

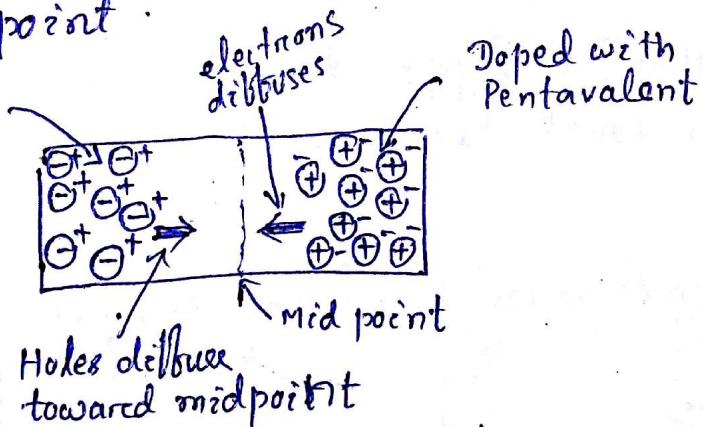
The P-N Junction

Manufacturing

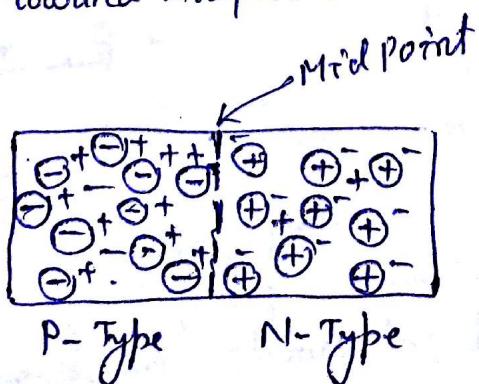
- A piece of semiconductor is doped with trivalent from one side and with pentavalent from other side then the concentration of majority carriers will diffuse towards mid point.

Doped with Trivalent

[1st Stage]



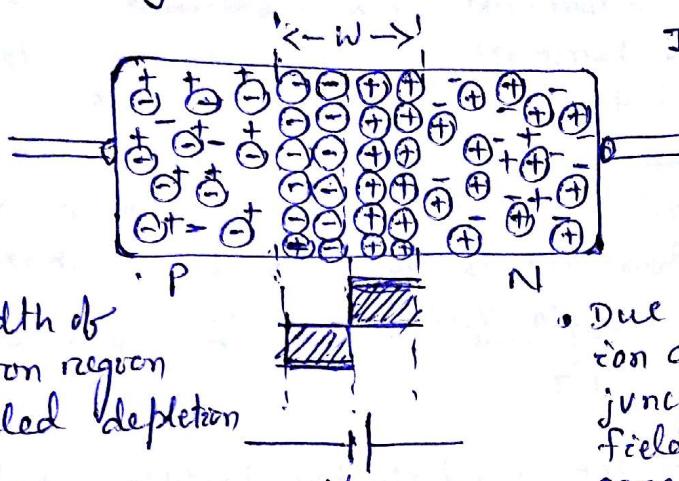
[2nd Stage]



- The donor atom of N-type donates one electron which is accepted by acceptor atom at P-type. This process is called recombination.

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- Due to the recombination process +ve charged ion [\oplus] is generated at N-type and -ve charged ion [\ominus] is generated at P-type near the mid point.
- So that junction (mid) region will be depleted of majority carrier, known as Depletion Region.



Junction Potential

$$V_T \approx 0.7\text{v in Si}$$

$$\approx 0.3\text{v in Ge}$$

- The width of depletion region is called depletion width.

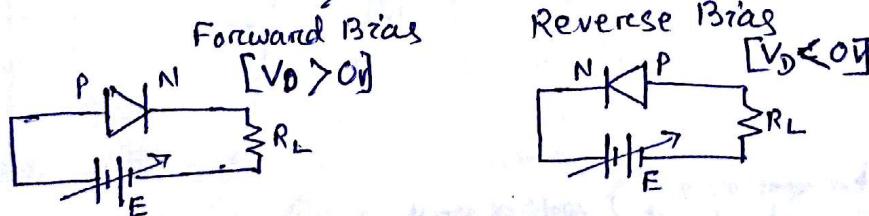
- Due to the charged ion arranged near the junction an electric field potential difference generated near junction known as Threshold Voltage or Barrier Potential.

- At No Bias (OR Room Temp) [$V_D = 0\text{v}$]

- The Barrier Potential is sufficient to oppose the further recombination process.
- So there will be no flow of current occurs in ~~P-N~~ Junction in no-bias condition.

Biassing

Application of external applied voltage to a device to operate with a const. level of voltage & current known as Biassing.



Symbol of Diode

The arrowhead shows the forward current direction.

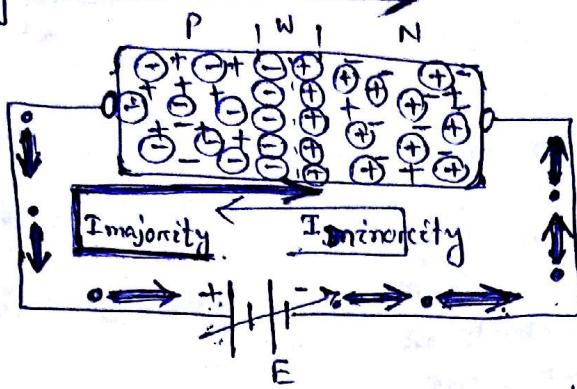


Forward Biassing

$$[V_D > 0]$$

I_D (unidirectional)

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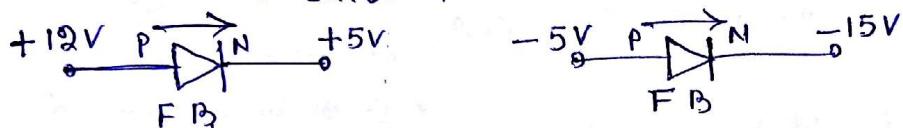


$$I_D = I_{\text{majority}} - I_{\text{minority}}$$

Reverse Saturation Current (I_S)

$$E \geq V_T$$

- When P-type is connected to +ve terminal & applied potential & n-type is connected to -ve terminal & applied potential then the diode (P-n junction) is said to be in Forward Bias.
- In other word if in a diode ~~there is a~~ the P-type is at higher potential than n-type then the diode is said to be at Forward Bias.

