Date..................

Fundamentals of Electronics Engineering

BEC101/ BEC201

Unit-1 :-

- Semiconductor Diode.
- Diode Application.
- Special Purpose two terminal Devices.

Unit-2 :-

- Bipolar Junction Transistor.
- Field Effect Transistor.

Unit-3 :-

Operational Amplifier : Introduction, Op-Amp basic, Practical Op Amp Circuits (Inverting Amplifier, Non-inverting Amplifier, Unit follower, Summing Amplifier, Integrator, Differentiator). Differential and common mode ~~operator~~ operation.

Unit-4 :-

Digital Electronics :

~~Fundamentals of communication Engineering~~ :

Teacher's Sign ....

Spiral

Date..................

Unit : 5

- Fundamentals of Communication Engineering
- Introduction to Wireless Communication

Semiconductor.

Types of Material:-

1) Conductor :- It is the material which allow electric current to pass through it easily.
2) Insulator :- does not allow electric current to pass through it easily.
3) Semiconductor :- - At low temp. it does not allow electric current to pass (Insulator)
   - At high temp. it allows electric current to pass (conductor)

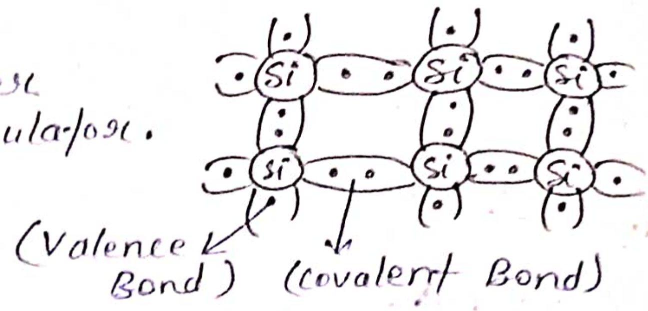
⇒ Free $e^{\ominus}$ exists in interatomic space.

Conductor	Insulator	Semi-Conductor.
Conductivity (σ) = 10^2 to 10^8 s/m	$\sigma = 10^{-11}$ to 10^{-19} s/m	$\sigma = 10^5$ to 10^{-6} s/m.
Resistivity (ρ) = 10^{-8}	$\rho = 10^{11}$ to 10^{16} ρ-m	ρ = depends of temp. at -20°c Si $\rho = 6.4\times10^2$ ρ
Overlapping of C.B and V.B.	forbidden Energy Gap = 6eV. (3-5)	forbidden Energy Gap $\leq$ 1eV
T↑, σ↓, ρ↑ Positive temp. Coeff. of R. (PTC)	T↑, ρ↓, R↓, σ↑ Negative temp. coeff. of R. (NTC)	T↑, ρ↓, R↓, σ↑ Negative temp. coeff. of R (NTC)

Semiconductor.
- Intrinsics or (Pure semi-conductor)
- extrinsic (Impure semi-conductor)
  - (P-type)
  - (N-Type)

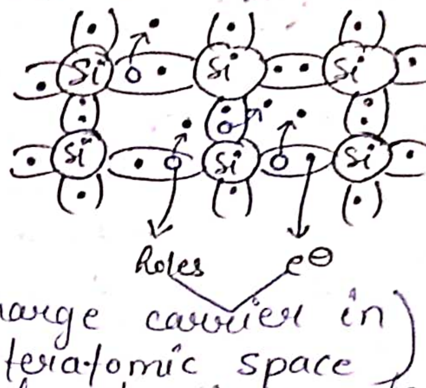
1) Intrinsic Semiconductor :-

⇒ At 0°K, no charge carrier is available so acts as insulator.



⇒ At 300°K, Some covalent Bonds & break down.

- No. of e⊖ = No. of holes.
- increase in charge carrier.



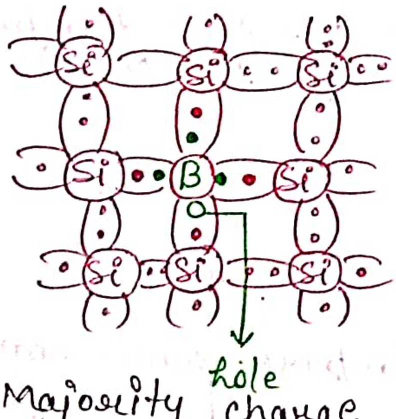
⇒ Carrier life time :- It is the interval of time from breaking of covalent Bond until it's recombination. It is average life time and in range of 1 micro-sec to nano-

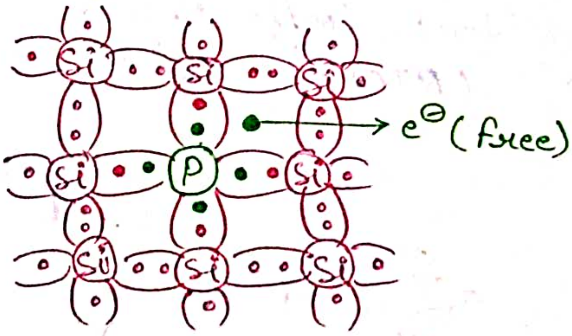
2) Extrinsic Semiconductor :-

Intrinsic + Impurity → Extrinsic

(Acceptor Impurity Trivalent P-type) (Ex:- B, Ga, In, Al)

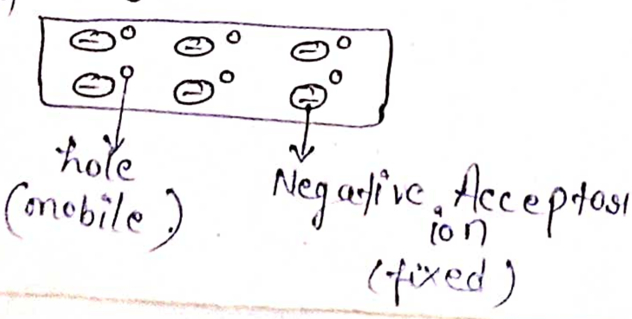
(Donor Impurity Pentavalent n-type. Ex:- P, As, Sb etc)

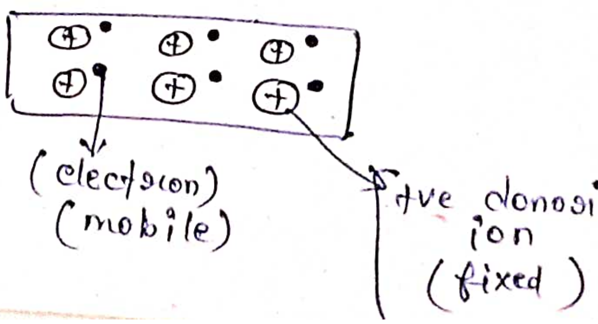




[Majority charge carrier - hole. Minority - electrons] (due to intrinsic)

[Majority charge carrier - e⊖ Minority ,, ,, - hole]





Why we prefer Silicon over Germanium ?

1) Temp. Sensitivity :- At room temp., Si crystal has fewer free e⁻ than Ge crystal. This implies that silicon will have much smaller collector cut off current than Ge.

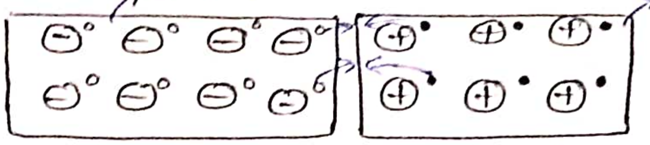
2) The variation of collector cut off current with temp. is less in Si compared to Ge.

PN-Junction Diode.

⇒ ① Doped one side of a semiconductor piece with an acceptor impurity and another side with a donor impurity.

Two-terminal or two electrode } → Semiconductor device } → P-n junction diode.

⇒ unidirectional device → [single direction of flow of current]

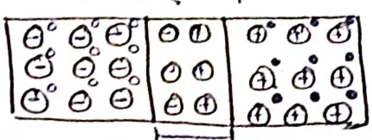


flow of e⁻ and holes to opp. side due to diffusion.

e⁻ + hole → recombine (ion without charge carrier)

→ after some time -ve ion / +ve ion will repell the e⁻/hole.

Depletion Layer :-



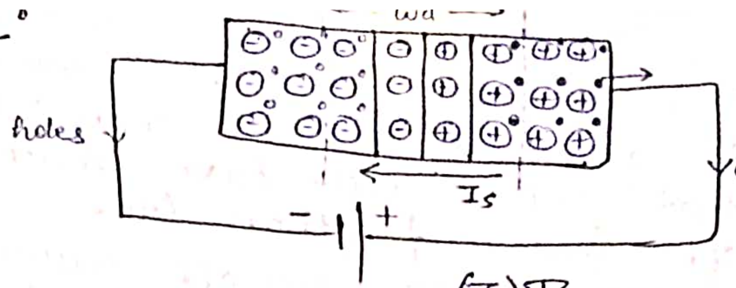
⇒ At the junction the carriers are depleted this region is termed as depletion region.

V_0 = Barrier potential, Contact potential, Diffusion ,, Built in ,,

Si = 0.7 V   Ge = 0.3 V

Biasing :- Applying external voltage to a diode is called biasing.

1) Zero Bias / No Bias - formation of depletion takes place (i = 0) [no external voltage applied]
2) Reverse Bias (-ve with P-type, +ve with n-type)
3) Forward Bias (-ve with n-type, +ve with p-type)



→ Wd is increased due to attraction b/w terminals and charge carriers

(I_s) Reverse saturation current low value of current due to minority charge carrier

No Applied Bias (V=0V) :-

At ~~any~~ the instant the two material are "joined" the e⊖ and the holes in the region of the junction will combine, resulting in the lack of free carriers in the region near the junction. The only ~~only~~ particle displayed in the region are only positive and negative ions remaining once the free carriers have been absorbed. The region of uncovered +ve and -ve ions is called depletion region due to the depletion of free carriers in the region

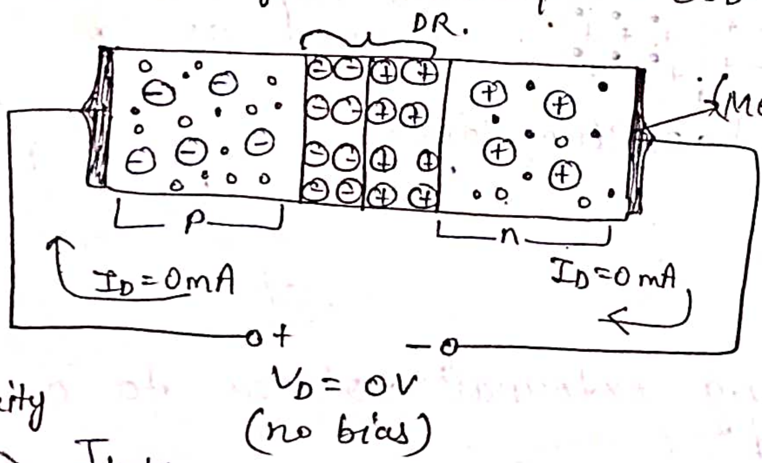
The no-bias situation is when no external voltage applied. It is simply a diode with two leads sitting isolated on a laboratory bench.

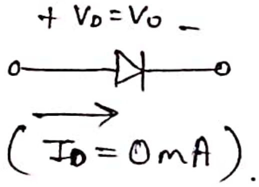
absence of voltage → zero current.

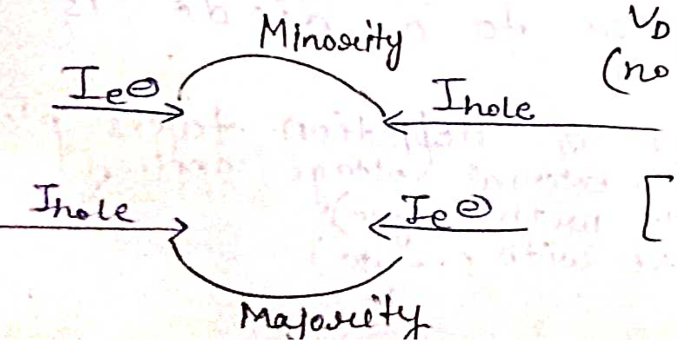
Polarity should be mentioned known as defined polarities

voltage applied → same drxn → +ve voltage (forward bias)
↓
opp. drxn → -ve voltage. (reverse bias)

Current will flow - n to p - ($I_D = 0$)







[net flow is zero]

I) Piece-Wise Linear Equivalent Circuit :-

Here, the forward voltage drop V_f has to overcome two voltage drops as under:-

i) potential barrier V_r (0.7 V for Si and 0.3 V for Ge)

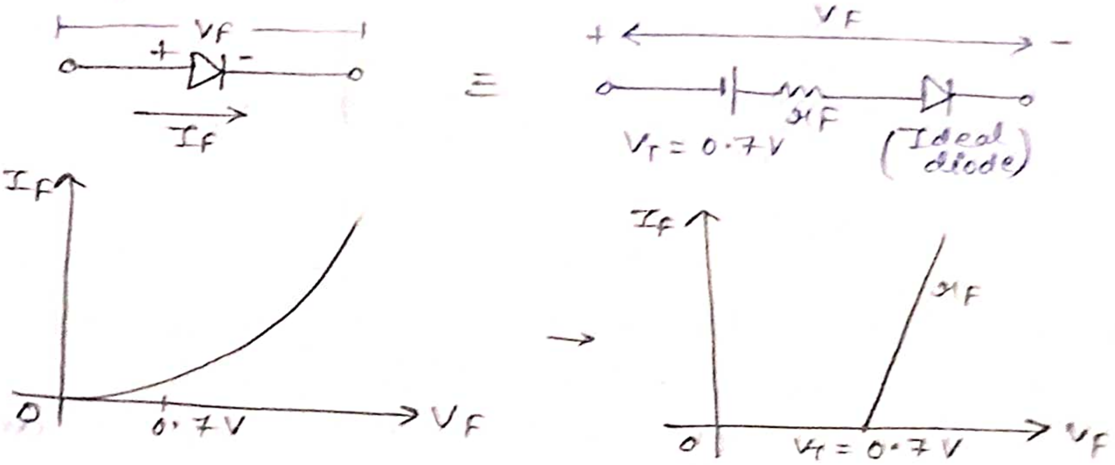
ii) forward resistance drop or internal drop $I_f r_f$ (avg. R)

$$V_F = I_f r_F + V_T$$

due to non-linear - r_f is ~~dynamic~~ varying

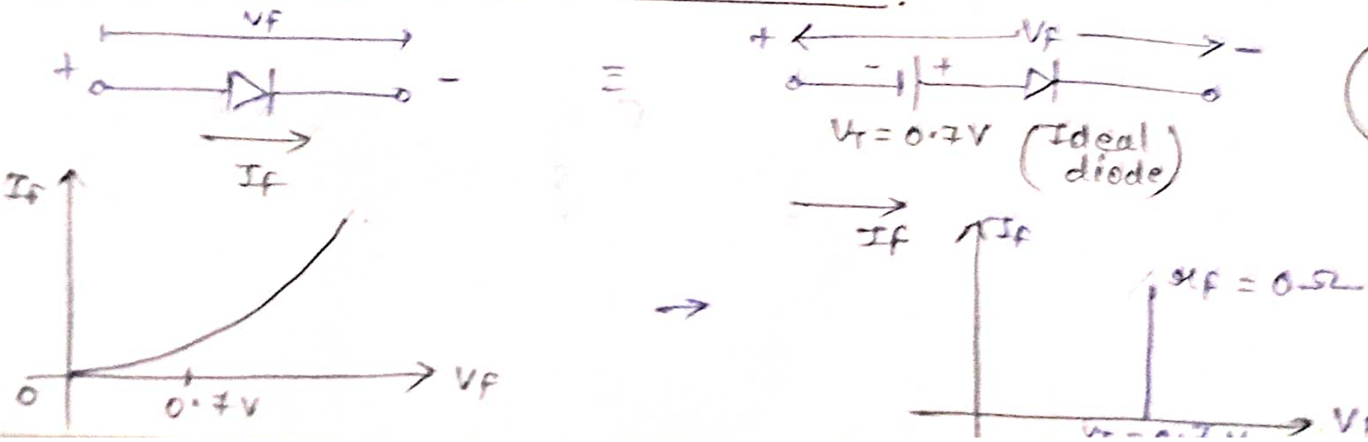
if linear - r_f is constant or (r_f avg.)

