Isem Osec

Basic Electronics (1)

Unit-I Semiconductor Diode and Applications

* Diode is a Semiconductor device which is made up of P-n material and it is unidirectional device.

Diode is a two terminal device. A semiconductor diode is simply p-n junction with connecting lead on each side. A diode is a one-way device offering low resistance when forward biased and behaves almost as a closed switch. It offers very high resistance when reverse biased and behaves almost as an open switch. An approximately diode constant voltage drop occurs across a forward-biased diode and this simplifies diode circuit analysis.

P-N Junction Diode :-

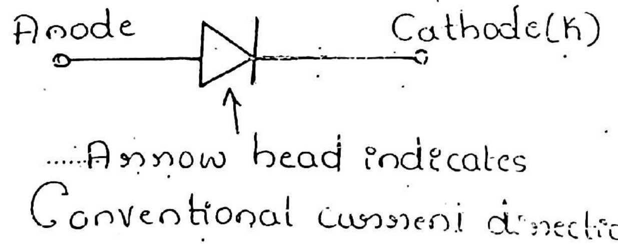
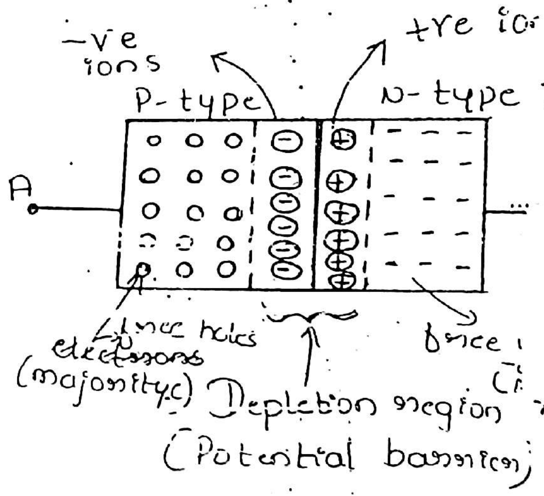
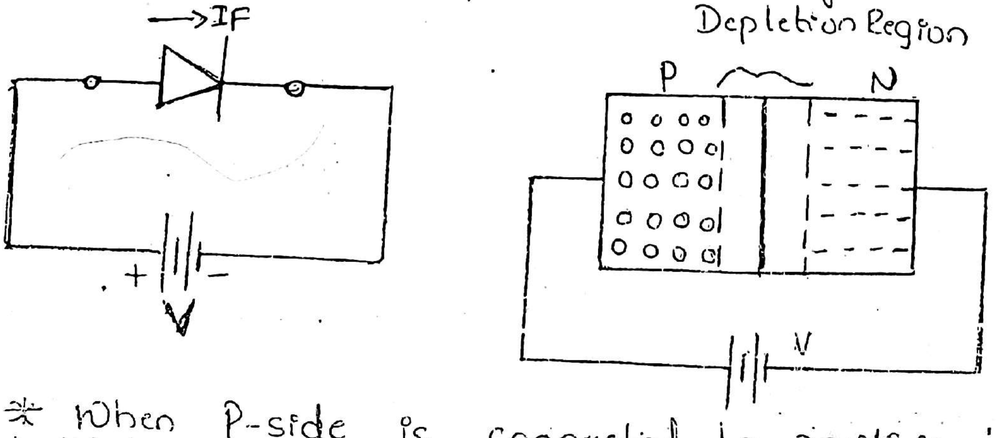


fig: Diode symbol :-



Forward biased P-N Junction :-

The word bias refers to a dc voltage that is applied across the junction by some externally connected source.



* When P-side is connected to positive terminal of the battery and N-side is connected ...

of the Battery, PN Junction is said to be forward biased.

* The holes on P-side, being positively charged are repelled from positive terminal of battery and driven towards the junction. Similarly electrons on N-side are repelled by negative terminal and driven towards the junction.

* The result is that, the width of the depletion region and the Barrier potential are reduced.

* When the Applied bias voltage is progressively increased from zero, the barrier voltage gets smaller until it effectively disappears and Charge Carriers easily flow across the junction.

* Electrons from N-side moves into p-region and now attracted across to the positive terminal of Battery. Similarly Holes from P-side moves into n-region & now attracted towards ~~the~~ negative terminal of Battery. Thus Current conduction is said to be due to both electrons and holes. The Junction is said to be Forward biased.

* The current flowing in this condition is called Forward current I_F

Forward Characteristics :-

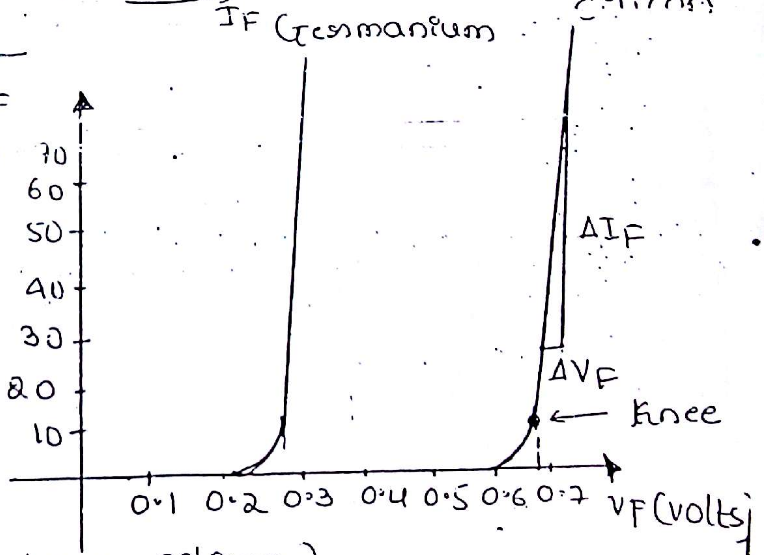


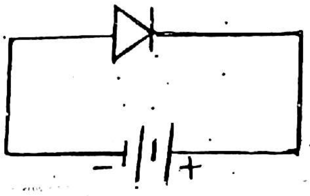
Fig shows forward Characteristics of Diode: (for silicon & Germanium)

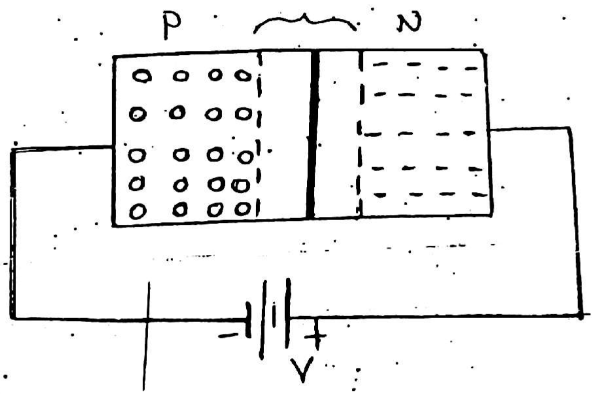
It is seen that very little forward current (I_F) flows until it exceeds the junction barrier potential. (0·3V for Germanium & 0·7 for silicon)

As V_F is increased beyond the knee of the Characteristics, the barrier potential has been Completely Overcome & I_F increases exponentially with increase of V_F. In this region a large Change in forward current ΔI_F Corresponds to very Small Change in forward voltage ΔV

This voltage of 0.7V is called Cut in voltage V_r. Thus we can say that diode turns ON for $V_F > V_r$, $V_r \rightarrow$ Cut in voltage of Diode / 0.7V for silicon.

Reverse biased P-N Junction :-





* When N-side is connected to positive terminal of Battery and P-side is connected to Negative terminal of external Battery source, P-N Junction is said to be reverse biased.

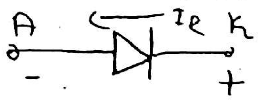
* Electrons from N-side attracted towards the positive terminal and holes from p-side are attracted to the negative terminal of Battery. Hence both holes & electrons moves away from the p-n junction.

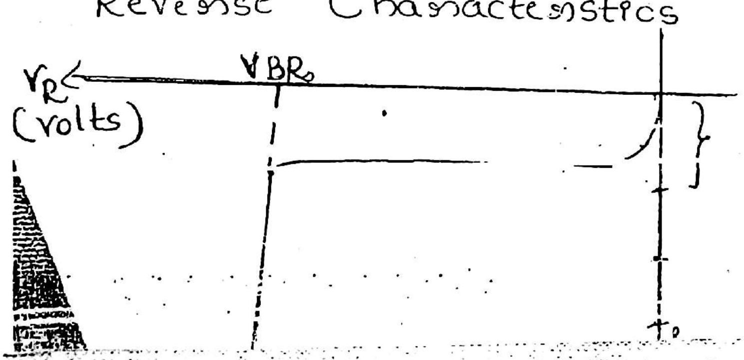
* ~~With the increase~~ of Applied This causes the depletion region to be widened and the barrier voltage to be increase.

* With the increase of Applied reverse voltage, there is an increase in the width of Depletion region, hence there is no possibility of majority charge carrier current flow across the junction and the junction is said to be reverse biased.

* The ~~majority~~ minority Carriers in p-region are electrons & in N-region are holes. Due to these ~~majority~~ minority charge carriers a small amount of reverse current flows. The current flowing in this condition is called reverse current I_R.

Reverse Characteristics





VBR $\rightarrow$ reverse breakdown vo

* When reverse biased, a very small current (nA), flow through silicon diode. Until the p-n junction breakdown at a voltage known as reverse breakdown voltage (VBR).
The diode is said to be OFF for the voltage loss than VBR.
Under this condition diode offers very high resistance.

The dynamic reverse resistance is defined as the ratio of the change in the reverse voltage to the change in reverse current $R_r = \frac{\Delta V_R}{\Delta I_R}$

Note :- A p-n junction diode can be destroyed under the following conditions:

The diode can be destroyed when

(i) It is oven heated by a high forward current (I_F) flowing through the diode, Power discipation $P = I_F^2 R_F$.
Where I_F → forward current & R_F → forward resistance of the diode.

(ii) A large reverse voltage causes the p-n junction to breakdown

Thus maximum forward current I_F (max) & maximum reverse voltage V_R(max) are important specifications given in the diode manufacturer's data sheets.

Diode Parameters :-

The important Diode Parameters are

(i) Forward voltage drop V_F
(ii) Maximum Forward Current I_F (max)
(iii) Reverse breakdown voltage VBR
(iv) Reverse Saturation Current I_R
(v) Dynamic resistance rd

The values of these quantities are normally

Diode Current Equation

The diode current depends on the voltage appli to it. The relationship between applied voltage V and the diode Current I is exponential and is mathematically given by the equation called diode current equation.

It is expressed as

$$I = I_0 [e^{V/\eta V_T} - 1] A$$

Where I_0 = reverse saturation current in ampere

V = applied voltage

η = 1 for Germanium

= 2 for silicon diode.

thermal voltage

V_T = Voltage equivalent of temperature (Thermal voltage) in volts. The voltage equivalent of temperature indicates dependence of diode current on temperature. ~~The voltage~~ equivalent of temperature V_T for given diode at temperature T is calculated as

$K = 1.38 \times 10^{-23} J/K$

$q = 1.6 \times 10^{-19} C$

$$V_T = V_T = \frac{kT}{q} \text{ or } \frac{T}{11600} = \frac{1}{q/k} = \frac{q}{1.6 \times 10^{-19}/1.38 \times 10^{-23} J/K}$$

Where k = Boltzman's Constant

T = Temperature in °K

T is absolute temperature in Kelvin

Thus at room temperature of 27°C

$\frac{q}{k} = 1160$

T = 27 + 273 = 300° Kelvin

The Value of V_T = ~~8.62 × 10⁻⁵ × 300~~ = 0.02586 V

$V_T = \frac{300}{11,600} = 0.026 V$

= 26 mV

The diode Current equation is applicable for all Condition of the diode i.e Unbiased diode, forward biased, reverse biased. When unbiased →

V = 0 hence we get

$$I = I_0 [e^0 - 1] = \text{'0A' current}$$

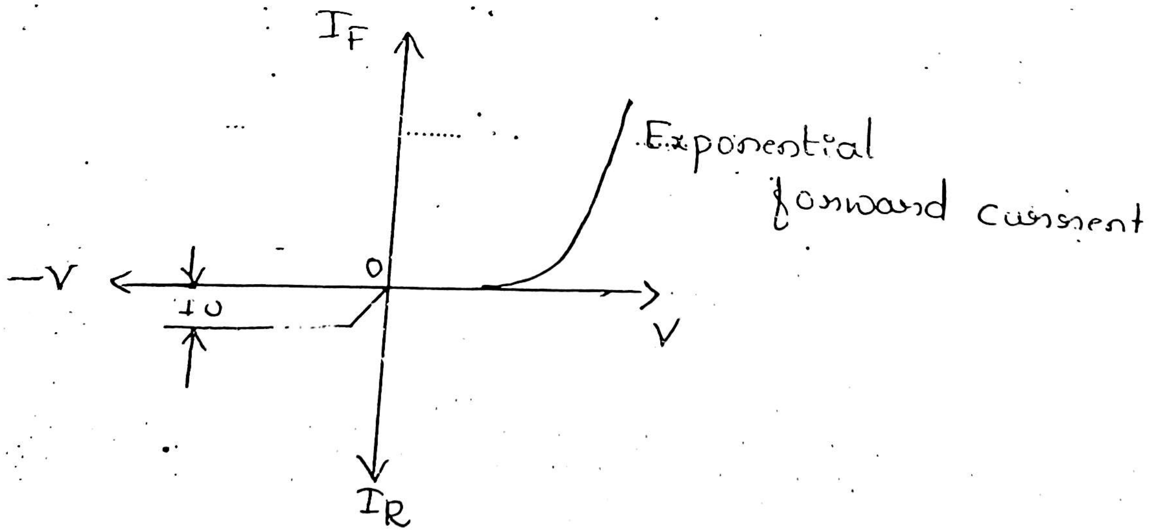
* For a forward bias Condition the bias voltage 'V' is considered as positive and hence exponential

index has positive sign. Due to this, $1 << e^{V/\eta V_T}$ hence neglecting '1' we get the equation for a forward Current as $I_F = I_0 e^{V/\eta V_T}$

This indicates that once bias voltage exceeds cut-in voltage, the forward current increases exponentially.

* In Reverse biased Condition, the bias voltage 'V' is treated negative and due to this exponential index has negative sign $e^{-V/\eta V_T} << 1$, Hence neglecting exponential term we get, $I_R \cong I_0(-1) = -I_0$

The above Equation indicates that under reverse biased condition, the current is reverse saturation current which is negative indicating that it flows in opposite directions to that of forward current and almost Constant.



Nature of VI Characteristics of diode.

Problems

1) A silicon diode has a reverse saturation current of 7.12 nA at room temperature of 27°C. Calculate its forward current, if it is forward biased with a voltage of 0.7V

Solⁿ

given $I_0 = 7.12\,nA = 7.12 \times 10^{-9} A$ $\quad V = 0.7V$ as a forward biased

$\eta = 2$ for silicon diode, $T = 27°C = 27 + 273 = 300°K$

Now $V_T = \frac{KT}{q} = 8.62 \times 10^{-5} \times 300 = 0.026V$

$= 26mV$

According to diode current equation.

$$I = I_0 \left(e^{\frac{V}{\eta V_T}} - 1\right)$$

$$\cancel{I = 7.12 \times 10^{-9}\left[e^{0.7/2\times0.026} - 1\right]}$$

$$I = 7.12 \times 10^{-9}\left[701894 - 1\right]$$

$$= 4.99 \times 10^{-3} A = \underline{5mA}$$

2) The diode current is 0.6mA. when the applied voltage is 500mV. Determine the value of η. assume $\frac{KT}{q} = 25mV$

Solⁿ given $I = 0.6mA$ $\quad V = 500mV$ $\quad \frac{KT}{q} = 25mV$

$V_T = \frac{KT}{q} = 25mV$

Let $I_0 = 0.1\mu A$

$$I = I_0\left[e^{\frac{V}{\eta V_T}} - 1\right]$$

$$0.6 \times 10^{-3} = 0.1 \times 10^{-6}\left[e^{\frac{500\times10^{-3}}{\eta\times25\times10^{-3}}} - 1\right]$$

$$6000 = e^{\frac{20}{\eta}} - 1$$

$$6000 + 1 = e^{20/\eta}$$

taking natural log on both sides

$$\ln 6001 = \ln e^{20/\eta}$$

$$\ln 6001 = \frac{20}{\eta}$$

[illegible] $\eta =$ [illegible] $\simeq$ [illegible]

(3) A germanium diode for which the reverse saturation current is 5uA has a forward current of 1A at 27°C. Calculate the forward voltage across it.

$$I = I_0 \left[e^{\frac{V}{\eta V_T}} - 1 \right]$$

given

$I_0 = 5\,\mu A$

$I = 1A$

$V_T = \frac{KT}{q} = 26\,mV$

$\eta = 1$ for Germanium

$$1 = 5\times10^{-6} \left[e^{\frac{V_F}{\eta V_T}} - 1 \right]$$

$$1 = 5\times10^{-6} \left[e^{V_F/26\times10^{-3}} - 1 \right]$$

$$\frac{1}{5\times10^{-6}} = \left[e^{\frac{V_F}{26\times10^{-3}}} - 1 \right]$$

$$\frac{1}{5\times10^{-6}} + 1 = e^{\frac{V_F}{26\times10^{-3}}}$$

$$\ln \left[\frac{10^6}{5} + 1 \right] = \ln e^{\frac{V_F}{26\times10^{-3}}}$$

$$12.2 = \frac{V_F}{26\times10^{-3}}$$

$$V_F = 0.3172$$

(4) For a silicon diode at a working temperature of 25°C the forward voltage applied across the diode is 0.5V. Determine its forward current if the reverse saturation current is 10mA

$$I = I_0 \left(e^{\frac{V}{\eta V_T}} - 1 \right)$$

$$V_T = \frac{T}{11600}$$

$$V_T = \frac{298}{11600} = 25.68\,mV$$

$\eta = 2$ for silicon

$$I = 10\times10^{-9} \left(e^{\frac{0.5}{2\times25.68\times10^{-3}}} - 1 \right)$$

$$= 10\times10^{-9} \left(e^{9.735} - 1 \right)$$

$$= 10\times10^{-9} \left(16898.83 - 1 \right)$$

$$= 0.169\,mA$$

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(5) 100

15) For a silicon diode at working temperature of 100 determine the forward voltage required to be applied. The reverse saturation current is 5μA forward current is 57mA $\eta = 2$

$I_0 = 5\times10^{-6}A$

$T = 100°C = 100+273 = 373°K$

Given $\eta = 2$

$$V_T = \frac{T}{11600}$$

$$= \frac{373}{11600}$$

$$= 0.032V$$

$I = 57mA$

$$I = I_0\left(e^{\frac{V}{\eta V_T}} - 1\right)$$

$$57\times10^{-3} = (5.4\times10^{-6})\left(e^{\frac{V}{2\times0.032}} - 1\right)$$

$$11.4\times10^{3} = \left(e^{\frac{V}{0.064}} - 1\right)$$

$$\ln(11400+1) = \ln e^{\frac{V}{0.064}}$$

$$9.341 = \frac{V}{0.064}$$

$$V = 0.598V$$

Find the factor by which the saturation current of a silicon diode will get multiplied when the temperature is increased from 27°C to 82°C

The approximate increased in I_0 is given by

$$I_{02} = (1.07)^{\Delta T}(I_{01})$$

So factor by which I_0 increases is given my

$$\text{Factor} = (1.07)^{\Delta T}$$

Now $\Delta T = 82 - 27 = 55°C$

Therefore factor $= (1.07)^{55} = 41.31$

Thus new I_0 at 80°C will be 41.31 times more

(7) The diode current is 0.6mA when the applied volt is 500mV. Determine the value of η assume $\frac{KT}{q} = 25mV$

Given :- $I_f = 0.6mA$ $V = 500mV$ $\frac{KT}{q} = 25mV$

$$I = I_0 \left[e^{\frac{V}{\eta V_T}} - 1 \right] \qquad I_0 = 0.1\mu A$$

$$0.6\times10^{-3} = 0.1\times10^{-6}\left[e^{\frac{500\times10^{-3}}{\eta\times25\times10^{-3}}} - 1 \right]$$

$$6000 = \left[e^{\frac{20}{\eta}} - 1 \right]$$

$$6000 + 1 = e^{\frac{20}{\eta}}$$

$$\ln(6001) = \frac{20}{\eta}$$

$$8.699 = \frac{20}{\eta}$$

$$\therefore \eta = 2.29$$

(8) A germanium diode is used in a rectifier circuit and is operating at a temp. of 25°C with a reverse saturation current of 1000μA. Calculate the value of forward current if it is forward biased by 0.22V. Assume the value of $\eta = 1$ for Ge.

