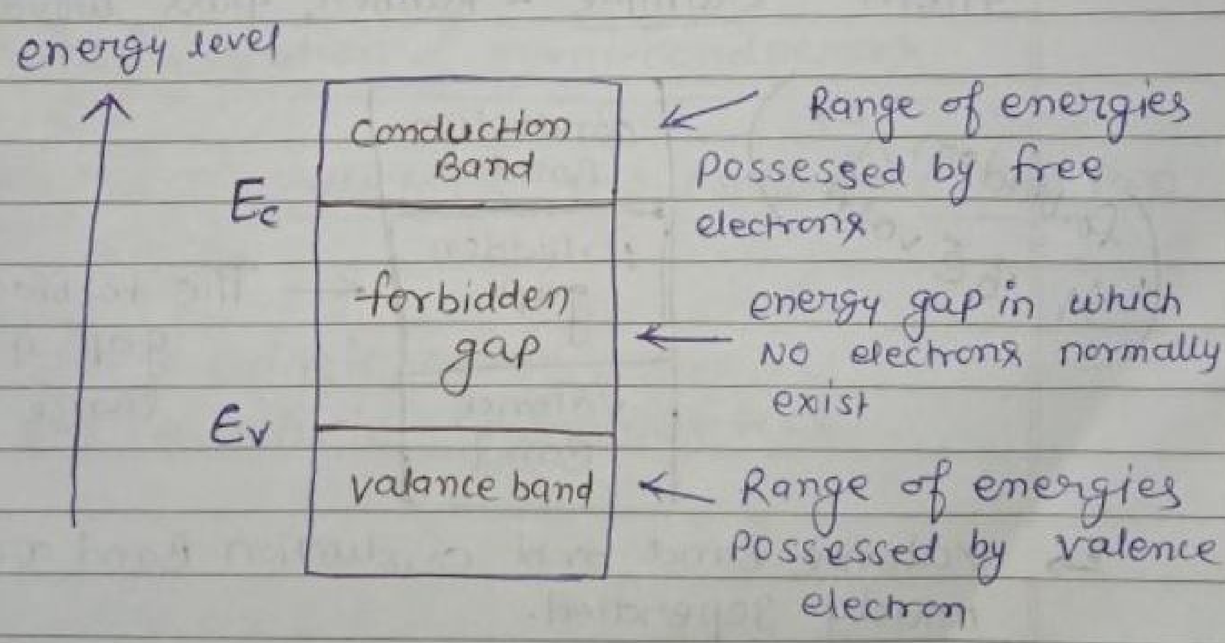
(1) **Diodes** → A diode is a device which allows flow of current in one direction. it is a polarised component with two leads, called the cathode and the anode. The cathode is normally marked with a silver or coloured band.




## Classification of Materials on Basis of energy Band Diagram

- Conductors
- Insulators
- Semiconductors

### energy level diagram

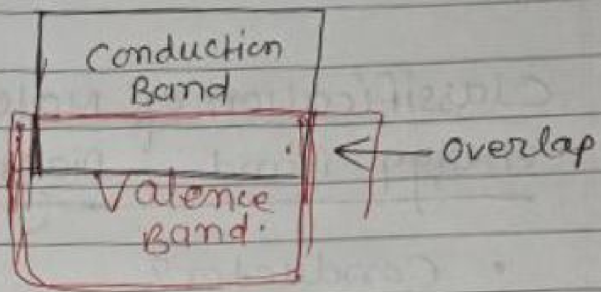


① Conductors -

- Conductors allow electric current to pass through them

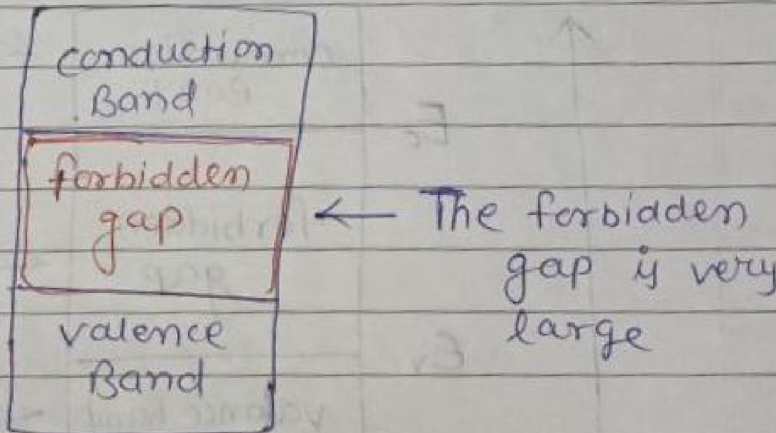
exa - copper, Al etc.

↳ Conduction band and valence band overlap कर जाते हैं।




② Insulators :- Insulators are those substances, which do not allow electric current to pass through them example - Rubber, glass, wood etc.

(forbidden gap is 6 e volt)

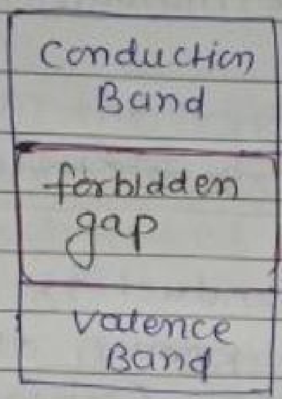



↳ valence Band and conduction Band are widely seperated.

**Semiconductors** – Semiconductors are those substances whose conductivity lies in b/w that of a conductor and an insulator.

exg – silicon, germanium, cealenium, gallium, arsenide etc.

{forbidden gap is ≃ 1 é volt}




→ energy gap is narrow (more than conductor, lesser than insulator)

↳ If Temperature increases semiconductors behaves conductors.

↳ Doping करने पर conductors behave करेगा

# Classification of semi-conductors

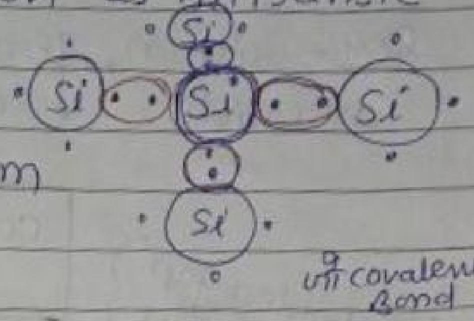
(1) Semiconductors are classified into two types

(a) intrinsic semiconductors
(b) Extrinsic semiconductors

## (a) Intrinsic semiconductors

↳ A semiconductor in an extremely pure form is known as intrinsic semiconductors

exa → Silicon
Germanium

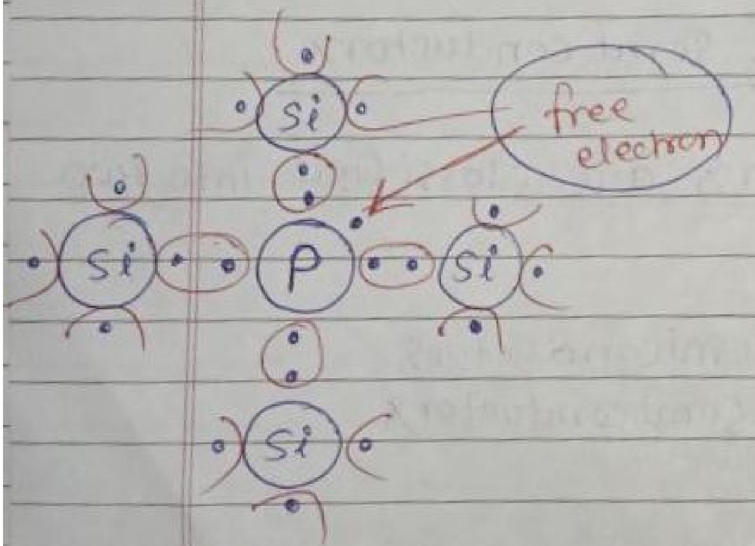


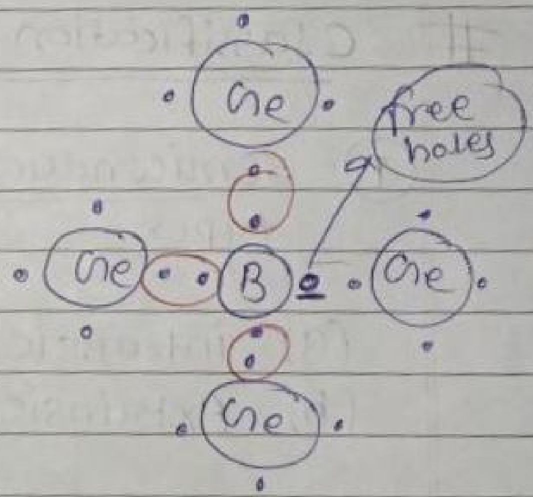

## (b) Extrinsic semiconductors

↳ A semiconductors in an impure form is known as extrinsic semiconductors. (pantavalent & trivalent को मिलाकर impure बना देते है)

N-type (if add pentavalent)

P-type (if add trivalent)




(Donar ions)

(acceptor ions)

↳ when an impurity is added to an intrinsic semiconductor its conductivity changes.

↳ this process of adding impurity to a semiconductor is called Doping and the impure semiconductor is called extrinsic semiconductor.

↳ Depending on the type of impurity added, extrinsic semiconductors are further classified as

N-type semiconductor
P- type semiconductor.

N-type semiconductor →

when a small quantity of pentavalent impurity is added to a pure semiconductor it is called as N-type semiconductor.

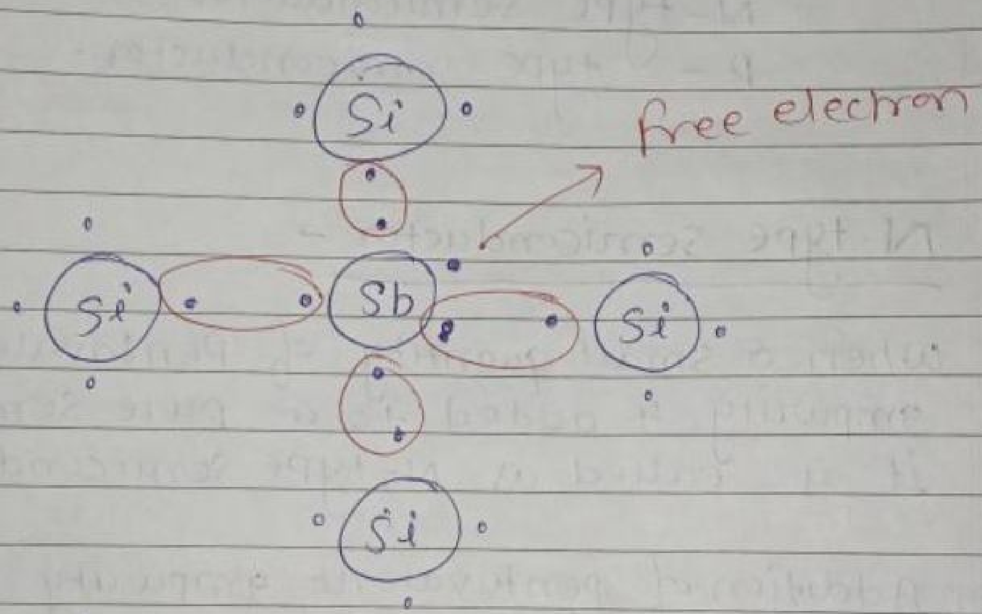
↳ Addition of pentavalent impurity provides a large number of free electrons in a semiconductor crystal

exa - for pentavalent impurities
- Arsenic
- Antimony
- Phosphorus.

↳ Such impurities which produce N-type semiconductors are known as Donor impurities.

Q Because they donate or provide free electrons to the semiconductor crystal

- To understand the formation of N-type semiconductor, consider a pure silicon crystal with an impurity say Antimony added to it




↳ The 5th valence electron of the pentavalent impurity finds no place in the covalent bond thus, it becomes nearly free and travels to the conductor band.

## P-type semiconductor

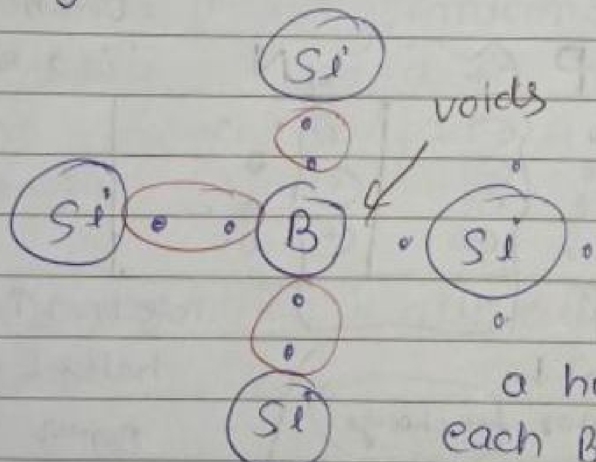
↳ when a small amount of trivalent impurity is added to a pure semiconductor it is called p-type semiconductor.

↳ The addition of trivalent impurity provides large Number of holes in the semiconductor crystals

exa Gallium
Indium
Boron

- Such impurities which produce p-type semiconductors are known as acceptor impurities

- Because the holes created can accept the electrons in the semi-conductor crystals.




This absence of electron is called a hole. therefore for each Boron atom added one hole is created a small amount of Boron provides millions of holes.

# P-N junction diode (unbiased condition)

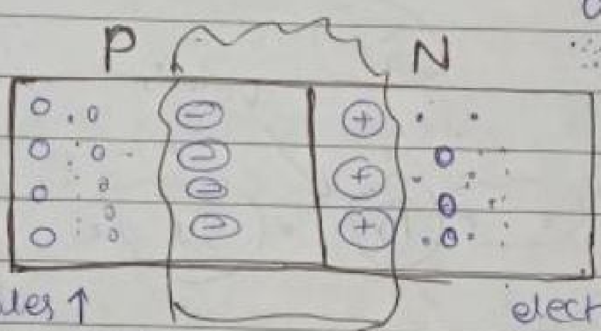

P-type & N-type material combined करने पर जो मिलता है। उसे ही Diode कहते है और semiconductor से मिलकर बना है। इसलिए semiconductor diode कहते है।

↳ P & N मिलाने पर जो junction बना उसे कहे P-N ~~कहे~~ junction कहते है


| | N-type | P-type |
|---|---|---|
| Majority carrier → ↑ | $e^-$ | holes |
| Minority carrier → ↓ | holes | $e^-$ |

O → holes

∴ → electrons

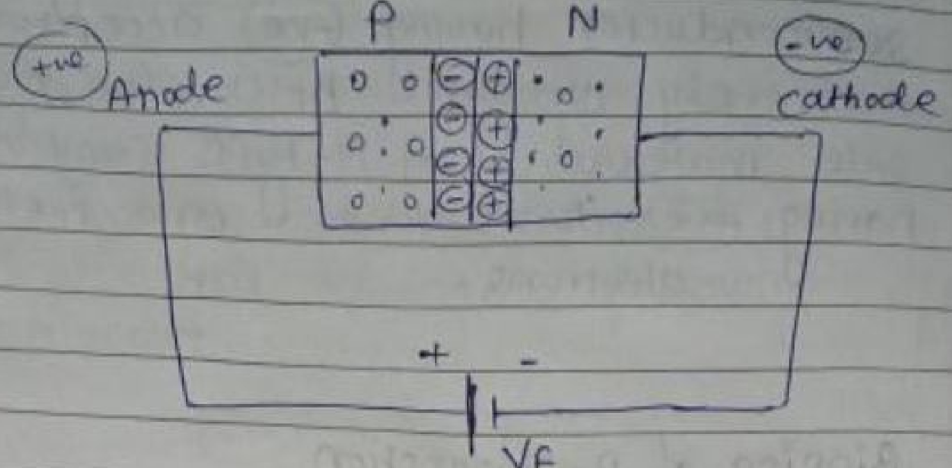



initially there is diffusion of charge carriers (electrons & holes) from both sides of the junction. these free charge carriers recombine near the junction due to which reason is formed which is known as depletion region.

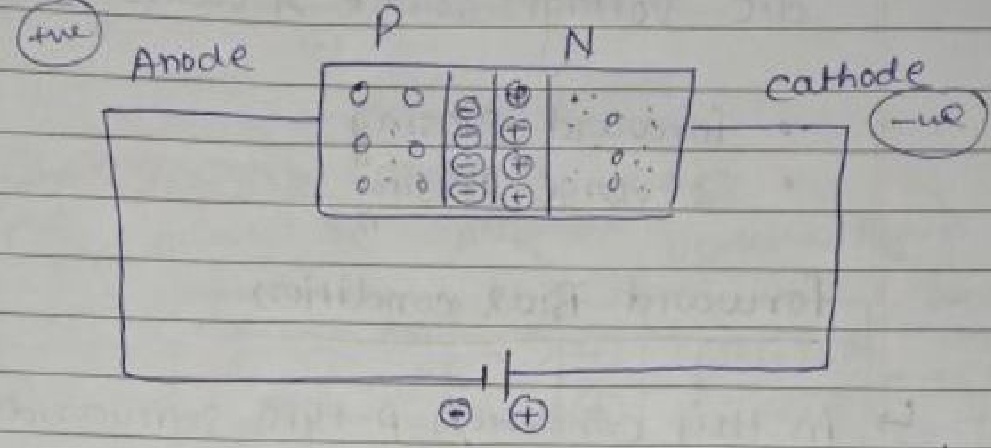
holes ↑
electrons ↓
acceptor -ve charge

electron ↑
holes ↓
Donar +ve charge

Depleetion layer/regin




forward biasing / Bais.




$V_R$ Reverse Biasing / Bais

↳ when a p-type semiconductor material is Suitably joined to n-type semiconductor the contact surface is called a p-N junction

↳ The p-N junction is also called as semiconductor diode

↳ The left side material is a P-type semiconductor having (-ve) acceptor ions and +vely charged holes. the right side material is N-type semiconductor having (+ve) donor ions and free electrons.

# Biasing of P-N Junction

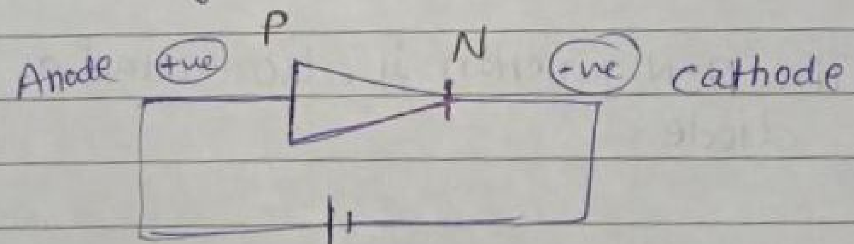
Connecting a P-N junction to an external d.c voltage source is called biasing

- forward Biasing
- reverse Biasing

forward Bias condition

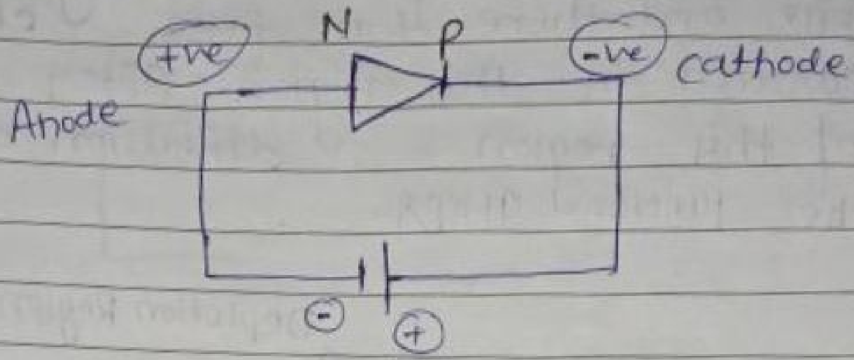
↳ in this condition P-type semiconductor is connected to positive and N-type semiconductor is connected to negative terminal of the battery. Due to this biasing we can observe following effects.

~~fig पीछे का page~~



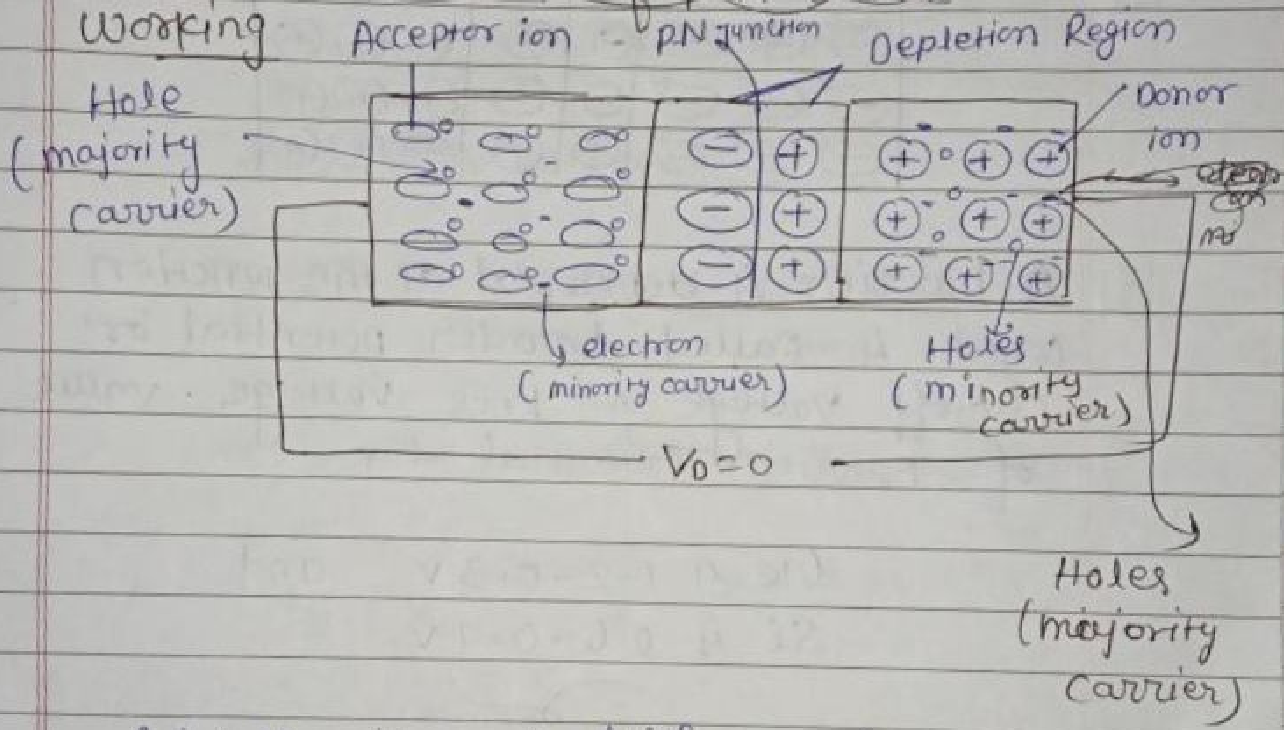
## Reverse Biasing

↳ In this condition N-type semiconductor is connected to positive and P-type is connected to Negative terminal of the battery. Due to this biasing following effects can occur.



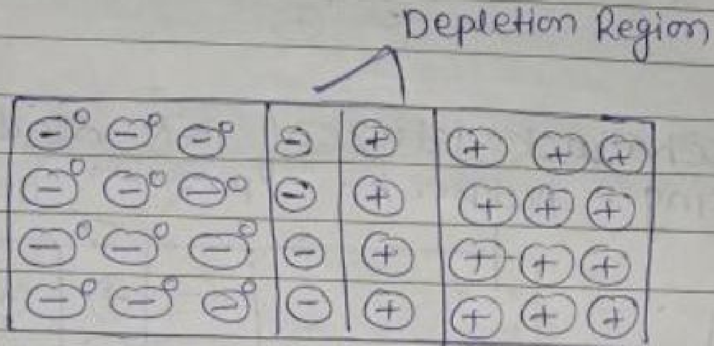

~~# V-I characteristics of P-N diode~~

Working




initially there is diffusion of charge carriers (electrons and holes) from both sides of the junction. These free charge carriers recombine near the junction due to which reason is formed which is known as depletion region.

↳ Due to recombination b/w electron and holes a region near the junction is formed which contains only immobile ions and there is no free charge carrier in this region. After formation of this region diffusion across the junction stops.




A barrier is developed at the junction which is called barrier potential 'or' cut-off voltage 'or' knee voltage. value of barrier potential for

Ge is 0.2 – 0.3 V and
Si is 0.6 – 0.7 V

barrier potential

# V-I characteristics of p-n diode

↳ Irrespective of whether the diode is forward bias or reverse Bias, the current $I_D$ flowing through the diode is related to the applied voltage $V_D$ by the equation.

$$\boxed{I_D = I_0 \left(e^{V_D/nV_T} - 1\right)}$$

where

$I_D$ = Diode current

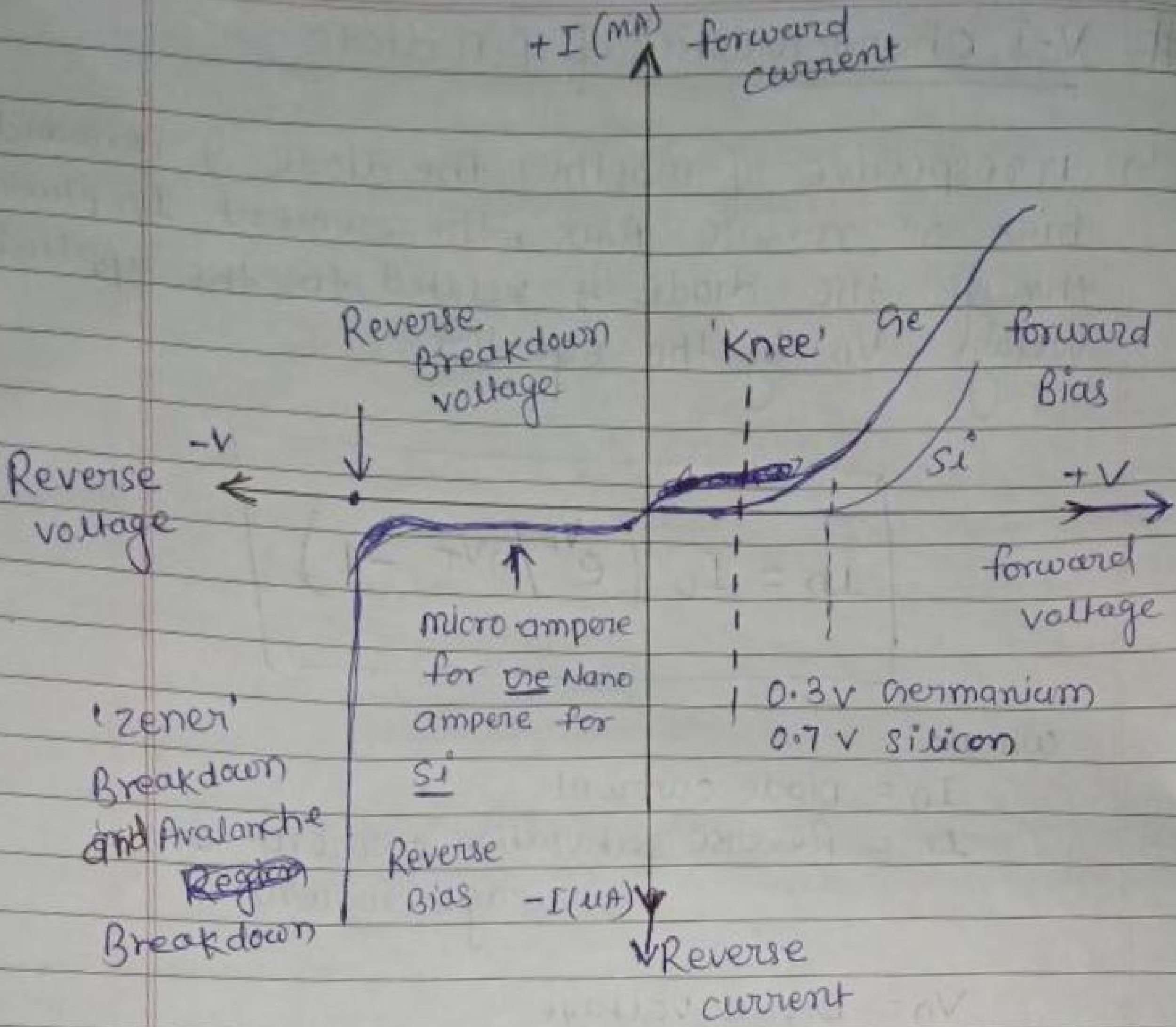
$I_0$ = Reverse saturation current or leakage current

$V_D$ = Diode voltage

$\eta$ (~~Ident~~ Ideality factor) = 1 for Ge and 2 fo Si

$V_T$ = volt Equivalent of Temperature

$\frac{T}{11600}$ volts (T should be in °K)




## # Breakdown mechanism in Reversed ~~Bia~~ Biased Diode

↳ If the reverse-bias applied to a P-N junction is increased; a point will reach when the junction breaks down and reverse current rises sharply. This specific value of the reverse bias voltage is called Breakdown voltage ($V_Z$)

1. Zener Breakdown
2. Avalanche Breakdown

① zener Breakdown -

- It occurs in highly doped diode. In Highly doped diode ~~with~~ width of depletion region is narrow

- So electric field is very high in the depletion region. so, force is very high.

↳ This High force pulled the valence electrons into conduction band by breaking covalent bonds

↳ These electrons becomes free electrons which are available for conduction

↳ A large No. of such free electrons will ~~Consti~~ Constitute a large reverse current and called the zener effect.

↳ Zener breakdown occurs less than 6V

② Avalanche Breakdown :-

↳ It occurs in lightly doped diode. in lightly doped diode width of depletion region is wide.

↳ So electric field is low so, force is low This low force cannot break the covalent bonds.

↳ As we gncrease the reverse voltage applied to the diode, the kinetic energy of minority carriers gncreases

↳ while travelling, these accelerated minority carriers will collide with the stationary atoms and gmpart some of the kinetic energy to the valence electrons present. These valence electrons will break their covalent bonds and jump into the conduction band to become free for conduction.

↳ Now these Newly generated free electrons get accelerated, they will knock out some more valence electrons by means of collision. This phenomenon is called as carrier multiplication or Avalanche effect

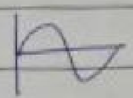
- Avalanche breakdown occurs greater than 6V.

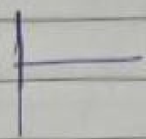
# Diode Applications -

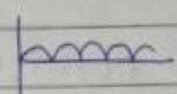
1. Rectifiers
2. clippers
3. clampers
4. voltage multipliers

## 1. Rectifiers → It is a device which convert AC into pulsating DC.

Note -

pure AC → 

pure DC → 

pulsating DC → 

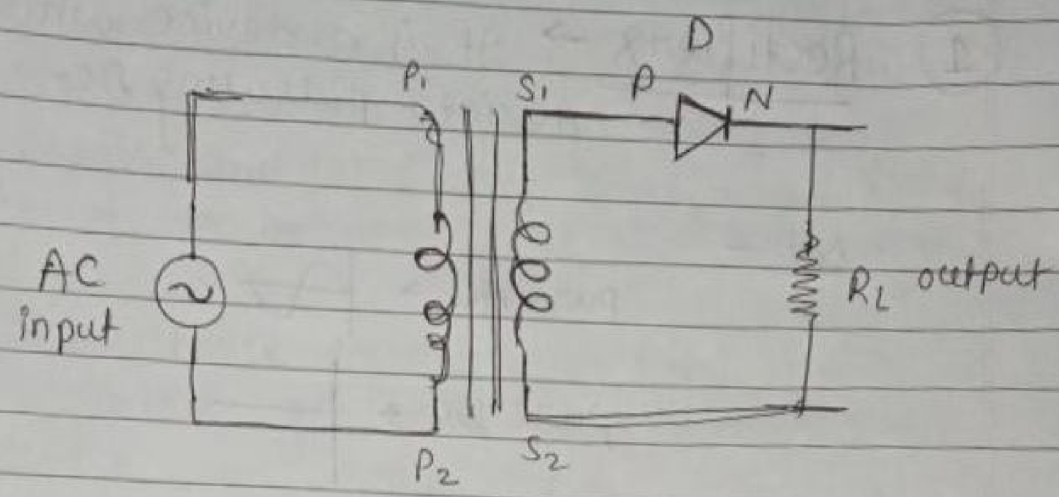
It is based on the fact that PN Junction diode will conduct heavily in forward bias and will not conduct in reverse bias.

Types of rectifier

there are two types of Rectifier

1. Half wave rectifier
2. full wave rectifier

① **Half wave rectifiers** - The rectifier which give output only for positive half cycle but not for -ve half cycle is called Half wave rectifier.

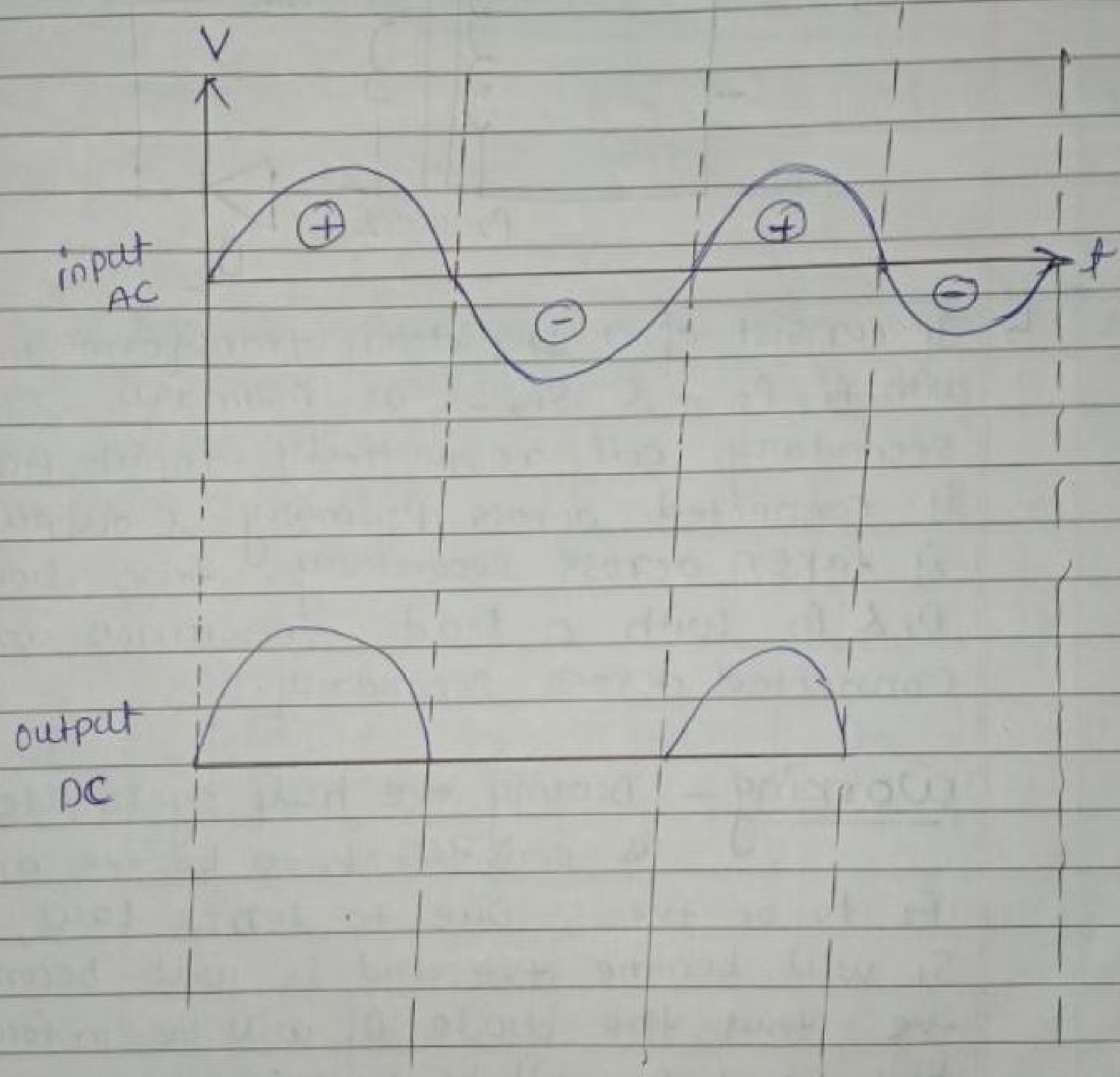



↳ It consist of a step down transformers with $P_1$ $P_2$ & $S_1$ $S_2$ as primary & secondary coils Respectively ~~respect~~ AC input is connected across primary. A PN junction diode with load resistance $R_L$ are connected arcross secondary.

**working** - During +ve half cycle let us consider $P_1$ to be negative and $P_2$ to be +ve Due to lenz's law $S_1$ become positive & $S_2$ will become -ve. Hence the diode will be in forward bais and will give output.

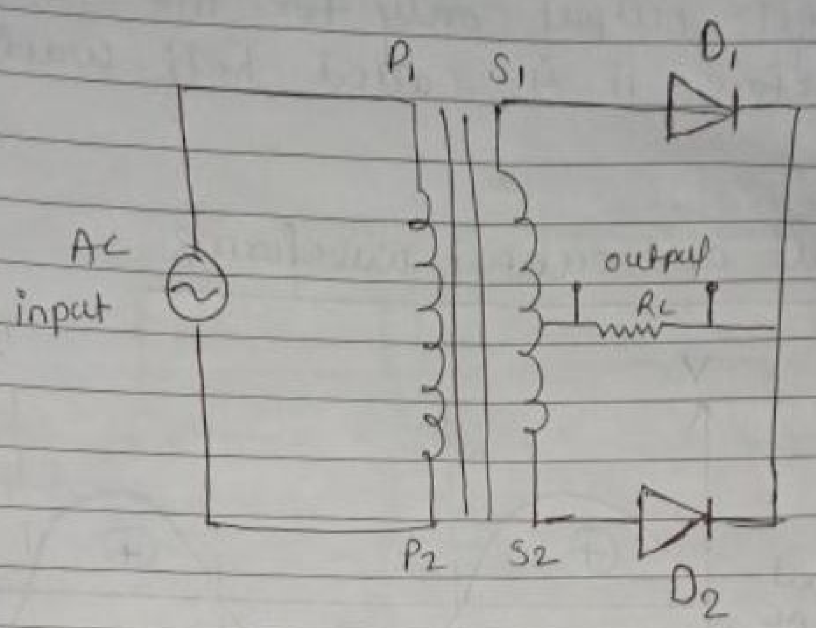
During negative half cycle, $P_1$ will become +ve and $P_2$ will become -ve. Due to lenz's law $S_1$ will become -ve and $S_2$ will become +ve. therefore the diode will be reverse bias and hence will not give output thus we get output only for the half cycle therefore, it is called half wave rectifier.

input and output waveforms



(2) **full wave Rectifiers** - The rectifier which gives output for positive half cycle as well as -ve half cycle is called full wave Rectifiers.