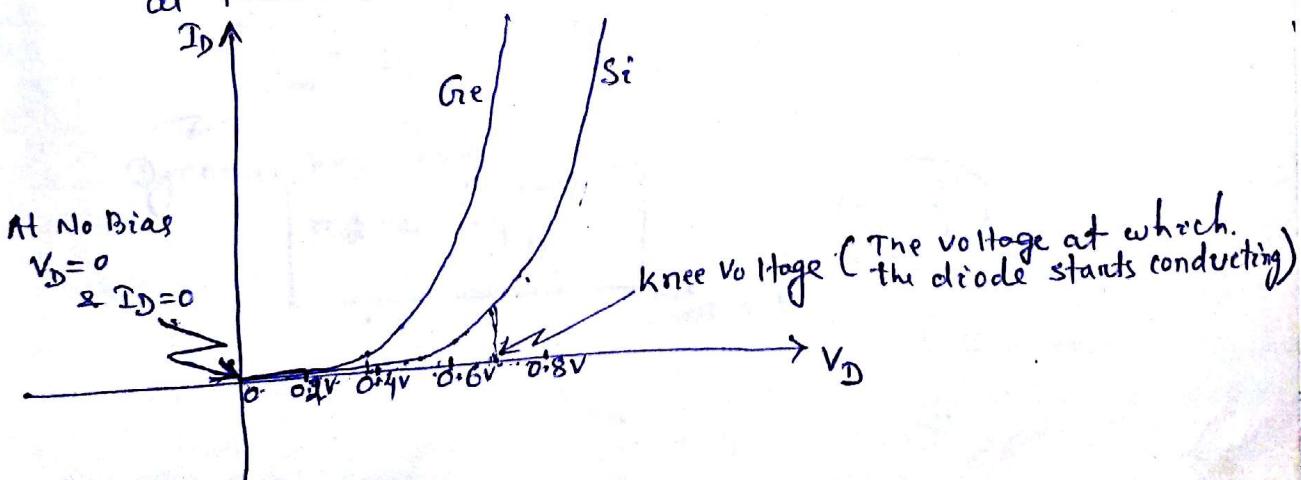


Operation

- Due to the applied potential, the +ve terminal will pressurize electrons (free) & holes to recombine with the ions near junction, which reduces the width (W) of barrier region.
- So due to ~~the~~ reduced width there will be a heavy flow of charge carriers occurs near junctions which causes a flow of current.
- When the variable applied potential increased then the current increased proportionally (exponentially).

V-I Characteristics

- ~~The~~ The diode voltage V_D at x-axis & diode current I_D at y-axis, known as V-I characteristics.



Diode Equation

$$I_D = I_s (e^{kV_D/T_K} - 1)$$

- where I_s = Reverse saturation current.

$$k = \frac{11,600}{n}$$

Note n for Ge = 1

$$T_K = T_c + 273^\circ$$

n for Si = 2

So diode current for Ge is more rapid than Si

* * * for +ve values of V_D *

So, for +ve values of V_D , I_D will be +ve and grow as $y = e^x$ (exponentially)

* * * for $V_D = 0$ *

$$I_D = I_s (e^0 - 1) = I_s (1 - 1) = 0 \text{ mA.}$$

* * * for -ve value of V_D *

So, $I_D = -I_s$ (Simply horizontal line)
very small.

Taking the derivative with respect to applied bias

$$\frac{d}{dV_D}(I_D) = \frac{d}{dV} [I_s (e^{kV_D/T_K} - 1)]$$

$$= \frac{k}{T_K} (I_D + I_s)$$

$$\approx \frac{k}{T_K} I_D$$

($\because I_D \gg I_s$)

(by taking $n = 1$
 $k = \frac{11,600}{1} = 11,600$)

& room temp $25^\circ C$

$$T_K = 25^\circ C + 273^\circ C = 298^\circ K$$

$$\Rightarrow \frac{dI_D}{dV_D} \approx \frac{11,600}{298} I_D$$

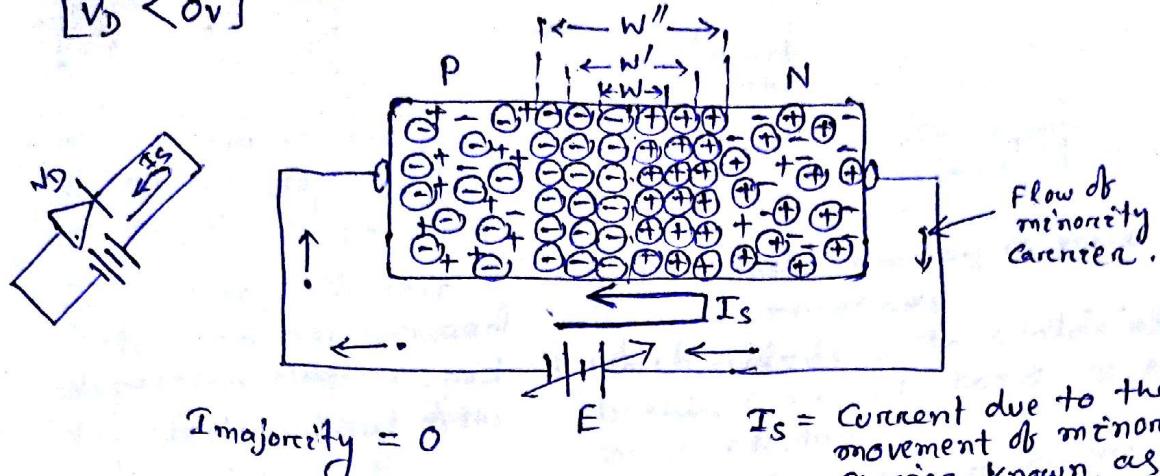
$$\Rightarrow \frac{dV_D}{dI_D} \approx \frac{0.026}{I_D}$$

Dynamic Resistance

$$r_{cd} = \frac{26 \text{ mV}}{I_D}$$

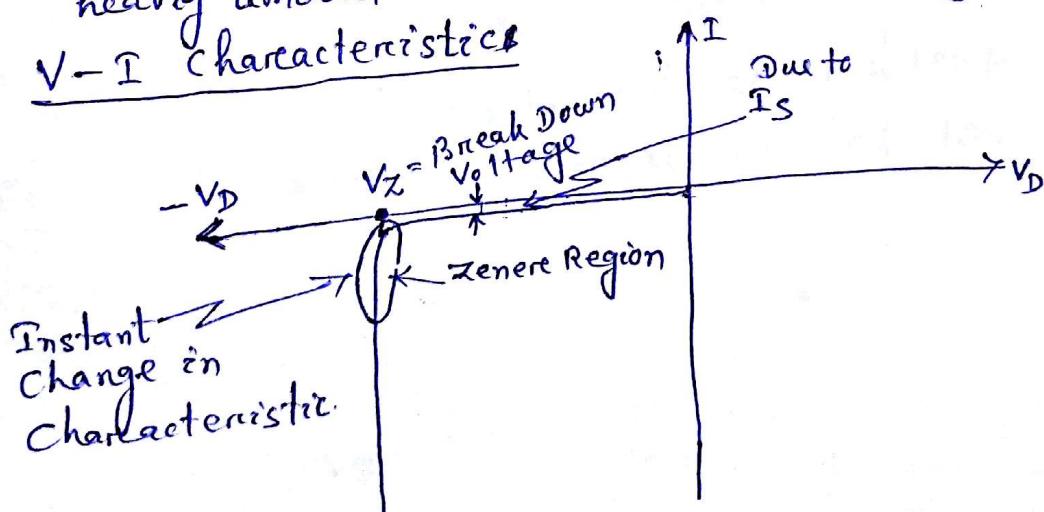
Ge
as well as Si

$$R = \frac{V}{I}$$

Reverse Bias[$V_D < 0V$]

I_S = Current due to the movement of minority carrier known as Reverse Saturation current.