Given : $T = 25°C$ $I_0 = 1000\mu A$ $V_f = 0.22V$
$\eta = 1$ $I_f = ?$

$$I_f = I_0\left(e^{\frac{V}{\eta V_T}} - 1 \right)$$

$$V_T = \frac{T}{11600} = \frac{298}{11600} = 25.68mV$$

$$I_f = 1000\times10^{-6}\left[e^{\frac{.22}{1\times25.68\times10^{-3}}} \right]$$

$$= 5.25A.$$

(9) A Germanium diode draws 40mA with a forward bias of 0.25V The junction is at room temp. of 293°K Calculate the reverse saturation current. Take $\eta = 1$

$$V_T = \frac{T}{11600} = \frac{293}{11600} = 0.025$$

$$I = I_0 \left(e^{\frac{V}{\eta V_T}} - 1 \right)$$

$$40 \times 10^{-3} = I_0 \left(e^{\frac{0.25}{1 \times 0.025}} - 1 \right)$$

$$40 \times 10^{-3} = I_0 \left(e^{10} - 1 \right)$$

$$I_0 = \frac{40 \times 10^{-3}}{22025.46}$$

$$I_0 = \underline{1.82 \mu A}$$

(10) The Saturation Current Density of a P-n junction Ge diode is 250mA/m² at 300°K find the voltage that must be applied across junction to cause a forward Current density of 10^5 A/m

Given $J_0 = 250 mA/m^2$.

$T = 300°K$

$V = ?$

$\eta = 1$ for Ge diode

$$J = J_0 \left(e^{\frac{V}{\eta V_T}} - 1 \right)$$

$$\frac{\text{Current}}{A} = \text{Current density}$$

$$10^5 = 250 \times 10^{-3} \left(e^{\frac{V}{26 \times 10^{-3}}} - 1 \right)$$

$$4 \times 10^5 = e^{\frac{V}{26 \times 10^{-3}}}$$

$$\ln(4 \times 10^5 + 1) = \frac{V}{26 \times 10^{-3}}$$

$$V = \underline{0.33V}$$

(11) An silicon diode $I_s = I_0 = 10nA$ operating at 25°c. calculate Diode current I_D for a forward bias of 0.6V.

$T = 25 + 273°K = 298°$ ~~kelvin~~

$$\frac{KT}{q} = V_T = \frac{qT}{q/k}$$

$V = 0.6V$

$I = 1.18 mA$ Very less Current

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Diode Applications :- Rectifiers :-

* A rectifier is an electronic circuit used for converting A.C voltage or current into D.C voltage or current.

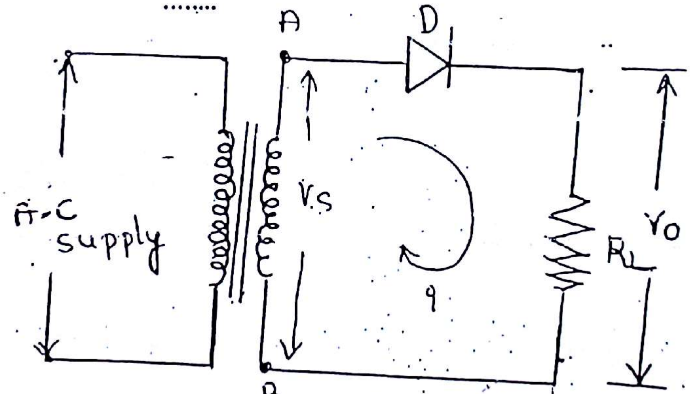
* The process of converting A.C signal into D.C signal is called Rectification.

⇒ Rectifiers are classified into two categories depending upon the period of conduction.

a) Half wave Rectifier

b) Full wave Rectifier → Full wave Rectifier with two diodes
→ Full wave Rectifier with 4 diodes (Bridge R)

(1) Half wave Rectifier :- Fig. shows circuit of half wave Rectifier. The A.C voltage to be ~~rectified~~ is applied across primary of transformer and the secondary of transformer is connected to load in series with a diode.

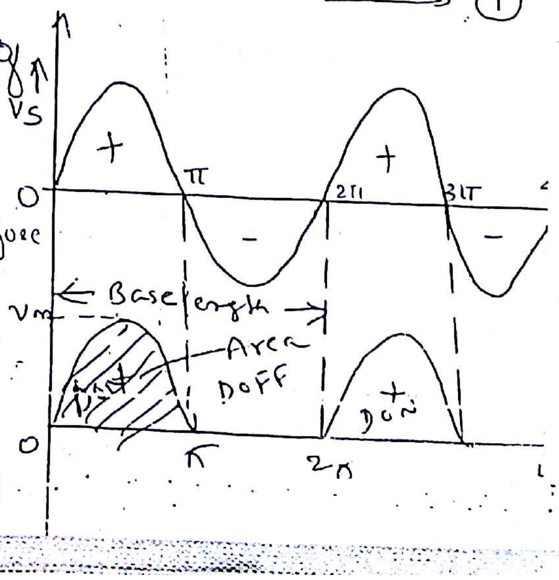


let the voltage across the secondary of the transformer available for rectification be

$V_s = V_m \sin\omega t$ → (1)

Operation

* During the positive half cycle of input voltage, terminal 'A' is positive and terminal 'B' is negative. The diode 'D' gets forward biased and conducts. Therefore current flows through the load R_L and the voltage appears across the load shown in waveform.



* During negative half cycle, terminal

The diode 'D' gets reverse biased and does not conduct. no current flows through the load R_L and hence voltage across the load is zero is shown in waveform.

* Since the diode conducts only during positive half cycles, Output voltage consists of positive half cycles as shown in waveform. Hence this is termed as a half wave Rectifier. Since current flows in one direction across the load, it is a unidirectional current or d.c. current.

To find D.C voltage across the load: [Vdc]

let the voltage across the secondary of transformer be

$V_s = V_m \sin\omega t$ and current $i = I_m \sin\omega t$

then load Peak current $I_m = \dfrac{V_m}{R_f + R_L + R_s} \rightarrow (1)$ (Transformer second winding R)

maximum load current is given

where $R_f \rightarrow$ ~~forward~~ resistance of diode

$V_m \rightarrow$ peak secondary voltage.

D.C value of load current:- Average current I_{dc}

$$I_{dc} = \frac{\text{Area enclosed by output load current}}{\text{Base length for one cycle.}}$$

$$I_{dc} = \int_0^{\pi} \frac{i_o\, d(\omega t)}{2\pi}$$

$i = I_m \sin\theta$ for $0 \le \theta \le \pi$

$i = 0$ for $\pi \le \theta \le 2\pi$

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

$$I_{dc} = \frac{I_m}{2\pi}\int_0^{\pi} \sin\omega t\, d(\omega t) = \frac{I_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$I_{dc} = \frac{I_m}{2\pi}\left\{-\left[\cos\pi + \cos 0\right]\right\}$$

$$= \frac{I_m}{2\pi}\left[-\{(-1)+1\}\right] = \frac{2 I_m}{2\pi}$$

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

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

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_o\, d\theta$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} i_o\, d\theta + \cancel{\int_{\pi}^{2\pi} i_o\, d\theta}\right]$$

No current from π to 2π

So

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

D. C voltage across the load $V_{dc} = I_{dc} R_L = \left(\frac{I_m}{\pi}\right) R_L$

$$V_{dc} = \frac{\left(\frac{V_m}{R_f + R_L}\right) R_L}{\pi} \quad \text{since } I_m = \frac{V_m}{R_f + R_L} \text{ from Eq}^n \text{ ①}$$

$$= \frac{V_m}{\pi}\left(\frac{R_L}{R_f + R_L}\right) \quad \text{dividing Nr \& Dr by } R_L$$

$$V_{dc} = \frac{V_m}{\pi\left(1 + \frac{R_f}{R_L}\right)}$$

$$\therefore V_{dc} = \frac{V_m}{\pi} \Rightarrow \because R_f << R_L \text{ for Ideal Diode}$$

Condition $R_f = 0$

R.M.S value of load current :-

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i_0^2 \, d(\omega t)} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_m \sin\omega t)^2 \, d(\omega t)}$$

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

$$= \sqrt{\frac{I_m^2}{2\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)_0^{\pi}} = \sqrt{\frac{I_m^2}{4\pi}\left(\pi - 0 + \frac{\sin 2\pi}{2} + 0\right)}$$

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

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

R.M.S voltage across the load

$$V_{rms} = I_{rms} \cdot R_L$$

$$= \frac{I_m}{2} \cdot R_L = \frac{\left(\frac{V_m}{R_f + R_L}\right) R_L}{2} \quad \text{Since } I_m = \frac{V_m}{R_f + R_L}$$

$$V_{rms} = \frac{V_m}{2}\left(\frac{R_L}{R_f + R_L}\right) \quad \text{dividing Nr \& Dr by } R_L$$

$$V_{rms} = \frac{V_m}{2\left(1 + \frac{R_f}{R_L}\right)} \quad \text{for ideal diode } R_f = 0$$

$$\boxed{V_{rms} = \frac{V_m}{2}} \longrightarrow (5)$$

To find Efficiency of Rectifier

Efficiency : It is defined as the ratio of DC power delivered to the load to the a.c Input power across the Secondary of transformer

$$\eta = \frac{\text{d.c output power across load}}{\text{A.C Input Power}} = \frac{P_{dc}}{P_{ac}}$$

* D.C Power delivered $P_{dc} = I_{dc}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L = \frac{I_m^2}{\pi^2} R_L$

* A.C Input Power $P_{ac} = I_{rms}^2 (R_f + R_L) = \left(\frac{I_m}{2}\right)^2 (R_f + R_L)$

$$= \frac{I_m^2}{4}(R_f + R_L)$$

$$\therefore \text{Efficiency} = \frac{P_{dc}}{P_{ac}} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}(R_f + R_L)} = \frac{4}{\pi^2}\left(\frac{R_L}{R_f + R_L}\right)$$

$$\eta = 0.406\left(\frac{R_L}{R_f + R_L}\right) \quad \div \text{ Nr \& dr by } R_L$$

$$\eta = \frac{0.406}{1 + \frac{R_f}{R_L}} \quad \text{for Ideal diode } R_f = 0$$

$$\eta = 0.406 \quad \text{or} \quad \%\eta = 40.6\%$$

Theoretically, the maximum value of efficiency for half wave rectifier is 40.6% if $\frac{R_f}{R_L}$ is equal to zero. Only 40.6% of A.C Input Power is converted in to d.C. power in halfwave Rectifier.

Ripple factor :- Ripple factor is defined as the ratio of r.m.s value of a.c Component present in the rectified Output to the d.c Component of the rectified output.

Ripple factor = $\frac{I_{ac}}{I_{dc}}$ or Ripple factor = $\frac{V_{ac}}{V_{dc}}$

Where V_{ac} is the r.m.s value of a.c component of voltage (Ripple Component)

V_{dc} is the d.c. component

Similarly I_{ac} is the rms value of a.c component of Output Current

I_{dc} is the d.c component of current

Output Current consists of both a.c & d.c components

Since Output Current is not pure d.c

Vector sum → i.e $I^2_{rms} = I^2_{ac} + I^2_{dc}$

A.C components ∴ $I^2_{ac} = I^2_{rms} - I^2_{dc}$ ÷ both sides by I^2_{dc}

$$\frac{I^2_{ac}}{I^2_{dc}} = \frac{I^2_{rms}}{I^2_{dc}} - 1 \quad \text{or}$$

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

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

$$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{\left(\frac{I_m}{2}\right)^2}{\left(\frac{I_m}{\pi}\right)^2} - 1} = \sqrt{\frac{\pi^2}{4} - 1}$$

Since the ratio $\frac{I_{ac}}{I_{dc}}$ = Ripple factor

∴ Ripple factor $R.F = \sqrt{\frac{\pi^2}{4} - 1}$

$R.F = 1.21$ or $\frac{I_{ac}}{I_{dc}} = 1.21$

It indicates that in a half wave Rectifier, the ac component across the load R_L is 1.21 times that of d.c component.

Peak Inverse Voltage :- Peak inverse voltage (PIV) is the maximum reverse voltage to which the diode can be subjected without breakdown of Junction under reverse biased condition of diode. If the reverse voltage across the diode is greater then its PIV rating, the reverse breakdown of the diode

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Peak Inverse voltage (PIV) for a half wave Rectifier is equal to Peak Secondary voltage (V_m) of the Transformer.

Regulation: It is defined as the variation of d.c output voltage from no-load to full-load voltage expressed as the percentage of Full-load voltage. It is a measure of how well the rectifier is able to maintain a Constant voltage between no-load and Full-load Conditions.

$$\% \text{ Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$V_{NL} = \frac{V_m}{\pi} \quad \& \quad V_{FL} = I_{dc} \cdot R_L$$

$$\therefore \% \text{ Regulation} = \frac{\frac{V_m}{\pi} - I_{dc} \cdot R_L}{I_{dc} \cdot R_L} \times 100$$

$$\% \text{ ~~Regulation~~} = \frac{\frac{V_m}{\pi} - \frac{I_m}{\pi} \times R_L}{\frac{I_m}{\pi} \times R_L} \times 100$$

$$= \frac{\frac{V_m}{\pi} - \frac{V_m R_L}{\pi (R_f + R_L)}}{\frac{V_m}{\pi (R_f + R_L)} R_L}$$

$$= \frac{\frac{V_m}{\pi}\left[1 - \frac{R_L}{R_f + R_L}\right]}{\frac{V_m}{\pi}\left(\frac{R_L}{R_f + R_L}\right)} = \frac{\frac{R_f + \cancel{R_L} - \cancel{R_L}}{(R_f + R_L)}}{\frac{R_L}{R_f + R_L}}$$

$$\% \text{ Regulation} = \frac{R_f}{R_L} \times 100$$

Advantages of HWR

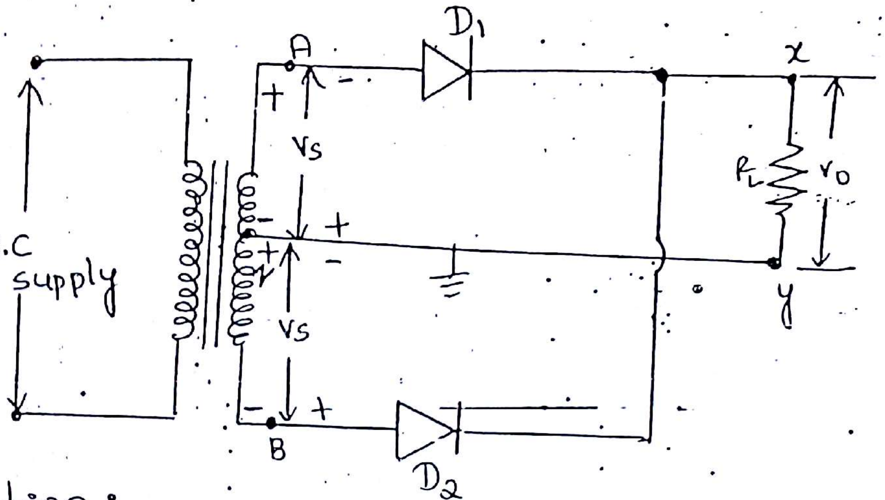
1. only one diode is required
2. No centre-tap is required on the transformer.
3. ~~PIV is same as secondary output voltage.~~
3. $PIV = V_m$

Dis-advantages of Half wave Rectifier

1. The ripple factor is very large R.F = 1.21
2. The Efficiency of Rectifier is very small i.e 40.6%
3. There will be Saturation of the Secondary winding of transformer.

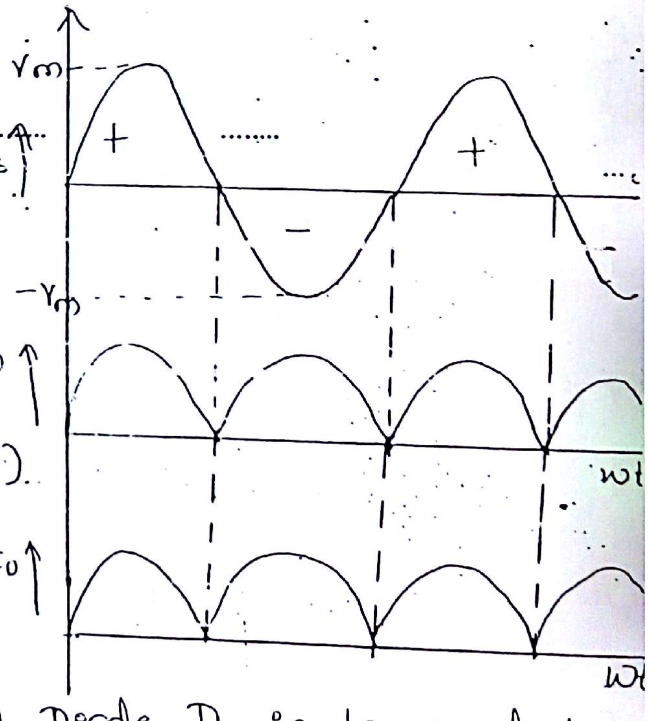
Full-wave Rectifier :-

Fig. shows circuit of full wave Rectifier. The A.C voltage to be Rectified is applied across primary of transformer and the secondary of transformer is connected to load in series with Diode. This circuit uses centre-tapped transformer.