Due to this concept non-linear → linear curves. This type of equivalent circuit is called piece-wise-linear equivalent.



II) Simplified Equivalent Circuit :-

In forward biasing the resistance r_f is usually very small. So if it is negelected not much error is introduce. So now, piece-wise linear equivalent circuit is now known as Simplified Equivalent Circuit.



i.e. At V_T, Knee voltage $r_F = 0$

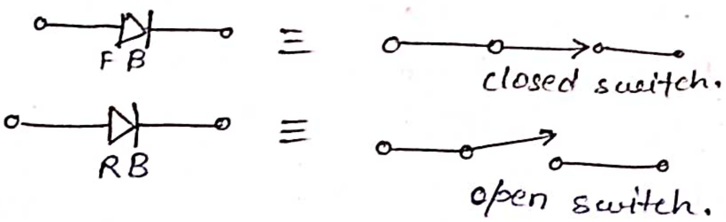
III) Ideal Diode : Ideal Equivalent Circuit :-

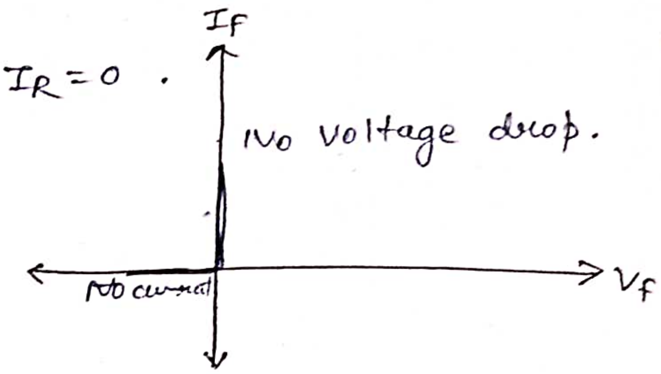
Since barrier potential V_T is very small, we can neglect V_T, In this case, the equivalent circuit is called ideal equivalent circuit.

From the characteristics of ideal diode, in forward bias $V_T = 0$ so, $I_D = max$. So, in FB diode is working as a perfect conductor. and in RB diode is working as a perfect insulator.

Use of Ideal Diode:

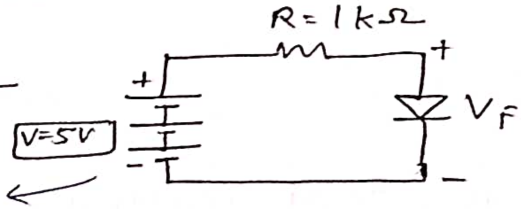
As a switch → $I_F = max$ and $I_R = 0$.

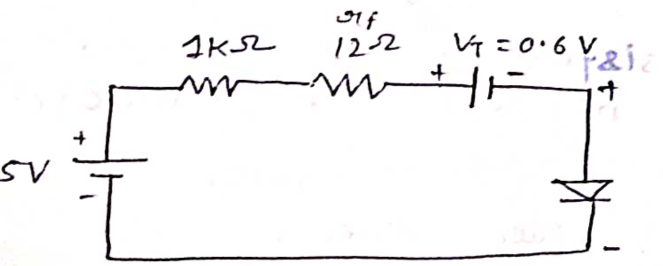




Example:- Calculate the diode voltage and current in the circuit. Using piece-wise linear model. Assume the piece-wise linear diode parameters as —

$V_T = 0.6\,V$, $r_f\ 12\Omega$





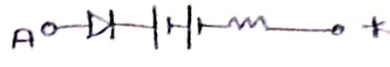
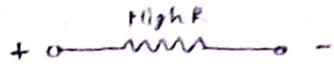
i) $I_F = \frac{5 - V_T}{1000+12} = \frac{5-0.6}{1012}$

$= 4.3\,mA$

ii) $V_F = V_T + I_F R_F$

$= 0.6 + (4.3 \times 10^{-3} * 12)$

$[V_F = 0.65\ \text{Volts}]$

(Parameter of Comparison)	Ideal Diode	Practical Diode.
Forward Resistance	0 Ω	few Ω
Reverse Resistance	∞	few hundred kΩ
Cut-in voltage	0 V	0.6 V for Si and 0.2 V for Ge
Reverse saturation current	zero	few nA for Si few μA for Ge
Equivalent circuit in the forward biased state		
Equivalent circuit in the reverse biased state		

THE DIODE RATINGS:

i) Average Current.

It is defined as average value of a periodic fun given by area under one cycle of the fun divided by the base.

ii) Maximum forward current.

The max. value of diode forward current, which a P-N junction (or diode) can carry without damaging itself, is known as its Maximum forward current. (IF)

iii) Peak Inverse Voltage. (PIV)

The max. value of reverse voltage that a P-N junction can withstand without damaging it is called its Peak Inverse Voltage (PIV).

iv) Maximum power rating

The max. power that a P-N junction or diode can dissipated without damaging it called as Maximum power rating.

III) v) Peak repetitive forward current.

This is the maximum instantaneous value of the repetitive forward current. Since it is at the this level for a brief period of time, its level can be higher than the continuous level.

vi) Peak forward surge current or non-repetitive peak forward current.

During turn-on, the device malfunctions and so there will be very high currents through the device for very brief intervals of time.

vii) Reverse saturation current.

Under reverse biased condition, ~~san~~ small number of electrons in p-region and attracted by positive end of battery and small number of holes in N-region are attracted by -ve terminal of supply. This phenomenon constitute the reverse current which is called as reverse saturation current.

Applications of P-N Junction Diode.

i) Rectifier circuit
ii) Clipping and clamping circuits.
iii) Voltage multipliers.

Breakdown Diodes.

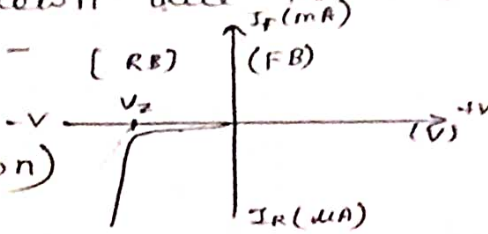
Breakdown Mechanism :-

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 to a value limited only by the external resistance connected in series. This specific value of the reverse bias voltage is called breakdown voltage. (V_z)

⇒ $V_z \propto$ width of deplition layer. $\propto \frac{1}{\text{doping level}}$

Process which causes junction breakdown due to increase in reverse bias voltage :-

(Zener Breakdown) (Avalanche Breakdown)



I) Zener Breakdown. :-

The zener breakdown is observed in the zener diode having V_z less than 5V or b/w 5 to 8 volts.

Example:- If $V_z < 5V$, so when a reverse voltage (5V or less) is applied to a zener diode, it causes a very intense electric field to appear across a narrow depletion region. ($E_w = 3 \times 10^5$ V/cm) which is strong enough to break the covalent bond and bring the $e^{\ominus}$ to conduction band. A large no. of such free $e^{\ominus}$ will constitute a large reverse current through the zener diode. and the breakdown is said to have occured due to zener effect.

To protect ZD → Resistance should be connected in ~~parall~~ series.

V_z depends on temp. of P-N junction diode. (inversely

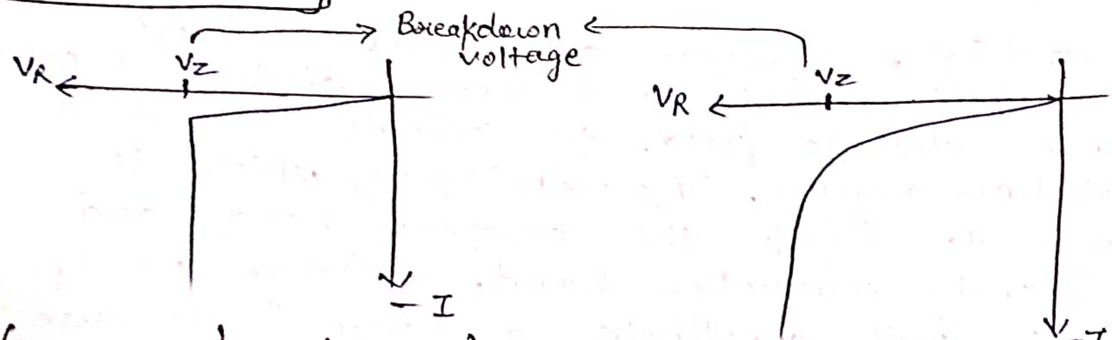
II) Avalanche Breakdown in Zener diode :-

The avalanche breakdown is observed in the zener diodes having V_z higher than 8V. Even though the mechanism is changed, the device is still called as zener diode. In RB cond^n, the conduction is due the minority charge carrier. As we ↑ reverse voltage → minority charge carrier accelerate. So, K.E. associated with them ↑. while travelling they collide with stationary atom and impart some energy to valence e⊖ present in covalent bond. and hence these e⊖ becomes free and reach to conduction band. And this chain contin.

In a very short time, a large no. of free minority e⊖ and holes will be available for conduction and the carrier multiplication process becomes self-substained. This self substained process is called "Avalanche Effect".

Ex.

$V_z \propto$ temp.

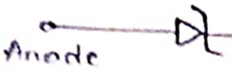


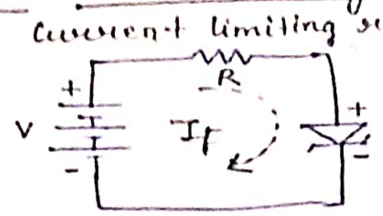
(zener breakdown) (Avalanche breakdown)

Zener Diode.

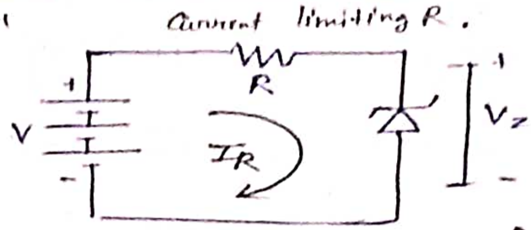
Zener diode is a reverse-biased heavily-doped PN-junction diode which operates in the breakdown region.

→ Circuit Symbol and Biasing of a Zener diode.





(Forward biasing of a zener diode)



(Reverse biasing of a zener diode.)

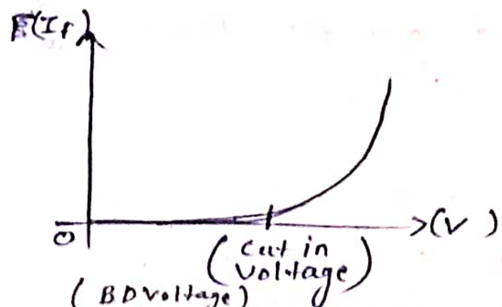
i) forward biasing :-
when the anode and cathode of the zener diode are connected with +ve and -ve terminal of the dc source respectively, the zener diode is said to be forward biased.

ii) Reverse Biasing :-
when the anode and cathode of the zener diode are connected with -ve and +ve terminal of the dc source respectively, the zener diode is said to be Reverse biased.

⇒ V-I Characteristics of a Zener diode :-

i) Forward Characteristics.

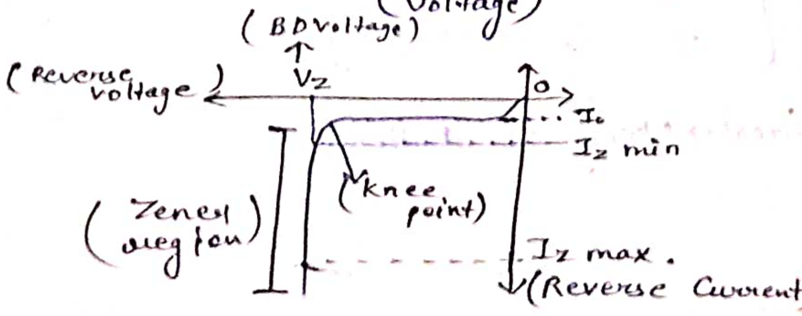
It is almost identical to the forward characteristics of a P-N Junction diode.



ii) Reverse characteristics.

I_o → due to thermally generated minority carrier.

V_z → I_z [Breakdown occured]



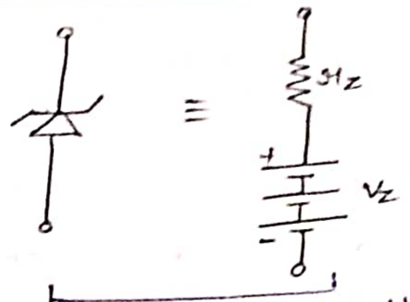
Applications of Zener Diodes :-

1) As voltage regulator
2) As peak clipper in waveshaping circuits.
3) As fixed reference voltage in transistor biasing circuits.
4) As meter protection against damage from accidental appⁿ of excessive voltage.

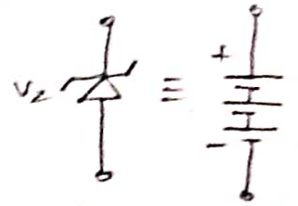
Equivalent Circuit of a zener Diode :-

r_z is dynamic resistance which could vary from few ohms to several hundred ohm ohm.

$$r_z = \frac{\Delta V_z}{\Delta I_z}$$



Practical eq. circuit of zener diode.



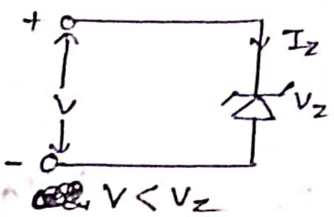
Ideal zener eq. diode circuit.