- When the P-type is at a lower potential than n-type then the diode is called at Reverse biased.
- The majority carriers move away from junction generating more mobile ions near the junction. Which increases the barrier width from w to w' to w'' .
- Majority Carriers do not cross the junction
So, $\Rightarrow I_{\text{majority}} = 0$
- But the minority carriers easily cross the junction and causes current flow. Due to the concentration of minority carrier is very less, so, the current (I_S = Reverse Saturation Current) will be very small amount, can be neglected.
- when the applied potential is increased, at a certain level breakdown occurs to give an heavy amount of current to destroy the diode.

V-I Characteristics

Break Down

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Zener Breakdown

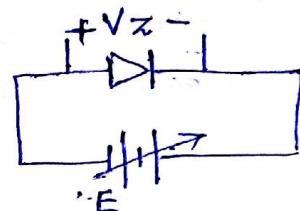
Avalanche Breakdown

- When diode is heavily doped the depletion region is very narrow.
- The strong electric field with an increased depletion region, pull the electrons out of the valence band.
- Means the covalent bond of stable atom breaks, to generate huge amount of carriers to cross the junction.
- Which gives very high current, destroy the diode.

- Due to the reverse bias applied potential, the velocity of minority carriers increases.
- So the kinetic energy of minority carriers increases.
- Which collide with stable atom breaks covalent bond, generates more electron.
- The similar process occurs as a chain reaction known as Avalanche effect.
- Flow of flood of charge carriers gives a heavy amount of current, destroy the diode.
- It occurs in lightly doped with a wide depletion layer.

PIV or PRV

- It is the maximum reverse bias potential that can be applied before entering the Zener region.
- Known as Peak Inverse Voltage
Peak Reverse Voltage.



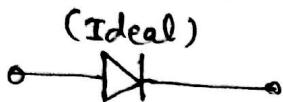
PIV rating of Si = 1000 V

PIV rating of Ge = 400 V

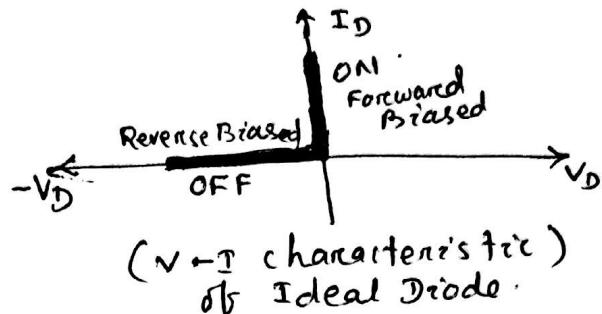
So, Si can be used at high temp. areas as 200°C whereas Ge at 100°C

Ideal Diode

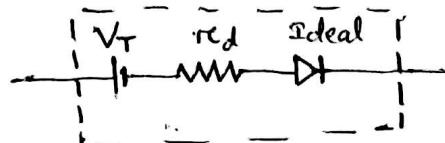
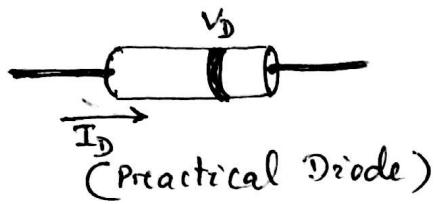
- It is an unidirectional device.
- It is ON when forward biased & OFF when reverse biased.



Symbol.



Equivalent Diagram of Practical Diode



where V_T = Threshold Voltage
or Cut-in Voltage

r_D = Diode internal resistance

Resistance Level

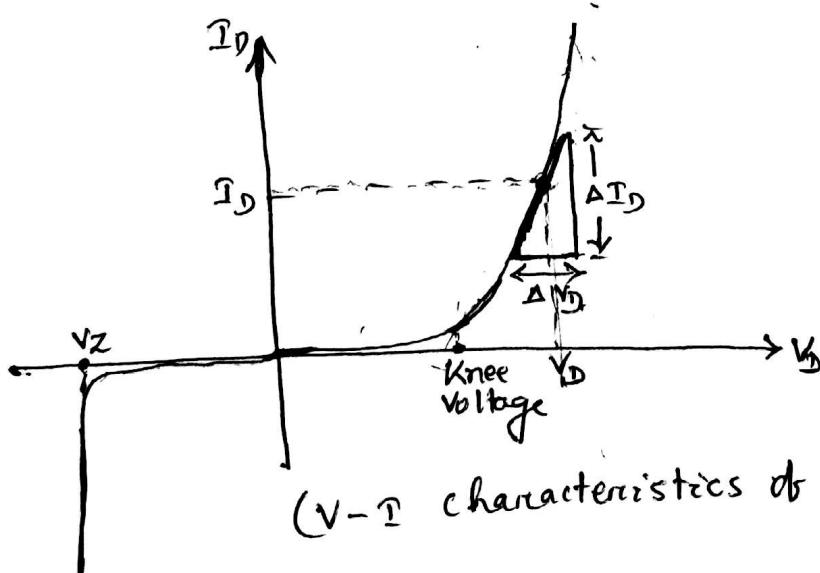
DC Resistance
or
static Resistance

$$R_D = \frac{V_D}{I_D}$$

AC Resistance

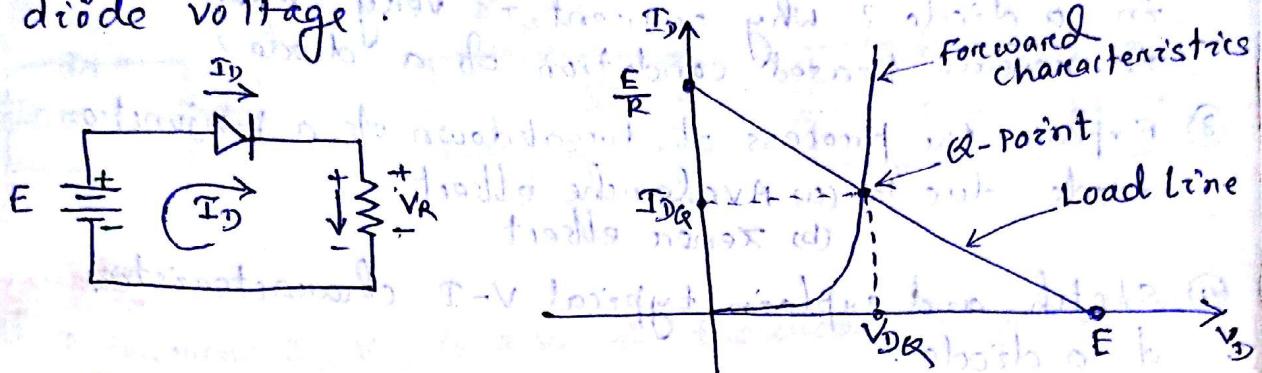
or
Dynamic Resistance

$$r_D = \frac{\Delta V_D}{\Delta I_D}$$



Load Line Analysis's

- In a diode circuit the load line is a line on the V-I characteristics between two points, they are maximum diode current & minimum diode voltage.