Operation :-

* During the +ve half cycle of Input voltage V_s, terminal 'A' is positive & terminal 'B' is -ve. Diode D_1 is forward biased & Diode D_2 is reversed biased.
* Therefore only diode D_1 conducts & the load current flows in the path ($A, D_1, x, R_L, y, 2$).
* During the -ve half cycle of Input voltage V_s, terminal A is -ve and terminal 'B' is +ve. Hence diode D_1 is reverse biased and Diode D_2 is forward biased.
* Therefore only diode D_2 conducts & the load current flows in the path ($B, D_2, x, R_L, y, 2$)
* Since during both +ve & -ve half of Input voltage, the current through the load flows from x to y, Output has positive polarity of voltage i.e rectified output is Obtained. Diodes D_1 & D_2 conducts in alternate half cycle



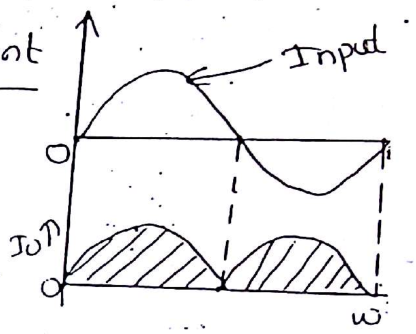
of Input voltage, This circuit is called Full-wave Rectifier. (10)

Let the voltage across the secondary of transformer available be $V_s = V_m \sin\omega t$ & current $i = I_m \sin\omega t$

Peak Current $I_m = \frac{V_m}{R_f + R_L}$ ⟶ (1)

D.C. Value of load Current: (I_{dc})

$$I_{dc} = \frac{\text{Area enclosed by output load current}}{\text{Base length for one cycle}}$$



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

$$I_{dc} = \frac{2\int_0^{\pi} i_o \, d(\omega t)}{2\pi} = \frac{1}{\pi}\int_0^{\pi} i_o \, d(\omega t)$$

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t) = \frac{I_m}{\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[-\cos\pi + \cos 0\right] = \frac{I_m}{\pi}\left[-(-1) + 1\right]$$

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

D.C. voltage across the load $V_{dc} = I_{dc} R_L$

$$V_{dc} = \left(\frac{2I_m}{\pi}\right) R_L = \frac{2\left(\frac{V_m}{R_f + R_L}\right) R_L}{\pi} \quad \text{since } I_m = \frac{V_m}{R_f + R_L}$$

$$V_{dc} = \frac{2}{\pi}\,\frac{V_m}{R_f + R_L} \times R_L$$

$$V_{dc} = \frac{2}{\pi}\,\frac{V_m}{\left(1 + \frac{R_f}{R_L}\right)} \quad \text{for ideal diode } R_f = 0$$

$$\therefore V_{dc} = \frac{2V_m}{\pi}$$

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R.M.S. value of load current

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i_0^2 \, d(\omega t)}$$

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

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

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

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

$$= \sqrt{\frac{I_m^2}{2\pi}\left(\pi - 0 + \frac{\sin 2\pi - 0}{2}\right)}$$

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

$$I_{rms} = \frac{I_m}{\sqrt{2}} \longrightarrow (4)$$

Efficiency of Rectifier :

$$\eta = \frac{\text{Output d.c power across the load}}{\text{Input A.C. power across the secondary}} = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L = \left(\frac{2 I_m}{\pi}\right)^2 R_L = \frac{4 I_m^2}{\pi^2} R_L$$

$$P_{ac} = I_{rms}^2 (R_f + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L) = \frac{I_m^2}{2}(R_f + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4 I_m^2}{\pi^2} \cdot R_L}{\frac{I_m^2}{2}(R_f + R_L)} = \frac{8}{\pi^2}\left(\frac{R_L}{R_f + R_L}\right)$$

$$\eta = \frac{0.812}{1 + \frac{R_f}{R_L}}$$ for ideal diode $R_f = 0$

$\eta_{Rectifier} = 0.812$ The maximum efficiency of full wave Rectifier is 81.2%.

Ripple factor:

Ripple factor = $\dfrac{\text{RMS value of AC Component}(I_{ac})}{\text{d.c component }(I_{dc})}$

Output Current consists of both a.c & d.c components

Vector sum → i.e $I^2_{rms} = I^2_{ac} + I^2_{dc}$

∴ output ripples $I^2_{ac} = I^2_{rms} - I^2_{dc}$

or $I^2_{ac} = I^2_{rms} - I^2_{dc}$ ÷ by I^2_{dc}

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

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

Since Ripple factor = $\dfrac{I_{ac}}{I_{dc}}$ ∴ Ripple factor = $\sqrt{\dfrac{I_m^2/2}{4I_m^2/\pi^2} - 1}$

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

∴ Ripple factor = 0.482

Ripple factor = 0.482 indicates that in centre-tapped transformer fullwave Rectifier the a.c component across the load R_L is only 0.482 times that of d.c components.

Peak Inverse Voltage:- Each diode in centre tapped full wave rectifier must be capable of withstanding a Peak reverse voltage of $2V_m$ volts. i.e PIV rating of diode $\geq 2V_m$ volts.

% Voltage Regulation = $\dfrac{R_f}{R_L} \times 100$ (similar to HWR)

Advantages of Full wave Rectifier:

i) The D.C output is twice that of half wave Rectifier

ii) The ripple factor is very low = 0.482

(ii) The Efficiency of Rectification is twice as that of Half wave Rectifier (81.2%)

4) No core saturation of the secondary winding of transformer.

Disadvantages:-

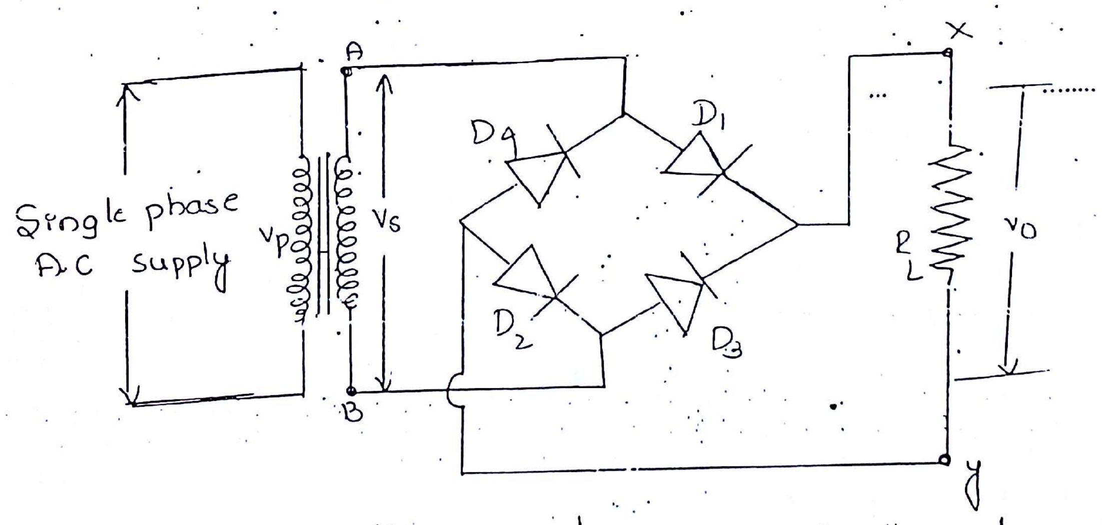
(i) It needs centre-tapped transformer, which is expensive

(ii) Peak Inverse voltage of diode is twice that of HWR

$PIV = 2V_m$

BRIDGE RECTIFIER:-

Fig. shows the circuit diagram of Full-wave Bridge Rectifier. The A.C voltage to be rectified is applied across the primary of the transformer and the secondary voltage is available for rectification. It uses four diodes which are arranged in the form of bridge and a ~~transformer~~ without centre tapping.



Let voltage across the secondary arm of the transformer available be $V_s = V_m \sin\omega t$.

Considering that cut in voltage of all diodes zero and R_f is the forward resistance of diode

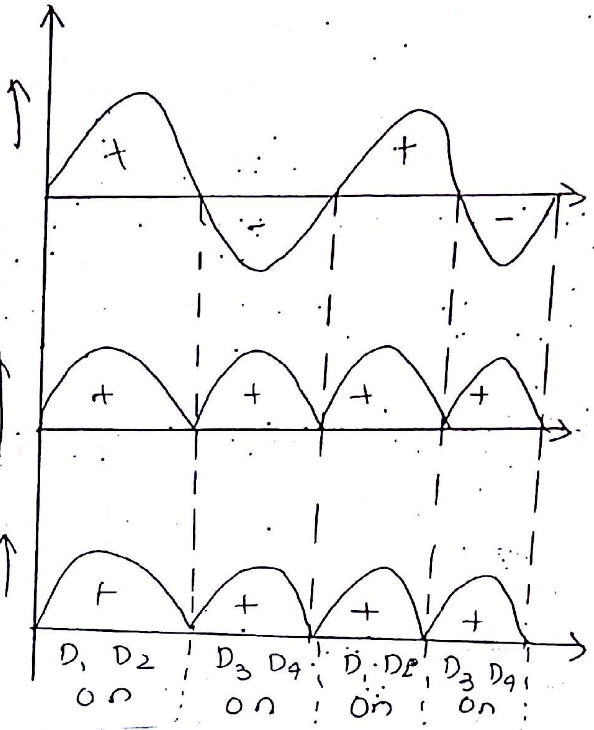
Peak current $I_m = \frac{V_m}{2R_f + R_L}$

At a time two diodes conduct, thus $2R_f$ is taken in the above equation.

12

Operation:-

* During positive half cycle of Input voltage, the voltage at terminal 'A' is positive & 'B' is -ve Diodes D_1 & D_2 are forward biased and D_3 & D_4 are reverse biased. then the current flows in the path $A D_1 X R_L Y D_2 B$ during the positive half cycle of Input voltage. Thus voltage is available across load as shown in the waveform.



* During the negative half cycle of Input voltage, voltage at terminal 'B' is +ve & at 'A' is negative. Hence diodes D_3 D_4 are forward biased & diodes D_1 & D_2 are reverse biased only diodes D_3 D_4 conduct & D_1 & D_2 does not conduct. The current flows in the path ($B D_3, X, R_L, Y D_4, A$)
* During both half cycles, the current through the load flows in the direction X to Y thus making the output uni-directional In otherwords, the output is a D.C. voltage.

Note:- Since the output waveform for a bridge rectifier is same as that of Full wave Rectifier with two diodes, Vdc, Idc, Vrms, Irms, ripple factor, Efficiency results are ~~between~~ same ~~these~~ can be determined in the same way as FWR (with centre tapped transformer type)!

But $I_m = \frac{V_m}{2R_f + R_L + R_s}$

Output D.C. voltage $V_{dc} = \frac{2V_m}{\pi}$

Output D.C current $I_{dc} = \frac{2I_m}{\pi}$

R.M.S Output voltage $V_{rms} = \frac{V_m}{\sqrt{2}}$

R.M.S Output Current $I_{rms} = \frac{I_m}{\sqrt{2}}$

Ripple factor $\gamma = 0.482$

$V_{dc} = \frac{2V_m/\pi}{1+\frac{2R_f}{R_L}}$

$I_m = \frac{V_m}{2R_f + R_L}$

$V_{rms} = \frac{V_m/\sqrt{2}}{1+\frac{2R_f}{R_L}}$

Efficiency of rectification $= \frac{0.812}{1+\frac{2R_f}{R_L}}$

maximum efficiency of Rectification = 81.2%

Advantages of Bridge Rectifier:-

(i) The centre-tapped transformer is not required in full wave Bridge Rectifier.

(ii) The peak Inverse voltage in Bridge Rectifier only V_m and not $2V_m$ as in the case of FWR. This is specially advantages in handling higher voltages

iii) The transformer Secondary Current is purely AC & D.C Core saturation is avoided. Therefore transformer utilization is better.

Disadvantage:-

* It require 4 diodes & hence diode voltage drop will be more

Filter Circuit:-

The output of Rectifier is not pure d.c but it is a pulsating d.c that is output Consists of D.C Components and a.c. ripples. The ripple Content of half wave rectified output is 121% of dc. Component where it is 48.3% of d.c component in full wave rectified output. In order to obtain smooth or pure d.c it is necessary to filterout the ripple Content.

The process of removing or minimizing the ripples in the output is called Filtering. A circuit that removes the ripples in the output of a rectifier is called a Filter eg: C, L, LC, RLC filters.

Shunt Capacitor Filter:- There are several types of Filter circuits However, the Simplest among them is a Capacitor filter, in which a very high value of Capacitor is Connected across the load. All the AC Components (ripples) are bypassed through the Capacitor & only D.C Component flows through the load. Consider a

Full wave ... the load ...

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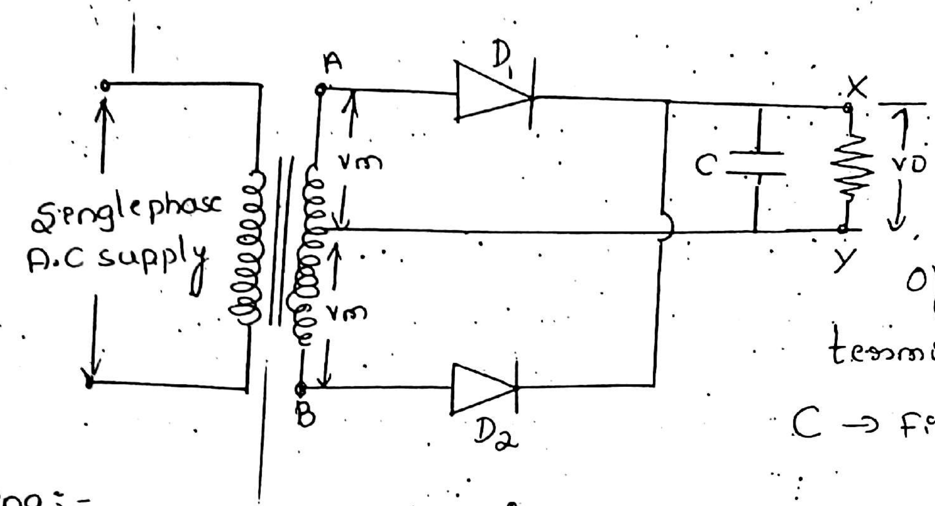
∴ Full wave Rectifier connected with a Capacitor across the load as shown.



x & y load terminals

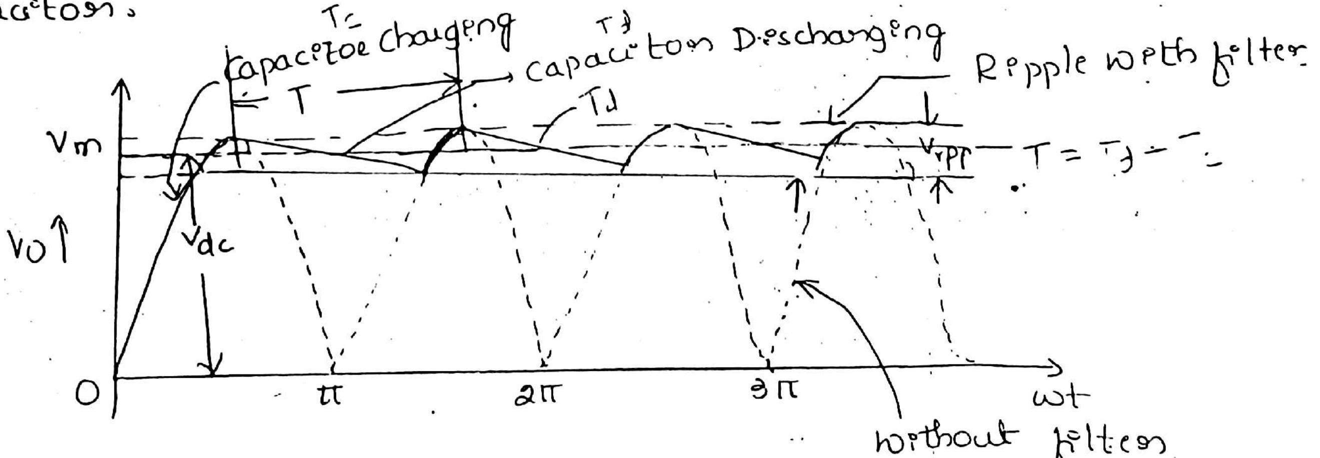
A & B secondary of transformer terminals

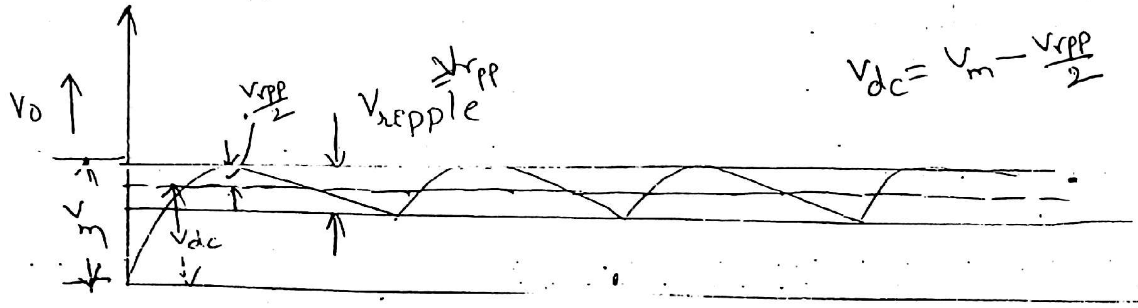
C → Filter Capacitor.

Working :-

* During the positive half cycle of Input voltage, the Diode D_1 conducts & charges the capacitor to the peak value (V_m) of the transformer secondary voltage. Diode D_1 stops conducting when the transformer secondary voltage falls below V_m.

* Now the capacitor starts discharging into R_L & the voltage across the capacitor begins to fall. The capacitor discharge is made slow by choosing a large value of Capacitor.





$$V_{dc} = V_m - \frac{V_{rpp}}{2}$$

The discharging of capacitor continues until ... for ... less

The discharging of capacitor continues until Diode D_2 starts conducting. Again in the next half cycle (−ve cycle). The capacitor 'C' starts charging only when diode D_2 is forward biased and starts conducting. Thus the output remains almost constant at V_m as shown in wave forms.

Note that with filter capacitor, the variation of V_o is smaller than that without filter capacitor. This clearly indicates that shunting of capacitor C across R_L considerably reduces the ripple content of output voltage. The ripple factor with 'C' filter is given by

$$\gamma = \frac{1}{4\sqrt{3}\, f R_L C}$$

$f \rightarrow$ frequency of A.C supply
$R_L \rightarrow$ load Resistance
$C \rightarrow$ filter capacitor.

From the above equation ripple canbe made small by using large value of Capacitor 'C'.