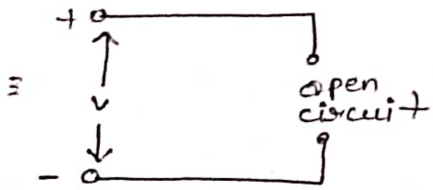
r_z is quite smaller than external resistance of the circuit in which zener diode is connected. $[r_z \approx 0)$

Analysis of Zener Diode Circuit :-

i) OFF STATE.

V_R across the zener diode is less than V_z but greater than 0V.





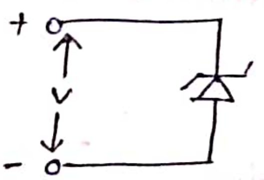
Equivalent zener diode circuit in 'OFF' state.

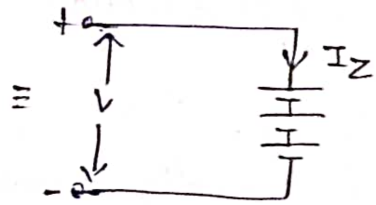
ii) ON State.

[V_z = constant
 I = increases by V

↓

(Ideal → Used as Battery)



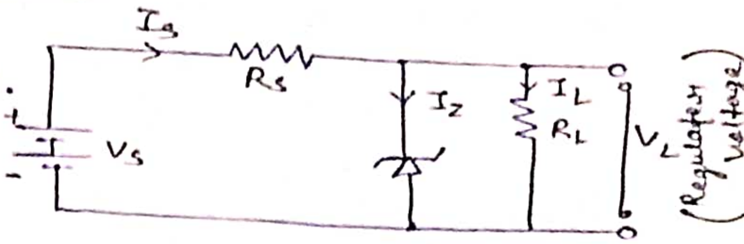


$V_z > V > 0$

Zener diodes As a Voltage Regulator.

i) Zener diode Shunt Regulator:

Zener diode is connected in parallel or shunt with the load. So it is called as Shunt Regulator.



For operating, $V_s > V_z$.

The input current is ⇒

$$V_s = I_s R_s + V_z$$

$$\boxed{I_s = \frac{V_s - V_z}{R_s}}$$

Ideal zener diode, $r_z = 0$

But practically, $I_z \cdot r_z$ = potential drop across diode.

$$V_L = V_z + I_z \cdot r_z$$

when neglected,

$$V_L = V_z$$

Current through the load Resistance —

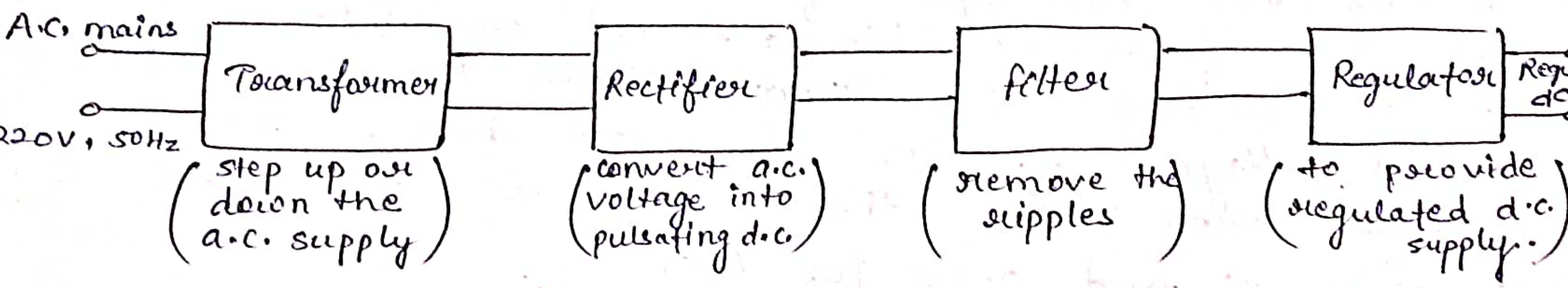
$$\boxed{I_L = \frac{V_L}{R_L}}$$

$$\boxed{I_s = I_z + I_L \quad \text{or} \quad I_z = I_s - I_L}$$

POWER SUPPLY.

Almost all electronic equipments contain a circuit called power supply. to change the mains a.c. into d.c.

The funn of different block :—



P-N JUNCTION AS RECTIFIER.

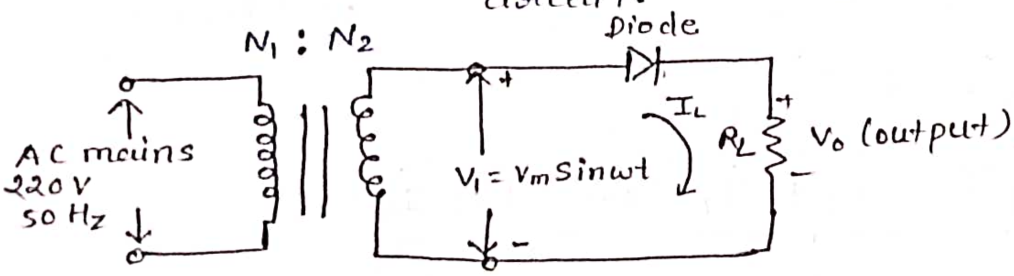
Convert a.c. voltage into the pulsating d.c. voltage.
These are of two types –

Rectifier.
- (Half-wave Rectifier)
- (Full-wave Rectifier)
  - (Centre-tap)
  - (Bridge)

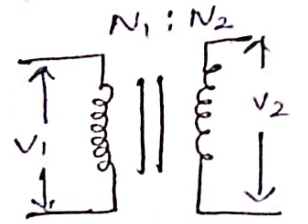
1) Half-Wave Rectifier :-

The transformer couples a.c. input voltage to the rectifier circuit.

fun^n of transformer →
- step up and step down
- provides isolation of a.c. power source from the rectifier circuit.



(Half wave Rectifier)

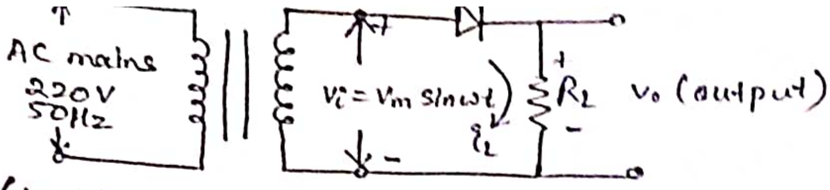


$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

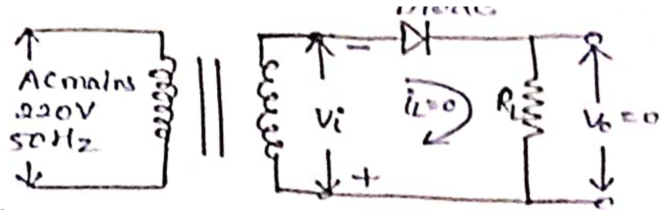
(Transformer)

The secondary a.c. voltage – $V_i = V_m \sin\omega t$

During +ve half cycle of input voltage, the diode is forward-biased – it conducts a current i_L flows through the load Resistance R_L to produce output voltage V_0. In forward bias, the voltage drop across the diode is very small (0.7 V for Si and 0.3 V for Ge)



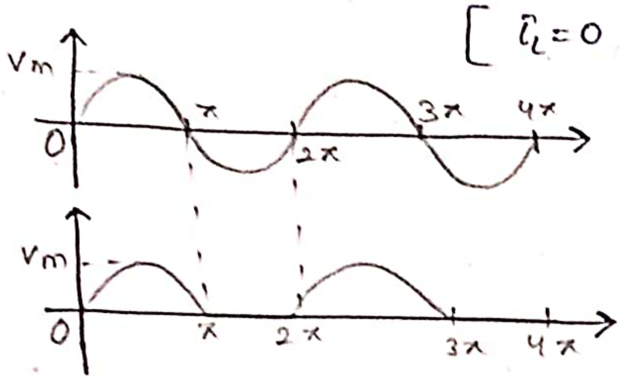
(Half-wave rectifier for +ve half cycle)



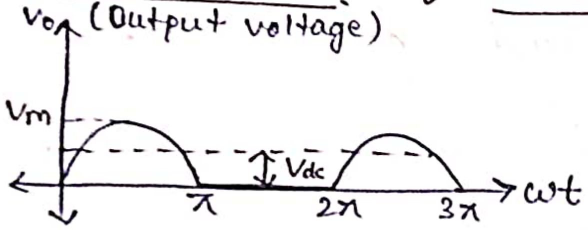
(Half-wave rectifier for negative half cycle)

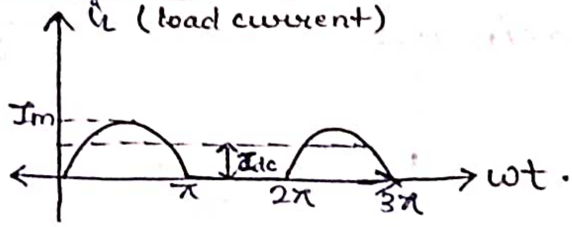
During the -ve half-cycle of input a.c. voltage, the diode is reverse-biased. Since, the diode is reverse biased, it does not conduct.

[$i_L = 0$ and $V_o = 0$]



Average or D.C. Values of Output Voltage and Load Current for a Half-Wave Rectifier.





$$V_o = V_m \sin(\omega t) \quad \text{for } 0 \le \omega t \le \pi$$
$$= 0 \quad \text{for } \pi \le \omega t \le 2\pi$$

$$V_{avg} = V_{dc} = \frac{\text{Area under the curve over the full cycle}}{\text{Base.}}$$

$$\text{Area} = \int_0^{2\pi} V_o \, d(\omega t) = \int_0^{\pi} V_o \, d(\omega t) + \int_{\pi}^{2\pi} V_o \, d(\omega t)$$

$$\text{Area} = \int_0^{\pi} V_m \sin(\omega t) \, d(\omega t) + \int_{\pi}^{2\pi} 0 .$$

$$\text{Area} = V_m \left[-\cos(\omega t)\right]_0^{\pi} + 0$$
$$= V_m \left[-\cos\pi - (-\cos 0)\right]$$
$$= V_m [1+1]$$
$$= 2V_m.$$

$$V_{dc} = \frac{2V_m}{2\pi} = \frac{V_m}{\pi} = 0.318\,V_m.$$

The d.c. value of output voltage is 31.8 percent of maximum a.c. input voltage.

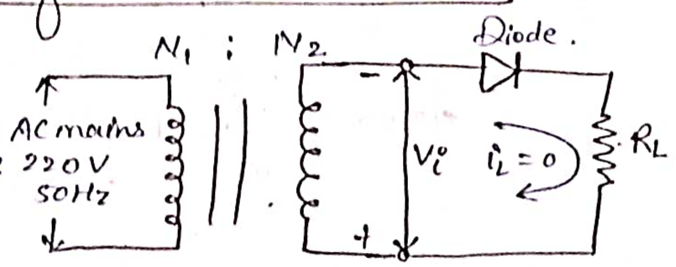
$$I_{avg} = I_{dc} = \frac{V_{dc}}{R_L}$$
$$V_{dc} = \frac{V_m}{\pi}$$
$$I_{dc} = \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}$$
$$\boxed{I_{dc} = 0.318\,I_m}$$

d.c. value of load current is 31.8% of the maximum value of load current.

$$V_{dc} = \frac{V_m}{\pi} - I_{dc} \cdot R_F$$
$$I_{dc} = \frac{V_m}{\pi(R_L + R_F)}$$

Peak Inverse Voltage for Half-Wave Rectifier.

During -ve cycle, the diode is reverse-biased and does not conduct. I in circuit is zero & $V_L = 0$, Hence acc. to KVL, whatever is applied input voltage, it will appear across the reverse-biased diode.



(Peak inverse voltage for half-wave rectifier)

The maximum value of this ... cycle of the occurs at the peak of the -ve cycle of the input voltage and is equal to V_m. This maximum voltage is called peak-inverse voltage (PIV).

Drawback of Half-wave Rectifier :-

i) The ripple factor is quite high.
ii) $\eta = 40\%$ (quite inefficient)
iii) Transformer is not fully utilized.

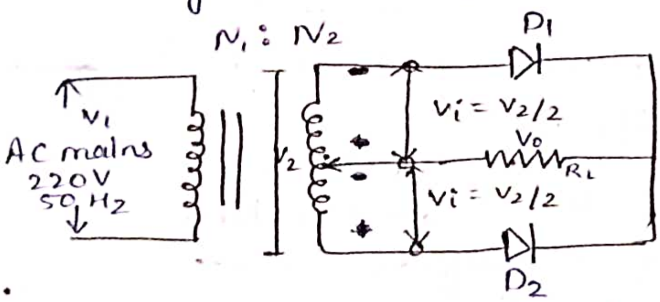
2) Full-wave Rectifier :-

Full-wave rectifier is that type of rectifier which utilizes both the half cycle of a.c. input voltage.

There are two types of full wave rectifier circuits :-
i) Centre-tap full-wave rectifier
ii) Full-wave Bridge Rectifier.

i) Centre Tap :-

The centre-tap full wave rectifier circuit makes use of two diodes D_1 and D_2 which are connected to the centre-tap secondary winding of the transformer.

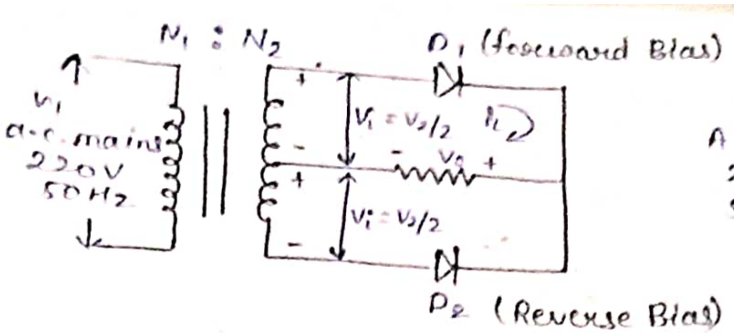


The voltage b/w one end of secondary and centre tap is equal to half of the secondary voltage.

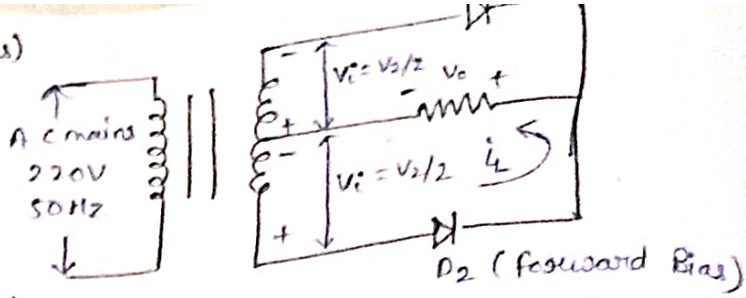
Working :-

let $v_i = V_m \sin\omega t$.