Applying KVL

$$E - V_D - IR = 0$$

Set $V_D = 0$

$$I_{\max} = \frac{E}{R} \Big|_{V_D=0}$$

Set $I_D = 0$

$$V_{D\max} = E \Big|_{I_D=0}$$

Q-Point or Operating Point

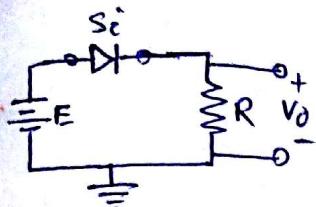
- It is the intersection point between V-I characteristic & load line on the forward characteristic curve.

- It indicates the diode operating voltage V_{DQ} & diode operating current I_{DQ} .

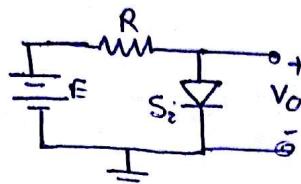
Note For different circuit value the load line will be different, which gives different operating point (V_{DQ}, I_{DQ}) .

DIODE Configuration with DC Inputs

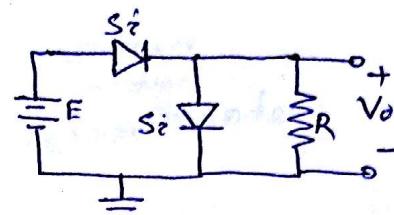
Series



Parallel

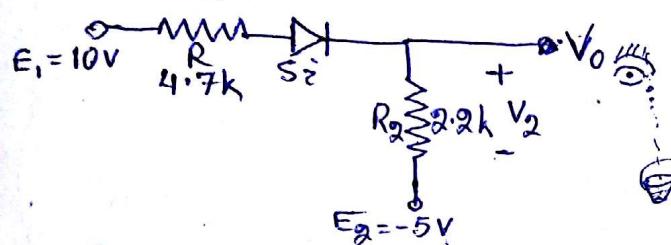


Series - Parallel



Example

(Q) Determine I , V_1 , V_2 & V_0 for the diode configuration -



• Neglecting internal resistance of diodes

• Assuming $V_T = 0.7V$

Answer

Ans Due to the diode is in forward bias, redrawing the figure again -

Applying KVL at Loop 1

$$E_1 - IR_1 - 0.7V - IR_2 - E_2 = 0$$

$$\begin{aligned} \Rightarrow I &= \frac{E_1 - E_2 - 0.7V}{R_1 + R_2} \\ &= \frac{10V - 5V - 0.7V}{4.7k + 2.2k} \end{aligned}$$

$$\Rightarrow I = \frac{14.3V}{6.9k} = 2.072mA$$

Applying KVL at Loop 1

$$V_1 - IR_1 = 0$$

$$\Rightarrow V_1 = IR_1 = 2.072mA * 4.7k$$

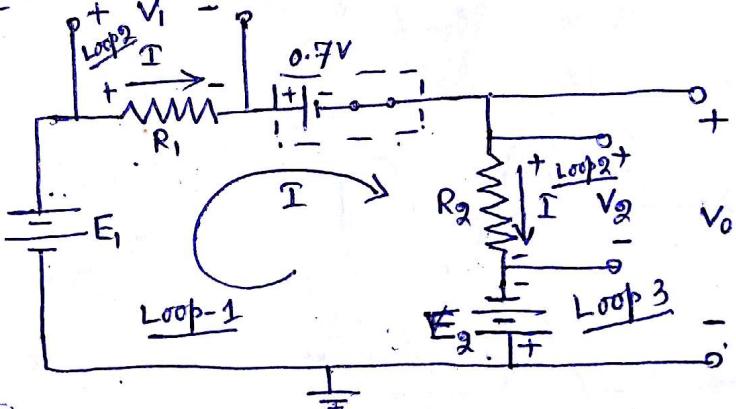
$$\Rightarrow V_1 = 9.74V$$

Applying KVL at Loop 2

$$V_2 - IR_2 = 0$$

$$\Rightarrow V_2 = IR_2 = 2.072mA * 2.2k$$

$$\Rightarrow V_2 = 4.56V$$



Applying KVL at Loop 3

$$V_0 - IR_2 + E_2 = 0$$

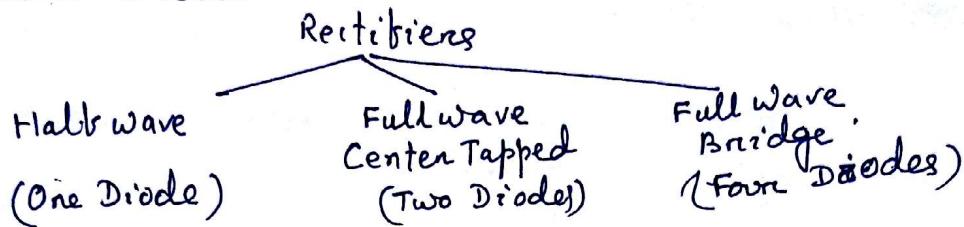
$$\Rightarrow V_0 = IR_2 - E_2$$

$$= 2.072mA * 2.2k - 5V$$

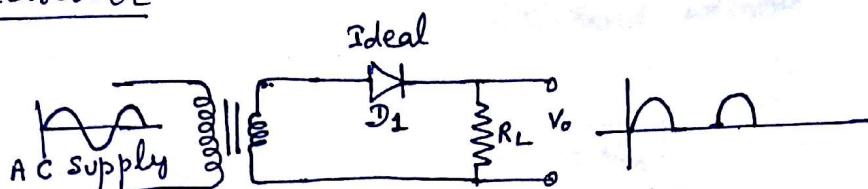
$$\Rightarrow V_0 = -0.44V$$

Rectifiers

It is a device, which converts a.c. voltage to pulsating d.c. voltage, using one diode or more diodes.