Derive an expression for ripple factor and D.C output voltage with C filter in HWR

⇒ The capacitor discharge through load R_L in the time period T_1

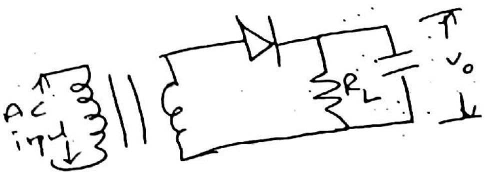


Fig: circuit diagram of HWR with C filter

$$Q_{discharge} = I_{dc} \cdot T_d \longrightarrow (1)$$

W.K.T $Q = CV$

$$Q_{charge} = C\, V_{pp} \longrightarrow (2)$$

Equating eq.^{n} (1) & (2)

$$Q_{discharge} = Q_{charge}$$

$$I_{dc}\, T_d = C \cdot V_{pp}$$

$$V_{pp} = \frac{I_{dc} \times T_d}{C}$$

For half wave rectifier charging time is very much less than T

$T_c << T$

Hence Td → Discharging time is almost equal to

$T_d \approx T$

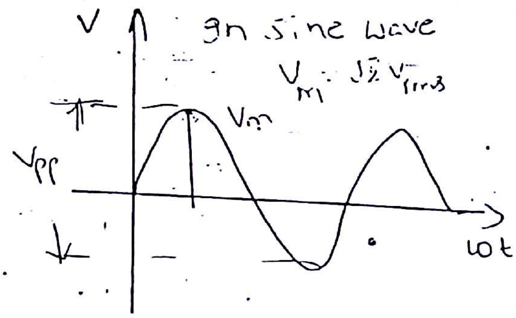
$T = T_c + T_d$

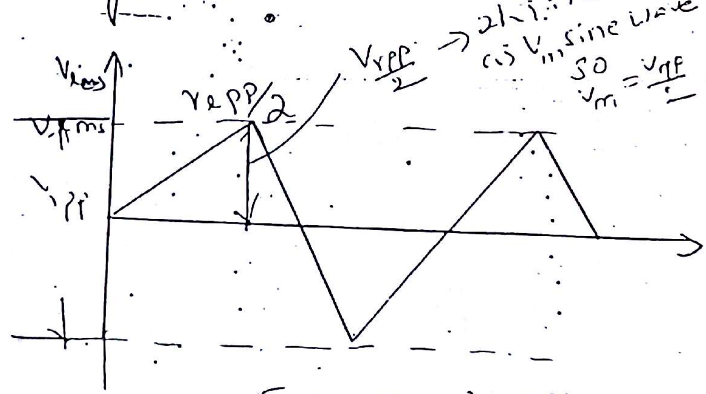
$T_c << T_d$

Hence $T = T_d$

$$V_{rpp} = \frac{I_{dc} \times T}{C} = \frac{I_{dc}}{fC} \rightarrow (4)$$

let us assume that ripple wave form i.e output waveform is in triangular





$I_{dc} = \frac{V_{dc}}{R_L}$

$\sqrt{3}\, V_{rms} = \frac{V_{rpp}}{2}$

In triangular wave $V_m = \sqrt{3}$ times V_{rms}

but Here $V_m = \frac{V_{rpp}}{2}$

Hence $\sqrt{3} \times V_{rms} = \frac{V_{rpp}}{2}$

$V_{rms} = \frac{V_{rpp}}{2\sqrt{3}}$

Substitute for I_{dc} in eqn (4)

$$V_{rpp} = \frac{V_{dc}}{R_L \times fC}$$

WKT $V_{rms} = \frac{V_{rpp}}{2\sqrt{3}}$

$$2\sqrt{3}\, V_{rms} = V_{rpp} \longrightarrow (5)$$

Substitute eqn (5) in (4)

$$2\sqrt{3}\, V_{rms} = \frac{V_{dc}}{R_L \times fC}$$

$$\frac{V_{rms}}{V_{dc}} = \gamma = \frac{1}{2\sqrt{3} R_L f C} \quad \text{In HWR.}$$

$$V_{dc} = V_m - \frac{V_{rpp}}{2 \ldots}$$

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$$V_{dc} = V_m - \frac{V_{dc}}{2R_L fC}$$

$$V_{dc} + \frac{V_{dc}}{2R_L fC} = V_m$$

$$V_{dc}\left(1 + \frac{1}{2R_L fC}\right) = V_m$$

$$V_{dc} = \frac{V_m}{\left(1 + \frac{1}{2R_L fC}\right)}$$

For Full wave Rectifier

$$Q_{discharge} = I_{dc} T_d$$

WKT $Q = CV$

$$Q_{charge} = C V_{epp}.$$

Equating eqn ① & ②

$$Q_{discharge} = Q_{charge}$$

$$I_{dc} T_d = C V_{epp}$$

$$V_{epp} = \frac{I_{dc} T_d}{C}$$

for full wave rectifier only discharging time is ~~very much~~ T. ~~less than T~~ $T_d = \frac{T}{2}$ ~~Reject~~

Hence $T_d \rightarrow$ discharging time is $T_d = T/2$

$$V_{epp} = \frac{I_{dc} \times T}{2C} = \frac{I_{dc}}{2fC}$$

Substitute for I_{dc} in eqn ③

$$V_{epp} = \frac{V_{dc}}{2R_L fC}$$

WKT $V_{rms} = \frac{V_{epp}}{}$

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$2\sqrt{3}\, V_{rrms} = V_{rpp}$

$$\frac{V_{rrms}}{V_{dc}} = \gamma = \frac{1}{4\sqrt{3}\, R_L f C}$$

$$V_{dc} = V_m - \frac{V_{rpp}}{2}$$

$$V_{dc} = V_m - \frac{V_{dc}}{4 R_L f C}$$

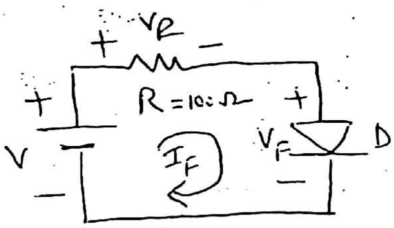
$$\Rightarrow V_{dc}\left(1 + \frac{1}{4 R_L f C}\right) = V_m$$

$$\Rightarrow V_{dc} = \frac{V_m}{\left(1 + \frac{1}{4 R_L f C}\right)}$$

Dc load line Analysis of a Diode:

A Dc load line is a straight line on the diode forward characteristic which describes all the conditions that exist in the operation of the circuit.

Consider a diode series circuit as shown in Fig.

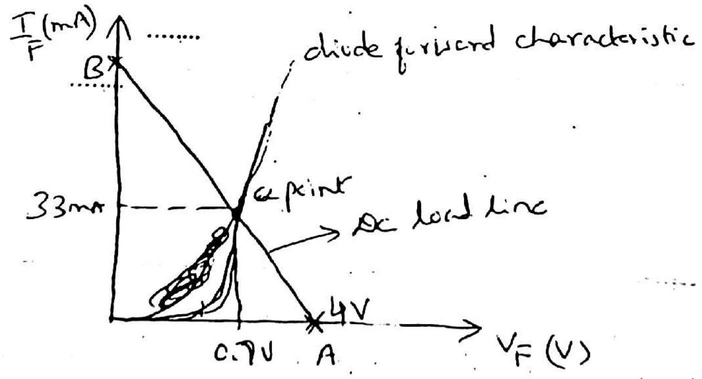


Where I_F = current through the diode

V_F = Voltage across the diode

V is the applied voltage

The Dc load line is a straight line drawn on the diode forward characteristic



The load line is plotted with any two values of circuit current–voltage pair.

By Applying Kirchhoff's voltage Law to the circuit

$$-V + V_R + V_F = 0$$

or $V = I_F R + V_F$ → is the equation of load line

In the above equation if $I_F = 0$, $V = V_F$

∴ $\overset{(4V)}{V_F = V}$, $I_F = 0$ is one point on the load line marked as A. $V_F = 4V$, $I_F = 0$

In the above equation

For $V_F = 0$, $I_F = \frac{V}{R}$

$\therefore V_F = 0$, $I_F = \frac{V}{R}$ is a second point on the load line marked as B.

$V_F = 0$, $I_F = \frac{4}{100} = 40mA$

Join AB to get the DC load line.

Observe that the DC load line intersects the diode characteristics at the point Q, which is called as operating point.

At the Q point value of current & voltage are

$$I_F = \frac{V - V_F}{R} = \frac{4 - 0.7}{100} = 33mA$$

$V_F = 0.7\,V$ for Silicon diode

Thus DC operating point or Q point specifies about the DC conditions that exist in the circuit.

(i) Problem on FWR :

1. A FWR supplies power to a 2kΩ load. The ac voltage applied to the diodes is 200-0-200V. If diode resistance is 15Ω. Determine.

- Average load current.
- Average load voltage
- Rms value of ripple voltage
- Rectification efficiency.

Sol The rms value of AC voltage across each half of the centre tapped transformer secondary winding is 200V.

Given $V_{rms} = 200$

$V_m = \sqrt{2}\, V_{rms}$

$V_m = \sqrt{2} \times 200 = 282.84V$

1) $I_m = \dfrac{V_m}{R_f + R_L} = \dfrac{282.84}{15 + 2\times10^3} = 140mA$

2) $I_{dc} = \dfrac{2I_m}{\pi} = \dfrac{2\times140\times10^{-3}}{\pi} = 89.36mA$

3) $V_{dc} = I_{dc} \times R_L = 89.36\times10^{-3} \times 2\times10^3 = 178.72V$

4) ripple factor is given by

$\gamma = \dfrac{\text{rms value of ripple voltage}}{\text{value of dc component of voltage}} = \dfrac{V_{ac}}{V_{dc}}$

Let us assume ~~We know~~ ripple factor for FWR = 0.48

$0.48 = \dfrac{\text{rms value of ripple voltage}}{V_{dc}}$

rms value of ripple voltage $= 0.48 \times V_{dc} = 0.48 \times 178.72$

(33)

5) Rectification efficiency

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 \qquad \eta = \frac{0.812}{1 + \frac{R_f}{R_L}}$$

$$= 80.5\%$$

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

For FWR $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{140 \times 10^{-3}}{\sqrt{2}} = 98.99mA$

$$\therefore \eta = \frac{(89.36 \times 10^{-3})^2 \times 2000}{(98.99 \times 10^{-3})^2 \times (15 + 2000)} \times 100 = 80.9\%$$

(Prob 2) In a two diode FWR circuit, the voltage across each half of the transformer is 100V. The load resistance is 950Ω and each diode has a forward resistance of 50Ω. Find the load current and r.m.s value of the input current.

$V_{rms} = 100V$; $R_L = 950\Omega$, $R_f = 50\Omega$, $I_{dc} = ?$ $I_L = ?$

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

$$I_m = \frac{V_m}{R_f + R_L} =$$

$$V_m = \sqrt{2} V_{rms} = \sqrt{2} \times 100 = 141.42V$$

$$I_m = \frac{141.42}{50 + 950} = 141.42 mA$$

$$I_{dc} = \frac{2 \times 141.42 \times 10^{-3}}{\pi} = 90.03 mA$$

I ... $= 99.98mA$

prob:- A full-wave rectifier using two diodes is supplied from an ac supply given by 220 sin314t Volts through a centre-tapped transformer of turns ratio 10:1. The load resistance is 1000 Ω and the diode forward resistance is 20 Ω. calculate

~~(a) Average load voltage (c) PIV across each diode~~

~~(b) Rms load current~~ (d) DC output power

(e) Frequency of output waveform.

(a) peak load current / Diode current $= \dfrac{V_m}{R_f + R_L}$

(b) Average / DC load current $= I_{dc} = \dfrac{2V_m/\pi}{R_f + R_L} = \dfrac{2I_m}{\pi}$

(c) rms load current $I_{rms} = \dfrac{V_m/\sqrt{2}}{R_f + R_L} = \dfrac{I_m}{\sqrt{2}}$

(d) Average DC load voltage $= \dfrac{2V_m/\pi}{1 + R_f/R_L} = \dfrac{2V_m}{\pi}$ (Ideal)

(e) rms load voltage $V_{rms} = \dfrac{V_m/\sqrt{2}}{1 + R_f/R_L} = \dfrac{V_m}{\sqrt{2}}$ (Ideal)

(f) efficiency $= \dfrac{0.812}{1 + R_f/R_L}$

(e) ripple factor 0.483

(g) PIV $= 2V_m =$

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

$$V_2 = \frac{N_2}{N_1} V_1 = \frac{1}{10} \cdot 220 \sin 314t$$

$R_f = 2\Omega$, $R_L = 1k\Omega$

$V_m = 22\,V$, $\omega = 314t$,

$$\omega = 2\pi f = \frac{\omega}{2\pi} = 50\,Hz$$

(e) for 1 cycle of ac input rectified output contains two cycles. Hence the frequency of output waveform is twice the frequency of a ac input.

$$f = 50\,Hz$$
$$= 2 \times 50 = 100\,Hz \ (c)$$

$$V_{dc} = 13.73 = \frac{2V_m/\pi}{1 + R_f/R_L}$$

$I_{dc} \times R_L$

$\frac{2I_m}{\pi} \times R_L$

$= \frac{V_m}{\pi(R_f + R_L)} \times R_L$

$= \frac{V_m/\pi}{1 + \frac{R_f}{R_L}}$

$$I_{rms} = I_m/\sqrt{2}$$

peak current (diode) $I_m = \frac{V_m}{R_f + R_L} = 21.57\,mA$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 15.25\,mA$$

(c) $PIV = 2V_m = 44V$.

$$\text{efficien} = \frac{0.812}{1 + \frac{R_f}{R_L}}$$

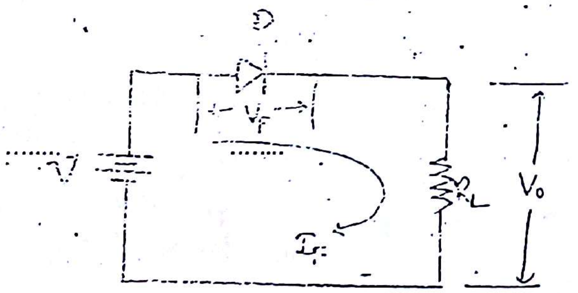
(21)

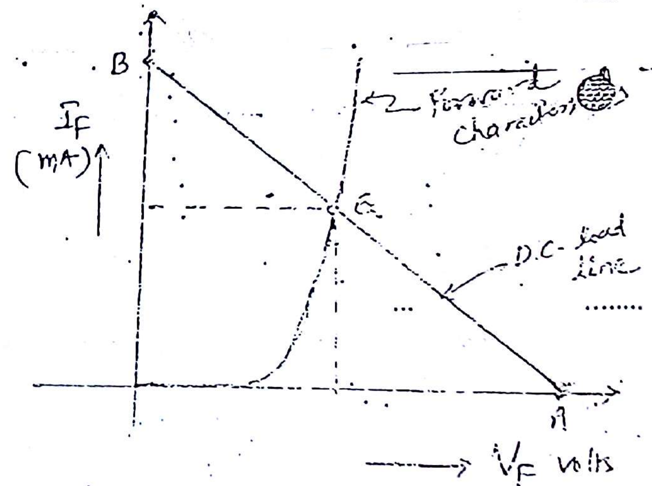
D.C. Load line Analysis : (Graphical Analysis)

A D.C. load line is a straight line on the diode forward characteristic which describes all the d.c. conditions that exist in the operation of the circuit. Because the load line is always straight, it canbe constructed by plotting any two corresponding current and voltage points and then drawing a straight line through them.

To determine two points on the load line, an equation relating voltage, current & resistance is first derived for the circuit.

Consider the diode series circuit, as shown in fig.





$I_F \rightarrow$ forward current
$V_F \rightarrow$ forward voltage
$R_L \rightarrow$ Load Resistance

Input voltage $V = V_F + I_F R_L \rightarrow (1)$

when $I_F = 0$; $V = V_F$ from $Eq^n (1)$

$\therefore V_F = V$ & $I_F = 0$ is one point on the load line marked as A on x-axis.

when $V_F = 0$ Then $Eq^n (1)$ $V = I_F R_L + 0$

$$\therefore I_F = \frac{V}{R_L}$$

$\therefore V_F = 0$ & $I_F = \frac{V}{R_L}$ is second point on load line marked as 'B' on Y-axis.

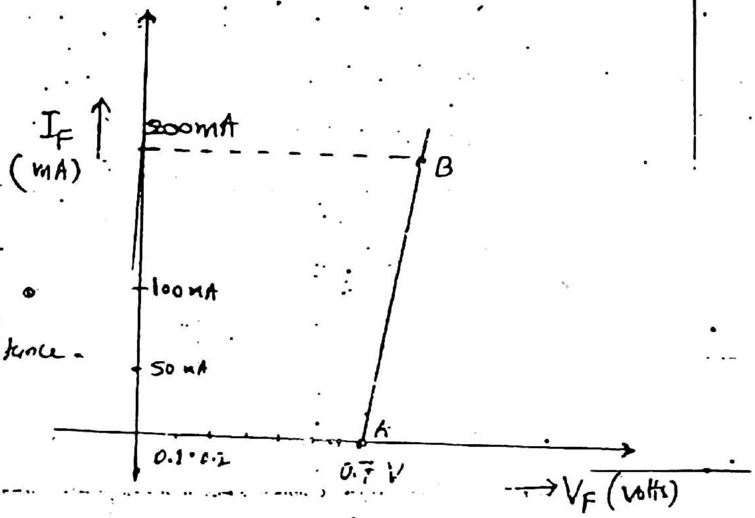
The line joining A and B is called the D.C. load line.

Q-point : The point where the forward characteristics intersect with load line is called operating point or Q-point or quiescent point or d.c. bias point. The operating point specifies the diode current I_F for a diode voltage V_F for the given load resistance

II Piecewise Linear Characteristics (Approximations)

When the forward characteristics of a diode is not available, a straight line approximation, called piecewise linear characteristic, may be employed.

To construct the piecewise linear characteristic, V_F is first marked (point A) on the horizontal axis. Then starting at V_F, a straight line is drawn with a slope equal to the diode dynamic resistance. (r_d)



Ex: Construct the piecewise-linear characteristic for a silicon diode that has $0.25\,\Omega$ dynamic resistance & 200 mA maximum forward current.

Soln: * Plot point A on the horizontal axis at $V_F = 0.7$ (since silicon diode)

given $r_d = 0.25\,\Omega$; $I_{F(max)} = 200\,mA$

$$r_d = \frac{\Delta V_F}{\Delta I_F}$$

$\therefore \Delta I = (200 - 0) = 200\,mA$

$$\therefore \Delta V_F = \Delta I_F \times r_d$$

$$= 200 \times 10^{-3} \times 0.25$$

$$\Delta V_F = 0.05\,V$$

* mark point 'B' at $I_F = 200\,mA$ and at $V_F = (0.7 + 0.05)\,V$
* Draw a straight line through point A & B.