**Construction**

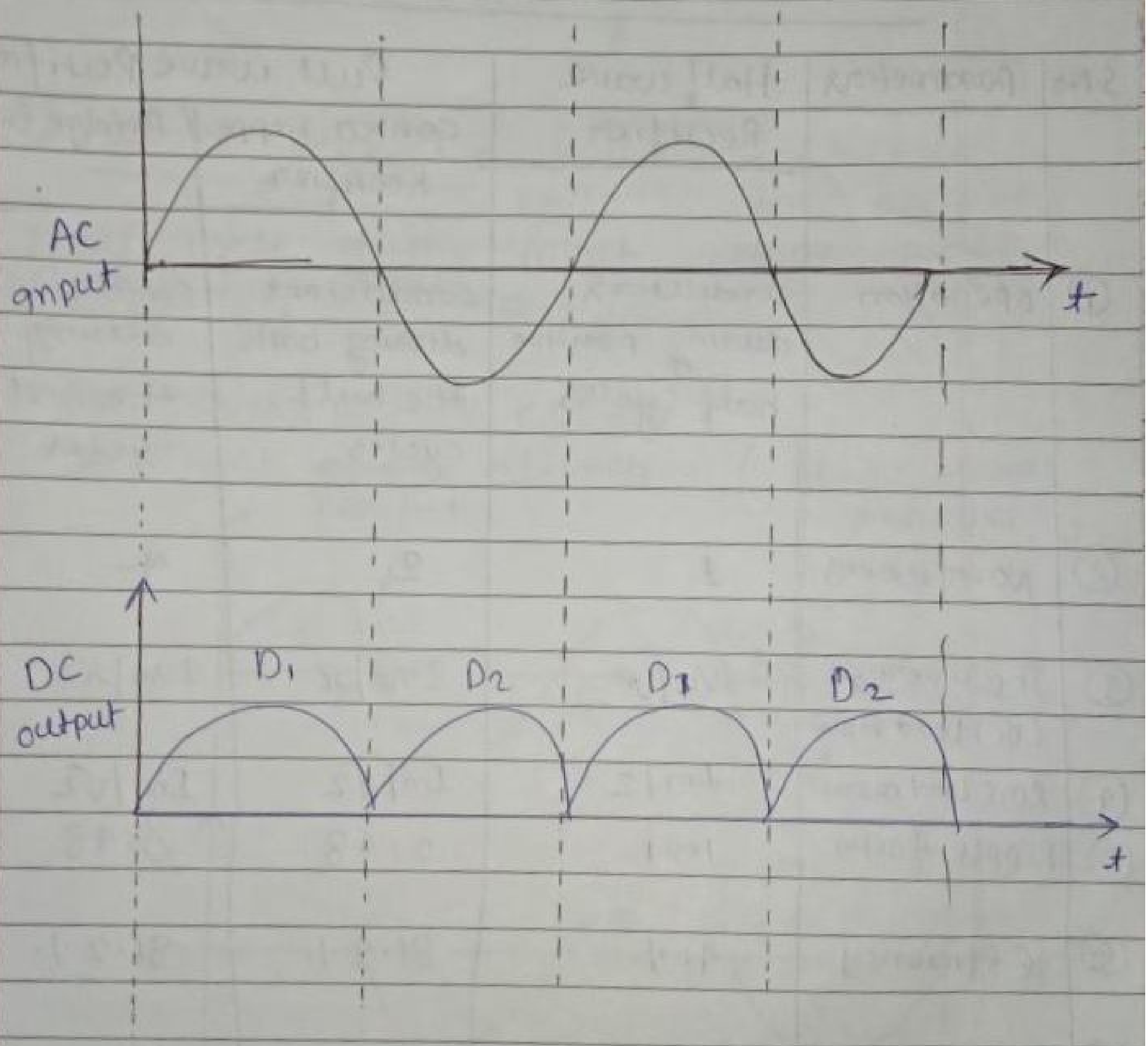



↳ It consist of a step down transformer with $P_1$, $P_2$ & $S_1$, $S_2$ as primary & secondary coil respectively. Input AC is connected across primary & output is taken across secondary. two diodes $D_1$ & $D_2$ with a load resistance are connected across secondary.

**Working** - During +ve half cycle, let us consider $P_1$ to be -ve and $P_2$ to be +ve. Due to lenz's law, $S_1$ will become +ve and $S_2$ will become -ve thus the diode $D_1$ will be in forward bias and $D_2$ will be reverse bias. Therefore we will get output through $D_1$

↳ for the -ve half cycle, $P_1$ will become +ve and $P_2$ will become -ve. Due to lenz's law $S_1$ will become -ve and $S_2$ will +ve therefore the diode $D_2$ in forward bias and hence we will get output through $D_2$ thus it gives output for both the half cycle therefore it is called full wave rectifier.

Input and output waveforms



Note – (i) efficiency of half wave rectifier is 40.2% &

efficiency of full wave rectifier is 80.4%

(ii) This pulsoting DC can be converted into pure DC by use of filter circuit like capacitor indicator etc.

# Comparison between HWR & FWR

| S.No | parameters | Half wave Rectifier | Full wave Rectifier: Center tapped Rectifier | Full wave Rectifier: Bridge Rectifier |
|---|---|---|---|---|
| (1) | operation | Conductors during positive half cycles | conductors during both the half cycles | Conducts during both the half cycles |
| (2) | NO. of diodes | 1 | 2 | 4 |
| (3) | The average (DC) load voltage | $V_m/\pi$ | $2V_m/\pi$ | $2V_m/\pi$ |
| (4) | Rms Load current | $I_m/2$ | $I_m/\sqrt{2}$ | $I_m/\sqrt{2}$ |
| (5) | Ripple factor | 1.21 | 0.48 | 0.48 |
| (6) | Efficiency | 41% | 81.2% | 81.2% |
| (7) | PIV | $V_m$ | $2V_m$ | $V_m$ |

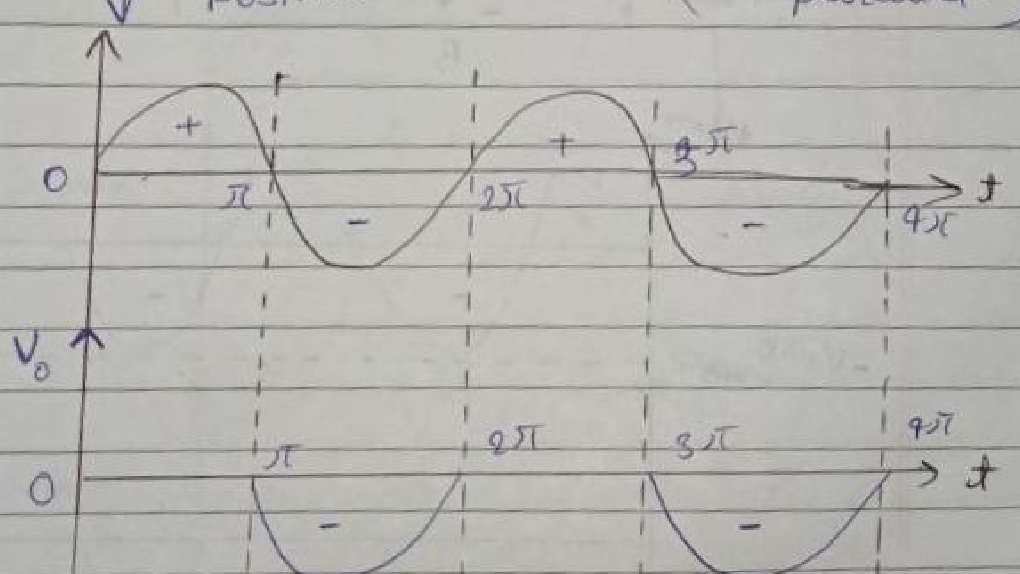
# Clipper circuits

clipper - clipper is a circuit which is used to clip-off 'or' remove some portion of input waveform. clippers are following type

1. positive clipper
2. Negative clipper
3. Baised clipper
4. combination clipper

(i) positive clipper - A positive clipper removes the positive half cycle of the input voltage. positive clipper is of two type:

(a) Series positive clipper
(b) Shunt ~~plosive~~ positive clipper (Shunt Means parallel.)

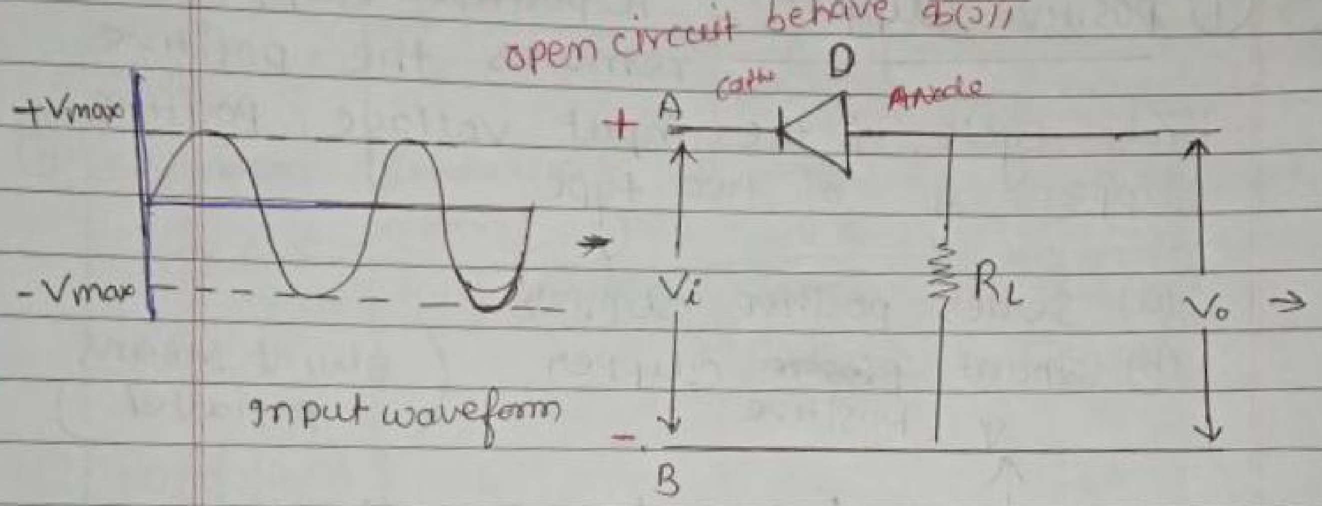


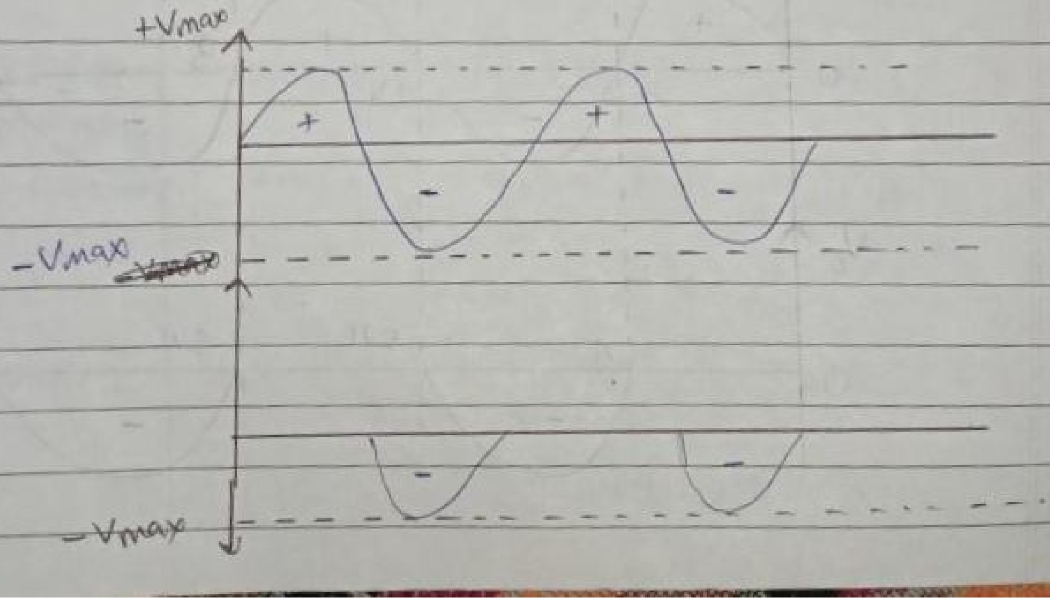
## (a) Series positive clipper

operation :-

↳ In positive cycle diode is reverse biased so, diode is off and output will be zero.

↳ In negative cycle diode is forward baised so, diode is on and output will be negative input cycle so $\boxed{V_0 = V_i}$

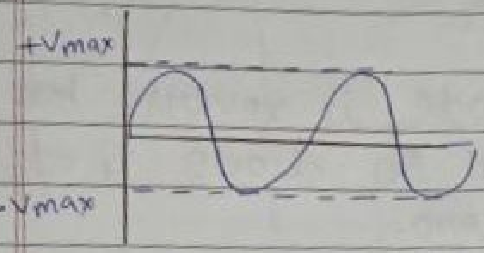


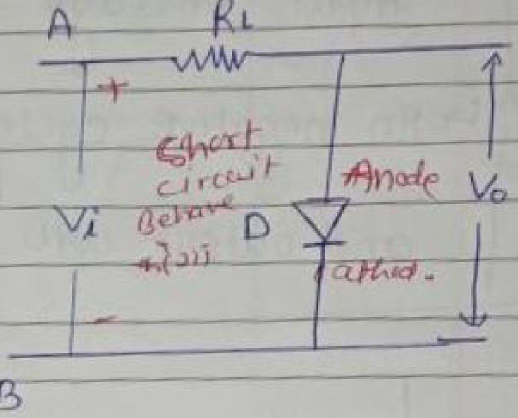
(b) Shunt ~~plastive~~ positive clipper

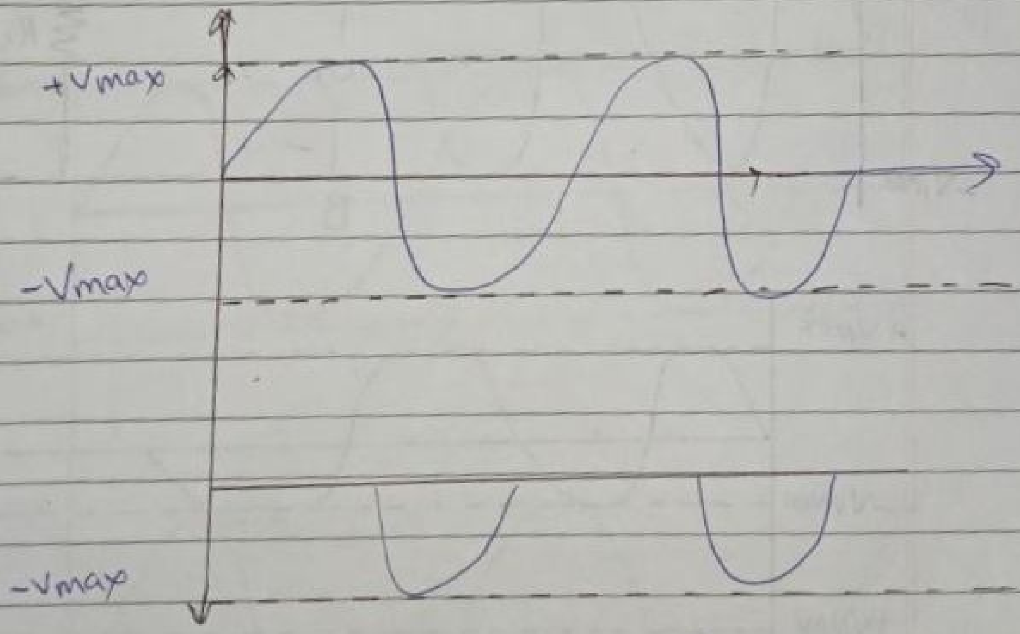
operation - In positive cycle diode is forward biased so diode is on and output will be zero.

In negative cycle diode is reverse biased so diode is off and output will be negative input cycle so $V_o = V_i$



input waveform



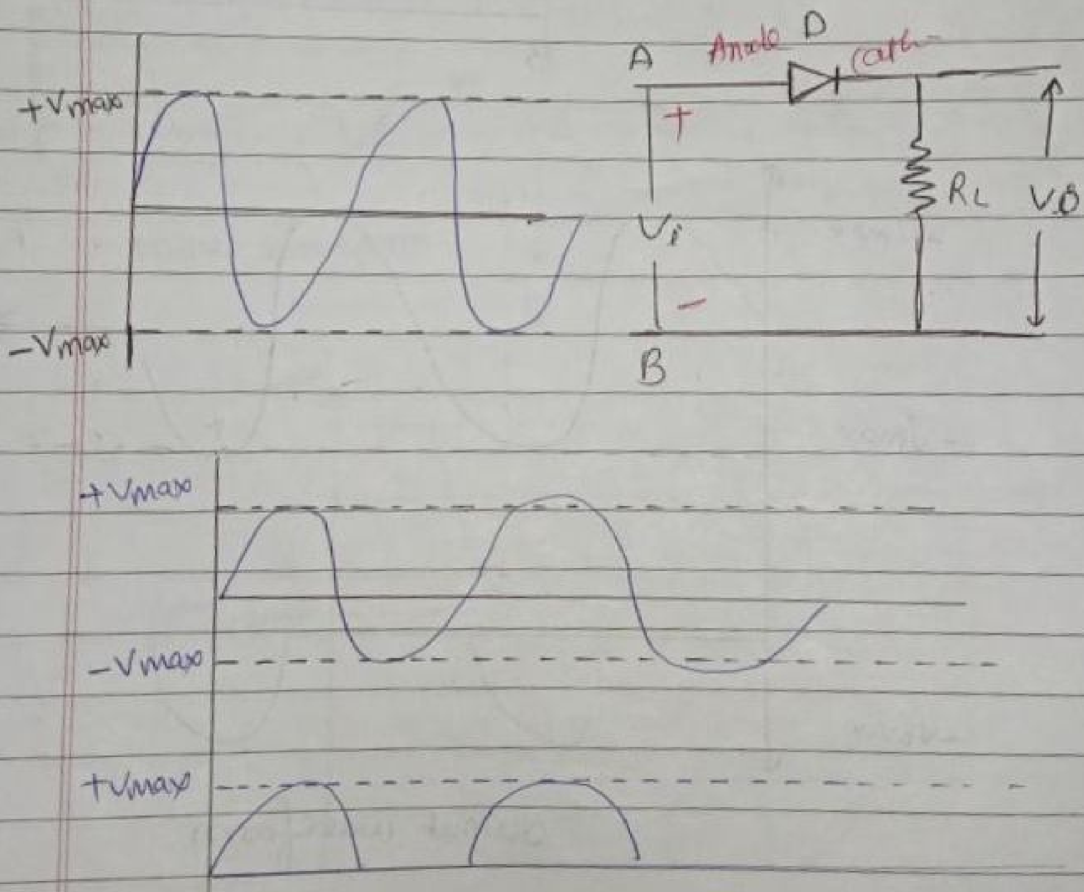
output waveform

(11) <u>Negative clipper</u> – A positive clipper removes the negative half cycle of the input voltage. Negative clipper is of two type.

(a) <u>Series Negative clipper</u>

<u>operation</u> → In positive cycle diode is forward biased so diode is on and input will be equal to input voltage

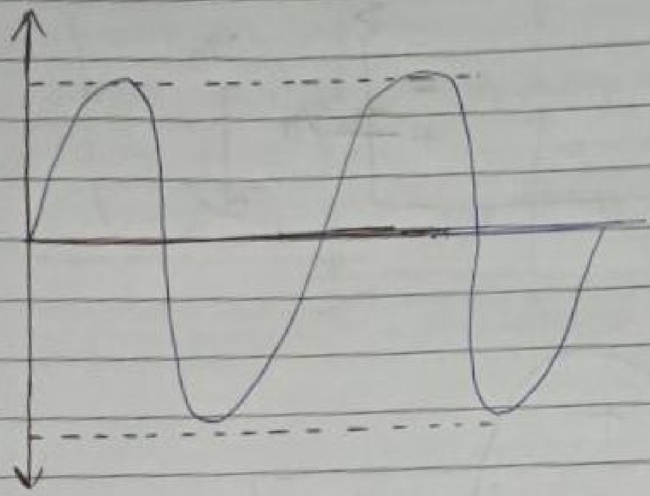
↳ In negative cycle diode is reverse biased so diode is off and output will be zero.

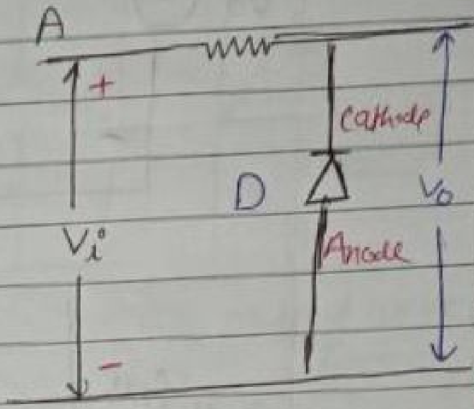


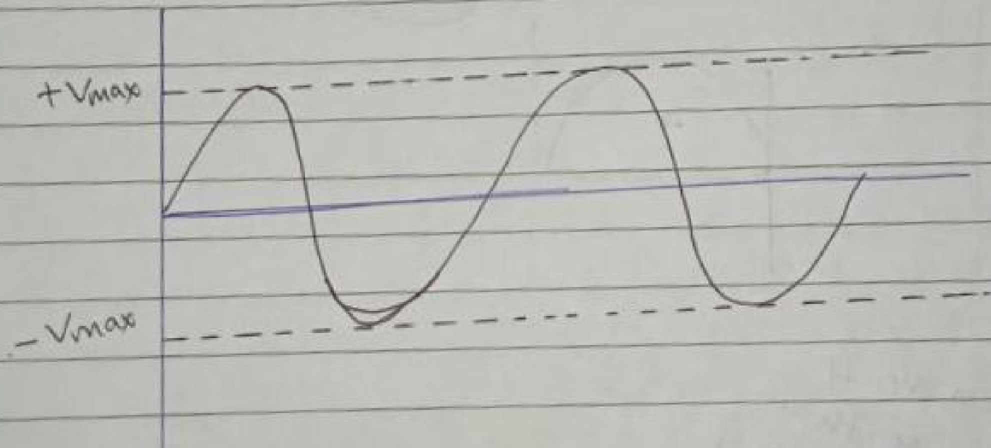
## (b) Shunt Negative clipper

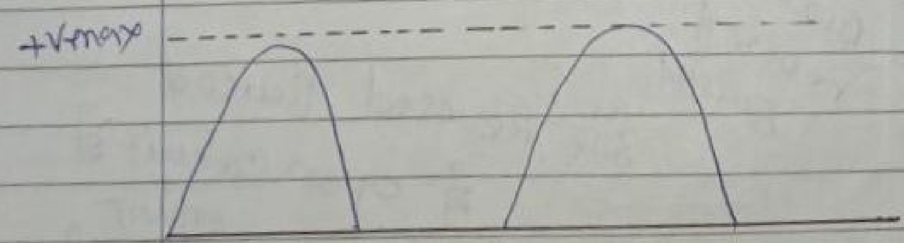
operation - in positive cycle diode is forward biased so diode is on and output will be equal to input voltage.

↳ in negative cycle diode is reverse biased. so diode is off and output will be zero.



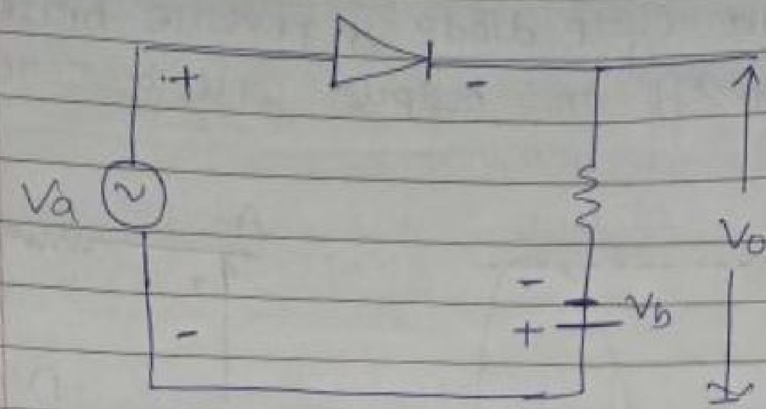


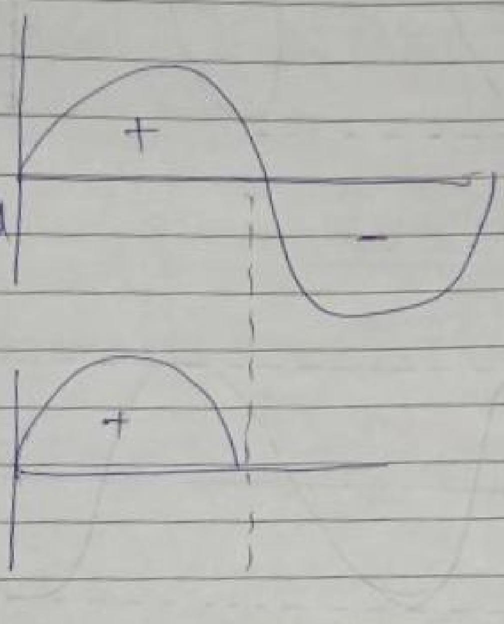



# (iv) Combination clipper

## (iii) Baised clipper




when Va is less than Vb Diode is forward



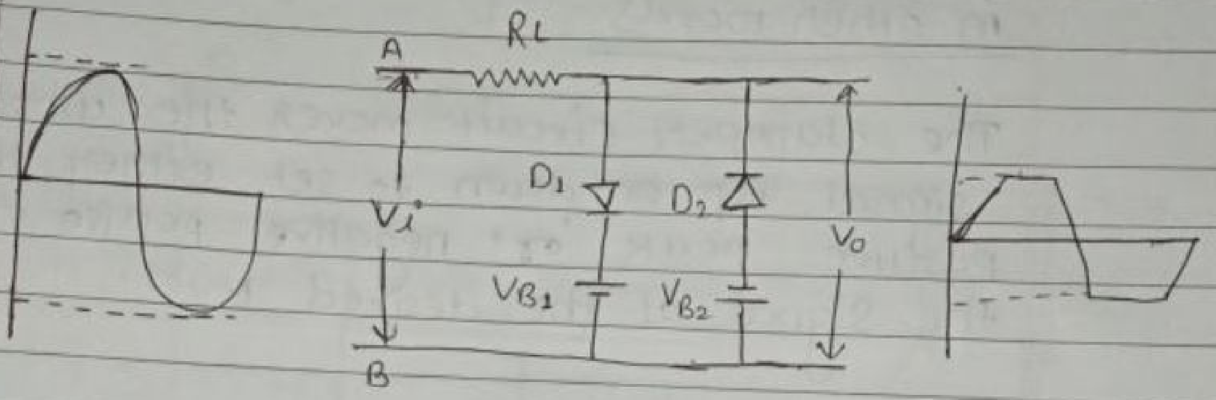

when Va is greater than Vb Diode is reversed Baised

और Reversed Baised में open circuit हो जाएगा

just ~~Rever~~ polarity chang करके second condition बनाना

## (IV) Combination clipper 'or' two way clipper

↳ Baised clipper is used to clip-off or remove a small portion of positive cycle or Negative cycle or both this is achieved by adding a battery in series with diode.




output wave form

# Clamper circuits

↳ A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal.

in other words

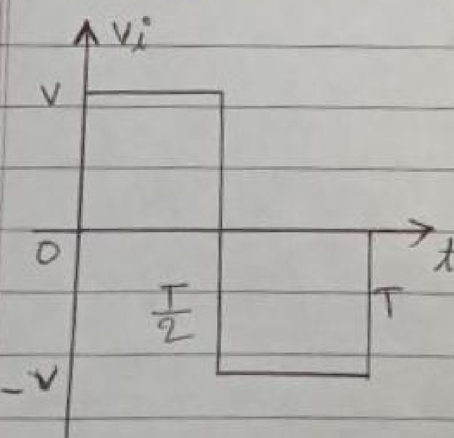
The clamper circuit moves the whole signal up or down to set either the positive peak or negative peake of the signal at the desired level.

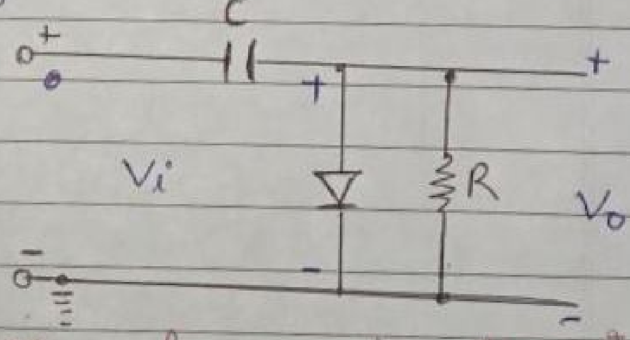
Negative clampers
Positive clampers

# Negative clammper circuit

in positive cycle

in positive cycle diode is forward ~~Ba~~ Biased ~~and~~ acts as short circuits so capacitor is quickly charged to ~~volt~~ voltage V.



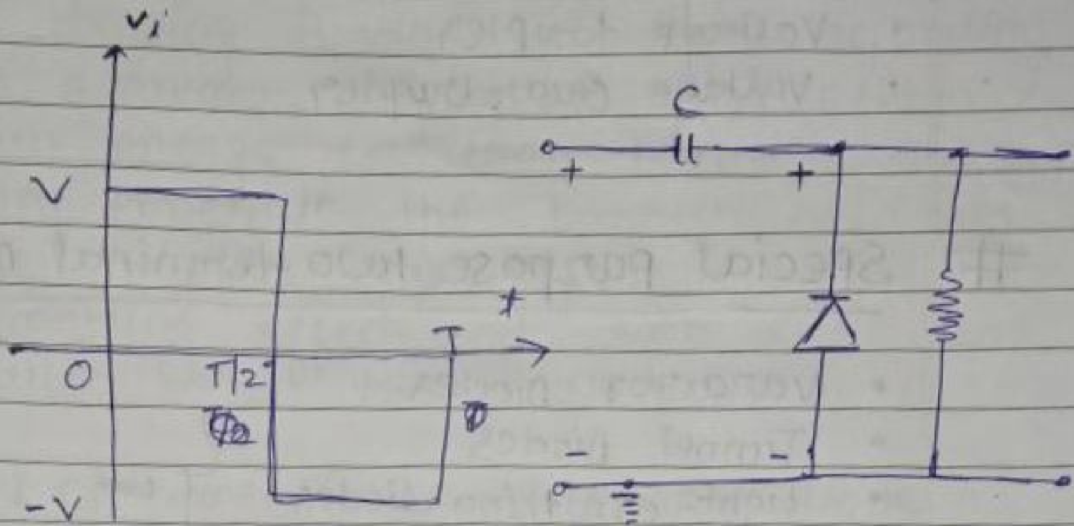




for negative cycle is

# Positive clamper circuit

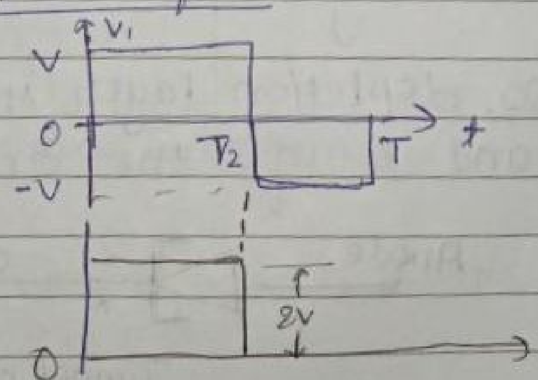
in Negative cycle

↳ In negative cycle diode is forward Biased and acts as short circuit. so capacitor is quickly charged to voltage V.




in positive cycle - in positive cycle diode is reverse biased and acts as open circuit, since the discharging time of capacitor is high so, capacitor maintains its voltage during negative cycle

input-output waveform



# Voltage mutiplier circuit

↳ voltage mutiplier circuits produce a DC output voltage, that is some multiple of the peak ac input voltage to this circuit

- voltage Doubler
- voltage tripler
- voltage Quardrupler

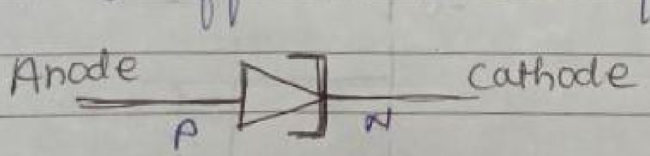
# Special purpose two terminal Devices

- varactor Diodes
- Tunnel Diodes
- Light-emitting diodes
- Photo diodes
- Liquid-crystal displays

- Tunnel diode – Tunnel diode is very Highly doped diode.

↳ The doping of tunnel Diode is 1000 times greater than simple Diode

↳ So, depletion layer is very narrow and is off the order of 10 nm.



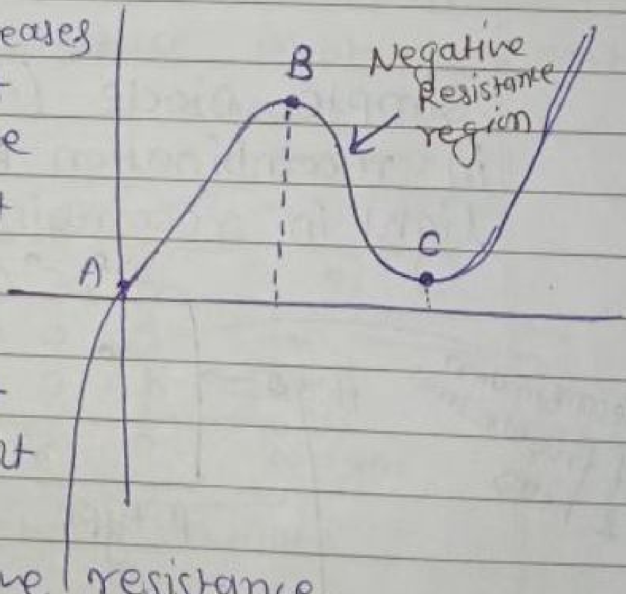

Tunnel diode symbol.

## Working principle of tunnel Diode

- In P-N junction a potential barrier exists. According to classical mechanics an electron can pass the barrier if it has an energy equal or greater than energy of potential barrier.

- If dopping is very high then according to quantum mechanics a electron with energy less than barrier energy can penetrate the barrier or cross the barrier, this effect is called tunneling effect and such diode are called tunnel diode.

## V-I characteristics of tunnel diode




**Point A to B** – current increases till point B at very low voltage due to tunnelling effect

**Point B to C** – current decreases till point C. At point C current is minimum and diode shows negative resistance.

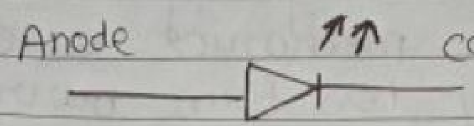
**After point C** – Tunnel diode works as normal diode

LED को forward baised में use करते है



- Light emmitting Diode (LED)

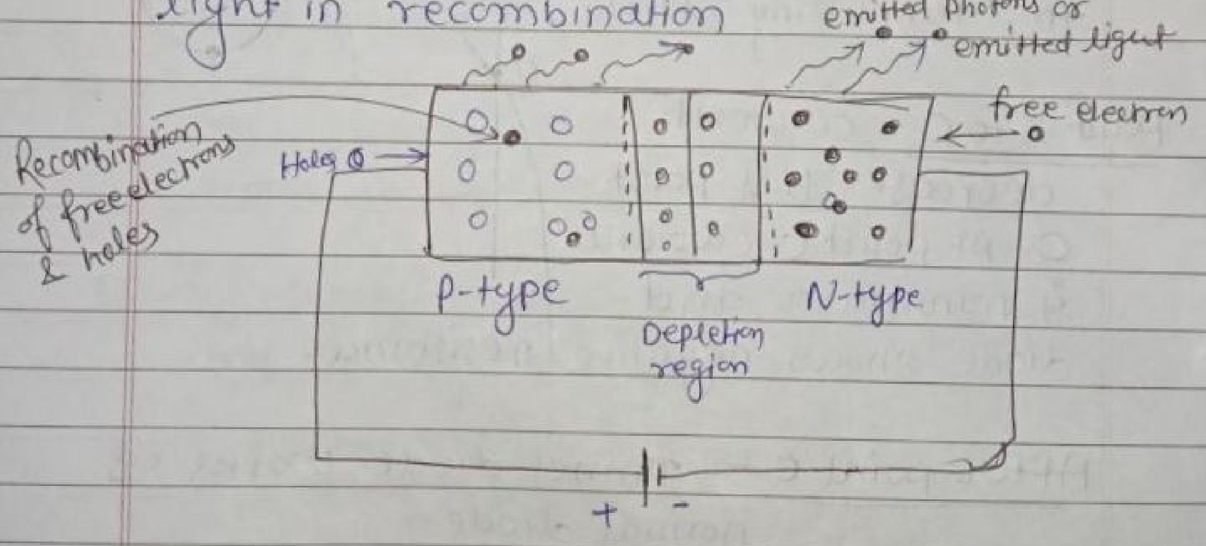
↳ Light emmitting diode (LED) is a special diode which give light, when forward biased. materials like gallium, phosphorous and arsenic are used for the manufacturing of LED




working principle of LED

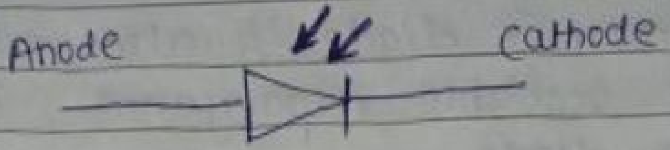
↳ when LED is forward baised then hole in p-type and electron in n-type start to cross the junction and recombine with each other

Simple Diode (si or Ge) produce heat in recombination process. but LED produce light in recombination



photodiode को Reverse Baised में use करते है।

# Photodiode

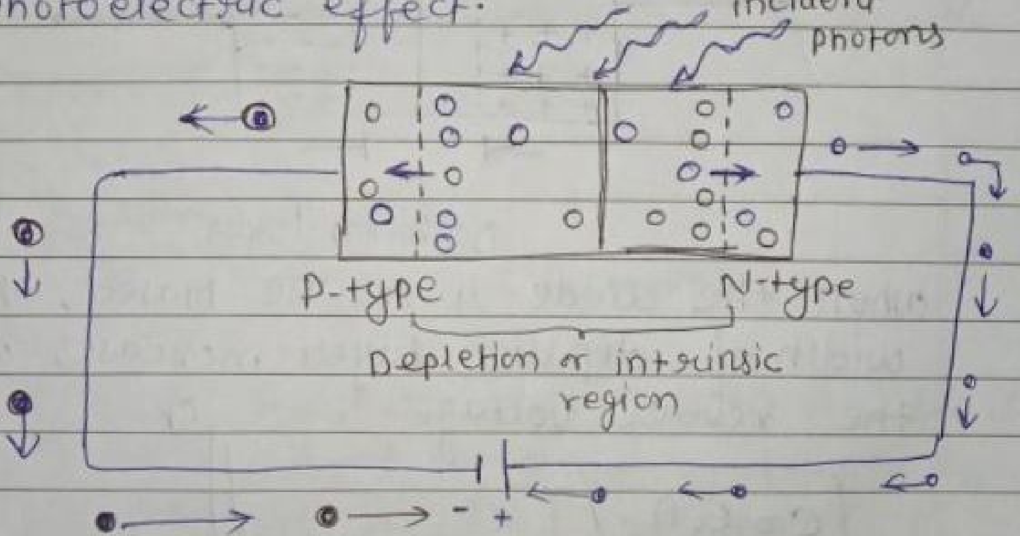



## Working principle

When a light or photon is used to illuminate P-N junctions then photon hits the immobile ions present in the Depletion layer.