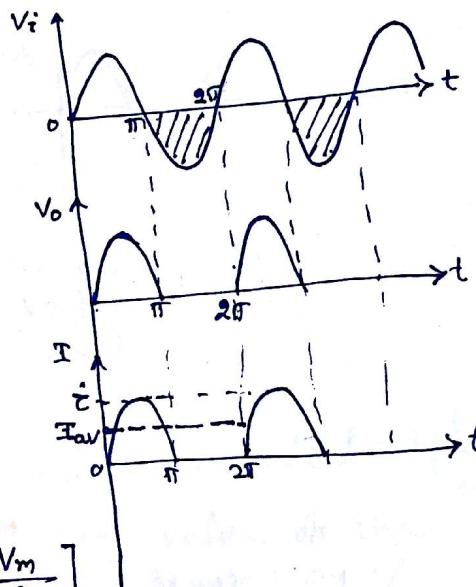
Half Wave Rectifier



- In +ve half of the i/p signal the diode will be forward biased to conduct to provide $V_0 = I R_L$ Volt
- In -ve half of the i/p signal the diode will be reverse biased, act as an open ckt, so does not conduct to provide $V_0 = 0$ Volt

$$\begin{aligned}
 I_{av} &= I_{dc} = \frac{\int_0^{\pi} i d\theta}{2\pi} \\
 &= \frac{1}{2\pi} \int_0^{\pi} \frac{V_m \sin \theta}{R_L} d\theta \\
 &= \frac{V_m}{2\pi R_L} \int_0^{\pi} \sin \theta d\theta \\
 &= \frac{V_m}{2\pi R_L} [-\cos \theta]_0^{\pi} \\
 &= \frac{V_m}{2\pi R_L} * 2 \\
 &= \frac{V_m}{R_L} * \frac{1}{\pi}
 \end{aligned}$$

[where $I_m = \frac{V_m}{R_L}$]



$$\begin{aligned}
 V_{dc} &= I_{dc} * R_L \\
 &= \frac{V_m}{R_L} * \frac{1}{\pi} * R_L
 \end{aligned}$$

(where $V_m = \sqrt{2} V_{rms}$)

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

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

$$\text{A.C. Power, } P_{ac} = I_{rms}^2 * R_L$$

$$= \left(\frac{I_m}{2}\right)^2 * R_L$$

$$\left[\text{for halfwave } I_{rms} = \frac{I_m}{2}\right]$$

$$\text{So Rectifier Efficiency} = \frac{\text{dc o/p Power}}{\text{ac i/p Power}}$$

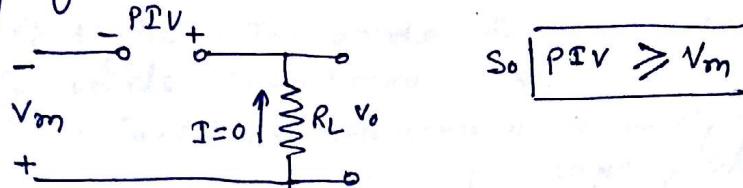
$$= \frac{(I_m/\pi)^2 * R_L}{(I_m/2)^2 * R_L}$$

$$= 0.406$$

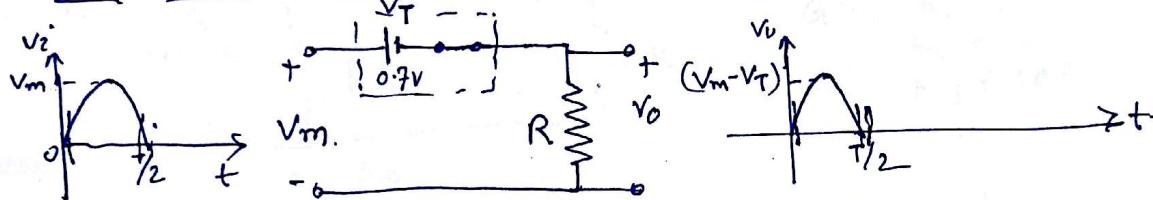
So max. rectifier efficiency $\eta = 40.6\%$.

PIV or PRV

Peak Inverse Voltage or Peak Reverse Voltage is the maximum voltage that a diode can withstand without destroying.



Practical half wave rectification



$$\text{So } V_{dc} = \frac{V_m - V_T}{\pi}$$

$$V_{dc} \approx 0.318 (V_m - V_T)$$

Ripple Factor

- The o/p contains pulsating components called ripples.
- Ripple factor is the ratio of RMS value of the ac component to the dc component. Denoted by \sqrt{r} .

$$\sqrt{r} = \frac{\text{RMS value of ac component}}{\text{D.C. component}}$$

$$= \frac{I_{ac} (\text{rms value of ac component at o/p})}{I_{dc} (\text{dc component at o/p})}$$

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

on half wave

$$\sqrt{r} = \sqrt{\left(\frac{\frac{I_m}{2}}{\frac{I_m}{\pi}}\right)^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \sqrt{1.4674}$$

$$\Rightarrow \sqrt{r} = 1.211$$

(23)

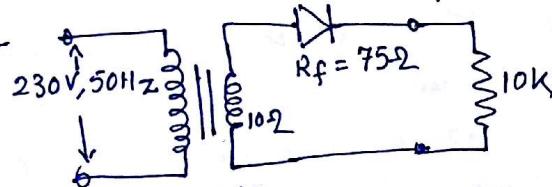
Disadvantages

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- The ripple factor is 1.21, which is quite high.
- The efficiency is 40.6%, practically it will be more less
- Transformer is not utilized in negative half of i/p ac signal so less utilization factor of transformer.
- The amount of average dc or $V_{DC} = 0.318 V_m$ is very less.

(Q) A half wave rectifier ckt is supplied from 230V, 50Hz supply with a step down ratio of 3:1 to a resistive load of $10\text{k}\Omega$. The diode forward resistance is 75Ω while transformer secondary resistance is 10Ω . Calculate maximum, average, RMS values of current; DC o/p voltage, efficiency of rectification and ripple factor.