D.C. Equivalent Circuit: An equivalent circuit for a device is a circuit that represents the device behavior. Forward biased diode is assumed to have a constant voltage drop (V_F) & negligible series resistance. A more accurate equivalent circuit includes the diode dynamic resistance (r_d) in series with the voltage cell (V_F).

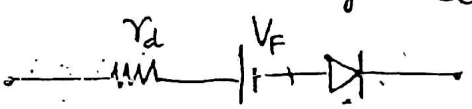
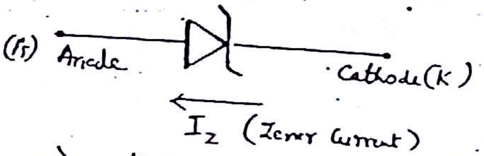


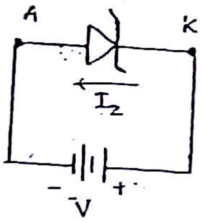
fig: Complete dc equivalent circuit

Zener diode Voltage Regulator

Zener Diode: The most important application of Zener Diode is as a d.c. voltage Regulator.

Symbol:





* when an ordinary PN junction diode is reverse biased, normally only a small reverse saturation current flows. If reverse voltage is increased sufficiently, the junction breakdown & large reverse current flows. Due to this excessive power dissipation may take place at the junction & the Diode may get damaged.

* But the Zener Diode is different. It is a heavily doped Silicon Diode that has been optimized to operate in the breakdown region. This diode is manufactured to have a specific breakdown voltage called the Zener Voltage V_Z. Some times it is also called breakdown diode because it is designed to operate in the Reverse breakdown region.

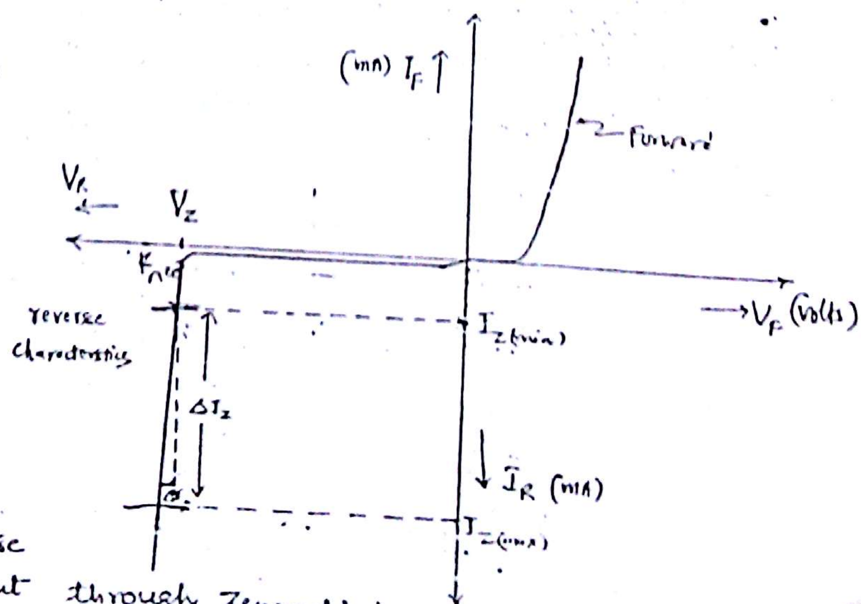
Characteristics of Zener Diode:

The typical V-I characteristics of a Zener Diode is shown.

* The forward characteristics of Zener Diode is simply same as that of an ordinary forward biased PN junction Diode.

* Usually Zener Diode is operated in reverse biased region.

* As we increase the Reverse voltage from zero, the current through Zener diode is almost zero, till the breakdown voltage V_Z reaches. When reverse voltage exceeds V_Z, current increases steeply ...



The important points on the reverse biased characteristics are

V_Z = Zener breakdown voltage

$I_{Z(min)}$ = minimum zener current necessary to maintain breakdown.

$I_{Z(max)}$ = maximum Zener current that is limited by the maximum power dissipation $P_{Z(max)}$ of the diode.

ie $P_{Z(max)} = V_Z \cdot I_{Z(max)}$

A very important parameter derived from the V-I characteristics is the Zener resistance ie $r_Z = \frac{\Delta V_Z}{\Delta I_Z}\ \Omega$

(typical values of r_Z range from 5 to 30 Ω)

** There are two mechanisms that cause breakdown in a Reverse biased P-N Junction.

<1> Zener breakdown <2> Avalanche breakdown:

<1> Zener breakdown: This breakdown occurs in a diode when depletion region is narrow. The Electric field strength (volts/width) can be very high when the depletion region is very narrow. This causes electrons to break away from their atoms, thus converting the depletion region from an insulating medium into a conducting medium. This is ionization by electric field and is also called Zener breakdown. It usually occurs at reverse bias voltages less than 5V.

<2> Avalanche breakdown: This happens when the depletion region is not narrow enough for Zener breakdown. Here Electric field is not strong enough to produce breakdown. Instead, due to the external applied voltage, the Electrons in the reverse saturation current can be given sufficient energy to strike the atoms within the depletion region. Due to this covalent bonds are broken & further electrons are generated. These Electrons inturn get accelerated & liberate more Electrons by Collisions. This is termed as ionization by collision. This process is called Avalanche breakdown. The result is sharp rise in current. ~~Normal~~ Normally it occurs at reverse bias voltages above 5V.

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Zener Voltage Regulator :

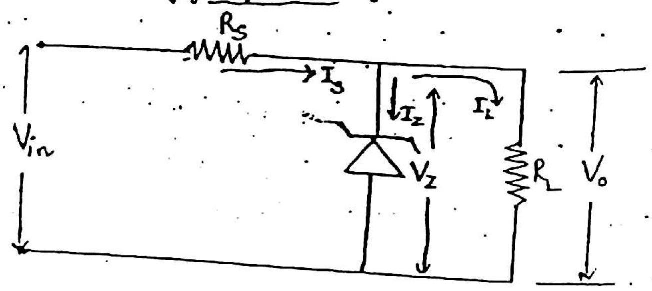


Fig. shows simple circuit of voltage Regulator using Zener diode. This circuit maintains constant voltage across a load almost at V_Z volts as input Voltage V_{in} or load resistor R_L undergo any changes.

* If the unregulated dc voltage V_{in} rises, the current through R_S increases. This Extra current is directed to the Zener diode instead of flowing through the load. The Zener diode Voltage is Virtually unaffected by the increase in this current. The load Voltage remains constant at Zener diode Voltage V_Z.

from the circuit, Source current $I_S = I_Z + I_L$ ⟶ (1)

or Current through Zener diode $I_Z = I_S - I_L$

* on the other hand, if R_L varies, then load current I_L also varies. Then Zener diode allows less current when I_L is increasing & it allows more current when I_L is decreasing. ~~but~~ Thus maintains the output voltage constant keeping product $R_L I_L = V_Z = V_o$

from the circuit, $V_{in} = I_S R_S + V_Z$ ⟶ (2)

The Power dissipated in the Zener diode is $P_Z = V_Z \cdot I_Z$

The Selection of R_S is very important here, from Eqn (2)

$$R_S = \frac{V_{in} - V_Z}{I_S} \longrightarrow (3)$$

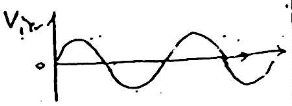
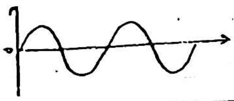
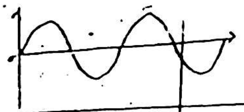
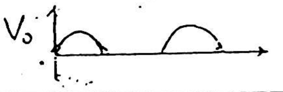
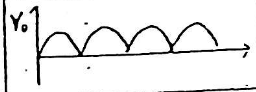
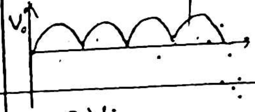
Sub eqn (1)

The above equation becomes ⇒ $$R_S = \frac{V_{in} - V_Z}{I_Z + I_L} \longrightarrow (4)$$

* For a fixed value of R_L, if the Input voltage V_{in} is varied, The Zener breakdown occurs for voltage $V_{in} > V_Z$. The output voltage after breakdown will be $V_o = V_Z$. The output voltage remains constant at V_Z irrespective of the Input voltage as long as V_{in} is greater.

31.

Comparision between HWR, FWR, Bridge Rectifier.

Parameter	Half Wave Rectifier	Full-wave	Bridge Rectifier
No of Diodes	1	2	4
Input wave form			
output wave form			
output d.c. voltage	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
output d.c current	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
Peak Inverse Voltage (PIV)	V_m	$2V_m$	V_m
Maximum Efficiency	40.6%	81.2%	81.2%
Ripple factor	1.21	0.48	0.48
Transformer	Centre tapped transformer is not required.	Centre tapped transformer is required	Centre tapped transformer not required.
Core saturation of secondary winding	Core saturation takes place	No core saturation	No core saturation.
Ripple frequency	f	2f	2f

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Clipping and clamping circuits :

Clipping circuits are also called as limiter circuits.
— are used to eliminate some portion of the input signal above or below a specified level.

Ex: halfwave rectifier can be considered as −ve clipper which removes −ve portion of AC input signal.

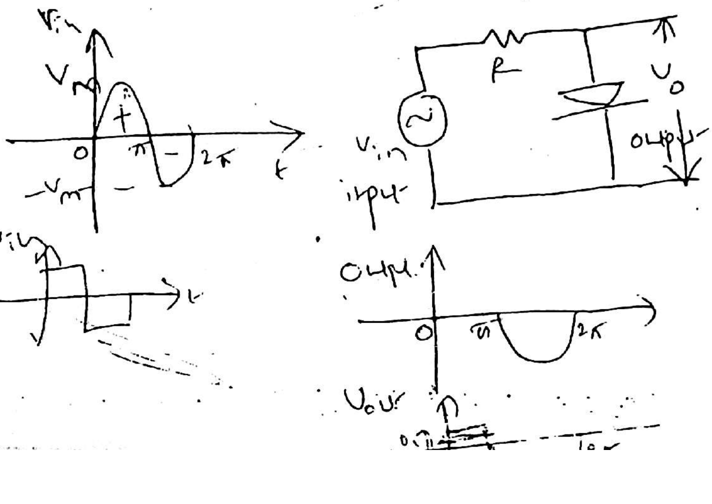
* they are used in electronic circuits so as to prevent the breakdown of transistors in amplifier ckt. clippers are used to measure the unknown frequency of the signal when amplitude is not important

Two types of clipping — Series: diode is connected in series with lop; parallel (Shunt): Diode is connected in parallel

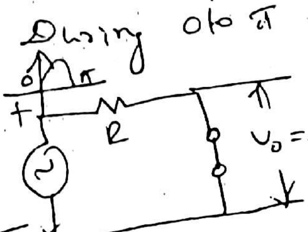
Shunt clippers : Here the diode is connected in shunt or parallel with the output port and

(a) positive shunt clipper
(b) Negative shunt clipper

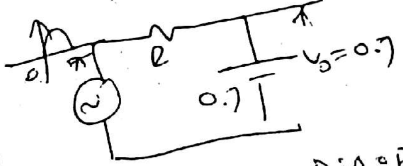
(a) positive clipper clipps off the positive part of the input signal Hence called +ve clipper



$V_{in} > 0$ $V_{out} = 0$
During 0 to π D goes on
$V_o = 0$

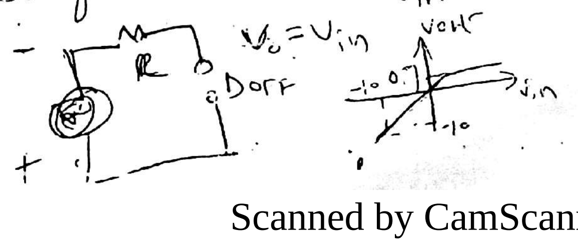


(IDEAL Diode)
D acts as S.C



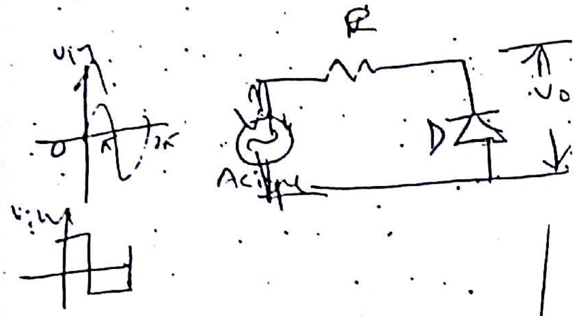
practically (with second Approx)

During π to 2π D is OFF $V_{in} < 0$
$V_o = V_{in}$



(b) Negative shunt clipper:

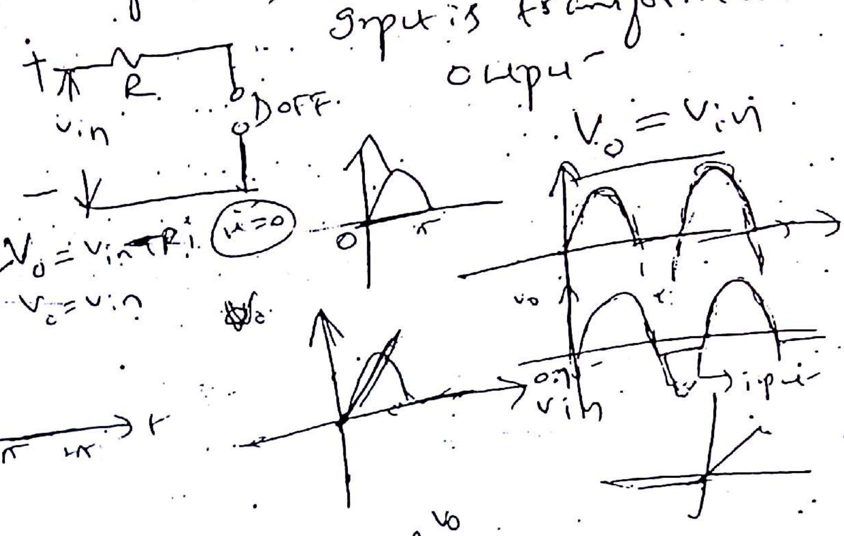
Clipps off -ve portion of the input.



During 0 to π, D is OFF

Input is transformed to output

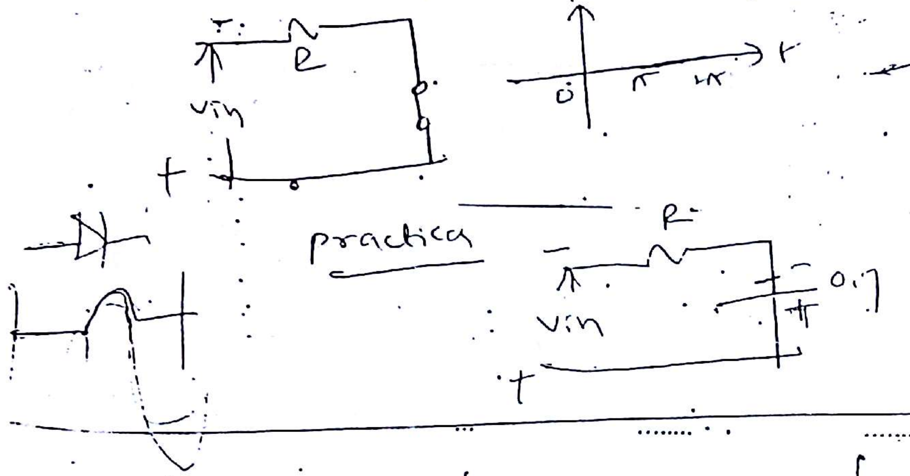
$V_o = V_{in}$



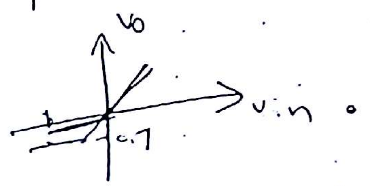
$V_o = V_{in} + R i$ ($i=0$)

$V_o = V_{in}$

During π to 2π



practical

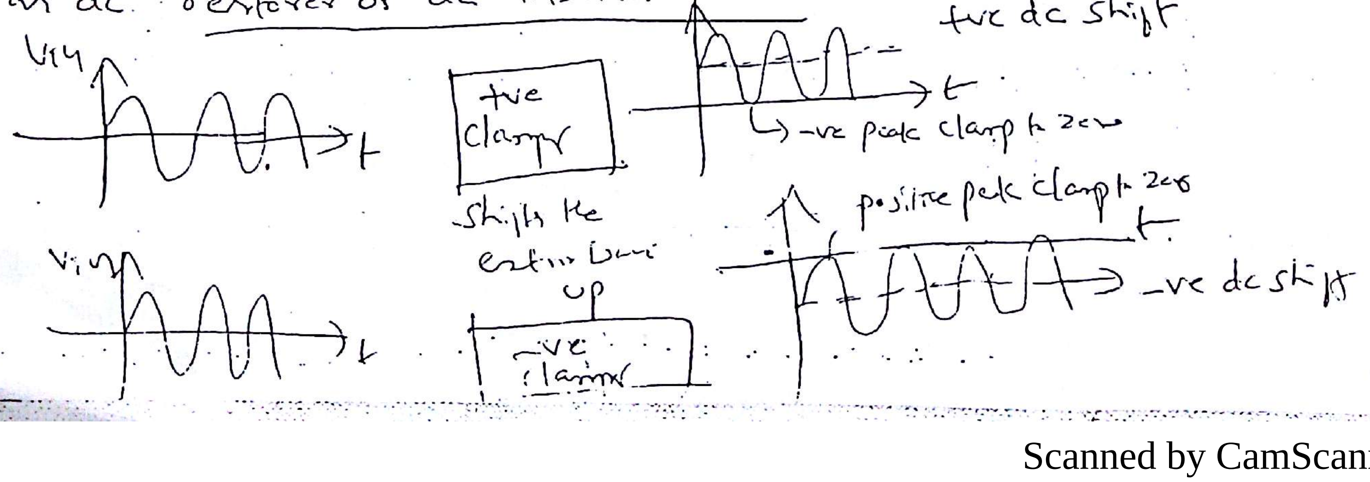


Classification of clamping circuits —

a) Negative clamper (or positive peak clamper

(b) positive clamper (or -ve peak clamper)

which comprises of resistors, Diodes and capacitors is used to restore a dc level to an electrical signal. clamping shifts the entire output signal voltage by a dc level. Since clamping circuits restore or reinserts the lost dc component, it is also termed as dc restorer or dc inserter circuit



+ve dc shift

-ve peak clamp to zero

Shifts the entire level up

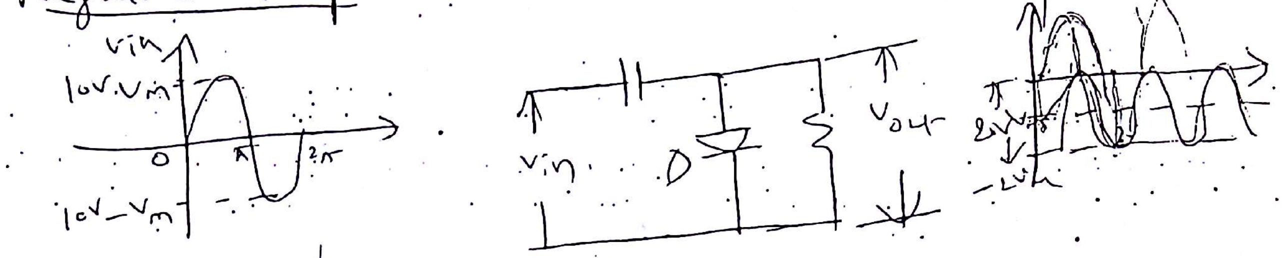
positive peak clamp to zero

-ve dc shift

25

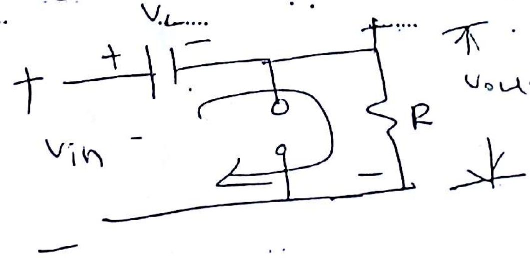
2

Negative clamper:



Assume capacitor is initially uncharged, when sinusoidal input voltage is applied, initially ~~between 0 to π/2 of the input D is on~~ and the D is FB. Capacitor acts as a short circuit and the capacitor setting up a current i in the closed loop and the capacitor starts to charge to input voltage $V_i = V_m$

Now at 90° of input V_{in}, the capacitor is fully charged to $V_c = V_m$, now the input starts decreasing Diode D is R.B.