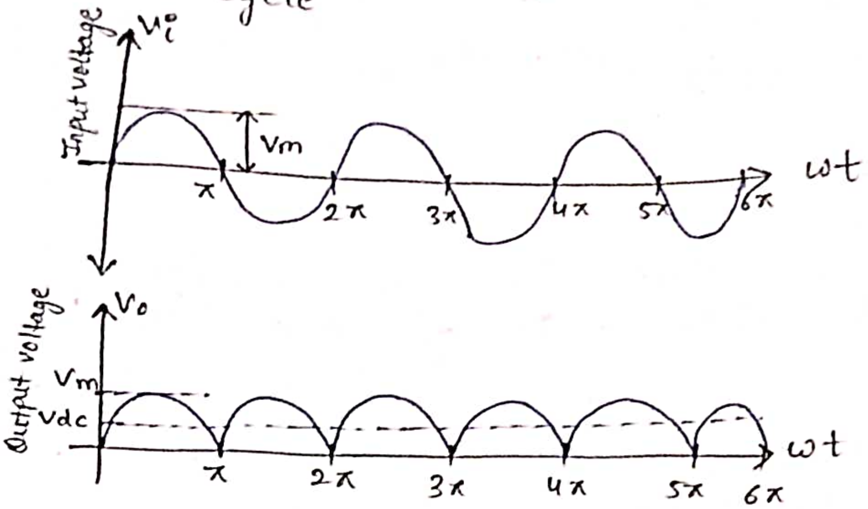
for +ve cycle D_1 is forward biased and D_2 is reverse biased. for -ve cycle D_1 is reverse biased and D_2 is forward biased.



(Centre-tap full wave rectifier for +ve cycle)

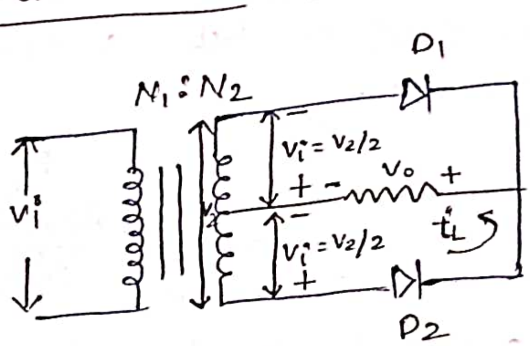


(Centre-tap full wave rectifier for -ve cycle)



⇒ Input and output waveforms for centre-tap full wave rectifier.

Peak Inverse Voltage of a Diode in Centre Tapped Full-wave Rectifier.



⇒ D_1 conducts and D_2 is cut-off.

let v_i be the instantaneous value of voltage across half of the secondary —

$$v_i = V_m \sin \omega t$$

V_m is the maximum or peak value across half of the secondary winding. Diode D_1 is forward bias and offers almost zero resistance. Therefore, the whole voltage V_m appears across the load Resistor R_L.

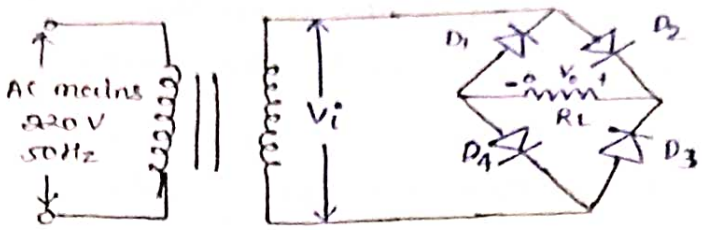
The total voltage across diode D_2 is the ... of the voltage V_m across the lower half of the secondary and V_m across the load resistor R_L.

$V_{reverse}$ across non-conducting diode) = $V_m + V_m$ = $2V_m$

(PIV = $2V_m$ for each diode in centre tapped full wave rectifier)

Full-wave Bridge Rectifier :-

Bridge rectifier uses four diodes which are connected across the secondary of the transformer.

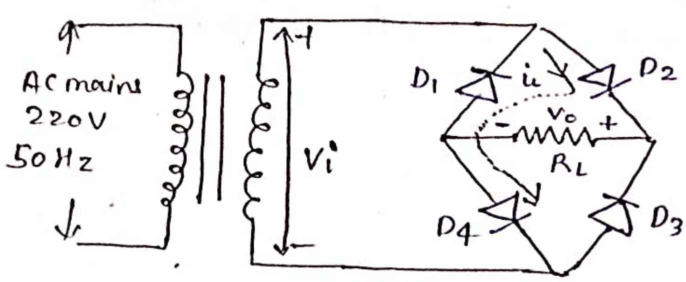


full-wave Bridge Rectifier.

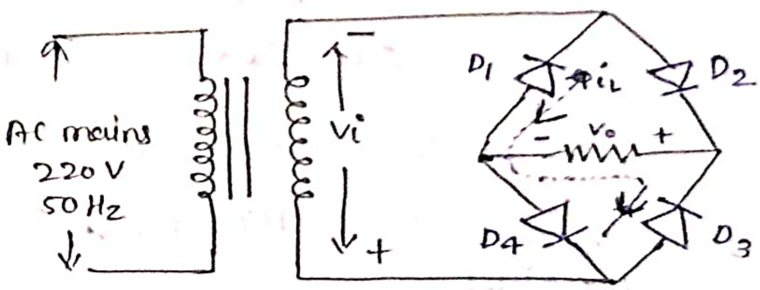
It is more efficient than centre-tapped bridge rectifier.

For +ve half cycle, the diodes D_2 and D_4 are forward biased and they conduct. The output voltage V_0 is developed across the load resistor R_L.

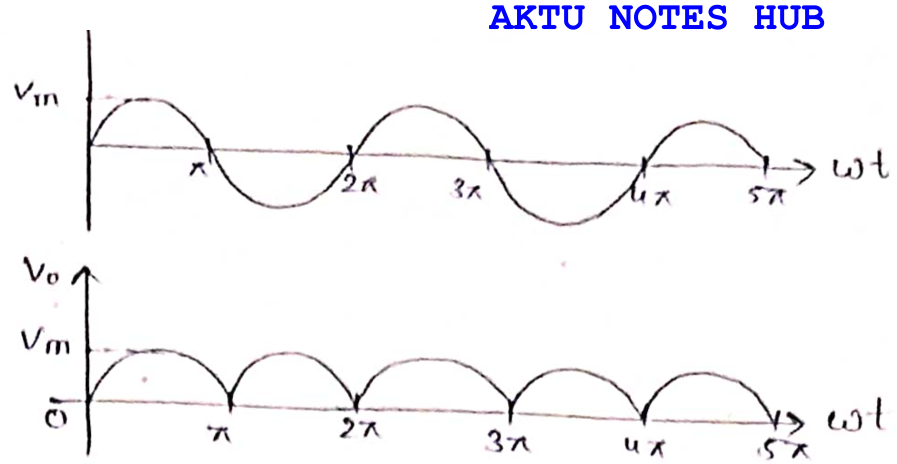
For -ve half cycle, the diodes D_1 and D_3 are forward biased and they conduct. The polarity of output voltage V_0 is same as that for +ve half cycle.



(for +ve half cycle)



(for -ve half cycle)



Peak Inverse voltage for a Diode in full-wave Bridge Rectifier:

When the secondary voltage reaches its positive peak value V_m. D_1 and D_3 are not conducting whereas D_2 and D_4 are conducting. So voltage drop across D_2 and D_4 is approx. zero because there is no resistance.

The total voltage V_m appears across the R_L. The reverse voltage across the non-conducting diode D_1 and D_3 is also V_m.

$$\therefore \boxed{PIV = V_m}$$

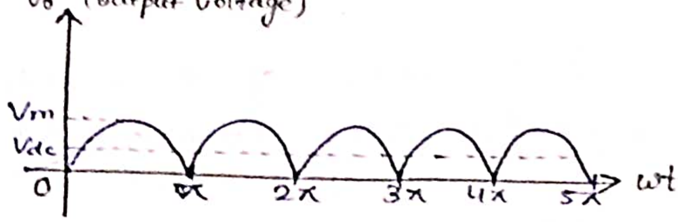
Advantages of Bridge over Centre-Tap Rectifier.

1) BR does not require CT secondary winding.
2) In BR, transformer is less costly because it is required to provide only half the voltage of an equivalent CT Transformer used in FWR circuit.
3) BR – $PIV = V_m$
   CT – $PIV = 2V_m$
   (costly.)

Disadvantages.

It needs four diodes. When low d.c. Voltage are required, there can be a problem that for low output dc the secondary voltage should be low and diode drops (1.4 v for si and 0.6 Ge) becomes important.

Average or D.C. Values of Output Voltage and Load current for a full wave Rectifier. :-



the output voltage may be expressed as -

$$V_o = \begin{cases} V_m \sin(\omega t) & \text{for } 0 \leq \omega t \leq \pi \\ -V_m \sin(\omega t) & \text{for } \pi \leq \omega t \leq 2\pi \end{cases}$$

$$V_{ag} = V_{dc} = \frac{\text{Area under the curve over the full cycle.}}{\text{Base}}$$

$$\text{Area} = \int_0^{2\pi} V_o \, d(\omega t)$$

$$= \int_0^{\pi} V_m \sin(\omega t)\, d(\omega t) - \int_{\pi}^{2\pi} V_m \sin(\omega t)\, d(\omega t)$$

$$= \left[-V_m \cos(\omega t)\right]_0^{\pi} + \left[V_m \cos \omega t\right]_{\pi}^{2\pi}$$

$$= V_m \left[-\cos\pi + \cos 0\right] + \left[\cos 2\pi - \cos\pi\right] V_m$$

$$= V_m \left[1 + 1 + 1 + 1\right]$$

$$\left[\text{Area} = 4 V_m\right]$$

$$\left[V_{dc} = \frac{\text{Area}}{\text{Base}} = \frac{4V_m}{2\pi} = \frac{2V_m}{\pi} = 0.636\, V_m\right]$$

the d.c. value of output voltage for full wave rectifier is 63.6 percent of maximum a.c. input voltage. This value is twice that of a half-wave rectifier.

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}$$

$$\boxed{I_{dc} = 0.636\, I_m}$$

Ripple Factor.

The output voltage or load current of a rectifier contains two components namely d.c. component and a.c. components. The a.c. components present in the output is called a ripple.

Smaller the ripple factor more effective is the rectifier.

Ripple factor, r = The r.m.s value of a.c. component of output voltage / The d.c. component of output voltage.

$$r = \frac{V_r(rms)}{V_{dc}} = \frac{I_r(rms)}{I_{dc}}$$

$$I_{rms} = \sqrt{I_{dc}^2 + I_r(rms)^2}$$

Dividing both side by I_{dc},

$$\frac{I_{rms}}{I_{dc}} = \sqrt{\frac{I_{dc}^2 + I_r(rms)^2}{I_{dc}^2}}$$

$$\frac{I_{rms}}{I_{dc}} = \sqrt{1 + \left[\frac{I_r(rms)}{I_{dc}}\right]^2}$$

→ simplify

$$\frac{I_r(rms)}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\left[r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \right]$$

Ripple Factor for a Half-Wave Rectifier.

for half-wave rectifier,

$$I_{dc} = \frac{I_m}{\pi}$$

I_{rms} = rms value of load current.

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)}$$

$$i_L = \begin{cases} I_m \sin\omega t & \text{for } 0 \leq \omega t \leq \pi \\ 0 & \text{for } \pi \leq \omega t \leq 2\pi. \end{cases}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{(1-\cos 2\omega t)}{2} \, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi \times 2}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[(\pi - 0) - (0 - 0)\right]}$$

$$= \sqrt{\frac{I_m^2}{4}}$$

$$\boxed{I_{rm} = \frac{I_m}{2}}$$

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1}$$

$$\boxed{r = 1.21}$$

Ripple Factor for a Full-Wave Rectifier

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$I_{dc} = \frac{2 I_m}{\pi}$$

(I_{rms} = rms value of load current)

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i_L^2 \, d(\omega t)}$$

$\because$ $i_L = I_m \sin \omega t$ for $0 \le \omega t \le \pi$

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2(\omega t) \cdot d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} \frac{1}{2}(1 - \cos 2\omega t)\, d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{\pi}\left(\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right)_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{\pi} \times \frac{\pi}{2}}$$

$$\left[I_{rms} = \frac{I_m}{\sqrt{2}} \right]$$

Substituting the values of I_{dc} and I_{rms},

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{I_m \pi}{\sqrt{2} \cdot 2 I_m}\right)^2 - 1}$$

$$= \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{r = 0.482}$$

$$\eta = \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_L + R_F)}$$

for half wave rectifier,

$$I_{dc} = \frac{I_m}{\pi}$$

$$I_{rms} = \frac{I_m}{2}$$

$$\eta = \frac{(I_m/\pi)^2 \times R_L}{(I_m/2)^2 \times (R_L + R_F)}$$

$$= \frac{4}{\pi^2} \times \frac{R_L}{R_L + R_F}$$

$$\eta = \frac{0.406}{1 + R_F/R_L}$$

This efficiency will be maximum when $R_L >> R_F$

$$\boxed{\eta_{max} = 0.406 = 40.6\ \%}$$

Efficiency of a full-wave Rectifier :-

$$I_{dc} = \frac{2 I_m}{\pi} \quad , \quad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\eta = \frac{\left(\frac{2 I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 \times (R_L + R_F)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{R_L + R_F}$$

$$\eta = \frac{0.812}{1 + R_F/R_L}$$

This efficiency will be maximum when $R_L >> R_F$

$$\eta_{max} = 0.812$$

$$\boxed{\eta_{max} = 81.2\ \%}$$

Transformer Utilization Factor.

TUF may be defined as the ratio of d.c. power delivered to the load and the a.c. rating of the transformer secondary.

$$TUF = \frac{\text{D.C. Power delivered to load}}{\text{A.C. Power rating of the Transformer Secondary.}}$$

$$\left[TUF = \frac{V_{dc} I_{dc}}{V_{rms} I_{rms}} \right] \quad (\text{for } R_L >> R_f)$$

Half wave Rectifier – TUF = 28.7 %
full " " – TUF = 81.2 %

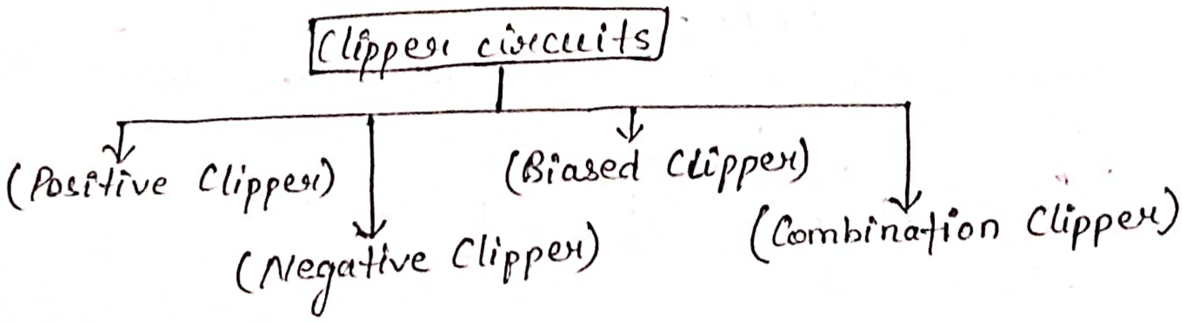
Diode Circuits.