Ans



Given $R_f = 75\Omega$
 $R_L = 10\text{k}$
 $R_s = 10\Omega$

$N_1 : N_2$

$$\frac{N_2}{N_1} = \frac{V_s(\text{RMS})}{V_p(\text{RMS})} \Rightarrow V_s(\text{RMS}) = \frac{1}{3} * 230V = 76.667V$$

$$\text{So } V_s = \sqrt{2} V_s(\text{RMS}) = \sqrt{2} * 76.667V = 108.423V$$

$$\text{So } I_{\text{max}} = \frac{V_s}{R_s + R_f + R_L} = \frac{108.423V}{10 + 75 + 10 * 10^3} = 10.75\text{mA}$$

$$I_{\text{average}} = \frac{I_m}{\pi} = \frac{10.75\text{mA}}{\pi} = 3.422\text{mA}$$

$$I_{\text{RMS}} = \frac{I_m}{2} (\text{for halfwave}) = \frac{10.75\text{mA}}{2} = 5.375\text{mA}$$

$$V_{DC} = I_{DC} * R_L = 3.422\text{mA} * 10\text{k}\Omega = 34.22V$$

$$P_{DC} = V_{DC} I_{DC} = 34.22V * 3.422\text{mA} = 0.1171\text{Watt}$$

$$P_{AC} = I_{\text{RMS}}^2 (R_s + R_f + R_L) = 0.2913\text{W}$$

$$\text{So \% Efficiency} = \% \eta = \frac{P_{DC}}{P_{AC}} * 100 = 40.19\%$$

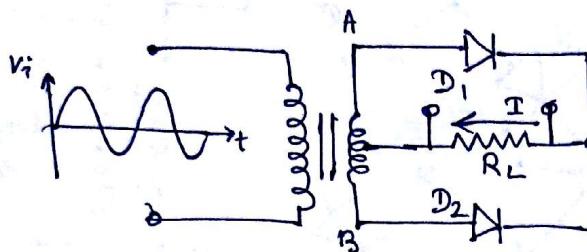
Ripple factor is constant for half wave rectifier

$$\text{i.e. } \gamma = 1.21$$

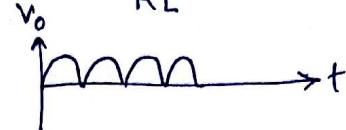
Centre - Tapped Full-Wave Rectifier

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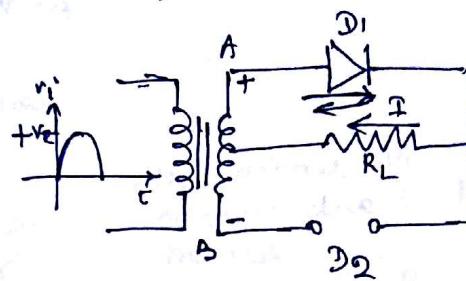
- Both the +ve & -ve half of i/p ac supply conduct.
- Two diodes are used.



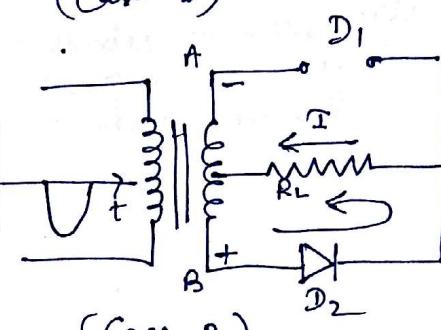
o/p is taken across the load resistance R_L .



- In +ve half cycle of the i/p ac signal the point "A" will be +ve & point B will be -ve.
- So D_1 conducts due to forward biased & D_2 act as open ckt due to reverse biased.



(Case - 1)



(Case - 2)

- So at o/p ~~the~~ will be $v_o = I R_L$ (+ve value)
- On -ve half of i/p ac signal the ~~reverse~~ point "A" will be -ve & point "B" will be +ve.
- So D_2 conducts & D_1 act as an open ckt.
- So o/p will be $v_o = I R_L$ (+ve value)

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

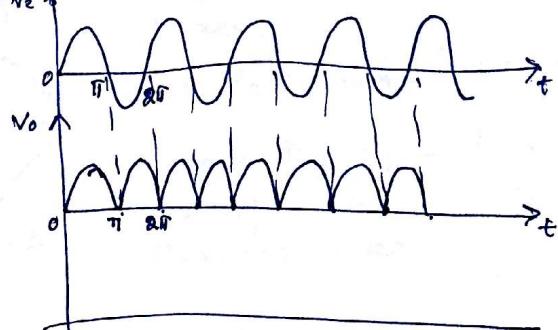
$$\Rightarrow I_{dc} = \frac{2Im}{\pi} \quad \text{for fullwave.}$$

$$V_{DC} = \frac{2Vm}{\pi}$$

$$I_{RMS} = \frac{Im}{\sqrt{2}}$$

$$P_{DC} = \frac{4}{\pi^2} \frac{\Omega_m^2}{2} R_L$$

$$P_{AC} = \frac{Im^2 (R_f + R_s + R_L)}{2}$$



$$\text{Efficiency \%} = 81.2\%$$

Ripple factor

$$\gamma = 0.48$$

less than halfwave

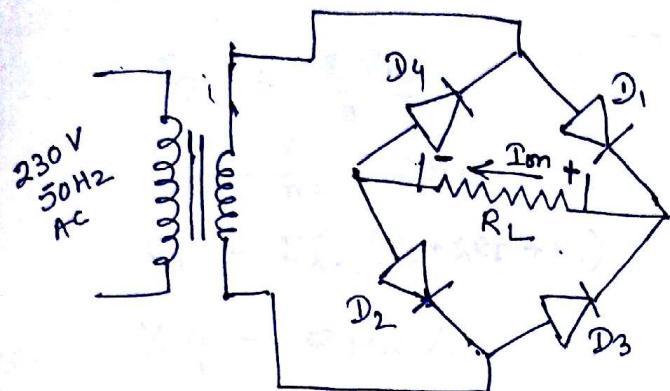
$$P_{AC} = 2 V_m$$

in fullwave Centre Tapped

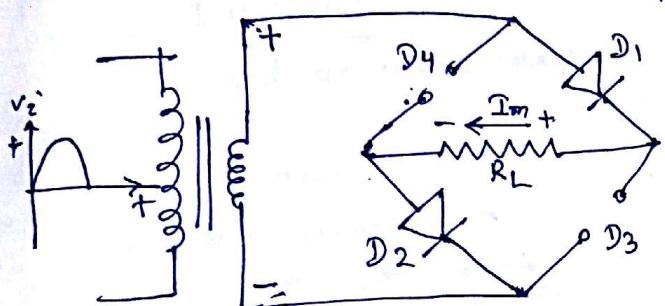
Full Wave Rectifier Using Bridge Rkt

(26)

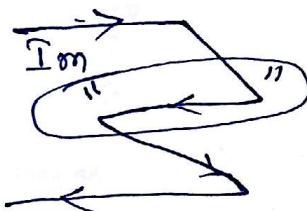
- Here four diodes are used without using Centre tapped transformer.