- If energy of photon is greater than 1.1 eV than covalent bond will break. So, electron hole pair are generated.

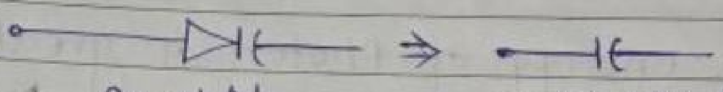
- Due to electric field, electron-hole pairs move away from the junction. Hence, holes move to anode and electrons move to the cathode to produce photocurrent this entire process is known as photoelectric effect.



## Varactor diode

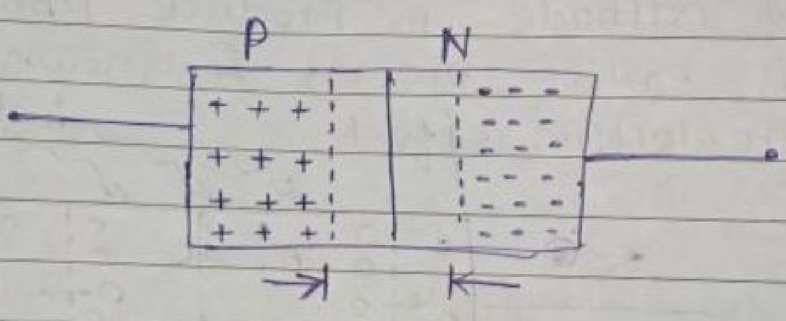
↳ The varactor diode is also called voltage variable capacitance 'or' varicap diode.

It is ~~Used~~ widely used in television receivers, FM Receivers for electronic ~~turning~~. tuning.



Symbol ⇒ equivalent circuit

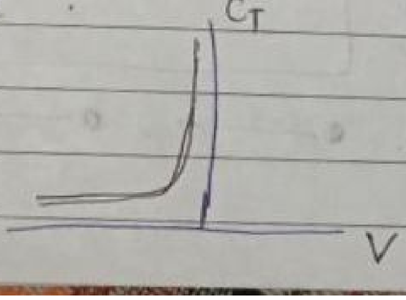
The P and n-regions are like the plates of a capacitor and the depletion layer is like the dielectric.




Depletion layer

when the diode is reverse biased, the width of depltion layer increases with the reverse voltage.

$$\boxed{C = \frac{\epsilon_0 A}{d}}$$

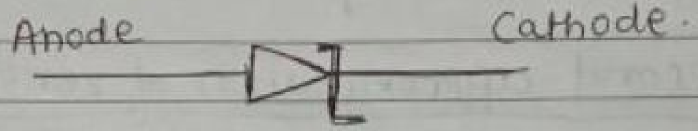


# Zener Diode-

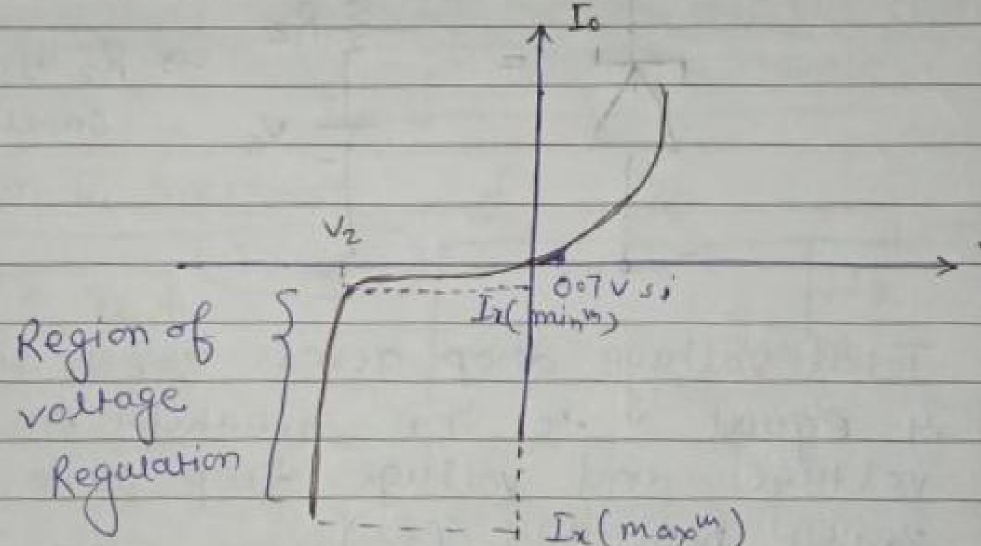
A zener Diode is a special type of P-N junction semiconductor diode.

It can work in forward bias as that of P-N junction diode and it can also work in reverse bias that makes it special.

it reverse bias zener diode works as a voltage Regulator.

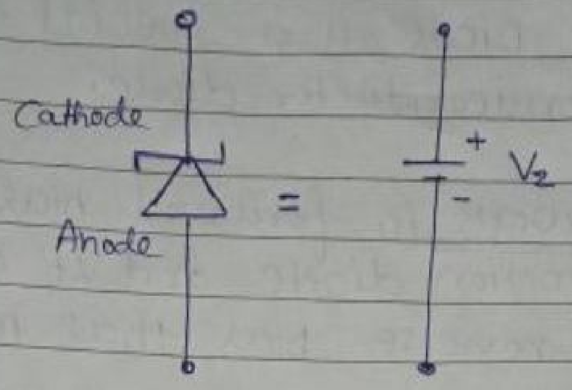



V-I Characteristics :-




↳ A voltage Regulator circuit Keep the load voltage constant irrespective changes in input voltage or load resistance.

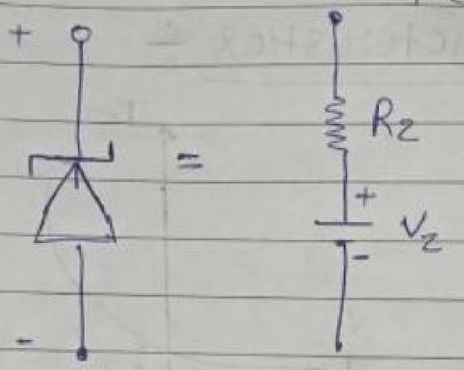
# Ideal Approximation of a zener diode




Zener diode operating in breakdown region ideally act like a battery of value equal to breakdown voltage.

# Second approximation of zener diode

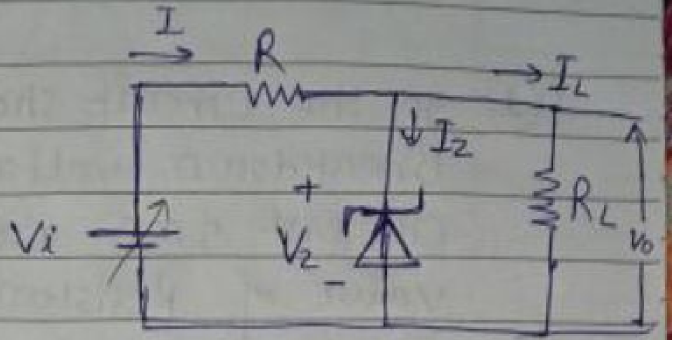
i.e called practical zener diode




→ $R_z$ is very small.

Total voltage drop across zener diode is equal to the breakdown voltage and voltage drop across zener Resistance ($R_z$)

## Regulating Action of zener diode with varying input voltage -



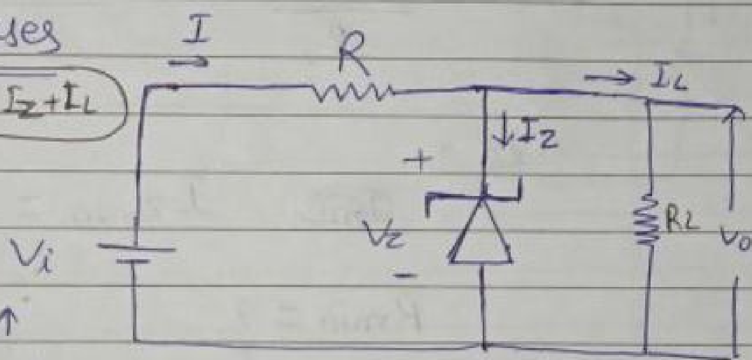

When $V_i$ increasing $V_o = V_Z$ as long as $I_Z < I_{Zmax}$

when $V_i$ decreasing $V_o = V_Z$ as long as ~~$I_Z > I_{Zmin}$~~
$I_Z > I_{Zmin}$

$$\boxed{I_Z = I - I_L}$$

## Regulating action of zener diode with varying load resistance :-

(i) when $R_L$ increases




$I = I_Z + I_L$

if $R_L \uparrow$, $I_L \downarrow$
but I remains constant
Since $I_L \downarrow$, $I_Z \uparrow$
Therefore output voltage $V_o = V_Z$ as long as $I_Z < I_{Zmax}$

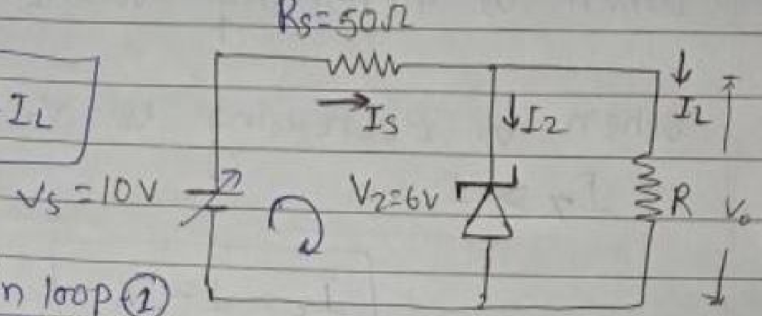
(ii) when $R_L$ Decreases
if $R_L \downarrow$, $I_L \uparrow$
Since $I_L \uparrow$, $I_Z$ decrease $V_o = V_Z$ as long as $I_Z > I_{Zmin}$

# Zener diode Shunt Regulator -

## Numerical problem

Q.(1) In the circuit shown zener diode has Breakdown voltage 6V and Knee Current 5 mA calculate the minimum value of Resistance R so that the output voltage remains constant at 6V

$$\boxed{I_S = I_Z + I_L}$$




Apply KVL in loop (1)

$$-V_S + 50 I_S + V_Z = 0$$

$$I_S = \frac{V_S - V_Z}{R_S} = \frac{V_S - V_Z}{50} = \frac{10-6}{50}$$

$$= 80\,mA$$

$\cancel{I_Z =}$

$\cancel{I_{Zmin}}$ $\quad I_{Z\,min} = 5\,mA$

$$R_{min} = ?$$

$$I_S = I_Z + I_{L\,max}$$

{ Here $I_S$ fix है तो $I_Z$ min को decrease करना पड़ेगा

$$I_S = I_{Zmin} + I_{Lmax}$$

$\cancel{I_S = 80\ 80mA}$

$$I_{L\,max} = I_S - I_{Z\,min}$$

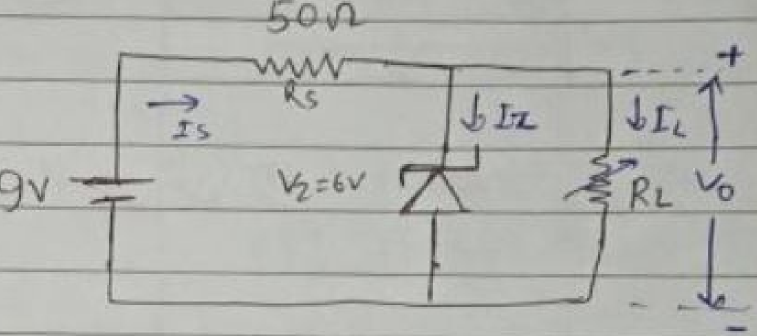
$$= 80\,mA - 5\,mA = 75\,mA$$

$$R_{min} = \frac{V_0}{I_{L\,max}} = \frac{6}{75 \times 10^{-3}} = 80\,\Omega$$

{ $V_0 \parallel V_L$ Hence

$V_0 = V_L = 6V$

Q② A zener diode with breakdown voltage of 6V, Knee current 5mA and max^m allowed power dissipation 300 mW is used in the circuit shown calculate minimum and max^m load current such that $V_0$ remains constant at 6V




$I_{Z\,min} = 5\,mA$

$P_{Z\,max} = 300\,mV$

$I_{L\,min}$, $I_{L\,max} = ?$

$$I_S = \frac{V_S - V_Z}{R_S}$$

$$\Rightarrow \frac{9-6}{50} = \frac{3}{50} = \frac{3 \times 10^3}{50}\,mA = 60\,mA$$

$$I_S = I_{Z\,max} + I_{L\,min}$$

$=$

$$I_{L min} = I_S - I_{z max}$$

$$\Rightarrow 60 - 50$$

$$= 10 mA$$

$$P_{z max} = V_z \times I_{z max}$$

$$I_{z max} = \frac{P_{z max}}{V_z}$$

$$= \frac{300}{6} = 50 mA$$

$$I_{L max} = I_S - I_{z min}$$

$$= 60 - 5$$

$$= 55\ mA$$

# Give the comparsion between an Ideal diode and practical diode?

↳ Difference b/w Ideal diodes and Practical diodes:

| Ideal diodes | Practical diodes |
|---|---|
| (i) Ideal diodes act as perfect conductor and perfect insulator | (i) Pratical diodes can not act as perfect conductor and perfect insulator |
| (ii) Ideal diode draws no current when reverse biased. | (ii) Practical diode draws very low current when reverse Biased. |
| (iii) It can not be manufactured. | (iii) It can be manufactured |
| (iv) It has zero cut-in-voltage | (iv) It has very low cut-in-voltage |
| (v) Ideal diode has zero voltage drops across its junction when forward biased. | (v) It has very low voltage drop across it, when forward biased. |
| (vi) Ideal diodes acts as perfect conductor and perfect insulator | (vi) Pratical diode act as perfect conductor and perfect insulator. |

# Module-02

## Transistor characteristics

# Bipolar junction transistor

- Construction
- operation
- Amplifying ~~action~~ action
- CB → common Base
- CE → common emitter
- CC → common collector configuration
- operating point
- voltage divider bias configuration

# Field effect Transister (FET)

- Construction
- Characteristic of (JFET)
- DE & EN MOSFET (DE → Depletion enhancement)
- Introduction to CMOS circuits.

# full form

1. FET- field effect transistor
JFET- Junction field effect transistor
MOSFET- metal oxide semiconductor field effect transistor
Cmos - complementary metal oxide semi-conductor.

## Transistor

↳ A semiconductor device consisting of two PN junction formed by sandwiching either P type 'or' N type between a pair of opposite type of is known as a transistor.

↳ Transistor is called bipolar device because its operation depends on the interaction of majority and minority carrier both

### Classification of Transistor

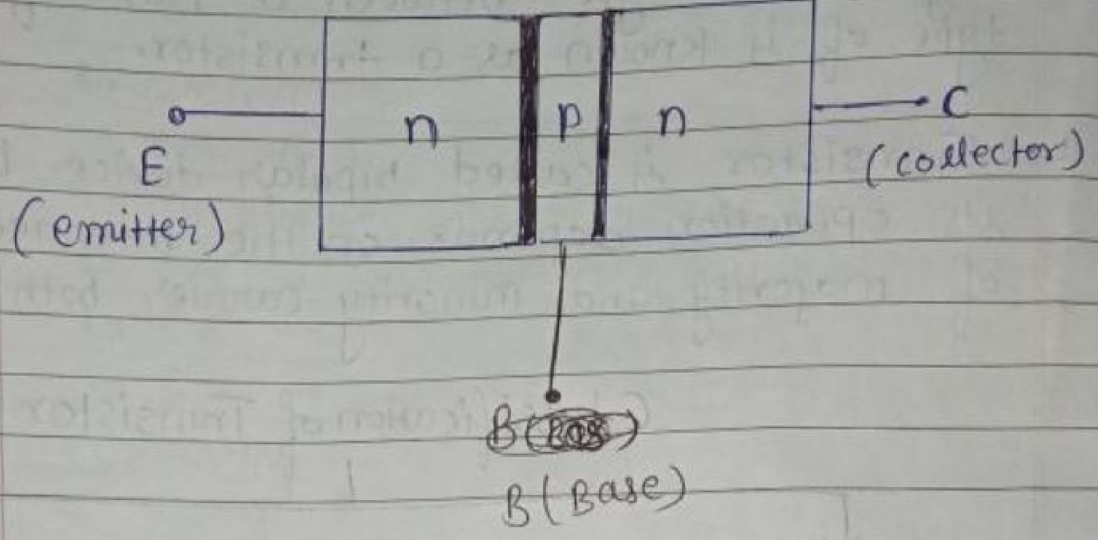
- BJT
  - npn
  - pnp
- FET
  - JFET
    - n-channel
    - p-channel
  - MOSFET
    - Depletion MOSFET
      - n channel
      - p channel
    - Enhancement MOSFET
      - n-channel
      - p channel

Note-(i) BJT is current controlled device from current source

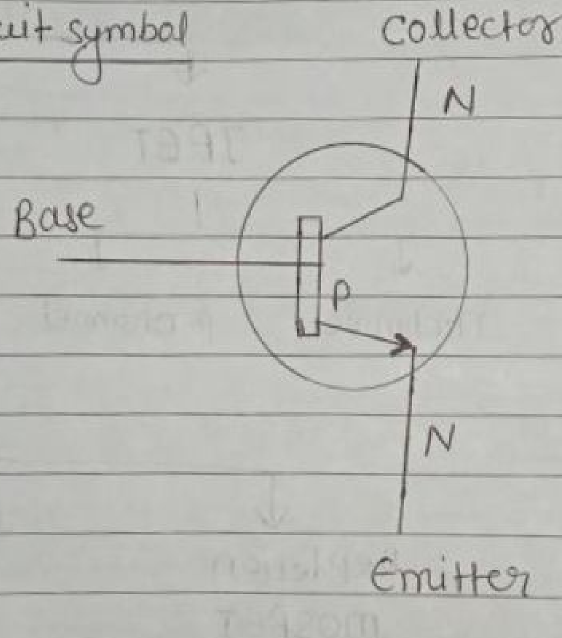
(ii) FET is ~~controlled~~ voltage controlled device from current source.

# Construction of transistor (BJT)

(i) n-p-n

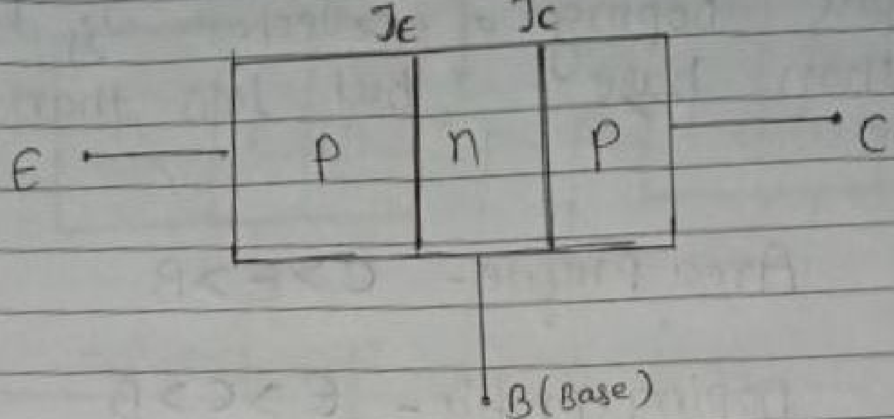


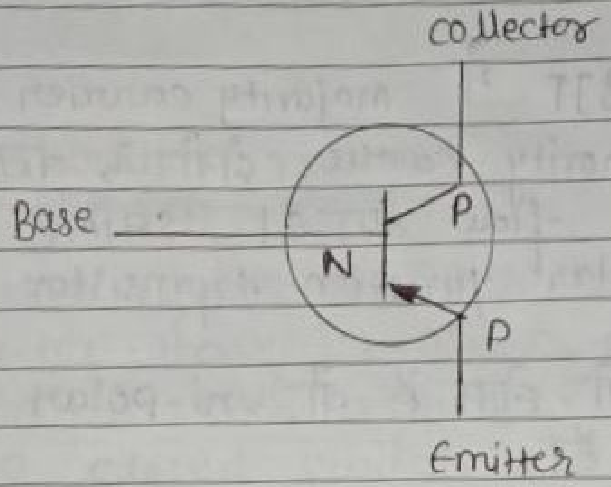

circuit symbol




n-p-n

(ii) p-n-p




- **Emitter** - It is the highest doping region in the transistor. it supplies (emits) carrier to the base. it supplies electron to the base in n-p-n and holes in p-n-p.

- **Base** - The middle part of transistor is called base. it is very thin and lightly doped. so most of the carrier coming from emitter passes to collector

- Collector - collector collect the carriers which are coming from base. Doping of collector is havier than base but less than emitter

Area profile - C>E>B

Doping profile - E>C>B

Note - BJT में majority carrier & minority carrier दोनों के वजह से current flow होता है। इसलिए इसे हम Bipolar junction transistor कहते हैं।

FET जो होता है वो uni-polar device होता है।

# Mode or working Regions of Transistor

Transistor operates in three modes

(i) Active region -

in active region emitter - base junction is forward biased and collector Base junction is reverse Biased. in this region transistor works as an amplifier.

fig (npn)

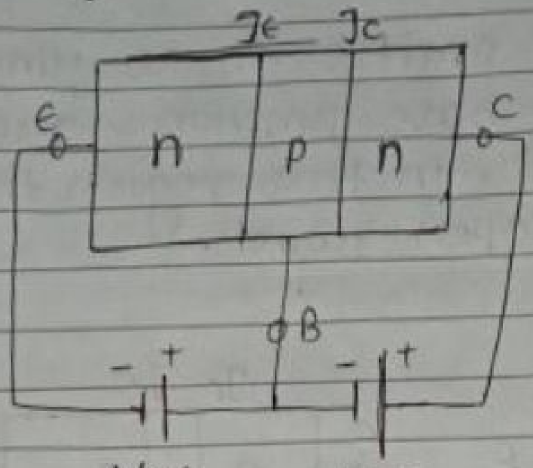
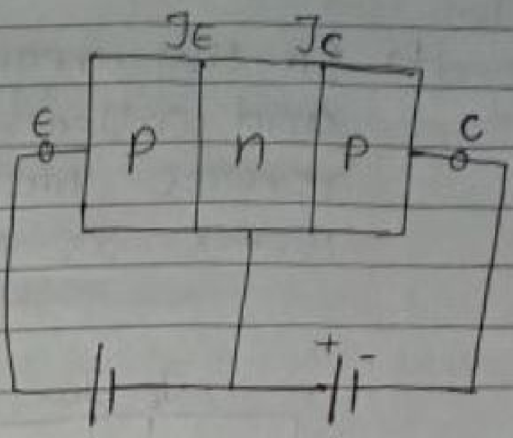
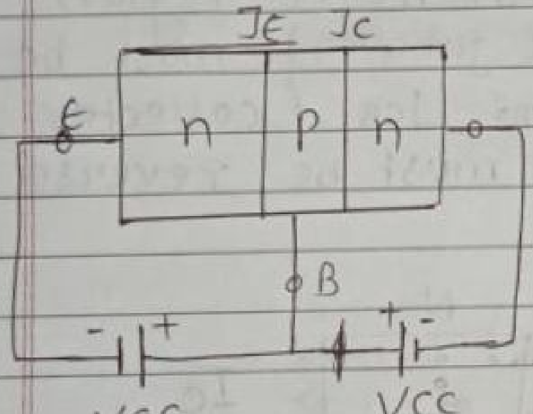


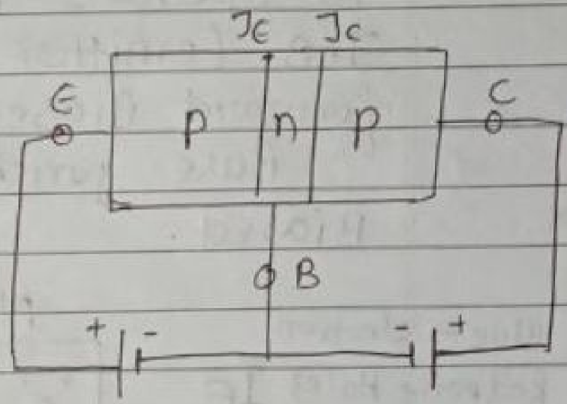

fig (pnp)




(ii) Saturation region

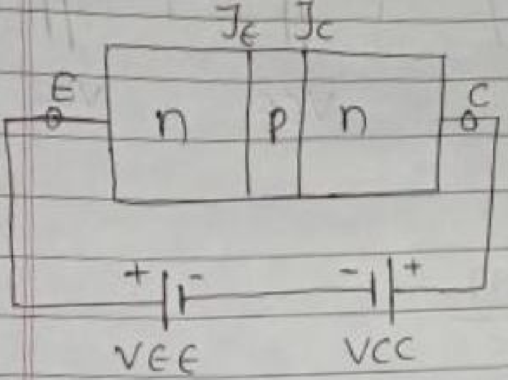
↳ in this region emitter-base junction and collector-base junction are forward Biased. in this region transistor works as a closed switch.

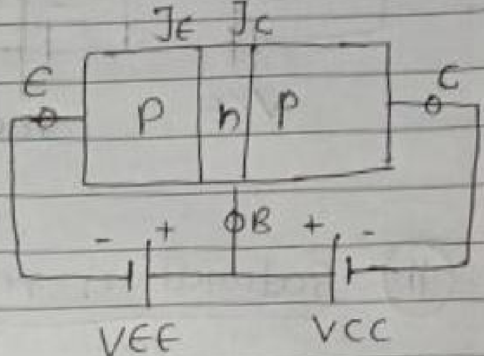


## (III) Cut-off region

↳ In this region emitter-base junction and collector-base junction are reverse biased. in this region transistor works as a open switch.

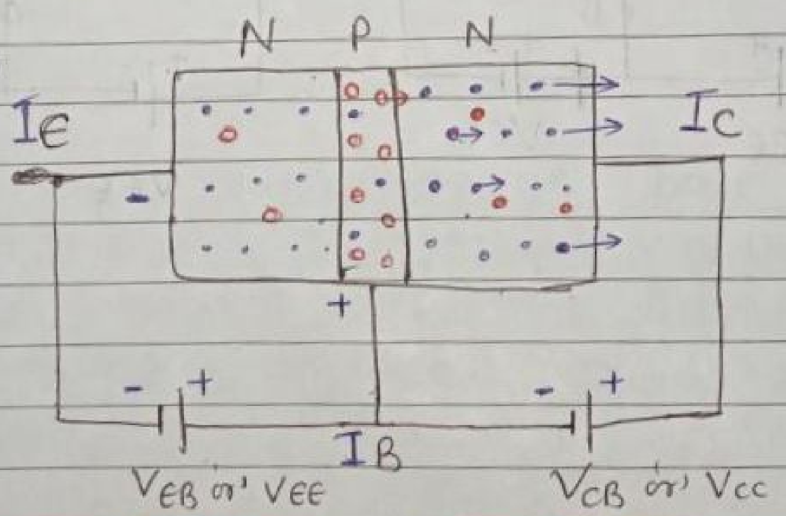



## # Operation of Transistor in Active region

↳ To operate BJT in Active region JEB (emitter Base junction) must be forward Biased and JCB (collector Base junction) must be reverse Biased.

Blue → electron
Red pen → Holes



- $J_{EB}$ is forward Biased by the Battery $V_{EE}$ by which the depletion region will decrease and a majority carrier flow will occur from emitter to base giving current $I_{majority}$ or $I_E$

- in base region there is recombination b/w electrons and holes due to which base current is obtained. As number of holes in base is very small, base current is very small

- $J_{CB}$ is reverse Biased by $V_{CC}$. so collector current is due to flow of majority charge carriers from both sides of the junction. In base minority carriers are electrons left after recombination and in collector minority carriers are holes.

$$\boxed{I_E = I_C + I_B}$$

# Transistor configuration or connection

↳ Transistor has three terminals emitter, base and collector. But we require four terminals to connect the transistor in a circuit as an amplifier. two for input and two for output.

↳ This is achieved by making one terminal of transistor common to input and output.

↳ So, transistor has three configurations based on the common terminal.

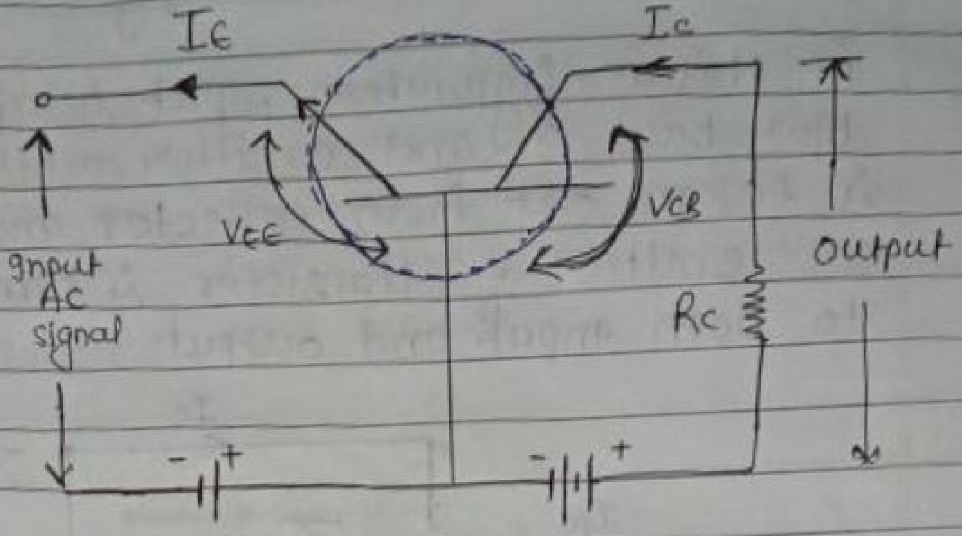
(i) Common base configuration (CB)

(ii) common emitter configuration (CE)

(iii) Common collector configuration (CC)

## CB (common base configuration)

- Input is applied b/w emitter and base
- output is taken out from collector and base
- Base is common b/w input and output




## DC current gain

↳ It is the ratio of output current ($I_C$) to the input current ($I_E$)

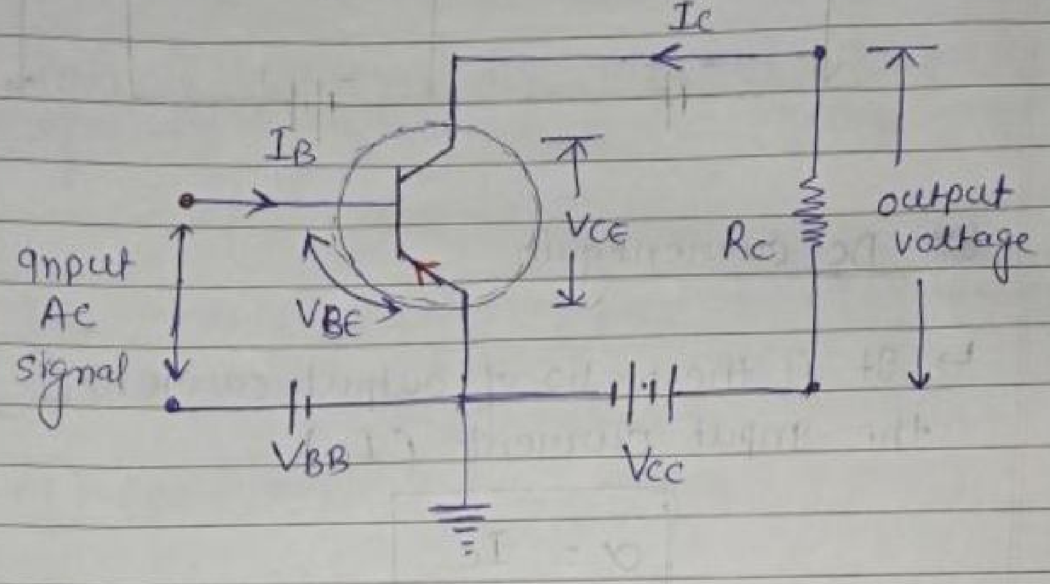
$$\boxed{\alpha = \frac{I_C}{I_E}}$$

Since $I_E > I_C$ so value of $\alpha$ is less than 1

value of $\alpha$ ranges from 0.90 to 0.99

## CE- (common emitter configuration)

in this configuration input is applied b/w base and emitter while output is taken out from collector and emitter. so, emitter of transistor is common to both input and output




### DC current gain

- It is the ratio of output current ($I_C$) to the input current ($I_B$)

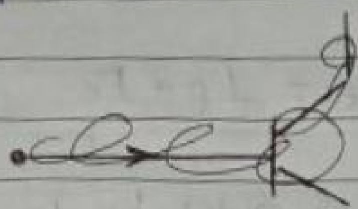
$$\boxed{\beta = \frac{I_C}{I_B}}$$

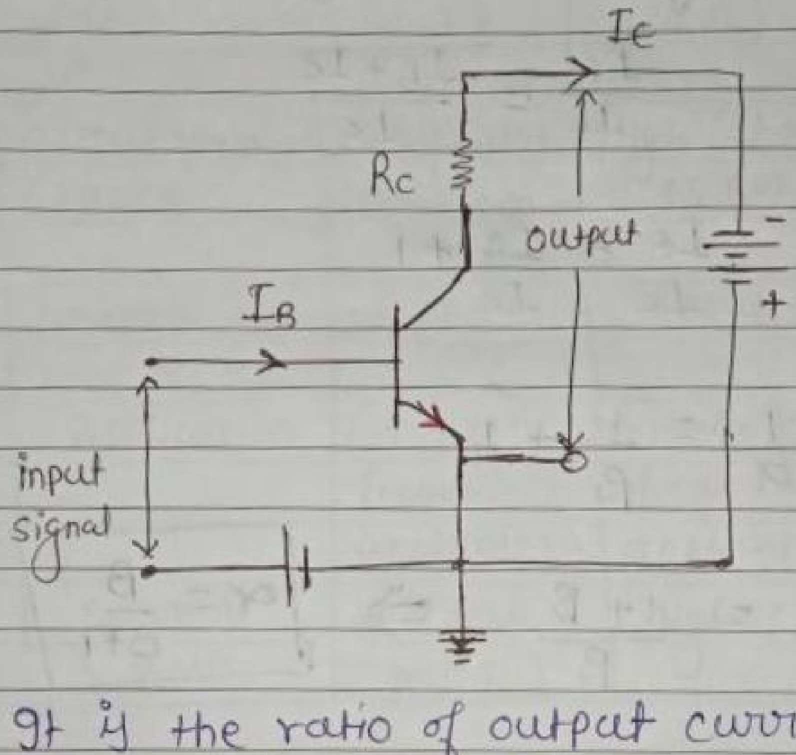
Since value of $I_B << I_C$ so, $\beta >> 1$ therefore, current gain is available in CE configuration

value of $\beta$ varies from 20 to 500.

## CC-Common collector configuration

In this configuration input is applied b/w base and collector while output is taken out from collector and emitter so, collector of transistor is common to both input and output.






It is the ratio of output current ($I_E$) to the input current ($I_B$)

$$\boxed{\gamma = \frac{I_E}{I_B}}$$

# Relation b/w $\alpha$ and $\beta$

$$\boxed{\alpha = \frac{I_C}{I_E}} \quad \text{and} \quad \boxed{\beta = \frac{I_C}{I_B}}$$

$$I_E = I_B + I_C$$

Dividing both sides by $I_C$

$$\frac{I_E}{I_C} = \frac{I_B + I_C}{I_C}$$

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1$$

$$\frac{1}{\alpha} = \frac{1+\beta}{\beta} \Rightarrow \boxed{\alpha = \frac{\beta}{\beta+1}}^{*}$$

$$\alpha(1+\beta) = \beta$$

$$\alpha + \alpha\beta = \beta$$

$$\alpha = \beta - \alpha\beta$$

$$\alpha = \beta(1-\alpha)$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$ *

# Comparison of transistor configuration or Connections

| SNO | Characteristic | Common base | Common emitter | Common collector |
|---|---|---|---|---|
| (1) | Input resistance | low (about 100 Ω) | Low (about 750 Ω) | very high (about 750 KΩ) |
| (2) | output resistance | very high (about 450 KΩ) | High (about 45 KΩ) | Low (about 50 Ω) |
| (3) | voltage gain | about 150 | about 500 | less than 1 |
| (4) | Application | for high frequency applications | for audio frequency applications | for impedance matching |
| (5) | current gain | No (less than 1) | High (β) | Appreciable |

Note - BJT → Bipolar devices → Both free electrons and holes

FET → Unipolar Devices : Either free electrons or holes.