Applications of diode which may be listed as under:-

1) Clipper Circuits Using Diode.
2) Clamper circuits Using Diode.
3) Voltage Multiplier Circuits.

CLIPPER CIRCUITS :-

A clipper is a circuit with which the waveform is shaped by removing or clipping a portion of the applied input signal waveform without distorting the remaining part.
Used in radar, digital and electronic system.

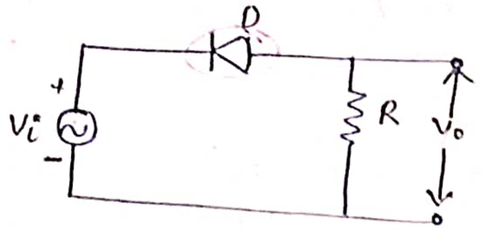


Positive Clipper.

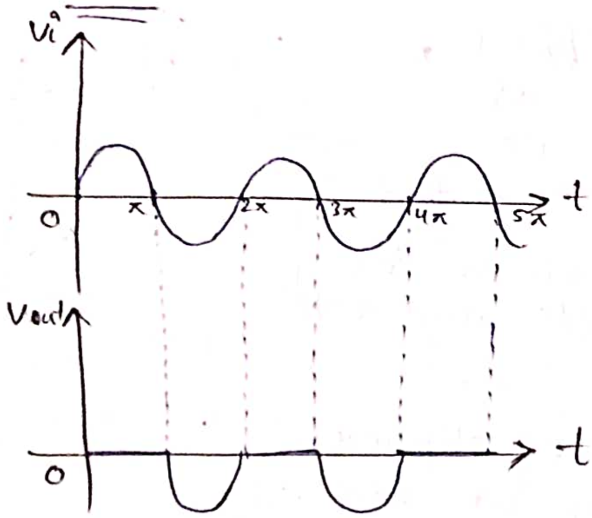
It removes the positive half cycles of the input voltage waveform.

Positive Clipper
- (Series positive Clipper)
- (Shunt positive Clipper)

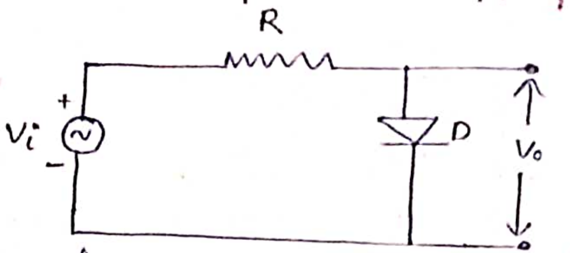
(Series positive Clipper)



for +ve cycle diode will not conduct. hence, work as an open circuit. So the all voltage drop at open ckt & $V_o = 0$.



(Shunt positive Clipper)



for +ve cycle D will conduct and act as short - circuit so no voltage will drop here, all will drop at R Hence $V_o = 0$.

$$20 - iR - V_D - 5 = 0$$

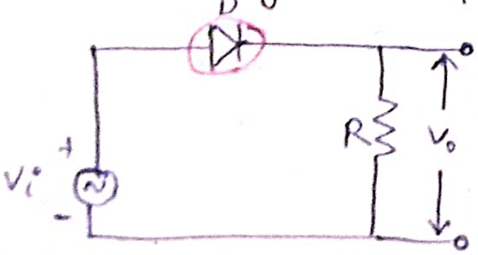
$$20 - 5 = iR - V_D$$

Negative Clipper.

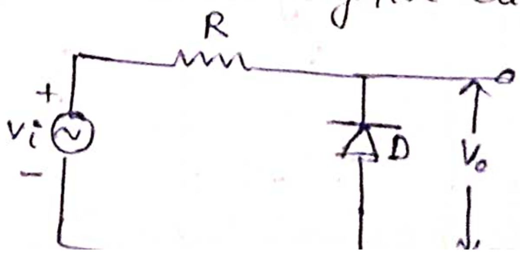
It removes the negative half cycle of the input voltage waveform.

Negative Clipper.
- (Series negative Clipper)
- (Shunt negative Clipper)

(Series negative Clipper)



(Shunt negative Clipper)



Series Negative Clipper

for +ve cycle, diode conducts and work as a short-circuit. So, $V_o = V_i$

for -ve cycle, diode work as open circuit hence no voltage for output.

Shunt Negative Clipper

for +ve cycle, diode does not conduct so all the input positive half cycle voltage appears at the output.

for -ve cycle, diode work as short circuit hence no voltage drop.

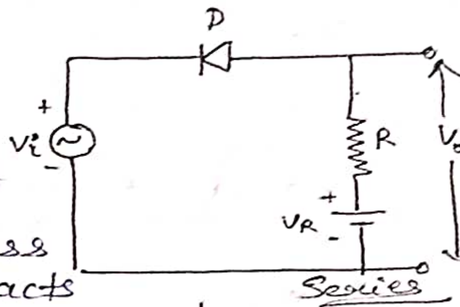
Biased Clipper

Used to remove a small portion of +ve or -ve half-cycle of the signal voltage and hence the biased clipper is used.

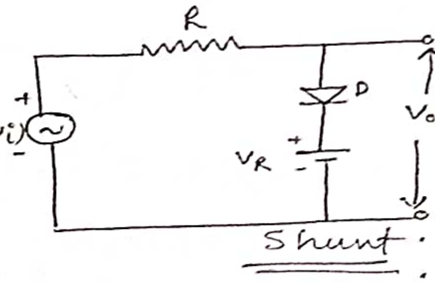
Biased Clipper may be of four types as under:-

a) Biased Positive Clipper:-

for biased series positive clipper, the diode does not conduct as long as the input voltage is greater than $+V_R$ and so the output remains at $+V_R$. when the input voltage becomes less than $+V_R$ the diode conducts and acts as a short-circuit. vice versa for -ve cycle.

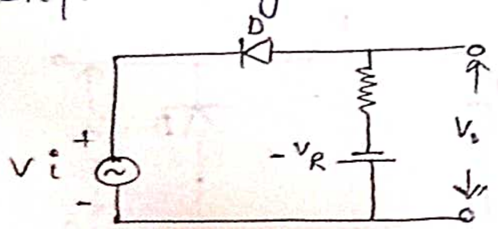


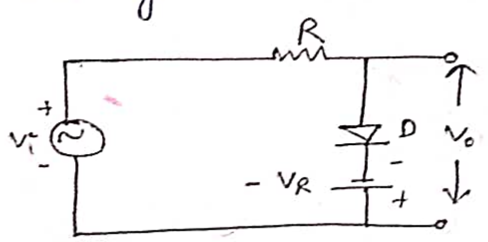
In the biased shunt positive clipper, the diode conducts as long as the input voltage is greater than $+V_R$ (V_i) and output remains at V_R until the input voltage becomes less than $+V_R$. when $V_i < +V_R \rightarrow$ open switch.



b) Biased positive Clipper with reverse polarity of the Battery.

entire signal above voltage $-V_R$ is clipped off.

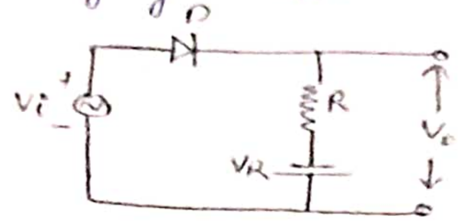


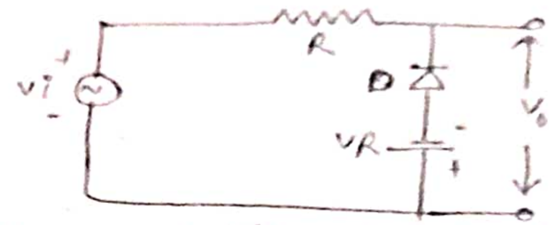


c) Biased Negative Clipper :-

$V_i \leq -V_R$, the diode does not conduct and Clipping takes place. (Series)

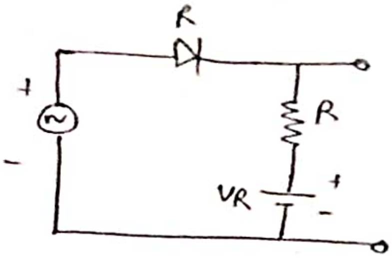
$V_i \leq -V_R$, the diode conducts and Clipping takes place. The Clipping can be shifted, up and down by varying $-V_R$.

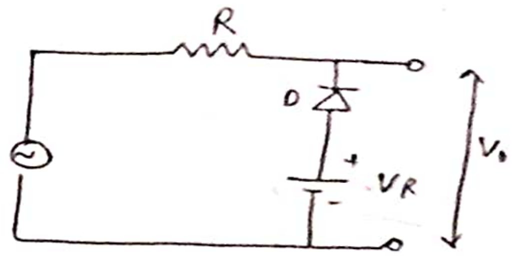




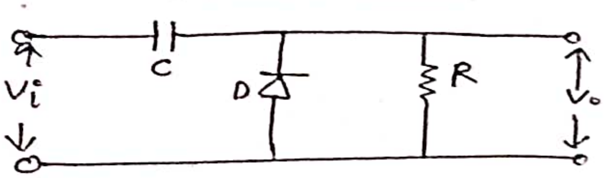
d) Biased Negative Clipper with reverse polarity of V_R

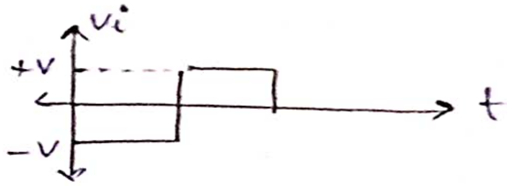
$+V_R$ is clipped off



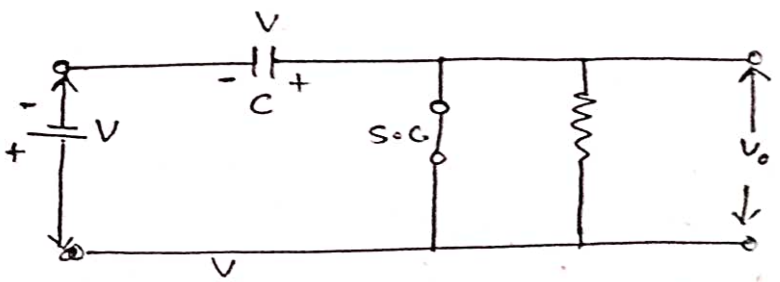


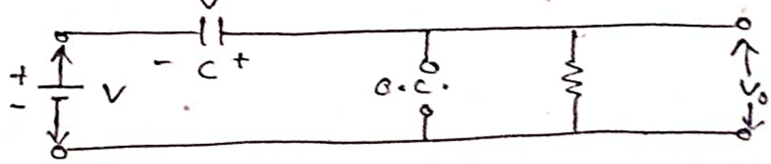
Clamping circuits shifts or clamps a signal to a different d.c. level. It introduces d.c. level to an ac. signal. Therefore, the clamping circuit is also known as d.c. Restorer.





Positive Clamper:-



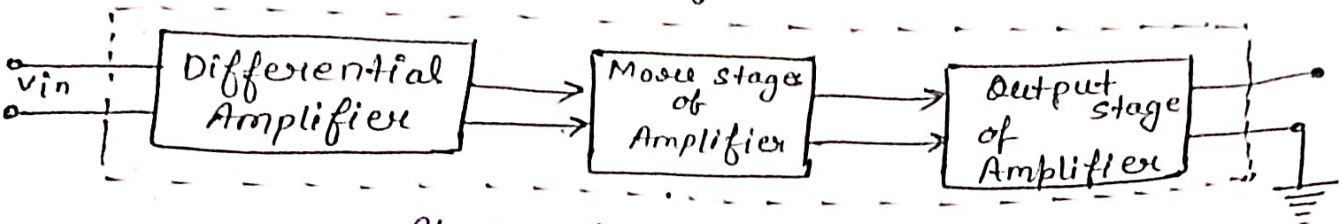


Operational Amplifier.

Operation Amplifier:- (op-Amp)

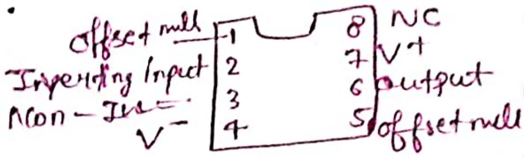
It is an active element designed to perform mathematical operational like Addition, substraction, ×, ÷, $\frac{d}{dx}$, ∫.

op-Amp can be used for AC as well as D.C.

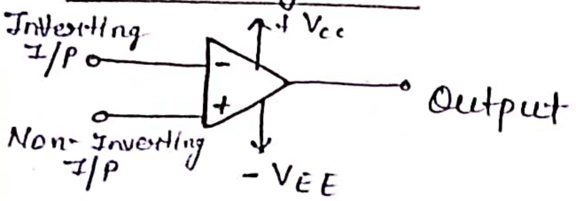


Block diagram of op-Amp.

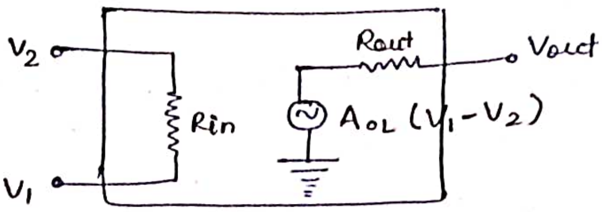
R_{in} is very ↑
R_{out} is very ↓



Circuit symbol:-



Equivalent Ckt:-



(A_{OL} = open loop gain)

[Input voltage difference is amplified in (op-Amp)]

Op-Amp Characteristics:-

Characteristics.	Ideal op-Amp	Practical (741) (op-Amp)
Open loop gain (A_{OL})	∞	10^6
Input Resistance (R_i)	∞	1MΩ to 2 MΩ
Output Resistance (R_o)	0	50Ω to 100Ω
open loop Bandwidth	∞	≈ 1 MHz
offset voltage	0	≤ 10 mV
offset current	0	10 nA
Common Mode Rejection Ratio (CMRR)	∞	90dB
Slew Rate	∞	1 V/µsec.