KVL

$V_{in} - V_c - V_{out} = 0 \rightarrow (1)$

$V_{out} = V_{in} - V_c$

But $V_c = V_m$

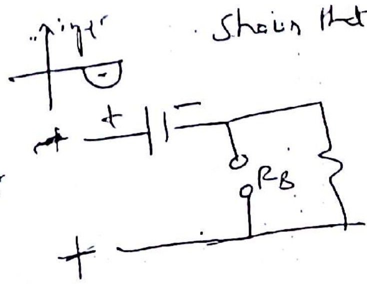
When $V_{in} = V_m$

$V_{out} = 0$

Shows that +ve peak is clamped zero

Once capacitor charged fully it cannot discharge, since it does not find low resistance path, $RC >> 10T$

Capacitor voltage V_c remain at V_m



When $V_{in} = -V_m$

$V_{out} = -V_m - V_m$

$= -2V_m$

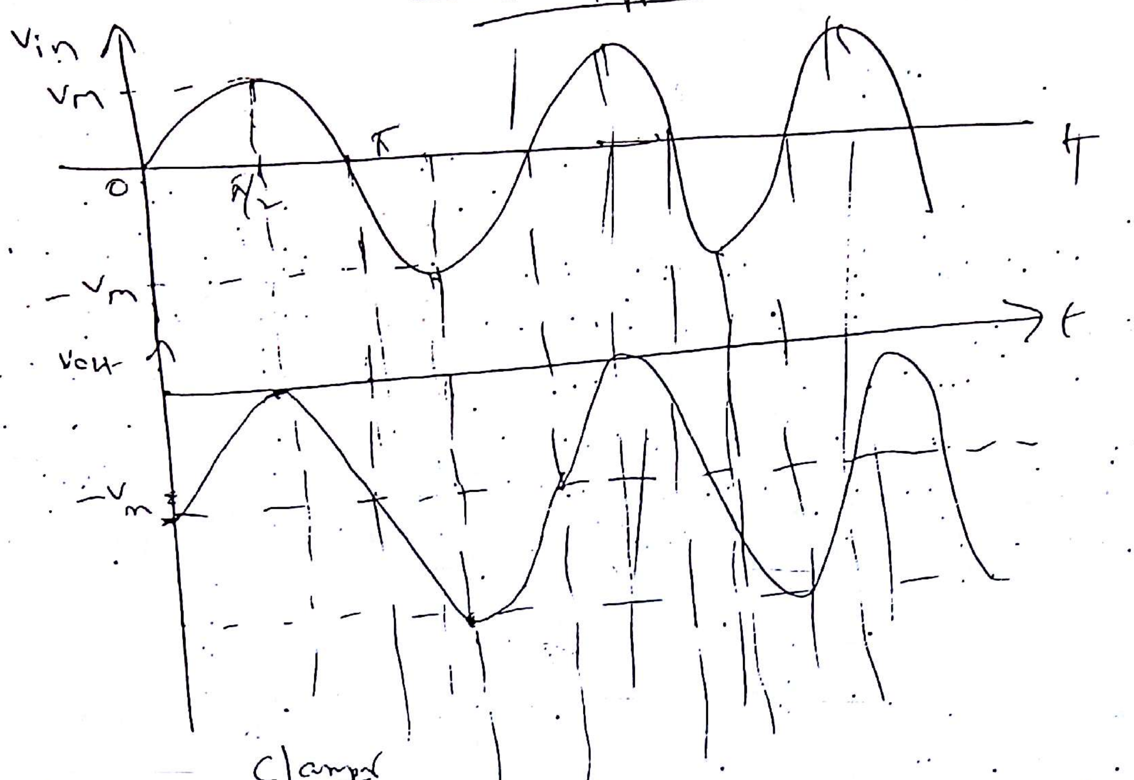
When $v_{in} = 0$

$V_{out} = -V_m$

* During -ve half cycle of input also D is R.B.

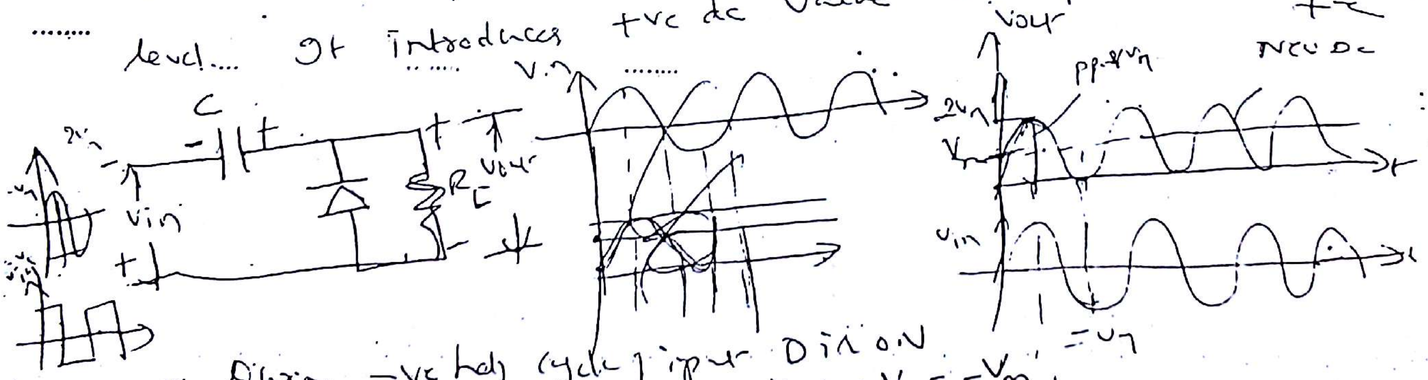
Note: D is RB after 90° i.e. $\frac{\pi}{2}$ of time period.

-ve Clipper



Positive ~~Clipper~~ Clamper :

It is also called as negative peak clamper, since the circuit clamps the -ve peak of the input signal to zero level... It introduces +ve dc value at output



. During -ve half cycle of input D is ON $V_c = -V_m$

capacitor is charged as

then D gets off for further cycle of input D Turns off permanently

Now $V_{out} = V_{in} - V_C \rightarrow$ KVL

But $V_c =$ is $-V_m$ charge to $-V_m$

. When $V_{in} = 0$

$V_{out} = -(-V_m) = +V_m$

When $V_{in} = +V_m$ $\quad V_{out} = +V_m - (-V_m) - 0$

When $V_{in} = -V_m$ $\quad V_{out} = -V_m - (-V_m) = 0$

① ㉖

Clamping circuit: Dc restorer or inserter

Another Application of Diode

Clamper circuit is electronic circuit where Dc level is shifted and the waveform is clamped either on the ...itive side or on the Negative side of the input.

These circuits are used in TV receivers to restore the dc reference signal to the ca...te video signal.

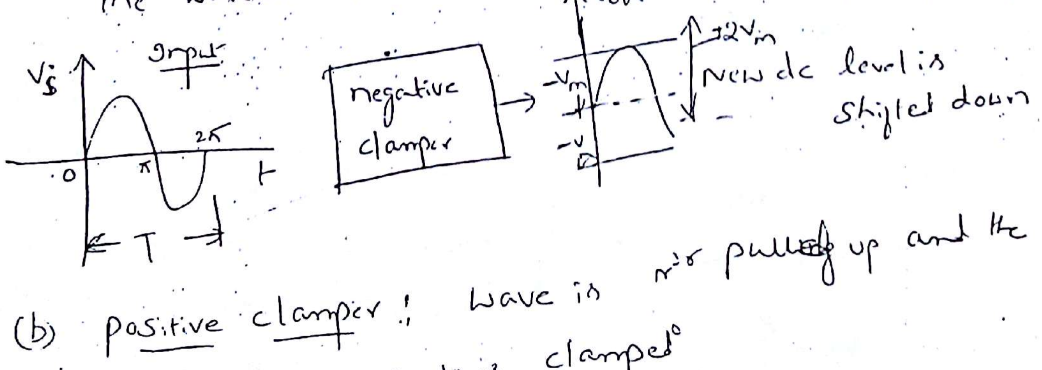
The circuit elements use diode, capacitor and a resistor. For proper op...n of the clamper the time constant $\tau = RC$ must large so that voltage across the capacitor does not ...arge significantly when the diode is not conduc $RC >> 10T$

There are two types of ...pers:

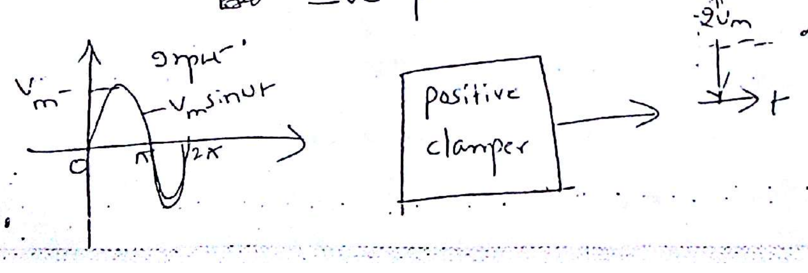
(a) negative clamper (b) pos...lamper

negative clamper means wavelevel up down or pu...

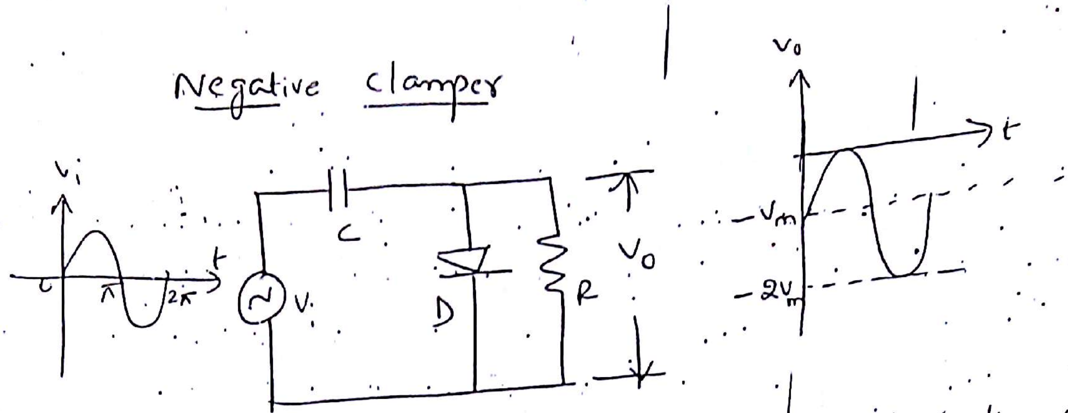
the wave down & +ve peak is ... zero



(b) positive clamper: wave is ...r pulled up and the -ve peak is clamped



Negative clamper



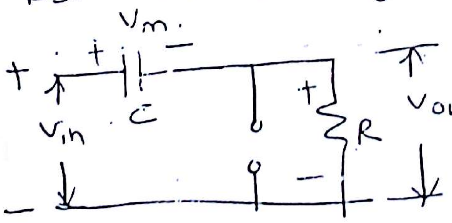
When a sinusoidal voltage is applied to the circuit, the Diode D during positive half cycle of input wave, is forward biased allowing the capacitor to charge to with the polarity. peak value V_m of the input voltage. ~~as~~ at 90° of input voltage.

as shown $+||-$.

$V_c = V_m$

~~Now Diode D gets reverse biased.~~

Now the input voltage starts to decrease and diode D is RB circuit diagram is as shown below



Since time constant RC is large the capacitor C will retain its charge.

$RC >> 10T$

By Applying KVL we get

$V_{in} - V_m - V_{out} = 0 \Leftarrow V_{in} - V_c - V_{out} = 0$

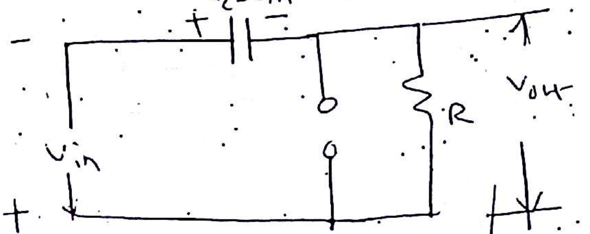
$V_{out} = V_{in} - V_m$

when $V_{in} = +V_m$

$V_{out} = 0$

Under steady state conditions Now output voltage clamped to zero volts when V_{in} is $+V_m$

Next during -ve half cycle of input voltage Diode D is still reverse biased. ckt diagram is



where $V_c = V_m$

$V_{out} = V_{in} - V_c$

But $V_{in} = -V_m$

$V_{out} = -V_m - V_m$

$V_{out} = -2V_m$

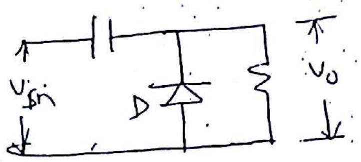
— thus -ve peak is clamped to $-2V_m$

+ve peak is clamped to 0 V.

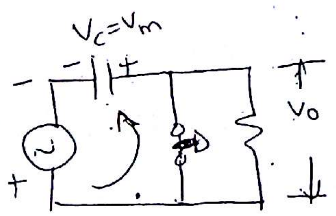
under steady state condition.

Positive clamper: positive clamper is also termed as negative peak clamper, since the circuit clamps the negative peak of the input signal to zero level. which introduces a +ve dc value at the output.

Fig shows the circuit diagram of +ve clamper circuit.



* Initially, During +ve half cycle of input Diode D is RB, And there will be no current in the circuit.
* Now During -ve half cycle of the input the current is flowing Diode is FB and the current is flowing as shown in fig. charging the capacitor C with the polarity as shown in fig. And the capacitor is charged to the peak value of the input voltage i.e $V_c = V_m$



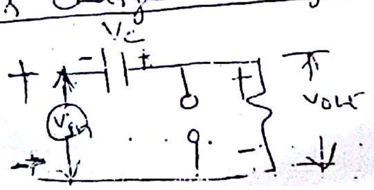
once the capacitor is charged Diode gets OFF

By Applying KVL

$V_{in} + V_c - V_{out} = 0$

$V_{in} - V_c - V_{out} = 0$

$V_{out} = V_{in} - V_c$



$V_{out} = V_{in} + V_c$

$V_{out} = V_{in} + V_c$ where $V_c = V_m$

when $V_{in} = 0$

$V_{out} = V_c$

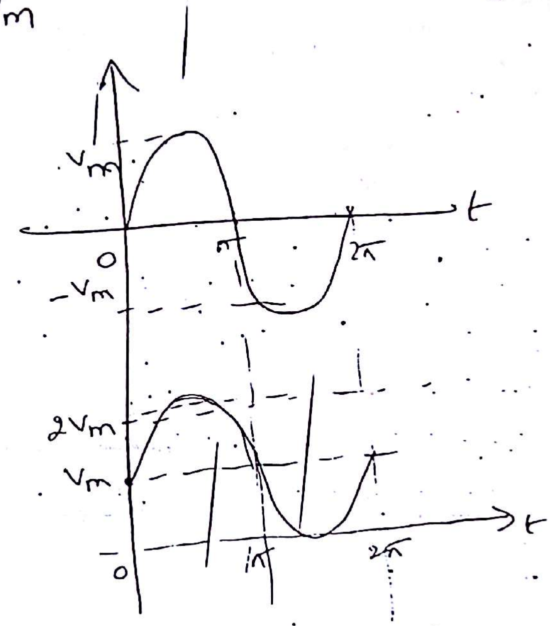
when $v_{in} = +V_m$

$V_{out} = \cancel{2V_m} = V_m + V_m$

$V_{out} = 2V_m$

when $v_{in} = -V_m$

$V_{out} = +V_m - V_m = 0$



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BIPOLAR JUNCTION TRANSISTOR

→ What is Transistor?

Transistor is a 3 terminal device : Base, emitter & Collector, can be operated in 3 configurations common base, common emitter & common collector.

→ TRANSISTOR.

The amplification in the transistor is achieved by passing i/p current signal from a region of low resistance to a region of a high resistance. This concept of transfer of resistance has given the name TRANSfer-resISTOR (TRANSISTOR)

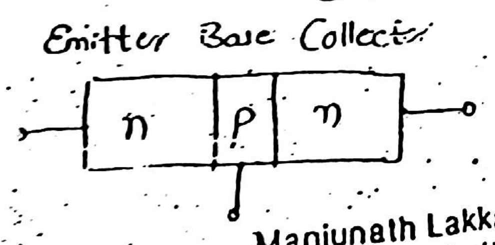
→ 2 types of Transistors:

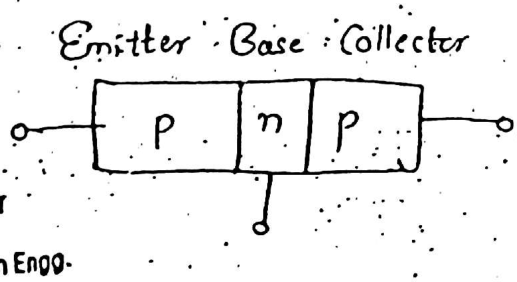
Unipolar Junction Transistor → current conduction is only due to 1 type of charge carriers, majority carriers.

Bipolar Junction Transistor
↓
current conduction, because of both the type of charge carriers holes & electrons.