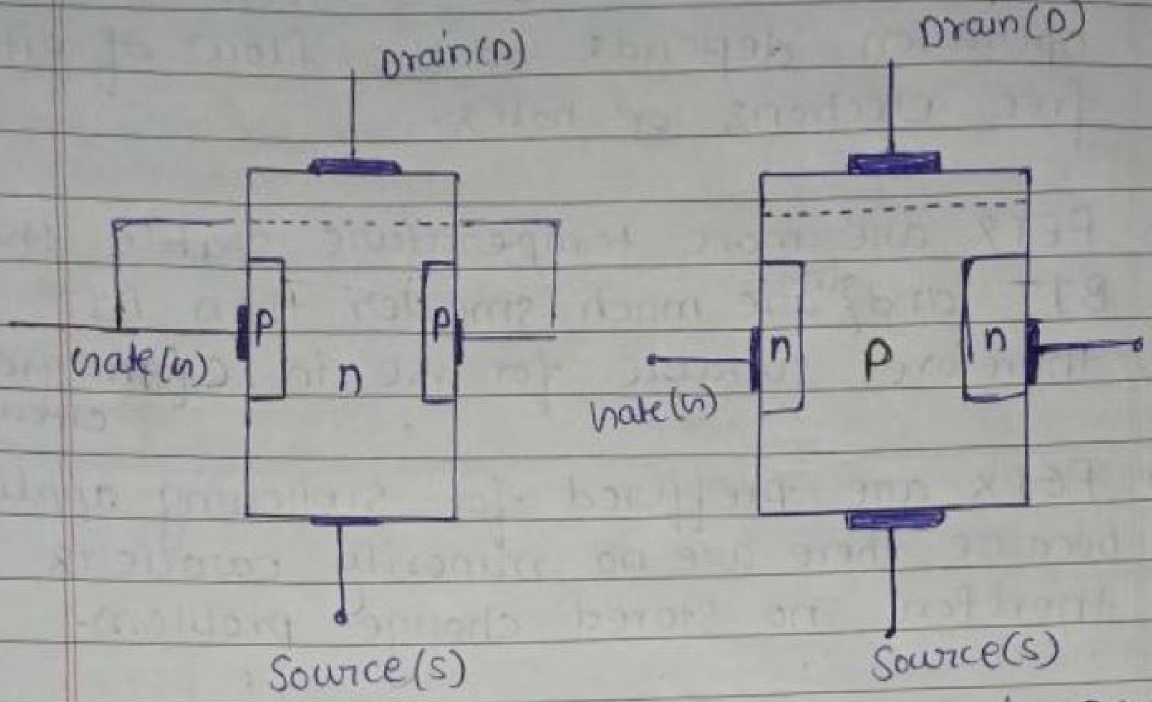
FD page No-

# field effect transistor (FET)

- FET is a unipolar Device because its operation depends on the flow of either free electrons or holes.
- FET's are more temperature stable than BJT and size are much smaller than BJT therefore suitable for use in IC (integrated circuit)
- FET's are preffered for switching applications because there are no minority carriers therefore no stored charge problem.
- less noisy
- FET input resistance is high
- FET has smaller Gain Bandwidth product

FET
- JFET
  - n-channel
  - p-channel
- MOSFET or IGFET
  - Depletion mosFET
    - n-channel
    - p-channel
  - enhancement mosFET
    - n-channel
    - p-channel.

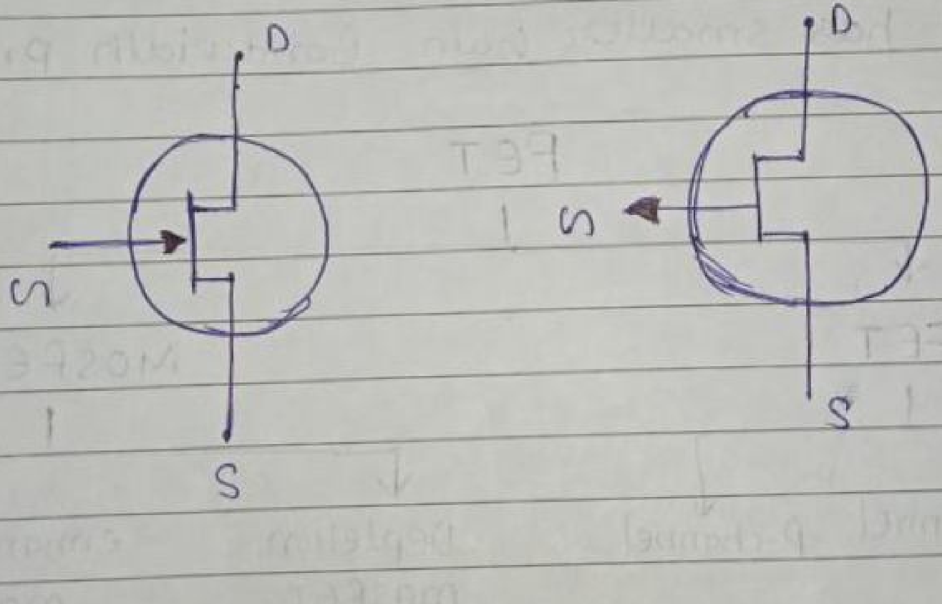
# Basic construction of JFET



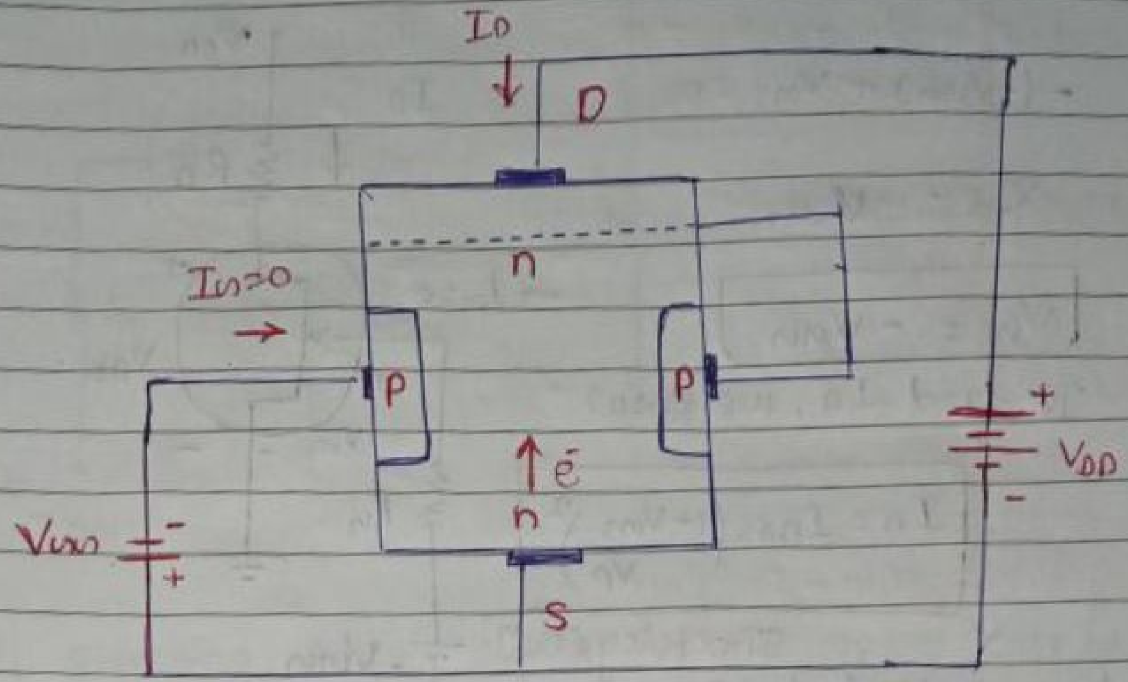

n-channel JFET

p-channel JFET

Symbol



# Operation or working




↳ we always kept Gate-Source diode in Reverse Bias.

↳ The more negative the Gate voltage, the Smaller the current between the source and drain

↳ therefore JFET is called as a voltage controll device.

# JFET Biasing

1. Gate Bias Circuit
2. Source Self Bias circuit
3. voltage Divider Bias circuit.

Rajeev's Pathshala

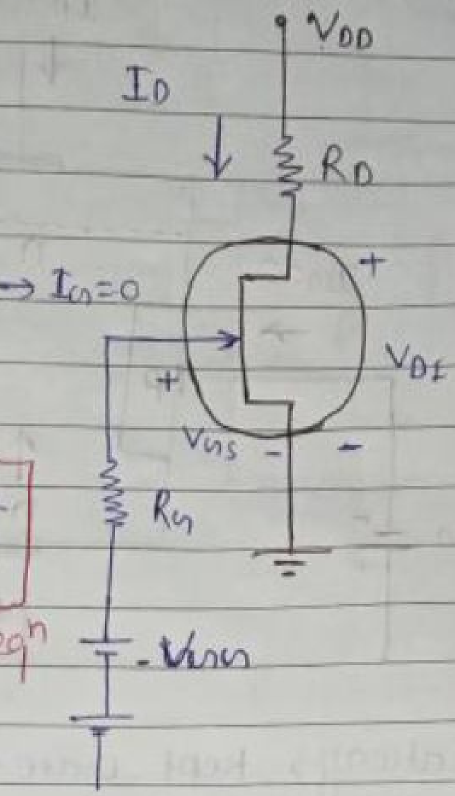
## ① Gate Bias circuit

Apply KVL in input loop

$-(-V_{GG}) + V_{GS} = 0$

$\cancel{V_{GS} = -V_{GG}}$

$$\boxed{V_{GS} = -V_{GG}}$$




To find $I_D$, we know

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

Shockley's eq$^n$

from output loop

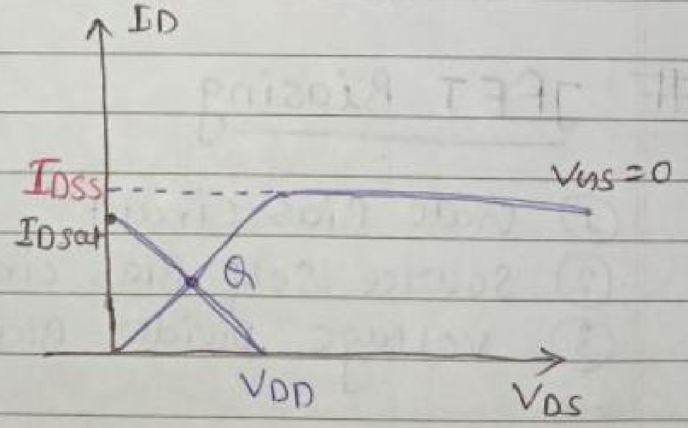
$\cancel{V_{DD} = V_{DD} - I_D R_D}$

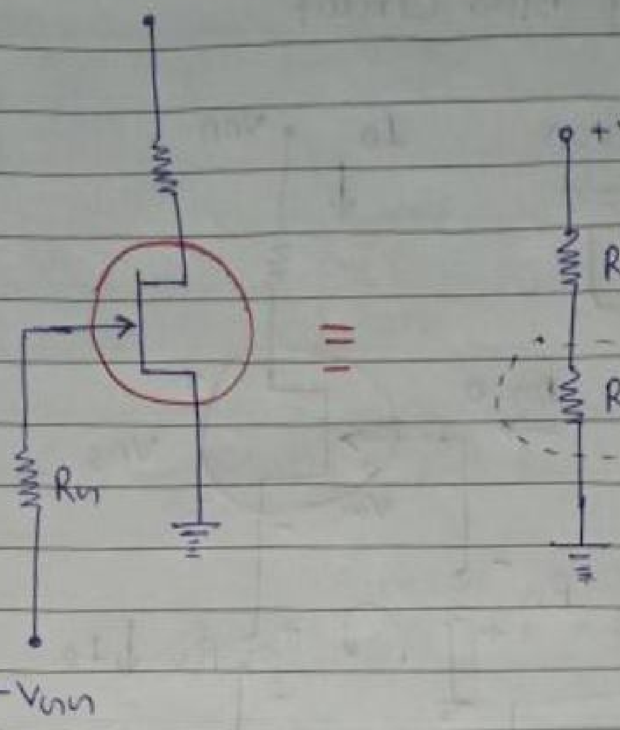
$$\boxed{V_{DS} = V_{DD} - I_D R_D}$$

$(V_{DS}, I_D)$ called operating point.

$I_{D sat} = \frac{V_{DD}}{R_D}$

$I_{D sat} << I_{DSS}$

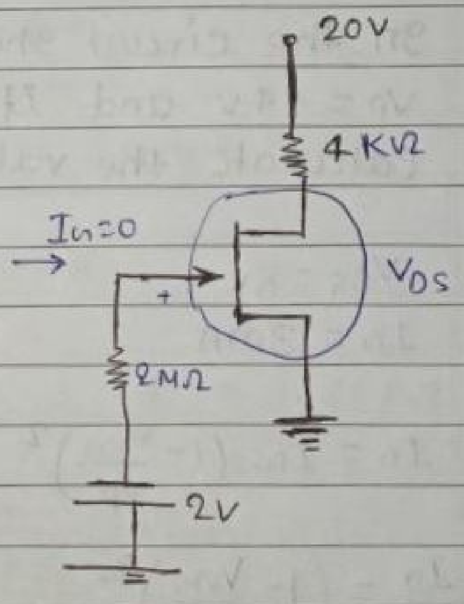





← JFET is equivalent to resistance.

↳ By selecting proper value of $R_D$ JFET can be biased in ohmic Region and can be used as a resistor.

Q. A JFET has $I_{DSS} = 10mA$ · $V_P = -4V$ in the circuit shown calculate $V_{GS}$, $V_{DS}$ and $I_{DS}$




Sol^n $2 + V_{GS} = 0$

$$\boxed{V_{GS} = -2V}$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$= 10\left(1 - \frac{-2}{-4}\right)^2$$

$$\boxed{I_D = 2.5\ mA}$$

$$V_{DS} = V_{DD} - I_D R_D$$

$$= 20 - 2.5 \times 4$$

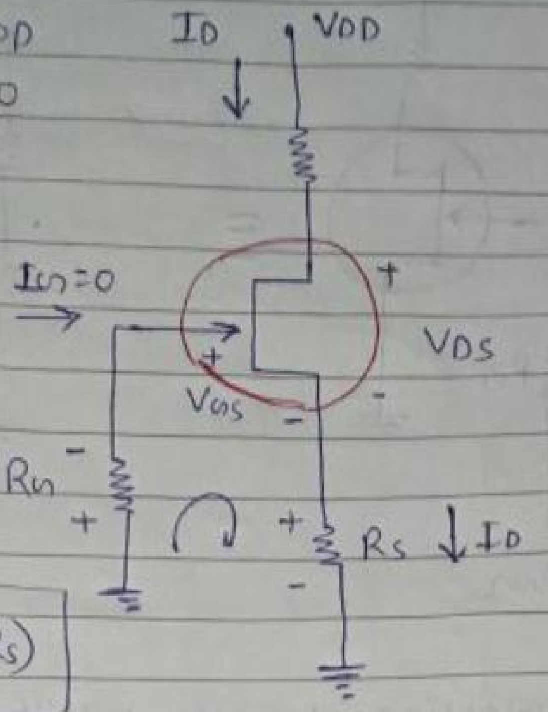
$$\boxed{V_{DS} = 10V}$$

## (2) Source Self Bias circuit

Apply KVL in input Loop

$\cancel{I_G R_G} + V_{GS} + I_D R_S = 0$

$$\boxed{V_{GS} = -I_D R_S}$$




Apply KVL in output Loop

$-V_{DD} + I_D R_D + V_{DS} + I_D R_S = 0$

$$\boxed{V_{DS} = V_{DD} - I_D(R_D + R_S)}$$

Note – this $V_{DS}$ should be kept higher than $|V_P| - |V_{GS}|$ through proper selection of $R_D$, to operate the JFET in saturation.

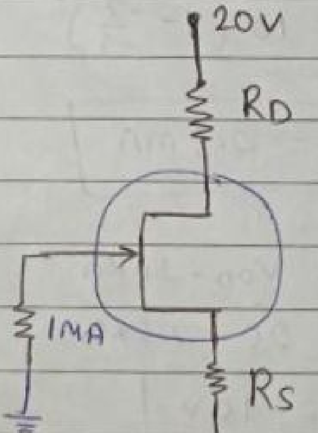
Q. In the circuit shown JFET has $I_{DSS} = 12mA$, $V_P = -4V$ and it is operating at $(8V, 3mA)$. Calculate the value of $R_D$ and $R_S$

$V_{DS} = 8V$

$I_D = 3mA$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\frac{I_D}{I_{DSS}} = \left(1 - \frac{V_{GS}}{V_P}\right)^2$$



$$\sqrt{\frac{I_D}{I_{DSS}}} = 1 - \frac{V_{GS}}{V_P}$$

$$\frac{V_{GS}}{V_P} = 1 - \sqrt{\frac{I_D}{I_{DSS}}}$$

$$V_{GS} = V_P\left[1 - \sqrt{\frac{I_D}{I_{DSS}}}\right]$$

$$= -4 \times \left[1 - \sqrt{\frac{3}{12}}\right] = -4\left[1 - \sqrt{\frac{1}{4}}\right]$$

$$\Rightarrow -4\left[1 - \frac{1}{2}\right]$$

$$= -4 \times \left(\frac{2-1}{2}\right) = -4 \times \frac{1}{2}$$

$$= -2\,V$$

$$\boxed{V_{GS} = -2V}$$

<u>for source ~~sel~~ self Bias circuit</u>

$$V_{GS} = -I_{DS} \times R_S$$

$$R_S = \frac{-V_{GS}}{I_D} = \frac{2}{3} = 0.66\,k\Omega$$

$$\boxed{R_S = 0.66\,k\Omega}$$

$$V_{DS} = V_{DD} - I_D(R_D + R_S)$$

$$(R_D + R_S) = \frac{V_{DD} - V_{DS}}{I_D} = \frac{20-8}{3} = 4\,K\Omega$$

$$R_D + R_S = 4\,K\Omega$$

$$R_D = 4 - R_S$$

$$= 4 - 0.66\,K\Omega$$

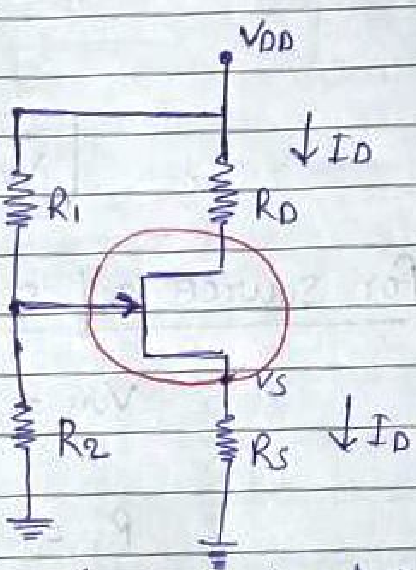
$$\boxed{R_D = 3.33\,K\Omega}$$ *

## (3) Voltage divider Bias circuit

$$V_G = \frac{V_{DD} \times R_2}{R_1 + R_2}$$

$$V_S = I_D R_S$$

$$V_{GS} = V_G - V_S$$




↳ $R_1$ & $R_2$ should be selected such that $V_{GS}$ lies between 0 & $V_P$

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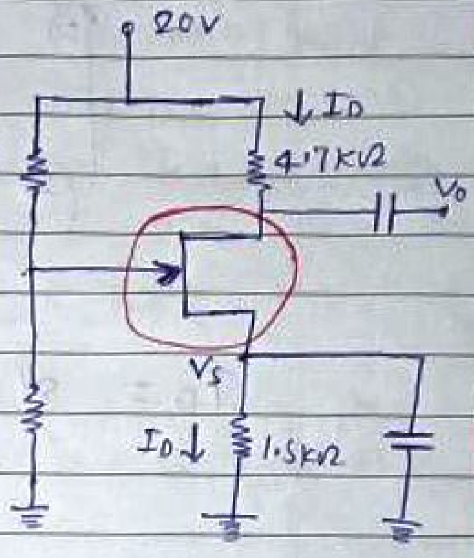
from output loop

$$V_{DS} = V_{DD} - I_D(R_D + R_S)$$

Note $\quad V_{DS} > |V_P| - |V_{GS}|$

Q. Determine the operating point for the given network.

$I_{DSS} = 8\,mA$
$V_P = -4V$




Sol$^n$

$$V_G = \frac{V_{DD} \times R_2}{R_1 + R_2}$$

$$= \frac{20 \times 270}{2.1 \times 10^3 + 270}$$

$$= 2.28\,V$$

$$V_S = I_D \times 1.5$$

$$V_{GS} = V_G - V_S$$

$$= 2.28 - I_D \times 1.5 \quad \text{—— (1)}$$

To find

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

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$$I_D = 8\left(1 - \frac{2.28 - I_D \times 1.5}{-4}\right)^2$$

$$I_D = 8\left(1 + \frac{2.28 + I_D \times 1.5}{4}\right)^2$$

$$= 8\left(\frac{4 + 2.28 + 1.5 I_D}{4}\right)^2$$

$$\Rightarrow \cancel{8}\left(\frac{6.28 - 6 I_D}{\cancel{16}\ 2}\right)^2$$

$$\Rightarrow \frac{1}{2}\left(\right.$$

$$I_D = \cancel{8}\left\{\frac{4(6.28 - 1.5 I_D)^2}{\cancel{16}_{2}}\right\}$$

$$2I_D \Rightarrow 39.44 - 18.84 I_D + 2.25 I_D^2$$

$$2.25 I_D^2 - 20.84 I_D + 39.44 = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$I_D = \frac{20.84 \pm \sqrt{(20.84)^2 - 4 \times 2.25 \times 39.44}}{2 \times 2.25}$$

$$I_D = 6.6\ mA,\ 2.65\ mA$$

$$V_{DS} = V_{DD} - I_D(R_D + R_S)$$

$$= 20 - 6.6(4.7 + 1.5)$$

$$\boxed{V_{DS} = -20.92\,V}$$

Negative so can't take.

$$V_{DS} = 20 - 2.65(4.7 + 1.5)$$

$$\boxed{V_{DS} = 3.57\,V}$$

Hence operating point will be $(3.57V, 2.65mA)$ A

## Transconductor

↳ Transconductance tells us how effectively the gate source voltage ($V_{GS}$) is controlling the Drain current ($I_D$).

↳ It is denoted by $g_m$ and it is ~~desi~~ defined as the ratio of ac drain current to the ac gate source voltage.

$$\boxed{g_m = \frac{i_d}{v_{gs}}} \quad , \quad \boxed{g_m = \frac{\partial I_D}{\partial V_{GS}}}$$

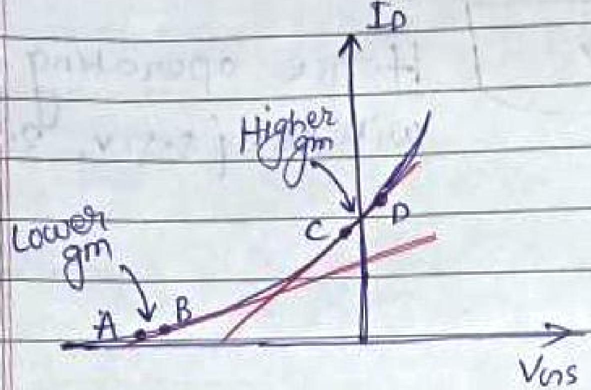
↳ The Higher the value of transconductance the more control the gate voltage has over the Drain current.

↳ The unit for transconductance is mho (℧)

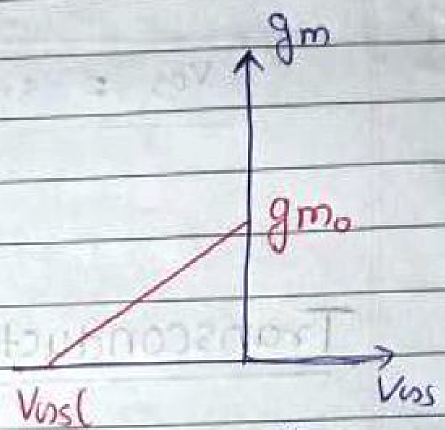
↳ The equivalent and modern unit for mho is siemens)

↳ changing the value of $g_m$ is useful in Automatic gain control.

Slope of Transconductance curve




fig(a) - Transconductance curve.




fig(b) - variation of $g_m$ with $V_{GS}$

↳ $g_m$ is the slope of transfer characteristics

↳ $V_{GS}(off)$ is difficult to measure accurately therefore it can be calculated with the help of following equation.

$$V_{GS}(off) = \frac{-2 I_{DSS}}{g_{mo}}$$

where $g_{mo}$ is the value of $g_m$ at $V_{GS}=0$

↳ for calculating $g_m$ for any value of $V_{GS}$.

$$\boxed{g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)}$$

$$g_m = \frac{2}{|V_P|}\sqrt{I_D \cdot I_{DSS}}$$

# Derive an equation for transconductance ($g_m$) in FET in the Saturation Region of ~~FET~~ FET

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2} \quad \text{——— (1)}$$

By definition

$$\boxed{g_m = \frac{\partial I_D}{\partial V_{GS}}}$$

Differentiate eqⁿ (1) with respect to $V_{GS}$

$$\frac{\partial I_D}{\partial V_{GS}} = 2 I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right) \times \left(\frac{-1}{V_P}\right)$$

$$\boxed{g_m = \frac{-2 I_{DSS}}{V_P}\left[1 - \frac{V_{GS}}{V_P}\right]}$$

or

$$\boxed{g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]}$$

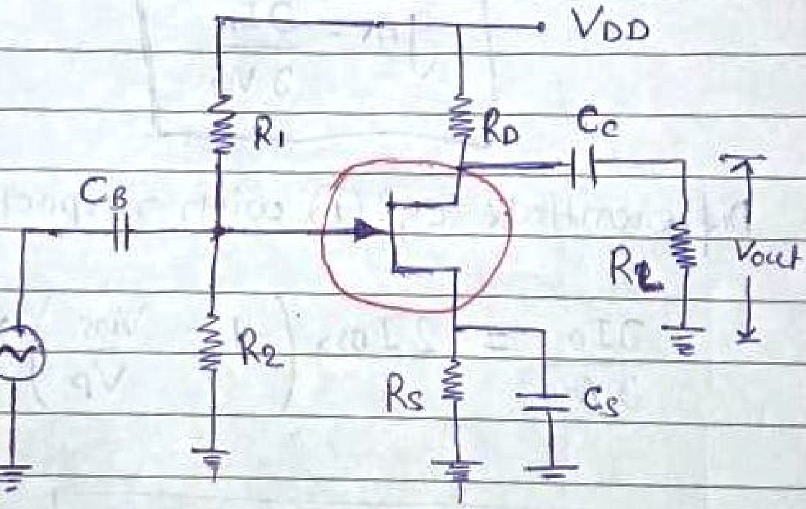
$$\left(\because g_{m0} = \frac{-2I_{DSS}}{V_P}\right)$$

# JFET Amplifiers

Analogy Between BJT & FET

S ≡ E
D ≡ C
G ≡ B

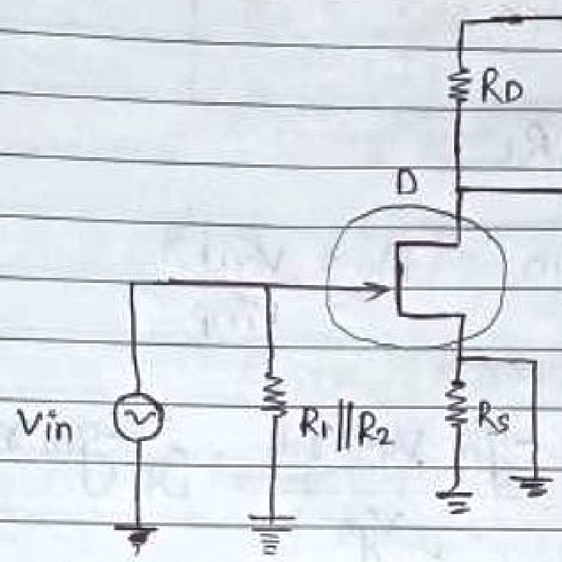
## ① Common Source (CS) Amplifier



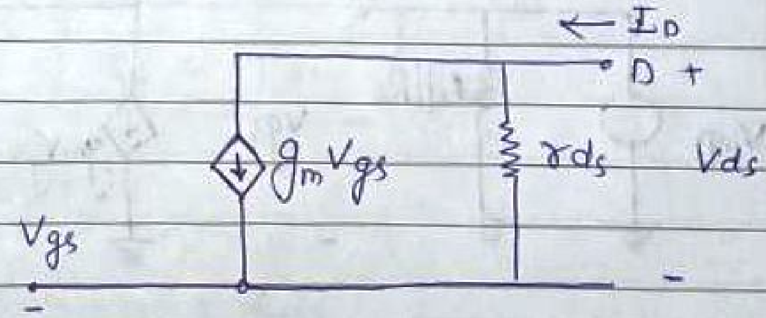

↳ common source Amplifier designed using voltage divider Bias circuit shown in fig.

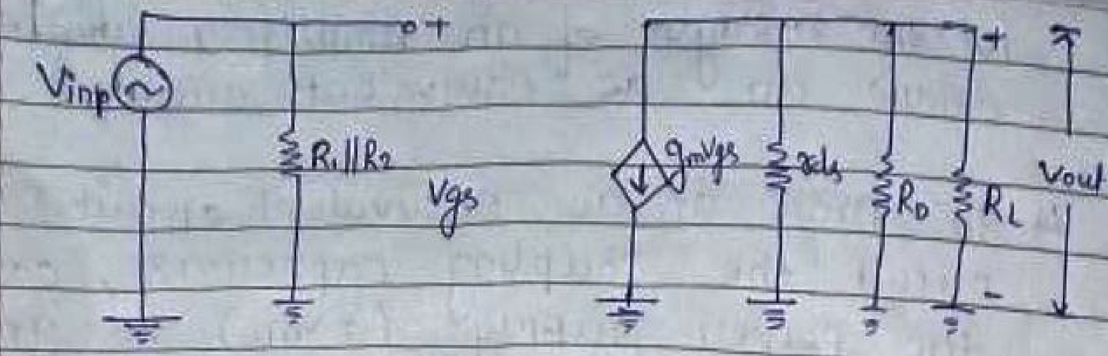
for the analysis of an Amplifier we have to draw an ac equivalent circuit.

↳ To Draw an ac equivalent circuit, short circuit the coupling capacitors, connect the power supply ($+V_{DD}$) to ground and replace the FET with its equivalent small signal model.




Small signal model of JFET






↳ $r_{ds}$ is dynamic drain resistance
Take it $\infty$, if it is not mention in Question

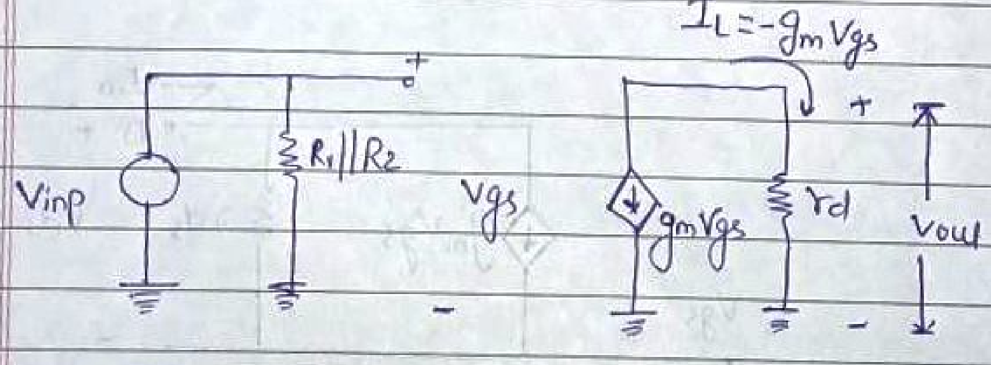
Drain Resistance

$$r_d = R_D \| R_L$$

The voltage gain $A_v = \dfrac{V_{out}}{V_{inp}}$

$$= \frac{-g_m \cancel{V_{gs}}\, r_d}{\cancel{V_{gs}}} = -g_m r_d$$

Redraw the circuit




$\boxed{A_v = -g_m r_d}$ where (-ve) sign shows 180° phase shift current gain

$$A_I = \frac{I_L}{I_g} = \frac{I_L}{0} = \infty$$

$$\boxed{A_I = \infty}$$

Input resistance

$$\boxed{R_i = \frac{V_{inp}}{I_g} = \infty}$$

$$R_i' = R_i \parallel R_x \quad \text{where } R_x \rightarrow \text{Biasing Resister}$$

$$= \infty \parallel (R_1 \parallel R_2)$$

$$R_i' = R_1 \parallel R_2$$

if in any circuit the Biasing Resister at gate is $R_G$

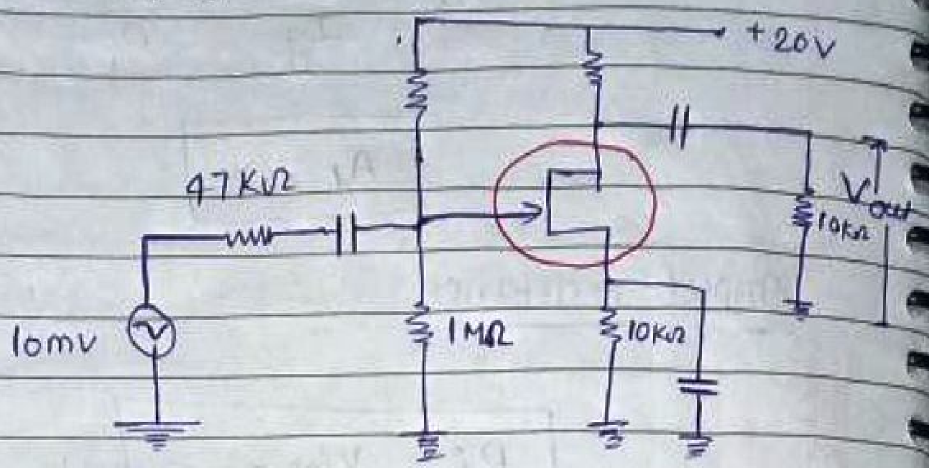
then $\boxed{R_i' = R_G}$

output Resistance

$$R_{out} = R_{ds}$$

$$\boxed{R_{out}' = R_{out} \parallel R_D}$$

Q. find the output voltage for the given amplifier if $g_m = 5000$




Sol^n

Identify the configuration

input Applied on : Gate
output taken from : Drain
Left terminal : Source

Therefore common Source Amplifier
for common source Amplifier

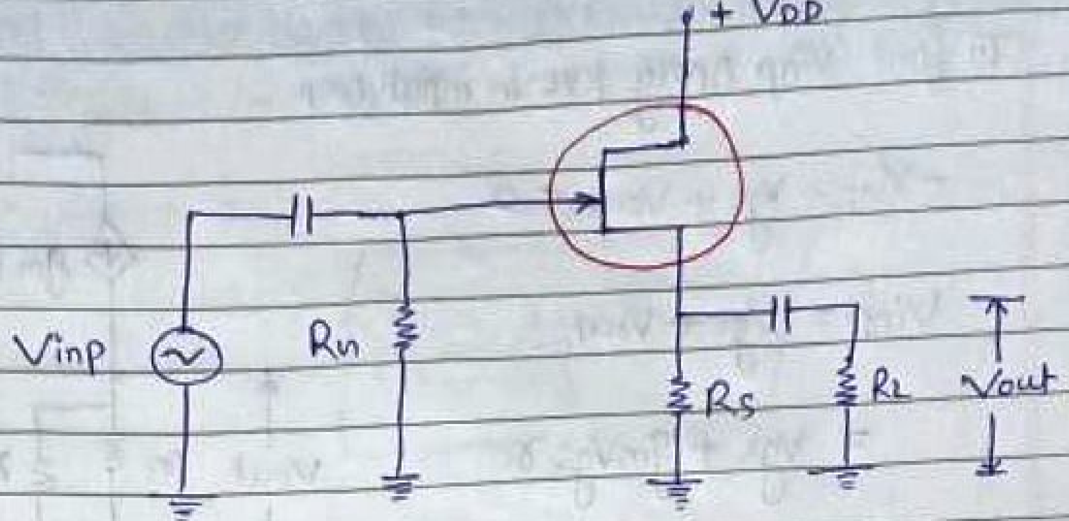
$$r_d = R_D \| R_L = 3.6 \| 10 = 2.65 K\Omega$$

Voltage gain $A_v = -g_m r_d$

$$= 5000 \times 10^{-6} \times 2.65 \times 10^{3} = -13.3$$

$$\boxed{A_v = 13.3}$$

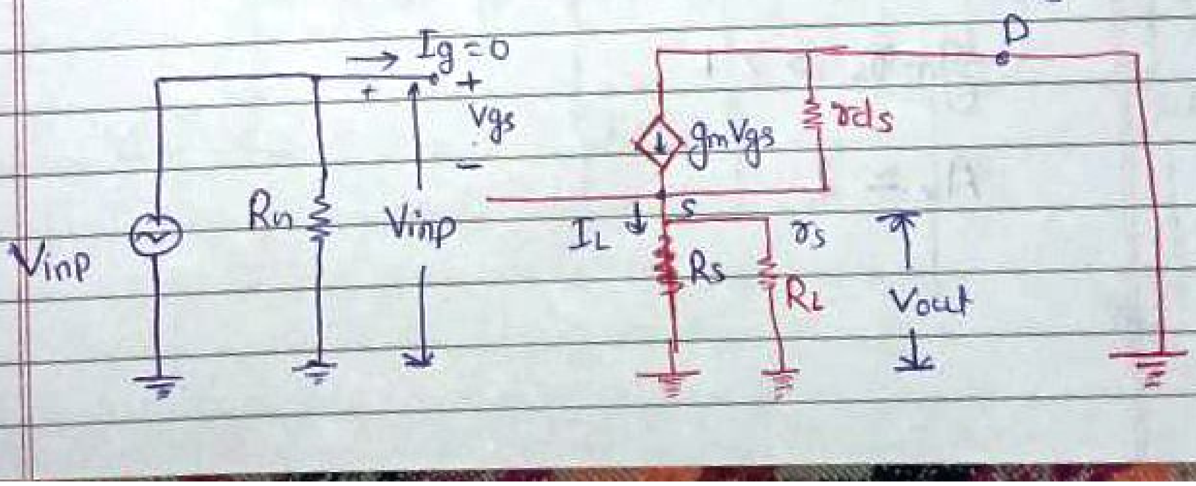
## (2) Common Drain Amplifier :- or Source follower




↳ The input is applied to Gate terminal the output is taken from source terminal Therefore the left terminal i.e Drain will be common.