Higher CMRR indicate better rejection of common input for ideal differential Amplifier $A_{CM} = 0$,

Hence $\boxed{CMRR = \infty}$

6) Slew Rate :-

Slew Rate is the measure of how fast the output voltage of op-Amp can change with respect to time.

mathematically,

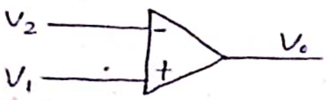
$$\text{Slew Rate (SR)} = \left.\frac{dV_o}{dt}\right|_{max}$$

It is specifies in V/ms
for ideal SR is ∞

$$\boxed{f_{max} = \frac{SR}{2\pi V}}$$

Transfer characteristics of op-Amp :-

It is the plot of output voltage (V_o) V/s difference input (V_d)



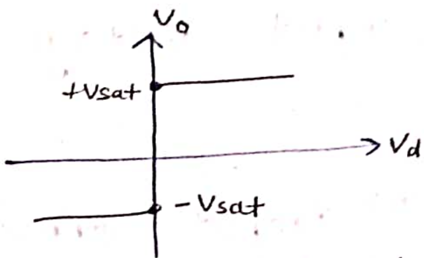
$$V_o = A_{OL}(V_1 - V_2)$$
$$V_o = A_{OL} V_d$$

i) Ideal op-Amp :-

for ideal op-Amp $A_{OL} = \infty$

If $V_d > 0 \Rightarrow V_o = +\infty \equiv +V_{cc} \equiv +V_{sat}$

If $V_d < 0 \Rightarrow V_o = -\infty \equiv -V_{cc} = -V_{sat}$



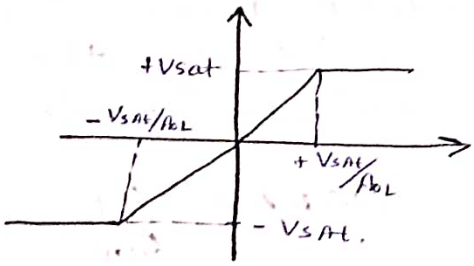
Transfer characteristic of ideal op-Amp.

2) Non-ideal op-Amp :-

A_{OL} = Large but finite.

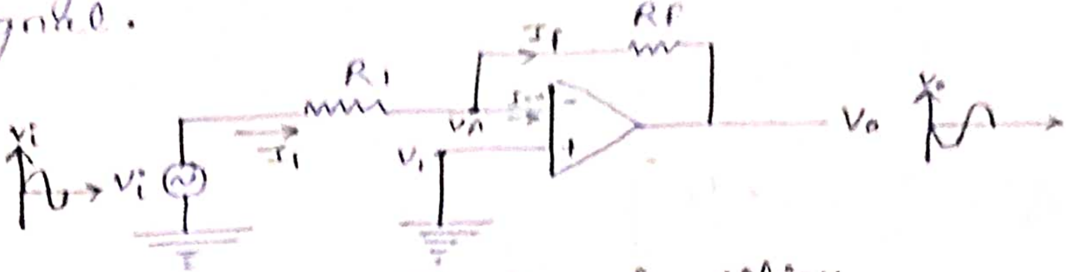
If V_d lies in the range $\frac{-V_{SAT}}{A_{OL}}$ to $\frac{+V_{SAT}}{A_{OL}}$, output will vary linearly with V_d.

for very small values of V_d op-Amp can be operated in linear region and for higher values of V_d op-Amp will be in Saturation region.



Inverting Amplifier :-

An op-Amp circuit that produces an Amplified output signal that is 180° out of phase with the input signal.



Inverting Amplifier.

Apply KCL at node A.

$$I_1 = I_f$$

$$\frac{V_i - V_a}{R_1} = \frac{V_a - V_o}{R_f} \quad \text{———— (i)}$$

for ideal op-Amp $V_1 = V_2$

$$V_1 = 0 \quad , \quad V_2 = V_a = 0$$

$$\frac{V_i - 0}{R_1} = \frac{0 - V_o}{R_f}$$

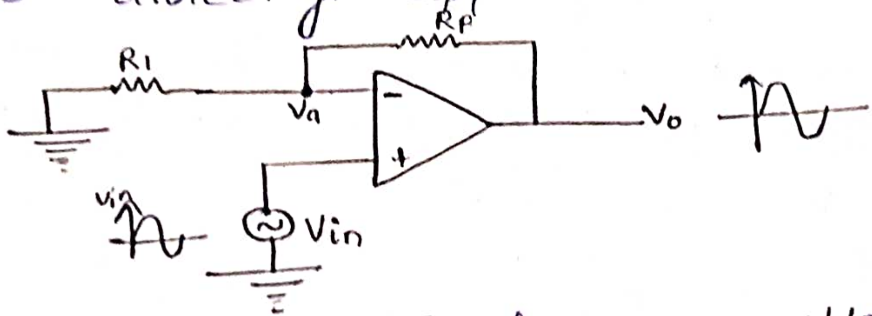
$$\frac{V_i}{R_1} = \frac{-V_o}{R_f}$$

$$\Rightarrow \boxed{V_o = -\left(\frac{R_f}{R}\right) V_i}$$

$$\left[\text{Gain} = A = \frac{V_o}{V_i} = -\frac{R_f}{R} \right]$$

Non-Inverting Amplifier :-

A non-Inverting Amplifier is an op-Amp Circu designed to provide positive voltage gain. The input is directly applied to Non-inverting term



Resistance Rf and R_1 forms a voltage divider.

$$V_a = \frac{V_o \times R_1}{R_1 + R_f}$$

From concept of virtual ground, $V_A = V_{in}$

$$V_{in} = \left(\frac{R_1}{R_1+R_f}\right) V_o$$

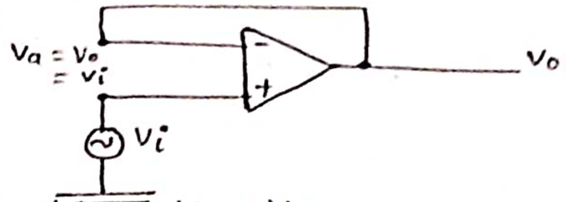
$$V_o = \left(\frac{R_1+R_f}{R_1}\right) V_i$$

$$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right) V_i}$$

$$\left[A_v = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}\right]$$

Voltage follower.

A voltage follower is an op-Amp circuit in which output follows the input. It is also called as unity gain Buffer Amplifier.



Due to physical short ckt, $V_a = V_o$

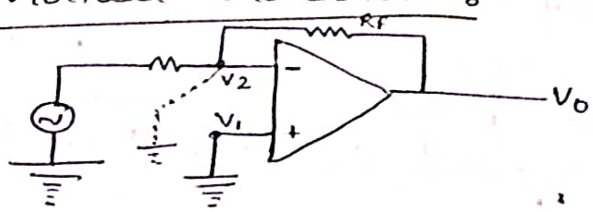
Due to virtual short ckt $\Rightarrow V_a = V_i$

$\therefore V_o = V_i$

$$\boxed{A_v = \frac{V_o}{V_i} = 1}$$

It is used as Buffer
It is used in Instrumentation Amplifier.

Concept of Virtual Ground :-



A point in any circuit is said to be grounded if the potential at that point is equal to the ground potential.

$$V_o = A_{OL}(V_1 - V_2)$$

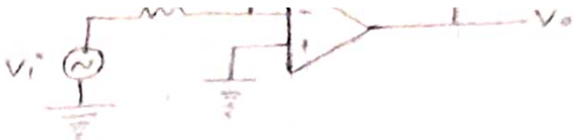
$$(V_1 - V_2) = \frac{V_o}{A_{OL}}$$

for ideal op-Amp $A_{OL} = \infty$

$$V_1 - V_2 = \frac{V_o}{\infty} = 0$$

$$\boxed{V_1 = V_2}$$

Ques $A_{0l} = -100$, $R_f = ?$



for inverting Amplifier,

$$V_o = \left(-\frac{R_f}{R}\right) V_i$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_f}{R}$$

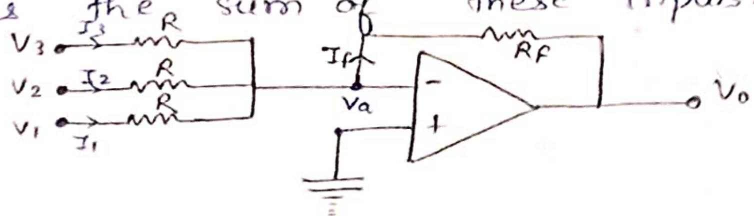
$$\Rightarrow -100 = -\frac{R_f}{2.2 \times 10^3}$$

$$\boxed{R_f = 0.22 M\Omega}$$

OP-Amp Application:-

Adder:- (Inverting)

It can accept two or more inputs and produces output as the sum of these inputs.



$V_a = 0$ (virtual Ground concept)

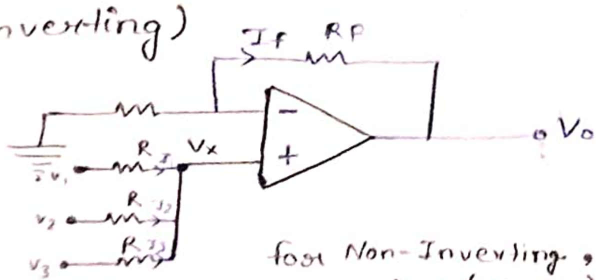
$$I_1 + I_2 + I_3 = I_f$$

$$\frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} = \frac{0 - V_o}{R_f}$$

$$\frac{1}{R}(V_1 + V_2 + V_3) = -\frac{V_o}{R_f}$$

$$\left[V_o = \left(-\frac{R_f}{R}\right)(V_1 + V_2 + V_3)\right]$$

Adder:- (Non-Inverting)



$$I_1 + I_2 + I_3 = 0$$

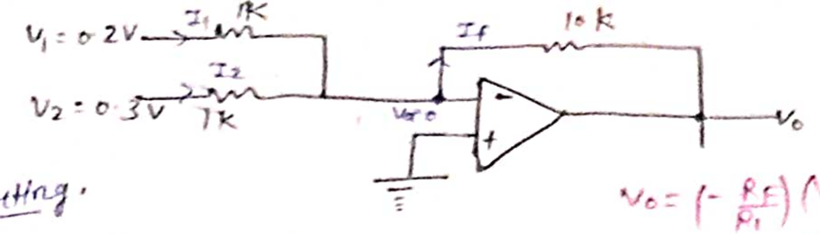
$$\frac{V_1 - V_x}{R} + \frac{V_2 - V_x}{R} + \frac{V_3 - V_x}{R} = 0$$

$$V_x = \frac{V_1 + V_2 + V_3}{3}$$

for Non-Inverting,

$$V_o = \left(1 + \frac{R_f}{R}\right)\left(\frac{V_1 + V_2 + V_3}{3}\right)$$

Ques.



$V_o = ?$

For Inverting.

$V_o = \left(-\frac{R_F}{R_1}\right)(V_1 + V_2)$

$= -\left(\frac{10\times10^3}{1\times10^3}\right)(0.5)$

$= -5V.$

$$\frac{V_o}{V_i} = -\left(\frac{R_F}{R}\right)$$

$$V_o = \left(-\frac{R_F}{R}\right)V_i$$

$V_a = 0$ (virtual ground)

$$I_1 + I_2 = \frac{0 - V_o}{R_F}$$

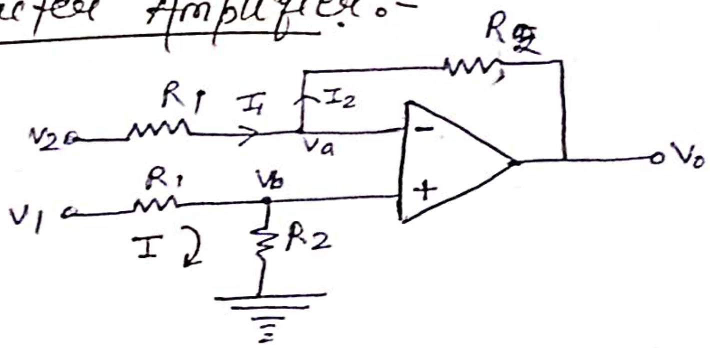
$$\frac{V_1}{R} + \frac{V_2}{R} = \frac{0 - V_o}{R_F}$$

$$\frac{0.2}{1} + \frac{0.3}{1} = -\frac{V_o}{10}$$

$$5 = -V_o$$

$$\boxed{V_o = -5V}$$

Substracter Amplifier :-



$$V_b = I R_2 = \frac{V_1}{R_1 + R_2} R_2$$

~~$I_1 = I_2$~~

$$V_a = \frac{R_2}{R_1 + R_2} V_2 + \frac{R_1}{R_1 + R_2} V_o$$

By virtual Ground,

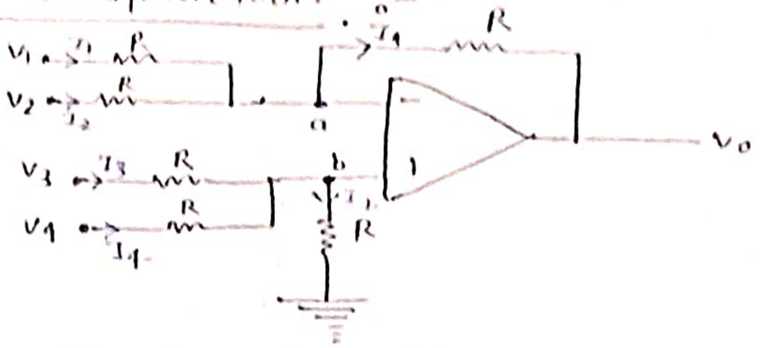
$$V_b = V_a$$

$$\left(\frac{V_1}{R_1 + R_2}\right) R_2 = \frac{R_2}{R_1 + R_2} V_2 + \frac{R_1}{R_1 + R_2} V_o$$

$$(V_2 - V_1) R_2 = -V_o R_1$$

$$\left[\frac{R_2}{R_1} = \frac{V_o}{V_1 - V_2}\right]$$

Adder / Subtractor :-



$I_1 + I_2 = I_a$ — (1)

$$\frac{V_1 - V_a}{R} + \frac{V_2 - V_a}{R} = \frac{V_a - V_o}{R}$$

$$\boxed{V_a = \frac{V_1 + V_2 + V_o}{3}}$$

$I_3 + I_4 = I_b$ — (2)