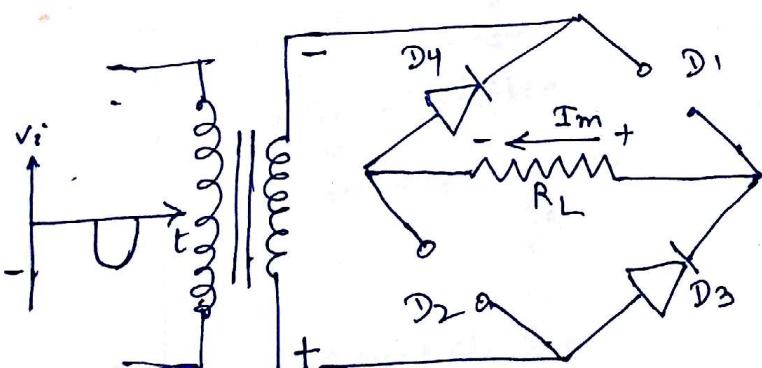
Case-I
+ve Half cycle of i/p signal



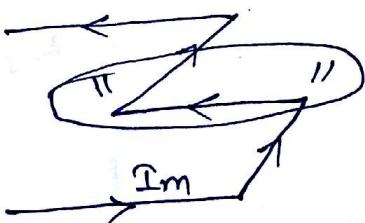
- Two diodes D_1 & D_2 will conduct due to forward biased.
- So $V_o = I_m R_L$ (+ve value)
- Diodes D_3 & D_4 will act as open ckt due to reverse biased.



Case-II
-ve half cycle of i/p signal



- Two diodes D_3 & D_4 will conduct due to forward biased.
- So $V_o = I_m R_L$ (+ve value)
- Diode D_1 & D_2 will act as open ckt due to reverse biased.



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

$$I_{RMS} = \frac{I_m}{\sqrt{2}}$$

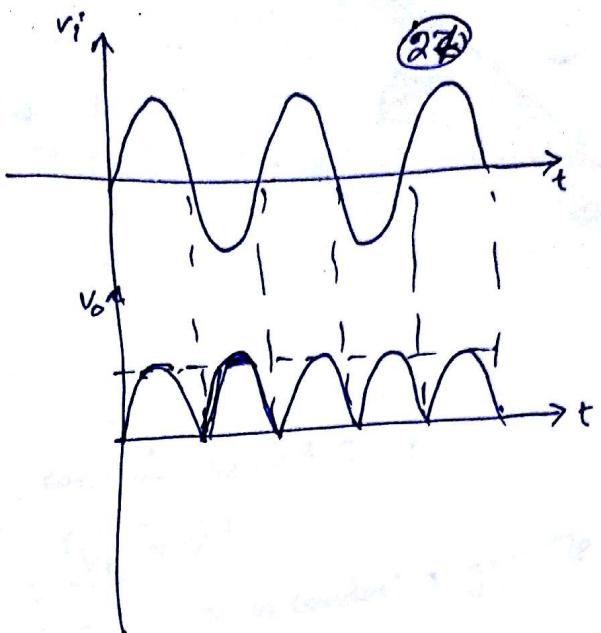
$$V_{DC} = \frac{2 V_m}{\pi}$$

$$P_{DC} = \frac{4}{\pi^2} I_m^2 R_L$$

$$P_{AC} = I_{RMS}^2 (R_S + 2R_f + R_L)$$

$$\gamma \cdot \eta = 81.2\%$$

$$\gamma = 0.48$$

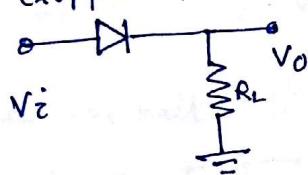


CLIPPERS

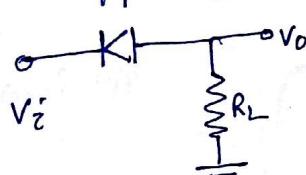
used as wave shaping chts.

Series

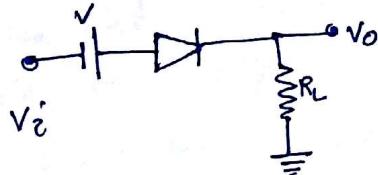
-ve clippers



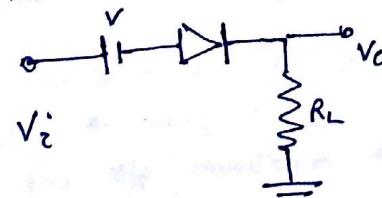
+ve clippers



+ve Biased clipper

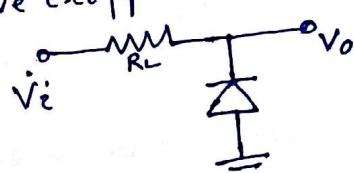


-ve Biased clipper

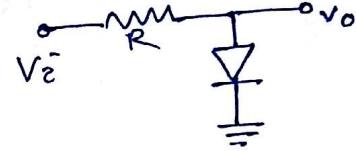


Parallel

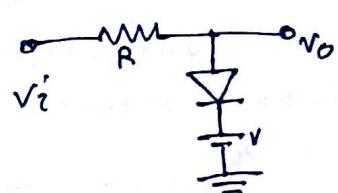
-ve clipper



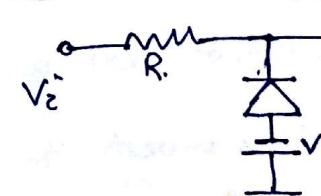
+ve clipper



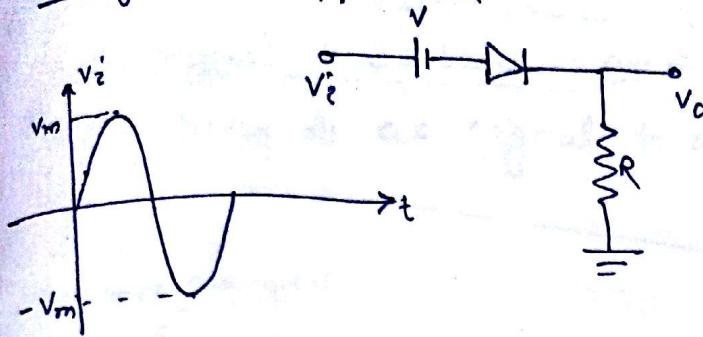
+ve Biased clipper



-ve Biased clipper



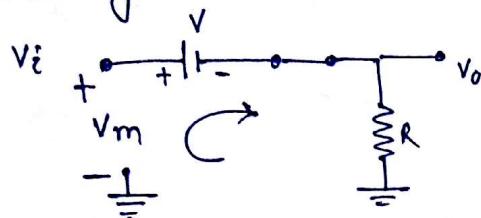
Analysis of Clipper ckt.



(27)

Case-I for +ve half of i/p

Finding out Transition Voltage, consider $V_d = 0$ & $I_d = 0$



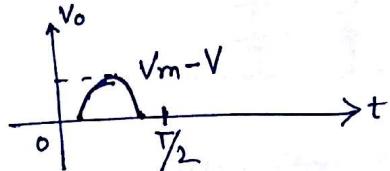
$$V_i = V$$

Diode conduct to give o/p.