↳ consider a source self bias circuit with Rout = 0

↳ for the Analysis draw the ac equivalent circuit by considering coupling capacitors as short circuit, connecting supply to the Load and Replace FET with small signal model



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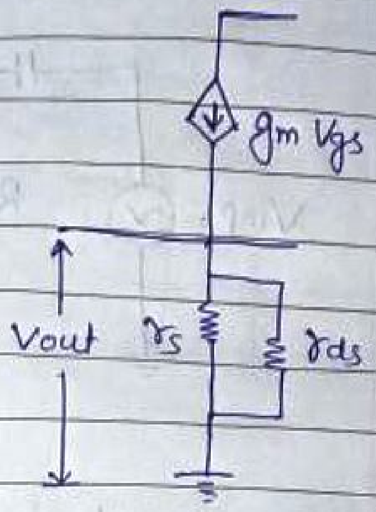
$$V_{out} = g_m V_{gs} r_s$$

To find Vinp Apply KVL in input loop

$$-V_{inp} + V_{gs} + V_{out} = 0$$

$$V_{inp} = V_{gs} + V_{out}$$

$$= V_{gs} + g_m V_{gs} r_s$$




$$A_v = \frac{V_{out}}{V_{inp}} = \frac{g_m V_{gs} r_s}{V_{gs} + g_m V_{gs} r_s}$$

$$\Rightarrow \frac{g_m r_s}{1 + g_m r_s}$$

Here $A_v$ is +ve therefore no phase sigut in output signal

$$A_v = \frac{g_m r_s}{1 + g_m r_s}$$

$$g_m r_s >> 1$$

$$A_v \simeq 1$$

Therefore common drain Amplifier is also called source follower because voltage at output node source exactly followers changes in input voltage.

↳ current Gain

$$\boxed{A_I = \frac{I_L}{I_g} = \infty}$$

↳ Input resistance

$$R_i = \frac{V_i}{I_g} = \infty$$

$$R'_i = R_i \,||\, R_G$$

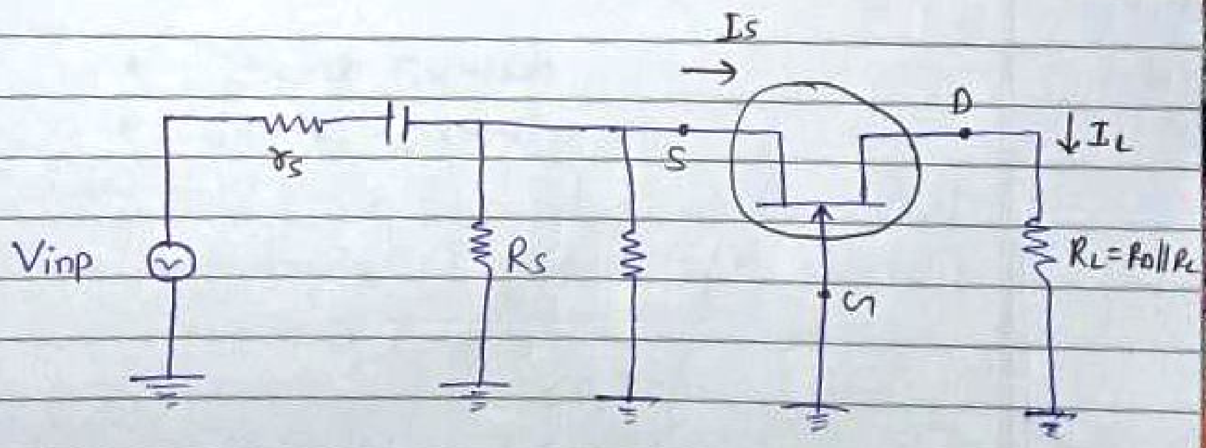
$$\boxed{R'_i = R_G}$$

output Resistance

$$R_{out} = r_{ds} \,||\, \frac{1}{g_m}$$

$$R'_{out} = R_{out} \,||\, R_s$$

③ Common Gate Amplifier



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↳ voltage gain $A_V = g_m R_L'$

↳ current gain $A_I = \frac{I_L}{I_S} = 1$

↳ Input Resistance.

$$R_i = \frac{V_i}{I_S} = \frac{1}{g_m} \quad (\because I_S = I_L = I_D)$$

$$\boxed{R_i' = R_i \| R_S}$$

↳ output Resistance

$$R_{out} = \infty$$

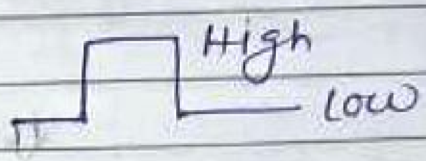
$$R_{out}' = R_{out} \| R_D$$

$$\boxed{R_{out}' = R_D}$$

# JFET Analog switch

↳ JFET can act as a switch. it can either transmits or blocks a small ac signal

$V_{GS}$ has two values ; either zero (0) or less than zero (<0)



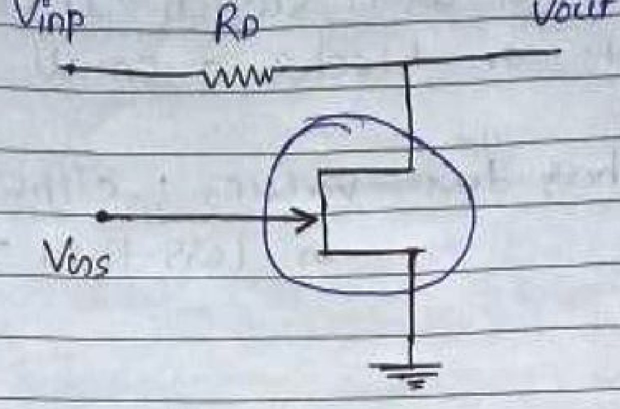

↳ when $V_{GS}$ is high
JFET is conducting
operates in ohmic region.

↳ when $V_{GS}$ is low
JFET is not conducting
operates in cut-off region.

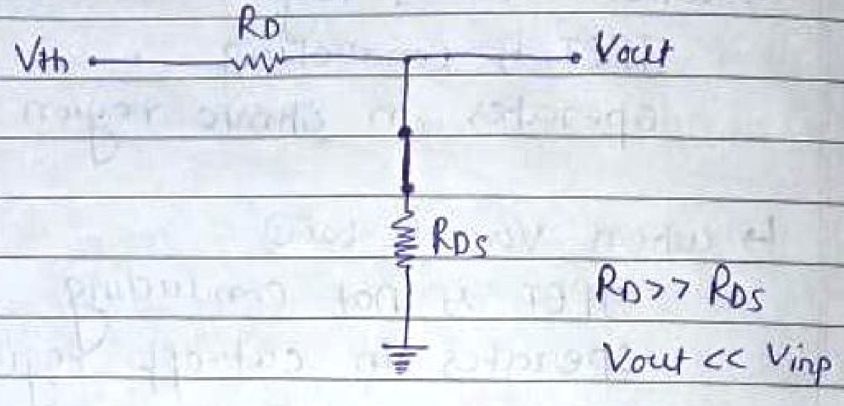
↳ Depending on the position of JFET in the circuit it can be used as

- Shunt switch
- Series switch

① Shunt switch

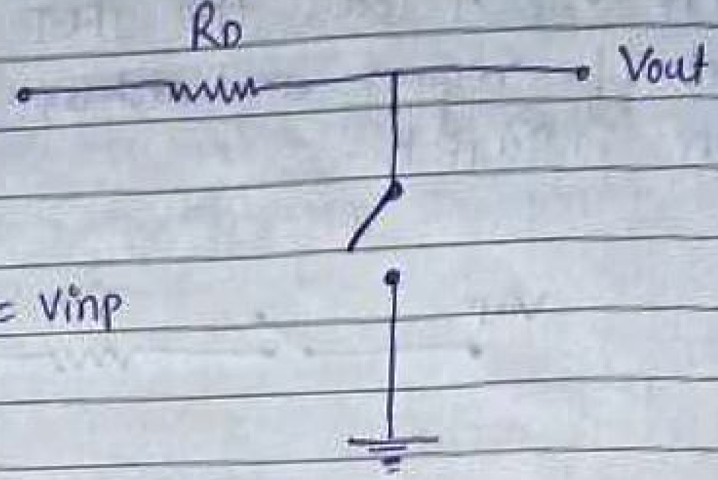



⇓



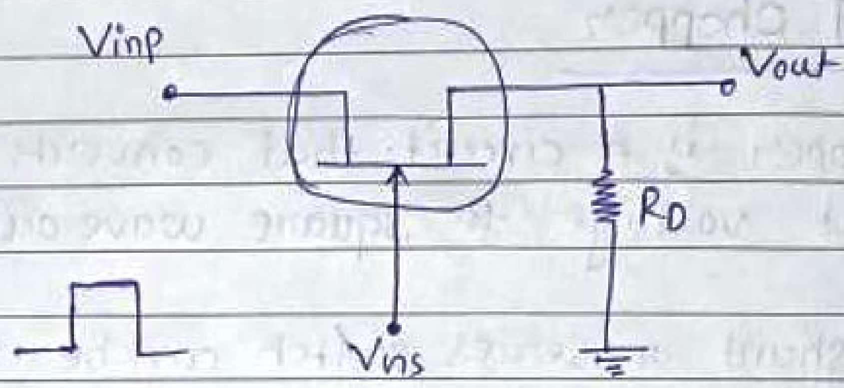

- when $V_{GS}$ is high, JFET operates in ohmic region and act as a closed switch

- when $V_{GS}$ is Low, JFET operates in cut-off region and act as open switch

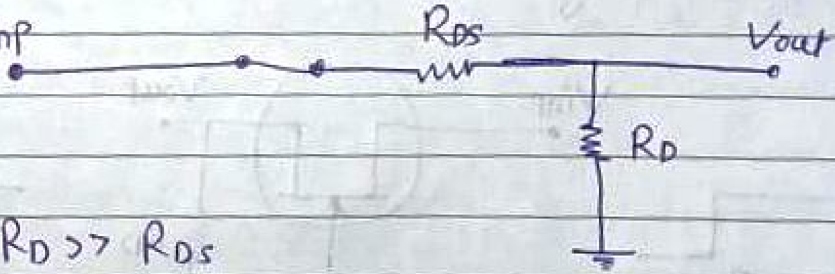



$V_{out} = V_{inp}$

## Series switch



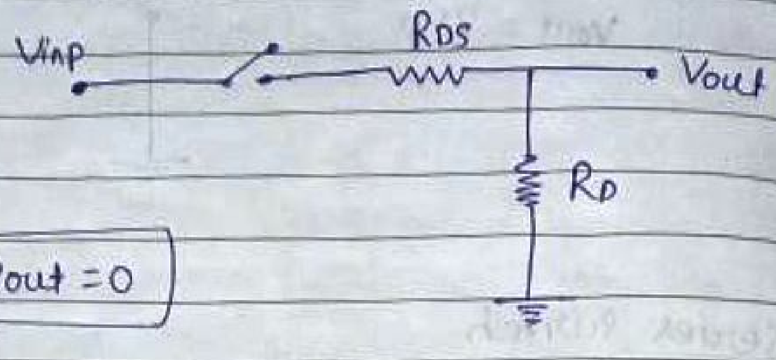

when $V_{GS}$ is high, the JFET operates in ohmic region and act as closed switch with equivalent Resistance $R_{DS}$




$\because R_D >> R_{DS}$

$V_{out} \simeq V_{inp}$

↳ when $V_{GS}$ is low, the JFET operates in cut off region and ~~act as open~~ act as open switch



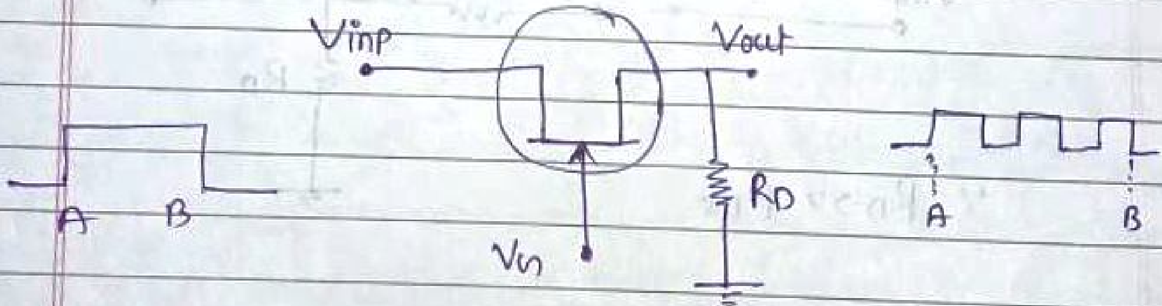

$$\boxed{V_{out} = 0}$$

## JFET chopper

↳ chopper is a circuit that converts a dc input voltage to square wave output.

A shunt or series switch can be used in JFET chopper

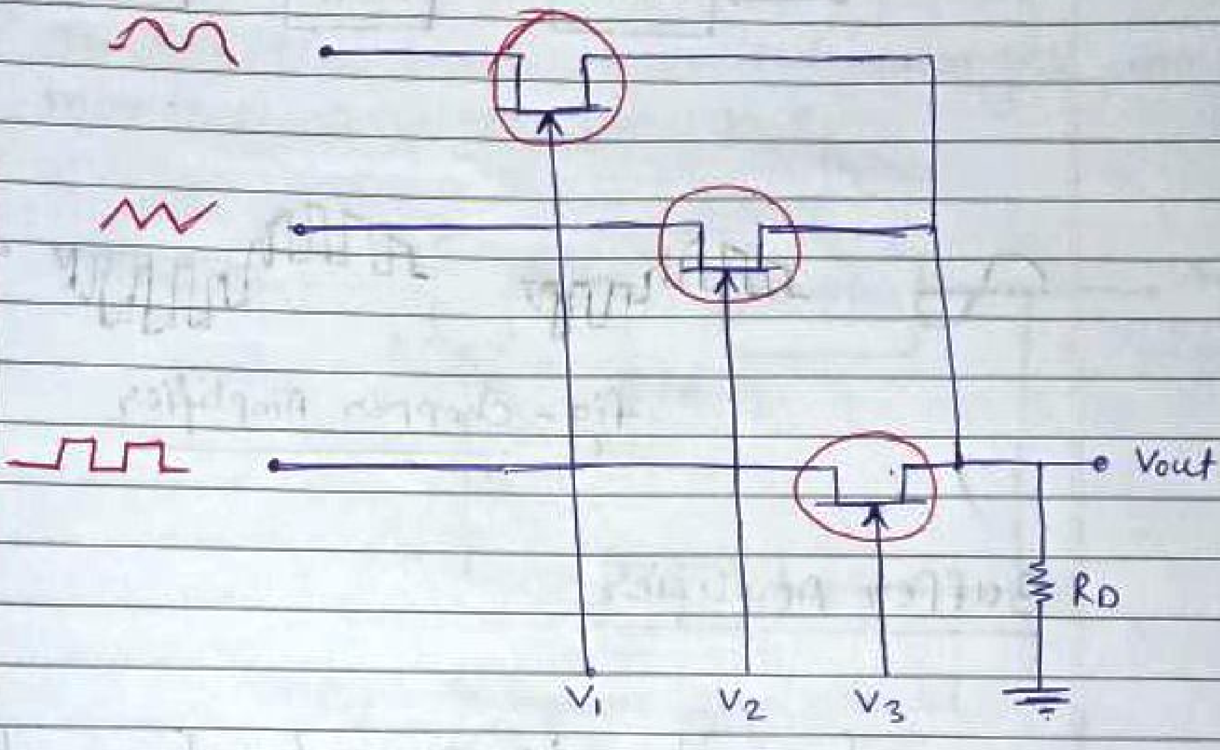
The series switch configuration of JFET can be used as a chopper if we apply a continous square wave at the gate terminal as shown in fig.



# JFET Applications

## ① JFET as multiplexer

multiplex means many to one
This circuit guides one or more of the input signals to the output line.




↳ Normally only one of the control signal is high

## Chopper Amplifier

- A chopper Amplifier can amplify low frequency ac signals as well as dc signals

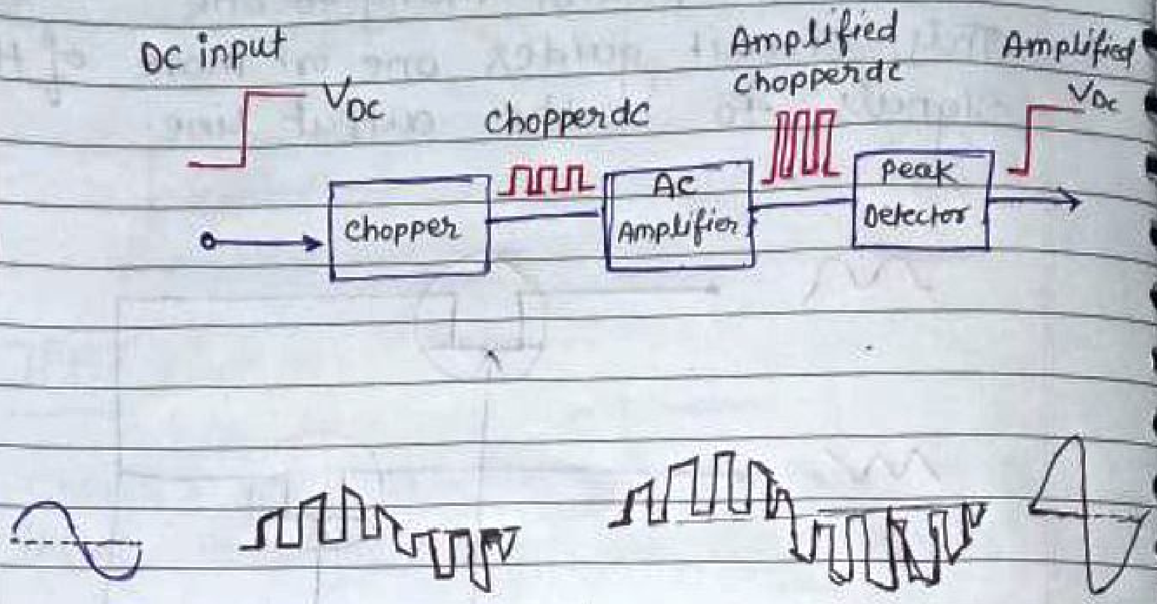
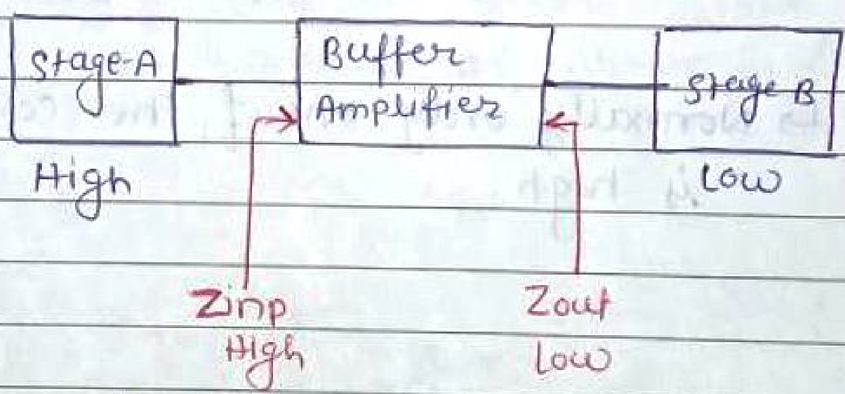



fig - chopper Amplifier

## Buffer Amplifier




- The source follower is an excellent buffer Amplifier because of its high input impedance and its low output impedance.

Rajeev's Pathshala

## Automatic gain control

↳ when a receiver is turned from a weak Station to a Strong station, the loudspeak will blare unless the volume is immediately decreased.

↳ The volume may also change because of fading some noise etc.

↳ To prevent these unwanted changes, most mordern receives use AGC.

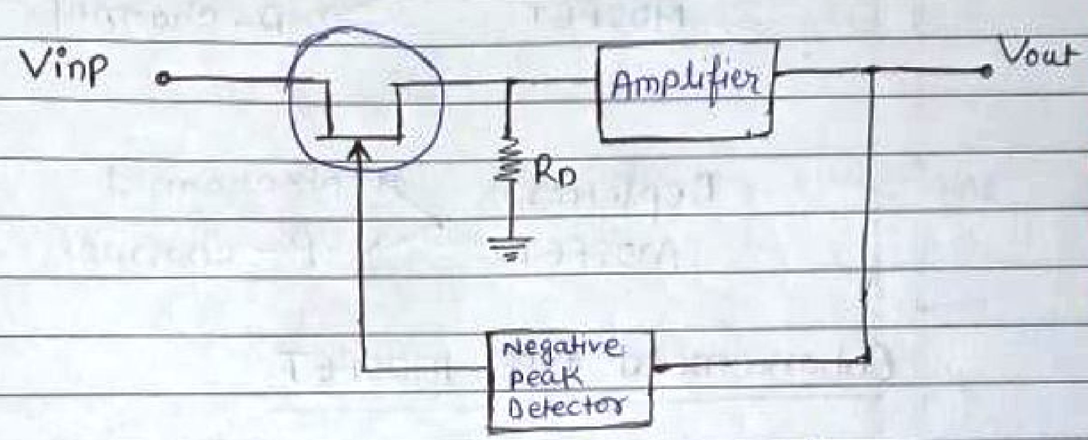



fig - Automatic gain control

Date / / 
Page

# MOSFET

↳ Metal oxide field effect Transistor (MOSFET) is a type of field effect transistor (FET) in which Gate is insulated from the channel.

Depending on the channel, whether it is enhanced 'or' permanently Diffused the MOSFET is further classified.

Enhancement MOSFET → N-channel, P-channel

Depletion MOSFET → N-channel, P-channel

## Enhancement type MOSFET

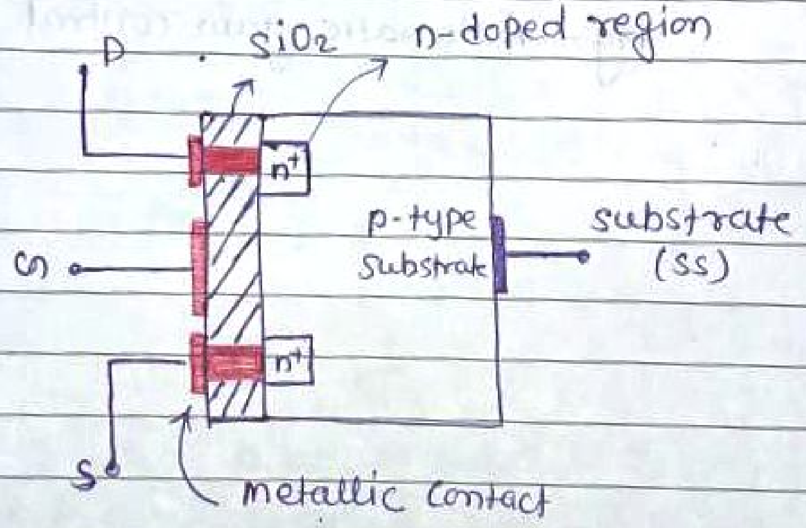
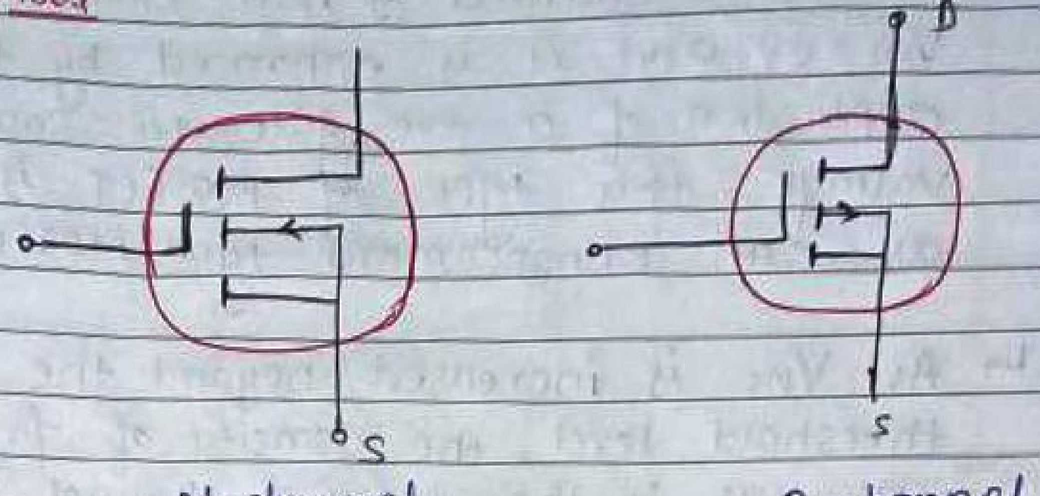
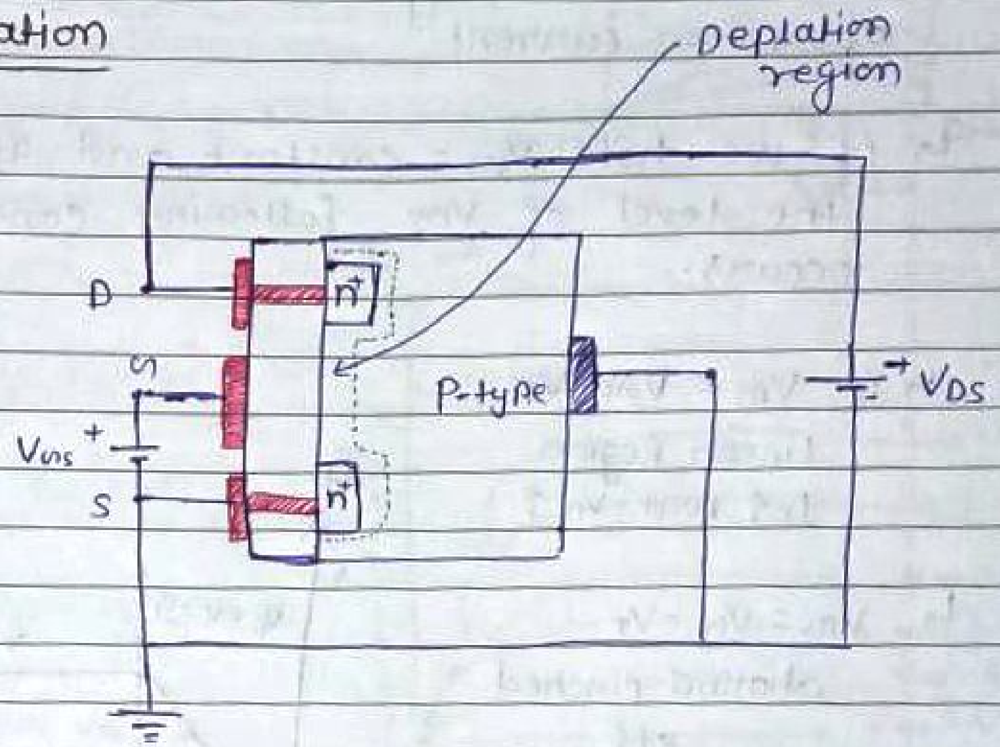



fig - N-channel Enhancement MOSFET

Symbol




Operation




↳ If $V_{GS} = 0V$ and $V_{DS} = +ve$, no current flow due to absence of channel

↳ if $V_{GS} = +ve$, $V_{DS} = +ve$

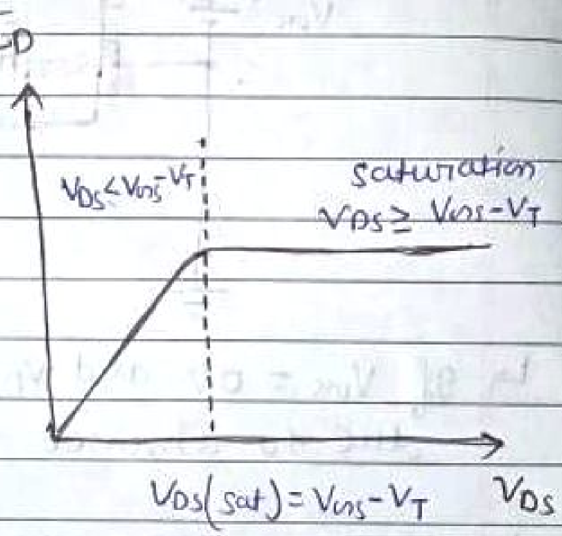
↳ The level of $V_{GS}$ at which the channel begins to conduct is called threshold voltage $V_T$

↳ Since the channel is non-existent with $V_{GS} = 0V$ and it is enhanced by the application of a +ve gate to source voltage this type of MOSFET is called as an enhancement type MOSFET

↳ As $V_{GS}$ is increased beyond the threshold level, the density of free carriers in the induced channel will increase resulting in an increased level of Drain current.

↳ if we hold $V_{GS}$ = constant and increase the level of $V_{DS}$ following conditions occurs.

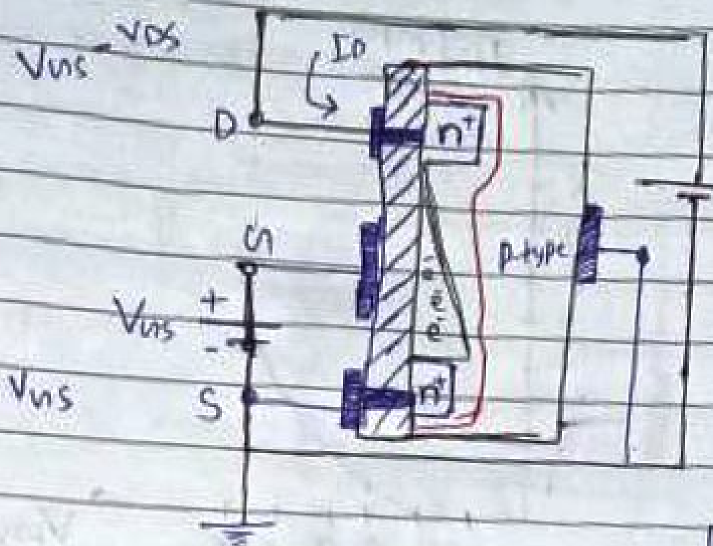
↳ if $V_{DS} < V_{GS} - V_T$
Linear Region
$I_D \uparrow$ with $V_{DS} \uparrow$

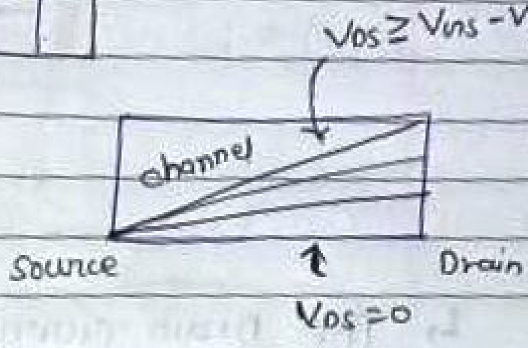



↳ $V_{DS} = V_{GS} - V_T$
channel pinched off

↳ $V_{DS} \geq V_{GS} - V_T$
Saturation Region

$I_D$ = constant $V_{DS} \uparrow$



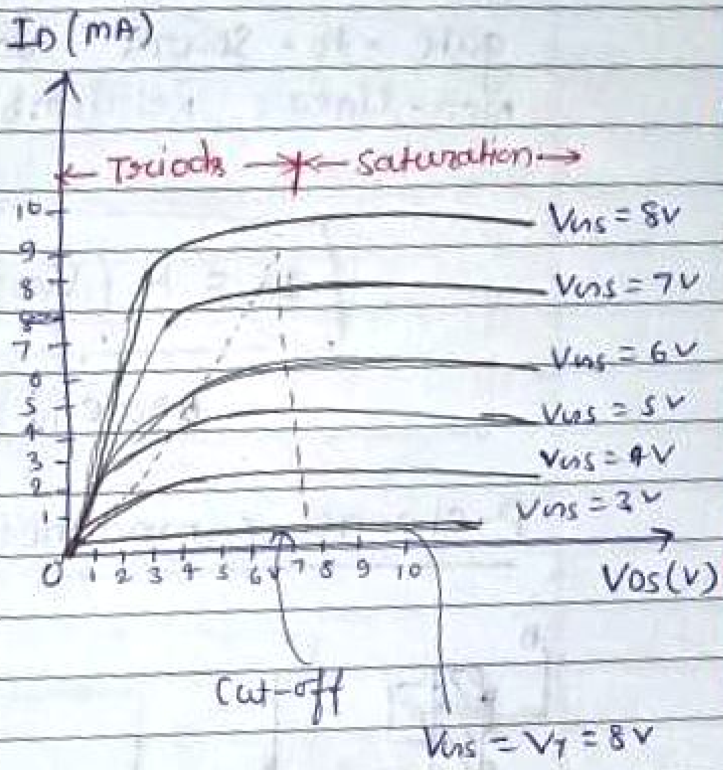




Drain characteristics:-

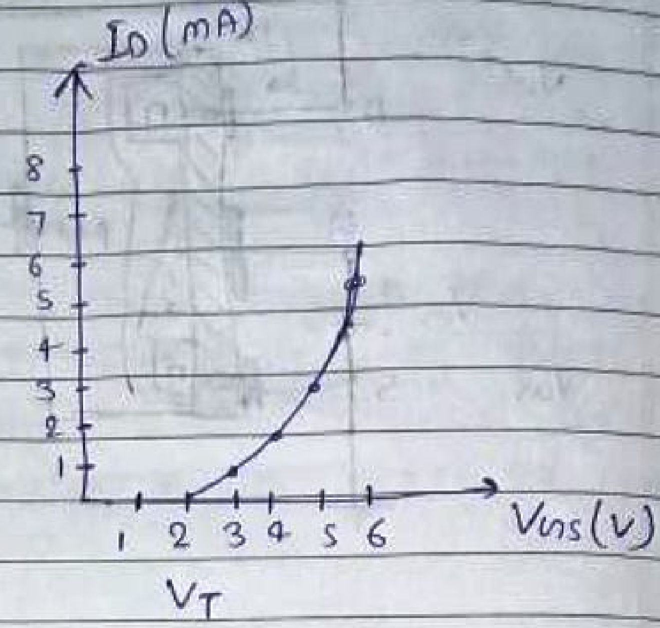
Cut off $V_{GS} < V_T$

Triode Region $V_{DS} < V_{GS} - V_T$

Saturation $V_{DS} \geq V_{GS} - V_T$



## Transfer characteristics

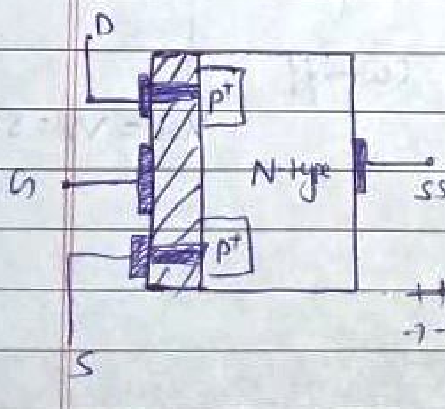


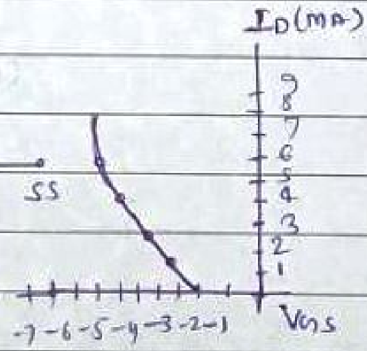

↳ The Drain current is related to applied gate-to-Source voltage by the following Non-linear Relationship.