$$\frac{-V_b + V_3}{R} + \frac{V_4 - V_b}{R} = \frac{V_b}{R}$$

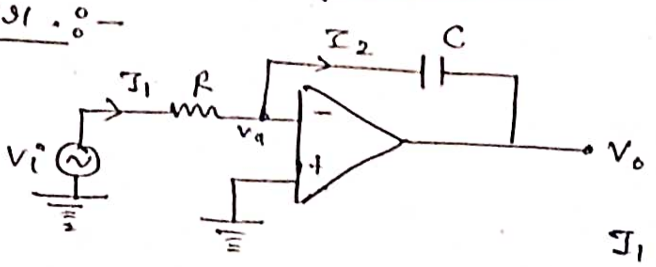
$$\boxed{V_b = \frac{V_3 + V_4}{3}}$$

$$V_a = V_b$$

$$V_1 + V_2 + V_o = V_3 + V_4$$

$$\boxed{V_o = V_3 + V_4 - V_1 - V_2}$$

Integrator :-



$V_a = 0$ (by virtual groun

$$I_1 = I_2$$

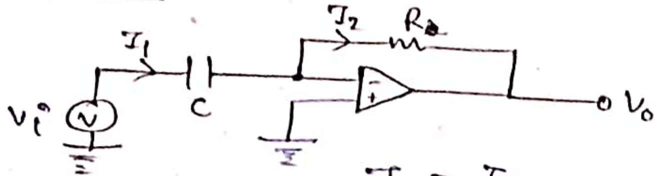
$$\frac{V_i - 0}{R} = C\frac{d}{dt}(0 - V_o)$$

$$\frac{V_i}{R} = -C\frac{dV_o}{dt}$$

$$\int -\frac{V_i}{RC}\,dt = V_o$$

$$\boxed{V_o = -\frac{1}{RC}\int V_i\,dt}$$

Differentiator :-

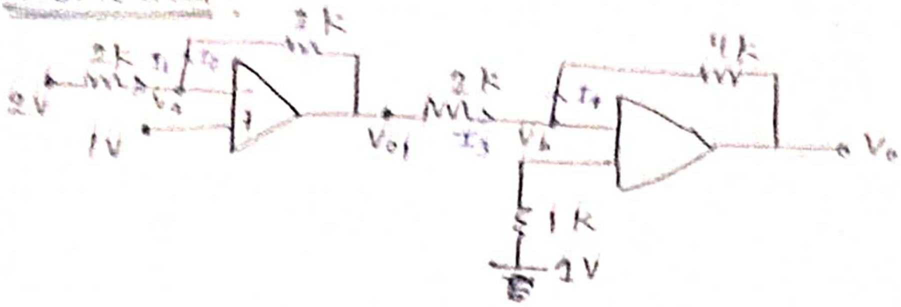


$$I_1 = I_2$$

$$C\frac{d(V_i - 0)}{dt} = \frac{0 - V_o}{R}$$

$$\boxed{V_o = -RC\frac{dV_i}{dt}}$$

Numerical.



$V_a = 1$ (Virtual Ground)

$I_1 + I_2 = 0$

$\frac{2 - V_a}{2} + \frac{-V_a - V_{01}}{2} = 0$

$\frac{1}{2} + \frac{-1 + V_{01}}{2} = 0$

$\boxed{V_{01} = -2}$

$I_1 = I_2$

$\frac{V_i - V_a}{2} = \frac{V_a - V_{01}}{2}$

$\frac{2-1}{2} = \frac{1 - V_{01}}{2}$

$\boxed{V_{01} = 0}$

$I_3 + I_4 = 0$

$\frac{V_{01} - V_b}{2} + \frac{-V_b + V_o}{4} = 0$

$\frac{-2 - V_b}{2} + \frac{-1 + V_o}{4} = 0$

$\frac{-3}{2} + \frac{1}{4} = \frac{-V_o}{4}$

$\frac{-6-1}{4}$

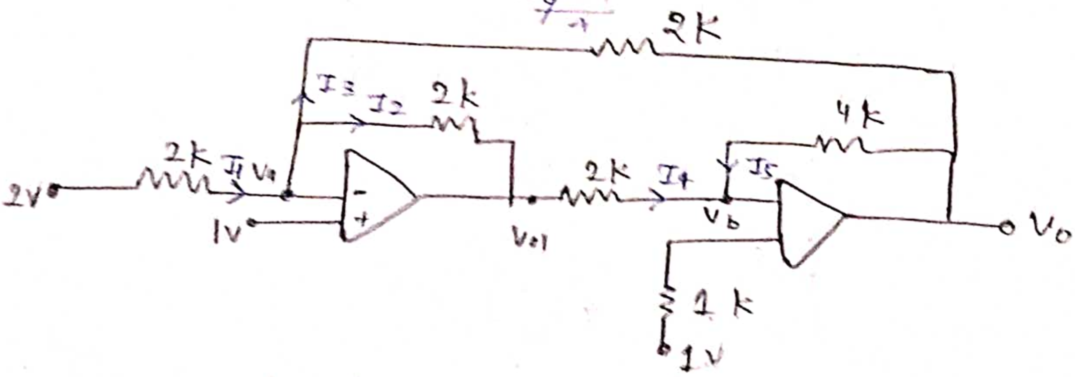
$I_3 = I_4$

$\frac{V_{01} - V_b}{2} = \frac{V_b - V_o}{2}$

$0 - 1 = \frac{1 - V_o}{2}$

$-2 - 1 = -V_o$

$\boxed{V_o = 3V}$



$V_a = 1$

$I_1 + I_3 + I_2 = 0$

$\frac{2 - V_a}{2} + \frac{-V_a + V_o}{2} + \frac{-V_a + V_{01}}{2} = 0$

$\frac{1}{2} + \frac{(-1 + V_o)}{2} + \frac{-1}{2} + \frac{V_{01}}{2} = 0$

$V_{01} + V_o - 1 = 0$

$I_4 + I_5 = 0$

$\frac{(V_{01} - 1)}{2} + \frac{(V_o - 1)}{4} = 0$

$\boxed{V_o = -1V}$

Bipolar Junction Transistor.

The output voltage, current or power are controlled by input current in a transistor. Therefore, it is also called a <u>current controller device</u>.

Raise the strength of an input signal weak signal. This property is called <u>amplification</u>.

Transistor
(Region)

(Emitter)	(Base)	(Collector)
function - inject charge carrier (e⁻ in NPN and holes in PNP) into the base.	fuⁿ :- to pass all the charge carrier to the collector.	fuⁿ :- to collect the charge carrier from base.
it is highly doped.	it is thin and lightly doped.	doping is between Emitter and base.
"More is the doping, more will be the available charge carrier"		

[Doping = Emitter > Collector > Base
Area = Collector > Emitter > Base]

On the basis of Region of Operation :-

1) Active Region :- EB - FB, CB - RB — Used in Amplifier because collector current depends on Base (Input) current!

2) Saturation Region :- EB - FB, CB - F.B — Act like a switch, don't depend on input current.

3) Cut-off Region :- EB - RB, CB - RB — Act as open switch, no current flows.

4) Inverted Region :- EB - RB, CB - FB — This region is of no importance.

Transistor Configuration.

1) Common base Configuration:- Base is made common.
Input → Emitter and base
Output → collector and base.

2) Common emitter configuration:- Emitter is made common
Input → Emitter / Base
Output → Collector / Emitter.

3) Common collector configuration:- Collector is common.
I/p → B-C
O/p → C-E

Current Gain of a Transistor in Common Base Configuration:-

DC current gain $\alpha = \frac{I_c}{I_E}$

where $(\alpha < 1)$ as $(I_c > I_E)$

Current Gain of a Transistor in Common Emitter Configuration:-

DC current gain $= \beta = \frac{I_c}{I_B}$

where $(\beta > 1)$ as $(I_c > I_B)$

Relation between Current gain α and β.

$$I_E = I_B + I_c$$

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

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

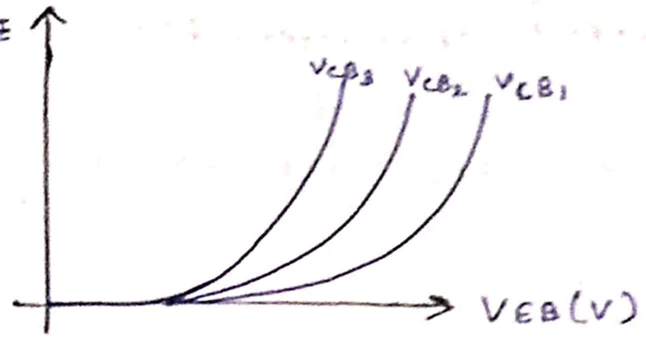
$$\frac{1}{\alpha} = \frac{\beta + 1}{\beta}$$

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

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

Input characteristics of CB configuration.

Graph b/w I_E and V_{EB}
V_{CB} = constant.



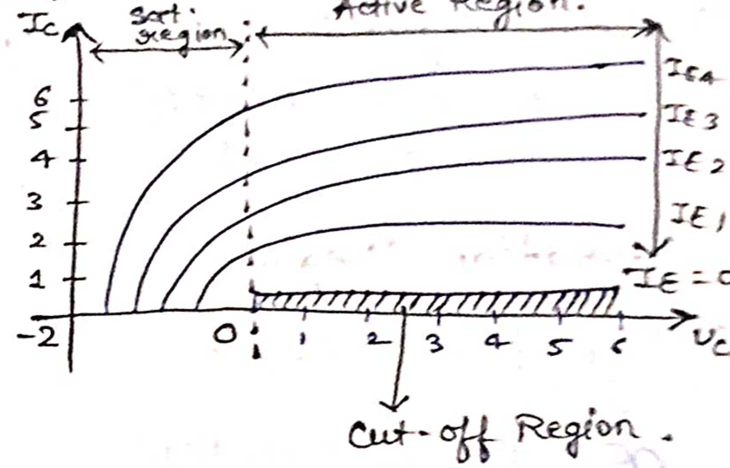
After knee voltage, I_E rises.
till knee voltage $I_E = 0$
for Si knee voltage = 0.7V
Ge " " = 0.3V

$[V_{CB_3} > V_{CB_2} > V_{CB_1}]$

Only for Active Region.

Output characteristics of CB Configuration:-

Graph b/w I_C and V_{CB}
I_E = constant.



1) Active Region:-
$I_E \approx I_C$
$I_E \propto V_{CB}$ (slowly)
Hence, R_o is very large.

$[I_{E_4} > I_{E_3} > I_{E_2} > I_{E_1}]$

2) Saturated Region:-
V_{CB} = -ve it means FB.
$\Rightarrow I_C \downarrow$
I_C does not depend much on I_E
As in sat. Region C-B junction FB so small increase in V_{CB} results in large increase in collector current.

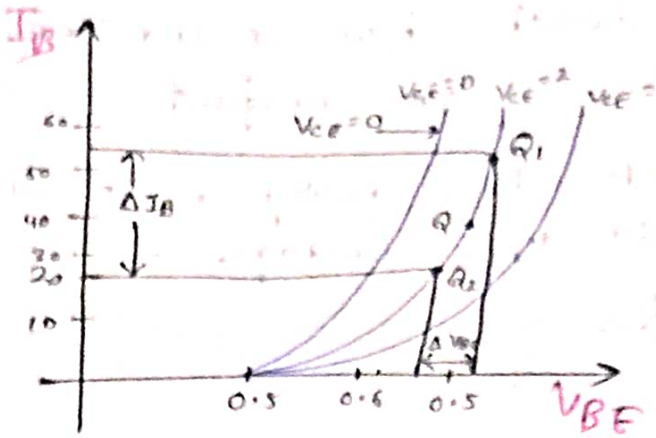
3) Cut-off Region:-
If $I_E = 0$ then $I_C \neq 0$ this value of I_C is known leakage current I_{CBO}, Both junction are reversed biased and so, cutoff Region.

Transistor characteristics of CE Configuration :

1) Input characteristics :

V_{CE} = constant

Graph b/w V_{BE} and I_B

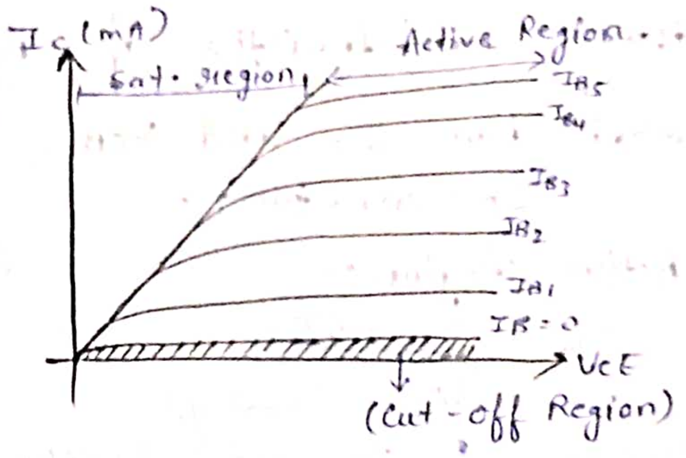


2) Output characteristics :-

1) Active Region :- [EB] → FB [CB] → RB

$R_o(CE) < R_o(CB)$

As $V_{CE} \uparrow \rightarrow I_C \uparrow$



2) Saturation Region :-

(-ve) $V_{CE} \downarrow \rightarrow I_C \downarrow$.

↓

CE → FB So (Sat. Reg.)

↓

I_C do not depent I_B.

3) Cut off Region :-

If $I_B = 0$ then $I_C \neq 0$, I_{CEO} is known as reverse leakage current I_{CEO}.

Current Gain in CC Configuration :-

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

Relation b/w γ and α :-

$$I_E = I_C + I_B$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

$$\gamma = \frac{\Delta I_E / \Delta I_E}{1 - \Delta I_C / \Delta I_E} = \frac{1}{1-\alpha}$$

$$\left[\gamma = \frac{1}{1-\alpha}\right]$$

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

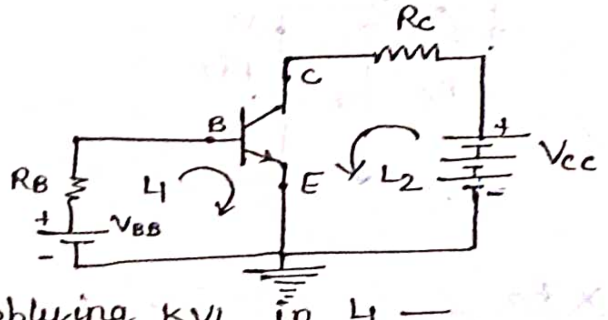
$$\alpha = \frac{\beta}{\beta+1}, \quad \beta = \frac{\alpha}{1-\alpha}$$

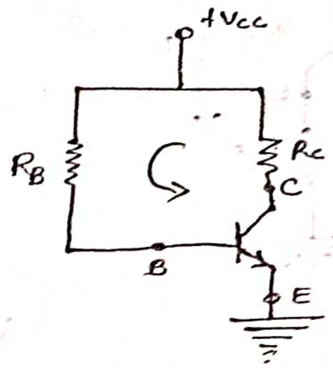
Comparision Between Three Transistor Configuration

Characteristics.	CB	CE	CC
R_i	Very low (40Ω)	low ($50k\Omega$)	very high ($750k\Omega$)
R_o	very high ($1M\Omega$)	High ($10k\Omega$)	low (50Ω)
current gain	< 1	(100) High	High (100)
leakage current	Very small	Very large	Very large
Appl^n.	high frequency appl^n	for audio freq. appl^n.	for impedence matching.