→ 2 types of BJT

(1) n-p-n type (2) p-n-p type





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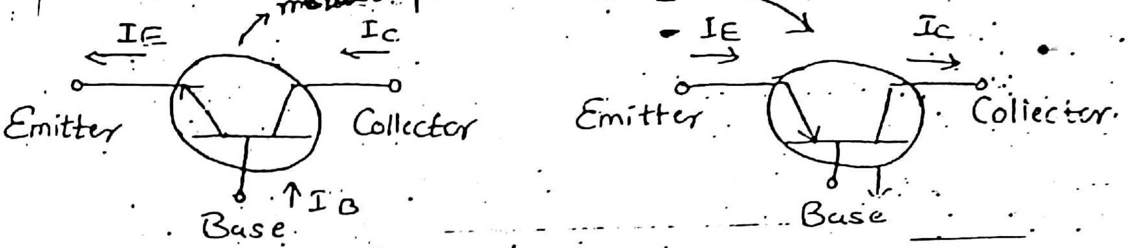
→ The middle region of each transistor type is called base & it is very thin & lightly doped.

→ Emitter & Collector are heavily doped. But doping level in emitter is slightly greater than that of collector.

→ Collector region-area is slightly more than that of emitter.

→ Symbols of npn & pnp transistors.



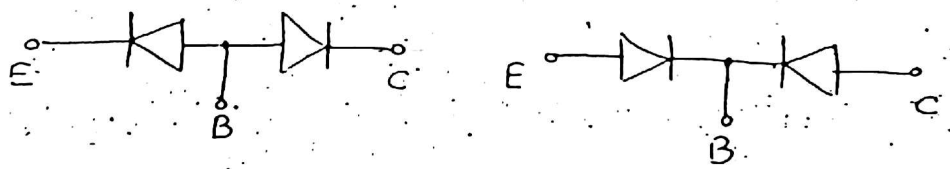
n-p-n

– Arrow indicates the direction of conventional current flow under forward bias.

p-n-p

→ Diode Equivalent transistor

→ The transistor can be considered as two p-n junction diodes connected back to back as shown below.



n-p-n transistor

p-n-p transistor

Two-diode Transistor analogy.

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→ One junction is between the emitter & the base & is called the emitter-base junction or simply the emitter junction J_E.

→ The other junction is between the base & collector and is called Collecter-base junction or simply Collector junction J_C.

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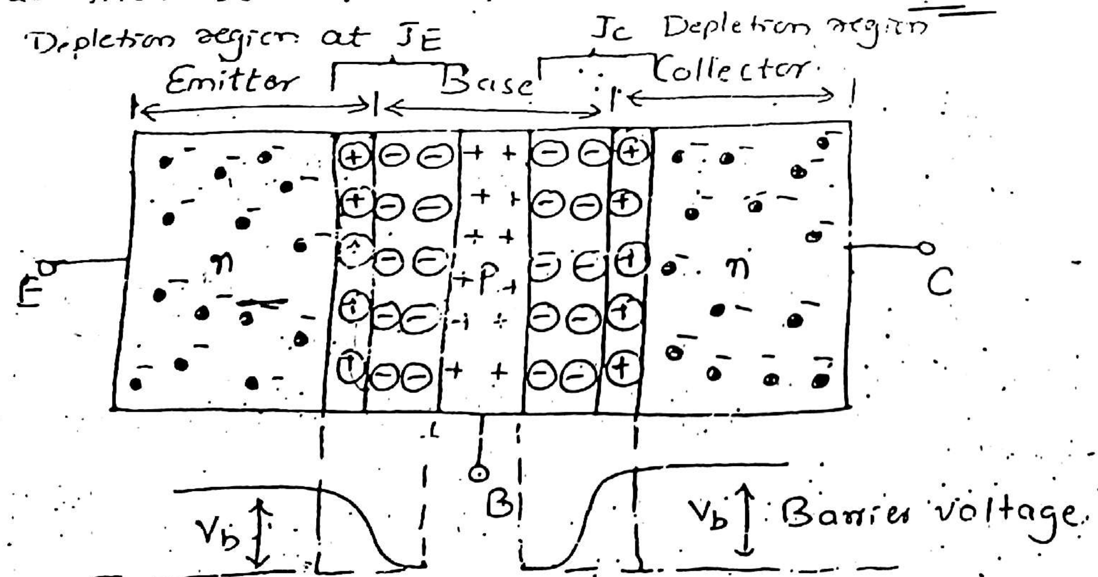
Unbiased Transistor

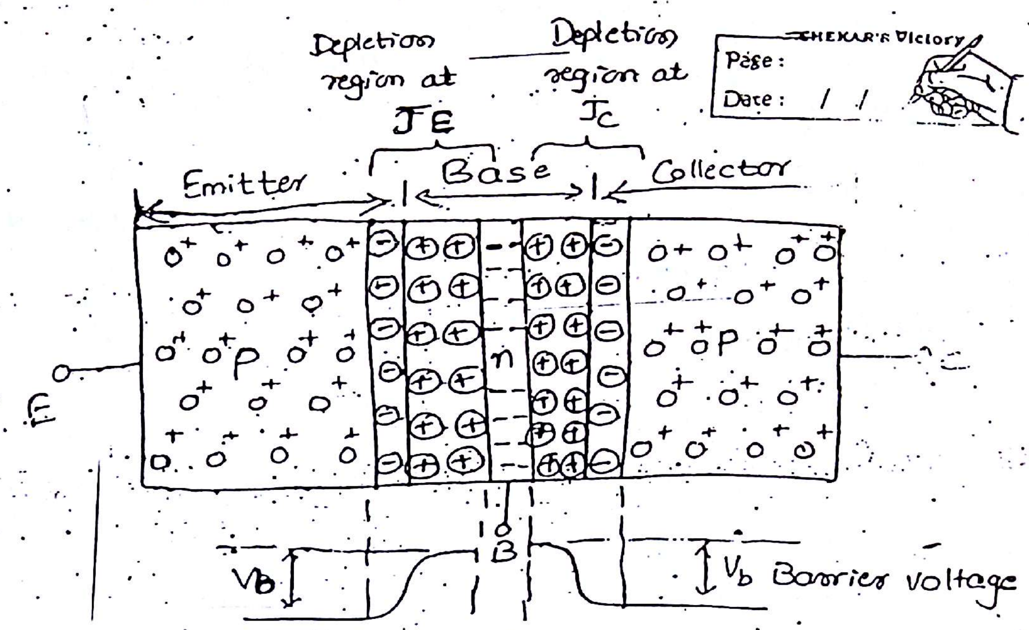
→ Unbiased transistor means a transistor with no external voltage (biasing) is applied.

→ Obviously, there will be no current flowing from any of the transistor leads.

→ Since transistor is like two p-n junction diodes connected back to back, there are depletion regions at both the junctions, emitter ~~junction~~ & collecter junction as shown below.



Unbiased npn transistor



Unbiased pnp transistor

Construction Details of Transistor:

→ P-type silicon is sandwiched betn two N-type silicon. Such a type of transistor is called NPN transistor.

→ Similar N-type silicon is sandwiched betn two layers of P-type silicon. Such a type of transistor is called PNP transistor.

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→ The transistors consists of 3 regions E, B & C.

→ The 3 regions doping is as follows.

1) Emitter: (E) — heavily doped — so that it can emit large no. of maj. carriers into the device.
— always forward biased wrt base — maj. carriers has to be pumped.
— the width of emitter region is moderate.

2) Base: (B) — lightly doped & very thin.
— also called as control terminal.
— passes most of the emitter injected charge carriers into the collector.
→ offers low resistance to emitter current

3) Collector: (C) — intermediate doping (betn heavily & lightly). (moderately doped)
Gold — it collects all majority carriers from base.
— Largest among 3 regions...

more deeply into the lightly doped side in order to include an equal no. of impurity atoms in the each side of the junction.

→ As shown in above fig. depletion region at emitter junction penetrates less in the heavily doped emitter and extends more in the base region.

→ Similarly, depletion region at collector junction penetrates less in the heavily doped collector & extends more in the base region.

→ As collector is slightly less doped than the emitter, the depletion layer width at the collector junction is slightly more than the depletion layer width at the emitter junction.

→ Barrier voltage is the voltage necessary to cause electrical conduction in a junction of two dissimilar materials.

→ Like diodes, a barrier voltage exists within the transistor.

→ The barrier voltage at each junction is +ve on the n-side & −ve on p-side.

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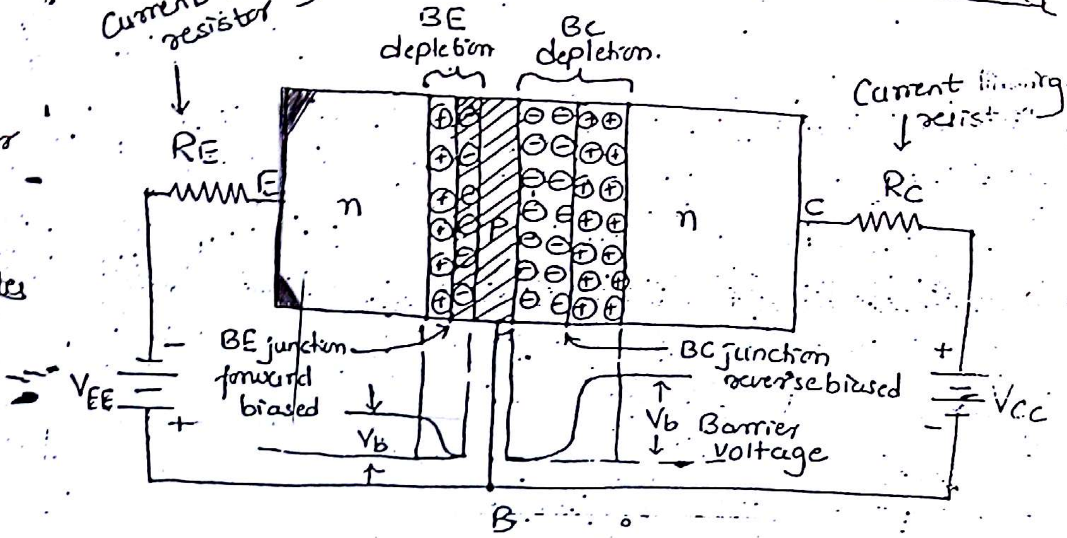
Working Principle of npn Transistor.



→ The base to emitter junction is forward biased d.c source V_{EE}. Thus, the depletion region at this j... reduced. The collector to base junction is reverse biased, increasing depletion region at collector to base junction as shown above.

→ The forward ~~biased~~ EB junction causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E. As these electrons flow through the p-type base, they tend to combine with holes in p-region.

→ Due to light doping, very few of the electrons injected into the base from the emitter recombine with holes to contribute base current, I_B & the remaining large no. of electrons cross the base region & move through the collector region to the +ve terminal of the external d.c source.

→ This contributes collector current I_C. Thus electron flow constitutes the dominant current in an npn transistor.

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→ While, the most of the electrons from emitter flow in the collector circuit & very few combine with holes in the base. Thus, the collector current is larger than the base current.

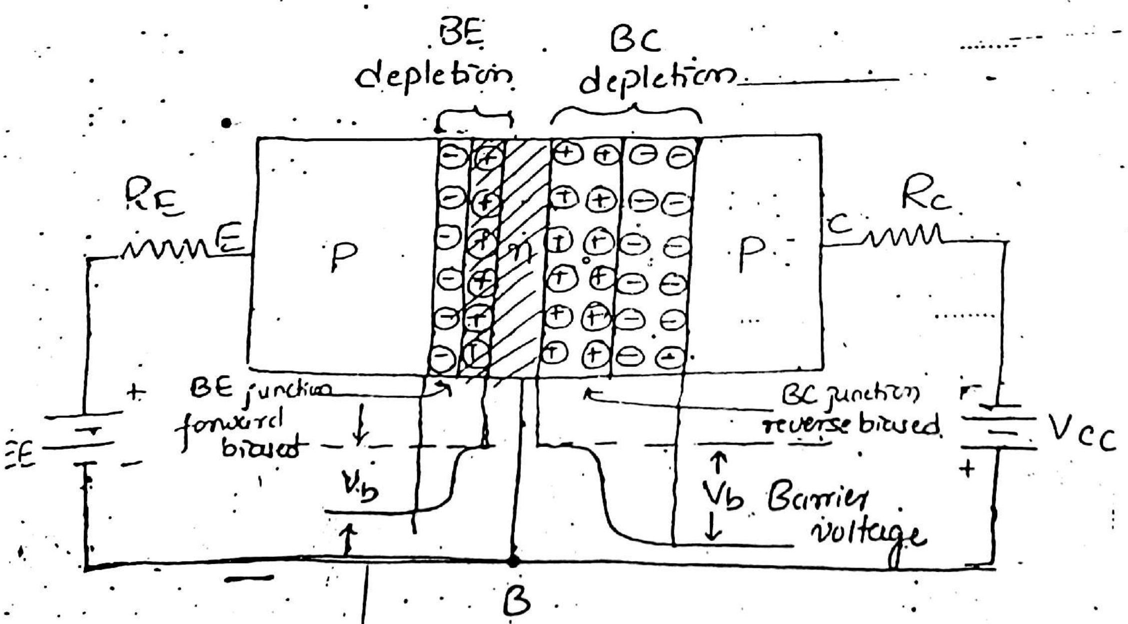
The relationship between these current is given by

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

Working Principle of pnp Transistor.

→ The pnp transistor has its bias voltages V_{EE} & V_{CC} reversed from those in the npn transistor.

→ This is necessary to forward-bias the emitter-base junction & reverse-bias the collector base junction.



→ The forward biased EB junction causes the holes in the P-type emitter to flow towards the base. This constitutes the emitter current I_E.

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→ As these holes flow through the n-type base, they tend to combine with electrons in n-region (base). As the base is very thin & lightly doped, very few of the holes injected into the base from the emitter recombine with electrons to ~~contribute~~ constitutes base current, I_B.

→ The remaining large no. of holes cross the depletion region & move through the collector region to the -ve terminal of the external d.c source. This constitutes collector current I_C. Thus the hole flow constitutes the dominant current in an pnp transistor.

Transistor Voltages

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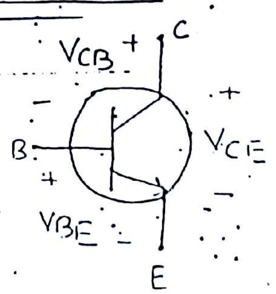
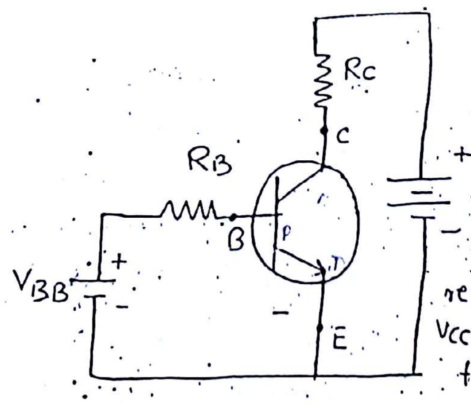


~~npn-transistor volta~~ polarities

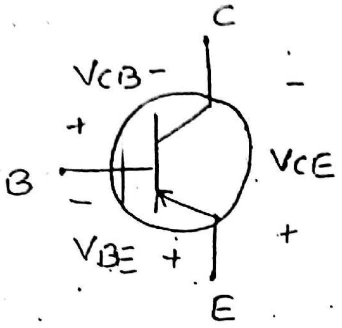


→ The -ve terminal of both the supply voltages are connected to emitter terminal of transistor.

→ To make CB junction reverse biased, the supply vtg. Vcc is always much larger than VBB.

Voltage source connections for npn transistor.

→ The voltage sources are connected to the transistor with series resistors. These resistors are called Current Limiting Registors.



pnp transistor voltages & polarities

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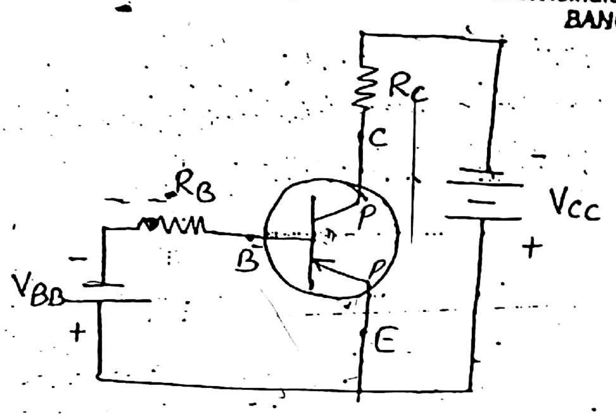


Voltage source connection for pnp transistor.

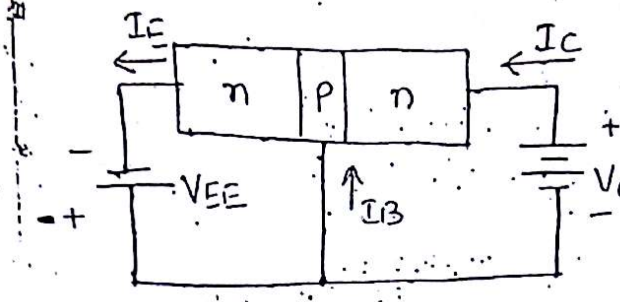
→ The source voltage +ve terminals are connected at the emitter terminal with Vcc larger than V_{BB} to keep ~~collecter~~ collecter-base junction reverse biased.

Junction Voltages

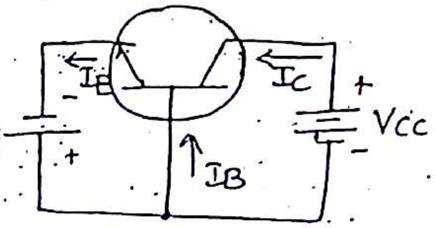
→ In different conditions such as active, saturation & cutoff there are different junction voltages. The junction voltages for npn transistor at 25°C are given below.

TYPE	$V_{CE\,sat}$	$V_{BE\,sat}$	$V_{BE\,active}$	$V_{BE\,cutin}$	$V_{BE\,cutoff}$
Si	0.2	0.8	0.7	0.5	0.0
Ge	0.1	0.3	0.2	0.1	-0.1

Transistor Currents



(a)



(b)

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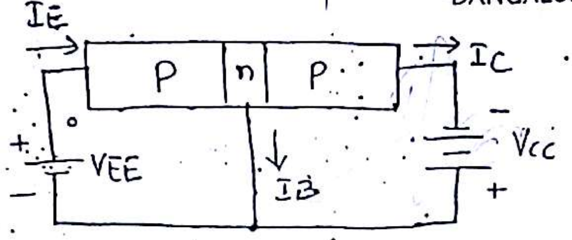

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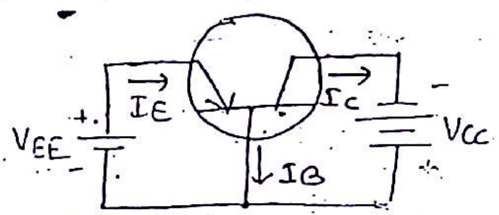

(d)

Transistor Conventional Current diagrams.