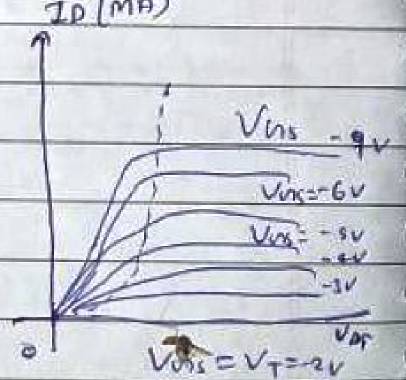
$$\boxed{I_D = K\left(V_{GS} - V_T\right)^2}$$

where K is a constant

## P-channel Enhancement type MOSFET

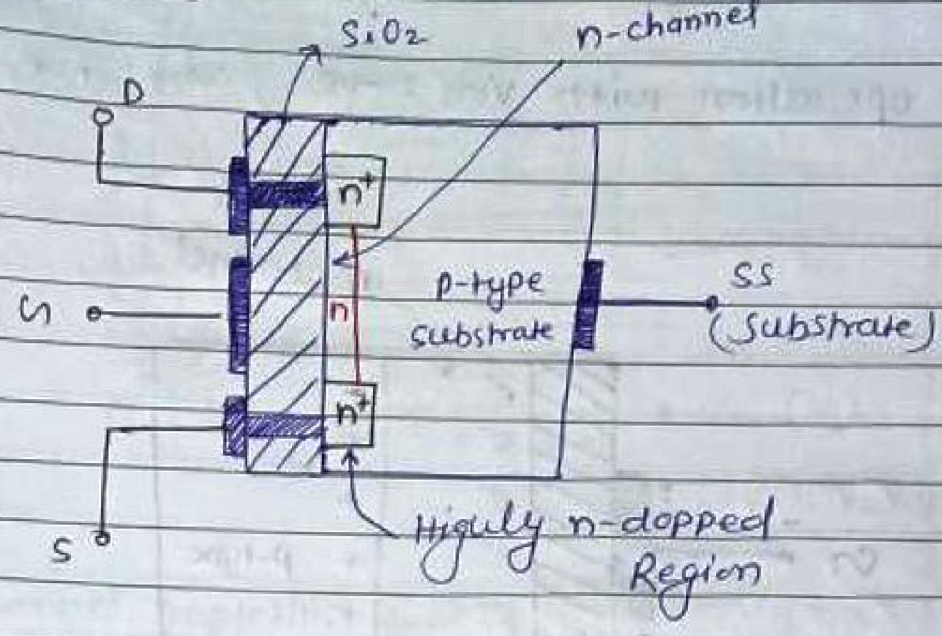


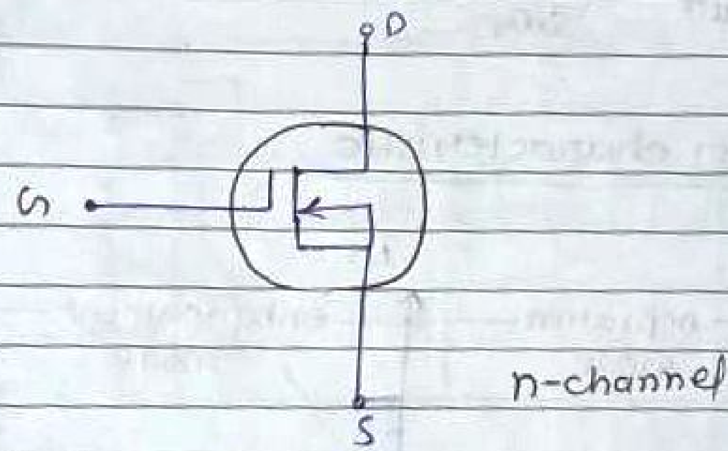



# Depletion type MOSFET

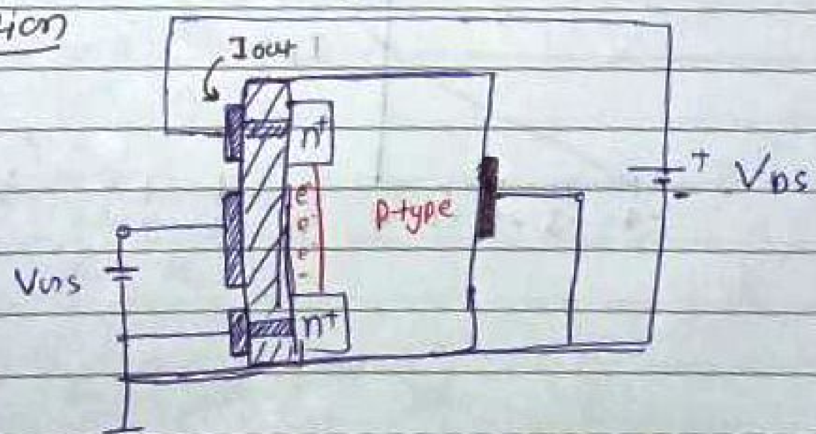
Construction




Symbol



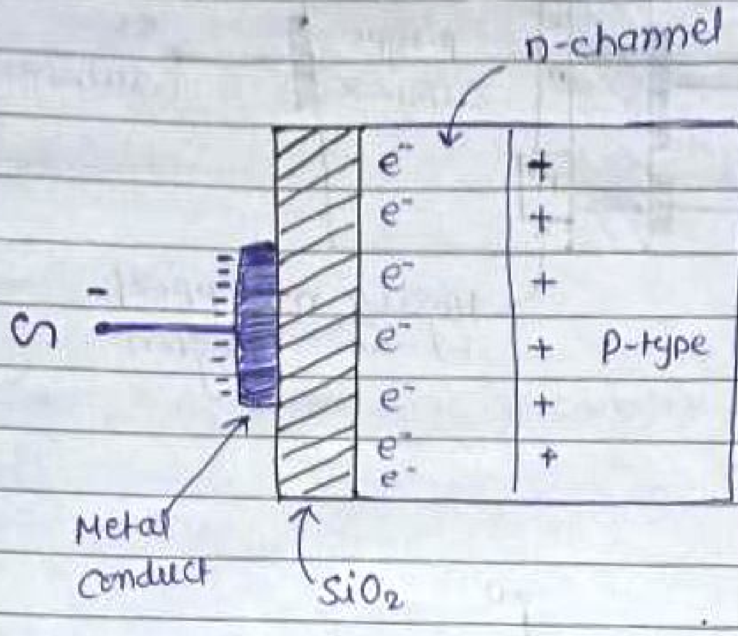

Operation



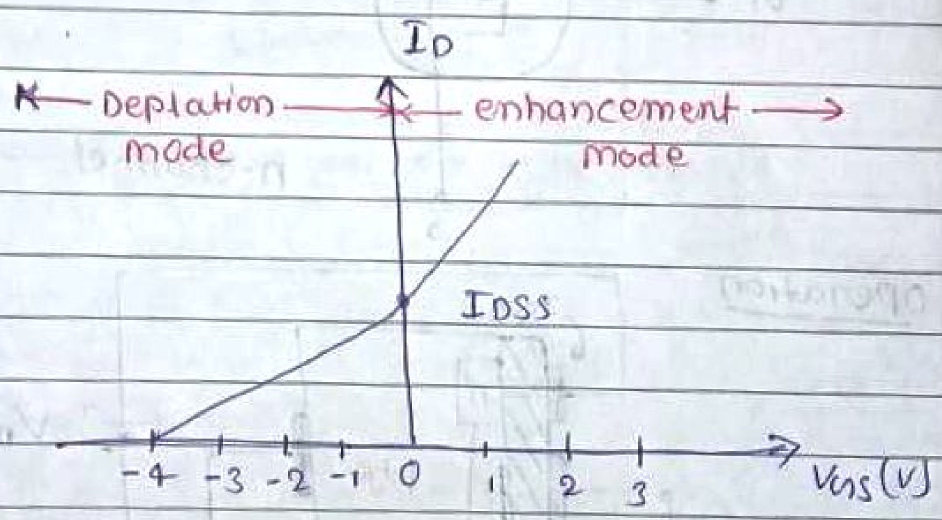
↳ operation with $V_{GS} = 0$ , $V_{DS}$ = +ve

↳ operation with $V_{GS}$ = +ve , $V_{DS}$ = +ve

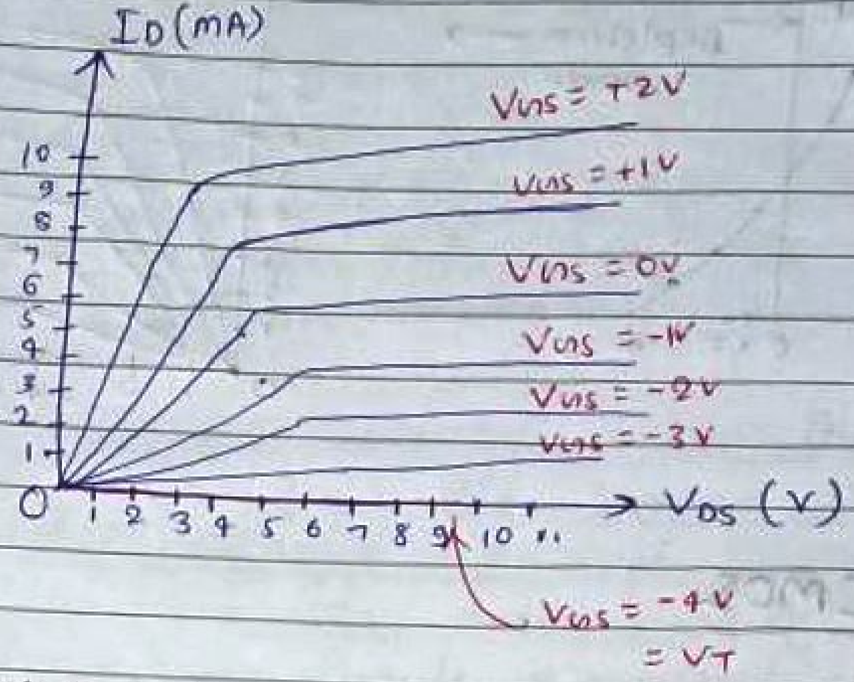
↳ operation with $V_{GS}$ = -ve , $V_{DS}$ = +ve



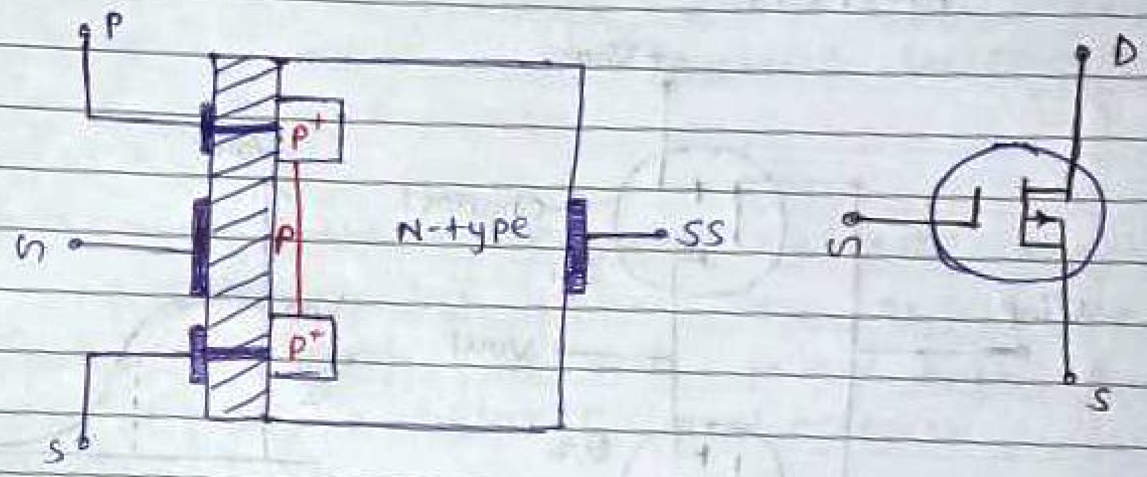

## Transfer characteristic



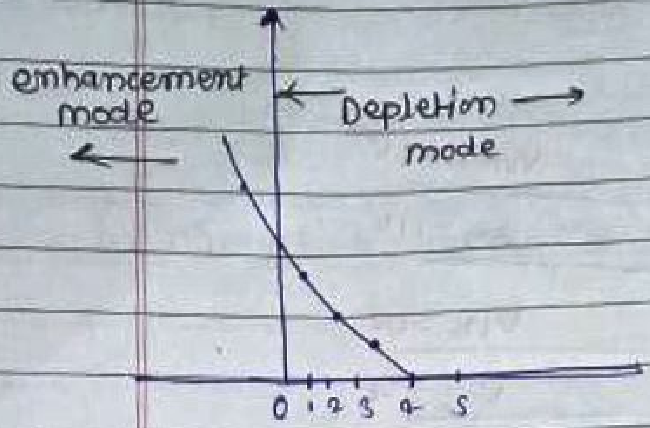
## Drain characteristics

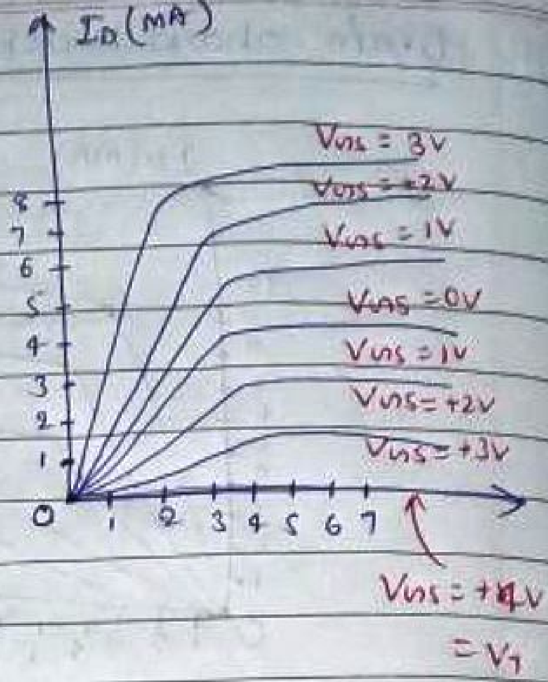



## P-channel Depletion type-mosfet



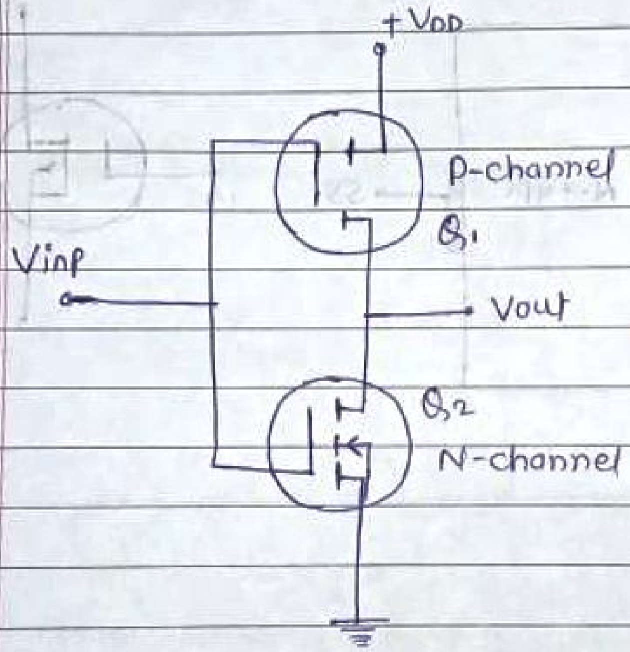

ID (mA)



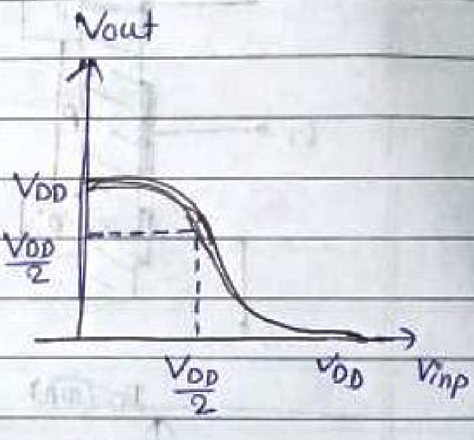




## CMOS

Complementry MOS (CMOS) can be designed by combining n-channel and p-channel MOSFETs




fig(a)




fig(b)

↳ when a CMOS circuit is used in a switching application the input voltage is either high (+VDD) or low (0V)

↳ when the input voltage is high, $Q_1$ is off and $Q_2$ is on in this case the shorted $Q_2$ pulls the output voltage down to ground

↳ when the input voltage is low, $Q_1$ is on and $Q_2$ is off Now the Shorted $Q_1$ pulls the output voltage upto $+V_{DD}$.

Since in both the cases output voltage is inverted the circuit is called CMOS inverter

↳ fig (b) shows how the output voltage varies with the input voltage when the input voltage is zero the output voltage is High and vice-versa.

Between ~~shows~~ the two extrems there is a crossover point where the input voltage equals to $V_{DD}/2$ At this point both MOSFET have equal resistance and output voltage equals $V_{DD}/2$

↳ The main advantage of CMOS is its extremely low power consumption therefore often used for battery powered applications such as - Calculators, digital watches and hearing aids etc.

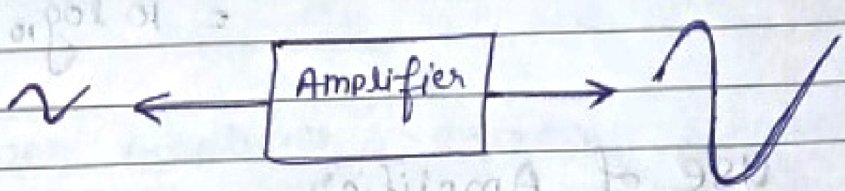
# Module - 3

Transistor amplifier and oscillator covering

## Amplifiers -

↳ An amplifiers is an electronic device that is used to increase strength of the signal applied to it.

↳ It increases voltage, current, power level of a signal which is applied to its input at the output




↳ Amplifer performs the process referred as amplification

↳ The amplifier produces amplification which is measured by its gain.

↳ Gain of amplifier is the ratio of output quantities (voltage, current & power) to the input quantities e.g. – voltage gain ($A_v$)

$$= \frac{V_o}{V_i} = [A_v]_{dB} = 20 \log_{10} (A_v]$$

- current gain $(A_I] = \frac{I_o}{I_i} = [A_I]_{dB}$

$$= 20 \log_{10} [A_I]$$

- power gain $(A_P) = \frac{P_o}{P_i} = [A_P]_{dB}$

$$= 10 \log_{10} (A_P]$$

## Use of Amplifier

↳ mostly electrical & electronic devices make use of amplifier for providing different amount of signal amplifications

↳ mostly the signals are too small in magnitude to drive or control the device of choice, ~~this~~ tuiy is where amplifiers are needed.

# Classification of an amplifiers

## (I) Based on number of stages

(a) single - stage Amplifier - this has only one transistor amplifier circuit.

(b) multi - stage amplifier - multiple transistor amplifier circuit

## (II) Based on its output

(a) Voltage Amplifier - increase Voltage level of input signal at output.

(b) power Amplifier - increase power level of input signal at output

## (III) Based on input signals

(a) Small signal amplifier

(b) Large signal amplifier

## (IV) Based on frequency range

(a) Audio frequency amplifier (AF Amplifier)
(b) Radio frequency amplifier (RF amplifier)

(V) Based on Coupling method

(a) RC coupled amplifier
(b) Transformer Coupled Amplifier
(c) Direct coupled Amplifier

(VI) Based on Transistor configuration

(a) common Emitter (CE) amplifier
(b) common Base (CB) amplifier
(c) common collector (CC) amplifier

(VII) Based on Biasing condition

(a) class A amplifier
(b) class B amplifier
(c) class C amplifier
(d) class AB amplifier.

# Small signal amplifiers

↳ Those amplifiers which handles input A.C signals (a few uv or few mv) are called small signal amplifiers

↳ Voltage amplifiers are generally a type of small signal amplifiers

↳ the small signal amplifiers are designed to operate over the linear portion of the output characteristic

↳ Therefore the transistor parameters such as gain, input impedance, output impedance etc do not change as the amplitude of the signal changes

↳ Such amplifier amplifies the signal with little or distortion.

# features of small signal Amplifiers

↳ Small signal amplifiers are also known as power amplifiers

↳ It has three main properties gain, input impedance and output impedance

↳ It operates in linear portion of output characteristic.

↳ It can provide very small or no distorsion

↳ It can handle low input A.C signals

↳ power handling capacity is very low

↳ Temperature may affects its performance.

# # Common emitter amplifiers

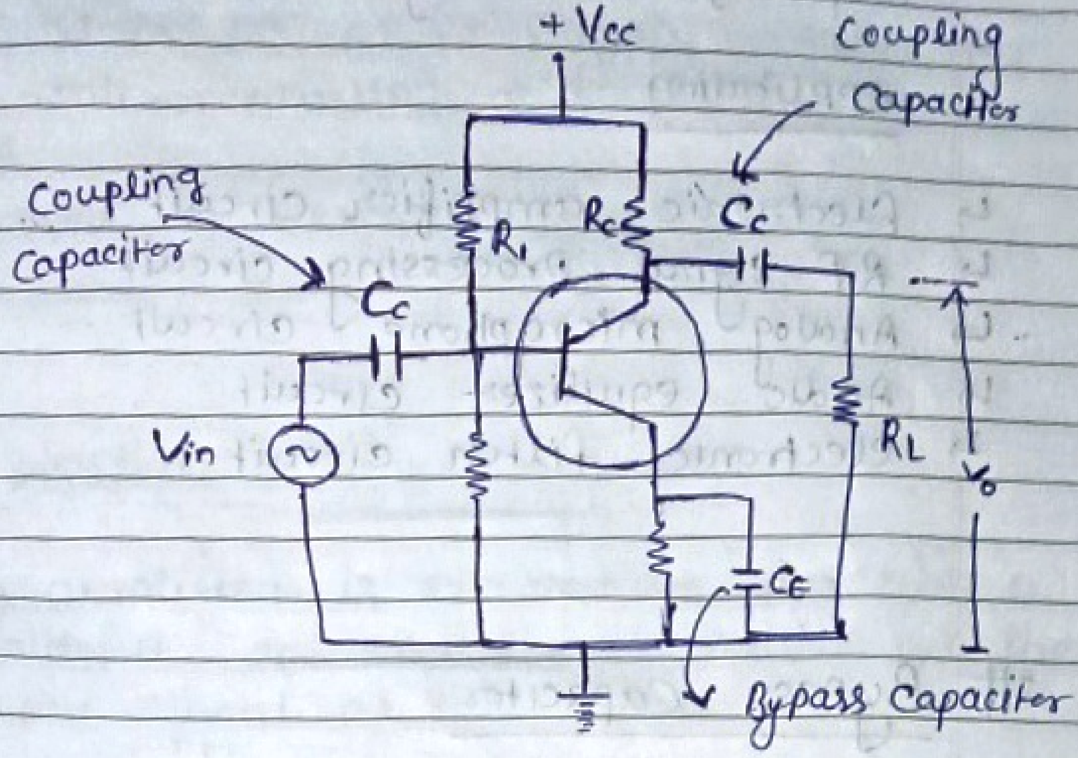



fig. Single stage CE transistor Amplier

## Coupling Capacitor

when a capacitor is used to couple or link two circuit in such a way that only high frequency signals (AC signal) can pass from one circuit to another circuit then it is called coupling capacitor

↳ It is mainly used to pass A.C. Signal and block d.c. signal.

↳ It provide low impedance path to A.C signals or high frequency signals and high impedance to low frequency d.c signals

Application

↳ Electronic amplifier circuit
↳ RF Signal processing circuit
↳ Analog microphone circuit
↳ Audio equilizer circuit
↳ electronic filter circuit

# Bypass Capacitor

↳ when capacitor is used in an electronic circuit in such a way that it will ground the A.C signals or High frequency signals then it is called the Bypass capacitor.

↳ It provides low impedance to AC signal or High frequency signals.

↳ In CE amplifier if bypass capacitor is not connected input A.C current produce large voltage drop across emitter resistance to reduce gain considerbly.

Application :-

↳ Amplifier circuit

↳ Used in DC power supply circuit for microcontroller and sensor.

↳ used in electronic tuning circuits.

# Distortion in CE - Amplifiers -

↳ An amplifier is expected to produce a faithful or undistorted version of the input signal at the output.

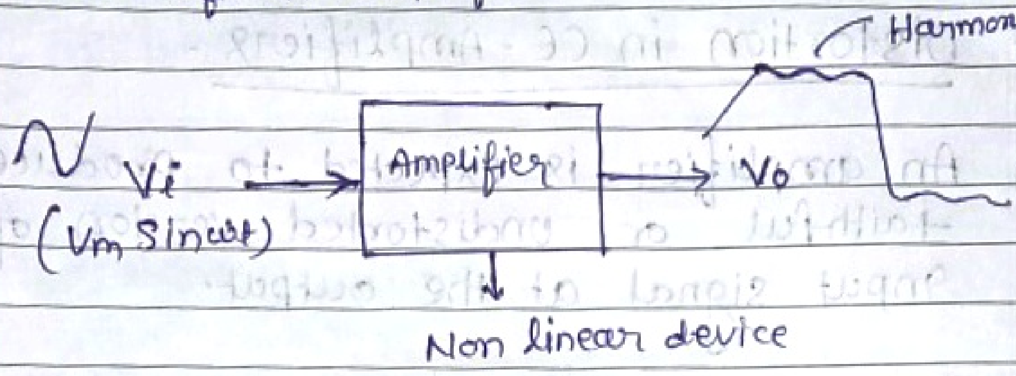
↳ for CE amplifier, an undistorted output signal (voltage) is obtained as long as the small signal condition $V_{be} << V_T$ is satisfied. this is because the BJT small signal model is valid if the nonlinear terms (degree 2 & higher) are negligibly small compared to the linear term in

$$\exp\left(\frac{V_{be}}{V_T}\right) = 1 + \frac{V_{be}}{V_T} + \frac{1}{2}\left(\frac{V_{be}}{V_T}\right)^2 + \cdots$$

Since the signal voltage $V_s \approx V_{be}$ in CE amplifier we have $V_s << V_T$ to avoid distortion in the output with $V_T = 25mV$ at room temperature the amplitude of $V_s$ should therefore be restricted to about 5mV.

→ Harmonic distortion :

- It is caused due to non-linearity nature of an amplifiers.




$$V_o = aV_i + bV_i^2 + cV_i^3 + \cdots$$

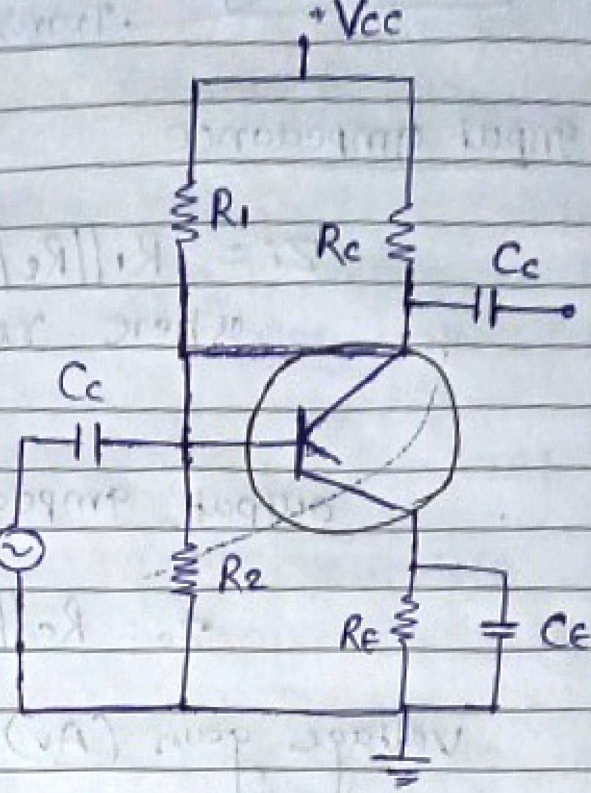
$$V_o = V_i + V_i^2$$

$$V_o = V_m \sin\omega t + V_m^2 \sin^2\omega t$$

$$= V_m \sin\omega t + \frac{V_m^2}{2}(1 - \cos 2\omega t)$$

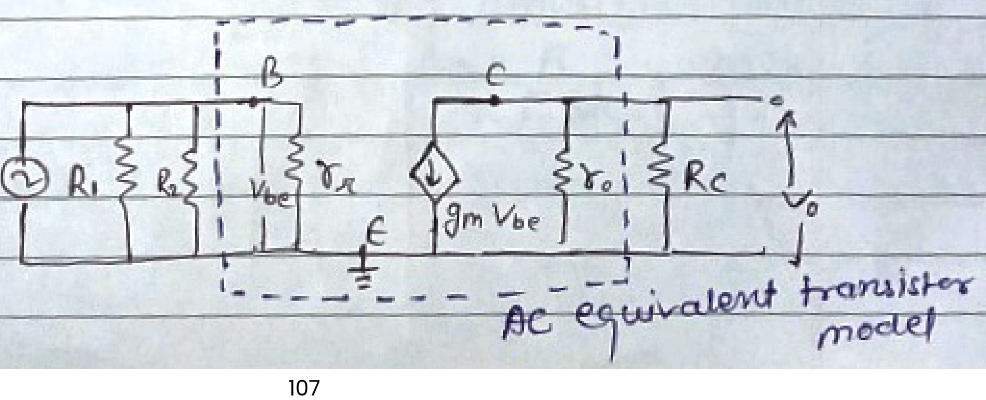
$$V_o = V_m \sin\omega t + \frac{V_m^2}{2} + \frac{V_m^2}{2}\sin\left(2\omega t + \frac{\pi}{2}\right)$$

# AC Equivalent circuit of CE Amplifier




for AC equivalent circuit we have to follow following steps

(i) Short all coupling and Bypass capacitors
(ii) Short D.C Sources
(iii) DO D.C analysis to get VCEQ & ICEQ
(iv) Draw AC equivalent circuit model



$$\boxed{r_\pi = \frac{\beta}{g_m}}$$

current gain

Transconductance

* Input Impedance

$$Z_i = R_1 || R_2 || r_\pi$$

where $r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C}$

output Impedance

$$Z_o = R_C || r_o \approx R_C$$

Voltage gain ($A_v$)

$$A_v = -g_m R_C = -\frac{\beta R_C}{r_\pi}$$

Rajeev's Pathshala

# Oscillators

↳ An oscillator is an electronic device which produces a continuous, repeated alternating waveform without an input.

↳ It basically convert unidirectional current flow from a DC source into an alternating waveform which is of the desired frequency as decided by circuit components.

↳ It works on the principle of positive feedback.

↳ It consists of transistor or operational amplifier, feedback circuit

## Barkhausen's criteria for oscillation

↳ condition which are required to be satisfied to operate the positive feedback circuit as an to operate are called as Barkhausen's criteria for sustained oscillation.

↳ for a positive feedback amplifier with voltage gain of $A_f = \frac{A}{1-A\beta}$, ~~Barr~~

Barkhausen's criteria state that

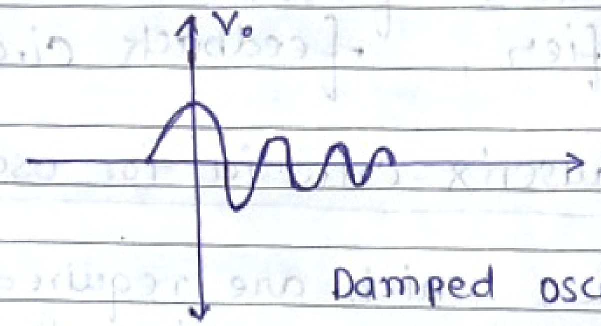
① The magnitude of the product of the open loop gain of the amplifier (A) and feedback factor or gain (B) is unity

i.e $|AB| = 1$

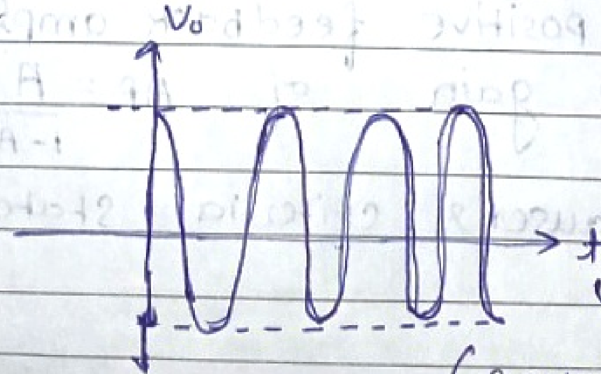
② the total phase shift around a closed loop must 0° or 360° or its integral multiple

i.e $\angle AB = 0°$ or $360°$

Case-1 $|AB| < 1$

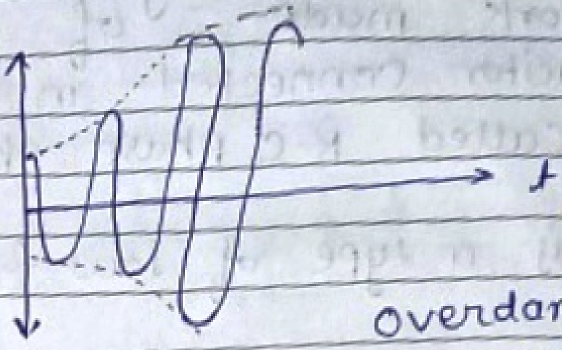



case-2 $|AB| = 1$



case-3

$|A\beta| > 1$




overdamped oscillation.

Feed back oscillator

Audio frequency (AF) oscillator (20Hz - 20KHz)

- R-C Phase Shift oscillator
- wein Bridge (oscillator)

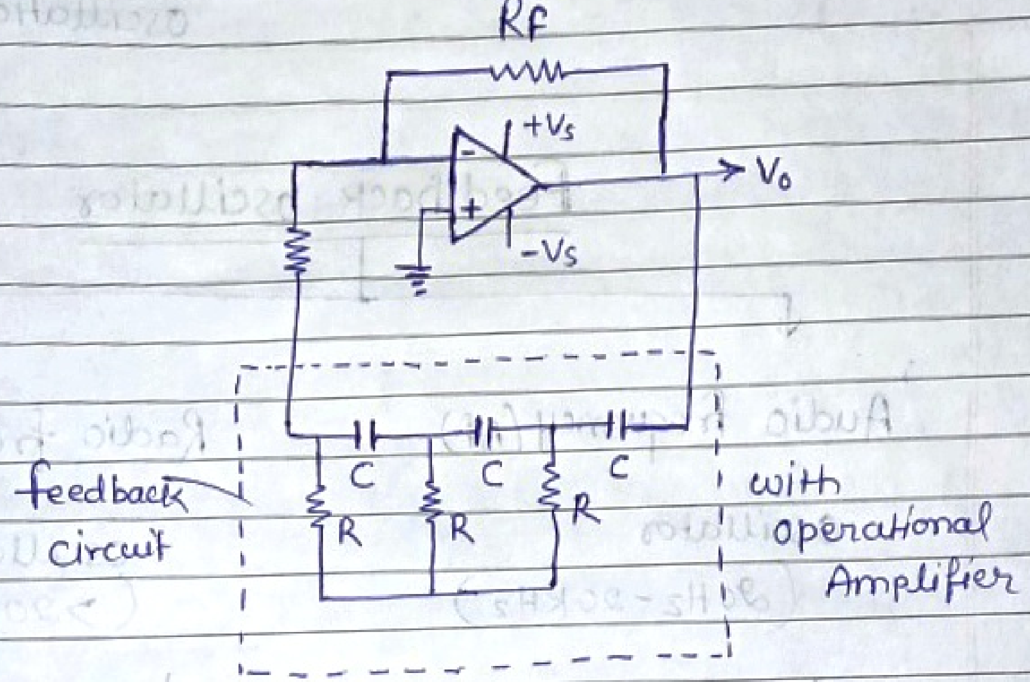
Radio frequency (RF) oscillator (>20KHz)

- LC oscillator
  - Hartley's OSC
  - Colpitt OSC
  - Clapp OSC
- crystal oscillator

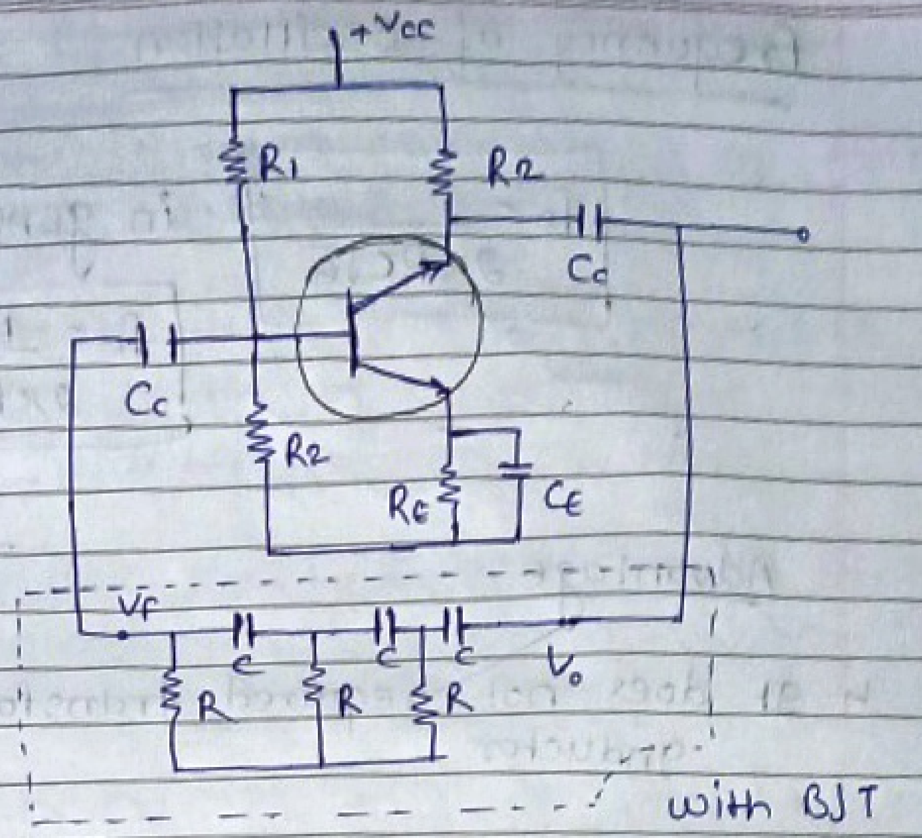
## R-C phase shift oscillator

↳ The oscillator circuit that produces a sine wave using a phase-shift network made of resistor and capacitor connected in feedback circuit is called R-C phase shift oscillator

It is a type of low frequency oscillator



Rajeev's Pathshala




with BJT

Working

↳ The circuit when switched ON oscillates at resonance frequency ($f_0$) the output of the amplifier is 180° phase shift as it is CE configuration.

↳ the fraction of output is feedback to input with pair of RC circuit each RC pair provide 60° ( so, 60°×3 = 180°) phase shift produce by feedback circuit

↳ The phase shift produce by amplifier and feedback circuit is 360° which is required condition to sustain oscillation.

## frequency of oscillation

$$\boxed{f_0 = \frac{1}{2\pi RC\sqrt{6}}}$$

in general

$$\boxed{f_0 = \frac{1}{2\pi RC\sqrt{2N}}}$$

**Advantage**

- It does not required transformer and inductor
- It can be used to produce low frequency
- The circuit provides good frequency stability (less cost)

**Disadvantage**

- Starting oscillation is difficult
- output produce is small

**Application**

- musical instrument
- GPS unit
- voice synthesizer.

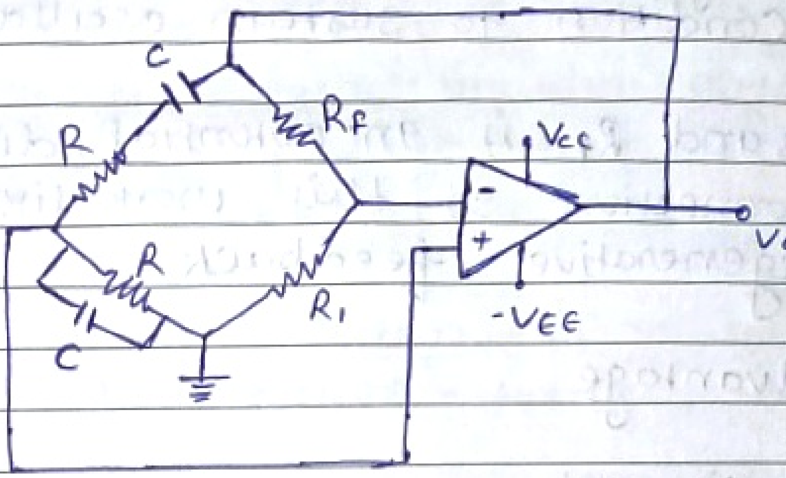
## Wein Bridge oscillator

- The wein Bridge oscillator is an electronic oscillator produces sine wave

- It consists two stages of amplifier and a bridge of ~~resistor o~~ resister and capacitor.

- It is also known as wheat stone Bridge type oscillator as it consists a wheat stone bridge in feedback.