Methods of Transistor Biasing

1) Fixed Bias.





Applying KVL in L1 —

L_1 $V_{BB} - I_B R_B - V_{BE} = 0$ — ①

L_2 $V_{CC} - I_C R_C - V_{BC} - V_{BE} = 0$

$V_{CC} - I_C R_C - V_{CE} = 0$ — ②

L_3 $V_{CC} - I_B R_B - V_{BE} - I_C R_C = 0$

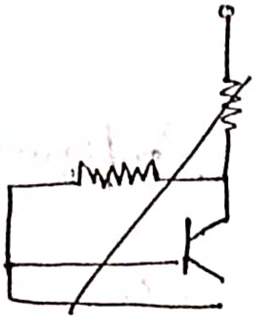
Stability factor $S = \frac{\beta+1}{1-\beta\left(\frac{dI_B}{dI_C}\right)}$

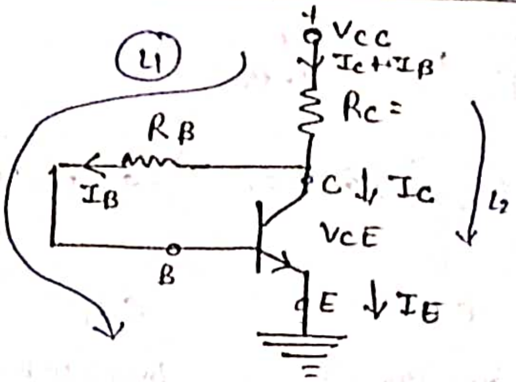
$\frac{dI_B}{dI_C} = 0$ because I_B is independent of I_C

$$S = \frac{\beta+1}{1-\beta(0)}$$

$$\boxed{S = \beta+1}$$

2) Collector to Base Bias Circuit.





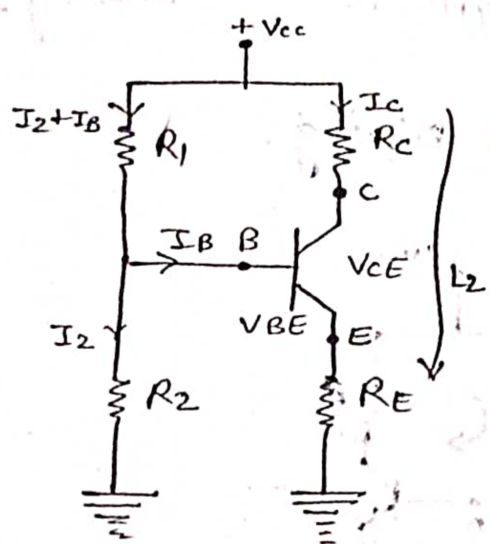
L_1 = Applying KVL

$V_{cc} - (I_C+I_B)R_C - I_B R_B - V_{BE} = 0$

$L_2 \Rightarrow V_{cc} - (I_C+I_B)R_C - V_{CE} =$

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_C}{R_B+R_C}\right)}}$$

3) Self-Bias or Voltage divider Bias.



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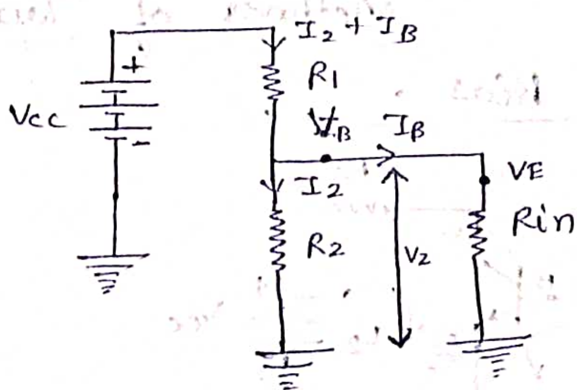


$$V_B = V_{cc} \times \frac{R_2}{R_1+R_2}$$

$$V_E = V_B - V_{BE}$$

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

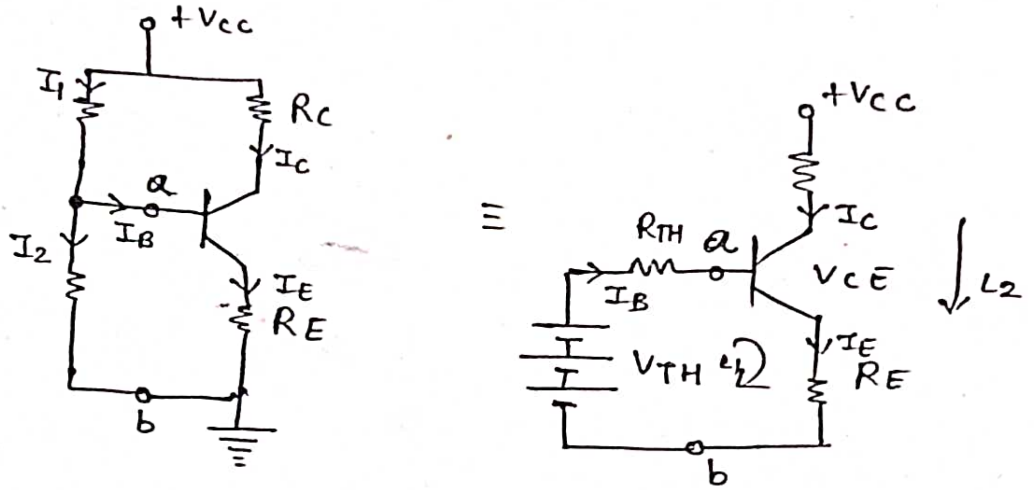
$$I_C \approx I_E$$

$$V_C = V_{CC} - I_C R_C$$

Applying KVL in L_2,

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

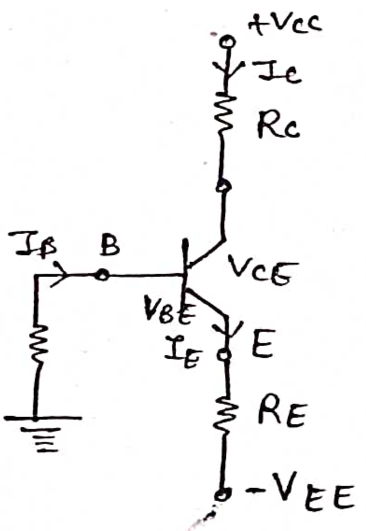
$$[V_{CE} = V_{CC} - I_C R_C - I_E R_E]$$



$$V_{TH} = \frac{R_2}{R_1+R_2} \times V_{CC} \quad , \quad R_{TH} = \frac{R_1 R_2}{R_1+R_2}$$

Then solve L_1 and L_2.

Emitter Bias Circuit :

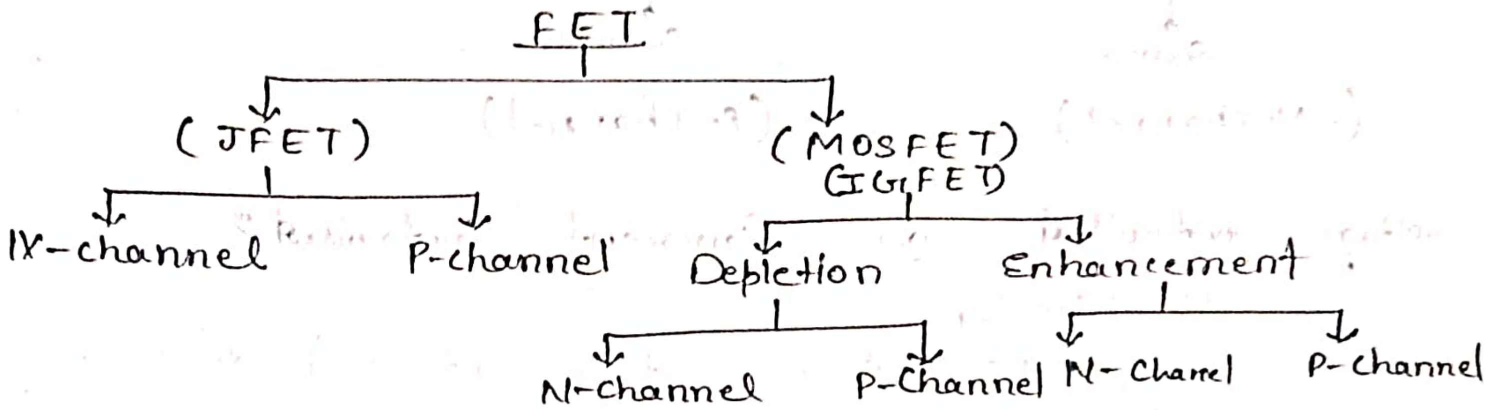


$$V_{EE} = I_B R_B + V_{BE} + I_E R_E$$

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

Field Effect Transistor.

Construction and characteristics of JFETs, Transfer characteristics, MOSFET (MOS) (Depletion and Enhancement) Type, Transfer characteristics.



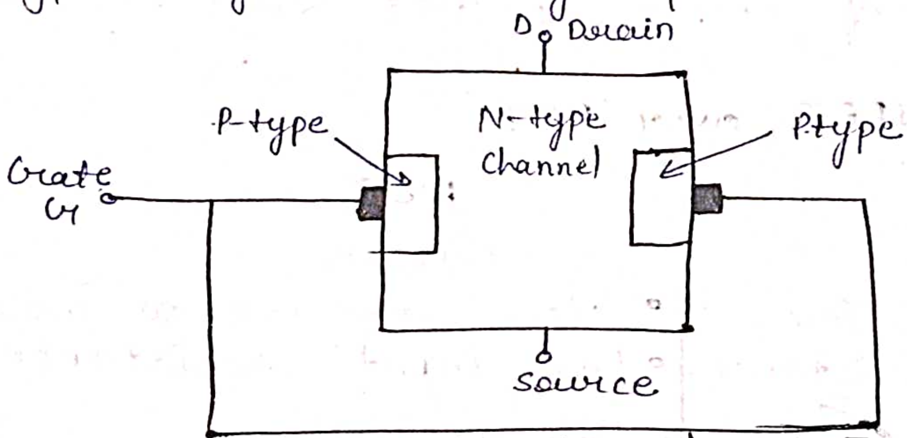
(JFET)

Junction Field-Effect Transistor.

1) N-type Channel JFET.

N-type channel – less doped

P-type regions – heavily doped



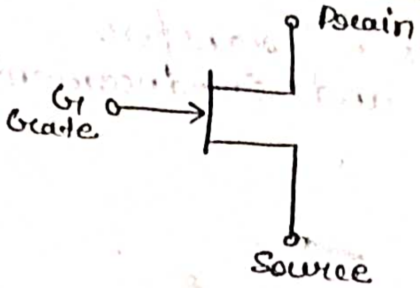
N-channel JFET

electrical connection – ohmic ~~status~~ contacts.

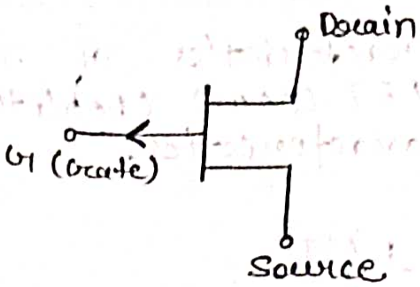
- Drain (e⁻ leave the s.c. bar)
- Source. (e⁻ enter in the s.c. bar)

P-type regions are connected internally and single wire is take out in the form of ~~drain~~ Gate (G)

Symbols for JFET.



(N-channel)



(P-channel)

Voltage controlled or Current Controlled?—

V_{GS} controls → I_D

That's why JFET is a voltage controlled device.

Why called FET?

Current flow is controlled by an EF set by an external voltage.

Unipolar or Bipolar?

Unipolar because ~~contro~~ current ~~is~~ flows due to only one type of charge particle. (holes or $e^{\ominus}$)

Advantages of JFET over BJT

JFET	BJT
Unipolar	Bipolar
immune to radiation.	less immune to radiation
very high input resistance.	Low input resistance.
less noisy.	it's noisy.
does not exhibit any offset current.	exhibit reverse saturation current.
Thermal Stable.	

Pinch off Voltage :

The gate-to-source (V_{GS}) at which the drain current is zero (or completely cut-off) is known as pinch off voltage. It is denoted by the symbol V_P or $V_{GS(off)}$

The value of pinch-off voltage V_P is negative for N-channel JFET. It depends upon –

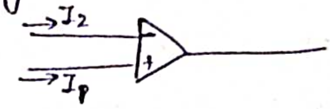
1) doping of the N and P regions of the device.
2) width of the original channel structure.

Important Definitions.

1) Input Bias Current :-

It is the average of two currents which flow into inverting and Non-inverting terminals of op. Amp.

$$I_0 = \frac{I_1 + I_2}{2}$$



Ideally it's value is zero.
but practically in 100's of nA.

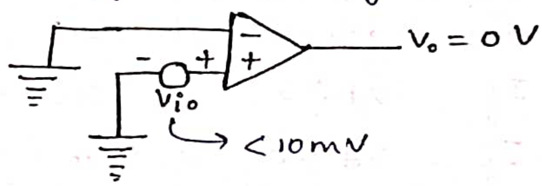
2) Input offset current :-

$$I_{io} = |I_1 - I_2| \quad \{\text{in few nA}\}$$

3) Input offset voltage :-

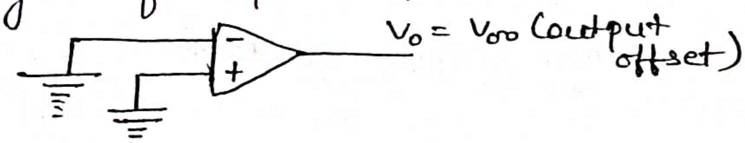
for ideal op. Amp – V_1 and V_2 grounded
V_o should be zero.

for practicle – V_o is not zero so,
A small amount of voltage is applied at the input terminals to make output voltage zero. This input voltage is called input offset voltage.



4) Output offset Voltage.

It is the output voltage of op-Amp when $V_1 = 0$ and $V_2 = 0$.



5) Common Mode Rejection Ratio (CMRR)

The common mode Rejection Ratio may be defined as the ratio of the differential voltage gain (A_d) to the common mode gain (A_{cm})

$$CMRR = \frac{A_d}{A_{cm}} \qquad A_d = \frac{V_o}{V_1 - V_2 = V_d}$$

In decibel

$$\boxed{CMRR = 20\log\left(\frac{A_d}{A_{cm}}\right)} \qquad A_{cm} = \frac{V_o}{V_{cm} = \frac{V_1 + V_2}{2}}$$