→ The collector current is indicated as I_C & base current as I_B & emitter current as I_E.

→ For both npn & pnp transistors

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

(I_E flows into the transistor & I_C & I_B flows out of the transistor)

Prob: In a certain transistor, the emitter current is 1.02 times as large as the collector current. If the emitter current is 12 mA, find the base current.

Soln. Given $I_E = 12\,mA$, & $I_E = 1.02\,I_C$.

$$1.02\,I_C = 12\,mA$$

$$\therefore I_C = \frac{12\times10^{-3}}{1.02} = \boxed{11.765\,mA}$$

$$\therefore I_B = I_E - I_C = 12\times10^{-3} - 11.765\times10^{-3} = \boxed{0.235\,mA} = \boxed{235\,\mu A}$$

Gold

...y, there is one more current component flows inside the transistor, called the reverse saturation current (I_{CBO}).

→ This reverse saturation current flows across the reverse biased collector junction when emitter is open circuited.

→ Hence the collector current is constituted by 2 components, namely the current due to injected charge carriers from emitter to collector crossing the base & current due to reverse saturation current.

→ Therefore, we have

$$\boxed{I_C = \alpha_{dc} I_E + I_{CBO}} = \boxed{\alpha_{dc}(1+\beta_{dc}) I_B + I_{CBO}}$$

→ Almost all of I_E crosses to the collector, and only a small portion flows out of the base terminal.

→ Typically 96% to 99.5% of I_E flows across the collector base junction to become collector current

→ α_{dc} is the emitter-to-collector current gain, or the ratio of collecter current to emitter current i.e.

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}}$$

Typical value

$$\boxed{\alpha = 0.9 \text{ to } 0.99}$$

practically

$$\boxed{\alpha_{dc} = \frac{I_C - I_{BO}}{I_E}}$$

→ β_{dc} is the base-to-collector current gain, or the ratio of collector current to base current.

$$\therefore \boxed{\beta_{dc} = \frac{I_C}{I_B}}$$

Typical value

$$\boxed{\beta = 0 \text{ to } 300}$$

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Relationship between α & β

We know that, $\beta = \frac{I_C}{I_B}$

We have, $I_E = I_C + I_B$ i.e., $I_B = I_E - I_C$

$$\therefore \beta = \frac{I_C}{I_E - I_C}$$

Dividing the numerator & denominator of RHS of above equation by I_E, we get,

$$\beta = \frac{I_C/I_E}{I_E/I_E - I_C/I_E}$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}} \qquad \left(\because \alpha = \frac{I_C}{I_E}\right)$$

We know that, $\alpha = \frac{I_C}{I_E}$ & $I_E = I_B + I_C$.

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

Dividing the numerator & denominator of RHS of above equation by I_B, we get,

$$\alpha = \frac{I_C/I_B}{I_B/I_B + I_C/I_B}$$

$$\boxed{\alpha = \frac{\beta}{1+\beta}} \qquad \left(\because \beta = \frac{I_C}{I_B}\right)$$

1) A transistor has $I_B = 100\mu A$ & $I_C = 2mA$, Find

i) β of the transistor

ii) α of the transistor

iii) Emitter current, I_E

iv) If I_B changes by $+25\mu A$ & I_C changes by $+0.6mA$. Find the new value of β.

Soln: Given $I_B = 100\mu A$, $I_C = 2mA$

i) $\beta = \frac{I_C}{I_B} = \frac{2\times10^{-3}}{100\times10^{-6}} = \boxed{20}$

ii) $\alpha = \frac{\beta}{1+\beta} = \frac{20}{1+20} = \boxed{0.952}$

iii) $I_E = I_B + I_C = 100\times10^{-6} + 2\times10^{-3} = \boxed{2.1mA}$

iv) New $I_B = 100\mu A + 25\mu A = 125\mu A$

New $I_C = 2mA + 0.6mA = 2.6mA$

$\therefore$ New $\beta = \frac{2.6\times10^{-3}}{125\times10^{-6}} = \boxed{20.8}$

) Given $I_E = 2.5mA$, $\alpha = 0.98$ & $I_{CBO} = 10\mu A$, Calculate I_B & I_C.

Soln: $I_C = \alpha I_E + I_{CBO} = 0.98\times2.5\times10^{-3} + 10\times10^{-6}$

$= \boxed{2.46mA}$

& $I_B = \frac{I_C}{\beta} = \frac{I_C(1-\alpha)}{\alpha} = \frac{2.46\times10^{-3}(1-0.98)}{0.98} = \boxed{50.2\mu A}$

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Transistor Configurations.

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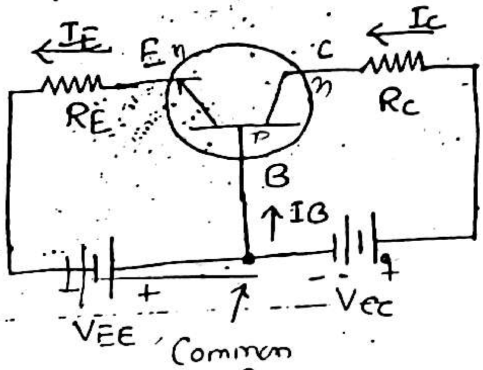
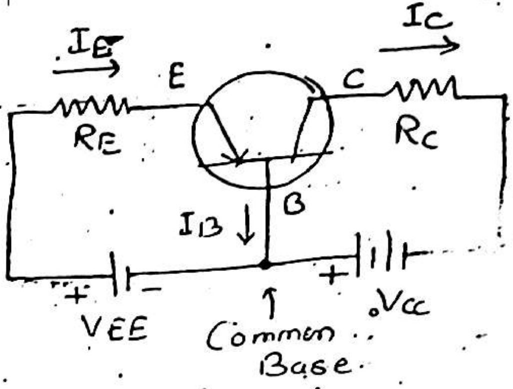
→ To understand complete electrical behavior of a transistor it is necessary to study the interrelation of the various currents & voltages.

→ These relationships can be plotted graphically which are commonly known as the Characteristics of Transistor.

1) Common Base Characteristics.



npn transistor



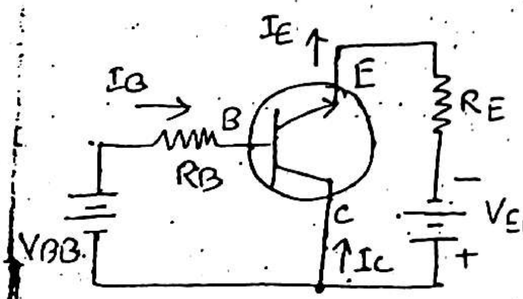
pnp transistor

→ Configuration input is applied betn emitter & base & o/p is taken from the collector & base.

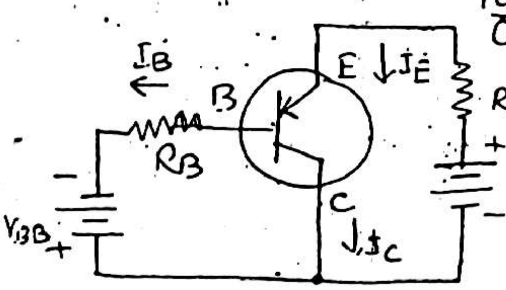
→ Hence, base of transistor is common to both i/p & o/p. Hence name Common Base Configuration.

2) Common Collector Characteristics.

Also known as Emitter Follower Configuration



npn transistor



pnp transistor

Common Emitter Configuration

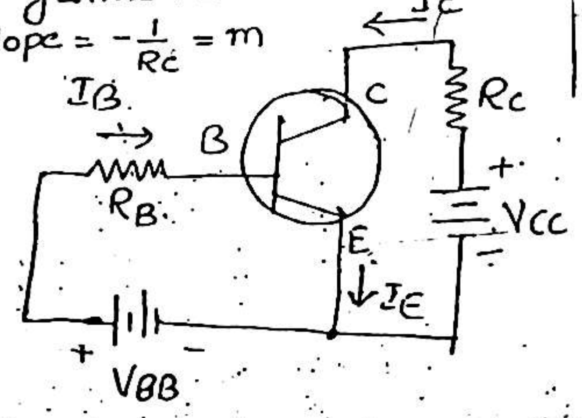
$$V_{CC} = I_C R_C + V_{CE}$$

$$\therefore I_C = \frac{V_{CC} - V_{CE}}{R_C} = -\frac{V_{CE}}{R_C} + \frac{V_{CC}}{R_C}$$

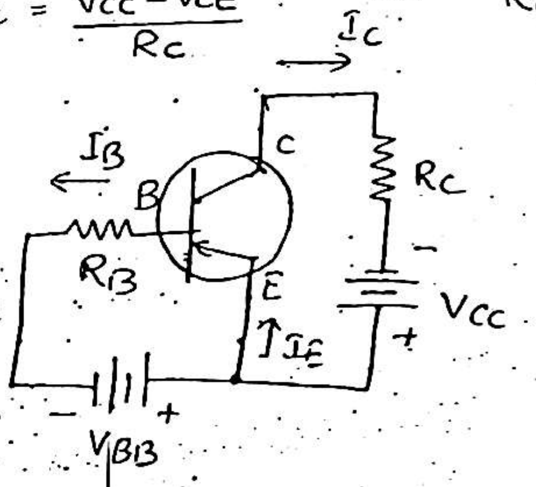
for straight line

$y = mx + c$

slope $= -\frac{1}{R_C} = m$



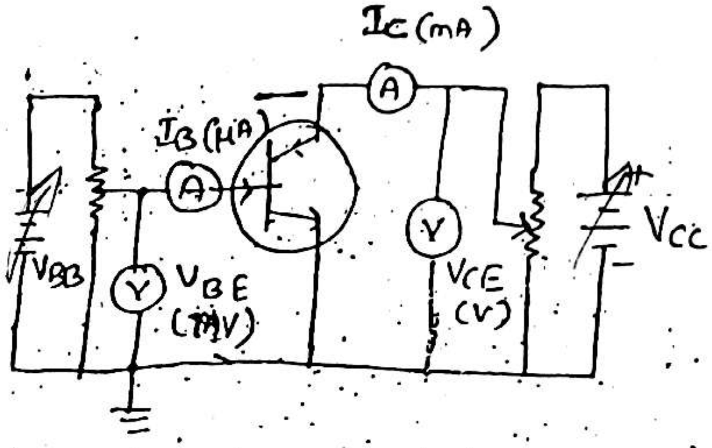
npn transistor



pnp transistor

→ In this configuration i/p is applied between base & emitter, and o/p is taken from collector & emitter. Here, emitter of the transistor is common to both i/p & o/p circuits, & hence the name common emitter configuration.

→ The i/p vtg in the CE configuration is the base-emitter voltage (V_{BE}) & the o/p vtg is the collector-emitter voltage (V_{CE}). The i/p current is I_B & o/p current is I_C.



npn transistor

Experimental setup to plot the CE characteristics

→ Transistor is connected to CE configuration to variable V_{BB} & variable V_{CC} supply.

→ A μA in base reads I_B, mA in collector reads I_C, dc mV betn base & emitter reads V_{BE} & dc V betn collector & emitter reads V_{CE}.

Procedure for Plotting i/p Characteristics

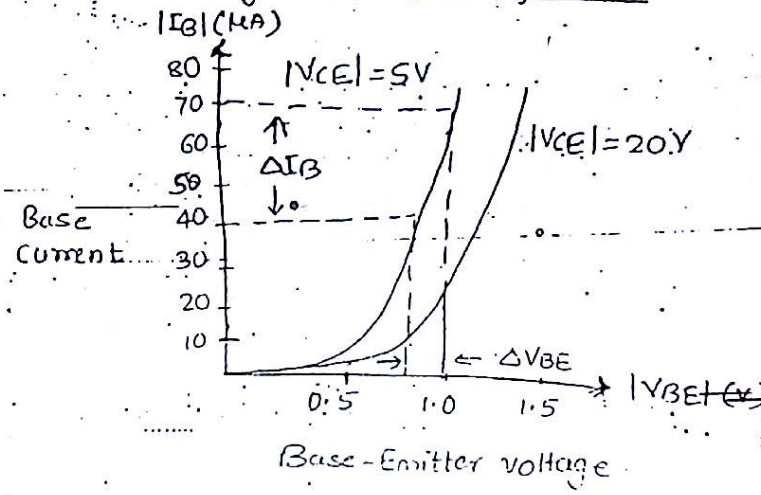
1) Adjust the collector supply voltage, V_{CC} to set V_{CE} at a fixed value, say 10V

2) Increase I_B in steps of $5\mu A$ & measure V_{BE}. Be sure that V_{CE} remains constant at fixed value.

3) Continue increasing I_B till we get sufficient readings to plot a smooth curve.

4) Adjust V_{CE} to new value say 15V & repeat the steps (2) & (3)

5) Plot the graph of I_B versus V_{BE} for different values of V_{CE}.



Explaination

→ It is the curve betⁿ an i/p voltage V_{BE} & i/p current I_B at constant collector-emitter vtg. V_{CE}.

→ The I_B is taken along Y-axis & V_{BE} is taken along X-axis as shown above

From the characteristics we observe the following imp. points.

1) The input resistance is the ratio of change in base-emitter vtg (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector emitter voltage V_{CE}. It is given by.

$$r_i = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}=\text{constant}}$$

... is the input to a transistor in the CE configuration is bet^n the base-to-emitter junction, the CE i/p characteristics resembles a family of forward biased diode curves.

3) After the cut-in-voltage, IB increases rapidly with small increase in VBE. Thus the dynamic i/p resistance is small in CE configuration.

4) For a fixed value of VBE, IB decreases as VCE is increased.

5) Voltages VBE & VCE are +ve for npn transistor & they are -ve for pnp transistor.

Procedure for plotting o/p characteristics

1) Adjust the VBB to set IB at fixed value, say 20μA.
2) Increase VCE in steps of 0.5V & measure Ic. Be sure that the base current remains constant at fixed value.
3) Continue increasing VCE till we get sufficient readings to plot a smooth curve.
4) Adjust IB to new value say 30 μA & repeat the steps (2) & (3).
5) Repeat (4) for more values of IB.
6) Plot the graph of Ic versus VCE for different values of IB.

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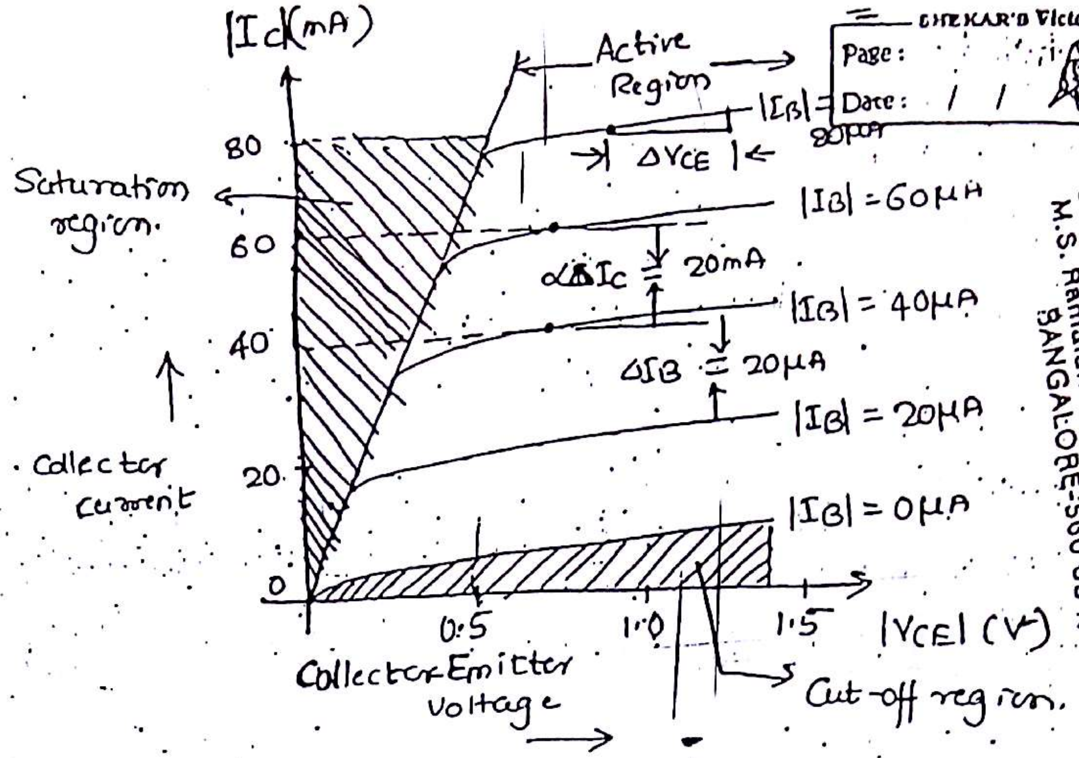

(1) This characteristics shows the relation between the collector current (I_C) & collector-emitter voltage (V_{CE}), for various fixed values of I_B. This characteristics is often called as Collector Characteristics.

2) The value of β_{dc} of the transistor can be found at any point on the characteristics by taking the ratio of I_C to I_B at that point, i.e; $\beta_{dc} = I_C / I_B$.

3) From the o/p characteristics, we can see that change in collector-emitter voltage (ΔV_{CE}) causes the little change in the collector current (ΔI_C) for constant base current I_B. Thus the o/p dynamic resistance is high in CE configuration

$$\boxed{r_o = \frac{\Delta V_{CE}}{\Delta I_C}\Bigg|_{I_B = \text{Constant or } \Delta I_B = 0}}$$

4) The o/p characteristics of common emitter configuration consists of 3 regions: Active, Saturation & Cut-off.

5) Active Region:

→ for the operation in the active region, the (J_E) is forward biased while (J_C) is reverse biased.

→ The (I_C) rise more sharply with increasing V_{CE} in the linear region of o/p characteristics of CE transistor.

Region

→ In this region, J_E and J_C both are forward biased.

→ The saturation value of V_{CE}, designated $V_{CE(sat)}$, usually ranges betn 0.1V to 0.3V.

7) Cut-off Region

→ The region below $I_B = 0$ is the cut-off region of operation for the transistor. In this region, both the junctions of the transistor are reverse biased.

→ for saturation : $I_B > \dfrac{I_C}{\beta_{dc}}$

→ for active region : $V_{CE} > V_{CE(sat)}$.

Special Features of Transistor in CE Mode

Characteristic	Common Emitter
Input resistance (Ri)	Low (1 KΩ)
Output resistance ~~(Ro)~~	High (~~40 KΩ~~)
Input current	I_B
Output current	I_C
Input voltage applied between	Base & Emitter
Output voltage taken between	Collecter & Emitter
Current amplification factor	$\beta = I_C / I_B$
Current gain (Ai)	High (20 to few hundreds)
Voltage gain (Av)	Medium
Applications	Provides both vtg & current gain > 1 & hence widely used in audio signal ampln.

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