- This bridge is also for measurement of unknown impedance

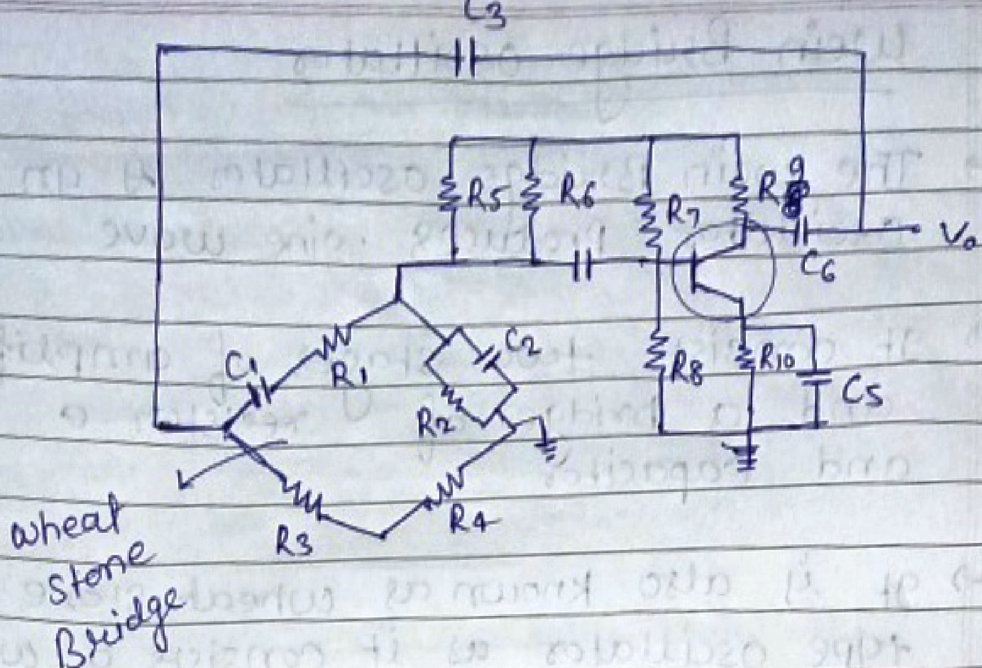



frequency of oscillation.

$$\boxed{f_0 = \frac{1}{2\pi RC}}$$

* $R_1 = R_2 = R_3 = R_4 = R$

* $C_1 = C_2 = C$




↳ Two transistor $T_1$ & $T_2$ are used to produce phase of 180° each i.e total phase shift at the input of balanced Bridge is 360° which is the required condition to sustain oscillator.

↳ $R_3$ and $R_4$ is in potential divider connection so this work like a Degenerative feedback.

Advantage

1. High gain
2. adjustable frequency of oscillation
3. Good frequency stability
4. produce pure sine waves

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Disadvantage

① Large number of components used
② Suitable to generate audio frequency only

③ Application

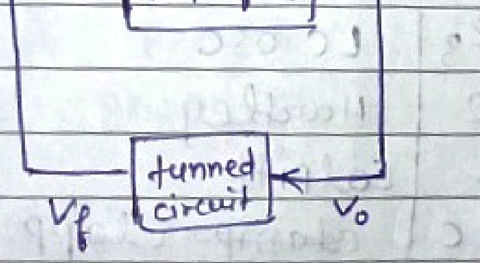
① Audio testing
② clock signal for testing filter

③ use in power amplifiers.

High frequency LC oscillators

↳ High frequency (radio frequency) LC oscillators consist a tuned or tank circuit in feedback along with a CE amplifier ie it has two section

(i) Amplifier Section – CE amplifier circuit
(ii) feedback section – tunned circuit

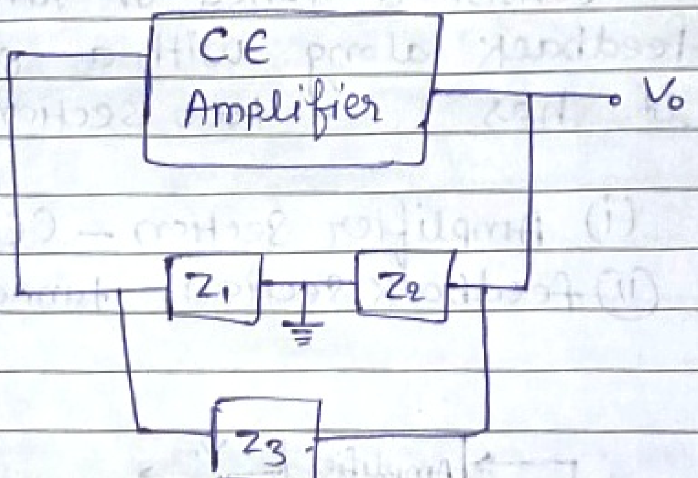


## Tanned or tank Circuit

It consists of inductance (L) connected in parallel with capacitor (C) the frequency of oscillations in the circuit depends upon the value of 'L' and 'C'.

LC oscillator ($f > 20KHz$)

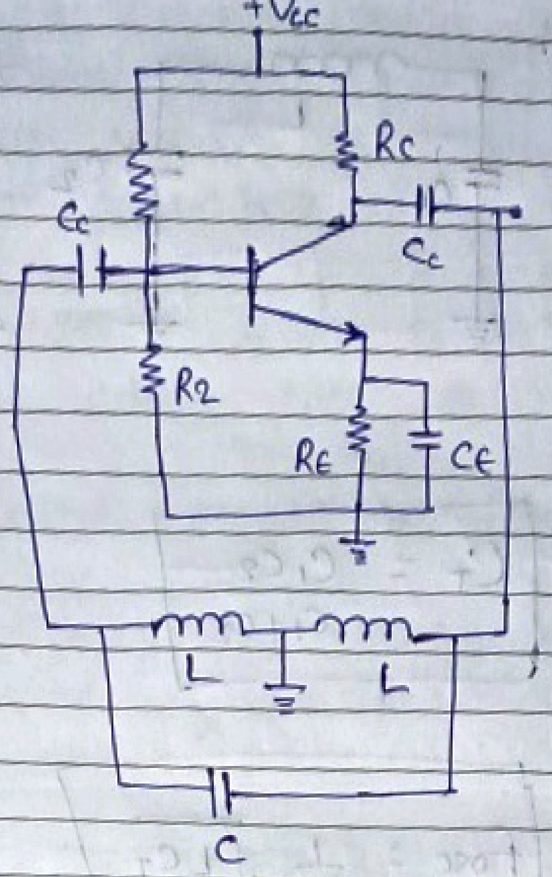
- Hartey's Oscillator
- Colpitt's oscillator
- Clapp's oscillator




| $Z_1$ | $Z_2$ | $Z_3$ | LC OSC |
|---|---|---|---|
| L | L | C | Hartley |
| C | C | L | Calpitt |
| C | C | LC | ~~clamp~~ Clapp OSC |

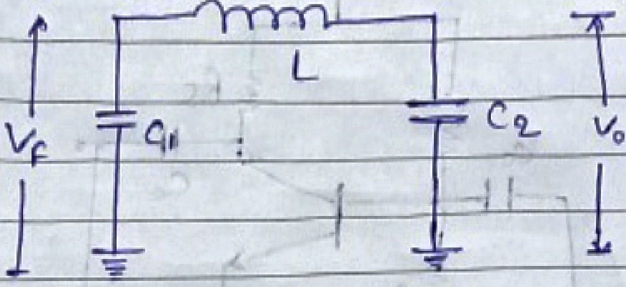
## (1) Hartley's oscillator

Circuit




- when the circuit is turned on the capacitor charges
- when capacitor is fully charged it will discharge through $L_1$ & $L_2$ setting up oscillation of frequency
- A transistor amplifier produces 180° phase shift at output and further tank circuit provide 180° phase shift to have total phase shift of 360°
- In this way feedback is properly phased to ~~[illegible]~~ produce continous undamped oscillation

## frequency of oscillation




$$\boxed{C_T = \frac{C_1 C_2}{C_1 + C_2}}$$

$$\boxed{f_{osc} = \frac{1}{2\pi} \sqrt{L C_T}}$$

$$\boxed{\text{feedback fraction} \ (\beta) = \frac{C_1}{C_2}}$$

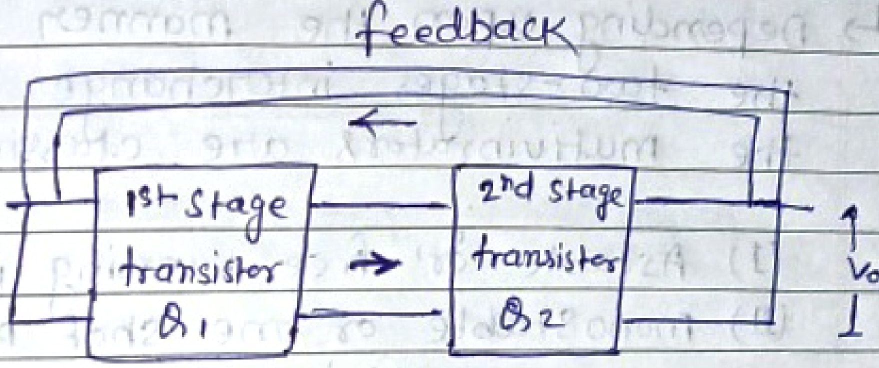
## Non sinusoidal oscillator

- An electronic circuit which generates non-sinusoidal like square, rectangular saw-tooth waves is known as non sinusoidal oscillator.

- multivibrators is an example of non-sinusoidal wave like square wave

- It is based on positive feedback

- It is basically two stage amplifier with output of one feedback to input

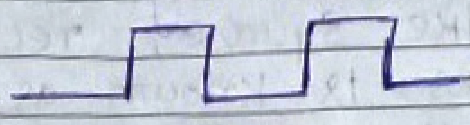


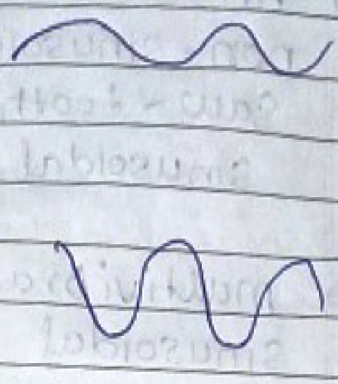

- The circuit ~~operation~~ operates in two states (ON and OFF) controlled by circuit conditions

- each amplifier stage supplies feedback to the other in such a manner that will drive the transistor of one stage to saturation (ON state) and other to cut-off (off state)

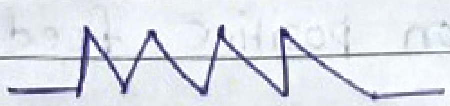
Non-sinusoidal wave | Sinusoidal wave

Square wave





Saw-tooth wave

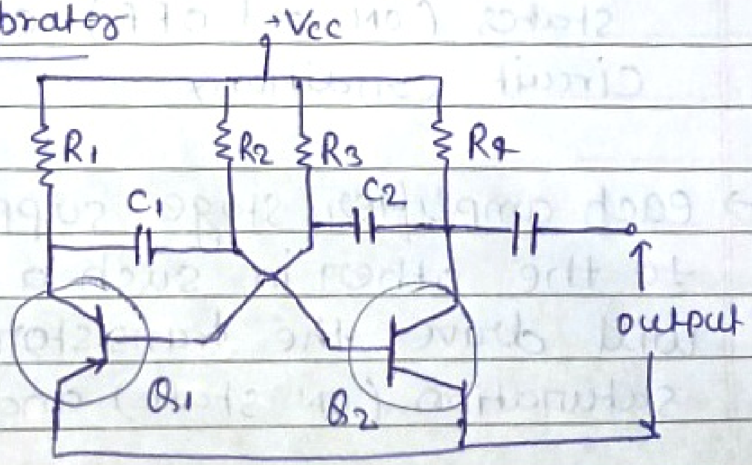


## Multivibrators ( Types )

↳ Depending upon the manner in which the two-stages interchange their states the multivibrators are classified as

(I) Astable or free running multivibrator
(II) monostable or one shot ~~mult~~ multivibrator
(III) Bistable or flip flop multivibrator.

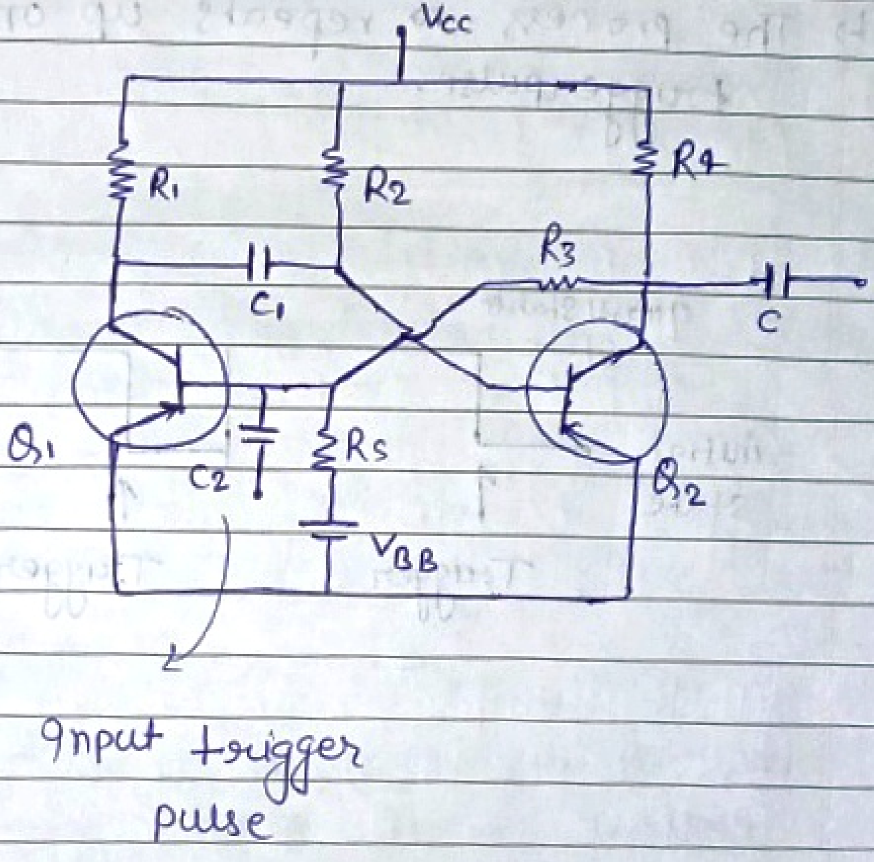
Astable multivibrator



↳ The astable multivibrator alternates ~~automatically~~ automatically between two states and remains in each for a time dependent upon circuit constant.

↳ It does not required an input and produces output as a square wave (non-sinusoidal)

## monostable multivibrator

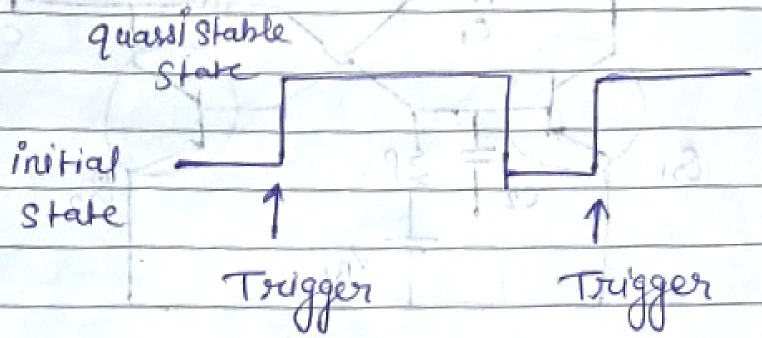


↳ The monostable multivibrator has one stable state and one quasi-stable state (i.e half stable state)

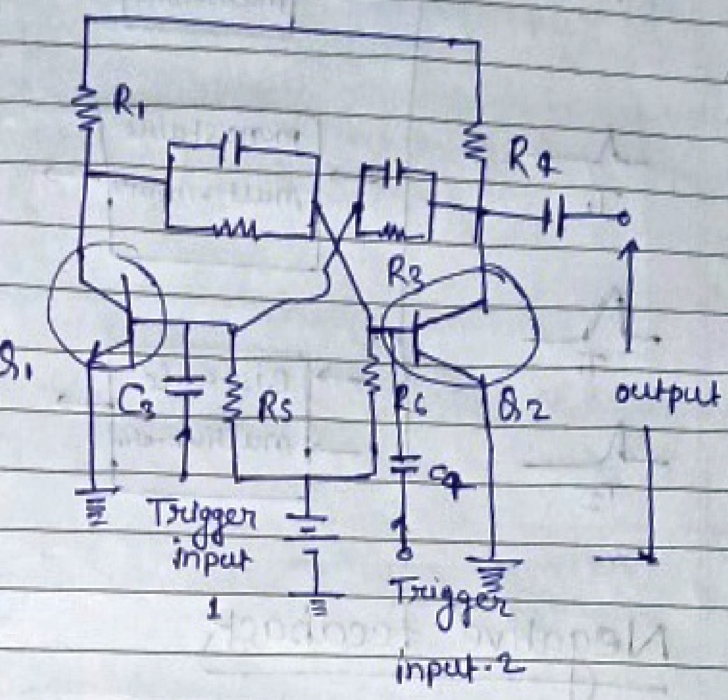
↳ The application of input pulse triggers the circuit into its quasi stable state in which it remains for a period determined by circuit constants

↳ after this period of time the circuit return to its initial stable states

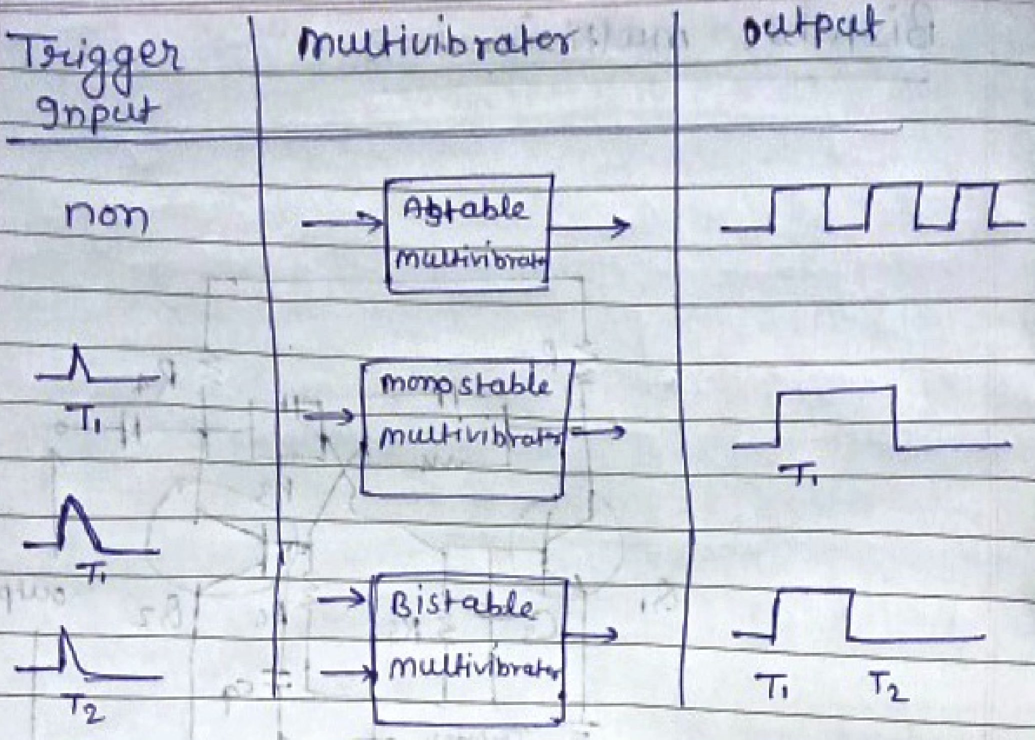
↳ The process repeats up on each trigger pulse.



## Bistable multivibrators :




- The bistable multivibrator has both the two stable state
- It requires the application of an external trigger input to change either one state to another
- Thus one pulse is used generate half cycle of square wave another pulse to generate the next half-cycle of square wave
- It has two possible state so it is also known as flip-flop multivibrator.

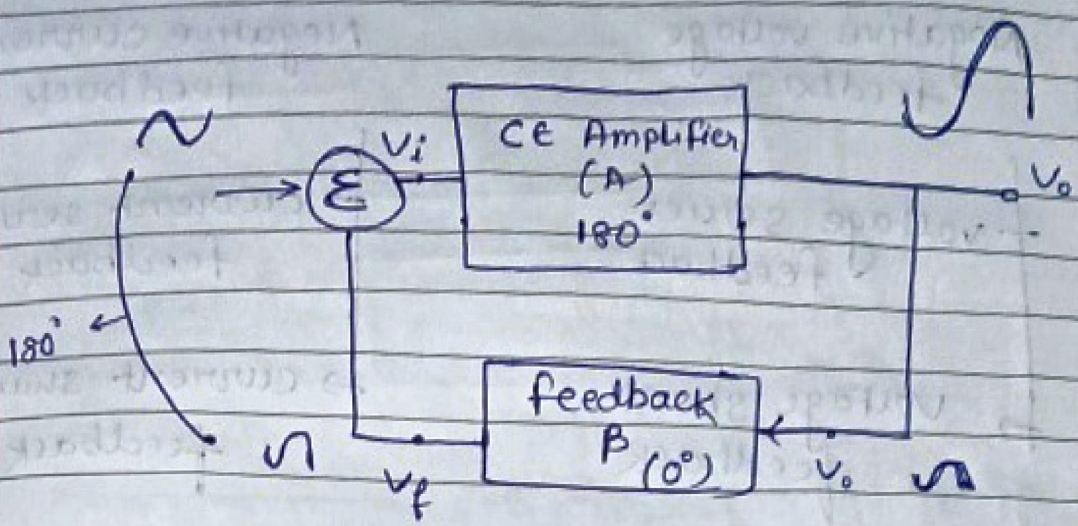



## Negative feedback

↳ It is the method of injecting a portion of the amplified output to the input in such a way that total closed-loop phase is 180° i.e feedback signal is out of phase (180°) with respect to input.

↳ In this amplifier circuit produces 180° phase shift to input at output, but feedback circuit produce no phase shift to portion of output signal injected to it

## Simplified Block diagram




### Gain

**At Input**

$\Rightarrow V_i = V_s - V_f$ —①

we know that

$$A = \frac{V_o}{V_i}$$

$$\boxed{V_i = \frac{V_o}{A}}$$

$$\beta = \frac{V_f}{V_o}$$

$$\boxed{V_f = \beta V_o}$$

from ①

$$\frac{V_o}{A} = V_s - \beta V_o$$

$$V_o\left[\frac{1}{A} + \beta\right] = V_s$$

$$V_o\left[\frac{1+A\beta}{A}\right] = V_s$$

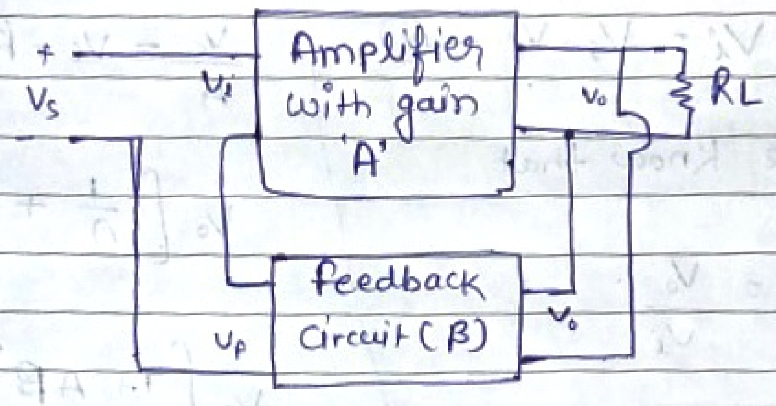
$$\frac{V_o}{V_s} = \frac{A}{1+A\beta}$$

$$\boxed{A_f = \frac{A}{1+A\beta}}$$

# Types of Negative feedback

- Negative voltage feedback
  - voltage series feedback
  - Voltage shunt feedback
- Negative current feedback
  - current series feedback
  - current shunt feedback

## (I) Voltage series feedback




- It is also known as series shunt feedback or shunt driven series fed feedback
- The feedback circuit is placed in shunt with output and series with input
- As feedback is connected in series with input its input impedance increases

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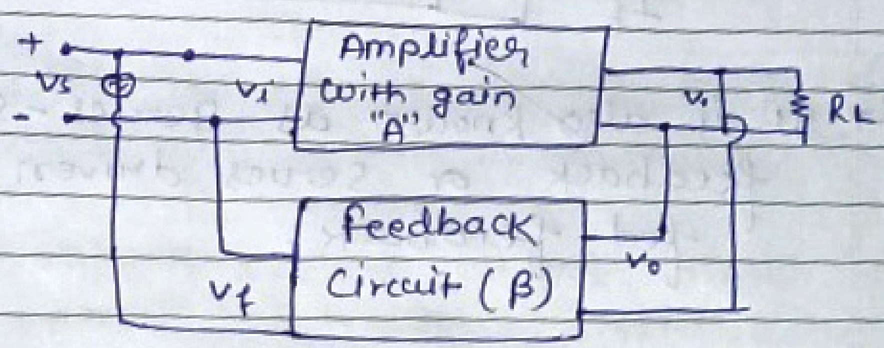
↳ Also feedback is connected in shunt with output its output impedance decreases

- Series mixing
- Shunt sampling

(II) Voltage shunt feedback




↳ It is also known as shunt - shunt feedback or shunt driven shunt fed feedback

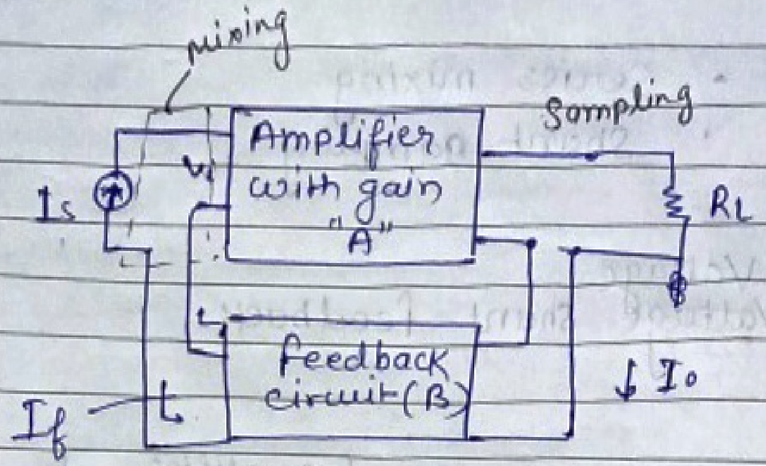
↳ The feedback circuit is placed in shunt with output and shunt with input

↳ As feedback is connected in shunt with input its input impedance decreases

↳ Also feedback is connected in shunt with output impedance decreases

- shunt mixing
- shunt sampling

## (III) current series feedback




↳ It is also known as series-series feedback or series driven series fed feedback.

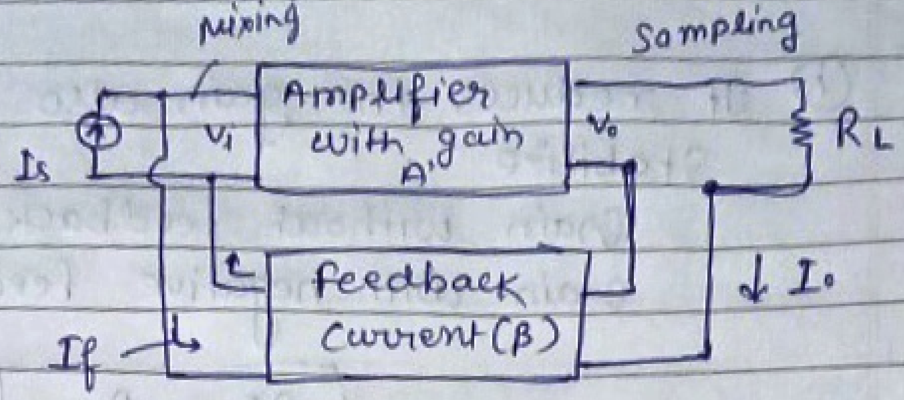
↳ The feedback circuit is placed in series with output and series with input

↳ As feedback is connected in series with input its input impedance ~~decreases~~ increases

↳ Also feedback is connected in series with output its output impedence increases

- Series mixing
- Series sampling

## (IV) Current shunt feedback




↳ It is also known as shunt - series feedback or series driven shunt fed feedback

↳ The feedback circuit is placed in series with output and shunt with input

↳ As feedback is connected in shunt with input its input impedance decreases.

↳ Also feedback is connected in series with output its output impedance increases

∴ shunt mixing
∴ series sampling

## Advantage

Note - $1 + A\beta$ - desensitivity factor

① It reduces the gain also make it Stabilize

Gain without feedback = A
Gain with negative feedback

$$\boxed{A_f = \frac{A}{1 + A\beta}}$$

Gain with negative feedback decreases with respect to gain without feedback by a factor of $(1 + A\beta)$

② It reduces the distortion. Let

D = Distorsion without feedback (Negative)

then

$$\boxed{D_f = \frac{D}{1 + A\beta}}$$

i.e distortion in output reduces by factor $(1 + A\beta)$ with the application of negative feedback.

③ Increase band width (improve frequency response)

Let $BW$ = Bandwidth without negative feedback

$$(BW)_f = BW\left[1 + A\beta\right]$$

i.e $BW$ with feedback increases by $(1 + A\beta)$ as compared to $BW$ without feedback

④ Reduce Noise

Let $N$ = noise without feedback
$N_f$ = Noise with negative feedback

then

$$\boxed{N_f = \frac{N}{1 + A\beta}}$$

⑤ $(Z_{in})_f = Z_{in}(1 + A\beta)$ ↑↑

$$(Z_o)_f = \frac{Z_o}{(1 + A\beta)} \quad \downarrow\downarrow$$

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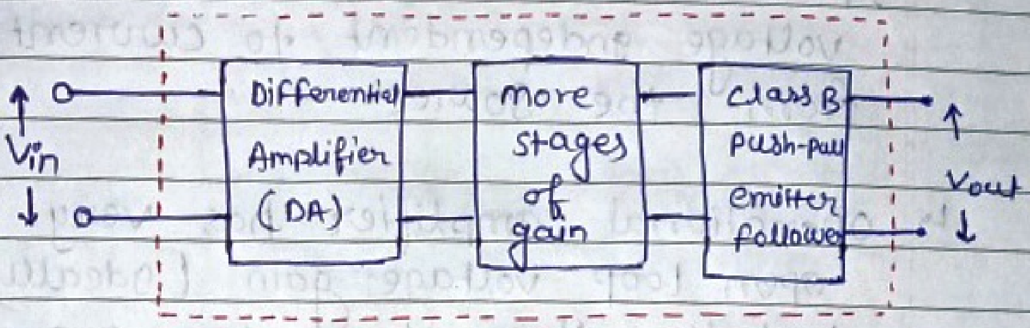
# Module - 4

## Operational Amplifiers

↳ An operational amplifier (OP-Amp) is a circuit that can perform mathematical operations as addition substraction, integration and differentiation.

↳ The block diagram of operational amplifier is shown below




↳ operational Amplifier is a multistage amplifier

↳ The input stage of an operational Amplifier is a differential amplifier (DA) which accept two input signals and amplifies difference between these two signals.

↳ The internal stages of operational-Amplifier are direct coupled i.e no coupling capacitors are used. the direct coupling allows the

Operational amplifier d.c as well as a.c signals

↳ An operational-amplifier has very high input impedance (ideally infinite) and very low output impedance (ideally zero)

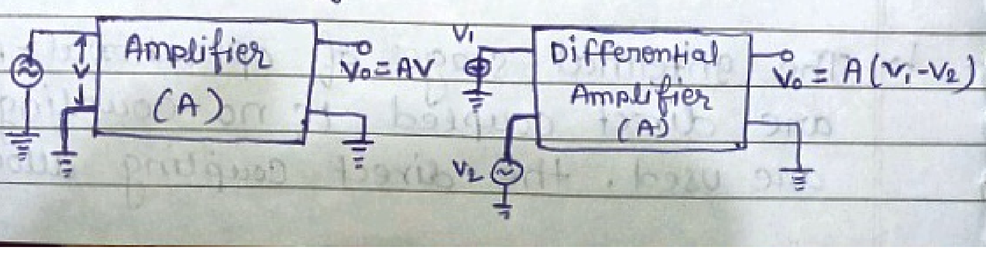
↳ The effect of high impedance is that it can draw very small current (ideally zero) from signal source

↳ The effect of low impedance is that it can provide a constant output voltage independent to current drawn from the source.

↳ Operational amplifier has very high open loop voltage gain (ideally infinite); typically ~~than~~ more than 200000.

# Differential Amplifier

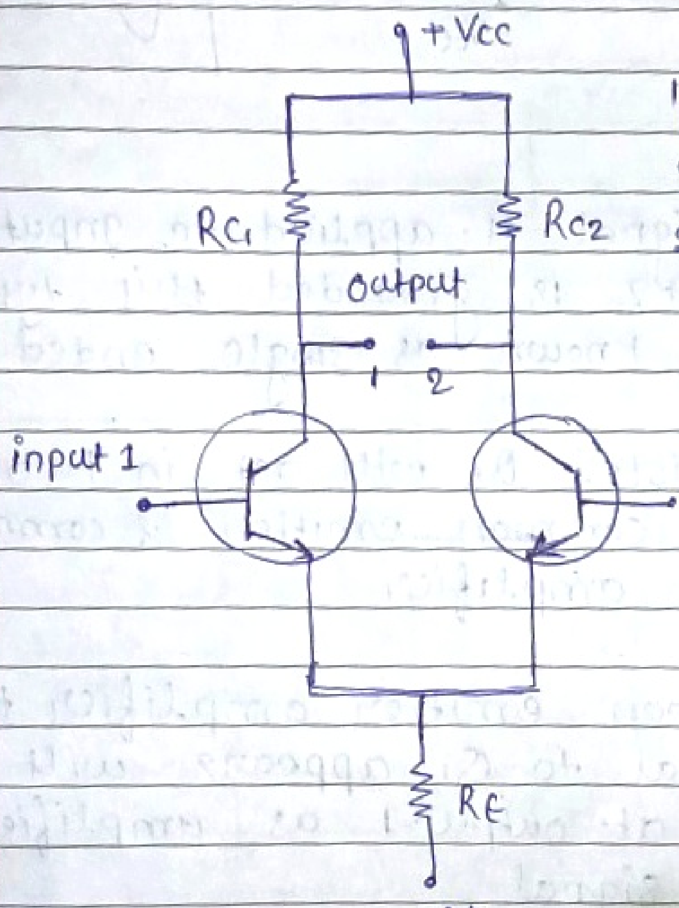
↳ A differential amplifier is a circuit that can accept two input signals and amplify the difference between these two signals.

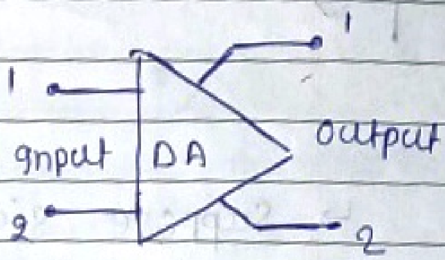


↳ Above fig shows block diagram of differen--tial amplifier there are two input voltage $V_1$ and $V_2$. Differential amplifier gives output ($V_0$) as $A(V_1 - V_2)$

↳ the first block diagram is an ordinary amplifier the input voltage V is amplified to "Av" at output where A is the amplifier gain.

Basic circuit




↳ The basic circuit of DA consist two transistor $Q_1$ and $Q_2$ that have ideally identical characteristic they share common power supply Vcc $R_E$ and $V_{EE}$

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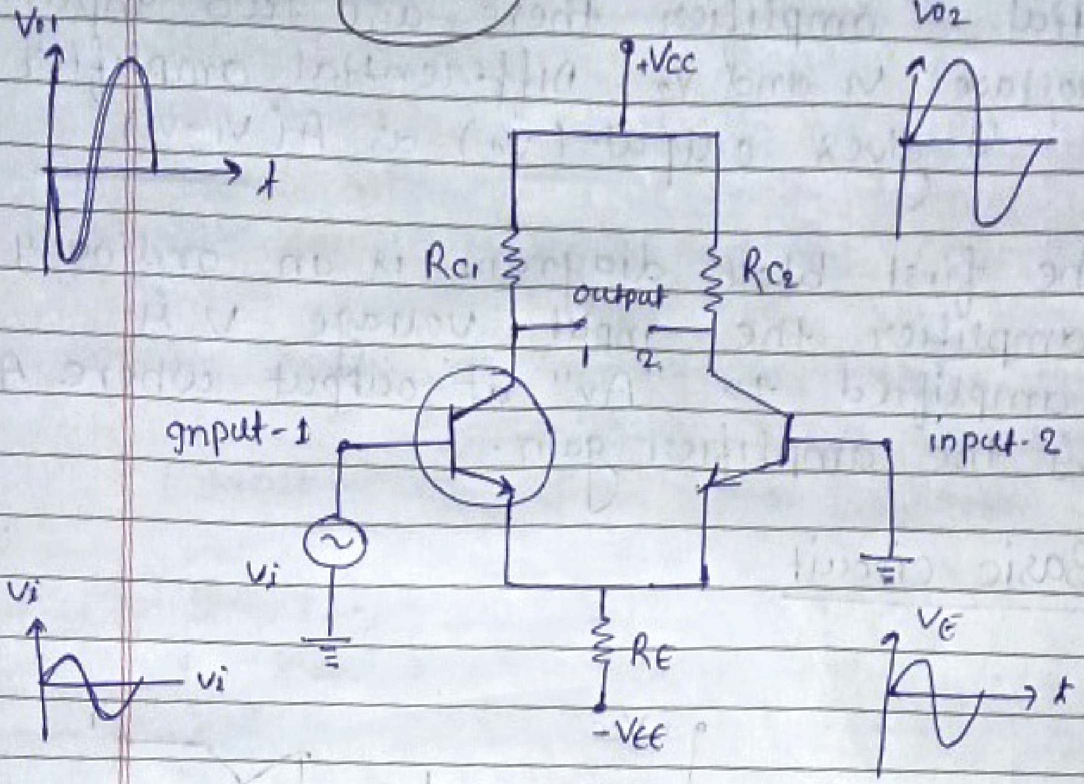
Operation (Case-I)




↳ Suppose signal is applied to Input 1 and Input 2 is grounded this type of DA is known as single ended DA.