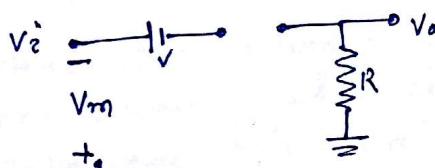
After the "V" level of i/p v_i the diode conduct

Applying KVL

$$V_i - V - V_o = 0 \\ \Rightarrow V_o = V_i - V$$

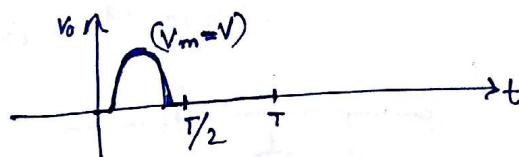


Case-II for -ve half of i/p



- Diode will be reverse biased to act as an open ckt.
- $V_o = 0V$

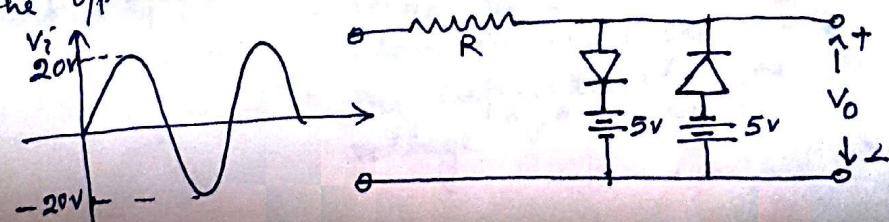
So final o/p



Uses

- clipper ckt's are used in communication to remove or clip the unwanted noise signals.
- Half wave Rectifier is also an example of clipper-ckt.

- (Q) Explain a Series clipper ckt showing the waveforms of inputs & outputs.
- (Q) Draw the o/p waveform of following ckt. Assume Si diode.

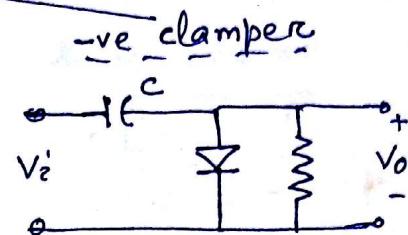
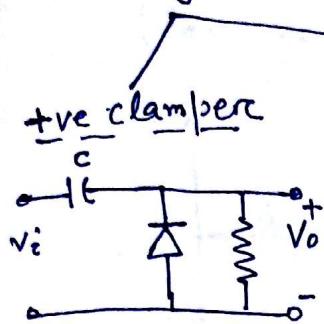


CLAMPERS

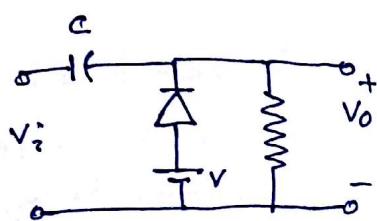
(28)

AC Signal + DC Level = O/p of clamps

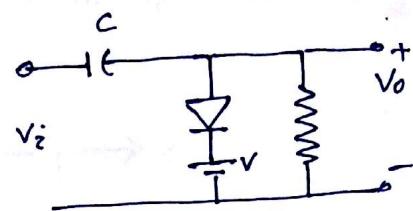
• Clamping is ac signal to a different dc level.



+ve Biased Clammer



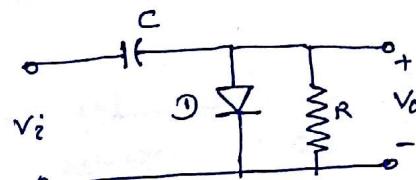
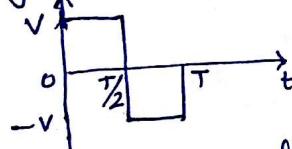
-ve Biased Clammer



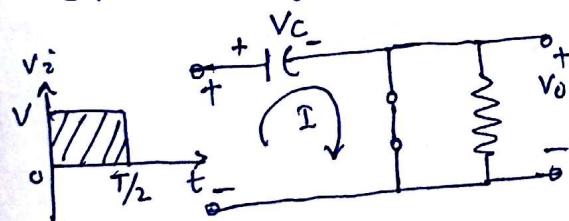
• Here three basic elements are capacitor, resistor & diodes.

• Here it is assumed that the capacitors charge instantaneously when diode is at "ON" state. And capacitors (discharge) act as a voltage source when diode is at "OFF".

Analysis



• First findout in which cycle (+ve or -ve) the diode is ON ; then start analysis first.



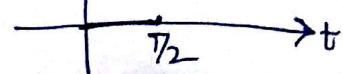
(for +ve half of i/p)

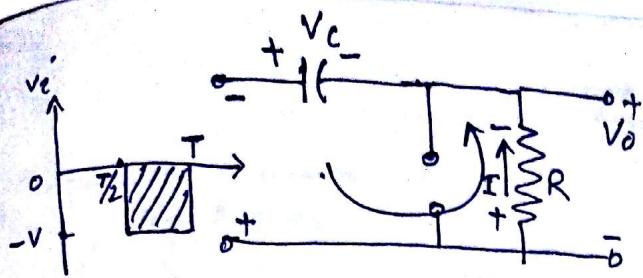
Applying KVL

$$V - V_C = 0$$

$$\Rightarrow V_C = V$$

- Here $V_o = 0$, b/c the current flows in short ckt path.
- The capacitor changes to voltage "V".

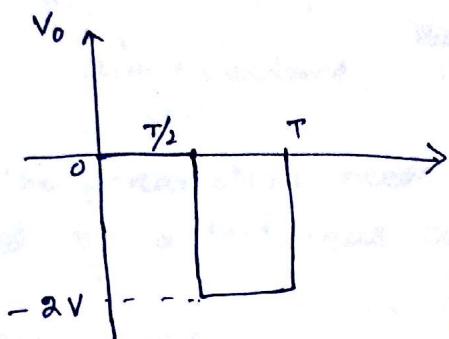




(for -ve half c/p)

Applying KVL

$$V_C + V - IR = 0 \\ \Rightarrow IR = 2V$$



$$+ V_0 + IR = 0$$

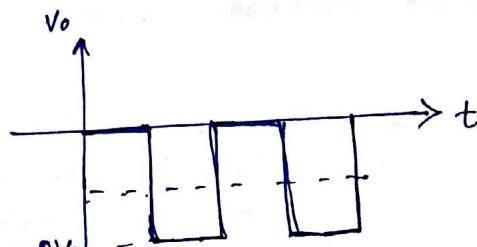
$$\Rightarrow V_0 = -IR$$

$$\therefore V_0 = -2V$$

- Diode acts as an open circuit
- Capacitor acts as voltage source "V". So $V_0 = -2V$

So final o/p

- It is a o/p of -ve clamper ckt.
- The e/p signal is clamped towards -ve side.



Diode Detector

- The rectification property of diode used in communication.
- In communication the diode detects the required wave and bypasses the undesired wave.