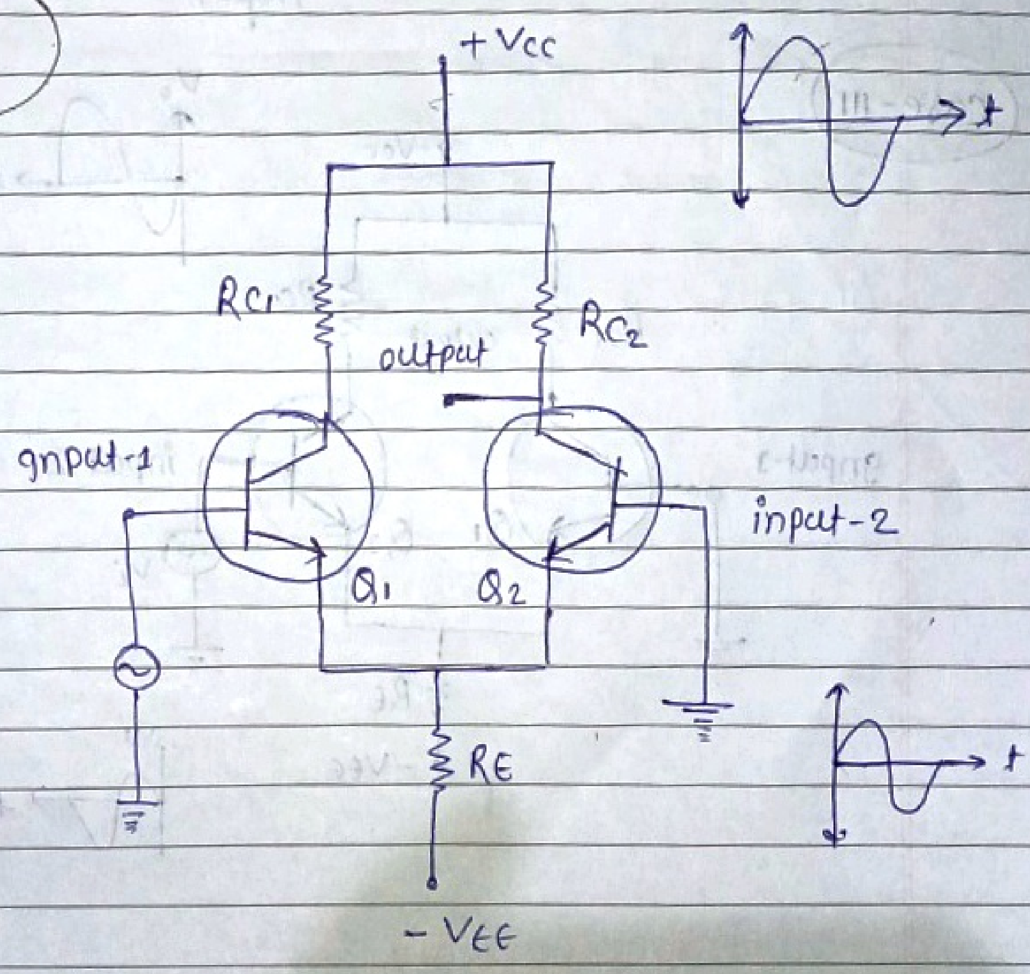
↳ The transistor $Q_1$ will act in two ways as a common emitter & common collector amplifier

↳ As a common emitter amplifier the Input signal to $Q_1$ appears will appear at output 1 as amplified Inverted signal

↳ As a common collector amplifier the appears on the emitter of $Q_1$ in phase with input and only slightly smaller

↳ Since emitter of $Q_1$ and $Q_2$ are common the emitter signal become input to $Q_2$ therefore $Q_2$ functions as a common base amplifier as a result the signal on the emitter of $Q_2$ will amplified and appears on output-2 in phase with emitter signal.

Case-II



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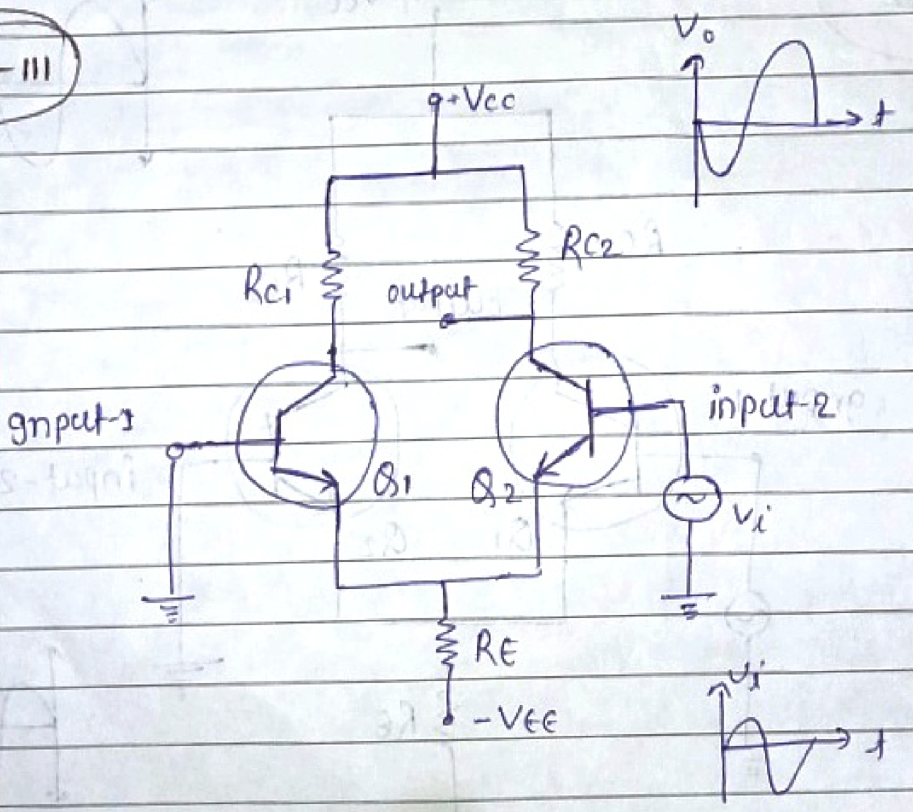
- Input signal is given to the base terminal of $Q_1$ and other input terminal of $Q_2$ is grounded

- A part of signal appears to the emitter of $Q_1$ and $Q_2$

- The transistor $Q_2$ is acts like common base amplifier to give output at collector terminal as inphase amplified signal.

- So this type of input is non-inverting input.

Case-III



↳ Input signal is given to $Q_2$ and input terminal of $Q_1$ is grounded

↳ the transistor $Q_2$ acts like common emitter configuration amplifier so output is taken at collector terminal of $Q_2$.

↳ The output is amplified but inverted so the amplifier has inverted input Differential Amplifier.

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# Operational - Amplifier Input modes

↳ The importance of Differential amplifier lies in the facts that the output is proportional to the difference between two input signals or amplify only one input signal simply by grounding the other input the input signal to a DA is are defined as.

(i) Common mode signal - when the input signals to DA ~~are~~ (Differential Amplifier) are inphase and exactly equal in amplitude, they are called common mode signal. the common mode signals are rejected (not amplified) as output ($V_0 = V_1 - V_2$) is zero, for $V_1 = V_2$

(ii) Differential mode signal - when input signals to a DA are 180° out of phase and exactly equal in amplitude they are called differential mode.

output $V_0 = 2V$ (for $V_1 = V$

$V_2 = -V$

$V_1 = -V_2$

## Parameters of operational - Amplifier

### ① open loop voltage gain

↳ It is the differential gain without any feedback path.
mathematically it is given by $A_v = \frac{V_0}{V_1 - V_2}$

### ② output offset voltage

The voltage present at the output of an operational - amplifier when its differential input voltage is zero is called as output offset voltage.

### ③ Common mode Rejection Ratio (CMRR)

CMRR of an operational - amplifier is defined as the ratio of the closed loop differential gain (Ad) to the common mode gain (Ac).

i.e $\boxed{CMRR = \frac{A_d}{A_c}}$

Note - Common mode gain (Ac) is the ratio of the common mode output voltage to the common mode input voltage.

(4) Slew Rate - It is defined as the Maximum rate of change of the output voltage due to a step input voltage

$$SR = \text{Max. of } \frac{dv_o}{dt} \quad \text{or} \quad \left|\frac{dv_o}{dt}\right|_{max}$$

it is Measured in V/msec

(5) Large signal voltage Gain -

↳ This is the ratio of the maximum allowable output voltage swing (usually one to several volts less than −V and +V) to the input signal required to produce a swing of ±10 volts.

(6) Power supply rejection Ratio (PSRR)

↳ It is the ratio of the change in input offset voltage to the crossponding change in one power supply with all remaining power voltages held constant. it is also called "power supply insensitivity"

(7) Input bias current - The average of the currents into the two input terminals with output at zero volts

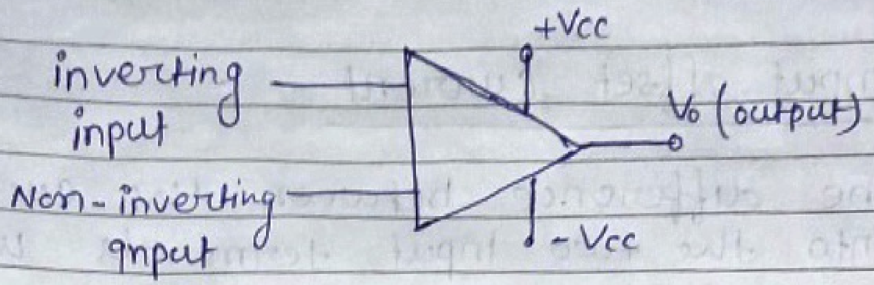
(8) Input offset current

↳ The difference between the currents into the two input terminals with the output held at zero.

(9) Output offset voltage

It is the voltage at output terminal with respect to ground when both the input terminal is grounded.

## Schematic Symbol of operational-Amplifier




- operational-amplifier have three main terminals two high input impedence terminals.

- out of two input terminal one is inverting and other is non-inverting terminals.

- It has one low impedance output terminal

- other than input output terminals, there are two power supply terminals i.e +Vcc & -Vcc

## open loop configuration

↳ The term open-loop indicates that no feedback in any form is fed to input from output.

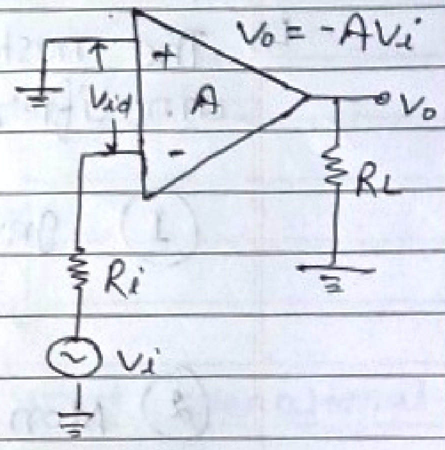
↳ when connected in open-loop the ~~open~~ operational-amplifier function as a very high gain amplifier

↳ There are three open-loop configuration

1. Differential Amplifier
2. Inverting Amplifier
3. Non-Inverting Amplifier

## Inverting Amplifier

↳ In this configuration input signal is applied to inverting input terminal of operational-amplifier and non-inverting terminal is connected to ground.




↳ the output voltages is 180° out of phase with respect to input.

## Closed-loop operational-amplifier configuration

↳ The operational amplifier can be effectively utilized in linear application by providing feedback from output to input, either directly or through another network.

↳ If the signal feedback is out of phase by 180° with respect to input, then feedback is referred to as negative or degenerative feedback.

↳ If the signal feedback is phase with that at the input, then the feedback is referred to as positive or negative feedback.

↳ The most commonly used closed loop amplifier configuration

(1) Inverting Amplifier (voltage shunt amplifier)

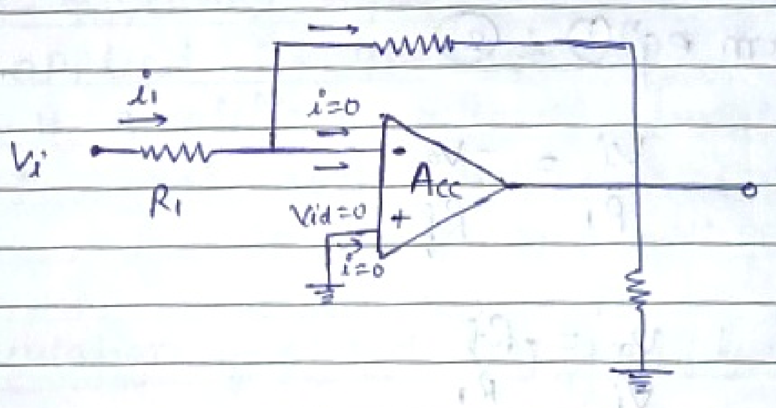
(2) Non-inverting Amplifier (voltage series amplifier)

## operational amplifier with negative feedback

There are two basic feedback connection used in order to understand operation of these two configuration, we make two assumption

1. the current drawn by either of the input terminal is negligible
2. the differential input voltage Vid must be zero.

## (1.) Inverting Amplifier




- This circuit is most widely used operational-amplifier circuit
- the output $V_o$ is fedback to the inverting terminal through feedback resistor ($R_f$) and $R_1$
- the input signal (a.c or d.c) is applied to the inverting terminal through $R_1$

↳ The non-inverting terminal is grounded.

↳ close loop gain of operational amplifier is represented by $A_{CL}$.

## Calculation of closed-loop gain ($A_{CL}$)

↳ The voltage at point 'a' is zero, because it is virtually grounded i.e $V_a = 0$

$$\boxed{i_1 = \frac{V_i - 0}{R_1} = \frac{V_i}{R_1}} \quad \text{---} (1)$$

also,

$$i_1 = \frac{0 - V_o}{R_f} = -\frac{V_o}{R_f} \quad \text{---} (II)$$

from eqn (1) & (2)

$$\frac{V_i}{R_1} = \frac{-V_o}{R_f}$$

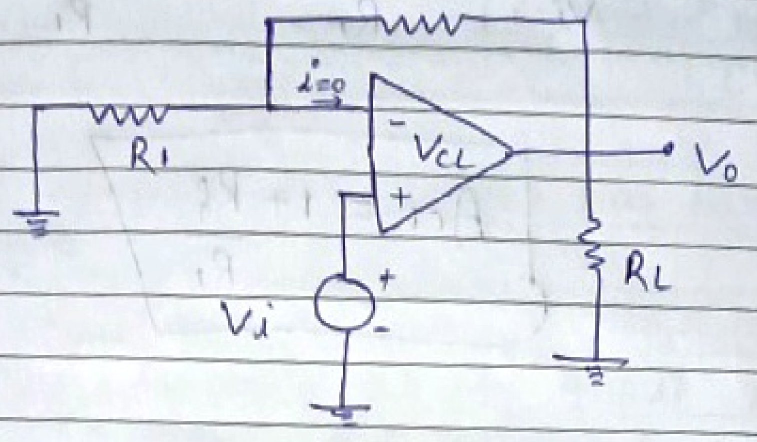
$$\frac{V_o}{V_i} = \frac{-R_f}{R_1}$$

$$\boxed{A_{CL} = \frac{-R_f}{R_1}}$$

~~Acl Vid = 0~~

~~$V_a - V_i = 0 \Rightarrow V_a = V_i$~~

## (2) Non-Inverting Amplifier




↳ If a signal (ac or dc) is applied to the non-inverting input terminal and feedback is applied to inverting terminal, the circuit amplifiers without inverting the input signal such circuit is called non-inverting amplifier.

Calculation of closed loop gain ($A_{CL}$)

As $V_{id} = 0$

$V_a - V_i = 0 \Rightarrow V_a = V_i$

Here $R_1$ and $R_f$ is potential divider resistor.

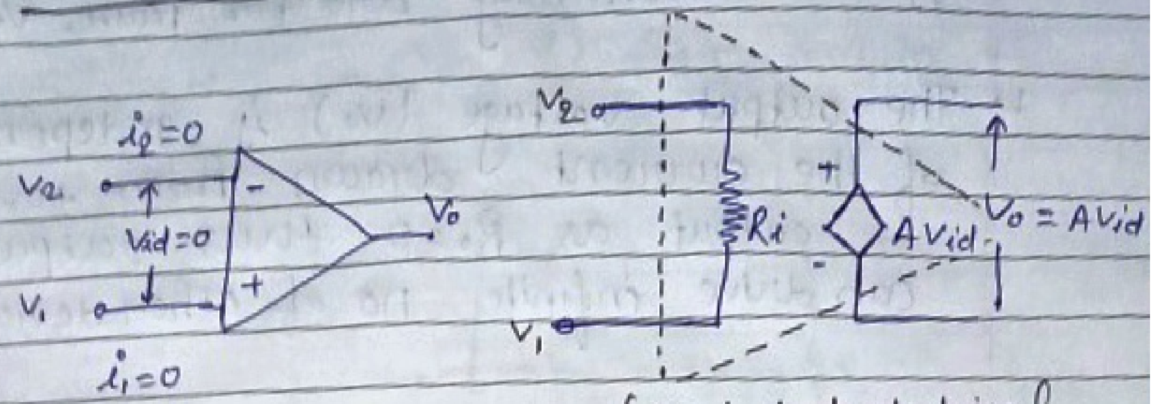
Using voltage division Rule

$$\boxed{V_i = \frac{V_o R_1}{R_1 + R_f}}$$

$$\frac{V_o}{V_i} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1}$$

$$\boxed{A_{CL} = 1 + \frac{R_f}{R_1}}$$

# Ideal operational-amplifier




(equivalent electrical circuit)

↳ Ideal operational amplifier has two input terminal

↳ - and + symbols at the input refers to inverting and non-inverting ~~term~~ terminals respectively.

↳ the operational-amplifier is said to be ideal if it has following characteristic

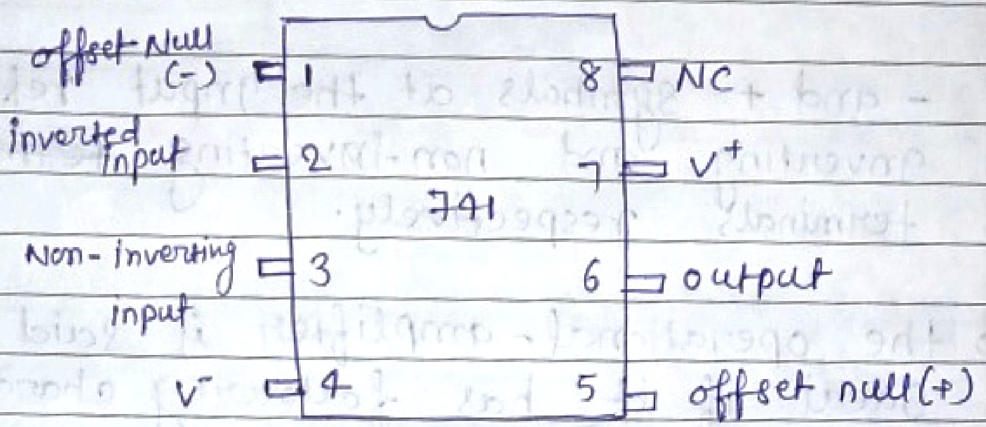
(a) open-loop voltages gain $(A) = \infty$ (infinite)
(b) input impedance $(R_i) = \infty$
(c) Bandwidth $(BW) = \infty$
(d) zero offset i.e $V = 0$ when $V_1 = V_2 = 0$

↳ An ideal operational-amplifier Draws no current at the both input terminals i.e $i_1 = i_2 = 0$ because of infinite input impedance

↳ Since gain is infinite the $V_{id} = V_1 - V_2$ is essentially zero for finite $V_o$.

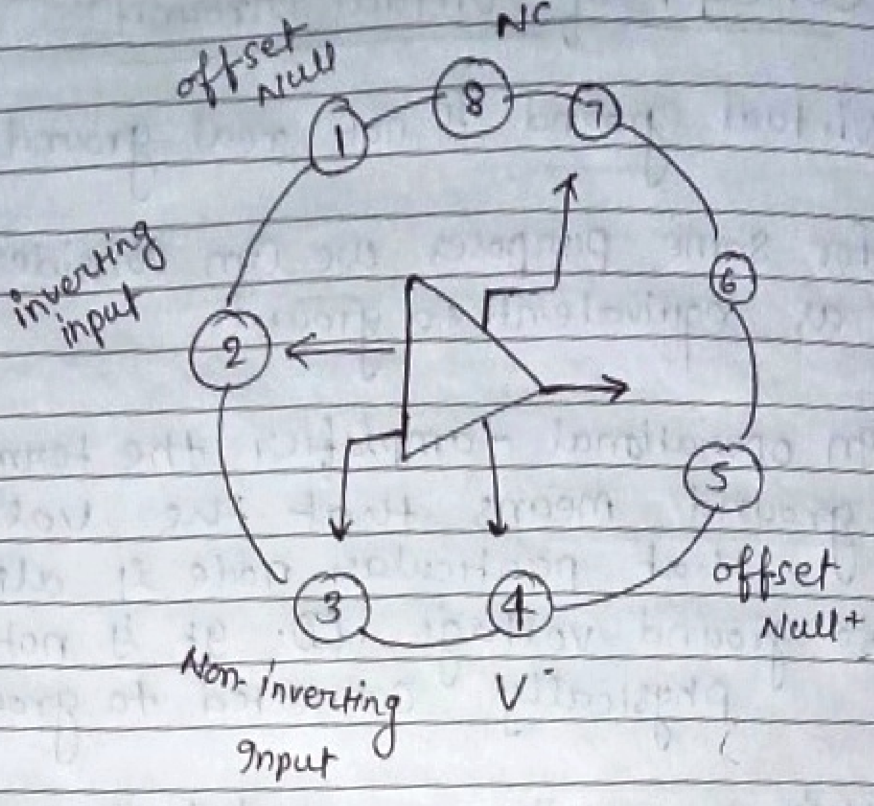
↳ The output voltage ($V_o$) is independent of the current drawn from the output as $R_o = 0$ thus output can drive infinite no. of other devices.

# Practical operational - amplifier IC 741




typical parameter of 741 IC

| parameter | typical Range | Ideal value |
|---|---|---|
| open loop gain | $10^5$ to $10^8$ | $\infty$ |
| input impedence | $10^5$ to $10^{13}$ $\Omega$ | $\infty$ |
| output impedence | 10 to 100 | 0 |




- The IC741 is a small chip
- It comprises eight pins
- pin 2, 3 and 6 are most significant
- pin 2 is inverting input terminal
- pin 3 is non-inverting input terminal
- pin 6 is output terminal

- IC741 mainly perform mathematical operation like addition, substraction division, multiplication differentiation integration etc

- pin 1 & 5 are offset null or balance terminal

- pin 4 & 7 has power supply pin

- Pin 8 has no connection.

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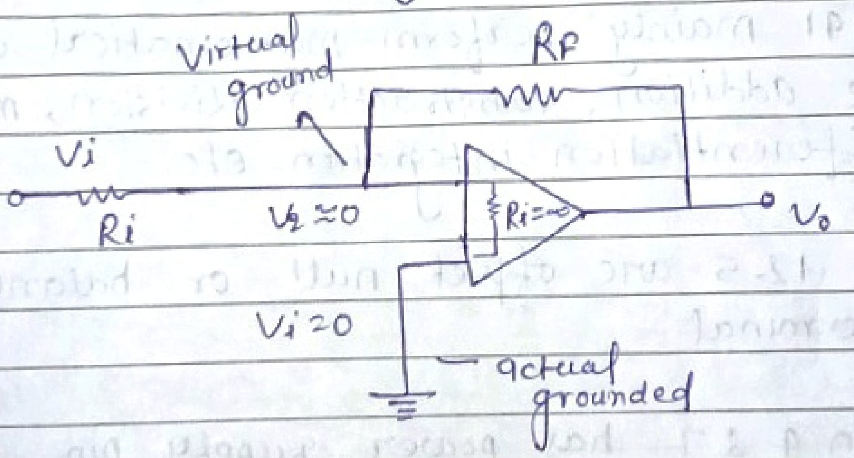
# Concept of Virtual Ground

- Virtual ground is not real ground.
- for some purposes we can consider it as equivalent to ground.
- In operational-amplifier the term virtual ground means that the voltage at that particular node is almost equal to ground voltage (0). It is not physically connected to ground.
- this concept is very useful in analysis of operational amplifier circuits and it makes calculation simple.
- this concept is only valid when negative feedback operational amplifier like inverting amplifier.



Input Impedance (Ideally)

$$R_i = \infty$$

Ideal gain $= \infty$

$$A_{cL} = \infty$$

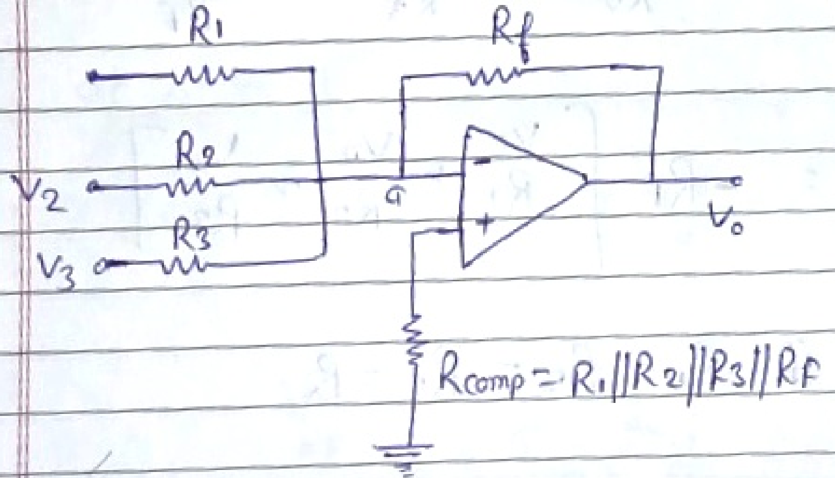
$$\frac{V_o}{V_i} = \infty = \frac{1}{0}$$

$$V_i = 0 \Rightarrow V_1 - V_2 = 0$$

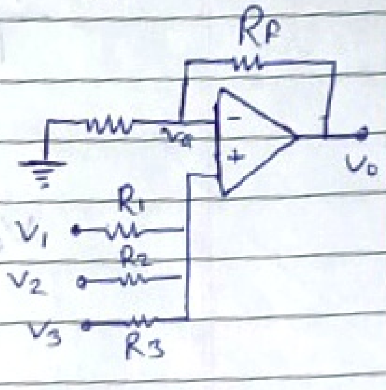
$$V_1 = V_2$$

# Application of operational Amplifier

(1) operational amplifier as Summing Amplifier




(Inverting)




(non-inverting)

↳ A typical summing amplifier with three input voltage $V_1, V_2, V_3$ three input resistor $R_1, R_2, R_3$ and a feedback resistor $R_f$ is shown.

↳ there is no voltage drop across Rcomp so

↳ the op-amp is ideal so $R_i = \infty$

<u>for inverting</u>

As node "a" is virtually grounded so

$$V_a = 0\ (V)$$

<u>Apply KCL at node "a"</u>

$$I_1 + I_2 + I_3 = I_f$$

$$\frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_3 - 0}{R_3} = \frac{0 - V_0}{R_f}$$

$$V_0 = -R_f\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]$$

if $R_1 = R_2 = R_3 = R$

$$\boxed{V_0 = \frac{-R_f}{R}\left[V_1 + V_2 + V_3\right]}$$

for non-inverting

at node "a" voltage = $V_a$

using KCL

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right] V_a$$

$$V_a = \frac{\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}$$

at node "b"

$$I_f = I = \frac{V_0 - V_a}{R_f} = \frac{V_a}{R}$$

$$\frac{V_0}{R_f} = \left(\frac{1}{R_f} + \frac{1}{R_a}\right) V_a$$

$$\boxed{V_0 = R_f\left[\frac{1}{R_f} + \frac{1}{R_a}\right] V_a}$$

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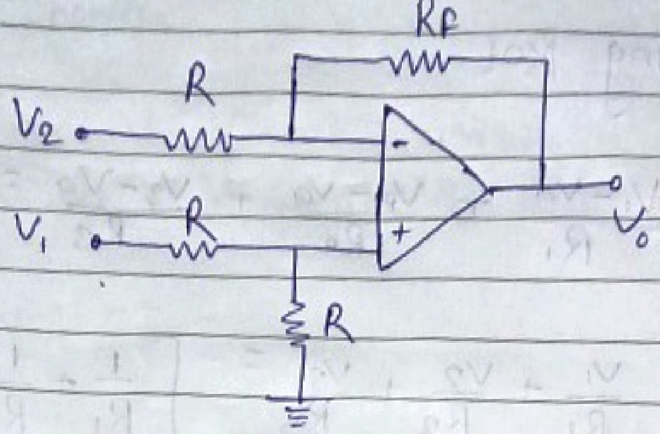
## (2) Operational Amplifier as Difference amplifier




↳ A basic Differential amplifier can be used as subtractor.

↳ All resistors are equal in value then output voltage can be derived by using superposition principle.

↳ To find output $V_{01}$ due to $V_1$ alone make $V_2 = 0$ then circuit Become a non inverting amplifier having input voltage $V_1/2$ at non inverting input terminal.

at node 'a'

Using voltage division Rule

$$V_a = \frac{V_1 R}{R + R} = \frac{V_1}{2}$$

↳ output voltage due to $V_2$ alone make $V_1 = 0$

$$V_{02} = \frac{-R}{R} V_2$$

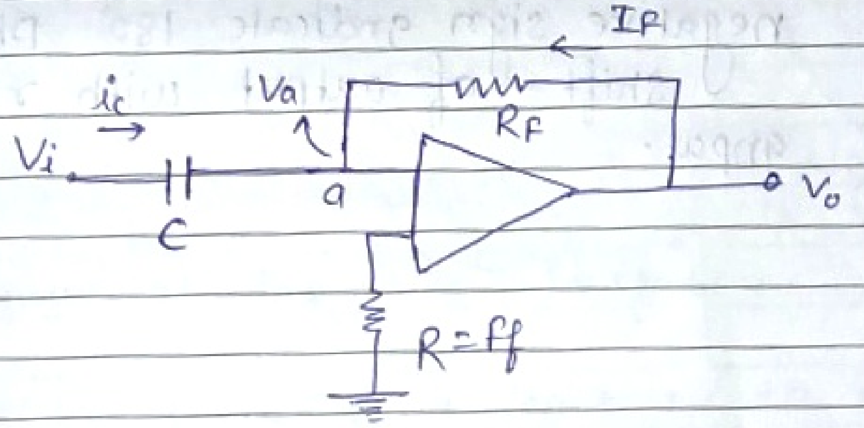
$$\boxed{V_{02} = -V_2}$$

So total output voltage

$$V_0 = V_{01} + V_{02}$$

$$\boxed{V_0 = V_1 - V_2}$$

## (3) operational Amplifier as differentiator




↳ one of the simplest of the operational amplifier circuits that contain capacitor is the differen -tiating amplifier

↳ It differentiate input waveform at output

Node 'a' is virtually grounded

So $V_a = 0$

at node "a" by KCL

$$i_c = I_f$$

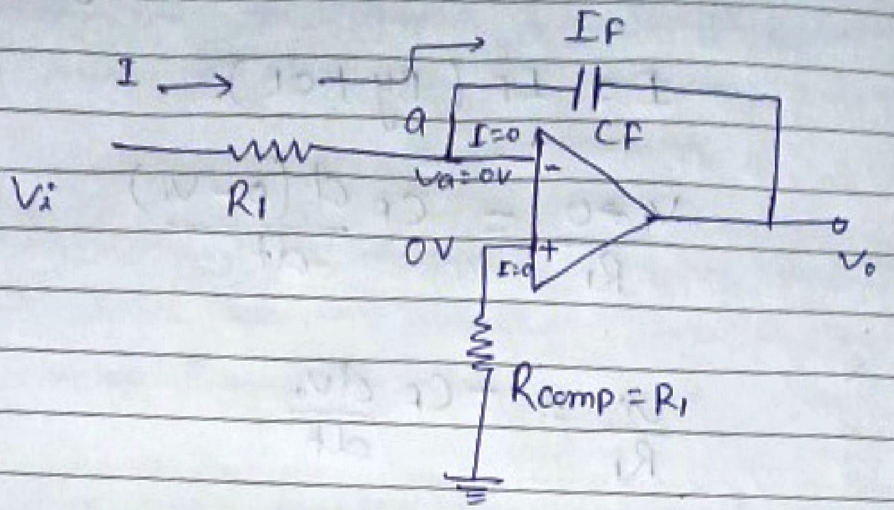
$$C\frac{dv_i}{dt} = \frac{0 - V_o}{R_f}$$

$$\boxed{V_o = -R_f C \frac{dv_i}{dt}}$$

$$|V_o| = \left|R_f C \frac{dv_i}{dt}\right|$$

negative sign indicate 180° phase shift of output with respect to input.

## (4) operational amplifier as integrator




- the circuit provides an output voltage which is proportional to the time integral of input and $R_1C_F$ is the time constant of the integrator.
- It may be noted that there is a Negative sign in the . so it is also known as inverting integrator.
- A resistor $R_{comp}=R_1$ is connected to non-inverting terminal to minimize the effect of input bias current

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at node "a" the voltage $V_a = 0$ (Virtually grounded)

$$I = I_F \text{ (By KCL)}$$

$$\frac{V_i - 0}{R_1} = C_F \frac{d(0 - V_0)}{dt}$$

$$\frac{V_i}{R_1} = -C_F \frac{dV_0}{dt}$$

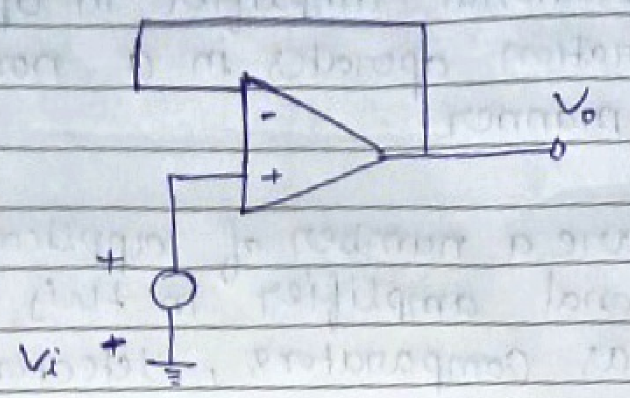
$$dV_0 = -R_1 C_F V_i dt$$

$$\int_0^{V_0} dV_0 = -R_1 C_F \int_0^t V_i dt$$

$$V_0 = -R_1 C_F \int_0^t V_i dt$$

$$\boxed{V_0(t) = -R_1 C_F \int_0^t V_i dt + V_0(0)}$$

## (5) Unity Gain Buffer

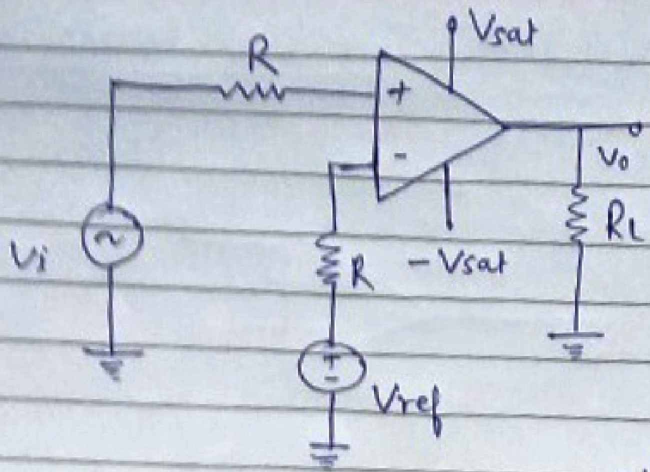


- A unity gain buffer (also called unity-gain amplifier) is a operational-amplifier circuit which has voltage gain of 1
- this means that it does not provide any amplification ~~to signal~~ or attenuation to the signal.
- the output voltage is same as input voltage in magnitude and phase i.e $V_i = V_o$
- The circuit is also known as voltage follower as output is equal to input exactly
- the use of this circuit lies in the fact that its input impedance is very high (i.e MΩ order) and output impedance is very low (i.e zero) so it draws negligible current from source
- thus it is used as buffer for impedance matching that is to connect high impedance to a low impedance.

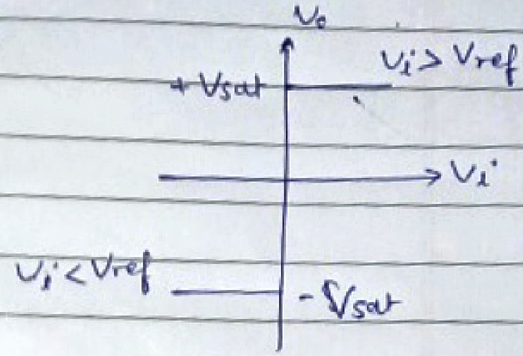
## Comparator

- In operational amplifier in open loop configuration operates in a non linear manner.
- There are a number of applications of operational amplifier in this mode such as comparators, detectors, limiters converters etc.
- A comparator is a circuit which compares a signal voltage applied at one input of an operational amplifier with a known reference voltage at the other input.
- there are basically two types of comparator

1. Non-inverting comparator
2. inverting comparator



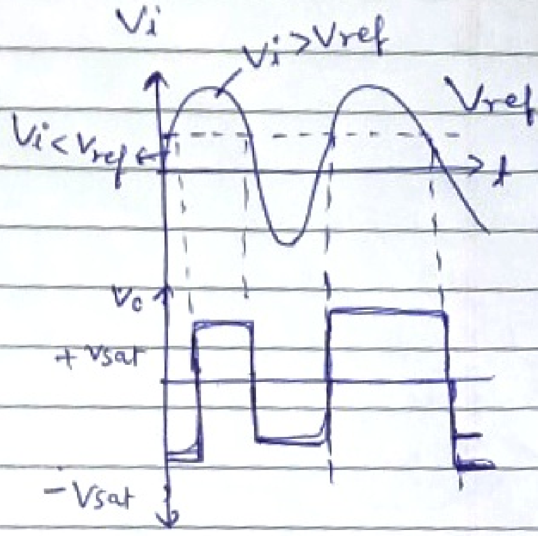

$V_{sat} = V_{cc}$




Case-I

- when $V_i < V_{ref}$
  the output voltage
  is given by $-V_{sat}$

  i.e $V_0 = -V_{sat}$




Case-II

- when $V_i > V_{ref}$
  the output voltage
  is given by $+V_{sat}$

  $V_0 = +V_{sat}$